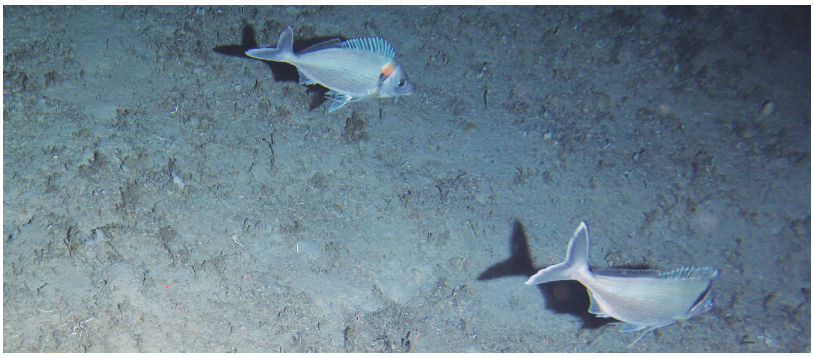
Australian Government
Australian Fisheries Management Authority

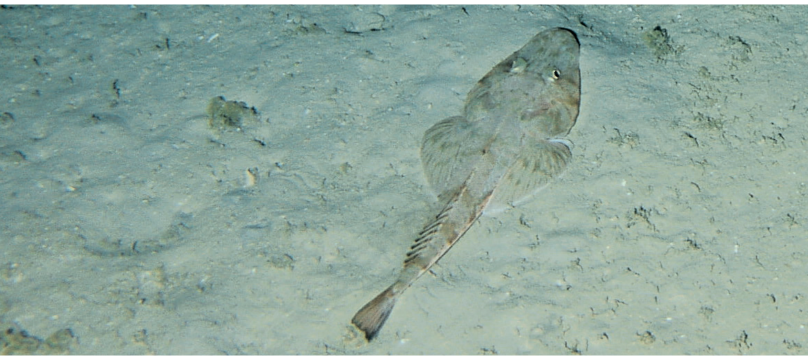
2015/0817 June 2018

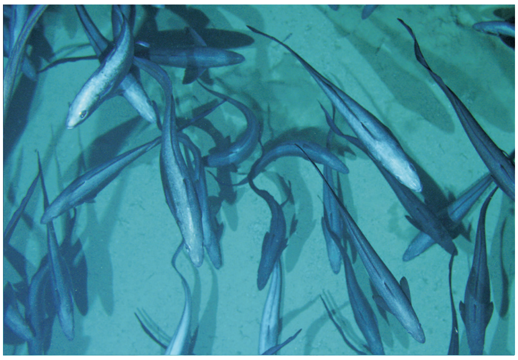
Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2016 and 2017

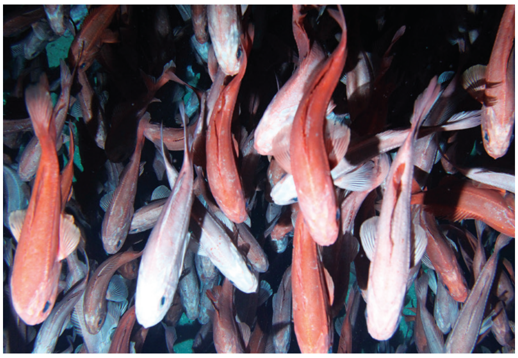
PART
2


2017









Principal investigator **G.N. Tuck**

www.afma.gov.au
Protecting our fishing future

Box 7051, Canberra Business Centre, ACT 2610 Tel **(02) 6225 5555** Fax (02) 6225 5500 **AFMA Direct 1300 723 621**

Stock Assessment for the Southern and Eastern scalefish and shark fishery 2016 and 2017.
Report Ref # 2015/0817.
By PI: Tuck, G.N.
June 2018 - ONLINE

ISBN 978-1-4863-1012-8

Preferred way to cite this report

Tuck, G.N. (ed.) 2018. Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2016 and 2017. Part 2, 2017. Australian Fisheries Management Authority and CSIRO Oceans and Atmosphere, Hobart. 837p.

Acknowledgements

All authors wish to thank the science, management and industry members of the south east, GAB and shark resource assessment groups for their contributions to the work presented in this report. Authors also acknowledge support from Fish Ageing Services (for fish ageing data) and AFMA (for the on-board and port length-frequencies, and in particular John Garvey, for the log book data). Toni Cracknell is greatly thanked for her assistance with the production of this report.

Cover photographs

Front cover, jackass morwong, orange roughy, blue grenadier, and flathead.

Report structure

Parts 1 and 2 of this report describe the assessments of 2016 and 2017 respectively

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2016 and 2017

Part 2: 2017

G.N. Tuck
June 2018
Report 2015/0817

Australian Fisheries Management Authority

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2017

TABLE OF CONTENTS

1. NON-TECHNICAL SUMMARY 1
   1.1 OUTCOMES ACHIEVED 1
   1.2 GENERAL 1
   1.3 SLOPE, SHELF AND DEEPWATER SPECIES 3
   1.4 SHARK SPECIES 5
   1.5 GAB SPECIES 6
2. BACKGROUND 8
3. NEED 9
4. OBJECTIVES 9
5. EXECUTIVE SUMMARY: CATCH RATE STANDARDIZATIONS FOR SELECTED SESSF SPECIES (DATA TO 2016) 10
   5.1 SUMMARY 10
   5.2 INTRODUCTION 10
   5.3 METHODS 10
   5.4 ACTION ITEMS AND ISSUES BY FISHERY 11
   5.5 ACKNOWLEDGEMENTS 20
   5.6 REFERENCES 20
6. BLUE-EYE AUTO-LINE AND DROP-LINE CATCH-PER-HOOK (DATA 1997 - 2016) 21
   6.1 INTRODUCTION 21
   6.2 INTRODUCTION 22
   6.3 OBJECTIVES 27
   6.4 RESULTS 30
   6.5 DISCUSSION 39
   6.6 CONCLUSIONS 41
   6.7 REFERENCES 41
7. CATCH RATE STANDARDIZATIONS FOR SELECTED SESSF SPECIES (DATA TO 2016) 43
   7.1 INTRODUCTION 43
   7.2 THE LIMITS OF STANDARDIZATION 43
   7.3 METHODS 44
   7.4 JOHN DORY 10 – 20 45
   7.5 SCHOOL WHITING 60 55
   7.6 SCHOOL WHITING TW 10 20 91 63
   7.7 SCHOOL WHITING TW 10 20 72
   7.8 MIRROR DORY 10 – 30 81
   7.9 MIRROR DORY 40 – 50 90
   7.10 JACKASS MORWONG 30 99
   7.11 JACKASS MORWONG 10 – 20 108
   7.12 JACKASS MORWONG 40 – 50 117
   7.13 SILVER WAREHOU 40 – 50 126
   7.14 SILVER WAREHOU 10 – 30 135
   7.15 FLATHEAD TW 30 144

7.16 Flathead TW 10 – 20 153
7.17 FlatheadDS2060 162
7.18 Redfish 10 – 20 170
7.19 Blue-Eye Trevalla TW 2030 179
7.20 Blue-Eye Trevalla TW 4050 188
7.21 Blue-Grenadier Non-Spawning 197
7.22 Pink Ling 10 – 30 206
7.23 Pink Ling 40 – 50 215
7.24 Ocean Perch Offshore 1020 224
7.25 Ocean Perch Offshore 1050 233
7.26 Ocean Perch Inshore 1020 245
7.27 Ocean Jackets 1050 254
7.28 Ocean Jackets GAB 263
7.29 Western Gemfish 4050 272
7.30 Western Gemfish 4050GAB 281
7.31 Western Gemfish GAB 290
7.32 Blue Warehouse 10 – 30 299
7.33 Blue Warehou 40 – 50 308
7.34 Deepwater Flathead 317
7.35 Bight Redfish 326
7.36 Ribaldo 10-50 335
7.37 RibaldoAL 344
7.38 Silver Trevally 1020 352
7.39 Silver Trevally 1020 - No MPA 361
7.40 Royal Red Prawn 10 370
7.41 Eastern Gemfish NonSpawning 10-40 379
7.42 Eastern Gemfish Sp 388
7.43 Alfonsino 397
7.44 Acknowledgements 406
7.45 References 406

8. CPUE STANDARDIZATIONS FOR SELECTED SHARK SESSF SPECIES (DATA TO 2016) 407

8.1 Executive Summary 407
8.2 Introduction 408
8.3 Methods 409
8.4 Gummy shark: South Australia Gillnet 411
8.5 Gummy shark: Bass Strait Gillnet 420
8.6 Gummy shark: Tasmania Gillnet 429
8.7 Gummy shark: Trawl 438
8.8 Gummy shark Bottom Line 447
8.9 School shark Trawl 456
8.10 Sawshark Gillnet 465
8.11 Sawshark Trawl 474
8.12 Sawshark Danish Seine 484
8.13 Elephant Fish: Gillnet 494
8.14 Acknowledgements 503
8.15 References 503

9. YIELD, TOTAL MORTALITY VALUES AND TIER 3 ESTIMATES FOR SELECTED SHELF AND SLOPE SPECIES IN THE SESSF 2017 504

9.1 Summary 504
9.2 Methods 505
9.3 Results 513
9.4 Acknowledgements 517
9.5 References 517
9.6 Appendix 1 – Data summary for John Dory 520
9.7 Appendix 2 – details of values that were used as estimates of total Z (shown highlighted) 521

10. TIER 4 ASSESSMENTS FOR BLUE EYE 522

10.1 INTRODUCTION 522
10.2 BLUE EYE NON-TRAWL 524

11. TIER 4 ANALYSIS FOR ELEPHANT FISH AND SAWSHARK 526

11.1 EXECUTIVE SUMMARY 526
11.2 INTRODUCTION 527
11.3 ELEPHANT FISH (CALLORHINCHUS MILII) DISCARDS 529
11.4 ELEPHANT FISH (CALLORHINCHUS MILII) - NO DISCARDS 531
11.5 SAWSHARK 533
11.6 APPENDIX: METHODS 535
11.7 REFERENCES 541

12. SCHOOL WHITING (*SILLAGO FLINDERSI*): ADDITIONAL DATA AND 2017 ASSESSMENT OPTIONS 542

12.1 SCHOOL WHITING 542
12.2 ACKNOWLEDGEMENTS 545
12.3 REFERENCES 545

13. DISCUSSION PAPER: OPTIONS FOR USE OF NSW DATA IN A SCHOOL WHITING ASSESSMENT IN 2017 546

13.1 CURRENT ASSESSMENT 546
13.2 ISSUE 546
13.3 ACKNOWLEDGEMENTS 547
13.4 REFERENCES 547

14. SCHOOL WHITING (*SILLAGO FLINDERSI*) STOCK ASSESSMENT BASED ON DATA UP TO 2016 – DEVELOPMENT OF A PRELIMINARY BASE CASE 548

14.1 EXECUTIVE SUMMARY 548
14.2 INTRODUCTION 548
14.3 ACKNOWLEDGEMENTS 557
14.4 REFERENCES 557
14.5 APPENDIX A 558

15. SCHOOL WHITING (*SILLAGO FLINDERSI*) STOCK ASSESSMENT BASED ON DATA UP TO 2016 588

15.1 EXECUTIVE SUMMARY 588
15.2 INTRODUCTION 589
15.3 METHODS 592
15.4 RESULTS AND DISCUSSION 615
15.5 ACKNOWLEDGEMENTS 635
15.6 REFERENCES 635
15.7 APPENDIX A 637

16. REDFISH (*CENTROBERYX AFFINIS*) STOCK ASSESSMENT BASED ON DATA UP TO 2016 – DEVELOPMENT OF A PRELIMINARY BASE CASE 664

16.1 EXECUTIVE SUMMARY 664
16.2 INTRODUCTION 664
16.3 RESULTS 674
16.4 ACKNOWLEDGEMENTS 677
16.5 REFERENCES 677
16.6 APPENDIX A 678

17. REDFISH (*CENTROBERYX AFFINIS*) STOCK ASSESSMENT BASED ON DATA UP TO 2016 691

17.1 EXECUTIVE SUMMARY 691
17.2 INTRODUCTION 691
17.3 RESULTS 699
17.4 FUTURE DIRECTIONS 707
17.5 ACKNOWLEDGEMENTS 711
17.6 REFERENCES 711

17.7 APPENDIX A 713
17.8 APPENDIX B 724

18. ORANGE ROUGHY EAST (*HOPLOSTETHUS ATLANTICUS*) STOCK ASSESSMENT USING DATA TO 2016 - DEVELOPMENT OF A PRELIMINARY BASE CASE 730

18.1 SUMMARY 730
18.2 INTRODUCTION 731
18.3 METHODS 733
18.4 RESULTS 743
18.5 DISCUSSION 752
18.6 ACKNOWLEDGEMENTS 753
18.7 REFERENCES 753
18.8 APPENDIX A 758

19. ORANGE ROUGHY EAST (*HOPLOSTETHUS ATLANTICUS*) STOCK ASSESSMENT USING DATA TO 2016 760

19.1 SUMMARY 760
19.2 INTRODUCTION 762
19.3 METHODS 765
19.4 RESULTS 774
19.5 DISCUSSION 796
19.6 ACKNOWLEDGEMENTS 798
19.7 REFERENCES 798
19.8 APPENDIX A 804

20. WESTERN ORANGE ROUGHY 806

20.1 SUMMARY 806
20.2 INTRODUCTION 806
20.3 OBJECTIVES 807
20.4 RESULTS 808
20.5 THE STATISTICAL ANALYSIS 810
20.6 ACKNOWLEDGEMENTS 818
20.7 REFERENCES 818
20.8 APPENDIX 1: ORANGE ROUGHY DATA 821

21. ON THE POTENTIAL EFFECTS OF A SEISMIC SURVEY ON COMMERCIAL FISHERY CATCH RATES IN THE GREAT AUSTRALIAN BIGHT 822

21.1 INTRODUCTION 822
21.2 RESULTS 827
21.3 DISCUSSION AND SUMMARY 827
21.4 RECOMMENDATIONS 828
21.5 ACKNOWLEDGEMENTS 829
21.6 REFERENCES 829
21.7 APPENDIX – SURVEY COORDINATES 830
21.8 APPENDIX – STANDARDIZATION RESULTS 831

22. BENEFITS 833

23. CONCLUSION 834

24. APPENDIX: INTELLECTUAL PROPERTY 836

25. APPENDIX: PROJECT STAFF 837

1. Non-Technical Summary

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2016 and 2017

PRINCIPAL INVESTIGATOR: Dr Geoffrey N. Tuck

ADDRESS:
CSIRO Oceans and Atmosphere
GPO Box 1538
Hobart, TAS 7001
Australia
Telephone: 03 6232 5222 Fax: 03 6232 5053

OBJECTIVES:

- Provide quantitative and qualitative species assessments in support of the four SESSFRAG assessment groups, including RBC calculations within the SESSF harvest strategy framework
- 2016: Provide Tier 1 assessments for Deepwater flathead, Gummy shark, Tiger flathead, Eastern gemfish (subject to SESSFRAG advice) and School whiting data analysis; and Tier 4 assessments for Blue eye trevalla and Mirror dory
- 2017: Provide Tier 1 assessments for Blue grenadier (deferred to 2018), Redfish, East Roughy and School whiting; Tier 3 for Alfonsino, John Dory; Tier 4 for E/W Deepwater shark, Ocean Perch, Oreo basket, Ribaldo, Royal Red Prawn, and Silver Trevally

1.1 Outcomes Achieved

The 2017 assessments of stock status of the key Southern and Eastern Scalefish and Shark fishery (SESSF) species are based on the methods presented in this report. Documented are the latest quantitative assessments for the SESSF quota species. Typical assessment results provide indications of current stock status, in addition to an application of the recently introduced Commonwealth fishery harvest control rules that determine a Recommended Biological Catch (RBC). These assessment outputs are a critical component of the management and Total Allowable Catch (TAC) setting process for these fisheries. The results from these studies are being used by SESSFRAG, industry and management to help manage the fishery in accordance with agreed sustainability objectives.

1.2 General

Catch rate standardisations

Catch-per-unit-effort (CPUE) data is an important input to many of the stock assessments conducted within the South East and Southern Shark Fishery (SESSF), where it is used as an index of relative abundance through time. The catch and effort logbook data from the SESSF, which is the source of

CPUE data, constitutes shot by shot data derived from a wide range of vessels, areas (zones), months, depths, and fishing gears. Catch rates used in the assessments are standardized to reduce the effects of factors such as which vessel fished, where and when fishing occurred, the gear used, at what depths fishing was conducted, and whether fishing occurred during the day or night. The intent is to focus on any changes in catch rates that occurred between years as a result of changes in stock size rather than changes that occur in any of these other factors. This intent is not always realized when there are unknown influential factors or factors for which we have no data, so interpretation of the catch rate trends should not necessarily be taken at face value. This is especially the case when there have been major management changes, such as the introduction of quotas or the more recent structural adjustment. Such large events can greatly influence fishing behaviour, which in turn influences catch rates. Because these changes affected the whole fleet at the same time it is not possible to standardize for their effects.

Catch rates, generally as kilograms per hour fished (though sometimes as catch per shot *e.g.* Danish Seine, or non-trawl methods), were natural log-transformed to normalize the data and stabilize the variance before standardization. A General Linear Model was used rather than using a Generalized Linear Model with a log-link. This simple analytical approach means that the exact same methods can be applied to all species/stock combinations in a relatively robust manner. The statistical models fitted were of the form: LnCE = Year + Vessel + Month + Depth Category + Zone + DayNight. There were interaction terms which could sometimes be fitted, such as Month:Zone or Month:Depth_Category. Data from all vessels reporting catches of a species were included although a preliminary data selection was made on a given depth range for each species for the zones of interest to focus attention on those depths contributing significantly to the fishery for each assumed stock and to reduce the number of empty categories within the statistical models.

Documented are the statistical standardization of the commercial catch and effort data for 21 species, distributed across 40 different combinations of stocks and fisheries ready for inclusion in the annual round of stock assessments. These include School Whiting, Eastern Gemfish, Jackass Morwong, Flathead, Redfish, Silver Trevally, Royal Red Prawn, Blue Eye, Blue Grenadier, Spotted/Silver Warehou, Blue Warehou, Pink Ling, Western Gemfish, Ocean Perch, John Dory, Mirror Dory, Ribaldo, Ocean Jackets, Deepwater Flathead and Bight Redfish.

A separate blue-eye catch catch per hook analysis found that diversity of methods used to fish for Blue-Eye and the patchy nature of the fishing grounds mean that there is no simple analysis that can be used to summarize the fishery as a whole. Nevertheless, it remains possible to focus on the methods that lead to the greatest proportion of the catches. It has proven possible to develop relatively simple algorithms that allows for an alternative, intuitively more realistic measure of CPUE. Separate and different algorithms for handling the drop-line and auto-line data within the catch and effort database are required to enable effort in each case to be characterized in terms of total number of hooks set.Using those algorithms the drop-line and auto-line data have again been re-structured and catch-rates estimates in terms of kg/hook for both methods have been generated. As has been done previously, it was possible to combine the two, using a catch weighted approach over the overlap period. When this was done for both the catch-per-hook and catch-per-day data the outcome of the standardization was rather different. The combined standardized CPUE has been noisy but relatively flat since 2002, whereas the trend catch-per-day CPUE has been noisy but downwards since about 1998.

Yield, total mortality values and Tier 3 analyses

Yield and total mortality estimates are provided for John dory caught in the SESSF. Yield estimates were made using a yield-per-recruit model with the following input: selectivity-at-age, length-at-age, weight-at-age, age-at-maturity, and natural mortality. Total mortality values corresponding to various reference equilibrium biomass depletions were calculated.

Recent average total mortality was estimated from catch curves constructed from length frequency information. Length frequency data were from ISMP port and/or onboard measurements. New ageing data were available for John Dory in 2017, the previous sampling was from 2011. Including the new ageing data (2010 to 2016), the 2018 RBC for John Dory is 485t, compared to the 2013 RBC of 203t.

Tier 4 analyses 1986 - 2016

The Tier 4 harvest control rule is applied to species for which there is no reliable information on either current biomass levels or current exploitation rates. Ideally, in line with the notion of being more precautionary in the absence of information, the outcome from these analyses should be more conservative than those available from higher Tier analyses; this is now explicitly implemented by imposing a 15% discount factor on the RBC as a precautionary measure, unless there are good reasons for not imposing such an discount on particular species. The default procedure will now be to apply the discount factor unless RAGs generate advice that alternative and equivalent precautionary measures are in place (such as spatial or temporal closures) or that there is evidence of historical stability of the stock at current catch levels. Tier 4 analyses require, as a minimum, knowledge of the time series of total catches and of catch rates, either standardized or simple geometric mean catch rates. This year, only standardized catch rates were used except where discards were explicitly included in the analyses.

Tier 4 assessments were conducted on Blue Eye, Mirror Dory East and West, Western Gemfish, Silver Trevally, Deepwater sharks, Ocean Perch and Mixed oreos. The Mirror Dory analyses treat the west and east as separate stocks, and also include the high levels of discards that occur in the east. Estimated RBCs for Mirror Dory East were 201t (199 t with discards), Mirror Dory West 123t (112t with discards), Western Gemfish Z4050 436t, silver trevally 445 t, Eastern Deepwater Sharks was 9t, Western Deepwater Sharks was 313 t, Offshore Ocean Perch was 344 t, Inshore Ocean Perch was 248t, Mixed Oreos was 135 t (256 t with discard), Ribaldo was 430t and Royal Red Prawn 431 t. The Blue eye estimated RBC was 482 t.

1.3 Slope, Shelf and Deepwater Species

School whiting

The 2009 assessment of school whiting (*Sillago flindersi*) was updated to provide estimates of stock status in the SESSF at the start of 2018. The 2009 stock assessment was updated with the inclusion of data up to the end of 2016, comprising an additional eight years of catch, discard, CPUE, length and age data and ageing error updates. A range of sensitivities were explored.

A preliminary base case was presented at the September SERAG meeting and a provisional base case at the November SERAG meeting, with improvements to the balancing of the conditional age-at-length in the provisional base case and incorporating fixes to a bug discovered in Stock Synthesis in the interim. Following the November SERAG meeting, the November provisional base case was updated by changing the spawning month from July to January, at the request of SERAG, and a further variation was produced with improvements to the estimated growth curve, again with January spawning. This gave a choice of 3 fully balanced alternative base cases to be considered by SERAG in December 2017. SERAG chose the base case with January spawning and improved growth fits.

The base-case assessment estimates that current spawning stock biomass is 47% of unexploited stock biomass (SSB_0). Under the agreed 20:35:48 harvest control rule, the 2018 recommended biological catch (RBC) is 1,606 t, with the long term yield (assuming average recruitment in the future) of 1,641 t. The average RBC over the three year period 2018-2020 is 1,615 t and over the five year period 2018-2022, the average RBC is 1,621 t.

Exploration of model sensitivity showed variation in spawning biomass across all sensitivities ranging from 39% to 57% of SSB_0 with greatest sensitivity to age at 50% maturity. A preliminary sensitivity removing all catch data north of Barrenjoey Point resulted in a depletion of 17%, but the resulting estimate of mortality was unrealistically low. This sensitivity was repeated with mortality fixed at 0.6, corresponding to the fixed value for mortality used in the 2008 assessment which resulted in a 2018 depletion of 39%.

Redfish

The base case assessment for eastern redfish (*Centroberyx affinis*) was updated from the last full assessment in 2014. A base case assessment was achieved according to the RAG-agreed model structure that did not separate length data by zone. The model fits to the catch rate data, length data and conditional age-at-length data reasonably well. The magnitude of the estimated recruitment in 2011 in the 2014 assessment has been greatly reduced in the 2017 assessment (although estimates of recent recruitment have increased compared to the period of poor recruitment during 2002-2010). The assessment estimates that the projected 2018 spawning stock biomass will be 8% of virgin stock biomass (projected assuming 2016 catches in 2017). Estimates of recruitment since the early 2000s have been lower than average (except for 2011, 2012), potentially as a consequence of directional environmental change influencing productivity. Low recruitment scenarios using average historical recruitment residuals from 2001 to 2010 for future projections of constant annual catches showed a markedly slow increase in spawning biomass for annual catches of 50t. Catches of 150t were not sustainable under this low recruitment assumption.

Initial difficulties in reaching a tuned base case according to the RAG-agreed model structure led to several attempts at alternative models (such as single and two selectivity models to fit to port and onboard length data, fixing parameters, and removing EBass and Sydney Fish Market length data). As part of the investigation into this issue, a breakdown of the length data by year, month, zone, onboard/port, discarded and retained was conducted. This revealed that there are distinct differences between Eastern Bass (EBass) and NSW port lengths. EBass port lengths are considerably larger than NSW port lengths, with ascending limbs beginning at ~10cm for NSW and ~15-20cm for EBass. This appears to be driven by different discard practices, as the distribution of caught fish lengths from the onboard length data are similar for EBass and NSW. As such, future models should consider data separated by zone, with a different discard function estimated for each zone.

Orange roughy

The stock assessment for Eastern Zone Orange Roughy (*Hoplostethus atlanticus*) was updated from the last assessment in 2015. As in the last assessment it assumes a stock structure that combines the Eastern Zone (primarily St Helens Hill and St Patricks Head) and Pedra Branca from the Southern Zone (all seasons). New data included since the previous stock assessment were recent research and commercial catches; relative spawning biomass estimates from the 2016 acoustic towed surveys at St

Helens Hill and St Patricks Head, a revised index of spawning biomass from the 2013 towed acoustic survey (which derived from a re-calibration of the survey gear), and new age composition data from catches taken in 2012 and 2016.

After examination of the likelihood profiles around the fixed parameters of natural morality (M) and the stock recruitment relationships steepness (h), a better fit and more plausible biological model was used as a final base-case that used an $M = 0.036$ rather than 0.04 and an $h = 0.6$ instead of 0.75. In the end after rebalancing of variances and effective sample sizes this had only minor effects on the model fit to the data (although minor improvements did occur). However, the productivity of the model was reduced so that the implied increase in the stock between 2014 and 2017 was no longer so great and yet still constituted a 5% increase in stock biomass from about 25%B_0 to about 30%B_0. The ageing data is intrinsically noisy, especially as the sample sizes are typical of SESSF fisheries but there are 80 year classes and samples of up to 600 fish still generate age-composition distributions with a very spiky appearance. Despite the limited data available the outcome from the model is relatively robust and stable although highly dependent upon the assumptions made about natural mortality and the steepness of the stock recruitment relationship.

The 2018 RBC was 709t for (M=0.036, h=0.6) and 1314t for (M=0.04, h=0.75). The respective depletions in 2017 were 0.298 and 0.338. A risk assessment was also conducted. Applying the projected catches from one base-case into the other base-case enables a test of the potential risk of applying the catches from one model when the other model is more correct. However, according to the predictions made by the current assessment model (within the precision of estimates currently possible), any differences derived from applying either predicted RBC time series (or average) over the next three years would be difficult to distinguish from applying the correct catches.

Western orange roughy

The recovery of the Eastern zone (roughy zone 10) Orange Roughy (*Hoplostethus atlanticus*) has raised interest in the current status of other Orange Roughy stocks, in particular that in the Western zone (zone 30). Previous stock assessments primarily used standardized CPUE but only analysed data to 2001. An updated CPUE standardization for catch and effort data from Orange Roughy zone 30 up to the beginning of the deep water closure that was installed in 2007 was conducted. While the model only described about 17% of the variation in the available data, which is a reflection of high levels of variation at the start and end of the time series, much of which was due to low numbers of observations. Nevertheless, between 2002 - 2006 there was a three-fold increase in the standardized CPUE.

1.4 Shark Species

Shark catch rate standardisations

For school shark, the standardized catch-per-unit effort has continued to increase, with the exception of 2014. This is a positive sign, which when combined with the observation of increased proportions of smaller school sharks is evidence of school sharks showing some signs of recovery. There has been an increase in gillnet gummy shark standardized CPUE in South Australia and Bass Strait since 2015, but around Tasmania remained flat since 2014. Standardized CPUE for trawl has increased steadily since 2012, remaining above the long-term average. By contrast, standardized CPUE for bottom line has remained flat and noisy since 2012. Elephant fish are a non-targeted species, as indicated by the large proportion of small shots (i.e. <30 kg). Gillnet standardized CPUE is flat and noisy, while decreasing in 2015, increased in 2016. In recent years discard rates for elephant fish have been very high, which may imply that their CPUE is in fact increasing. Sawshark are considered to be a bycatch group which is supported by the high proportion of < 30 kg. Trawl caught sawshark standardized indices exhibit a noisy but flat trend, with an increase in 2014 reaching the long term average and an overall decrease below the long term average in 2016. By contrast, Danish seine (which has the highest proportion of shots < 30 kg among methods) CPUE has been flat since 2006 and increased above the long-term average in 2015.

Saw shark and elephant fish Tier 4 analyses

The Tier 4 assessment is used to calculate RBCs for saw sharks (*Pristiophorus* sp.) and elephant fish (*Callorhinchus milii*). In 2014, standardized gillnet-CPUE for elephant fish fell below the long-term mean, with increases in recent years. However, the annual standardized-CPUE indices do not include discards, which since 2007, and particularly since 2011 have been found to be large. Including discards in the calculation of CPUE, total catch and updated recreational catch in a Tier 4 analysis increased CPUE, and increased the estimated RBC (469.09 t). This RBC estimate corresponds to a 163.5 t increase compared to the 2015 RBC estimate (305.614 t). When discards are relatively high, as is the case with elephant fish then including discards more closely reflects the fishery dynamics. The Tier 4 method used to adjust CPUE to account for discarding assumes that a portion of each shot of elephant fish catch is discarded. If a significant portion of shots of elephant fish catch are entirely discarded then this assumption is violated and the adjustment will be biased high because catches that were entirely discarded, contributed to, and inflated, the estimated discard rate, but did not contribute to the standardized CPUE. In addition, once discard rates become greater than 0.5 then more fish are discarded than landed. As the discard rate increases the multiplier effect this has increases in a non-linear fashion (see Appendix). Above a rate of approximately 0.6 or 0.65 the risk of the total catches being biased high by the inclusion of discards will increase. Given the discard rates of elephant fish, the question arises of whether to accept the discard modified Tier 4 assessment or whether to use the non-discard adjusted assessment without removing discards from the RBC when generating a TAC. Given the high discard rates for elephant fish, it was recommended by SharkRAG that a Tier 4 analysis excluding discards be conducted. The RBC estimate for elephant fish (excluding discards) was 293 t. This corresponds to a 12.36 t decrease compared to the 2015 RBC estimate. The estimated RBC for sawshark was 519 t, an approximate 16.4 t reduction compared to the RBC estimated in 2015.

1.5 GAB Species

Seismic survey analysis

The 2015 FIS occurred at the same time as a seismic survey approximately in the center of the GAB. The concern was raised that the seismic survey, which entails the use of large scale transducers that couple couple a large amount of acoustic energy into the ocean, had led to the results of the 2015 FIS being biased low. The commercial catch and effort data were examined to determine whether there were unexpected or unusual effects occurring at the same time. Results showed a significant drop in the observed CPUE from the fishery independent survey of the fishery in the GAB, conducted in 2015, that was very likely negatively influenced by it being run coincidently with the seismic survey. Fortunately, the seismic survey does not appear to have had a lasting impact on Deepwater Flathead CPUE, which returned to typical values in the first month following the seismic survey. Catches took on a different pattern from usual, which may indicate that the drop off in commercial CPUE altered the fleet's fishing behaviour. This work suggests that future Fishery Independent Surveys of fish stocks should not be undertaken at the same time as a proximate seismic survey (where proximate could mean within 60 or possibly many more nautical miles). Given the scale of the bias in CPUE from the 2015 seismic survey, the results from the 2015 FIS should not be included in future stock assessments of either Deepwater Flathead or Bight Redfish.

KEYWORDS: fishery management, southern and eastern scalefish and shark fishery, stock assessment, trawl fishery, non-trawl fishery

2. Background

The Southern and Eastern Scalefish and Shark Fishery (SESSF) is a Commonwealth-managed, multi-species and multi-gear fishery that catches over 80 species of commercial value and is the main provider of fresh fish to the Sydney and Melbourne markets. Precursors of this fishery have been operating for more than 85 years. Catches are taken from both inshore and offshore waters, as well as offshore seamounts, and the fishery extends from Fraser Island in Queensland to south west Western Australia.

Management of the SESSF is based on a mixture of input and output controls, with over 20 commercial species or species groups currently under quota management. For the previous South East Fishery (SEF), there were 17 species or species groups managed using TACs. Five of these species had their own species assessment groups (SAGs) – orange roughy (ORAG), eastern gemfish (EGAG), blue grenadier (BGAG), blue warehou (BWAG), and redfish (RAG). The assessment groups comprise scientists, fishers, managers and (sometimes) conservation members, meeting several times in a year, and producing an annual stock assessment report based on quantitative species assessments. The previous Southern Shark Fishery (SSF), with its own assessment group (SharkRAG), harvested two main species (gummy and school shark), but with significant catches of saw shark and elephantfish.

In 2003, these assessment groups were restructured and their terms of reference redefined. Part of the rationale for the amalgamation of the previous separately managed fisheries was to move towards a more ecosystem-based system of fishery management (EBFM) for this suite of fisheries, which overlap in area and exploit a common set of species. The restructure of the assessment groups was undertaken to better reflect the ecological system on which the fishery rests. To that end, the assessment group structure now comprises:

- SESSFRAG (an umbrella assessment group for the whole SESSF)
- South East Resource Assessment Group (Slope, Shelf and Deep RAG)
- Shark Resource Assessment Group (Shark RAG)
- Great Australian Bight Resource Assessment Group (GAB RAG)

Each of the depth-related assessment groups is responsible for undertaking stock assessments for a suite of key species, and for reporting on the status of those species to SESSFRAG. The plan for the resource assessment groups (South East, GAB and Shark RAGs) is to focus on suites of species, rather than on each species in isolation. This approach has helped to identify common factors affecting these species (such as environmental conditions), as well as consideration of marketing and management factors on key indicators such as catch rates.

The quantitative assessments produced annually by the Resource Assessment Groups are a key component of the TAC setting process for the SESSF. For assessment purposes, stocks of the SESSF currently fall under a Tier system whereby those with better quality data and more robust assessments fall under Tier 1, while those with less reliable available information are in Tiers 3 and 4. To support the assessment work of the four Resource Assessment Groups, the aims of the work conducted in this report were to develop new assessments if necessary (under all Tier levels), and update and improve existing ones for priority species in the SESSF.

3. Need

A stock assessment that includes the most up-to-date information and considers a range of hypotheses about the resource dynamics and the associated fisheries is a key need for the management of a resource. In particular, the information contained in a stock assessment is critical for selecting harvest strategies and setting Total Allowable Catches.

4. Objectives

- Provide quantitative and qualitative species assessments in support of the four SESSFRAG assessment groups, including RBC calculations within the SESSF harvest strategy framework
- 2016: Provide Tier 1 assessments for Deepwater flathead, Gummy shark, Tiger flathead, Eastern gemfish (subject to SESSFRAG advice) and School whiting data analysis; and Tier 4 assessments for Blue eye trevalla and Mirror dory
- 2017: Provide Tier 1 assessments for Blue grenadier, Redfish, East Roughy and School whiting; Tier 3 for Alfonsino, John Dory; Tier 4 for E/W Deepwater shark, Ocean Perch, Oreo basket, Ribaldo, Royal Red Prawn, and Silver Trevally

5. Executive Summary: Catch rate standardizations for selected SESSF Species (data to 2016)

Malcolm Haddon and Miriana Sporcic

CSIRO Oceans and Atmosphere, GPO Box 1538, Hobart, TAS 7001,
Australia

5.1 Summary

This document attempts to summarize the main findings made in Haddon and Sporcic (2017) regarding the standardization of 42 fisheries using statistical models customized to suit each set of circumstances. Visual summaries of all optimum statistical models are presented along with tables of the properties of each dataset and any issues that the standardizations may have raised for each species.

5.2 Introduction

The latest CPUE standardization document (Haddon and Sporcic, 2017) has been produced in an effort to reduce the tedious repetitive aspects of relatively routine analyses typically requierd when dealing with fisheries statistics. Such automation is only suitable for processes that have achieved a degree of agreement concerning methods and details. In the SESSS, CPUE standardizations have been produced and developed since the late 1990s (e.g. Haddon, 1999) and they make an ideal candidate for such automation. Changes in methodology are uncommon from year to year and there are very many analyses to be conducted.

The final document is relatively long because now many more diagnostic plots and tables can be included to enhance our capacity to understand what factors are potentially influencing catch rates.

This present document aims to summarize the results within (Haddon and Sporcic, 2017) across all species and tabulate any issues raised by the data from particular species.

5.3 Methods

Part of the output from Haddon and Sporcic (2017) is a table of the optimum statistical models for each fishery analysed. To provide a visual summary of these outcomes all 42 CPUE trends are individually plotted and a Loess curve fitted to the annual mean CPUE estimates to illustrate the general trend. In addition, the root mean square error (RMSE), sometimes referred to as the root mean squared deviation (RMSD), is calculated to provide an indication of how variable the mean annual estimates are around the central trend line. Essentially this is attempting to measure the average difference between two time series. The equation used for the RMSE was:

$$RSME = \sqrt{\frac{\sum_{i=1}^{n}\left(\hat{I}_i - \hat{L}_i\right)^2}{n}}$$

where $\hat{I}_i$ is the expected mean CPUE in year i, $\hat{L}_i$ is the predicted Loess trend value for year i, and n is the number of years. The *loess* function in **R** was used for the calculations (R Core Team, 2017).

Two forms of the same data were plotted; the first with a constant y-axis scale to provide a visual impression of the variation of CPUE through time in each fishery relative to every other fishery, and a second where each plot is given its own y-axis scale to maximize the vertical contrast and exhibit the details of any trends that exist.

5.3.1 *Analyses Included*

For some species/fisheries analysed, the conclusion reached was that they were there primarily for historical reasons. Thus, prior to Mirror Dory being considered separately on the east and west coasts (Mirror Dory 10, 20, and 30, and Mirror Dory 40 and 50) a single analysis of the whole of Mirror Dory was made. For reasons that are no longer clear this combined analysis is still produced, which has the potential to be confusing and so it is recommended here that it be stopped. Such decisions are required for Inshore Ocean Perch and Western Gemfish4050GAB; Mirror Dory 10-50, here, has already been omitted, a decision to confirm that is required.

5.4 *Action Items and Issues by Fishery*

5.4.1 *Introduction*

The eponymous section from each fishery's analyses is extracted and printed to be considered for further action. Where a fishery/species is listed with no action items below it this implies none were written in the original document (Haddon and Sporcic, 2017). The intent of this section is to highlight to the RAG and other stakeholders potential issues that would receive further attention to resolve.

JohnDory1020

A potential change in fishing behaviour is suggested to have occurred since about 2014, which is evidenced by changes in the distribution of log-transformed CPUE each year. From 2014 a number of widely spread spikes in the histograms have become apparent, most especially in 2015 and 2016. The underlying driver for these changes is not immediately apparent.
```{r child="cpuetabsfigs.rmd"}

**SchoolWhiting60**

The qqplot suggests that the assumed Normal distribution of the log-transformed CPUE (in fact log(catch per shot) may be invalid, as relatively high proportions of the tails of the distribution deviate from the expected straight line. Further work is required to determine the reason behind the frequent occurrence of spikes of low values of catch-per-shot and how they may best be described or explained.
```

SchoolWhitingTW

Again the last three years 2014 - 2016 appear to have exhibited an alteration in fishing behaviour as evidenced by the changing distributions of records of catch at depth, why this has occurred in the last three years remains unknown.

SchoolWhitingTW1020

The depth distribution of catches has not been stable from year to year, which may reflect the fact that there are only few vessels contributing seriously to this fishery.

MirrorDory1030

No issues identified.

MirrorDory4050

It is recommended that the CPUE time-series only be used from 1995 onwards because the catches before then are relatively minor. Whatever the case, from 1990 the CPUE trend appears to be relatively flat and noisy around the long term average with periods above and below.

JackassMorwong30

The RAG recommended depth for Jackass Morwong 30 is from 70 - 300 m. However, there are records in Zone 30 from 0 - 500 metres but only significant catches out to 200m or 250m at most. The reasons for the earlier specific depth selection need to be re-iterated and an examination of the effect of making the current depth selection explored.

JackasssMorwong1020

The structural adjustment altered the effect of the vessel factor on the standardized result. However, log(CPUE) has also changed in character from 2014 - 2016, with spikes of low catch rates arising.

JackasssMorwong4050

The vessel factor changed its influence from 2001 onwards reflecting the increase in catches from 2001 and suggesting the fishery changed remarkably at that time. The reasons behind this change should be explained in more detail.

SilverWarehou4050

After consideration of Silver Warehou catches in zones 40 - 50 by year and vessel, the period around 1999 - 2006 appears exceptional, or at least contains exceptional vessels, all of which left the fishery after the structural adjustment. This suggests that there have been transitional periods in the time-series of CPUE. This **urgently** needs more attention because this may imply that CPUE may no longer be acting as a valid index of relative abundance through time.

SilverWarehou1030

After consideration of Silver Warehou catches in zones 10 - 30 by year and vessel the period around 1992 - 2006 appears exceptional, or at least contains exceptional vessels. This suggests that there have been transitional periods in the time-series of CPUE. This **urgently** needs more attention because of the potential implications this has for the index of relative abundance through time.

FlatheadTW30

The number of records and corresponding catch in 1986 and 1987 are very low. Also, the depth distribution spread over a large range for these two years compared to all other years in the fishery. It is therefore recommended to removes these two years from the time series for analysis.

FlatheadTW1020

After consideration of Tiger Flathead catches in the east by year and vessel for the period around 1992 - 2006 appears to be different from catches by vessel from 2007. This suggests that there have been transitional periods in the time-series of CPUE. This **urgently** needs more attention because of the potential implications this has for the index of relative abundance through time.

FlatheadDS2060

It is recommended that an exploration of the fishery dynamics be evaluated to determine whether the CPUE values are being influenced by the species being targeted within individual shots (e.g. is there interference between shots catching mostly flathead comapred to shots catching mostly School Whiting?). This will be important for determining whether estimated annual indices adequately reflect stock abundance.

Redfish1020

After consideration of redfish catches in zones 10 and 20 by year and vessel, the period around 1993 - 2006 appears to be different to other years. This suggests that there have been transitional periods in the time-series of CPUE. This **urgently** needs more attention because of the potential implications this has for the index of relative abundance through time.

BlueEyeTW2030

Given the on-going low catches, and the recent even lower catches, the major changes in the fleet contributing to the fishery, the dramatically changing caharater os the CPUE data itself, and the recent disjunction between the nominal catch rates and the standardized catch rates it is questionable whether this time-series of CPUE is indicative in any useful way of the relative abundance of Blue-Eye Trevalla. Whether this analysis should be continued should be considered.

BlueEyeTW4050

If this analysis is to continue then the early CPUE data from 1988 - 1991 should be explored in more detail to ensure it is representative of the fishery and does not contain systematic errors. After introducing quota the CPUE distributions became more consistent through time, although relatively low numbers of observations are now contributing to a change in their character in the latest years.

BlueGrenadierNS

No issues identified.

PinkLing1030

A detailed consideration be given to the change in vessel effects following the structural adjustment to ensure that the time-series of Pink Ling CPUE was not broken by this management intervention.

PinkLing4050

Further work on the effect of the structural adjustment is required for Pink Ling in zones 40 and 50.

OceanPerchOffshore1020

No issues identified.

OceanPerchOffshore1050

The generally lower CPUE for Offshore Ocean Perch in zones 30, 40, and 50 suggest it is not a major target species in those zones. It is recommended that the Tier 4 for Offshore Ocean Perch continue using the analysis presented in Offshore Ocean Perch for zones 10 and 20 as catch rates in those zones would seem to be more indicative of the main location for the stock.

OceanPerchInshore1020

As the discarding rate continues to be very high ~90% of all catches) it is recommended that this analysis not be conducted as it may mistakenly be assumed to be informative of the stock's relative biomass through time.

OceanJackets1050

No issues identified.

OceanJacketsGAB

No issues identified.

gemfish4050

No issues identified.

gemfish4050GAB

This analysis is recommended to be abandoned as misleading through it combining the data from two biological stocks.

gemfishGAB

No issues identified.

bluewarehou1030

No issues identified.

bluewarehou4050

Exploration of the early CPUE data could be made to examine whether there are obvious or consistent errors leading to mean CPUE values 4 times greater than the long term average.

deepwaterflathead

No issues identified.

bightredfish

No issues identified.

ribaldo

It is recommended that the geographical distribution of catches be explored to determine how representative of the entire stock's distribution the early years are.

RibaldoAL

The first two or three years of data need to be examined to determine how representative these data are of the whole stock. It may also benefit from being converted to catch-per-hook rather than catch-per-shot.

SilverTrevally1020

Further exploration of the reasons behind the recent deviation of the standardized time-series from the nominal geometric mean are required to provide a more detailed explanation for these changed dynamics.

SilverTrevally1020nompa

Further exploration of the reasons behind the recent deviation of the standardized time-series from the nominal geometric mean are required to provide a more detailed explanaiton for these changed dynamics.

RoyalRedPrawn

No issues identified.

EasternGemfishNonSp

No issues identified.

EasternGemfishSp

No issues identified.

Alfonsino

No issues identified.

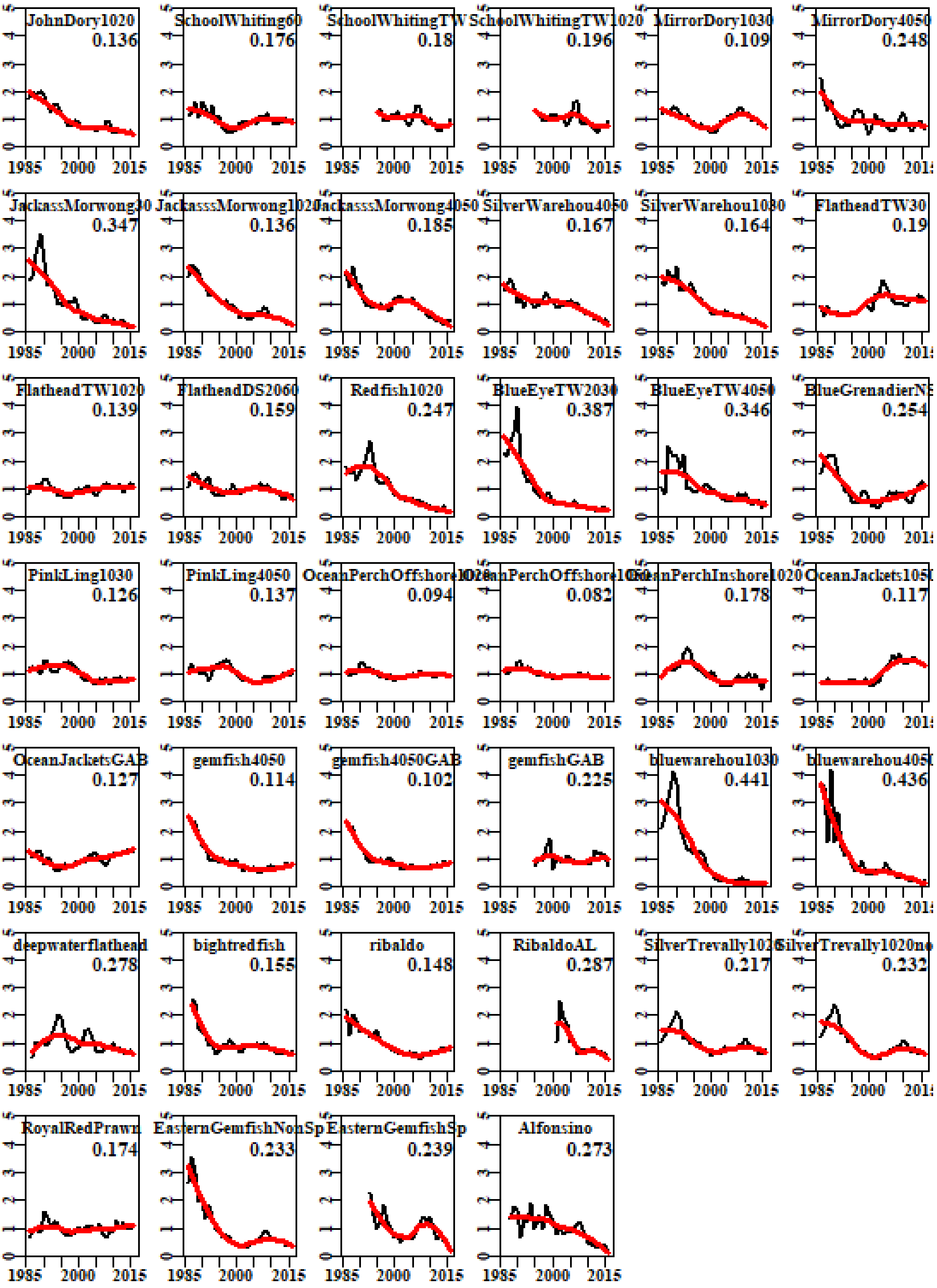


Figure 5.1. The optimal standardized CPUE trend for each fishery analysed. In each case, the black line represents the standardization and the red line is a loess best fitting trend. The title in each plot is the fishery and the number at top right is the root mean squared deviation. All y-axes have a maximum of 5.0.

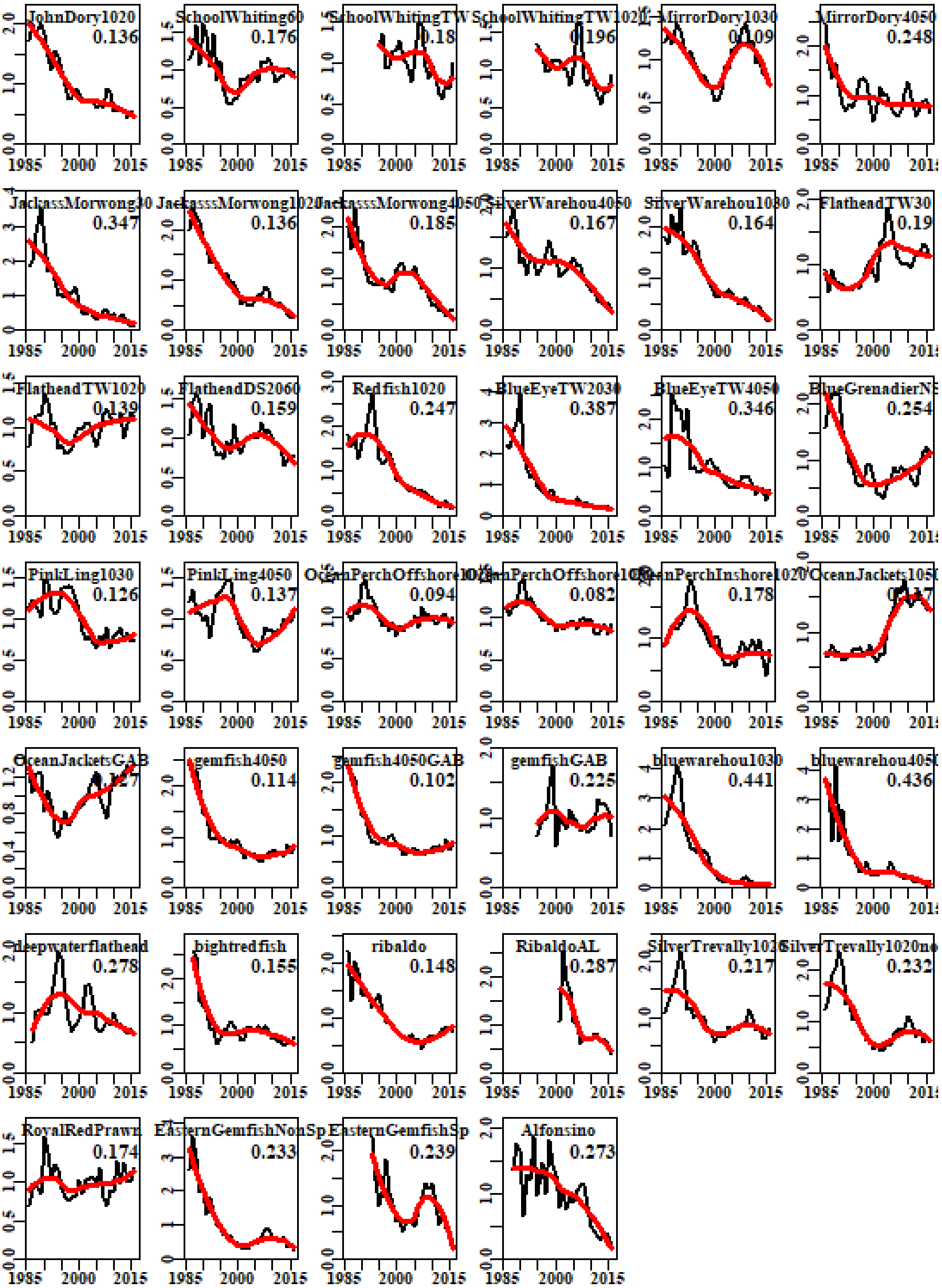


Figure 5.2. The optimal standardized CPUE trend for each fishery analysed. In each case, the black line represents the standardization and the red line is a loess best fitting trend. The title in each plot is the fishery and the number at top right is the root mean squared deviation. All y-axes have individual scales.

Table 5.1. The basic properties of each dataset, including the number of observations used in the optimum analysis, the number of parameters fitted in the optimum model, and the proportion of the total variation the model accounted for, and the shallowest and deepest depths.

	Nobs	Npars	Adj_r2	Ldepth	Udepth
JohnDory1020	142943	234	25.53	0	200
SchoolWhiting60	87274	139	12.98	0	100
SchoolWhitingTW	22008	257	40.72	0	140
SchoolWhitingTW1020	15073	145	44.25	0	140
MirrorDory1030	97130	274	35.23	0	600
MirrorDory4050	32976	170	33.32	0	600
JackassMorwong30	21075	152	34.79	60	300
JackasssMorwong1020	116158	247	27.99	60	300
JackasssMorwong4050	13905	160	36.89	60	360
SilverWarehou4050	62753	169	23.81	0	600
SilverWarehou1030	73798	262	22.64	0	600
FlatheadTW30	24265	295	23.23	0	300
FlatheadTW1020	275862	272	17.71	0	400
FlatheadDS2060	214495	120	39.22	0	200
Redfish1020	101505	236	30.62	0	400
BlueEyeTW2030	12695	208	53.51	0	1000
BlueEyeTW4050	13142	168	44.31	0	1000
BlueGrenadierNS	140995	321	36.39	100	1000
PinkLing1030	101313	275	29.92	250	600
PinkLing4050	79952	185	29.30	200	780
OceanPerchOffshore1020	82587	238	29.93	200	700
OceanPerchOffshore1050	115992	319	35.91	200	700
OceanPerchInshore1020	16612	233	35.30	0	200
OceanJackets1050	89892	273	27.51	0	300
OceanJacketsGAB	53517	110	26.83	0	300
gemfish4050	33356	159	43.88	100	700
gemfish4050GAB	44846	226	46.42	100	650
gemfishGAB	10014	105	53.65	100	650
bluewarehou1030	37301	251	38.95	0	400
bluewarehou4050	13202	163	30.96	0	600
deepwaterflathead	75105	155	36.61	50	350
bightredfish	52134	141	31.36	50	300
ribaldo	22712	242	31.08	0	1000
RibaldoAL	5503	128	42.71	0	950
SilverTrevally1020	58819	224	30.64	0	200
SilverTrevally1020nompa	33881	221	33.98	0	200
RoyalRedPrawn	25253	272	43.67	200	680
EasternGemfishNonSp	38689	296	40.19	0	600
EasternGemfishSp	15579	157	30.67	300	500
Alfonsino	3998	230	55.07	0	950

5.5 Acknowledgements

Thanks goes to the CSIRO database team for their preliminary processing of the catch and effort data as received from the Australian Fisheries management Authority. In addition, one author (MH) is indebted to FRDC for funding the project 2012/201 'Improving Catch Rate Standardizations', which provided the time to explore ways of making the mass production of CPUE standardizations more efficient and defensible.

5.6 References

Haddon, M. (1999) Standardization of Catch/Effort data from the South-East Pink Ling Fishery. South East Fishery Assessment Group Paper. 16p.

Haddon, M and M. Sporcic (2017). Catch rate standardizations for selected SESSF Species (data to 2016). CSIRO Oceans and Atmosphere, Hobart. 379 p.

R Core Team (2017). *R: A language and environment for statistical computing.* R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

6. Blue-Eye Auto-Line and Drop-Line Catch-per-Hook (Data 1997 - 2016)

Malcolm Haddon

CSIRO Oceans and Atmosphere, GPO Box 1538, Hobart, TAS 7001, Australia

6.1 Introduction

In 2014, analyses based on catch-per-record were no longer considered to adequately represent the state of the Blue-Eye stock due to the advent of a number of issues: 1) a reported expansion of whale depredations on auto-line catches in association with the changed behaviour of the fishing vessels in the presence of whales, 2) a restriction of fishing location options due to an increase in the number of marine closures over known Blue-Eye fishing grounds, and 3) a movement of fishing effort much further north off the east coast of New South Wales and Queensland has altered the reliability of the current CPUE analyses as an indicator of Blue-Eye relative abundance across the range of the fishery. As a result the 2013 CPUE standardizations for Blue-Eye, and the Tier 4 analyses dependent upon them, were no longer considered to provide an adequate representation of trends across and within the Blue-Eye fishery, which could leave the stock status uncertain.

Catch-per-record for Blue-Eye had been used for CPUE analyses since 2009 (Haddon, 2010). In 2009, the log book records of effort in the two methods was a mixture of total number of hooks, number of lines with number of hooks per line, and other combinations plus errors (this confused mixture was the main reason for using catch-per-record in the first place even though it was known to obscure effort variability). Since then the data entry has been more consistent leading the way for an attempt at generating CPUE as catch-per-hook, a measure of catch rate deemed to be more realistic and closer to the reality of the fishery. As with the catch-per-record this will generate two time-series, an early one for drop-line that over-laps a later one for auto-line, but the time-series are now of sufficient length that the general trends should be apparent.

Catches in what is now the GHT made up the majority of the fishery prior to 1997 but records from then are poor and there are multiple estimates of total catches and none are available with any reliable spatial detail. In the last six to seven years, related to the move of a larger proportion of the total catch away from the east coast of Tasmania, the use of alternative line methods (rod-reel, hand-line, and others) has increased, although, possibly in response to reductions in the available quota, catches by these methods have started to decline again. In some years, notably 2002, 2005, 2007, and 2011 - 2014 catches in the High Seas fisheries also increased markedly.

One of the foundations of the current Tier 4 Blue-Eye assessment is that the CPUE for drop-line and auto-line can be combined. This is the case because both have used catch-per-record (or day) as their unit of CPUE and on that basis their CPUE was comparable (Haddon, 2010). The combination was required because, in 2009, each method alone only had a rather short time-series of usable CPUE (sufficient catches, records and representative coverage of the fishery) that could be used for assessment purposes. Now catch-per-hook is used as the basis for the standardization but the combination of drop-line and auto-line is still required to maintain the CPUE estimates within the early reference period of 1997 - 2006.

An objective of the current work was to repeat previous analyses used to generate the total-hooks-set per record but including all the most recent data. Separate data selection rules and database manipulations (separate algorithms) developed for Drop-Line and Auto-Line data sets (Haddon, 2016) were repeated with updated datasets such that the outcome provided estimates of the total number of hooks set for each record. These data were used to generate catch-per-hook catch rate data which were in turn used in catch rate standardizations for the two methods.

The two time series of CPUE were combined using catch weighting and scaling the two series to the same mean CPUE of 1.0 for the period of 2002 - 2006, which was the period of overlap. For the catch-per-hook data to be acceptable required there to be sufficient records to provide a reasonable spatial coverage of the fishery as well as reasonably precise estimates of the annual mean values. Drop-Line CPUE were consider acceptable from 1997 - 2006 and Auto-Line data were acceptable from 2002 - 2015.

The analysis using catch-per-hook exhibits a noisy but flat trajectory not seen in the catch-per-record, which appears to be declining. All analyses have limited numbers of observations and hence are relatively uncertain. Given this uncertainty it does not matter greatly whether the analysis of catch-per-hook is restricted to zones 20 - 50, as has been done previously, or extended to include the GAB zones 83, 84, and 85.

Until management decisions are made concerning which geographical management units are to be used with Blue-Eye it would appear to be potentially misleading to omit the GAB auto-line catches when analyzing auto-line CPUE. The GAB catches are included in the TAC allocated to Blue-Eye and it is assumed that decisions to fish in different locations are made in the context of the full geographical range (implied management unit) available within which to take the TAC. It is thus recommended that, unless decisions are made to alter the implicit management unit currently used, the CPUE time-series relating to SESSF zones 20, 30, 40, 50, 83, 84, and 85, be used in subsequent Tier 4 analyses rather than the series relating only to zones 20 to 50.

6.2 Introduction

Blue-Eye trevalla (*Hyperoglyphe antarctica*) is managed as a single stock but its stock status is difficult to assess because, as a species, its adults are widely but patchily distributed, although its juveniles stages are widely dispersed. Not only is it patchily distributed but the fishery differs markedly by area through the application of different methods and histories of exploitation. The differences in exploitation history along with sampling different areas in different years may have been sufficient to have led to the appearance of heterogeneity in the biological characteristics of different populations. There is little consistency between consecutive years in the age structure and length structure of samples (Figure 1); for example, cohort progression is difficult or impossible to follow. This lack of consistency has thwarted previous attempts at apply-ing a Tier 1 integrated assessment to Blue-Eye and has made the application of the Tier 3 catch-curve approach equally problematical (Fay, 2007a, b). Such spatial hetero-geneity has recently been reviewed and further evidence presented, all of which sup-ported the notion that there were spatially structured differences between Blue-Eye populations between regions around the south-east of Australia (Williams et al., 2016).

Table 6.1. The number of records and catches (t) per year for auto-line, drop-line, and trawl vessels reporting catches of Blue-Eye Trevalla from 1997 - 2016. Data filters were to restrict the fisheries included to SET, GAB, SEN, GHT, SSF, SSG, and SSH. Methods were limited to AL, DL, TW, and TDO. Finally only CAAB code = 37445001 that identifies *Hyperoglyphe antarctica* were included.

	AL-Catch	AL-Record	DL-Catch	DL-Record	TW-Catch	TW-Record
1997	0.267	3	271.942	575	104.567	1500
1998	27.253	50	343.505	738	82.074	1398
1999	61.590	77	377.032	981	100.329	1712
2000	90.931	93	384.409	1078	95.042	1893
2001	47.884	76	335.873	799	90.218	1809
2002	134.067	234	223.074	619	67.998	1548
2003	219.676	487	221.649	587	28.918	1210
2004	329.608	1345	158.491	520	48.767	1559
2005	301.303	1150	93.779	368	42.969	1169
2006	354.582	1098	114.639	328	66.105	924
2007	455.096	667	46.011	129	38.321	834
2008	281.384	621	15.549	76	36.046	806
2009	325.893	590	30.158	112	39.386	618
2010	236.620	495	42.023	253	43.480	647
2011	267.318	567	59.381	244	23.268	626
2012	217.815	475	34.107	140	10.792	425
2013	190.515	363	7.762	54	22.893	359
2014	227.041	305	10.242	68	29.381	340
2015	192.782	277	52.161	98	25.128	301
2016	187.422	302	84.913	125	12.871	244

The Blue-Eye fishery has a relatively long history and while there is a long history of catches by trawl the majority of the catch has always been taken by line-methods (generally less than 10% of catches are taken by trawl since 2003; Table 6.1). Unfortunately, fisheries data from line methods, in the GHT fishery, only began to be collected com-prehensively from late in 1997 onwards (Table 6.1). In addition, in 1997 Auto-Line fishing was introduced as an accepted method in the SESSF although only very little fish-ing was conducted in 1997 and only in the last two months (Table 6.1, Figure 6.2). Auto-line related effort and catches increased from 2002 - 2003 onwards at the same time that drop-line records and catches began to decline (Figure 6.2; Table 6.1).

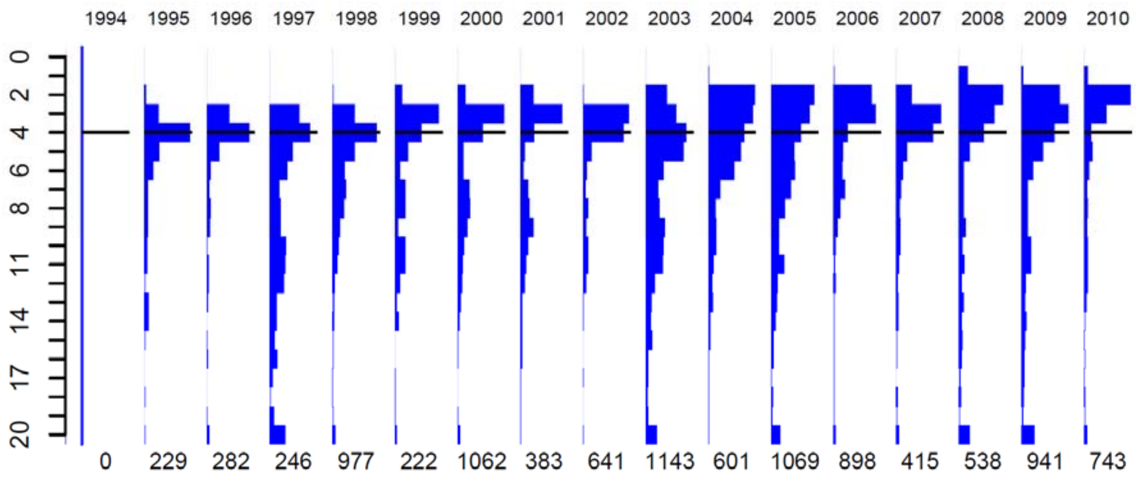


Figure 6.1. Age distributions sampled from the catches of Blue-Eye (*Hyperoglyphe antarctica*) for the years 1995 - 2010 (Thomson et al, 2016). The sample sizes in the bottom row of numbers should be sufficient to provide a good representation if the stock were homogeneous in its properties.

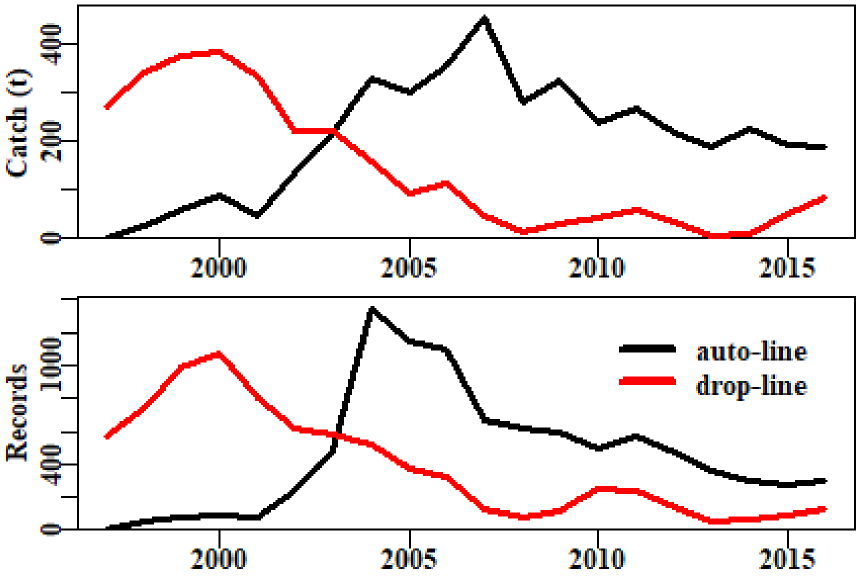


Figure 6.2. The trends in the number of records and the catches of Blue-Eye from 1997 - 2016 by the two main line methods (Table 6.1); most catches are now taken by auto-line.

In the two years, 2013 - 2014, the drop-line catches dropped to 10 t or less while auto-line catches continue to dominate the fishery. However, in 2015, drop-line catches in-creased to about 47 t, while auto-line catches dropped by about 30 t from the previous year (Table 6.1; Figure 6.2).

6.2.1 *Current Management*

When the Harvest Strategy Policy was implemented in 2007 (DAFF, 2007) a Tier 4 assessment was used to provide advice on annual recommended biological catch (RBC) levels for Blue-Eye instead of a Tier 1 assessment (after both a Tier 1 statistical catch-at-age model and a Tier 3 catch-curve approach were rejected; Fay, 2007a, b). The Tier 4 uses standardized CPUE as an empirical performance measure of relative abundance that is assumed to be representative of the whole stock. The average CPUE across a target period is selected by the RAG to provide the target reference point, which implies a limit CPUE reference point (0.41667 x target reference point) below which targeted fishing is to stop. In between the target and the limit there is a harvest control rule that reduces the RBC as CPUE declines. The appropriate characterization of CPUE is therefore very important in this fishery (Little et al., 2011; Haddon, 2014b).

By 2007 the auto-line fishery was already dominating the Blue-Eye fishery but the time series of significant catches by that method was relatively short (only six years from 2002 - 2007; Table 6.1 and Figure 6.2). At that time some way of extending the time series was required to allow for the application of the Tier 4 methodology. Unfortunately, in the log-book records there was, and sometimes still is, often confusion in how to record effort (in terms of number of lines and number of hooks per line, or number of line drops, or length of main line) so it was not feasible at that time to estimate CPUE as a catch-per-hook. Instead CPUE was based on catch-per-record, which was equivalent to catch-per-day. The CPUE standardization conducted in 2008 on data from 1997 - 2007 (Haddon, 2009) was the first time that the catch-per-day data from drop-line was combined with auto-line catch-per-day data, with a justification presented to the RAGs. This was followed in 2009 by a summary of the separate auto-line and drop-line CPUE and a more detailed defence for their combination (Haddon, 2010). While it was appreciated that the two methods are very different, the intent of combining their data was always to extent the time series of line-caught Blue-Eye back to 1997 rather than 2002. Despite this extension of time, the early Tier 4 Blue-Eye analyses had overlap between the reference period (1997 - 2006) and the CPUE grad over the final four years (2004 - 2007); it took three more years for that overlap to cease.

In 2013 the stock status for Blue-Eye (*Hyperoglyphe antarctica*) was assessed using a standardized CPUE time series from the combined auto-line and drop-line fisheries, which combined data from the two methods from 8 zones (SESSF zone 10 - 50 with 83 - 85). In addition, the time series of CPUE for trawls, relating to SESSF zones 20 - 30 (eastern Bass Strait and eastern Tasmania) and 40 - 50 (western Tasmania and western Bass Strait) were examined, although these trawl fisheries only relate to a small fraction of the total fishery so less attention is given them (Haddon, 2014 a, b). This was repeated in 2014 (Sporcic and Haddon, 2014), however, because of the unaccounted influences of factors such as the introduction of closures (both all methods and solely for auto-line), depredations by whales, and having to ignore significant catches taken with other new methods, these standardizations, and the Tier 4 analyses dependent upon them, were no longer considered to provide an adequate representation of trends within, and hence the status of, the Blue-Eye fishery.

One outcome of this was the determination to re-examine the available data to deter-mine whether it would be possible to generate a CPUE series based upon some meas-ure of catch-per-hook rather than catch-per-day. The use of catch-per-hook would al-low more fine detail to be discerned and might provide a more informative time-series, although the two time-series might be more difficult to combibe validly. The method of processing the data and clarifying the data-base issues has now been worked through (Haddon, 2015b, 2016) and this enables the analysis to be repeatable by anyone.

Table 6.2. Catch by SESSF Zone of Blue-Eye (*Hyperoglyphe antarctica*). Data filtered on species, fisheries and are restricted to catches by auto line and drop-line. Only Zones 20, 30, 40, 50, 83, 84, 85, 91, and 92 have significant catches.

	20	30	40	50	83	84	85	91	92
1997	81.546	80.730	40.989	45.977			5.778	5.503	
1998	72.374	159.187	64.648	40.856			1.968	1.590	
1999	64.636	195.056	76.726	55.078			0.972	21.590	0.050
2000	38.413	244.359	119.280	59.822		0.357	5.504	1.100	0.750
2001	20.659	222.357	87.241	29.127	0.150	2.814	4.345	3.186	4.740
2002	34.257	152.365	63.106	56.887		1.561	5.380	33.664	7.850
2003	46.456	144.738	117.674	39.364		27.547	4.875	57.910	2.400
2004	69.567	137.520	94.846	50.727	12.610	61.078	53.414	5.045	0.180
2005	85.138	103.016	59.525	43.133	19.478	29.273	42.395	4.881	4.700
2006	67.365	122.376	80.403	28.130	31.405	43.306	77.628	10.375	2.500
2007	50.193	228.395	41.324	28.367	29.801	106.441	15.337		
2008	44.786	112.203	51.837	13.668	28.942	32.267	13.214		
2009	51.024	137.503	79.919	38.055	1.633	15.368	15.415	10.515	1.350
2010	25.642	86.945	51.006	69.919	6.549	9.532	15.929	7.932	3.935
2011	30.838	92.670	42.424	18.131	20.576	40.692	14.159	33.688	23.081
2012	21.176	66.602	71.830	17.454	8.417	9.736	3.752	42.938	10.017
2013	13.151	51.497	84.457	14.594	0.465	16.158	13.250	1.131	
2014	3.878	71.226	87.235	21.989	2.107	33.759	11.629	4.505	0.510
2015	9.031	54.336	75.865	24.084	2.490	22.160	3.621	37.833	9.872
2016	7.557	49.053	69.982	35.283		27.313	9.576	42.901	26.211

6.2.2 *Fishery Changes*

The fishery as a whole has included a number of large-scale changes in fishing methods and the area of focus for the fishery. Catches in what is now the GHT were signifi-cant prior to 1997 but detailed data for that earlier period are not readily available. Catch estimates, have been derived from combining State with Commonwealth estimates, taken from earlier assessment summaries (Tilzey, 1999; Smith and Wayte, 2002; Table 6.5) and have the status of being an agreed catch history. While trawl catches have continued at a low (< 10%) but steady level since 2003 there has been a switch from drop-line (alternatively demersal-line) to auto-line. Also, related to the move of a proportion of the total catch away from the east coast up to the north-east seamount region, in the last five to seven years the use of alternative line methods (rod-reel, hand-line, etc) has increased, although perhaps now that the TAC is decreasing the proportion of the total catch being taken by these *minor line* methods is declining again.

Multiple issues have combined to cast doubt on the use of the combined auto-line and drop-line CPUE data based on catch-per-day or catch-per-record; the issues included reported whale depredations, the effects of closures, and the advent of a number of new line fishing methods north of -35° S, all of which have, or have been reported to have, increased since the increase in use of the auto-line method. In amongst a detailed consideration of the CPUE for all areas and methods (Haddon, 2015) an examination of the line data was made to determine whether it would be possible to go through the database records for the Blue-Eye fishery and generate a catch-per-hook index to see if the use of the rather crude catch-per-day index was affecting the outcome of the standardization. This was done and now a repeatable method is available.

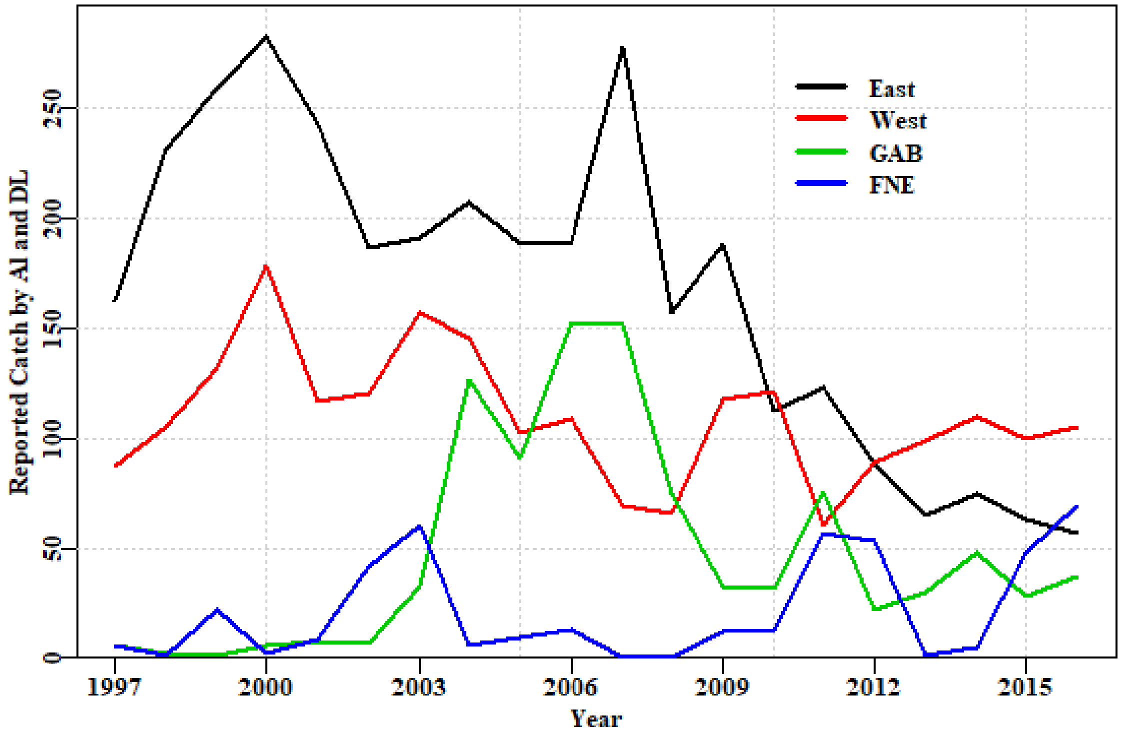


Figure 6.3. The total reported catches from 1997 - 2016 taken by auto-line and drop-line combined across the east (zones 20, 30), the west (zones 40, 50), the GAB (zones 83, 84, 85) and the far north east (zones 91, 92).

6.3 Objectives

The intent of this report is to attempt to estimate the Blue-Eye Trevalla CPUE in terms of catch-per-hook for both the drop-line and the auto-line fisheries. The specific objectives were to:

1. Review and amend the database records for the drop-line fishery to allow for the calculation of a catch-per-hook CPUE as done previously.
2. Review and amend the database records for the auto-line fishery to allow for the calculation of a catch-per-hook CPUE as done previously.
3. Compare the catch-per-hook standardized data for the two fisheries with that from the catch-per-day standardization for Blue-Eye Trevalla.

6.3.1 Report Structure

1. The report will first of all review the current distribution of catches across all methods and areas.
2. In the analysis of catch-per-hook first the drop-line fishery data will be considered, the database amended in a defensible manner, and a re-analysis of the CPUE using catch-per-hook made.
3. The same process of amending the database where appropriate followed by a rea-nalysis will be applied to the auto-line fishery.

The implications of these analyses will be examined in the discussion.

6.3.2 *Catch Rate Standardization*

6.3.2.1 Data Selection

Blue-Eye catches were selected by method and area for CPUE analyses. CPUE from these specific areas were standardized using the methods described below and reported elsewhere (Haddon, 2016a).

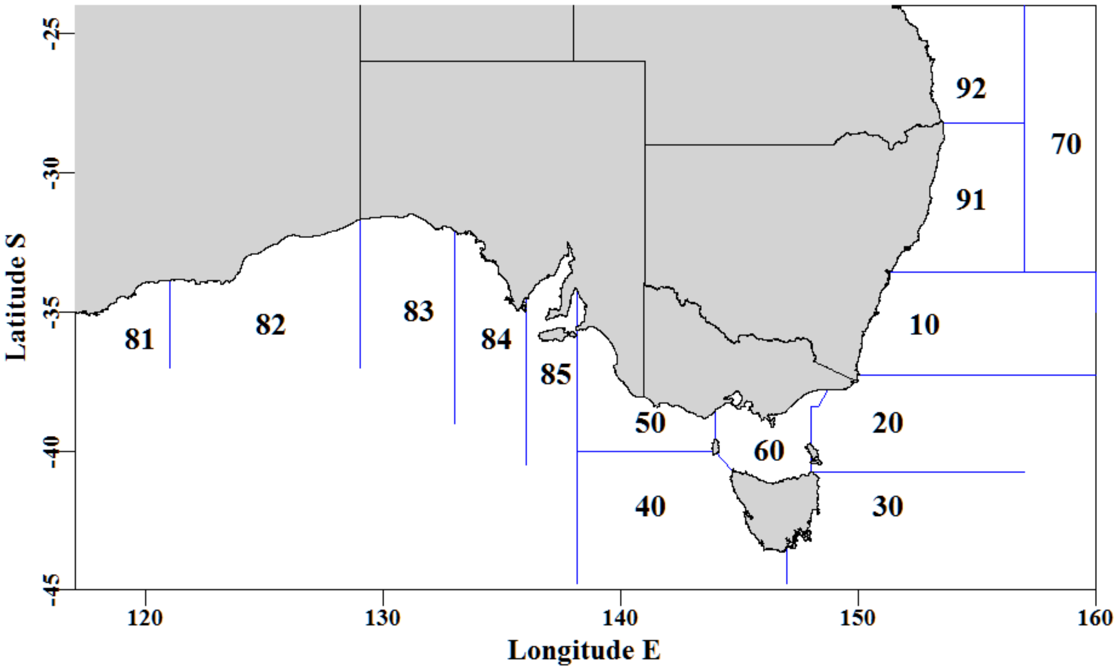


Figure 6.4. A schematic diagram depicting the statistical reporting zones in the SESSF, as used in this document. The GAB fishery is to the west of Zone 50. The main SESSF trawl zones are zones 10 - 50. Each zone extends out to the boundary of the EEZ, except for zones 50 and 60, and for zones 92 and 91, which are bounded by zone 70.

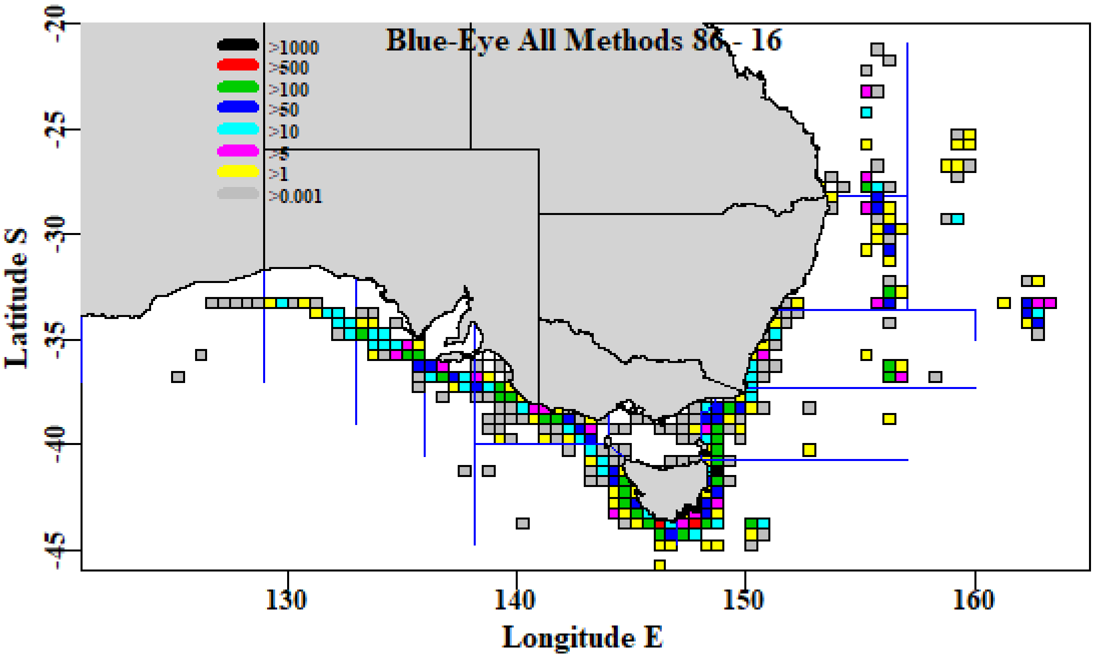


Figure 6.5. All reported catches of Blue-Eye by all methods from 1986 - 2016 in 0.5 degree squares. At least two records per square were required for inclusion in the map (all data were used in the analyses). The legend units are in tonnes summed across all years.

6.3.3 *General Linear Modelling*

Where trawling was the method used, catch rates were kilograms per hour fished. For the drop-line and auto-line methods, except for an analyses of catch-per-day for comparison, the database effort values were processed to generate total number of hooks set in a consistent manner. Once the database records were amended for internal consistency, then analyses based on catch-per-hook were conducted. All catch rates were natural log-transformed and a General Linear Model was used rather than using a Generalized Linear Model with a log-link on the untransformed data; this has advantages in terms of normalizing the data while stabilizing the variance, which the Generalized Linear Model approach does not always achieve appropriately (Venables & Dichmont, 2004). The statistical models were variants on the form: LnCE = Year + Vessel + Month + DepthCategory + Zone. In addition, there were interaction terms which could sometimes be fitted, such as Month:Zone or Month: DepthCategory, although with the use of finer spatial areas other simpler models or more idiosyncratic terms were occasionally used. Thus, the CPUE, conditioned on positive catches of the species of interest, was statistically modelled with a normal GLM on log-transformed CPUE data:

$$\mathrm{Ln}(CPUE_i) = \alpha_0 + \alpha_1 x_{i,1} + \alpha_2 x_{i,2} + \sum_{j=3}^{N} \alpha_j x_{ij} + \varepsilon_i$$

where $\mathrm{Ln}(CPUE_i)$ is the natural logarithm of the catch rate (either kg/h, kg/shot, or kg/hook) for the i-th shot, x_{ij} are the values of the explanatory variables j for the i-th shot and the α_j are the coefficients for the N factors j to be estimated (α_0 is the intercept, α_1 is the coefficient for the first factor, etc.).

6.3.4 *The Year Effect*

For the lognormal model the expected back-transformed year effect involves a bias-correction to account for the log-normality, this then focuses on the mean of the distribution rather than the median:

$$CPUE_t = e^{(\gamma_t + \sigma_t^2/2\ )}$$

where γ_t is the Year coefficient for year *t* and σ_t is the standard deviation of the log transformed data (obtained from the analysis). The year coefficients were all divided by the average of the year coefficients to simplify the visual comparison of catch rate changes:

$$CE_t = \frac{CPUE_t}{(\sum CPUE_t)/n}$$

where $CPUE_t$ is the yearly coefficients from the standardization, $(\sum CPUE_t)/n$ is the arithmetic average of the yearly coefficients, *n* is the number of years of observations, and CE_t is the final time series of yearly index of relative abundance.

6.4 Results

6.4.1 *Reported Catches*

Blue-Eye have been a target species before the formation of the SESSF, with large early catches reported from eastern Tasmania taken primarily by drop-line. The estimates of total catch through time vary in their completeness and quality and earlier reviews have generated different values (Table 6.5). In particular, prior to 1997, non-trawl catches were only poorly recorded. At very least these early estimates indicate the significant scale of fishing mainly by drop-line, prior to the introduction of auto-line vessels.

Table 6.3. The number of observations available taken by auto-line as determined by the data selection made on the complete catch and effort dataset on Blue-Eye.

	Total	Method	Depth	Years	Zones	Fishery
Records	53480.00	9918.000	9342.000	9250.000	8735.000	8697.000
Difference	0.00	43562.000	576.000	92.000	515.000	38.000
Catch	11917.98	4442.450	4180.813	4091.207	3796.426	3774.958
DeltaC	0.00	7475.526	261.637	89.606	294.781	21.468
%DiffC	0.00	62.725	5.889	2.143	7.205	0.565

Table 6.4. Catch by SESSF Zone of Blue-Eye (*Hyperoglyphe antarctica*) taken by auto-line. Total is all Blue-Eye catches by any method and any zone, Other is all other catches except for auto-line in zones 20, 30, 40, 50, 83, 94, and 85. AL is all catches in 20 - 85 taken by auto-line.

	Total	Other	AL	20	30	40	50	83	84	85
1997	464.069	463.802	0.267			0.267				
1998	444.979	429.990	14.989		0.033	14.956				
1999	546.140	499.471	46.670	35.575	1.725	9.370				
2000	657.408	629.109	28.299	12.210	6.061	10.028				
2001	580.054	539.822	40.232	2.000	23.634	14.598				
2002	462.267	330.901	131.366	2.640	65.100	42.326	21.300			
2003	561.987	405.001	156.986	20.574	93.788	38.724	3.900			
2004	600.595	330.844	269.751	55.986	81.121	71.255	22.214	5.418	15.316	18.442
2005	441.415	143.282	298.133	84.748	59.833	57.163	36.472	19.058	5.145	35.715
2006	534.261	189.853	344.407	67.075	66.585	77.940	25.672	31.117	0.330	75.689
2007	555.464	107.790	447.673	48.001	195.262	41.074	23.907	29.791	94.300	15.337
2008	342.072	64.172	277.900	44.439	98.763	50.407	11.408	27.543	32.127	13.214
2009	423.599	110.792	312.807	47.014	124.045	79.403	30.518	1.633	15.368	14.826
2010	379.072	149.130	229.942	25.422	66.128	47.497	63.093	5.764	7.153	14.884
2011	430.158	204.617	225.541	30.835	69.045	37.861	14.159	20.576	40.127	12.938
2012	314.091	134.066	180.025	21.176	55.333	70.428	11.183	8.417	9.736	3.752
2013	263.840	77.855	185.985	13.151	45.406	84.451	13.334	0.465	16.152	13.025
2014	304.346	84.788	219.558	3.866	66.351	87.153	19.442	0.607	31.049	11.089
2015	274.632	90.897	183.735	9.031	51.790	75.712	22.563	0.541	20.487	3.611
2016	297.239	116.548	180.691	6.620	35.586	68.561	33.036		27.313	9.576

Table 6.5. Early estimates of total Blue-Eye Trevalla catches, tonnes, across all methods within the SET area. The North Barrenjoey is included as being extra South-East Trawl area catches. Tilzey (1998) is only for catches north of Barrenjoey. Recent catches from 2005 are derived from Catch Documentation Records (CDR).

Year	Recent	Tilzey1998	Tilzey1999	Smith_Wayte2002
1980			207	207
1981			257	257
1982			276	276
1983			236	236
1984		7	388	350
1985		9	510	525
1986		38	285	341
1987		105	345	468
1988		210	505	725
1989		174	531	717
1990		243	647	819
1991		181	599	717
1992		60	633	643
1993		38	634	628
1994	801.327	27	729	730
1995	740.046	19	716	725
1996	893.428	16	868	890
1997	733.985		1040	989
1998	472.287			566
1999	572.689			651
2000	656.847			710
2001	586.572			648
2002	512.111			
2003	588.064			
2004	633.794			
2005	496.316			
2006	546.700			
2007	740.396			
2008	438.611			
2009	418.548			
2010	393.971			
2011	354.600			
2012	332.397			
2013	354.972			
2014	269.331			
2015	299.075			
2016	433.325			

6.4.2 *Effort Units*

GHT effort reporting is in terms of the main *EffortCode* with an *EffortSubCode* included. There are two main codes although there are also 56 records with unknown Code and SubCode (Table 6.6). Initially in 1997 and 1998 the main unit of effort was the Number-of-Lines-Set (NLS), however, as this could lead to confusion of whether total hooks set meant per line set or the total for the day it is fortunate that NLS was made obsolete sometime in 1999. This in turn led to the major issue with the auto-line effort reporting being that the Total Hooks Set switched from being an EffortSubCode to being an EffortCode sometime in 1999 (Table 6.7). This source of confusion appears to have propagated confusion in the log-book entries for a number of years following the changes and is the main reason this data needs review.

Table 6.6. A tabulation of the different Unit types identified (rows) and Sub-Units codes identified (columns). NLS is number of lines per shot (obsolete after 1999) and THS is Total Number of Hooks per Shot, finally TLM is Total Length of Mainline used.

	Unknown	THS	TLM
Unknown	56	0	0
NLS	0	71	0
THS	0	0	8570

Even before database confusions such as the switch of Total-Hooks-Set was corrected as best it could be, the number of records available for CPUE standardization only rose above 100 from 2002 onwards. From 1997 - 2001 the number of records were sparse as was the geographical spread of the distribution of catch (Table 6.7). In 2000 the catches and records are also distorted by relatively high catches being taken down on the Cascade Plateau, although the auto-line catches from that area are only minor.

Table 6.7. The catches and number of records in each year under the different EffortCodes. NLS is number of lines per shot (obsolete after 1999) and THS is Total Number of Hooks per Shot.

Year	Unknown	NLS	THS	Unknown	NLS	THS
1997		0.267		0	3	0
1998		14.989		0	28	0
1999		43.727	2.943	0	40	9
2000			28.299	0	0	29
2001			40.232	0	0	65
2002			131.366	0	0	226
2003			156.986	0	0	433
2004	2.89		266.861	56	0	1140
2005			298.133	0	0	1135
2006			344.407	0	0	1074
2007			447.673	0	0	652
2008			277.900	0	0	612
2009			312.807	0	0	555
2010			229.942	0	0	489
2011			225.541	0	0	529
2012			180.025	0	0	434
2013			185.985	0	0	352
2014			219.558	0	0	292
2015			183.735	0	0	251
2016			180.691	0	0	293

6.4.3 *Vessels per Year*

A total of 14 vessels have reported catches of Blue-Eye caught using auto-line since 1997, although a maximum of 11 report in any single year (Figure 6.5). The active fleet expanded between 2002 - 2004. The structural adjustment occurred from November 2005 to November 2006 and that (along with TAC changes) appears to have stabilized numbers at about six vessels, with only three or four contributing in recent years. However, the four lowest catching vessels, across all years 1997 - 2016, have only landed totals of either 0.815, 3.55, 6.0, or 6.256 t of Blue-Eye in between 1 - 6 years of fishing. By selecting only those vessels catching more than 10 tonnes across all years a more representative number of vessels reporting significant catches per year is obtained (Figure 6.5). However, for the standardization analysis no selection on minimum catch was made.

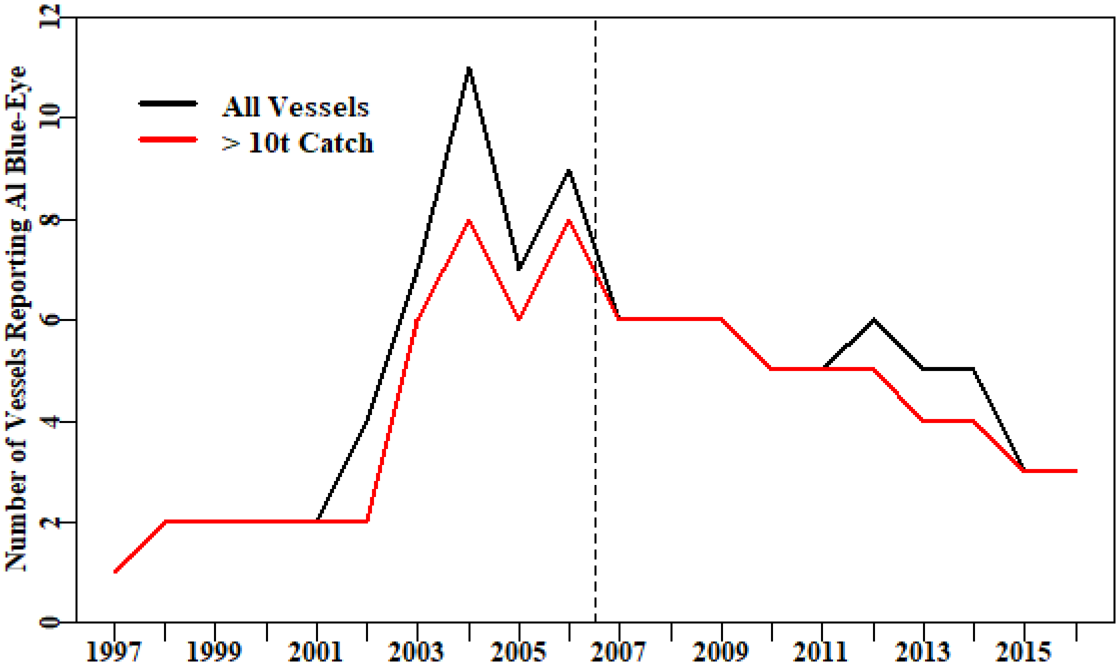


Figure 6.6. The number of auto-line vessels reporting Blue-Eye catches per year of the fishery compared with the number of vessels that caught more than a total of 10 tonnes over the 20 years from 1997 - 2016. Vertical dashed line is 2006.5, identifying the structural adjustment.

6.4.4 *Catch-per-Hook*

Table 6.8. The data selection criteria used followed by the steps in the database manipulations that were used to generate a relatively clean column of total-hooks-set for Auto-Line. EV = EffortValue and ESV - EFFortSubValue within the database.

Step	Description
Total	All Blue-Eye records in the AFMA catch and Effort database
Method	Only those records reporting a method of ‘AL’
Depth	Only depths between 200 - 600 metres
Years	Only data from 1997 - 2015
Zones	Only records reporting zones 20, 30, 40, 50, 83, 84, 85
Fishery	Only records reporting either ‘SEN’ or ‘GHT’
E-THS	Transfer the EV to hooks
9798ESV	Transfer ESV recorded as THS to hooks
H0-ESVgt0	Transfer the ESV if it was > 0 and the EV = 0
noEffort	Remove records with no effort; neither EV nor ESV
ESVgtUV	Transfer ESV which are > EV where EV > 1000 and hooks > 20
CEgt10	Remove 2 remaining records with CPUE > 10Kg/hook
Hlt1000	Remove 2 records with fewer than 1000 hooks.

Table 6.9. The sequence of data selection and editing and their effects on the amount of Blue-Eye catch and number of records. The manipulation codes are described in Table 6.8.

	Records	Difference	Catch	DeltaC	%DiffC
Total	53480	0	11917.976	0.000	0.00
Method	9918	43562	4442.450	7475.526	100.00
Depth	9342	576	4180.813	261.637	94.11
Years	9250	92	4091.207	89.606	92.09
Zones	8735	515	3796.426	294.781	85.46
Fishery	8697	38	3774.958	21.468	84.97
U-THS	8697	0	3774.958	0.000	84.97
9798SUV	8697	0	3774.958	0.000	84.97
H0-SUVgt0	8697	0	3774.958	0.000	84.97
noEffort	8615	82	3768.456	6.502	84.83
SUVgtUV	8615	0	3768.456	0.000	84.83
CEgt10	8605	10	3757.776	10.680	84.59
Hlt1000	8568	37	3742.738	15.038	84.25

Once catch-per-hook CPUE data were available these could then be standardized using standard methods. Standardizations only begin in 2002 after which sufficient data to be representative are available.

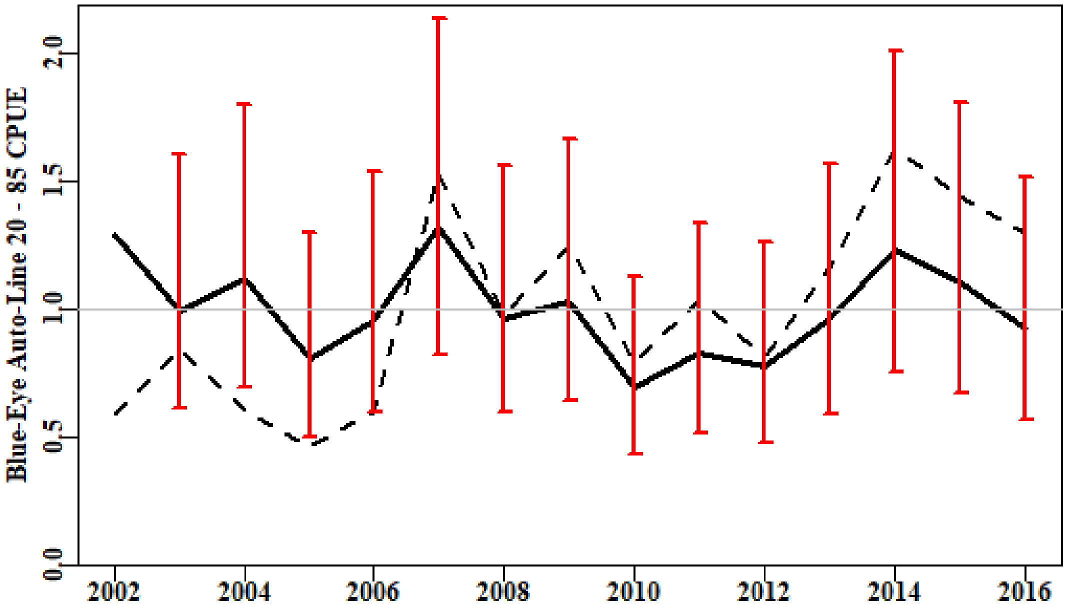


Figure 6.7. The standardized CPUE for Blue-Eye taken by auto-line from 2002 - 2016 from zones 20, 30, 40, 50, 83, 84, and 85. While the error bars are wide note the relative flattening of the trend in the solid standardized trend compared to the increasing trend in the unstandardized geometric mean (dashed line).

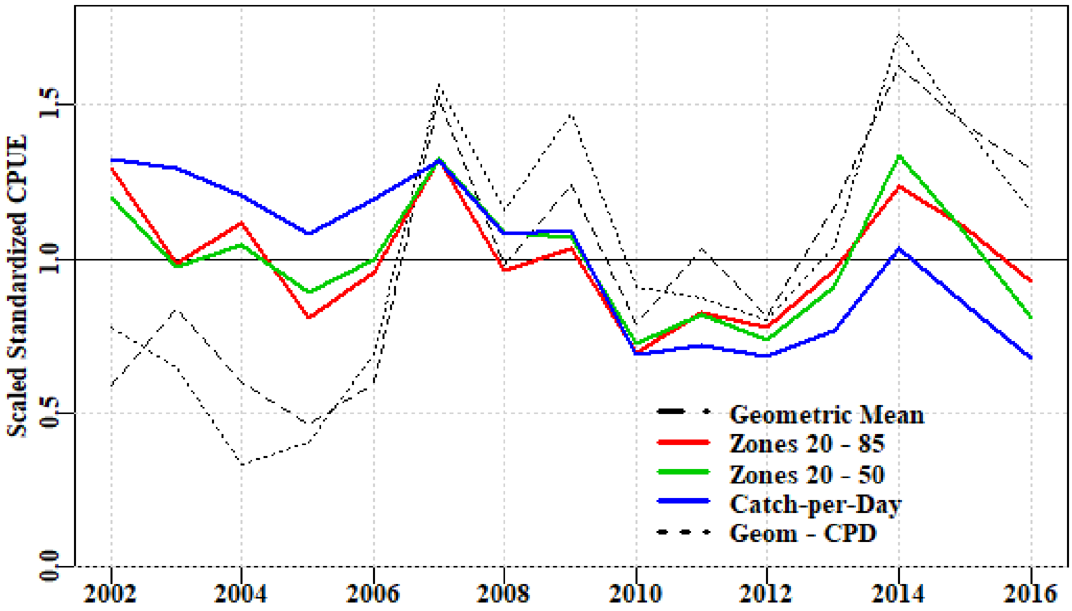


Figure 6.8. A comparison of the standardized catch rates for auto-line vessels using catch-per-day (blue line and dotted black line), and catch-per-hook (red, green, and dashed black line). All three main lines have high levels of uncertainty (e.g. Figure 6.6), but the relative flattening of the catch-per-hook trajectory is clear. All trends were scaled to an average of 1.0.

The optimum statistical model fitted to the available data from 2002 - 2016 was LnCE = Year + Vessel + Month + Zone + DepCat + DayNight + Month:Zone in each case. Catch-per-hook from zones 20 - 85 and from zones 20 - 50, were compared with the catch-per-day analysis from zones 20 - 50 (Table 6.10; Figure 6.7). Only minor differences are apparent between the inclusion of the GAB data (zones

83 - 85) and considering only zones 20 - 50. However, the catch-per-hook estimates generate a flatter trend than that deriving from the catch-per-day analysis.

Table 6.10. The geometric mean unstandardized CPUE for zones 20 - 85 by catch-per-hook (Geom-cph) and catch-per-day (Geom-cpd), and the optimum models from standardizations of all Auto-Line Blue-Eye catches as catch-per-hook (cph) from zones 20 - 85 (y2085), zones 20 - 50 (y2050), and as catch-per-day (cpd) for zones 20 - 50 (yCPD). The final column is the total reported catch from the records included in the 20-85 AL CPUE analyses.

Year	Geom-cph	Geom-cpd	z2085	z2050	ceCPD	AL Catch
2002	0.5894	0.7782	1.2912	1.1962	1.3215	131.366
2003	0.8403	0.6499	0.9882	0.9719	1.2937	156.966
2004	0.6013	0.3364	1.1163	1.0448	1.2044	265.447
2005	0.4656	0.4071	0.8081	0.8919	1.0789	297.430
2006	0.5962	0.6899	0.9555	0.9983	1.1923	344.008
2007	1.5246	1.5666	1.3229	1.3225	1.3171	446.264
2008	0.9772	1.1590	0.9647	1.0835	1.0814	275.976
2009	1.2430	1.4707	1.0310	1.0667	1.0924	302.014
2010	0.7889	0.9092	0.6951	0.7239	0.6879	228.394
2011	1.0345	0.8743	0.8256	0.8200	0.7166	223.640
2012	0.8138	0.8025	0.7771	0.7392	0.6826	179.075
2013	1.1661	1.0370	0.9629	0.9061	0.7661	184.361
2014	1.6258	1.7320	1.2315	1.3370	1.0321	219.558
2015	1.4383	1.4339	1.1035	1.0875	0.8574	183.373
2016	1.2949	1.1532	0.9264	0.8103	0.6757	180.691

6.4.5 *Combine Drop-Line with Auto-Line*

With a standardized Drop-Line CPUE index available for 1997 - 2006, and an auto-line index from 2002 - 2016 the standardized time series in each case are both scaled to have a mean of 1.0 during the overlap period of 2002 - 2006, and both series (using catch-per-hook CPUE) exhibit similar variation around the longer term average of 1.0. For the provision of management advice it would be possible to use a catch-weighted average of the two lines over the period of overlap (Figure 6.8; Table 6.11).

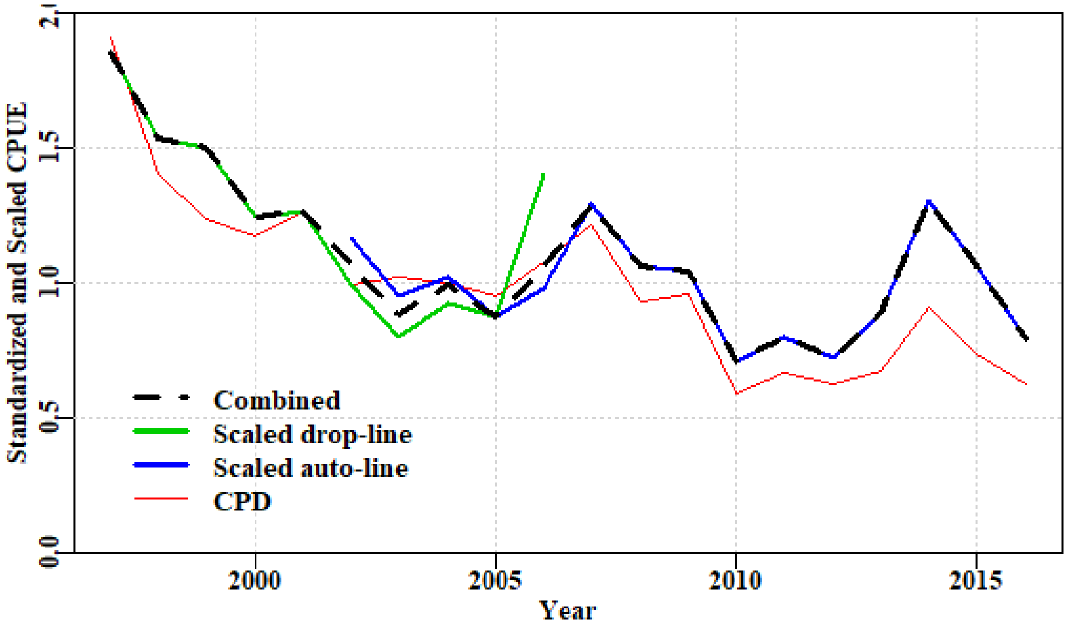


Figure 6.9. A comparison of Blue-Eye standardized catch-per-hook estimates for Drop-Line and Auto-Line catches of Blue-Eye from zones 20 - 50. A catch-weighted average of the lines from the two methods leads to a compromise in the years 2002 - 2006. If the 2001 auto-line estimates had been included this would have raised the average in 2001 slightly but at that point in time Drop-Line catches still dominated (Table 6.1). Catch-per-Day across the combined Drop-Line and Auto-Line catches is include as a dotted line.

Table 6.11. The optimum standardized CPUE (scaled to a mean of 1.0) for both drop-line, ceDL, and auto-line, ceAL, all for zones 20 - 50. These are re-scaled so that the average CPUE between 2002 - 2006 = 1.0 in both cases (the columns with a scale postfix. The catch weighted CPUE (combined) is only catch weighted over the 2002 - 2006 overlap period. The relative catches by method are in alC (auto-line) and dlC (drop-line). ceCPD is the optimum standardized CPUE as measured by catch-per-day

	ceDL	ceAL	scaleDL	scaleAL	combined	ceCPD	alC	dlC
1997	1.4977		1.8588		1.8588	1.9120	0.267	242.435
1998	1.2406		1.5397		1.5397	1.4059	14.989	318.441
1999	1.2115		1.5036		1.5036	1.2362	46.670	336.133
2000	1.0037		1.2457		1.2457	1.1730	28.299	372.543
2001	1.0179		1.2633		1.2633	1.2635	40.232	311.101
2002	0.8013	1.1962	0.9945	1.1720	1.0710	0.9937	131.366	173.513
2003	0.6441	0.9719	0.7994	0.9523	0.8816	1.0257	156.986	135.032
2004	0.7456	1.0448	0.9254	1.0237	0.9974	1.0024	230.575	84.059
2005	0.7079	0.8919	0.8786	0.8739	0.8747	0.9509	238.215	48.581
2006	1.1297	0.9983	1.4021	0.9781	1.0588	1.0802	237.272	55.729
2007		1.3225		1.2958	1.2958	1.2179	308.245	38.766
2008		1.0835		1.0615	1.0615	0.9313	205.017	15.299
2009		1.0667		1.0451	1.0451	0.9604	280.980	17.818
2010		0.7239		0.7093	0.7093	0.5952	202.140	24.755
2011		0.8200		0.8034	0.8034	0.6709	151.900	30.748
2012		0.7392		0.7243	0.7243	0.6303	158.120	17.928
2013		0.9061		0.8877	0.8877	0.6727	156.342	7.003
2014		1.3370		1.3099	1.3099	0.9125	176.813	3.853
2015		1.0875		1.0655	1.0655	0.7401	159.096	1.727
2016		0.8103		0.7939	0.7939	0.6251	143.803	14.368

6.5 Discussion

6.5.1 *Assumptions about CPUE*

There are some important assumptions in the analyses conducted in this document. These assumptions apply to all species whose stock status assessments rely on CPUE. The first assumption is that changes in CPUE directly reflect changes in the relative stock abundance rather than the influence of other factors such as the structural adjustment, or reduced catch rates through whale depredations or from whale avoidance behaviour from shifting into less optimal CPUE areas. In addition, the various closures in the south-east are assumed to have little or only minor effects on catch rates as are the recent reductions in TAC, which mostly coincide with the introduction of important Blue-Eye closures on the east coast of Tasmania. In addition there would appear to have been large and sudden changes in the fishing behaviour with regard the total number of hooks set in a shot (Haddon, 2016a). CPUE reflects fishing behaviour and, potentially, any factor that may lead to a change in fishing behaviour may affect CPUE. Such things are confounded with stock size changes. That is, a change in the CPUE brought about by a management change, can easily be confused for a change in the stock. Catch rate standardization is a method of using statistical methods in an attempt to take account of such external factors, with common examples of important potentially influential factors being which vessel is fishing, where they are fishing, at what depth they are fishing, and what month they are fishing. The process of standardization is completely dependent upon the availability of quality data concerning the factors being considered.

6.5.2 *Other Factors Affecting CPUE*

There are some influential factors whose potential effects upon CPUE would be diffi-cult to identify and isolate as a confounding effect with stock size. Any influence that occurs as an apparently instant transition so that for a sequence of years it is not there but after a given date it is present (such as the introduction of a closure, or a change in almost all the vessels fishing following the structural adjustment, or a limitation placed on maximum effort or catch per day) is very difficult to correct for, if at all.

In the case of a closure, if the closure is on favoured fishing grounds then there will undoubtedly be a change in fishing behaviour (which, in the case of Blue-Eye is con-founded with reductions in TAC). While it is known where the vessels would not be operating it is not known where effort that would have been expended in the now closed region will be transferred to.

The structural adjustment between Nov 2005 - Nov 2006 led to a reduction in the number of vessels operating in the Blue-Eye fishery and this is very apparent in the trawl fleet and the drop-line fleet, both of which decline significantly in numbers from 2005 - 2007 onwards. Such a reduction in vessel numbers, and which vessels are actually fishing, may have altered fishing behaviour in ways that are not characterized in the standardization. In the case of Blue-Eye drop-line vessels, a major change did occur in how effort was being reported with the proportion of records reporting single lines instead of multiple lines increasing dramatically (Haddon, 2015). This is mixed up with the big change in the vessels actually fishing with most significant drop-line fishers leaving the fishery after the structural adjustment (one remained). Such transitions invalidate application of the statistical standardization and almost the only thing that can be done is to treat the different periods separately.

One large issue with the analysis of any of the line and hook methods is uncertainty over the representativeness of any single year's data for the fishery. The minor-line methods are still patchily distributed over different sea-mounts and off-shore areas and even auto-line and drop-line have widely varying coverage between years across the different important statistical reporting zones within the SESSF. This is especially the case with auto-line following its adoption in 1997; for example, there were significant catches in only four zones, 20 - 50, from 2002 onwards and catching in the GAB only started to become important from 2003/2004 onwards. Similarly, although also inversely, after 2006 reducing catches by drop-lining meant they did not occur consistently every year in all four zones 20 - 50 and have remained at low and declining levels (< 20t) throughout that period.

6.5.3 *Catch-per-Record vs Catch-per-Hook*

The use of catch-per-day or record stemmed from early records of effort data being confused so that for example, with drop-lines the number of separate lines used and the number of hooks per line were sometime placed in each others fields on the log-books and thereby in the database. For a single and particular species in particular areas it was, however, possible to examine what appeared to be atypical data and reverse obvious errors (for example cases of 200 lines each of 10 hooks, should obviously be reversed). This use of a different measure of effort gives a different time-series of CPUE than when catch-per-day or record is used. The use of catch-per-day avoids the issue of the remarkable change in effort reporting that appears to have followed the structural adjustment. Intuitively, however, catch-per-hook appears a more realistic reflection of the variation of practice within the fishery. It is certainly an area that requires further analysis and consideration.

Using catch-per-record means that when significant changes occur in fishing behaviour these would be missed. By missing such major changes, inappropriate data can contin-ue to be used as still representing the fishery. Thus, if catch-per-record data is to con-tinue being used for the provision of management advice then some extra data selection will need to be made to focus on those fishing events that are more typical of the fishery. However, what such data selection would entail is not known.

The auto-line fleet only began to expand and distribute catches from about 2002 on-wards, other changes include the first gear limitation (to 15,000 hooks maximum) in 2001 and the rapid expansion of the auto-line fleet from 2002 onwards. The data up to 2000/2001 are not widely distributed spatially each year and are not distributed among many vessels. For this reason it is difficult to justify using the auto-line data before 2002.

Even though the GAB only began to be seriously fished by auto-line vessels from 2003/2004 onwards, it has become an important part of the fishery. Catches from the GAB (and the far North East) are counted against the available quota/TAC for Blue-Eye and decisions concerning where to fish presumably entail a consideration of all areas available to be fished. Currently the tier 4 assessment uses only the standardization from zones 20 - 50, which reflects the earlier usage. However, until decisions are made about exactly what geographical management units are to be used with Blue-Eye it would appear that leaving out the GAB zones with significant catches would have the potential to generate misleading results. It would seem sensible therefore to use the standardization from zones 20 - 85 rather than just 20 to 50. As it happens the inclusion of the GAB catches in the analysis of catch-per-hook does not alter the trend in standardized CPUE in any important way.

6.6 Conclusions

The diversity of methods used to fish for Blue-Eye and the patchy nature of the fishing grounds mean that there is no simple, catch-all analysis that can be used to summarize the fishery as a whole. Nevertheless, it remains possible to focus on the methods that lead to the greatest proportion of the catches.

- It has proven possible to develop relatively simple algorithms, which if followed lead to the clarification of effort in terms of total hooks set that in turn allows for an alternative, intuitively more realistic measure of CPUE.
- Separate and different algorithms for handing the drop-line and auto-line data within the catch and effort database are required to enable effort in each case to be characterized in terms of total number of hooks set.
- Using those algorithms the drop-line and auto-line data have again been re-structured and catch-rates estimates in terms of kg/hook for both methods have been generated.
- As has been done previously, it was possible to combine the two, using a catch weighted approach over the overlap period. When this was done for both the catch-per-hook and catch-per-day data the outcome of the standardization was rather different. The combined standardized CPUE has been noisy but relatively flat since 2002, whereas the trend catch-per-day CPUE has been noisy but downwards since about 1998.

Given the current structure of the auto-line fishery, which dominates recent catches, it is recommended that the CPUE time-series from zones 20, 30, 40, 50, 83, 84, and 85, be used in subsequent Tier 4 analyses. This would be more representative of the current fishery as it is presently pursued than restricting the series to zones 20 - 50 only.

6.7 References

Fay, G. (2007a) Tier 3 Calculations for Blue-Eye Trevalla (*Hyperoglyphe antarctica*) using data up to and including 2005. Pp 520 - 527 in Tuck, G.N. (*ed.*) (2007) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2006-2007. Volume 1*: 2006. AFMA Project 2006/813. CSIRO Marine and Atmospheric Research, Hobart. 570p.

Fay, G. (2007b) Data appraisal and progress on Harvest Strategy Evaluation for Blue-Eye Trevalla: update for July 2007 SlopeRAG meeting. Pp 474 - 497 in Tuck, G.N. (*ed.*) (2007) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2006-2007. Volume 2*: 2007. AFMA and CSIRO Marine and Atmospheric Research, Hobart. 584p.

Kimura, D.K. (1981) Standardized measures of relative abundance based on modelling log(c.p.u.e.), and their application to pacific ocean perch (*Sebastes alutus*). Journal du Conseil International pour l'Exploration de la Mer. 39: 211-218.

Haddon, M. (2009) Catch rate standardizations 2008 (for data 1986 - 2007) pp 30 - 168 in Tuck, G.N. (*ed.*) 2009. *Stock Assessment for the Southern and Eastern Scale-fish and Shark Fishery 2008*. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 645 p.

Haddon, M. (2010) Blue-Eye Summary (TBE - 37445001 - *H. antarctica*. Pp 99 - 104 in Tuck, G.N. (*ed*) (2010) *Stock Assessment for the Southern and Eastern Scale-fish and Shark Fishery: 2009*. CSIRO Marine and Atmospheric Research, Hobart. 428p.

Haddon, M. (2014a) Standardized Catch Rates for Selected Species from the SESSF. (Data 1986 - 2012). Pp 57 - 275 in Tuck, G.N. (*ed*) (2014) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2013. Part 2.* AFMA Project 2011/0814. CSIRO Wealth from Oceans, Hobart. 486p.

Haddon, M. (2014b) Tier 4 Analyses in the SESSF, including Deep Water species. Data from 1986 - 2012. Pp 352 - 461 in Tuck, G.N. (*ed*) (2014) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2013. Part 2.* AFMA Project 2011/0814. CSIRO Wealth from Oceans, Hobart. 486p.

Haddon, M. (2014c) Blue-Eye Fishery Characterization. Pp 329 - 351 in Tuck, G.N. (*ed*) (2014) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2013. Part 2.* Australian Fisheries Management Authority and CSIRO Wealth from Oceans, Hobart. 486p.

Haddon, M. (2015) Blue-Eye Fishery Characterization 1986 - 2013. Pp 277 - 327 in Tuck, G.N. (*ed*) (2014) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2014. Part 2.* Australian Fisheries Management Authority and CSIRO Wealth from Oceans, Hobart. 432p.

Haddon, M. (2016) Blue-Eye Auto-Line and Drop-Line CPUE Characterization (data from 1986 to 2014) pp 435-474 *in* Tuck, G.N. (*ed.*) (2016) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2015. Part 2.* Australian Fisheries Management Authority and CSIRO Oceans and Atmosphere Flagship, Hobart. 493 p.

Haddon, M. (2016a) *Blue-Eye Auto-Line and Drop-Line CPUE Characterization and Catch-per-Hook 1986 - 2015.* A paper presented to SERAG November 2016. CSIRO. Hobart. 51p.

Haddon, M. (2016b) *Blue-Eye* (Hyperoglyphe antarctica) *Tier 4 Analysis using Catch-per-Hook for Auto-Line and Drop-Line from 1997 - 2015.* A paper presented to SERAG November 2016. CSIRO Oceans and Atmosphere. Hobart. 25p.

Smith, A.D.M. and S.E. Wayte (eds) (2002) *The South East Fishery 2002.* Compiled by the South East Fishery Assessment Group. Australian Fisheries Management Authority, Canberra. 271p.

Sporcic M. and M. Haddon (2014) *Catch rate standardization for selected SESSF species (data to 2013).* Report to SLOPE and SHELF RAGs 2014. CSIRO Oceans and Atmosphere. Hobart, 228p.

Tilzey, R. (ed) (1998) *The South East Fishery 1997.* Fishery Assessment Report. Compiled by the South East Fishery Assessment Group, Australian Fisheries Man-agement Authority, Canberra. 214p.

Tilzey, R. (ed) (1999) *The South East Fishery 1998.* Fishery Assessment Report. Com-piled by the South East Fishery Assessment Group, Australian Fisheries Management Authority, Canberra. 199p.

Venables, W. and C. M. Dichmont (2004). GLMs, GAMs and GLMMs: an overview of theory for applications in fisheries research. *Fisheries Research* **70**: 319-337.

Williams, A., Hamer, P., Haddon. M., Robertson, S., Althaus, F., Green, M. and J. Kool (2016) *Determining Blue-eye Trevalla stock structure and improving methods for stock assessment.* Final Report FRDC Project No 2013/015. Fisheries Research Development Corporation and CSIRO Oceans and Atmosphere, Hobart, 123p.

7. Catch rate standardizations for selected SESSF Species (data to 2016)

Malcolm Haddon and Miriana Sporcic

CSIRO Oceans and Atmosphere, GPO Box 1538, Hobart, TAS 7001, Australia

7.1 Introduction

Commercial catch and effort (CPUE) data are used in very many fishery stock assessments in Australia as an index of relative abundance. Using CPUE in this way assumes there is a direct relationship between catch rates and exploitable biomass. However, many other factors can influence catch rates, including vessel, gear, depth, season, area, and time of fishing (e.g. day or night). The use of CPUE as an index of relative abundance requires the removal of the effects of variation due to changes in these factors on the assumption that what remains will provide a better estimate of the underlying biomass dynamics. This process of adjusting the time series for the effects of other factors is known as standardization and the accepted way of doing this is to use some statistical modelling procedure that focuses attention onto the annual average catch rates adjusted for the variation in the averages brought about by all the other factors identified. The diversity of species and methods in the SESSF fishery means that each fishery/stock for which standardized catch rates are required entails its own set of conditions and selection of data. This report updates standardized indices (based on data to 2016 inclusive) for over 40 different stocks within Australia's Southern and Eastern Scalefish and Shark Fishery (SESSF).

7.2 The Limits of Standardization

The use of commercial CPUE as an index of the relative abundance of exploitable biomass can be misleading when there are factors that significantly influence CPUE but cannot be accounted for in a generalized linear model (GLM) standardization analysis. Over the last two decades there have been a number of major management interventions in the South East Scalefish and Shark Fishery (SESSF) including the introduction of the quota management system in 1992 and that of the Harvest Strategy Policy (HSP) and associated structural adjustment in 2005 - 2007. The combination of limited quotas and the HSP is now controlling catches in such a way that many fishers have been altering their fishing behaviour to take into account the availability of quota and their own access to quota needed to land the species taken in the mixed species SESSF.

Some stocks, such as flathead, are currently near or around their target stock size and catch rates are at historically good levels. As a result of this success, some fishers report having to avoid catching species, such as flathead, so as to avoid having to discard and to stay within the bounds of their own quota holdings. Such influences on catch rates would tend to bias catch rates downwards, or at very least add noise to any CPUE signal, which could lead to misinformation passing to any assessment. Currently, there is no way to handle this issue but care needs to be taken not to provide incorrectly conservative advice or inappropriately high catch targets. Included in the management changes is the on-going introduction of numerous area closures imposed for a range of different reasons.

7.3 Methods

7.3.1 Catch Rate Standardization

7.3.1.1 Preliminary Data Selection

The methods used when standardizing commercial catch and effort data in the SESSF continue to be discussed in the Commonwealth stock assessment RAGs because the catch rate time series (and associated standardized indices) are very influential in many of the assessments. Data were initially selected from the ORACLE database by CAAB code to obtain all data relating to a given species. Then selections were made using R (R Core Team, 2017) with respect to fishery (e.g. SET, GHT, GAB, etc), within a specified depth range and method (e.g. trawl, Auto Line, Danish seine etc) in specified statistical zones within the years specified for each analysis.

7.3.1.2 General Linear Modelling

In each case, catch rates, generally as kilograms per hour fished (though sometimes as catch per shot e.g. School Whiting caught by Danish Seine, or catch-per-hook for Blue-Eye Trevalla), were natural log-transformed. A General Linear Model was used rather than using a Generalized Linear Model with a log-link; this has advantages in terms of normalizing the data while stabilizing the variance, which the Generalized Linear Model approach does not always achieve appropriately (Venables & Dichmont, 2004). This relatively simple analytical approach means that the exact same methods can be applied to all species in a relatively robust manner. The statistical models were variants on the form: Ln(CPUE) = Year + Vessel + Month + Depth Category + Zone + DayNight. In addition, there were interaction terms which could sometimes be fitted, such as Month:Zone and/or Month:DepthCategory. Thus, the CPUE, conditioned on positive catches of the species of interest, was statistically modelled with a normal GLM on log-transformed CPUE data:

$$Ln(CPUE_i) = \alpha_0 + \alpha_1 x_{i,1} + \alpha_2 x_{i,2} + \sum_{j=3}^{N} \alpha_i x_{i,j} + \varepsilon_i$$

where Ln($CPUE_i$) is the natural logarithm of the catch rate (usually kg/hr, but sometimes kg/shot) for the i-th shot, x_{ij} are the values of the explanatory variables j for the i-th shot and the α_j are the coefficients for the N factors j to be estimated (where α_0 is the intercept, α_1 is the coefficient for the first factor, etc.).

7.3.1.3 The Mean Year Estimates

For the lognormal model the expected back-transformed year effect involves a bias-correction to account for the log-normality; this then focuses on the mean of the distribution rather than the median:

$$CPUE_t = e^{(\gamma_t + \sigma_t^2/2)}$$

where γ_t is the Year coefficient for year t and σ_t is the standard deviation of the log transformed data (obtained from the analysis). The year coefficients were all divided by the average of all the Year coefficients to simplify the visual comparison of catch rate changes.

$$CE_t = \frac{CPUE_t}{(\sum CPUE_t)/n}$$

where $CPUE_t$ is the yearly coefficients from the standardization, (□CPUEt)/n is the arithmetic average of the yearly coefficients, n is the number of years of observations, and CE_t is the final time series of yearly index of relative abundance.

7.3.1.4 Model Development and Selection

In each case an array of statistical models are fitted sequentially to the available data, with the order of the non-interaction terms being determined by the relative contribution of each term to model fit.

This sequential development of the standardization models for each species simplifies the search for the optimum model and requires a consideration of different performance statistics such as the AIC (Akaike's Information Criterion, the smaller the better; Burnham and Anderson, 1992) or adjusted R^2 (the larger the better; Neter et al, 1996). In addition, the examination of the various diagnostic plots and tables allows for an improved interpretation of the observed trends.

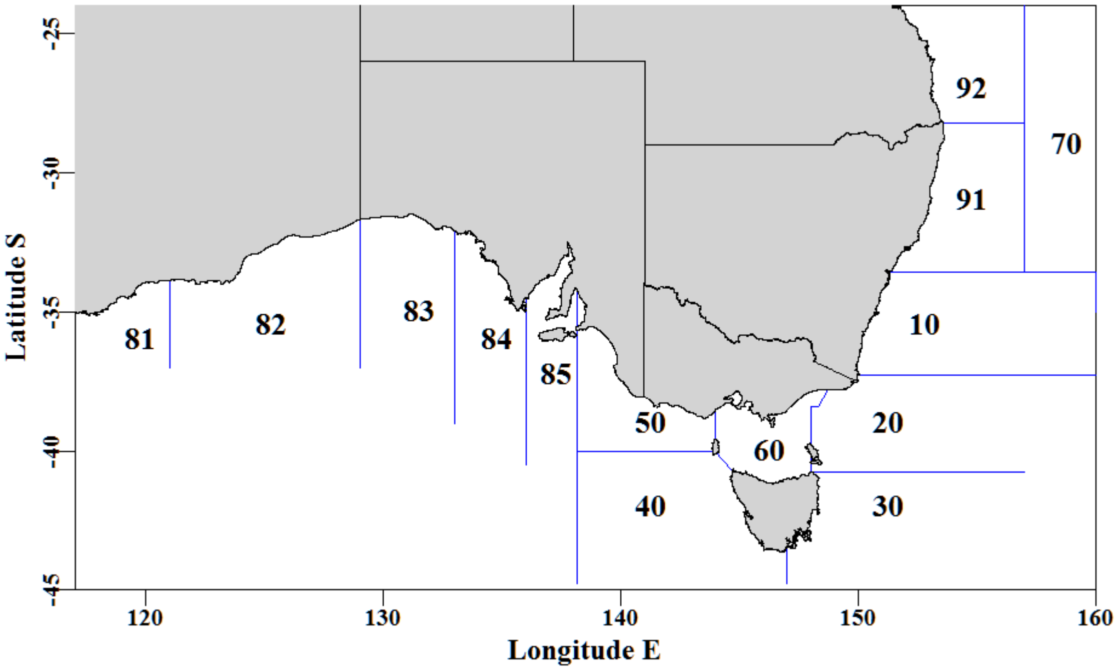


Figure 7.1. The statistical reporting zones in the SESSF.

7.4 John Dory 10 – 20

John Dory (DOJ- 37264004 - *Zeus faber*) have been caught primarily by trawl in zones 10 and 20 between the years 1986 - 2016. Small catches have also been recorded by gillnet and Danish seine. Initial data selection was based on criteria provided in Table 7.5 from the Commonwealth logbook database.

A total of 8 statistical models were fitted sequentially to the available data.

7.4.1 *Inferences*

A significant proportion of the shots each year were < 30kg, which suggests this is rarely a targeted species, low and even availability, or high levels of small fish (Figure 7.3).

The terms Year, Vessel and DayNight had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE based on the AIC and R^2 statistics. The qqplot suggests that the assumed Normal distribution is valid, with small deviations at the upper tail of the distribution.

Standardized CPUE has been below the long term average since 1997 (Figure 7.2).

7.4.2 *Action Items and Issues*

A potential change in fishing behaviour is suggested to have occurred since about 2014, which is evidenced by changes in the distribution of log-transformed CPUE each year. From 2014 a number of widely spread spikes in the histograms have become apparent, most especially in 2015 and 2016. The underlying driver for these changes is not immediately apparent.

Table 7.1. JohnDory1020. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:DepCat.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	231.7	6417	202.2	90	12.1	1.7250	0.000	66.562	0.329
1987	206.1	4662	181.6	78	14.5	1.9944	0.021	43.587	0.240
1988	182.0	4540	161.6	73	13.5	1.8460	0.021	45.331	0.280
1989	217.9	4814	188.5	70	14.3	2.0183	0.021	49.276	0.261
1990	167.9	3701	136.8	60	13.0	1.8413	0.023	40.157	0.294
1991	172.3	4041	126.7	53	11.9	1.4687	0.023	43.912	0.347
1992	130.8	3938	109.1	49	9.6	1.2359	0.023	43.579	0.399
1993	240.4	5431	181.1	55	11.6	1.5530	0.022	58.523	0.323
1994	267.9	6556	209.4	55	11.1	1.4677	0.021	72.785	0.348
1995	185.7	6043	167.3	52	10.1	1.2433	0.021	68.695	0.411
1996	160.8	6391	146.3	59	8.4	0.9781	0.021	67.772	0.463
1997	87.8	4468	79.2	60	6.3	0.7610	0.023	44.061	0.556
1998	109.0	5091	98.5	53	6.9	0.7901	0.022	52.434	0.532
1999	132.8	5547	121.0	56	7.8	0.9330	0.021	57.914	0.479
2000	164.1	6962	147.3	59	7.2	0.8647	0.020	66.841	0.454
2001	129.3	6627	116.3	50	5.8	0.7258	0.021	61.710	0.531
2002	151.0	6688	136.4	49	6.7	0.7109	0.021	58.400	0.428
2003	156.9	6558	137.3	51	6.7	0.6890	0.021	59.710	0.435
2004	166.0	7094	147.7	51	6.8	0.7296	0.020	65.909	0.446
2005	107.4	4934	88.6	48	5.7	0.6043	0.022	41.398	0.467
2006	85.4	3727	71.6	43	5.8	0.6784	0.024	34.561	0.483
2007	62.5	2844	51.7	23	6.0	0.6173	0.026	25.784	0.499
2008	116.8	3852	103.0	26	8.7	0.9296	0.024	37.912	0.368
2009	91.7	3148	79.7	23	8.3	0.8581	0.025	31.637	0.397
2010	62.0	3078	52.4	24	5.3	0.5447	0.026	29.044	0.554
2011	74.8	3428	57.4	22	5.3	0.5696	0.025	32.122	0.560
2012	67.1	3387	56.6	22	5.3	0.5644	0.025	31.992	0.565
2013	63.5	2686	49.0	23	5.7	0.5922	0.026	25.084	0.512
2014	46.6	2648	35.4	23	3.8	0.4421	0.026	21.777	0.615
2015	73.6	2800	54.8	29	5.7	0.5592	0.026	24.591	0.449
2016	66.9	2030	35.4	24	5.1	0.4644	0.030	17.304	0.489

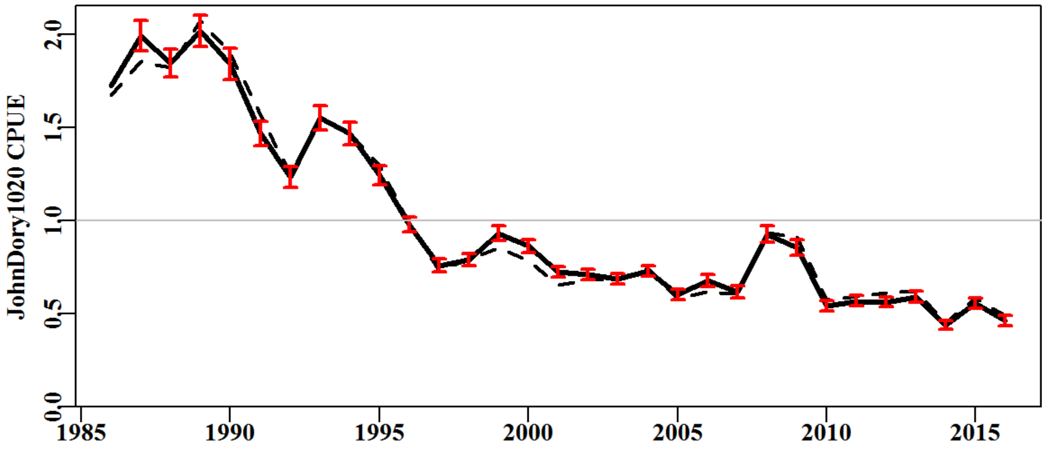


Figure 7.2. JohnDory1020 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

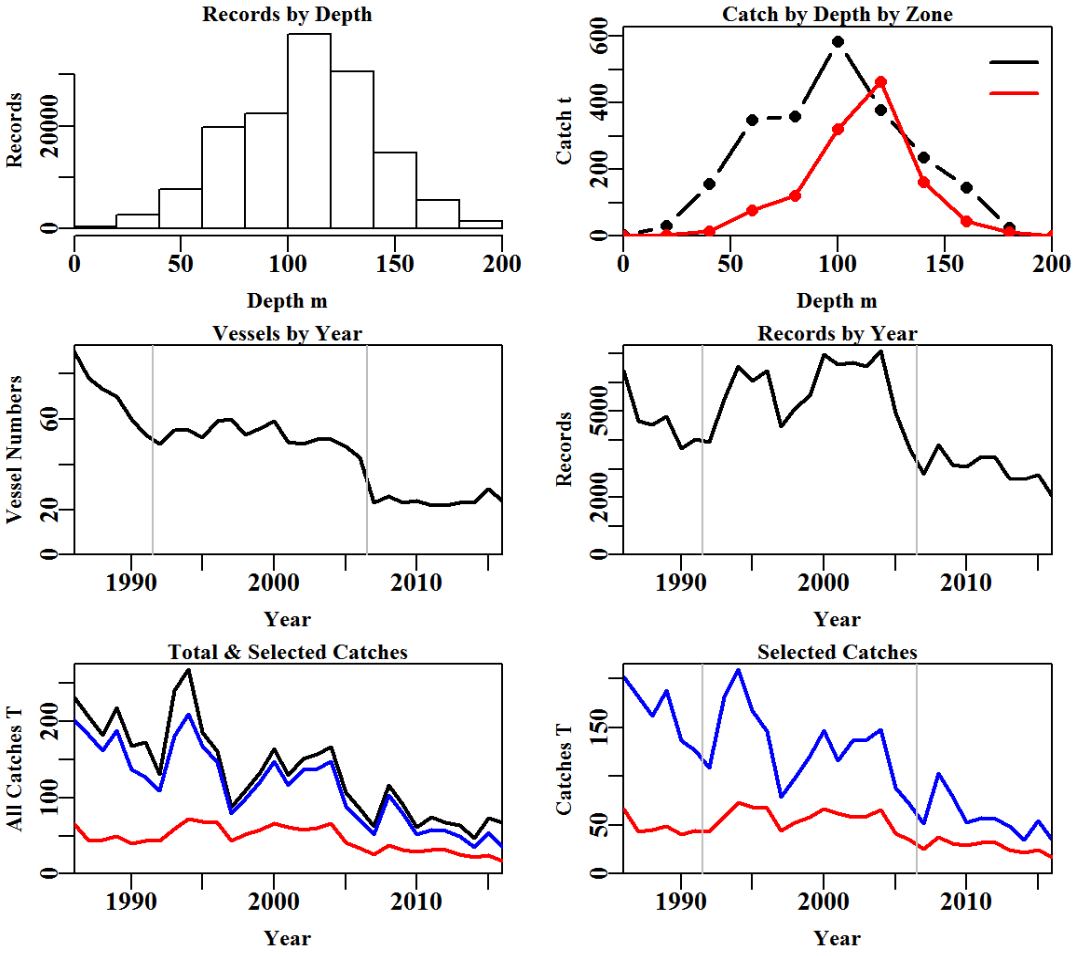


Figure 7.3. JohnDory1020 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.2. JohnDory1020 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	227978	206833	202785	199885	169010	144253	144131
Difference	0	21145	4048	2900	30875	24757	122

Table 7.3. The models used to analyse data for JohnDory1020.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DayNight
Model4	Year + Vessel + DayNight + DepCat
Model5	Year + Vessel + DayNight + DepCat + Month
Model6	Year + Vessel + DayNight + DepCat + Month + Zone
Model7	Year + Vessel + DayNight + DepCat + Month + Zone + Zone:Month
Model8	Year + Vessel + DayNight + DepCat + Month + Zone + Zone:DepCat

Table 7.4. JohnDory1020. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:DepCat.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	30489	178008	26790	144131	31	13.1	0.00
Vessel	14671	159133	45665	144131	200	22.2	9.13
DayNight	12414	156653	48144	144131	203	23.4	1.21
DepCat	10570	153455	51342	142943	213	24.3	0.86
Month	9372	152152	52646	142943	224	24.9	0.64
Zone	9333	152107	52690	142943	225	24.9	0.02
Zone:Month	8700	151412	53385	142943	236	25.3	0.34
Zone:DepCat	8180	150867	53930	142943	234	25.5	0.61

Table 7.5. .JohnDory1020. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	JohnDory1020
csirocode	37264004
fishery	SET
depthrange	0 - 200
depthclass	20
zones	10, 20
methods	TW, TDO, TMO, OTT
years	1986 - 2016

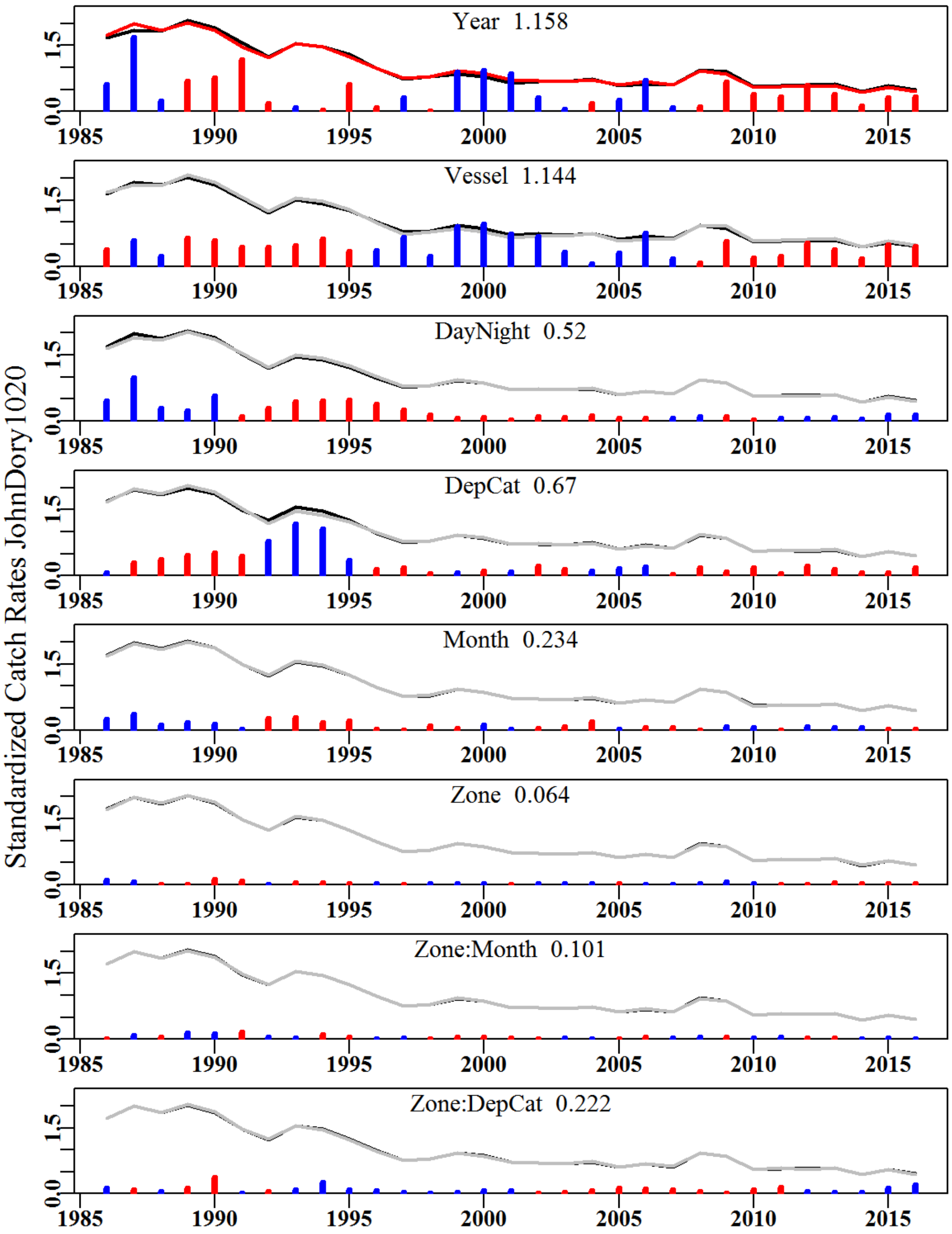


Figure 7.4. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

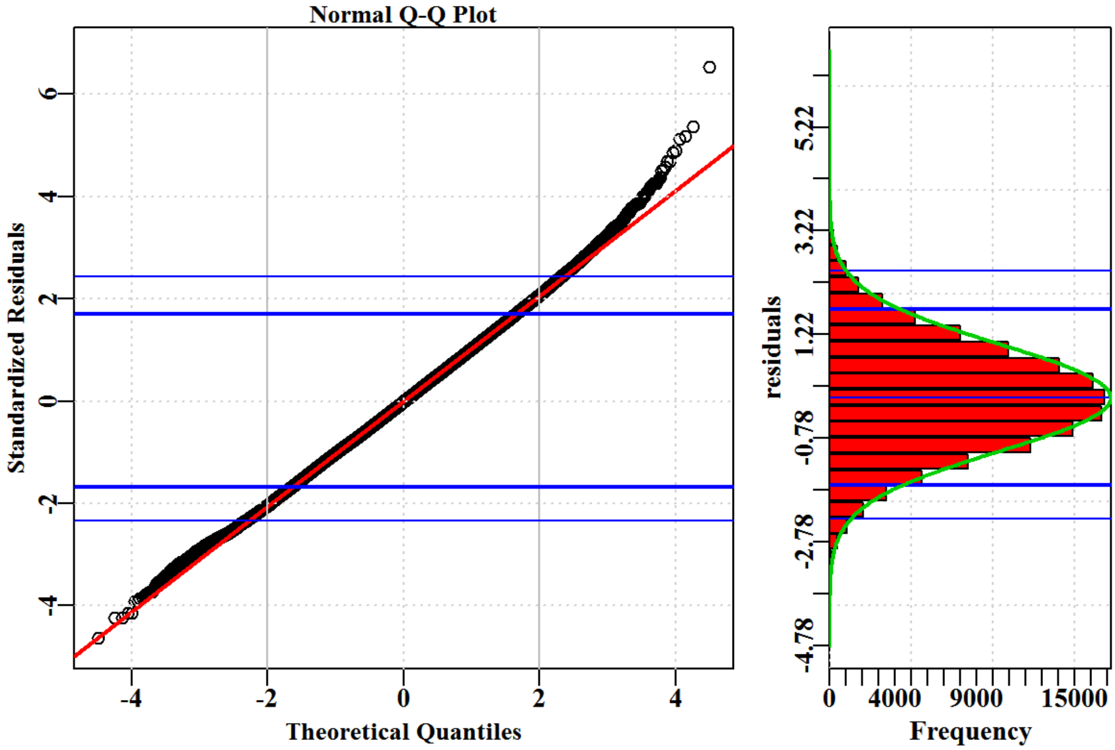


Figure 7.5. JohnDory1020. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

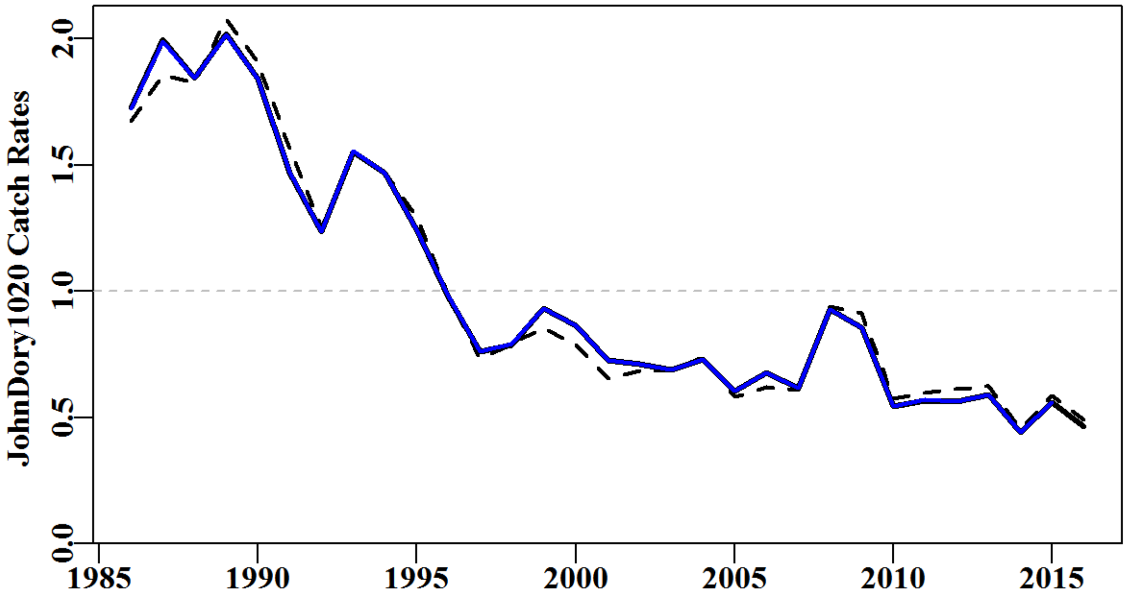


Figure 7.6. JohnDory1020. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

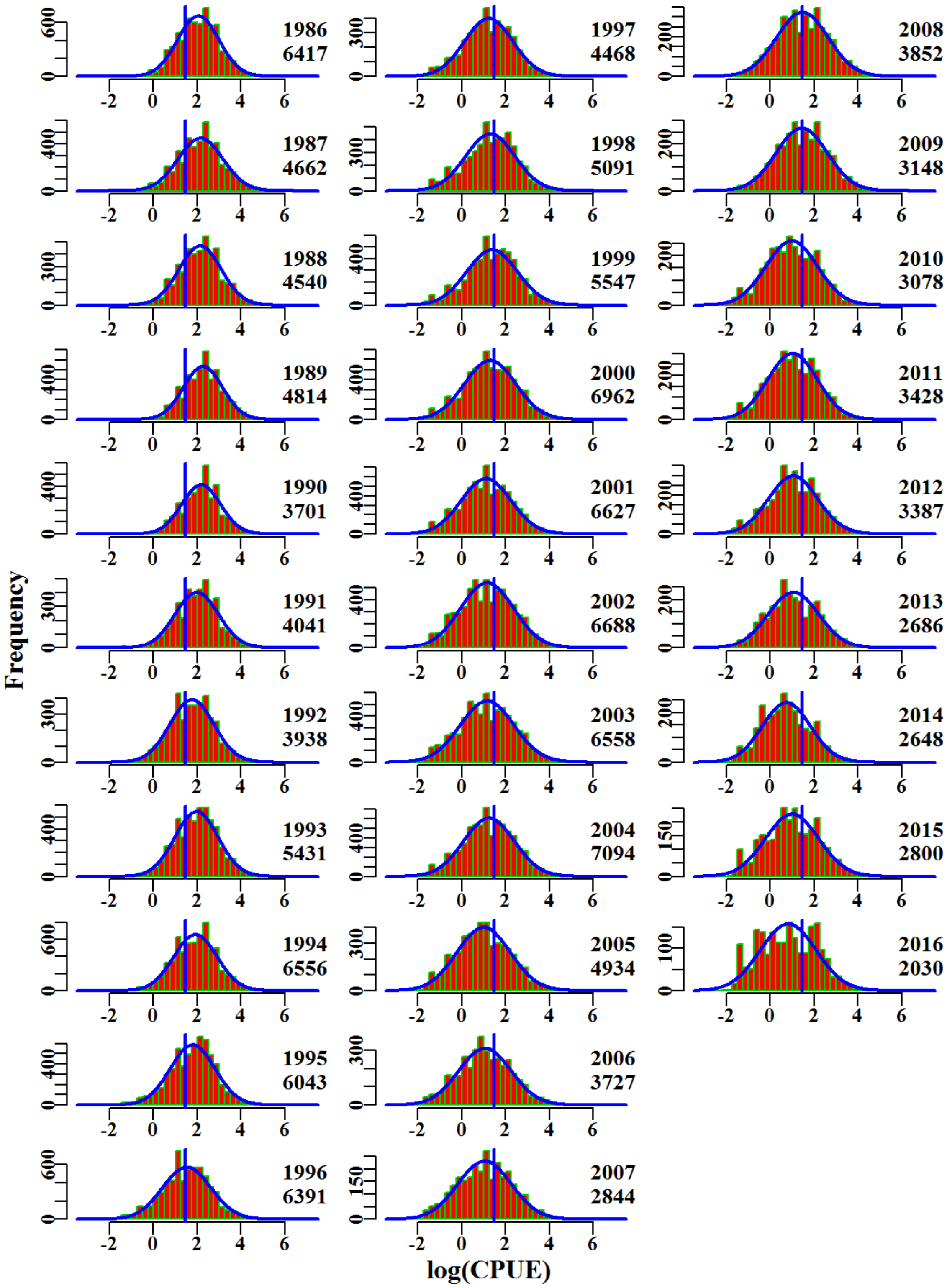


Figure 7.7. JohnDory1020. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

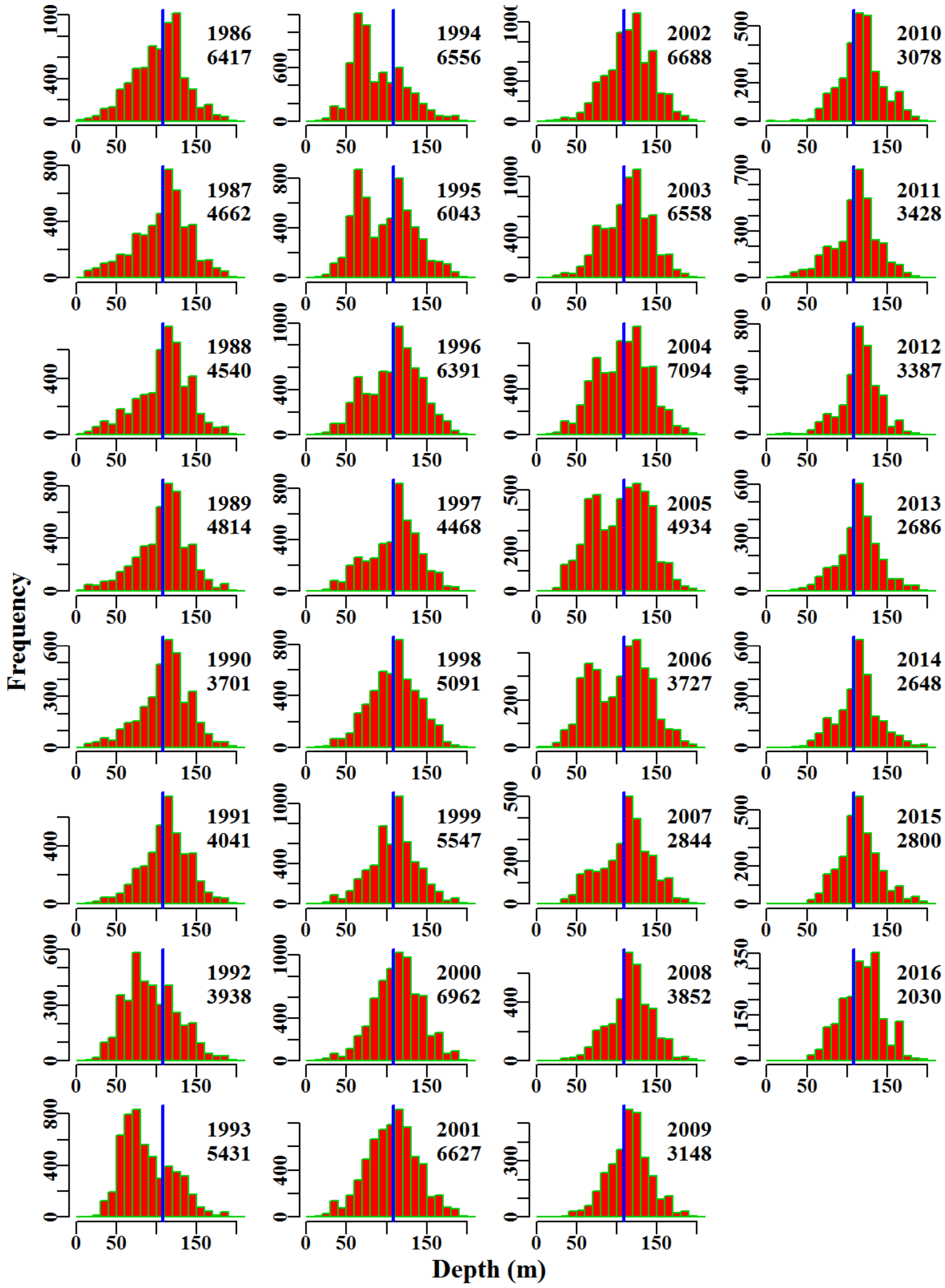


Figure 7.8. JohnDory1020. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

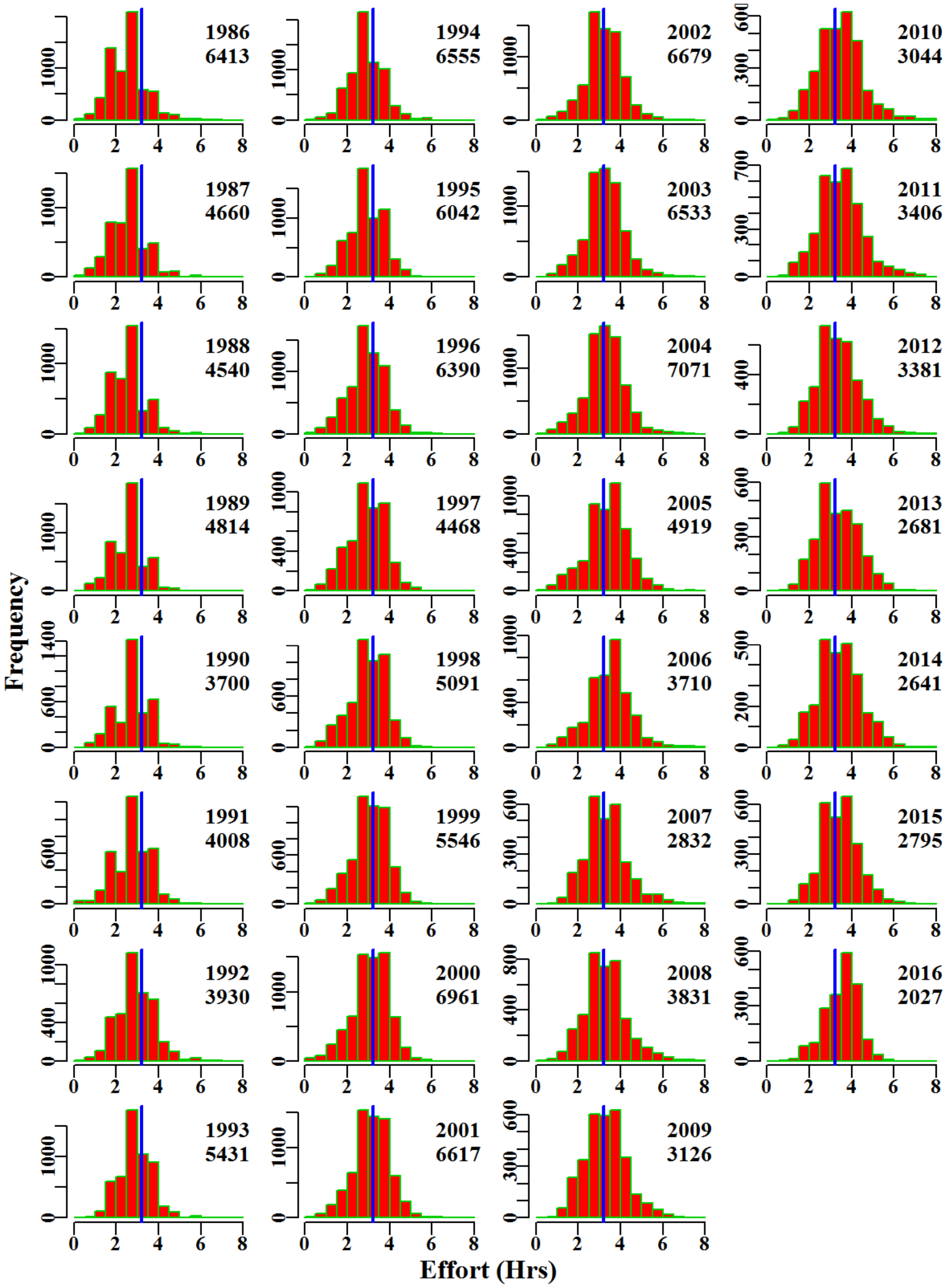


Figure 7.9. JohnDory1020. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.5 School Whiting 60

School Whiting (WHS - 37330014 - *Sillago flindersi*) are taken primarily by Danish seine (and within State waters). A total of 8 statistical models were fitted sequentially to the available data.

7.5.1 *Inferences*

The early years of this data exhibit relatively large inter-annaul variation, far greater than the stock itself could be under-going. This suggests either flaws in the data or some unknown factor having a sporadic effect upon the fishery. Since a low point in 1997 catch rates have been slowly rising and have been approximately at the long term average over the last five years.

The terms Year, Daynight, Vessel and Month had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE based on the AIC and R^2 statistics.

Since 2013, there has been fewer catches in deeper waters (i.e. greater than 50 m). Standardized CPUE exhibits a flat trend since 2012 with the last three years exceeding the long term average based on 95% CIs.

7.5.2 *Action Items and Issues*

The qqplot suggests that the assumed Normal distribution of the log-transformed CPUE (in fact log(catch per shot) may be invalid, as relatively high proportions of the tails of the distribution deviate from the expected straight line. Further work is required to determine the reason behind the frequent occurrence of spikes of low values of catch-per-shot and how they may best be described or explained.

The influence of the vessels fishing changed in about 2003 onwards, and this was reinforced by the DayNight term. The vessel effect also changed dramatically from 2014 - 2016, at which time the distribution of catches among the vessels participating became more even than previously.

Table 7.6. SchoolWhiting60. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/shot), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was DepCat:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	1302.4	5667	1181.6	26	263.2	1.1337	0.000	18.652	0.016
1987	996.0	4125	923.6	23	270.8	1.2540	0.029	12.371	0.013
1988	1255.7	3820	1177.8	25	376.8	1.5934	0.030	10.378	0.009
1989	1061.5	4449	995.5	27	260.3	1.0596	0.029	14.195	0.014
1990	1930.4	6268	1860.5	24	354.1	1.6333	0.027	15.522	0.008
1991	1630.3	4881	1520.4	26	404.1	1.4501	0.029	11.938	0.008
1992	854.1	2980	777.5	23	366.6	1.0455	0.033	8.303	0.011
1993	1694.9	4925	1548.6	24	445.2	1.4916	0.029	10.270	0.007
1994	946.2	4501	878.9	24	271.5	0.8731	0.029	12.818	0.015
1995	1212.6	4234	1059.6	21	338.5	1.1067	0.030	9.385	0.009
1996	898.2	4214	706.8	22	222.8	0.7274	0.030	14.330	0.020
1997	697.4	3218	461.8	20	200.1	0.5536	0.032	11.801	0.026
1998	594.2	2958	462.3	20	214.8	0.5340	0.033	10.775	0.023
1999	681.3	1914	418.9	21	341.7	0.6047	0.039	6.172	0.015
2000	700.9	1926	345.9	18	265.4	0.6335	0.038	7.111	0.021
2001	890.9	1997	429.4	19	297.4	0.8824	0.039	6.795	0.016
2002	788.3	2192	429.2	20	258.7	0.8722	0.037	7.765	0.018
2003	866.2	2355	463.5	20	275.7	0.9129	0.037	8.042	0.017
2004	604.9	1771	334.6	20	262.5	0.8366	0.040	6.971	0.021
2005	662.7	1750	311.4	20	233.3	0.9377	0.041	6.147	0.020
2006	667.5	1428	270.3	18	259.3	0.8391	0.043	5.375	0.020
2007	535.4	1488	347.0	14	330.4	1.1093	0.042	4.493	0.013
2008	502.2	1260	317.1	15	370.4	1.0978	0.045	4.320	0.014
2009	462.6	1569	350.7	15	307.2	1.1732	0.042	5.291	0.015
2010	408.9	1179	272.9	15	339.8	1.0369	0.046	4.255	0.016
2011	373.9	1579	260.3	14	199.0	0.8365	0.042	6.471	0.025
2012	435.8	1566	302.5	14	261.6	0.9046	0.042	5.609	0.019
2013	510.6	1791	339.8	14	248.5	0.9210	0.040	6.694	0.020
2014	698.8	2071	485.4	14	336.4	1.0175	0.039	6.204	0.013
2015	741.1	2467	565.8	14	327.1	0.9727	0.037	7.598	0.013
2016	698.7	2335	561.5	15	305.9	0.9555	0.038	7.843	0.014

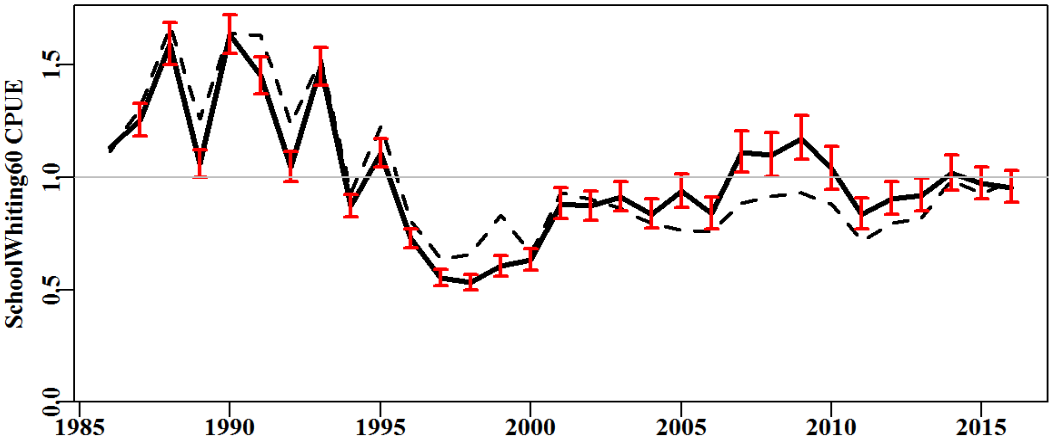


Figure 7.10. SchoolWhiting60 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

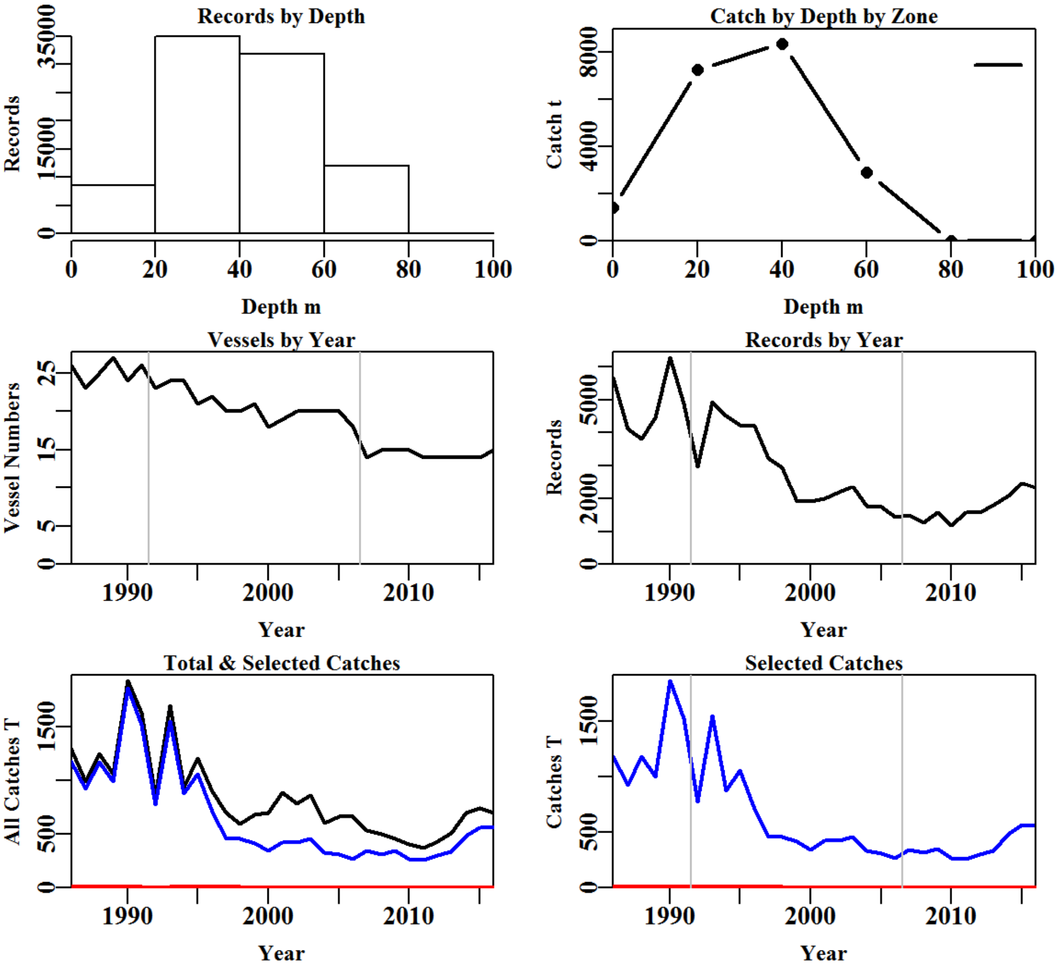


Figure 7.11. SchoolWhiting60 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.7. SchoolWhiting60 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	138159	130025	127729	125678	94675	91873	88878
Difference	0	8134	2296	2051	31003	2802	2995

Table 7.8. The models used to analyse data for SchoolWhiting60

	Model
Model1	Year
Model2	Year + DayNight
Model3	Year + DayNight + Vessel
Model4	Year + DayNight + Vessel + Month
Model5	Year + DayNight + Vessel + Month + DepCat
Model6	Year + DayNight + Vessel + Month + DepCat + DayNight:DepCat
Model7	Year + DayNight + Vessel + Month + DepCat + DepCat:Month
Model8	Year + DayNight + Vessel + Month + DepCat + DayNight:Month

Table 7.9. SchoolWhiting60. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was DepCat:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	64148	182786	7839	88878	31	4.1	0.00
DayNight	60399	175224	15401	88878	34	8.0	3.97
Vessel	57763	169921	20704	88878	82	10.8	2.73
Month	56605	167680	22945	88878	93	11.9	1.17
DepCat	55162	163836	26789	87274	98	12.4	0.45
DayNight:DepCat	54917	163334	27291	87274	109	12.6	0.26
DepCat:Month	54616	162661	27964	87274	139	13.0	0.59
DayNight:Month	54901	163223	27402	87274	131	12.7	0.29

Table 7.10. SchoolWhiting60. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	SchoolWhiting60
csirocode	37330014
fishery	SET
depthrange	0 - 100
depthclass	20
zones	60
methods	DS
years	1986 - 2016

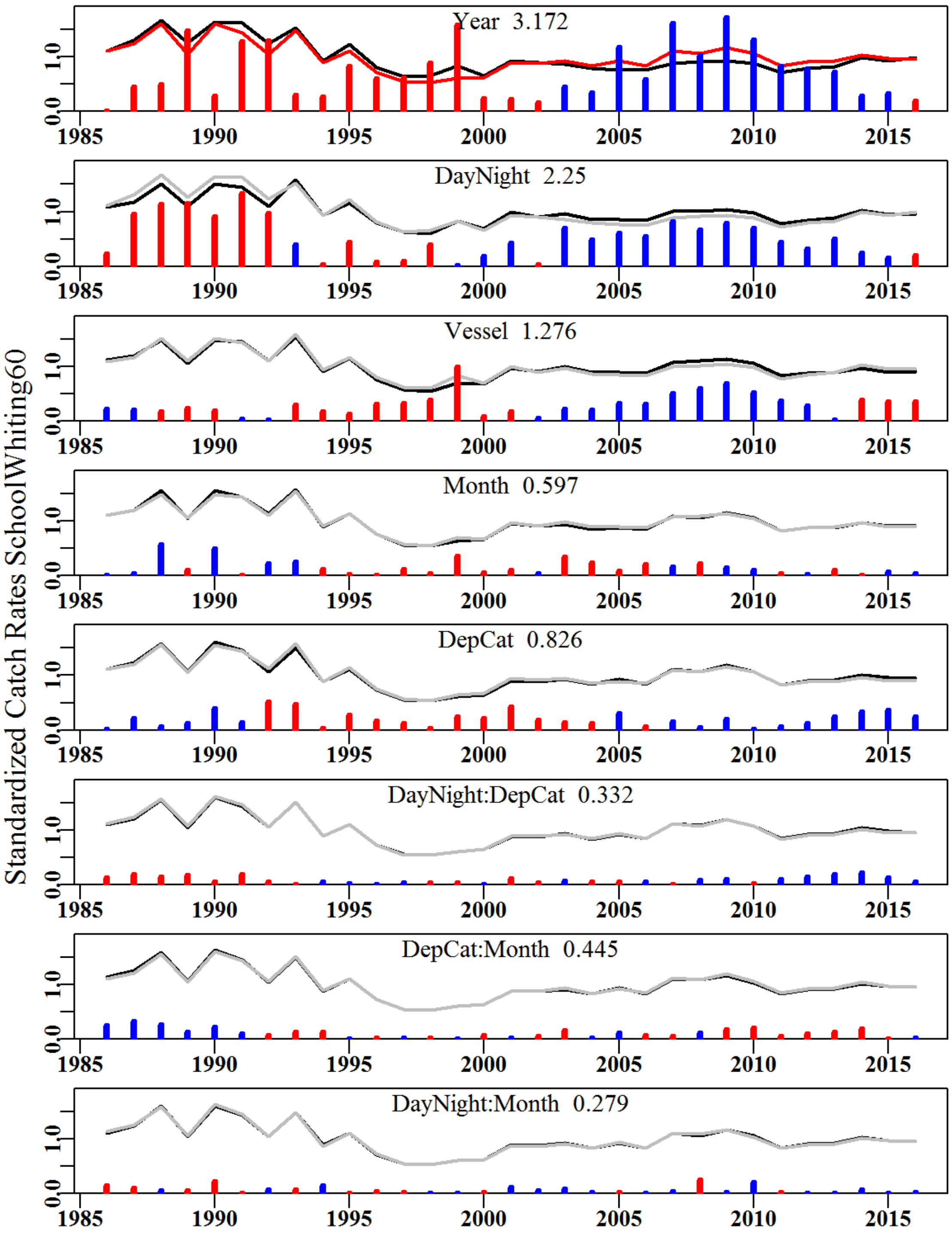


Figure 7.12. SchoolWhiting60. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

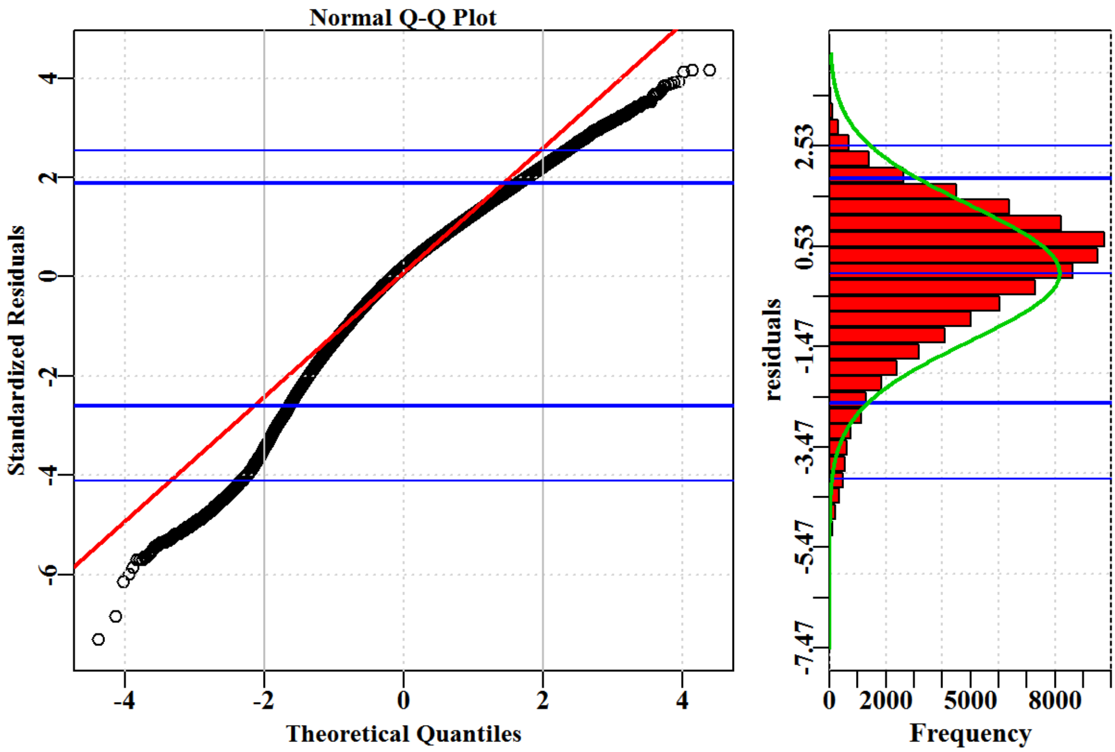


Figure 7.13. SchoolWhiting60. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

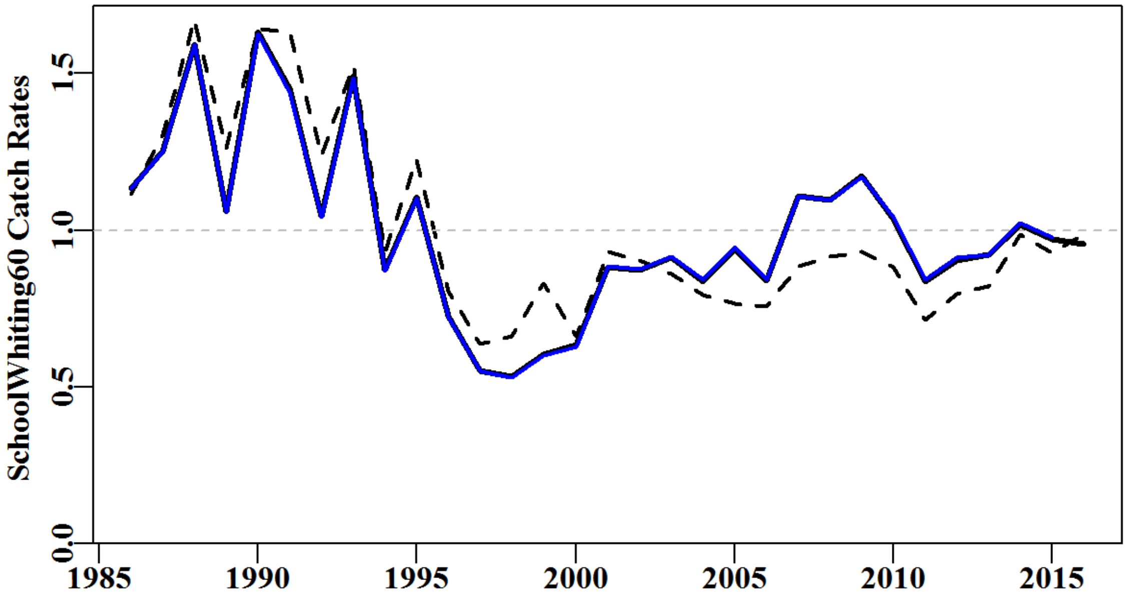


Figure 7.14. SchoolWhiting60. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

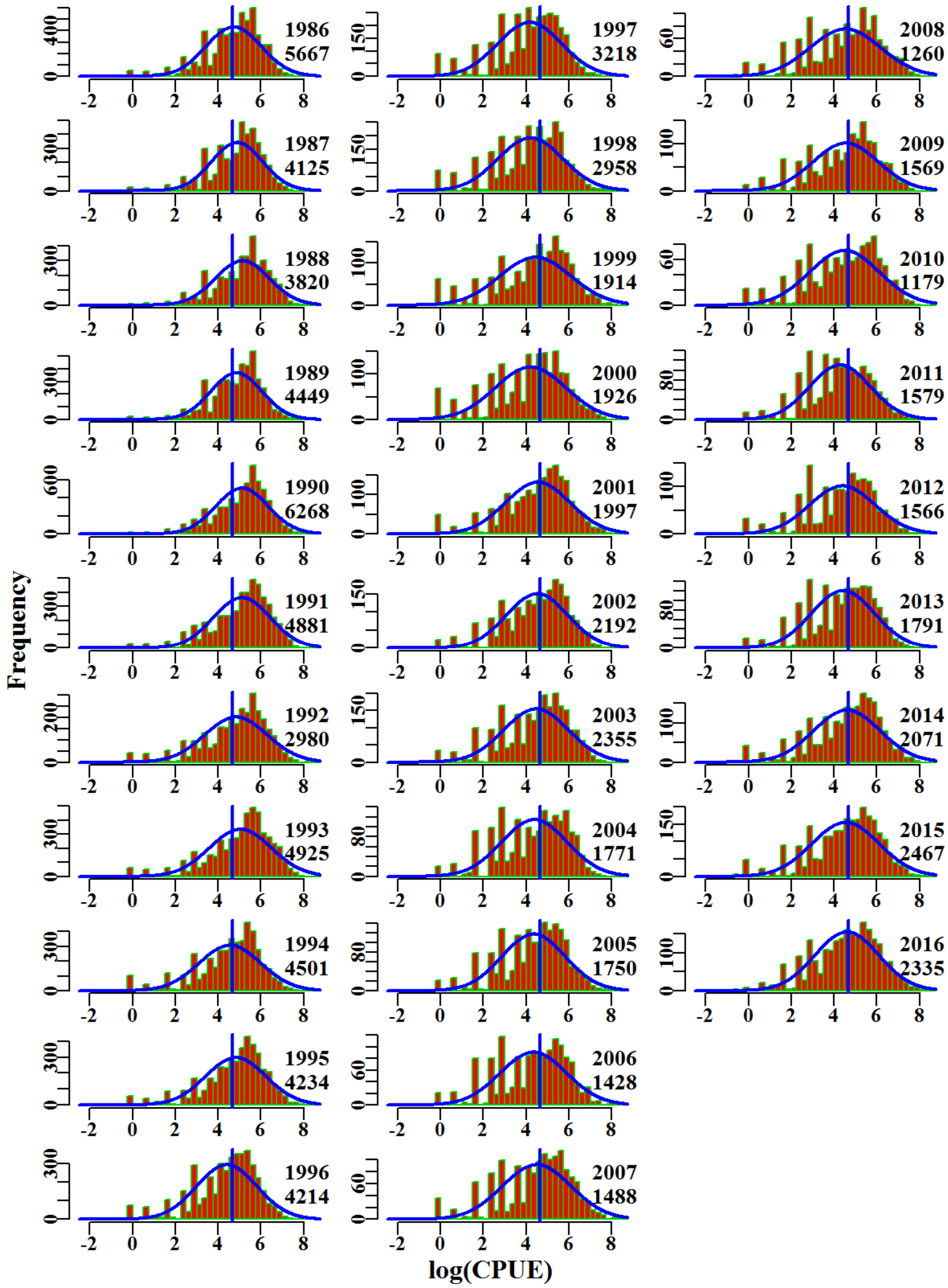


Figure 7.15. SchoolWhiting60. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

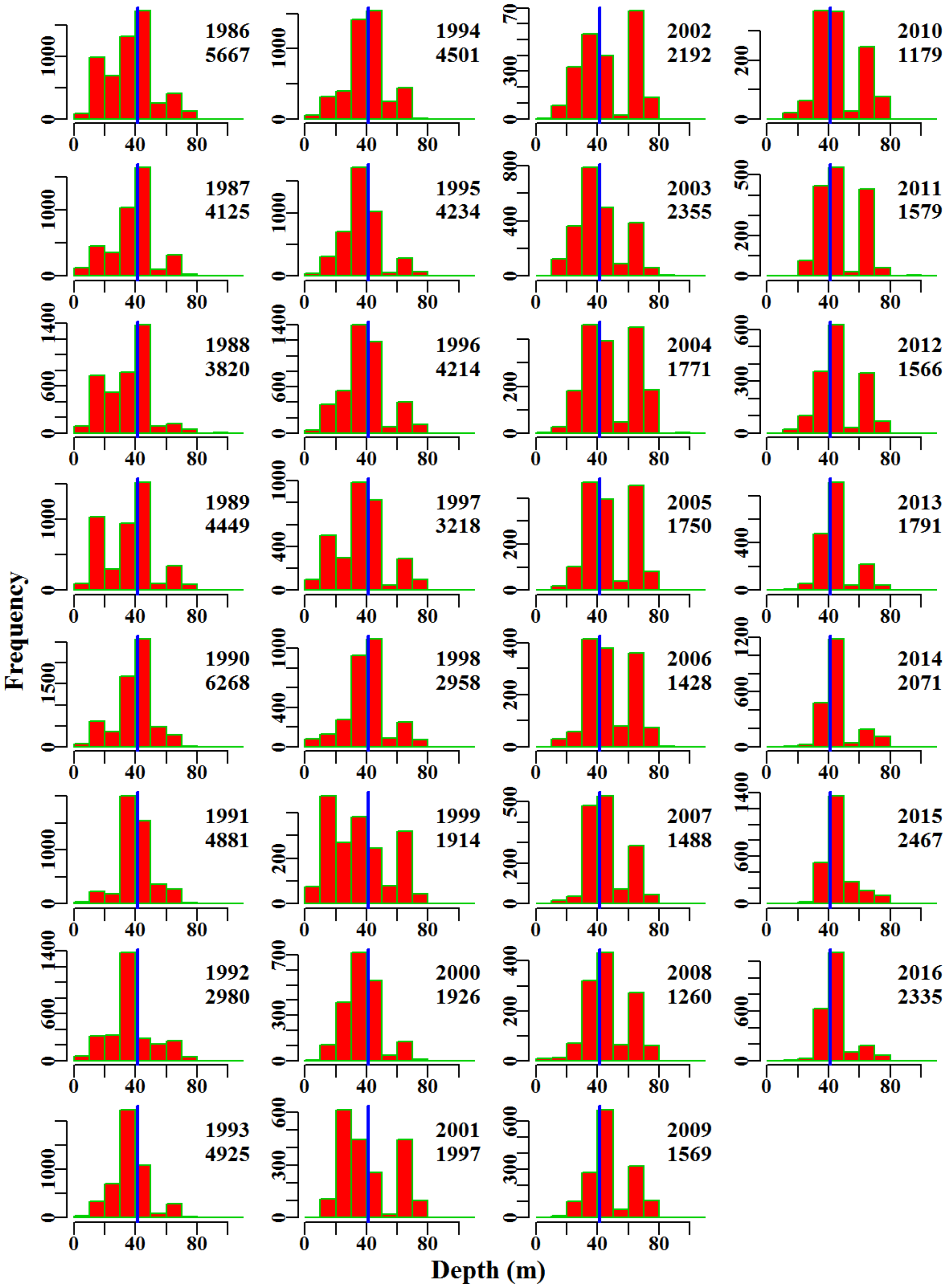


Figure 7.16. SchoolWhiting60. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.6 School Whiting TW 10 20 91

School Whiting (WHS - 37330014 - *Sillago flindersi*) are taken by trawl in zones 10, 20 and 91. All vessels and all records were employed in the analysis for the years 1995 - 2016. Catch rates were expressed as the natural log of catch per hour (catch/hr). This is the first time this analysis has been undertaken. A total of 8 statistical models were fitted sequentially to the available data. Only minor catches are taken in zone 20 but maximum catches by depth category illustrate that catches in zones 10 and 91 are of the same order. Zone 91 catches are strictly State catches and while included here are excluded in the next analysis for comparison.

7.6.1 *Inferences*

Most trawl caught school whiting occur between ~ 40 - 60 m, extending out to 150 m. Since 2014, catches have also been reported in deeper waters. Annual catches since 2009 have been smaller compared to previous years.

The terms Year, Vessel, DayNight, and DepCat had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE based on the AIC and R^2 statistics. The qqplot suggests that the assumed Normal distribution is valid, with small devaitions at the tails.

Standardized CPUE returned to the long term average in 2016, the first time since 2008 (Figure 7.17).

7.6.2 *Action Items and Issues*

Again the last three years 2014 - 2016 appear to have exhibited an alteration in fishing behaviour as evidenced by the changing distributions of records of catch at depth, why this has occurred in the last three years remains unknown.

Table 7.11. SchoolWhitingTW. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was DepCat:Month

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1995	1212.6	279	41.8	16	66.2	1.2167	0.000	1.036	0.025
1996	898.2	518	86.6	21	80.2	1.3600	0.095	0.970	0.011
1997	697.4	905	102.7	23	63.5	0.9395	0.086	3.155	0.031
1998	594.2	717	81.9	25	54.4	0.9470	0.088	2.878	0.035
1999	681.3	890	107.5	27	63.2	1.1483	0.086	2.808	0.026
2000	700.9	1234	154.6	30	69.3	1.1447	0.083	3.775	0.024
2001	890.9	2111	311.9	34	92.8	1.2643	0.080	7.907	0.025
2002	788.3	1661	171.8	36	73.1	1.0444	0.082	5.973	0.035
2003	866.2	2453	292.8	40	68.4	0.9874	0.079	9.464	0.032
2004	604.9	2058	188.9	39	47.9	0.7679	0.080	10.047	0.053
2005	662.7	1971	252.8	37	71.2	1.0794	0.081	7.578	0.030
2006	667.5	1443	225.9	28	75.5	1.4908	0.082	5.845	0.026
2007	535.4	504	88.1	15	106.2	1.4509	0.095	2.135	0.024
2008	502.2	842	106.9	15	67.1	0.9456	0.087	3.760	0.035
2009	462.6	445	37.0	17	46.8	0.8113	0.096	2.629	0.071
2010	408.9	467	48.0	17	60.2	0.9782	0.096	2.289	0.048
2011	373.9	497	65.0	15	83.2	0.8242	0.095	2.328	0.036
2012	435.8	511	45.5	16	49.7	0.6116	0.094	3.125	0.069
2013	510.6	668	57.5	14	44.5	0.5563	0.090	4.046	0.070
2014	698.8	823	72.3	18	52.8	0.7577	0.088	4.214	0.058
2015	741.1	776	55.7	19	36.7	0.6817	0.089	4.995	0.090
2016	698.7	578	66.2	14	70.2	0.9918	0.093	3.074	0.046

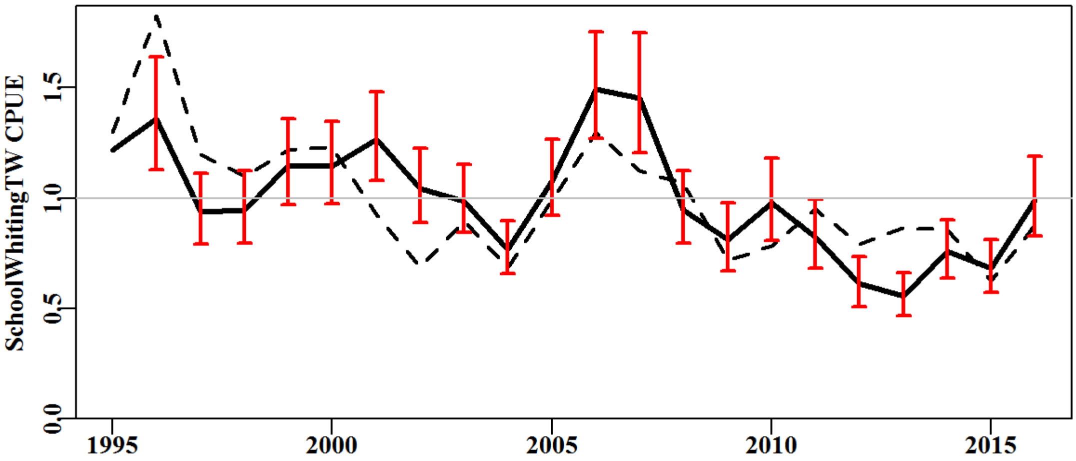


Figure 7.17. SchoolWhitingTW standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

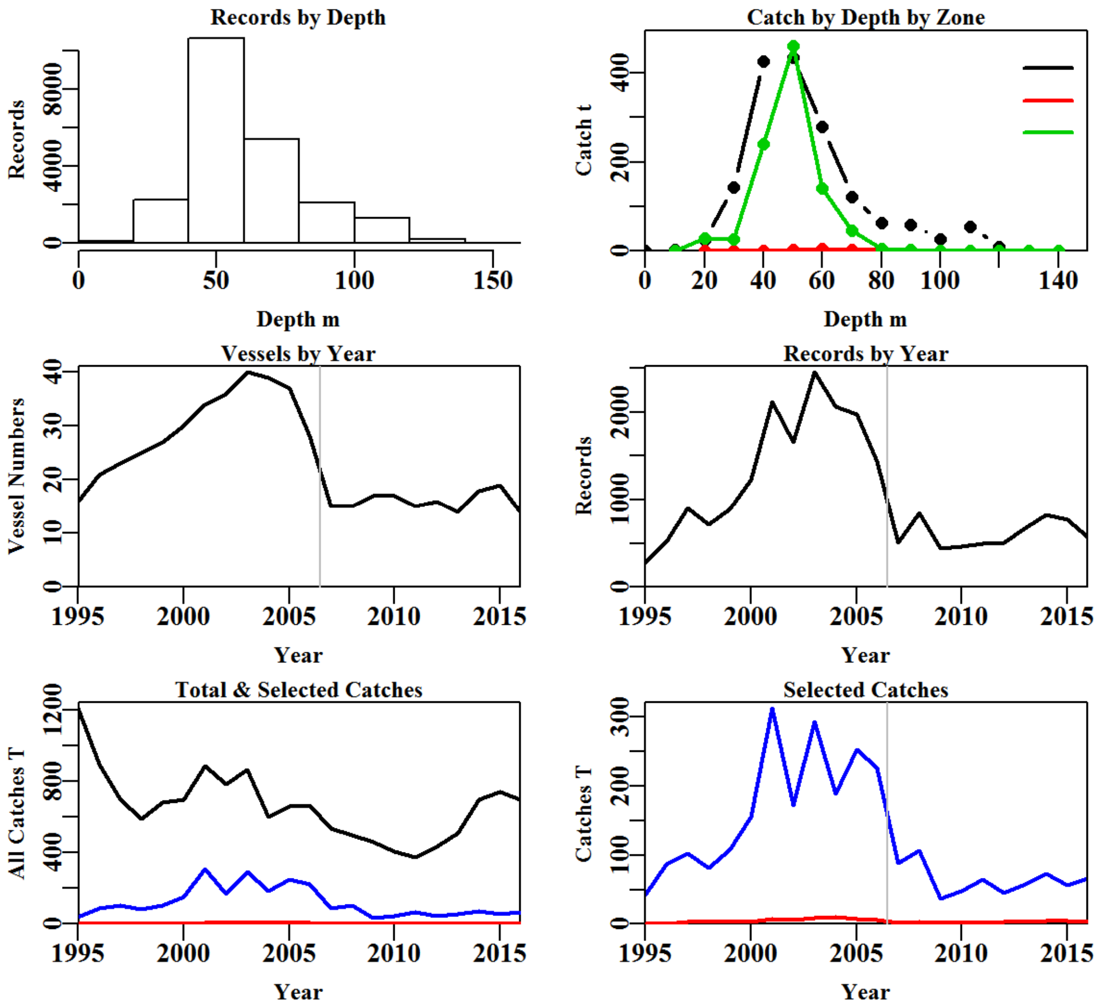


Figure 7.18. SchoolWhitingTW fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.12. SchoolWhitingTW data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	138159	105125	104799	60579	23175	22379	22351
Difference	0	33034	326	44220	37404	796	28

Table 7.13. The models used to analyse data for SchoolWhitingTW

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DayNight
Model4	Year + Vessel + DayNight + DepCat
Model5	Year + Vessel + DayNight + DepCat + Month
Model6	Year + Vessel + DayNight + DepCat + Month + DayNight:DepCat
Model7	Year + Vessel + DayNight + DepCat + Month + DepCat:Month
Model8	Year + Vessel + DayNight + DepCat + Month + DayNight:Month

Table 7.14. SchoolWhitingTW. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was DepCat:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	19865	54254	1239	22351	22	2.1	0.00
Vessel	12182	38239	17254	22351	90	30.8	28.68
DayNight	10043	34740	20753	22351	93	37.1	6.32
DepCat	9087	32936	22556	22008	107	39.6	2.45
Month	9023	32808	22684	22008	118	39.8	0.20
DayNight:DepCat	8763	32343	23149	22008	145	40.6	0.78
DepCat:Month	8821	32100	23392	22008	257	40.7	0.92
DayNight:Month	8950	32629	22864	22008	142	40.1	0.26

Table 7.15. SchoolWhitingTW. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	SchoolWhitingTW
csirocode	37330014
fishery	SET
depthrange	0 - 150
depthclass	10
zones	10, 20, 91
methods	TW, TDO
years	1995 - 2016

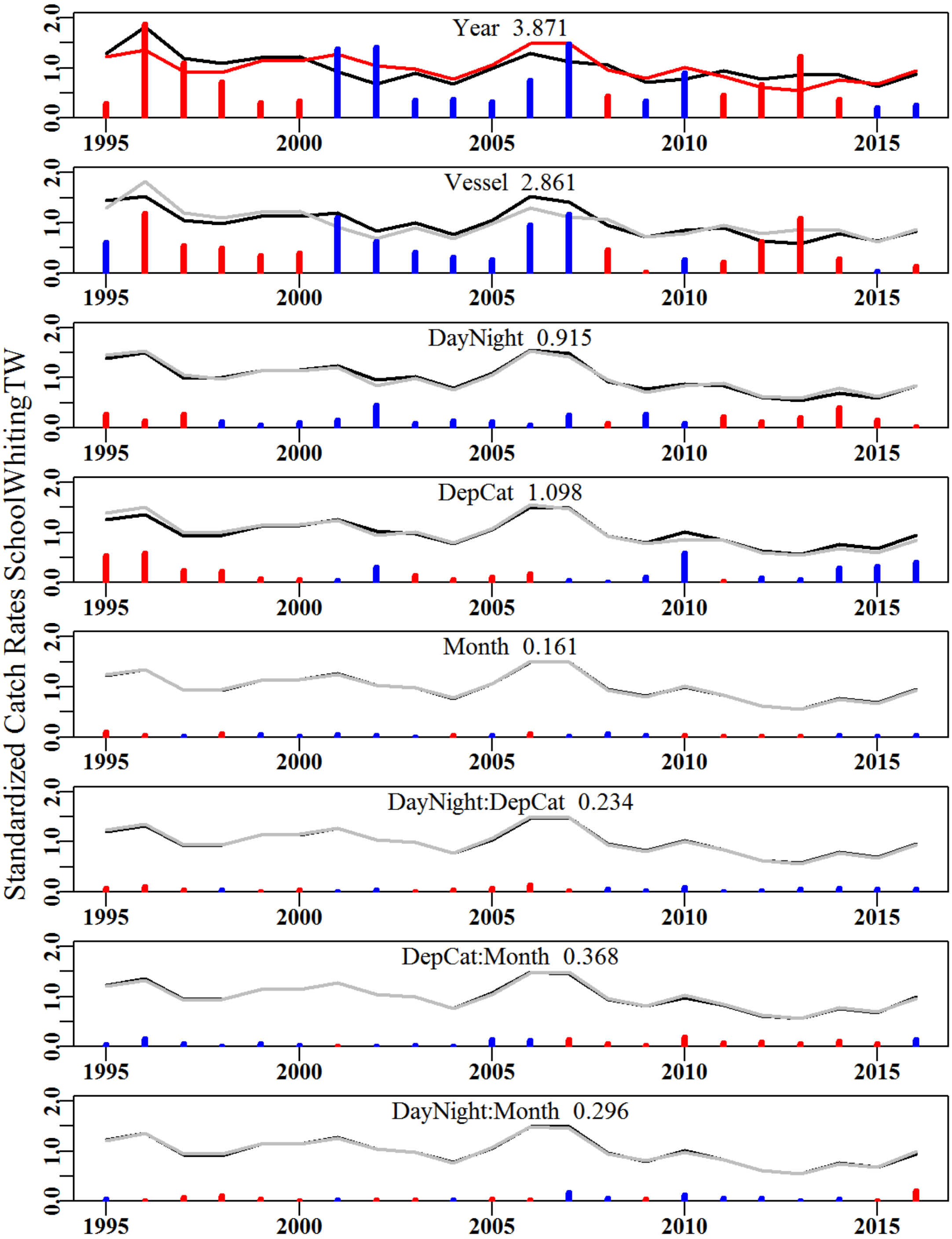


Figure 7.19. SchoolWhitingTW. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

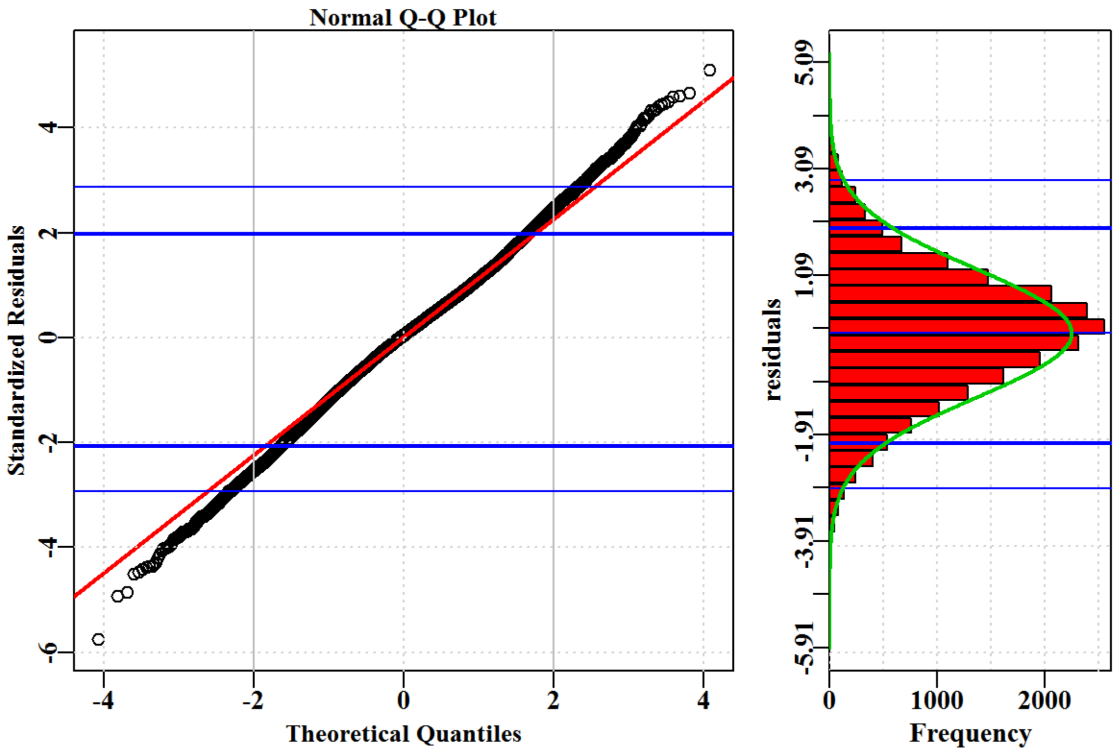


Figure 7.20. SchoolWhitingTW. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

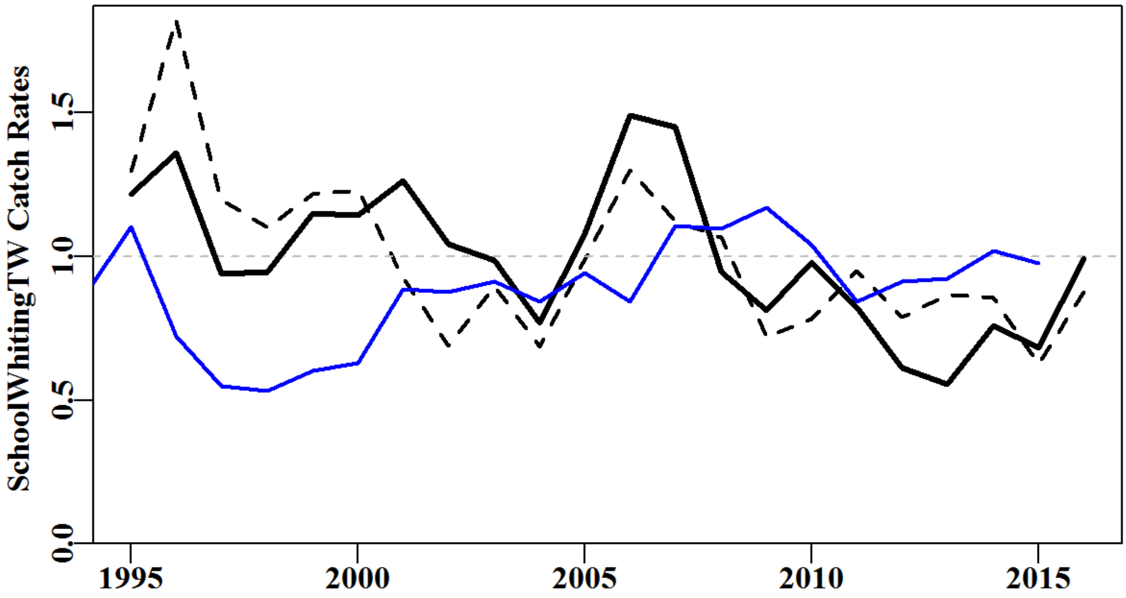


Figure 7.21. SchoolWhitingTW. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

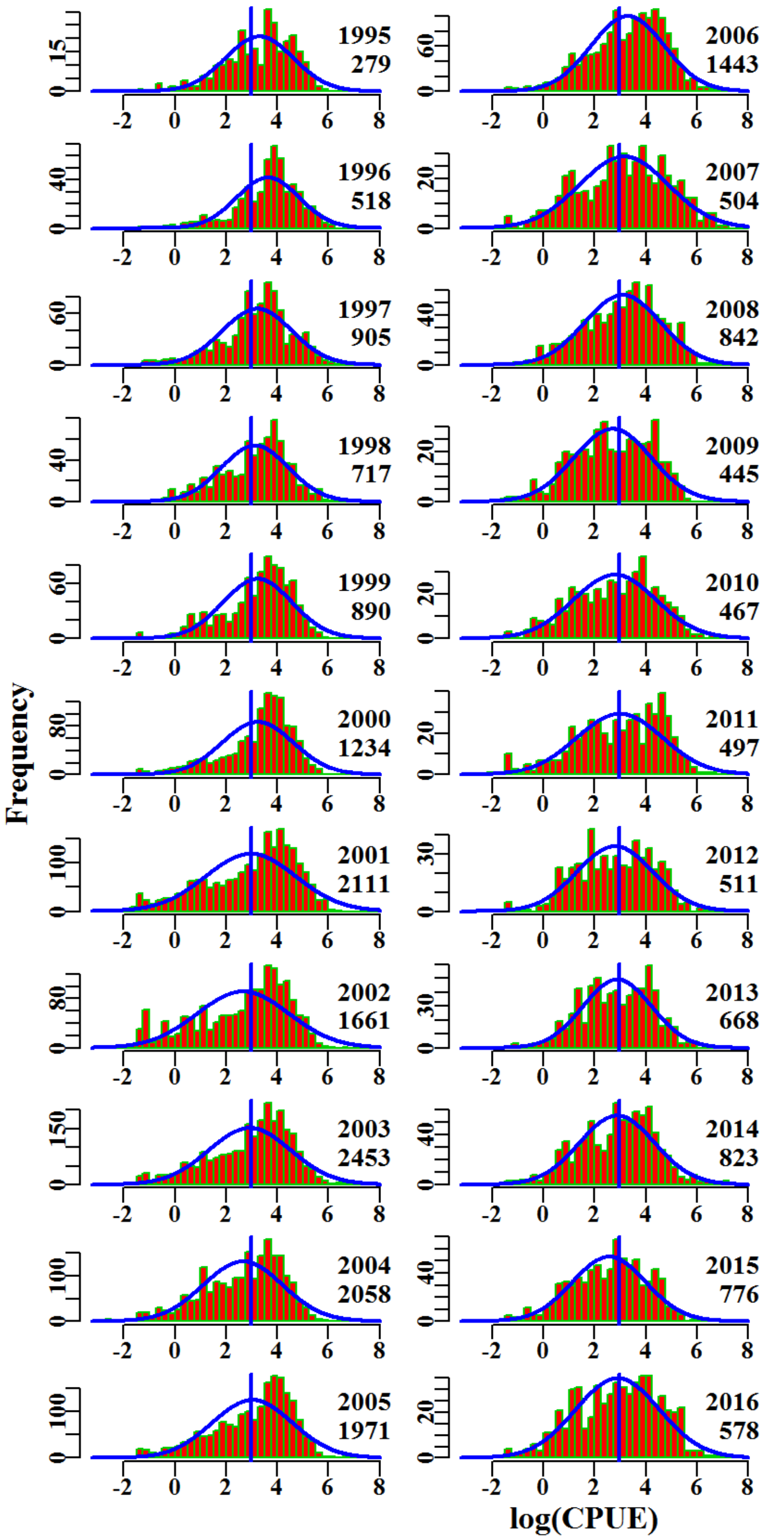


Figure 7.22. SchoolWhitingTW. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

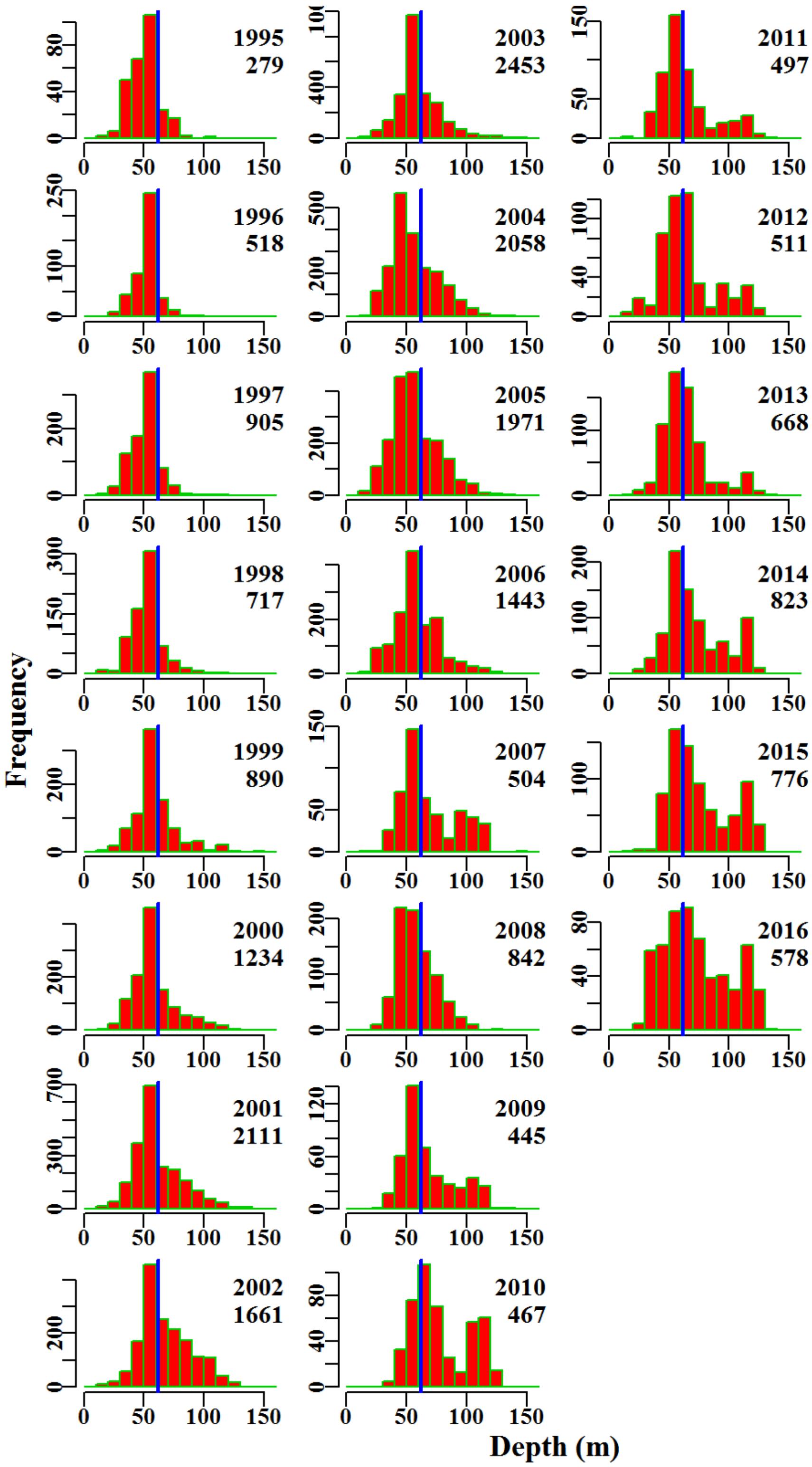


Figure 7.23. SchoolWhitingTW. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

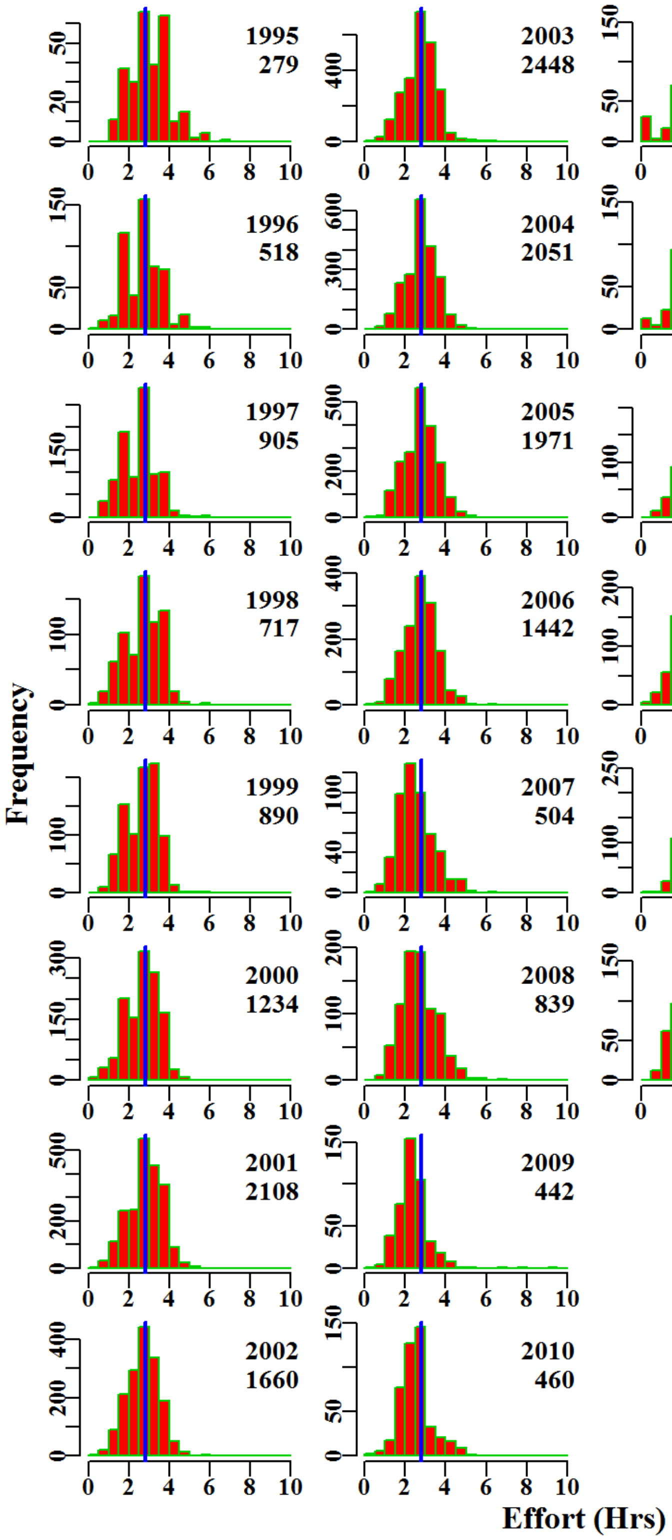


Figure 7.24. SchoolWhitingTW. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.7 School Whiting TW 10 20

7.7.1 Inferences

School Whiting (WHS - 37330014 - *Sillago flindersi*) are taken by trawl in zones 10 and 20. All vessels and all records were employed in the analysis for the years 1995 - 2016. Catch rates were expressed as the natural log of catch per hour (catch/hr). Initial data selection was based on criteria provided in Table 7.20 from the Commonwealth logbook database. This analysis omits zone 91, which, even though the fishery is a clear and natural extension of the Commonwealth fishery (as evidenced by plotting the location of each shot) being State waters and catches they are omitted from the standardization for comparison with the complete analysis. A total of 8 statistical models were fitted sequentially to the available data, and the order of the non-interaction terms added based on the relative contribution of each term to model fit.

The terms Year, Vessel, DayNight, and DepCat and one interaction (DayNight:DepCat) had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE based on the AIC and R^2 statistics. The qqplot suggests that the assumed Normal distribution is valid.

The standardized CPUE trend is relatively noisy and flat except between 2006 - 2007 (i.e. around the time of the structural adjustment) (Figure 7.25). The log-transformed cpue data is a close fit to ta normal distribution.

7.7.2 Action Items and Issues

The depth distribution of catches has not been stable from year to year, which may reflect the fact that there are only few vessels contributing seriously to this fishery.

Table 7.16. SchoolWhitingTW1020. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was DayNight:DepCat.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1995	1212.6	153	23.9	13	97.2	1.3531	0.000	0.679	0.028
1996	898.2	187	33.1	18	132.6	1.2166	0.156	0.537	0.016
1997	697.4	502	62.1	21	99.4	0.9732	0.126	2.310	0.037
1998	594.2	314	32.8	25	70.8	0.9672	0.131	1.695	0.052
1999	681.3	487	51.5	27	72.1	1.1374	0.125	2.082	0.040
2000	700.9	796	99.0	30	89.5	1.1123	0.119	2.785	0.028
2001	890.9	1454	179.6	34	87.0	1.1429	0.115	6.865	0.038
2002	788.3	1300	127.8	36	78.0	1.0280	0.116	4.971	0.039
2003	866.2	1656	193.1	38	78.3	0.9997	0.115	7.274	0.038
2004	604.9	1286	91.3	38	40.2	0.7924	0.115	7.229	0.079
2005	662.7	1259	133.3	37	64.8	1.0253	0.116	6.455	0.048
2006	667.5	949	140.1	28	79.8	1.6314	0.118	4.660	0.033
2007	535.4	443	81.9	15	123.0	1.6020	0.127	1.860	0.023
2008	502.2	523	67.9	15	80.0	0.8822	0.124	2.380	0.035
2009	462.6	376	30.3	17	46.1	0.7936	0.129	2.204	0.073
2010	408.9	389	38.2	17	55.4	0.9625	0.130	2.144	0.056
2011	373.9	424	50.0	15	83.8	0.7828	0.128	1.956	0.039
2012	435.8	427	40.1	16	57.1	0.6535	0.127	2.455	0.061
2013	510.6	509	45.8	14	50.3	0.5387	0.125	2.820	0.062
2014	698.8	698	64.0	18	59.1	0.7746	0.122	3.582	0.056
2015	741.1	654	48.0	19	39.0	0.6934	0.123	4.209	0.088
2016	698.7	504	57.8	14	73.7	0.9371	0.126	2.824	0.049

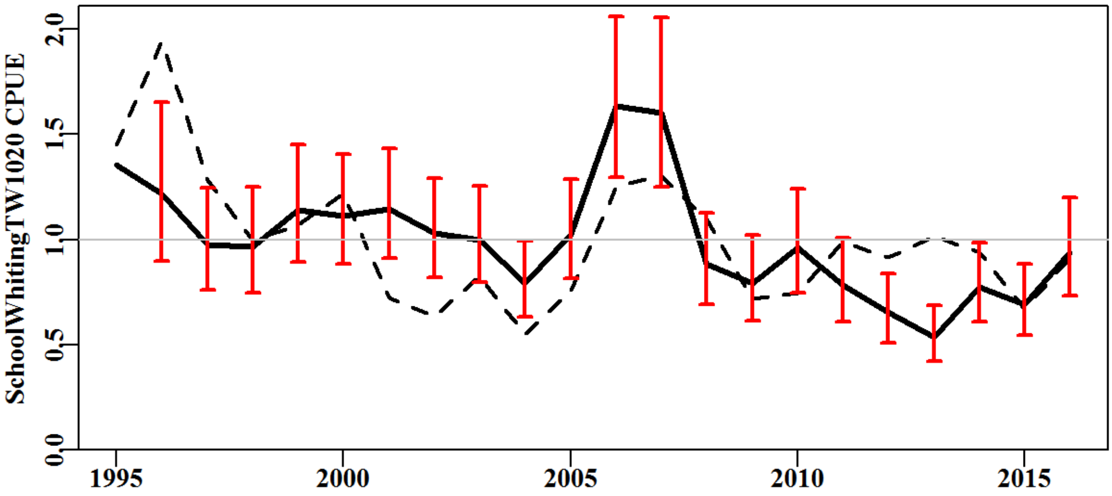


Figure 7.25. SchoolWhitingTW1020 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

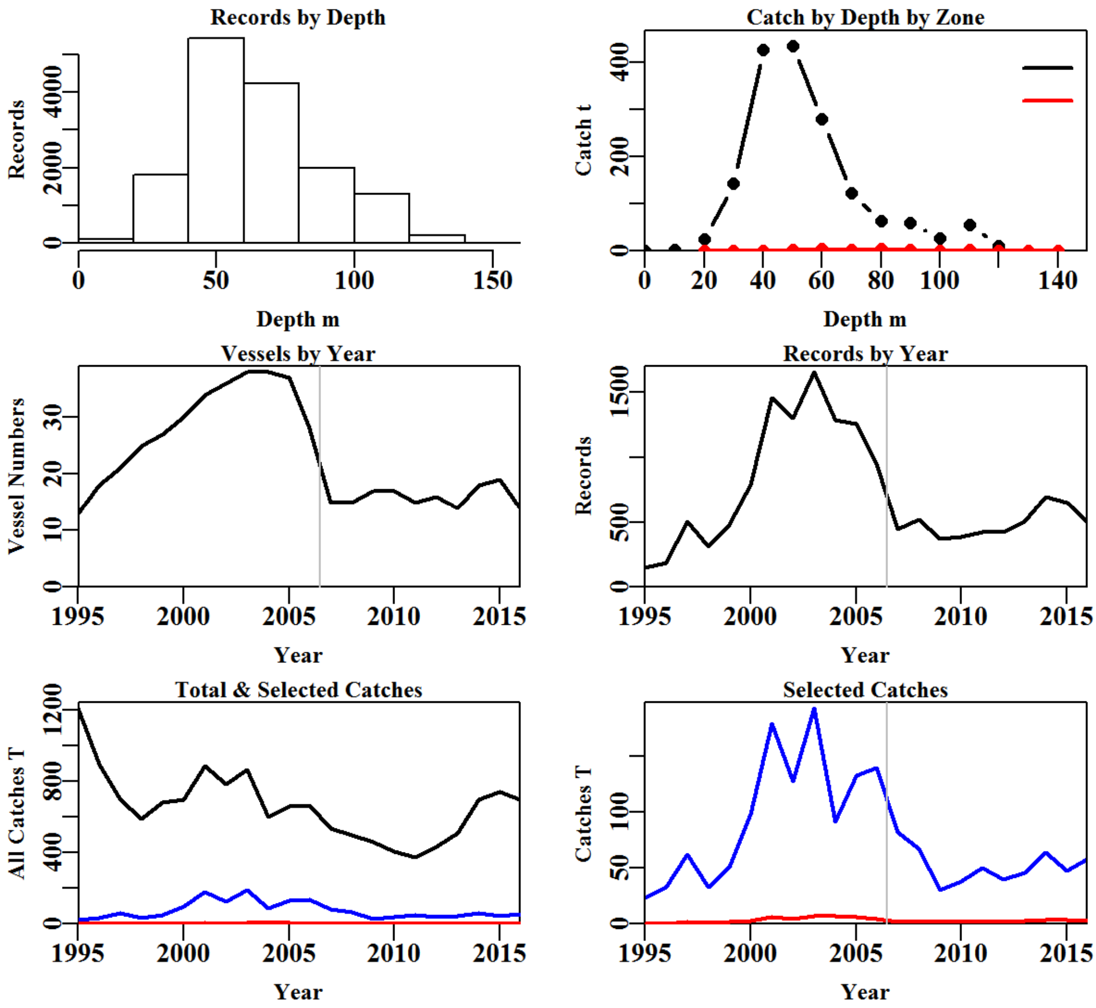


Figure 7.26. SchoolWhitingTW1020 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.17. SchoolWhitingTW1020 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	138159	105125	104799	60579	16110	15318	15290
Difference	0	33034	326	44220	44469	792	28

Table 7.18. The models used to analyse data for SchoolWhitingTW1020.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DayNight
Model4	Year + Vessel + DayNight + DepCat
Model5	Year + Vessel + DayNight + DepCat + Month
Model6	Year + Vessel + DayNight + DepCat + Month + DayNight:DepCat
Model7	Year + Vessel + DayNight + DepCat + Month + DepCat:Month
Model8	Year + Vessel + DayNight + DepCat + Month + DayNight:Month

Table 7.19. SchoolWhitingTW1020. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was DayNight:DepCat.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	16546	44990	1138	15290	22	2.3	0.00
Vessel	11007	31040	15088	15290	90	32.3	29.98
DayNight	9203	27576	18552	15290	93	39.9	7.54
DepCat	8363	25883	20245	15073	107	42.8	2.98
Month	8298	25733	20395	15073	118	43.1	0.29
DayNight:DepCat	8026	25182	20946	15073	145	44.2	1.12
DepCat:Month	8190	25086	21042	15073	256	44.0	0.91
DayNight:Month	8256	25580	20548	15073	142	43.4	0.25

Table 7.20. SchoolWhitingTW1020. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	SchoolWhitingTW1020
csirocode	37330014
fishery	SET
depthrange	0 - 150
depthclass	10
zones	10, 20
methods	TW, TDO
years	1995 - 2016

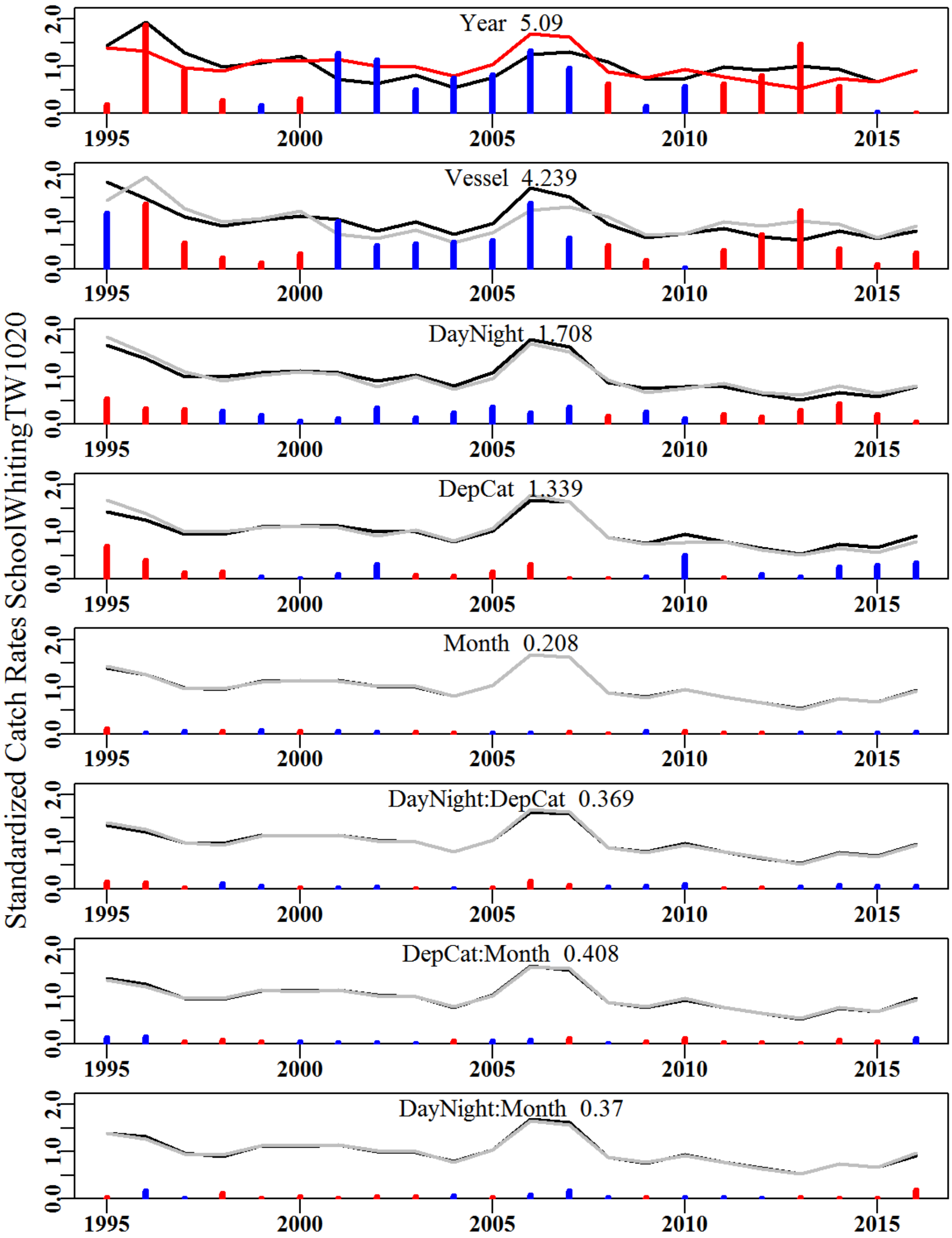


Figure 7.27. SchoolWhitingTW1020. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

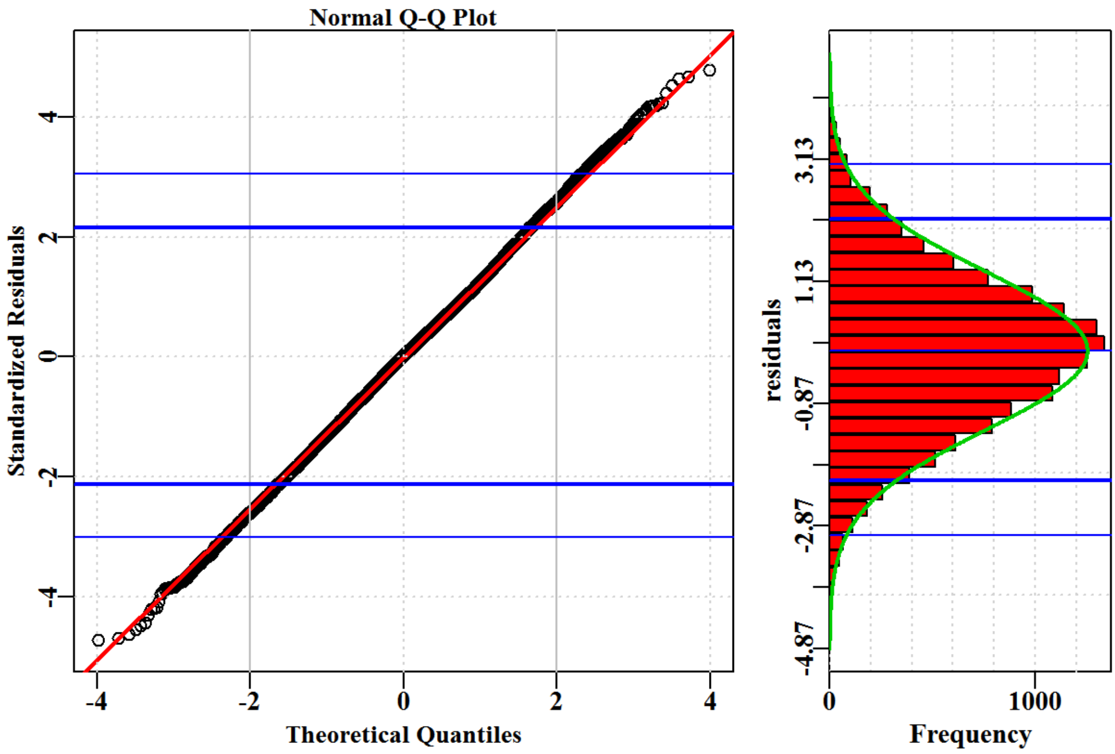


Figure 7.28. SchoolWhitingTW1020. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

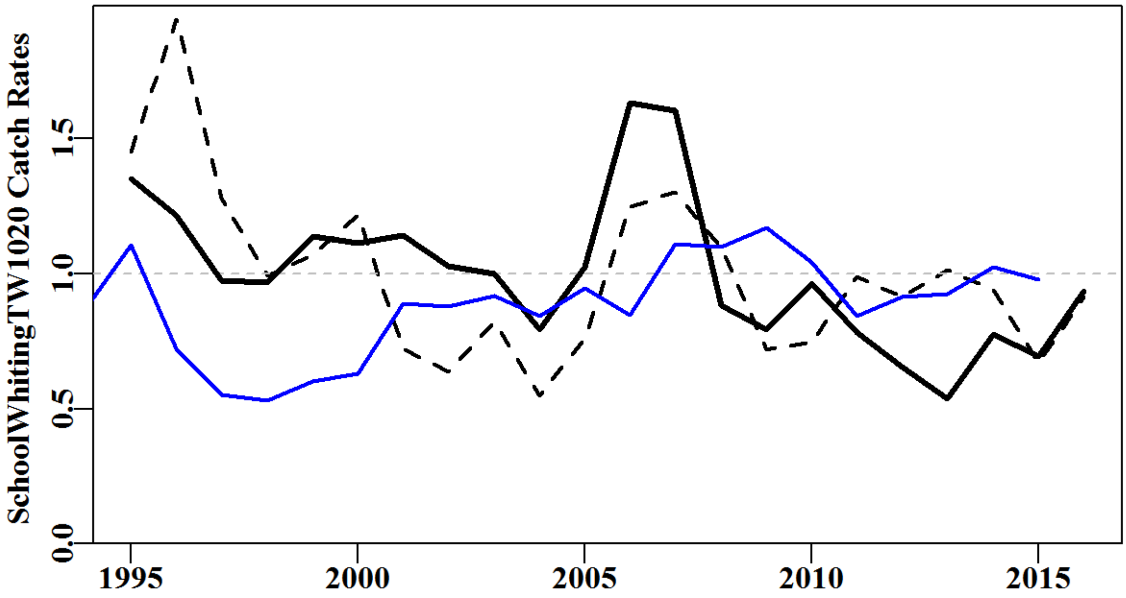


Figure 7.29. SchoolWhitingTW1020. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

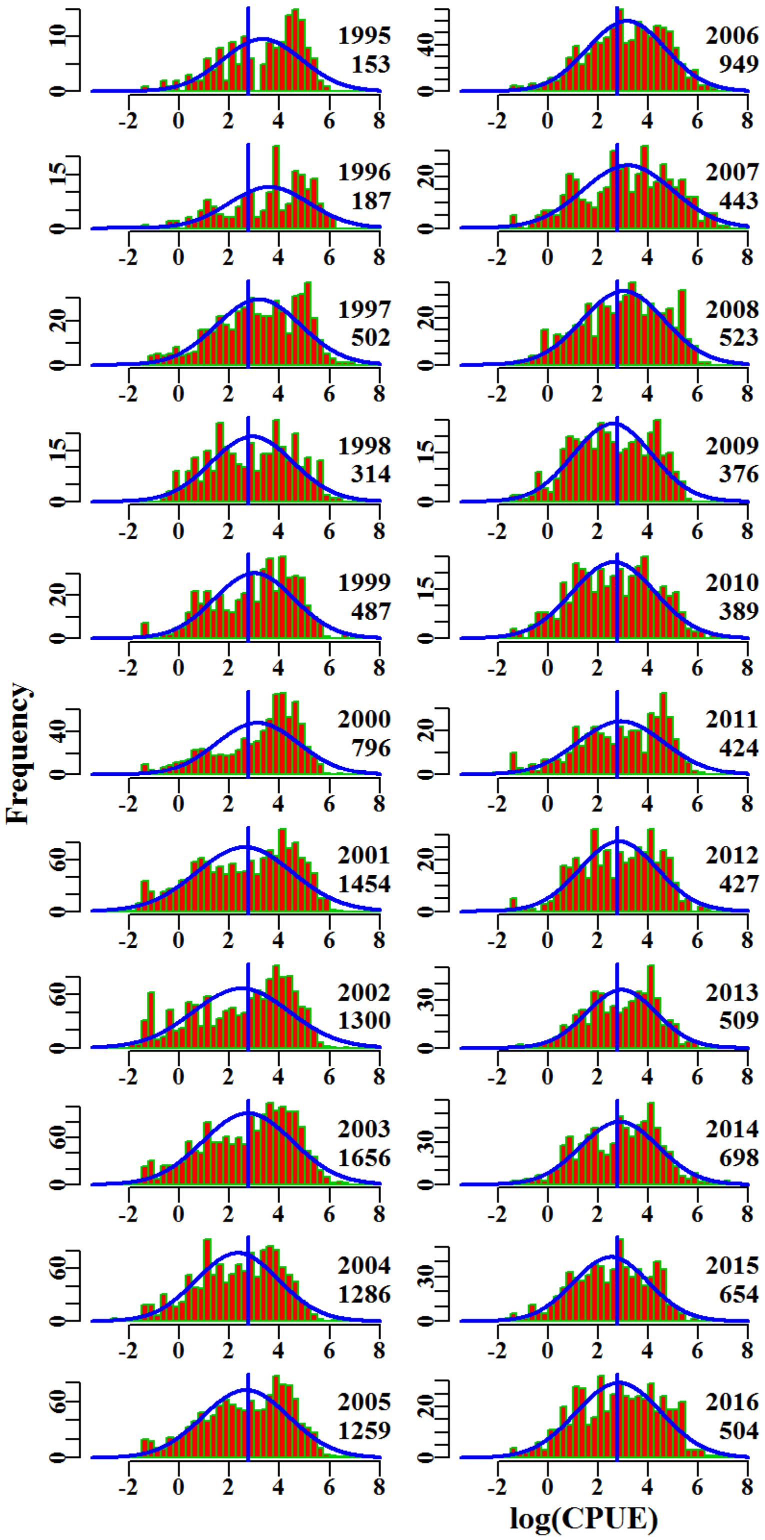


Figure 7.30. SchoolWhitingTW1020. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

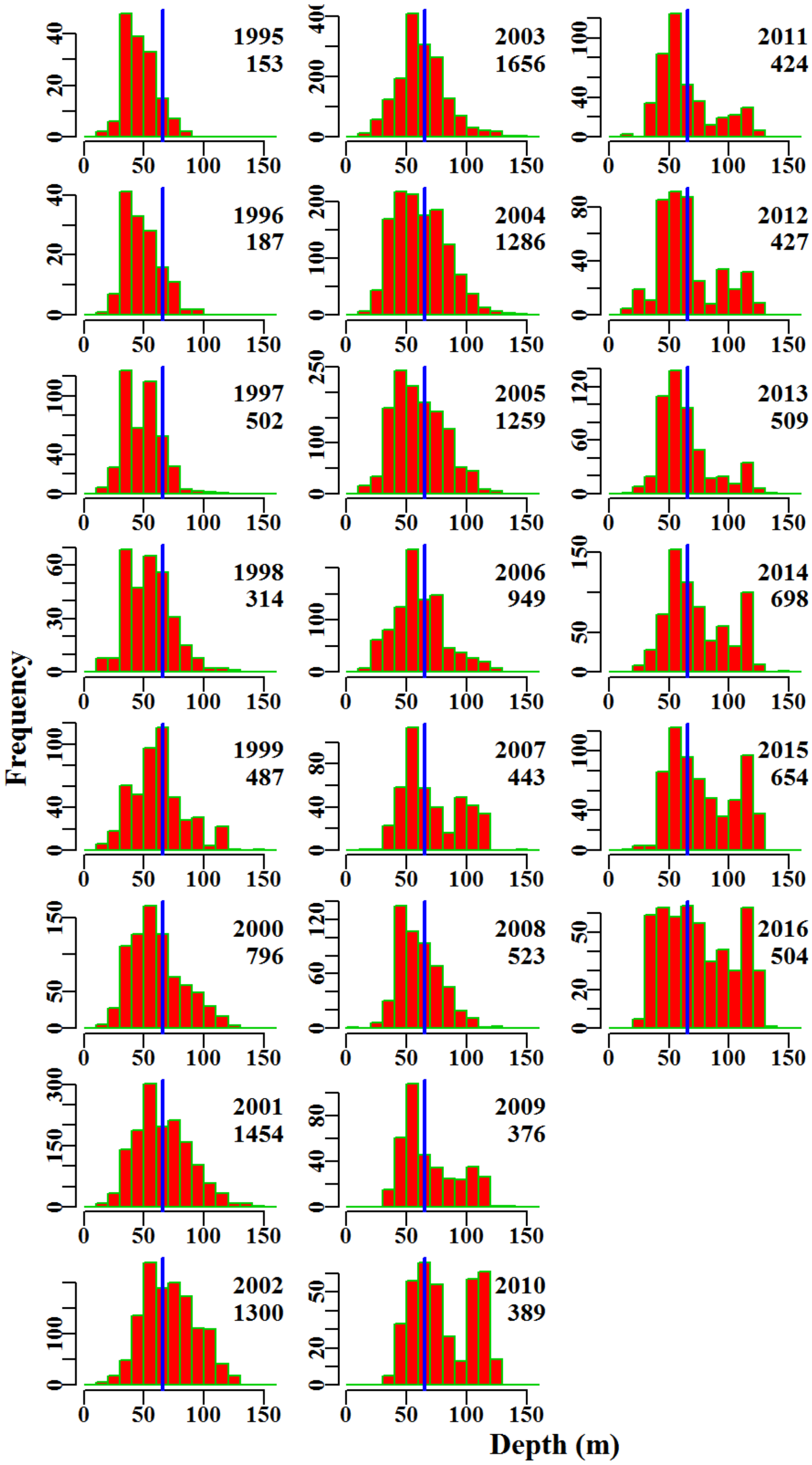


Figure 7.31. SchoolWhitingTW1020. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

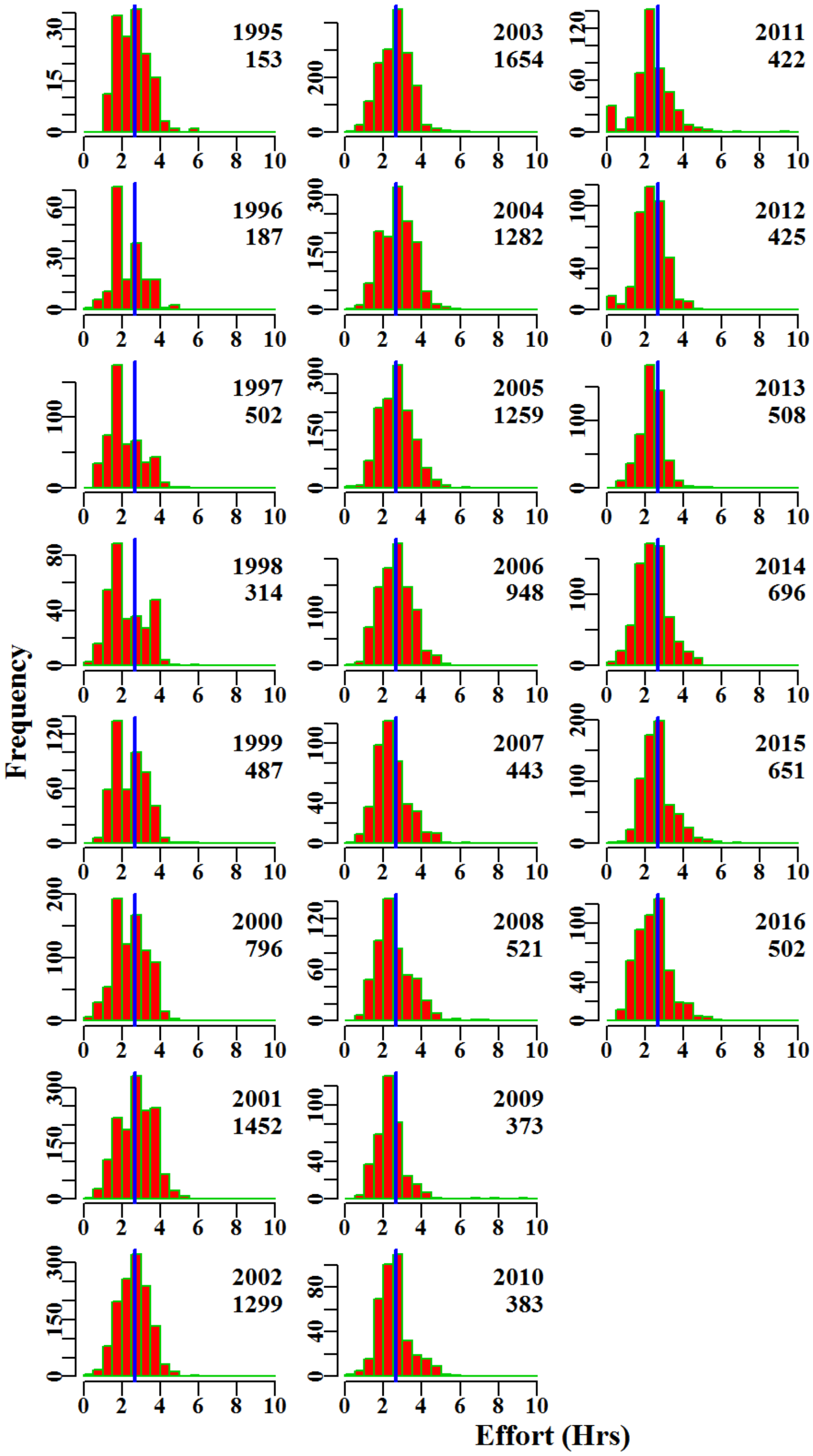


Figure 7.32. SchoolWhitingTW1020. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.8 Mirror Dory 10 – 30

Mirror Dory (DOM - 37264003 - *Zenopsis nebulosus*) has a long history within the SESSF with catches being taken widely and by multiple methods. Initial data selection was based on criteria provided in Table 7.25 from the Commonwealth logbook database. A total of 8 statistical models were fitted sequentially to the available data.

7.8.1 *Inferences*

The terms Year, Vessel, DepCat, and Month had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE based on the AIC and R^2 statistics. The qqplot suggests that the assumed Normal distribution is valid (Figure 7.36).

The Mirror Dory fishery in zones 10 - 30 exhibits large scale, apparently cyclical changes in CPUE. In an approximate manner as catches decline so do catch rates, and as catches increase so does the CPUE. This is unexpected as the intensity of fishing is usually expected to be negatively correlated with CPUE. It may be the case that catches and CPUE change relative to availability of the stock rather than the influence of the fishery on the stock. Better evidence is needed to make such an assertion with confidence. Over the period when CPUE was lower than average (about 1995 - 2004) there was an increase in small shots of < 30kg (Figure 7.35), which is suggestive or either low availability of high levels of small fish.

Standardized CPUE has declined from 2009 - 2016. It differs from unstandardized CPUE early in the fishery (1986 - 1990), and in the second half of the fishery (2000 - 2007) and in the most recent three years (2014 - 2016). The most recent changes appear strongly correlated with changes in the average depth of fishing with a shift to more relatively shallow water fishing, compared to the second half of the fishery.

7.8.2 *Action Items and Issues*

No issues identified.

Table 7.21. MirrorDory1030. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	402.0	3140	367.9	80	39.2	1.1963	0.000	16.343	0.044
1987	450.8	2961	413.6	70	40.7	1.3060	0.033	15.241	0.037
1988	346.0	3067	313.2	77	33.7	1.1792	0.033	19.277	0.062
1989	591.6	2997	513.7	70	54.4	1.4167	0.033	15.825	0.031
1990	295.8	1811	254.4	61	36.4	1.3473	0.038	10.173	0.040
1991	240.3	2020	170.9	68	27.1	1.1677	0.038	16.199	0.095
1992	167.0	2039	140.9	57	22.3	1.0174	0.038	18.054	0.128
1993	306.2	3012	267.1	62	32.4	1.1029	0.034	22.106	0.083
1994	297.3	3496	262.0	62	25.9	0.9749	0.033	30.065	0.115
1995	244.9	3498	196.3	58	21.7	0.8772	0.033	33.116	0.169
1996	352.7	4393	212.2	69	16.7	0.7692	0.032	43.425	0.205
1997	459.6	4775	288.1	65	19.5	0.8156	0.032	45.383	0.158
1998	355.8	4103	230.5	55	19.4	0.7293	0.032	39.074	0.170
1999	309.5	4225	234.9	59	19.3	0.6465	0.033	39.689	0.169
2000	171.1	4601	142.7	64	11.3	0.5102	0.032	46.611	0.327
2001	243.4	4544	128.9	54	10.0	0.5095	0.033	46.515	0.361
2002	449.6	5041	194.6	53	14.0	0.6394	0.032	44.520	0.229
2003	613.9	5363	405.7	58	29.9	0.9213	0.032	41.182	0.102
2004	507.4	4274	292.7	57	25.8	0.8731	0.033	32.509	0.111
2005	579.9	4417	423.6	55	37.1	1.1210	0.033	30.585	0.072
2006	419.6	3230	297.6	44	35.3	1.1273	0.035	23.726	0.080
2007	289.6	2223	203.2	22	33.8	1.2156	0.038	16.421	0.081
2008	396.2	2495	317.7	26	47.7	1.3514	0.037	17.765	0.056
2009	476.5	2232	338.5	27	55.3	1.4301	0.038	16.074	0.047
2010	580.0	2105	383.5	25	70.8	1.2001	0.039	13.496	0.035
2011	514.5	2254	347.1	26	64.3	1.2117	0.038	14.605	0.042
2012	365.5	1739	287.8	24	67.1	0.9583	0.041	11.134	0.039
2013	279.9	1646	212.2	24	56.2	0.9923	0.041	10.617	0.050
2014	190.0	1736	112.5	25	24.7	0.8311	0.041	15.075	0.134
2015	240.4	2133	165.0	27	32.1	0.8145	0.039	17.207	0.104
2016	249.4	2068	202.4	26	42.0	0.7471	0.040	13.269	0.066

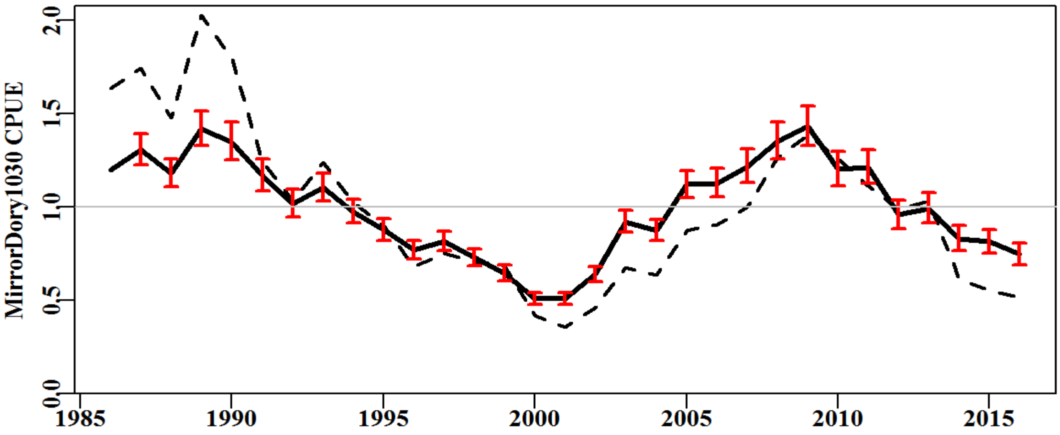


Figure 7.33. MirrorDory1030 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

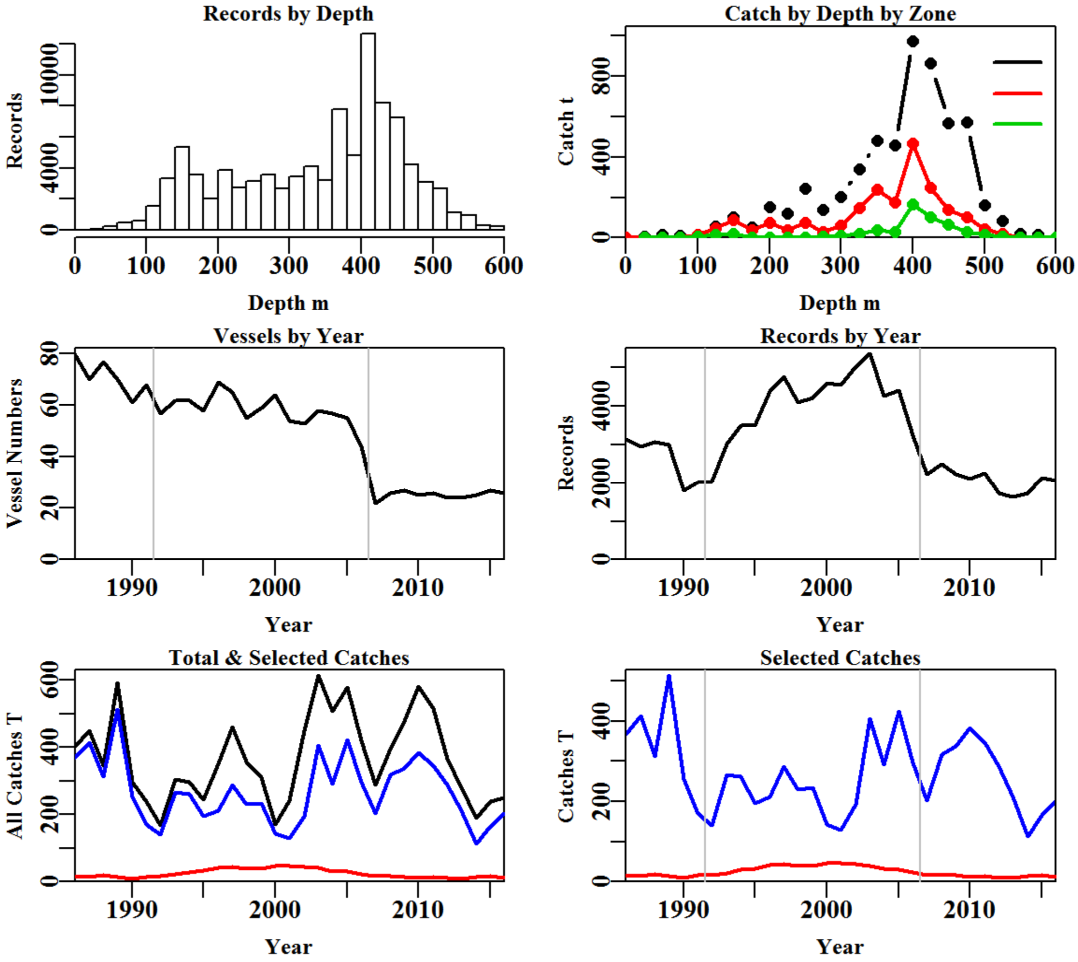


Figure 7.34. MirrorDory1030 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.22. MirrorDory1030 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	141731	138773	137653	137059	100084	97687	97638
Difference	0	2958	1120	594	36975	2397	49

Table 7.23. The models used to analyse data for MirrorDory1030

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + Month
Model5	Year + Vessel + DepCat + Month + Zone
Model6	Year + Vessel + DepCat + Month + Zone + DayNight
Model7	Year + Vessel + DepCat + Month + Zone + DayNight + Zone:Month
Model8	Year + Vessel + DepCat + Month + Zone + DayNight + Zone:DepCat

Table 7.24. MirrorDory1030. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	71135	202186	19508	97638	31	8.8	0.00
Vessel	54196	169355	52340	97638	212	23.4	14.67
DepCat	42993	150480	71215	97130	236	31.6	8.14
Month	41050	147465	74229	97130	247	32.9	1.36
Zone	40225	146212	75483	97130	249	33.5	0.57
DayNight	39435	145019	76675	97130	252	34.1	0.54
Zone:Month	37702	142389	79305	97130	274	35.2	1.18
Zone:DepCat	39114	144400	77294	97130	299	34.3	0.25

Table 7.25. MirrorDory1030. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	MirrorDory1030
csirocode	37264003
fishery	SET
depthrange	0 - 600
depthclass	25
zones	10, 20, 30
methods	TW, TDO, TMO, OTT
years	1986 - 2016

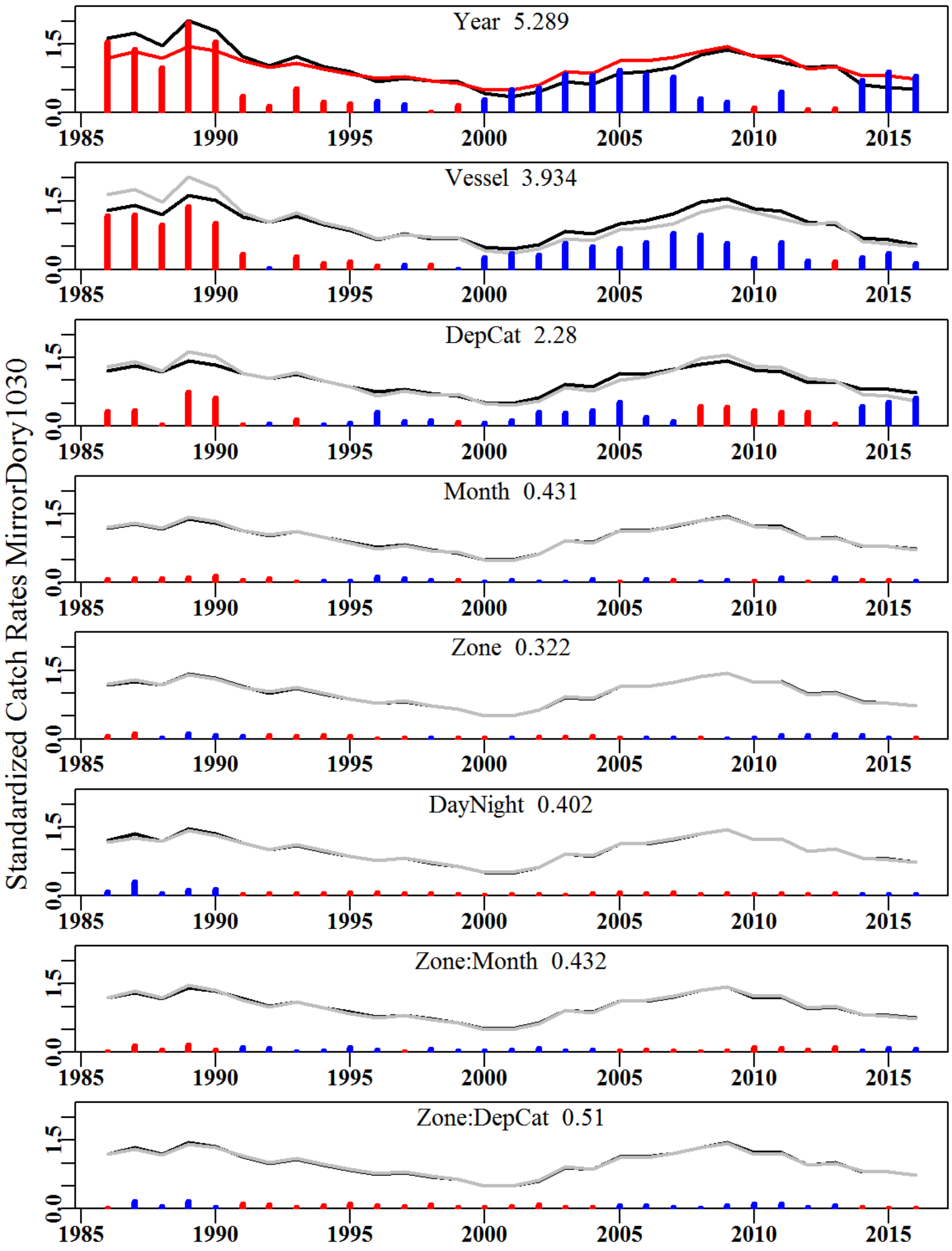


Figure 7.35. MirrorDory1030. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

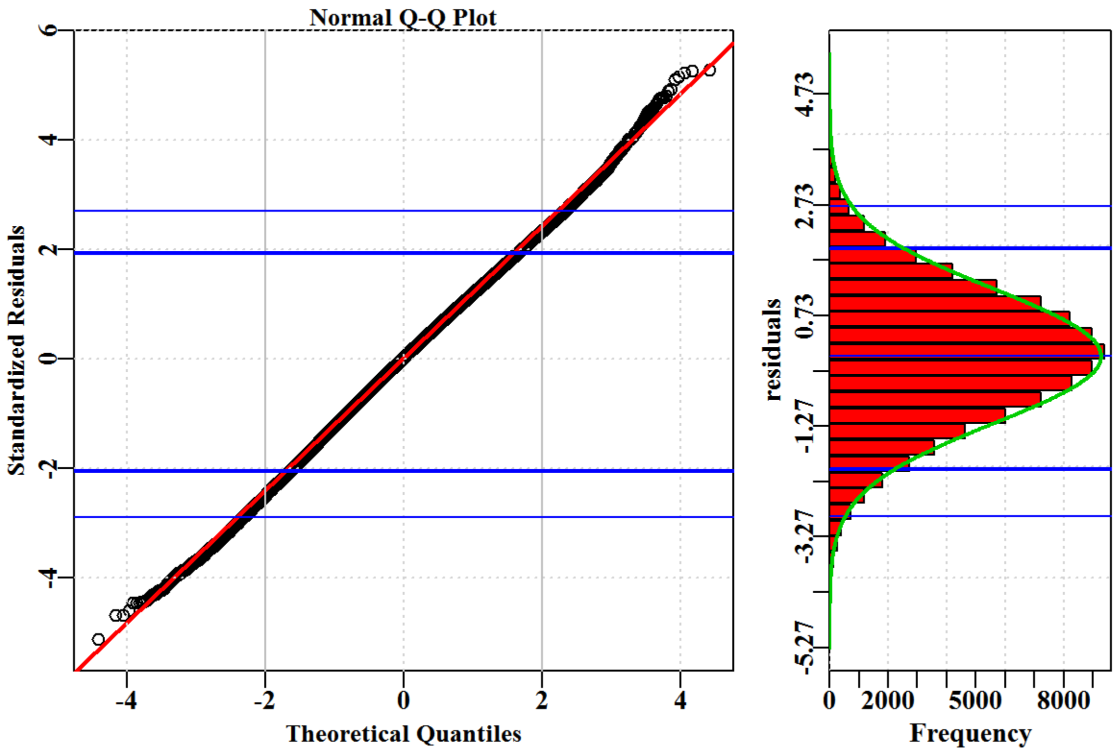


Figure 7.36. MirrorDory1030. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

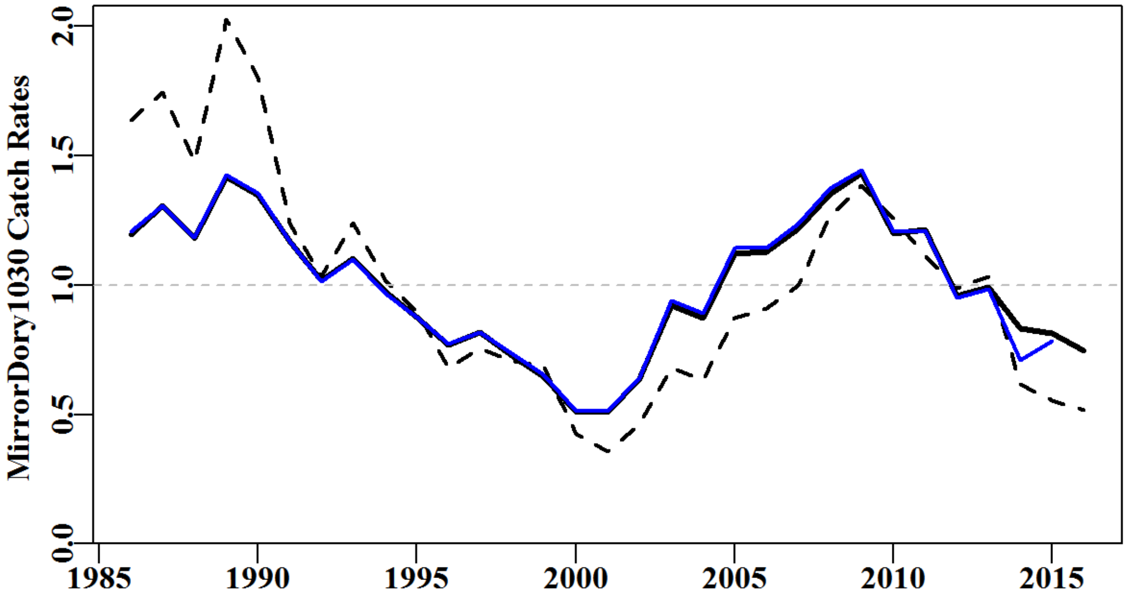


Figure 7.37. MirrorDory1030. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

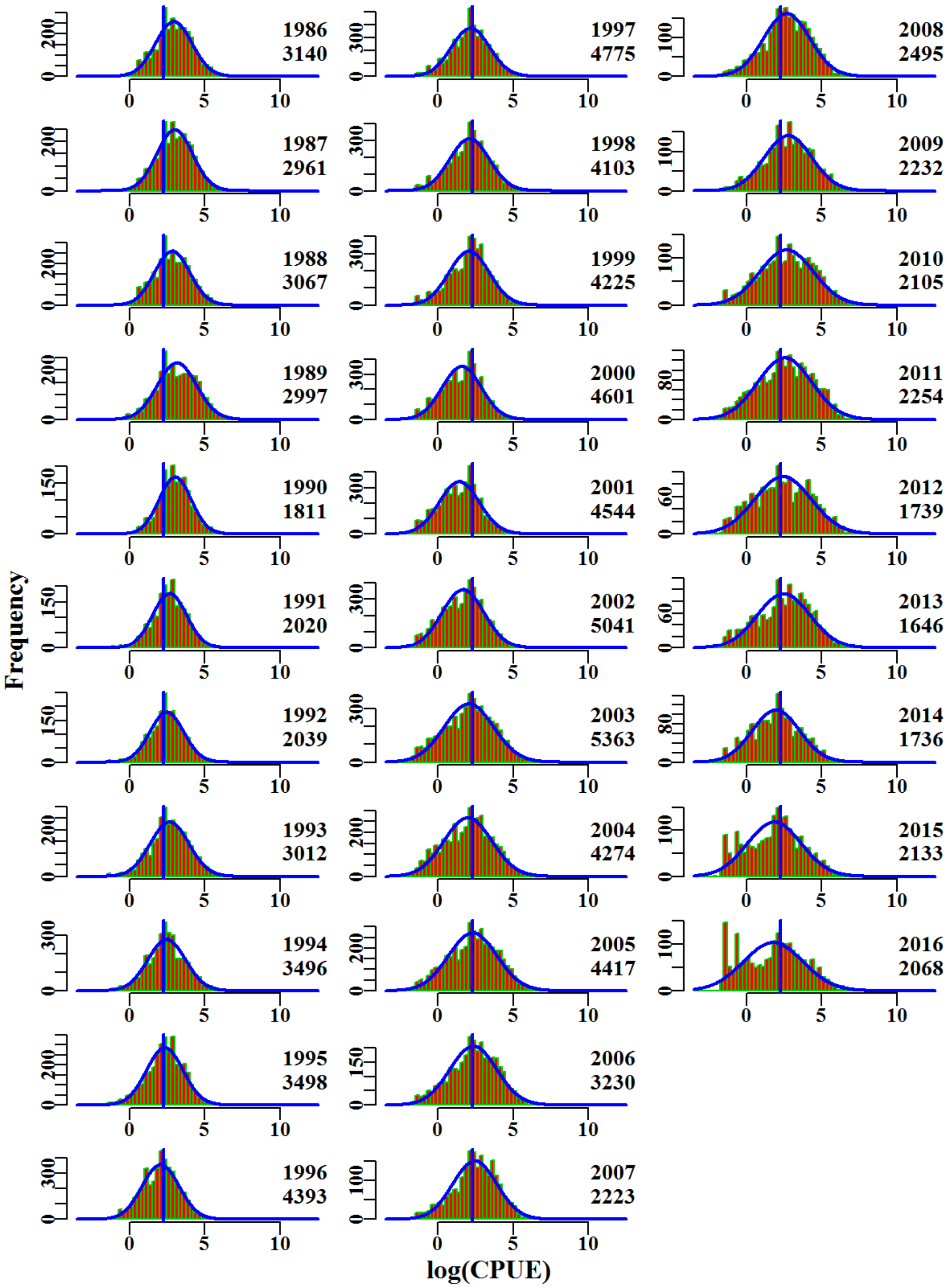


Figure 7.38. MirrorDory1030. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

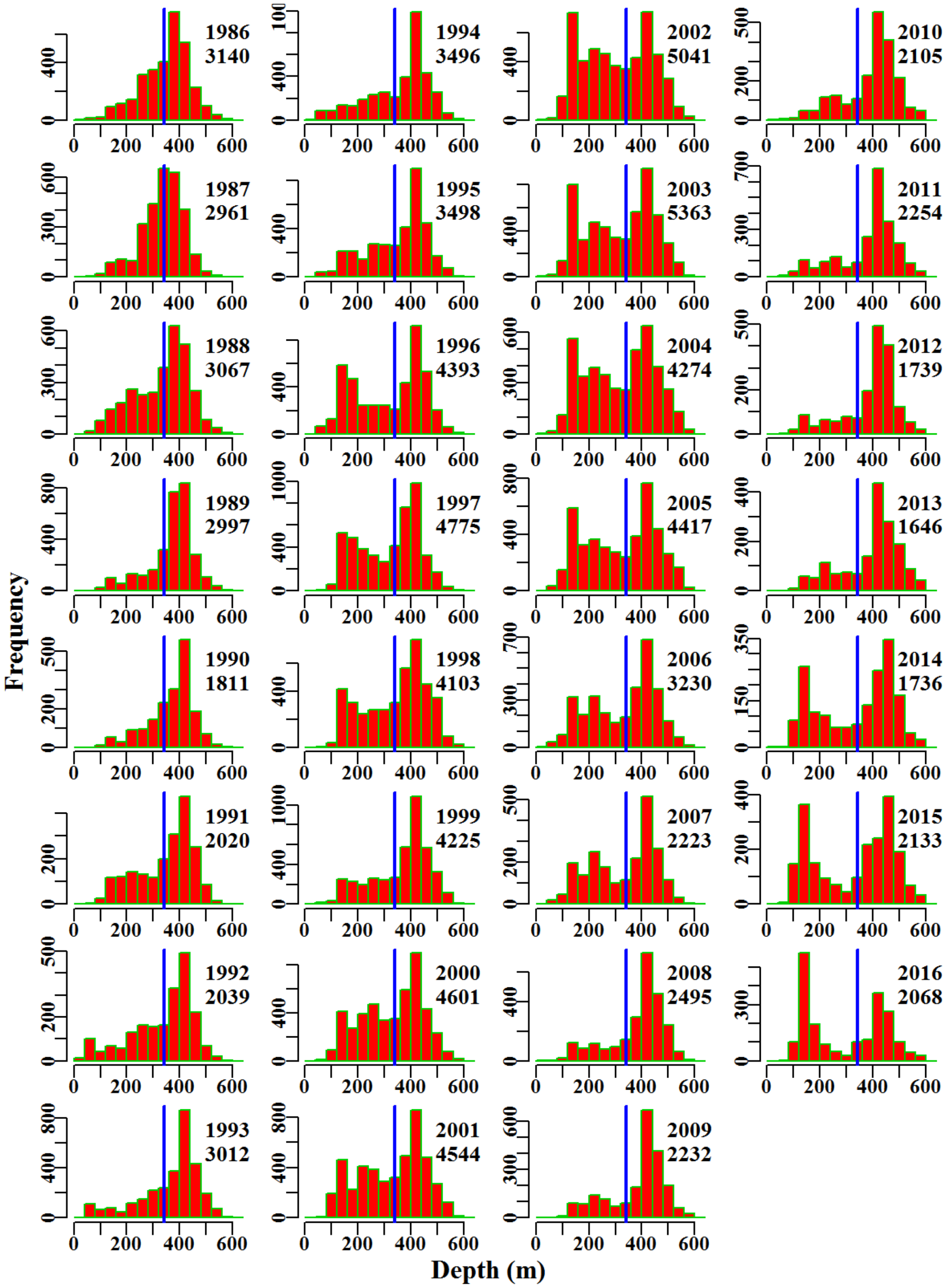


Figure 7.39. MirrorDory1030. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

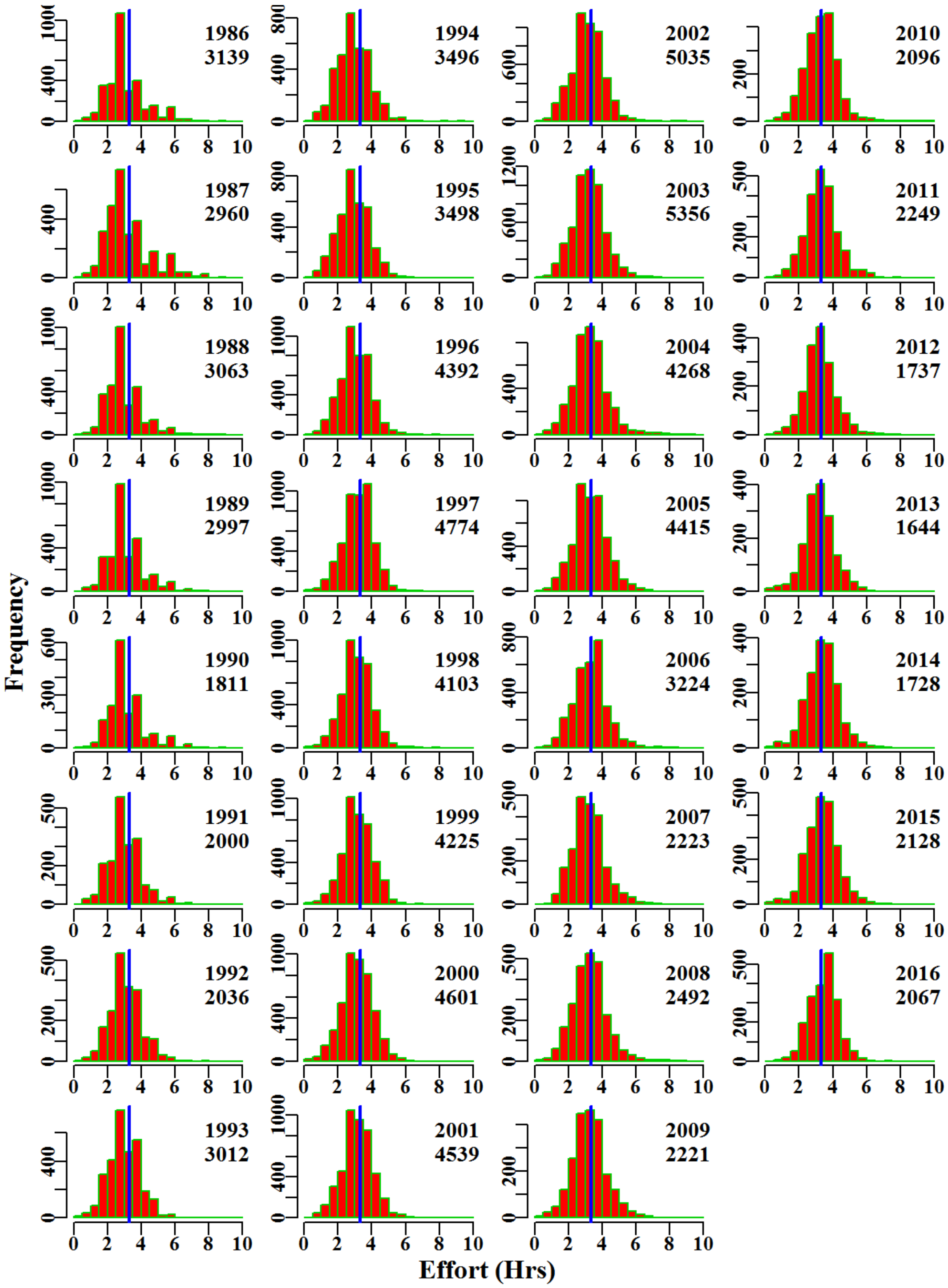


Figure 7.40. MirrorDory1030. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.9 Mirror Dory 40 – 50

Trawl caught Mirror Dory (DOM - 37264003 - *Zenopsis nebulosus*) using methods TW, TDO, TMO, OTT, in zones 40, 50, and depths 0 to 600 within the SET fishery for the years 1986 - 2016 were analysed. These constitute the criteria used to select data from the Commonwealth logbook database (Table 7.30). A total of 8 statistical models were fitted sequentially to the available data.

7.9.1 *Inferences*

Mirror Dory catches in the west appear to be episodic with peaks in 1997, 2001 - 2003, and 2010 and 2011, which roughly coincides with minor peaks in CPUE in a manner similar to that observed in the east, although with a more rapid cycle and less extreme variation. As on the east coast in the last few years, there has been an increase of reported catches in waters of 200 m, which is unusual for Mirror Dory in the west. The statistical model fit is very good with the deviations at the extremes in the qqplot being made up of far less than 5% of records at each end.

The amount of catch remains minor until about 1995 (Table 7.26) after which the amount of catch and the number of records remains at levels that permit usable analyses, with relatively tight precision levels around the mean estimates, to be made.

7.9.2 *Action Items and Issues*

It is recommended that the CPUE time-series only be used from 1995 onwards because the catches before then are relatively minor. Whatever the case, from 1990 the CPUE trend appears to be relatively flat and noisy around the long term average with periods above and below.

Table 7.26. MirrorDory4050. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	402.0	58	7.4	11	37.2	2.4710	0.000	0.390	0.053
1987	450.8	142	15.5	23	36.1	1.6670	0.187	0.929	0.060
1988	346.0	122	15.0	17	37.2	1.3370	0.197	0.940	0.063
1989	591.6	71	11.1	15	45.3	1.6677	0.209	0.545	0.049
1990	295.8	95	10.0	14	37.9	1.1616	0.214	0.505	0.051
1991	240.3	209	12.8	17	17.8	0.8323	0.186	2.667	0.209
1992	167.0	206	8.3	20	14.6	0.6875	0.188	1.870	0.225
1993	306.2	277	18.1	18	16.8	0.8038	0.183	3.187	0.176
1994	297.3	330	18.2	20	14.8	0.7388	0.181	4.166	0.229
1995	244.9	709	38.1	23	15.4	0.9522	0.178	7.957	0.209
1996	352.7	1438	115.1	26	23.4	1.3102	0.177	12.924	0.112
1997	459.6	1906	148.3	24	24.4	1.3237	0.177	16.756	0.113
1998	355.8	1469	116.2	20	27.6	1.2593	0.178	12.719	0.109
1999	309.5	1318	63.3	23	17.1	0.8189	0.178	13.751	0.217
2000	171.1	980	22.5	30	7.9	0.4562	0.179	11.495	0.512
2001	243.4	2469	106.2	29	14.1	0.7901	0.177	29.001	0.273
2002	449.6	3163	240.8	28	24.8	1.1681	0.177	28.145	0.117
2003	613.9	2434	155.2	28	20.7	0.9736	0.177	20.602	0.133
2004	507.4	2210	159.9	25	20.3	0.9757	0.177	16.913	0.106
2005	579.9	1773	100.2	23	15.2	0.7718	0.177	15.780	0.158
2006	419.6	1063	65.5	19	15.8	0.6457	0.178	8.828	0.135
2007	289.6	1177	64.9	16	14.5	0.5775	0.178	11.829	0.182
2008	396.2	883	58.7	17	16.3	0.6756	0.179	8.712	0.148
2009	476.5	1335	123.3	14	20.0	1.0301	0.178	9.591	0.078
2010	580.0	1597	177.7	14	26.5	1.2547	0.177	9.629	0.054
2011	514.5	1667	159.1	16	21.7	0.9495	0.177	9.506	0.060
2012	365.5	1018	70.2	15	16.7	0.5580	0.179	7.585	0.108
2013	279.9	643	55.1	15	20.7	0.7533	0.180	5.070	0.092
2014	190.0	833	67.3	14	19.6	0.8698	0.179	6.648	0.099
2015	240.4	947	70.7	13	17.4	0.8762	0.179	6.944	0.098
2016	249.4	624	41.5	13	16.5	0.6430	0.180	4.795	0.115

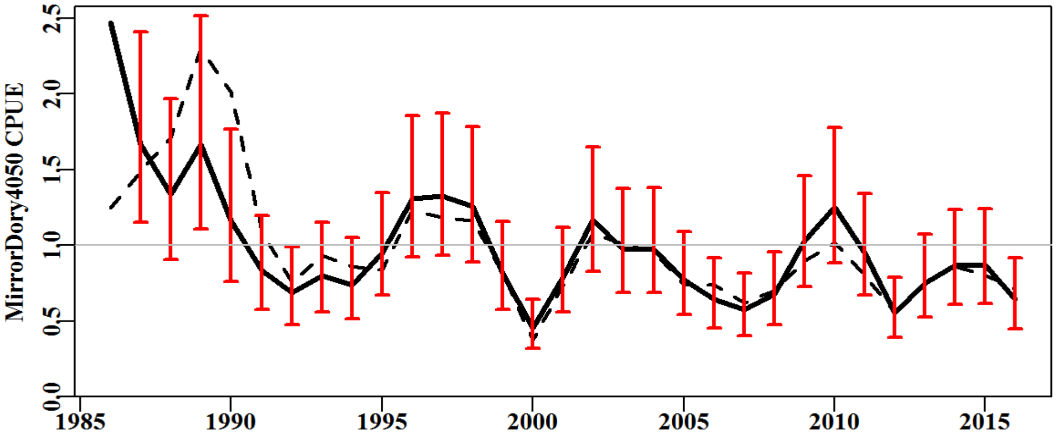


Figure 7.41. MirrorDory4050 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

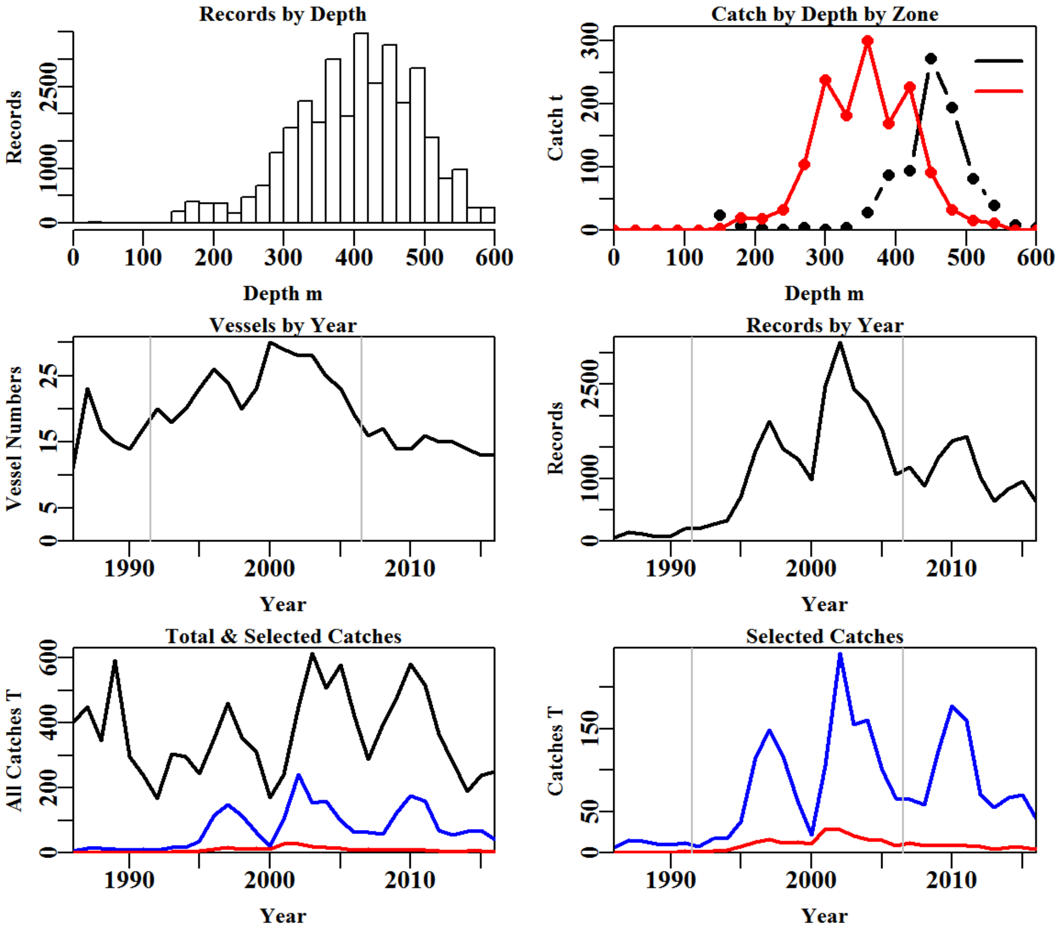


Figure 7.42. MirrorDory4050 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.27. MirrorDory4050 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	141731	138773	137653	137059	33298	33222	33166
Difference	0	2958	1120	594	103761	76	56

Table 7.28. The models used to analyse data for MirrorDory4050.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + Month
Model4	Year + Vessel + Month + DepCat
Model5	Year + Vessel + Month + DepCat + DayNight
Model6	Year + Vessel + Month + DepCat + DayNight + Zone
Model7	Year + Vessel + Month + DepCat + DayNight + Zone + Zone:Month
Model8	Year + Vessel + Month + DepCat + DayNight + Zone + Zone:DepCat

Table 7.29. MirrorDory4050. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	11466	46776	2277	33166	31	4.6	0.00
Vessel	4835	38085	10968	33166	124	22.1	17.51
Month	3309	36349	12705	33166	135	25.6	3.53
DepCat	1592	34283	14770	32976	155	29.3	3.75
DayNight	495	33156	15897	32976	158	31.7	2.32
Zone	79	32738	16316	32976	159	32.5	0.86
Zone:Month	-305	32337	16716	32976	170	33.3	0.80
Zone:DepCat	24	32644	16409	32976	179	32.7	0.15

Table 7.30. MirrorDory4050. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	MirrorDory4050
csirocode	37264003
fishery	SET
depthrange	0 - 600
depthclass	30
zones	40, 50
methods	TW, TDO, TMO, OTT
years	1986 - 2016

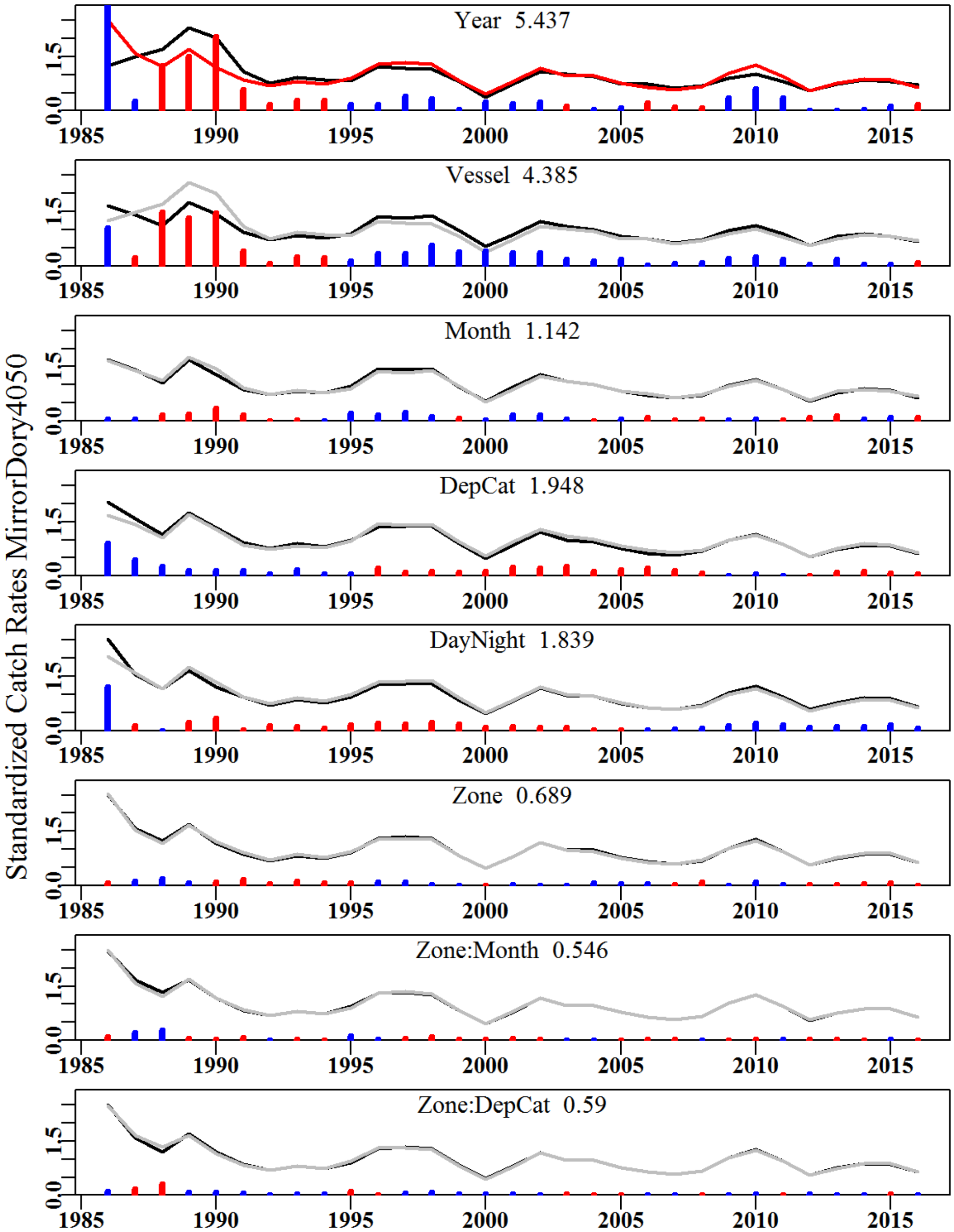


Figure 7.43. MirrorDory4050. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

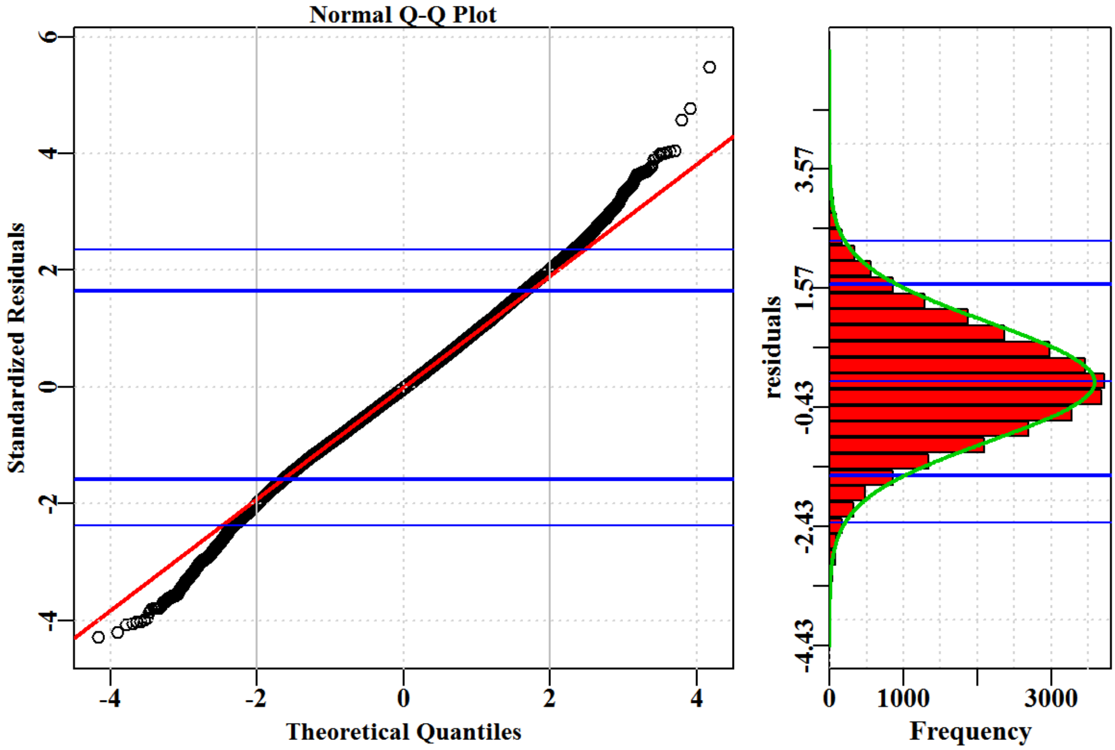


Figure 7.44. MirrorDory4050. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

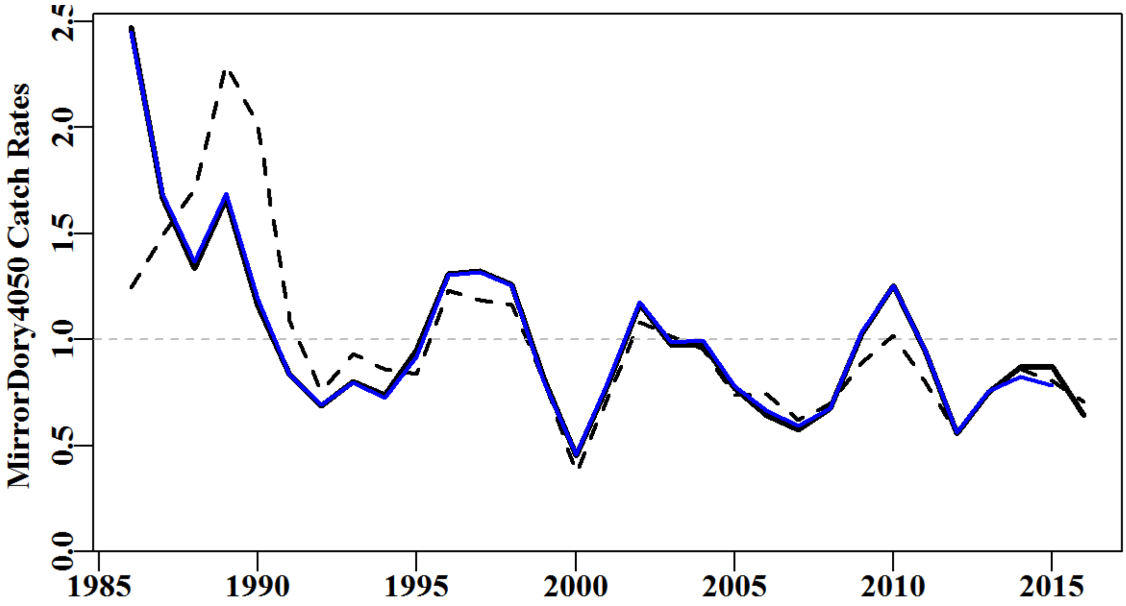


Figure 7.45. MirrorDory4050. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

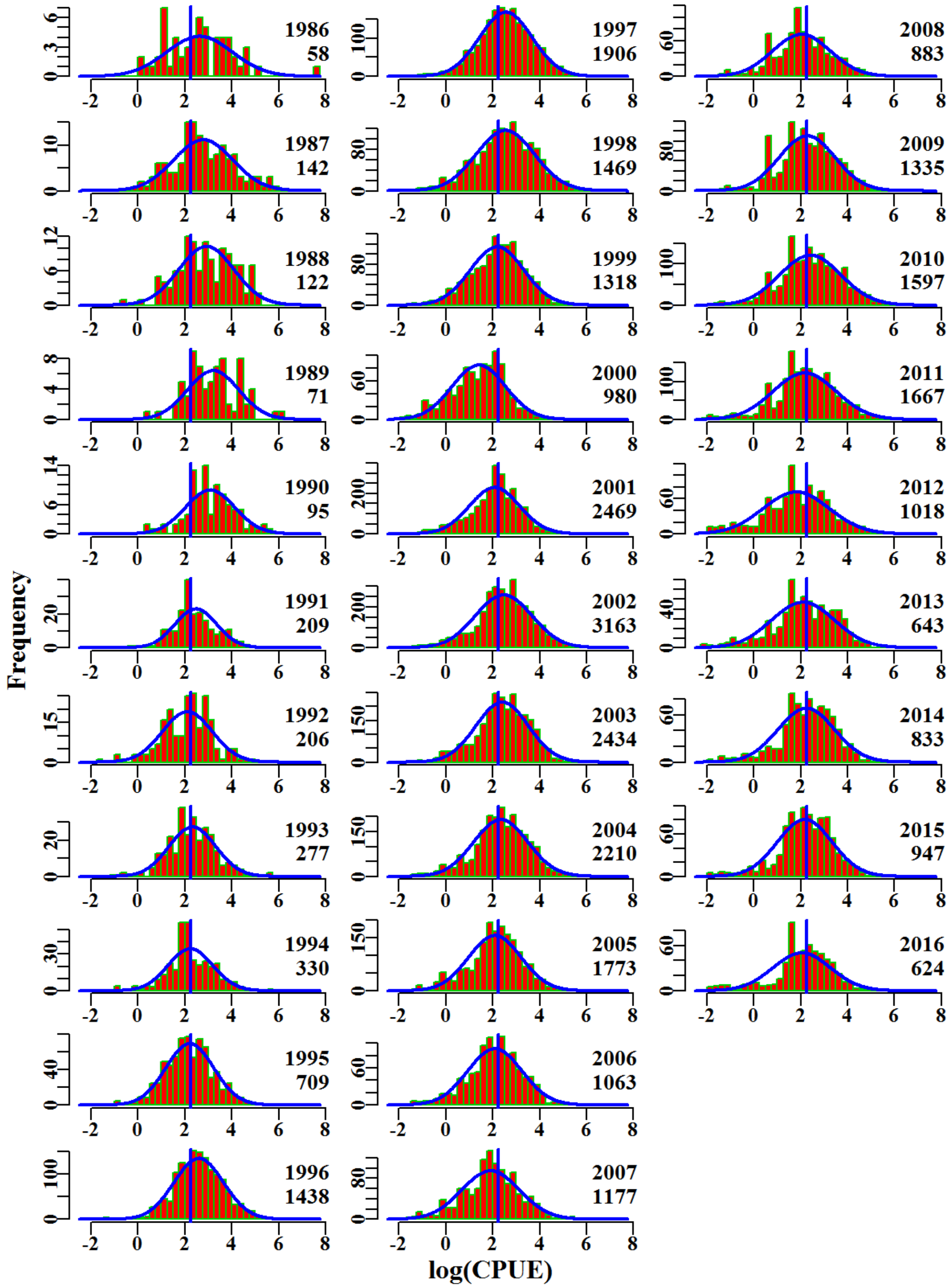


Figure 7.46. MirrorDory4050. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

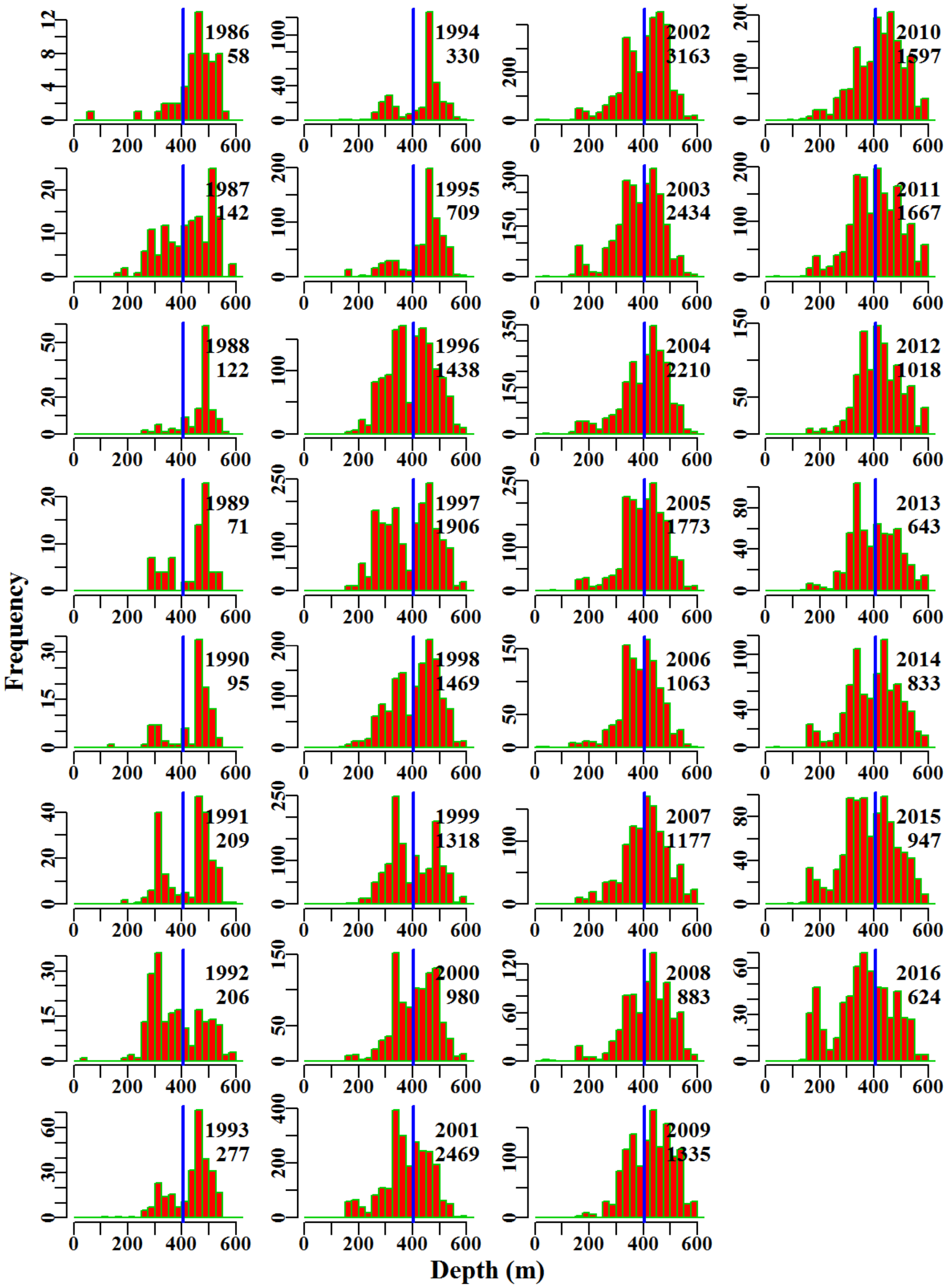


Figure 7.47. MirrorDory4050. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

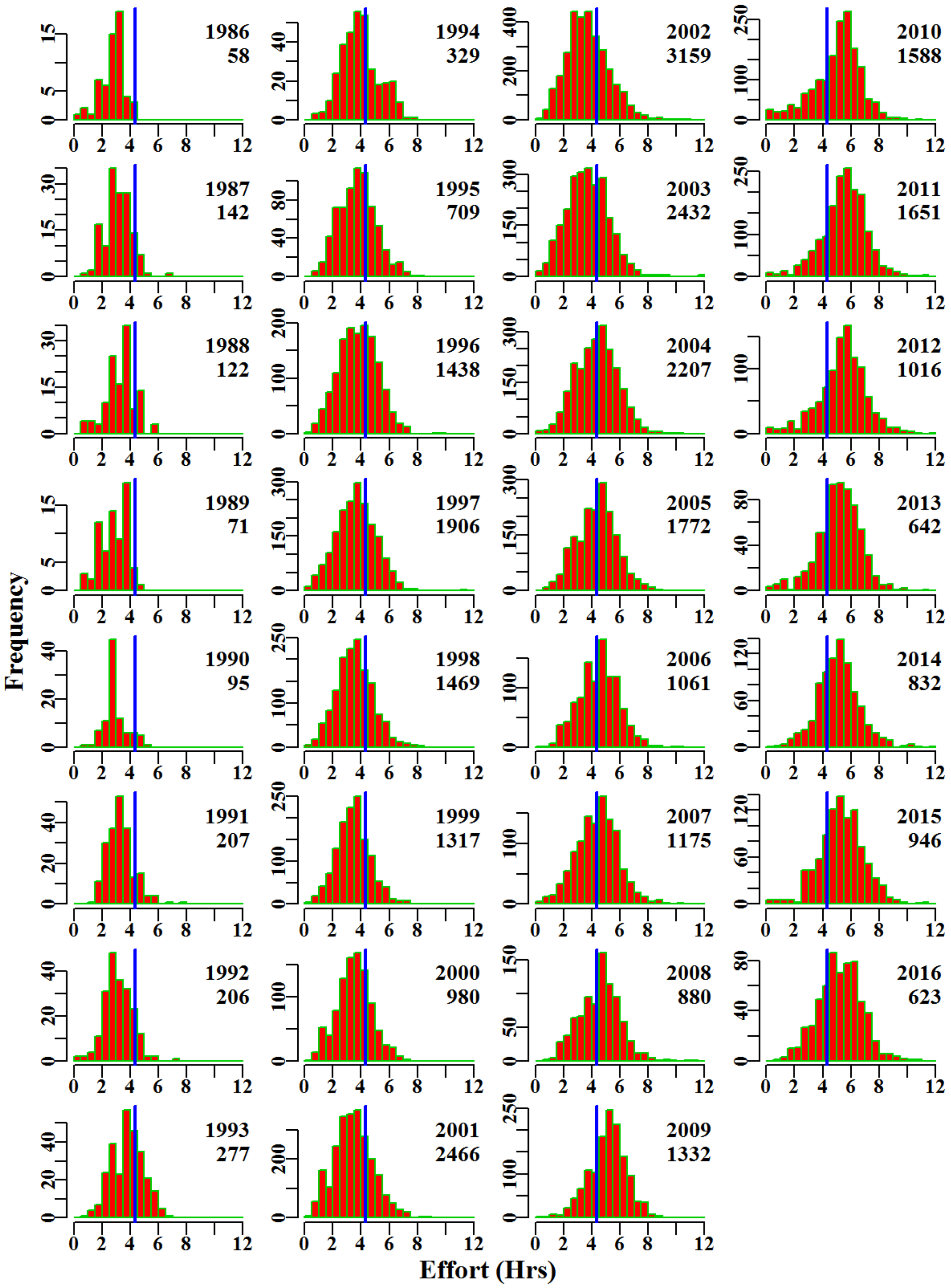


Figure 7.48. MirrorDory4050. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.10 Jackass Morwong 30

Jackass Morwong (MOR - 37377003 - *Nemadactylus macropterus*) was one of the 16 species first included in the quota system in 1992, which reflects its long history within the SESSF. The criteria used to select data from the Commonwealth logbook database (Table 7.35). A total of 7 statistical models were fitted sequentially to the available data, with the order of the non-interaction terms added based on the relative contribution of each term to model fit.

7.10.1 *Inferences*

The terms Year, Month, Vessel and DepCat had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE based on the AIC and R^2 statistics. The qqplot suggests a possible departure of that the assumed Normal distribution, with small deviations at the lower tail of the distribution.

With only 69 records and 30 t of reported catch in 1986, it is recommended that the standardization analysis should begin in 1987 or 1988 (Table 7.31).

Annual standardized CPUE has been below the long term average since about 2001 and not statistically different from each other over these years (Figure 7.49).

7.10.2 *Action Items and Issues*

The RAG recommended depth for Jackass Morwong 30 is from 70 - 300 m. However, there are records in Zone 30 from 0 - 500 metres but only significant catches out to 200m or 250m at most. The reasons for the earlier specific depth selection need to be re-iterated and an examination of the effect of making the current depth selection explored.

Catches are low in 1986 and the distribution of log(cpue) only stabilizes approximately from 1989 onwards (and possibly later), which suggests that including tose earlier years in teh standardization should be reconsidered.

Table 7.31. JackassMorwong30. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was DayNight.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	982.8	69	29.9	6	162.3	1.8537	0.000	0.255	0.009
1987	1087.7	210	57.5	13	103.0	1.9902	0.179	0.765	0.013
1988	1483.5	283	207.9	13	270.9	2.7758	0.177	0.684	0.003
1989	1667.4	687	475.0	19	231.9	3.5043	0.169	0.775	0.002
1990	1001.4	386	148.9	26	150.8	2.5316	0.170	0.901	0.006
1991	1138.1	427	189.5	29	150.6	1.6885	0.168	1.150	0.006
1992	758.3	335	106.8	18	108.3	1.8235	0.173	1.080	0.010
1993	1015.0	1042	325.9	27	104.7	1.4636	0.163	2.438	0.007
1994	818.4	762	180.2	22	71.7	1.0067	0.164	2.130	0.012
1995	789.5	826	185.3	19	68.9	0.9942	0.165	4.244	0.023
1996	827.2	890	161.4	19	54.5	0.9578	0.164	5.249	0.033
1997	1063.4	940	202.4	15	71.4	1.0601	0.164	3.452	0.017
1998	876.4	772	191.7	15	74.2	1.0373	0.164	2.123	0.011
1999	961.5	855	246.9	17	91.4	1.2302	0.165	2.310	0.009
2000	945.2	552	123.8	23	66.5	0.7906	0.167	2.157	0.017
2001	790.2	812	110.8	19	43.3	0.5179	0.163	5.359	0.048
2002	811.2	1044	108.9	15	34.7	0.4390	0.162	6.423	0.059
2003	774.6	1126	187.1	19	59.7	0.5818	0.162	5.993	0.032
2004	765.5	1500	201.3	15	41.5	0.4341	0.161	8.806	0.044
2005	784.2	1159	137.7	17	34.7	0.3262	0.162	7.453	0.054
2006	811.3	1127	154.5	14	40.4	0.4057	0.163	5.385	0.035
2007	607.9	714	111.6	8	49.7	0.5661	0.165	2.415	0.022
2008	700.4	768	119.0	9	50.7	0.5731	0.165	2.603	0.022
2009	454.4	463	54.3	10	37.9	0.4042	0.169	1.849	0.034
2010	380.0	372	58.2	9	46.8	0.4423	0.172	1.689	0.029
2011	428.0	451	48.3	8	34.6	0.2967	0.169	2.037	0.042
2012	395.6	561	92.5	8	54.9	0.3934	0.168	1.909	0.021
2013	323.9	599	103.4	10	57.8	0.4295	0.167	2.700	0.026
2014	216.6	368	53.7	9	38.0	0.2107	0.171	2.313	0.043
2015	152.5	458	30.7	11	18.6	0.1349	0.169	3.163	0.103
2016	183.4	772	48.8	10	19.6	0.1362	0.165	5.948	0.122

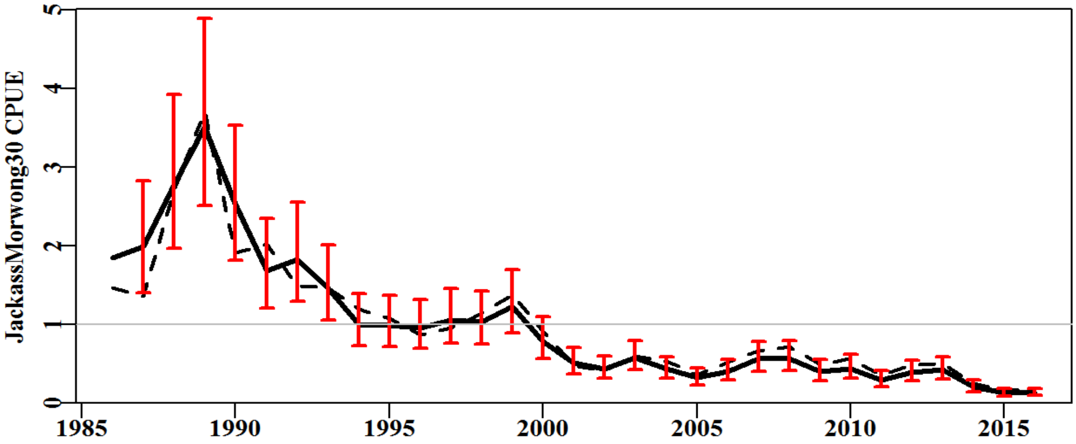


Figure 7.49. JackassMorwong30 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

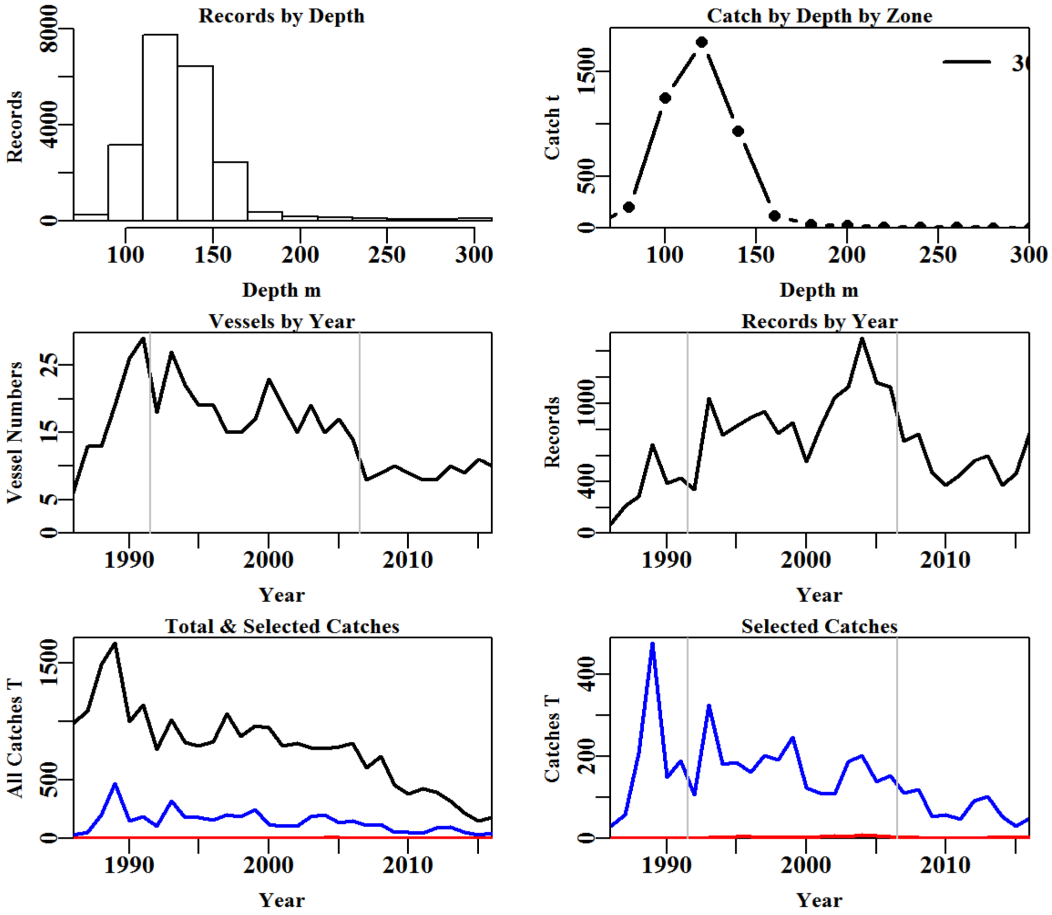


Figure 7.50. JackassMorwong30 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.32. JackassMorwong30 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	250941	230813	206077	202184	21629	21333	21330
Difference	0	20128	24736	3893	180555	296	3

Table 7.33. The models used to analyse data for JackassMorwong30

	Model
Model1	Year
Model2	Year + Month
Model3	Year + Month + Vessel
Model4	Year + Month + Vessel + DepCat
Model5	Year + Month + Vessel + DepCat + DayNight
Model6	Year + Month + Vessel + DepCat + DayNight + Zone:Month
Model7	Year + Month + Vessel + DepCat + DayNight + Zone:DepCat

Table 7.34. JackassMorwong30. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was DayNight

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	11864	37092	9801	21330	31	20.8	0.00
Month	10028	33999	12895	21330	42	27.4	6.57
Vessel	8714	31684	15210	21330	137	32.0	4.64
DepCat	8040	30431	16462	21075	149	33.9	1.94
DayNight	7769	30033	16861	21075	152	34.8	0.86
Zone:Month	7769	30033	16861	21075	152	34.8	0.00
Zone:DepCat	7769	30033	16861	21075	152	34.8	0.00

Table 7.35. JackassMorwong30. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	JackassMorwong30
csirocode	37377003
fishery	SET
depthrange	70 - 300
depthclass	20
zones	30
methods	TW, TDO, TMO, OTT
years	1986 - 2016

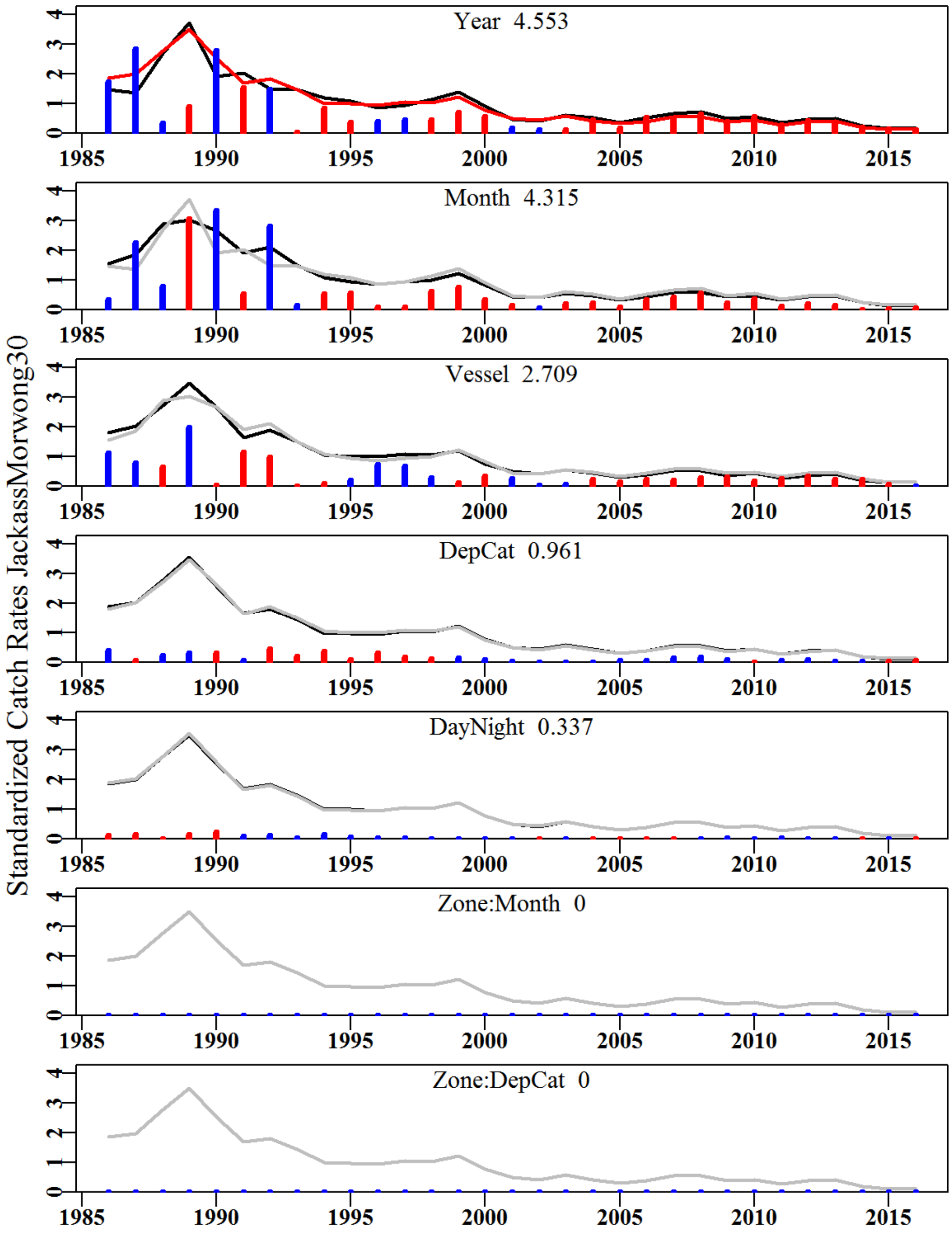


Figure 7.51. JackassMorwong30. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

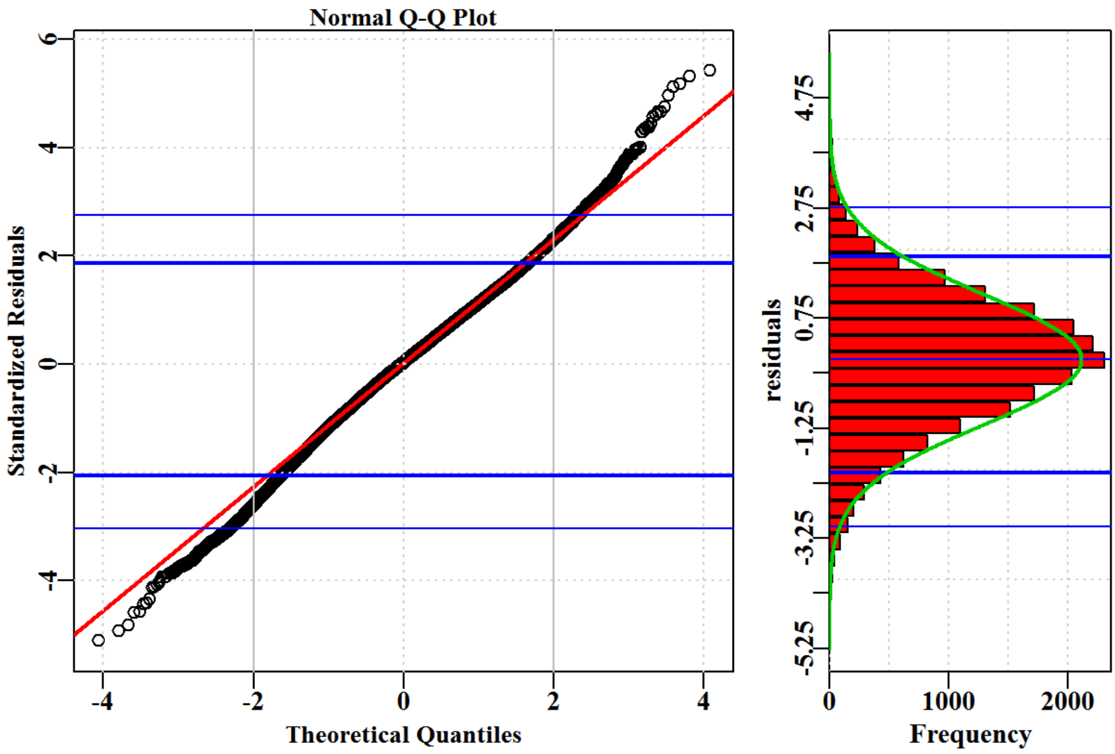


Figure 7.52. JackassMorwong30. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

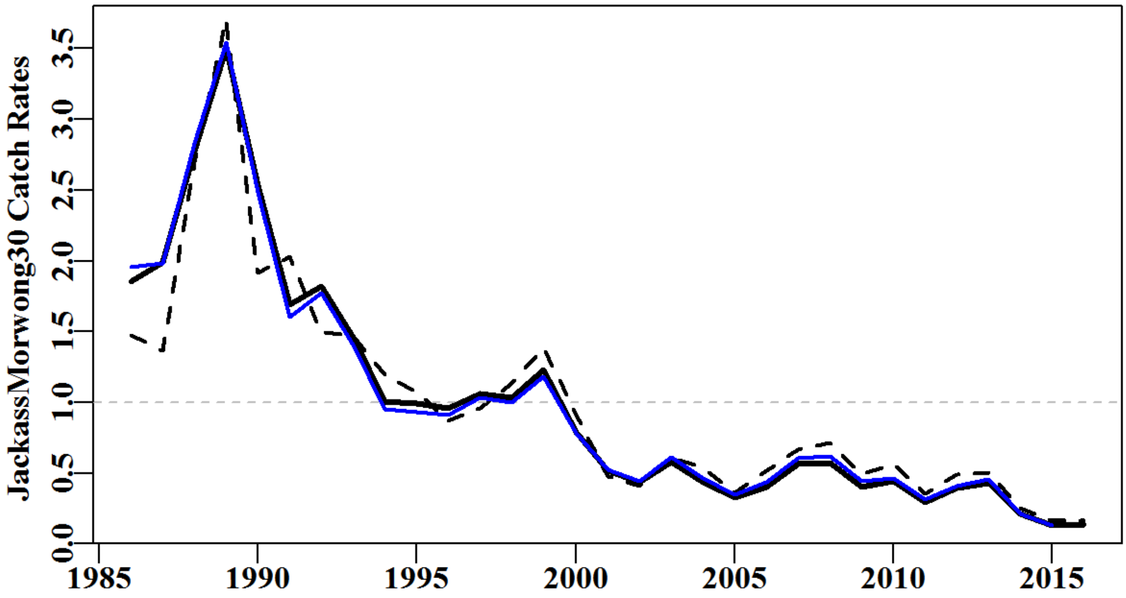


Figure 7.53. JackassMorwong30. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

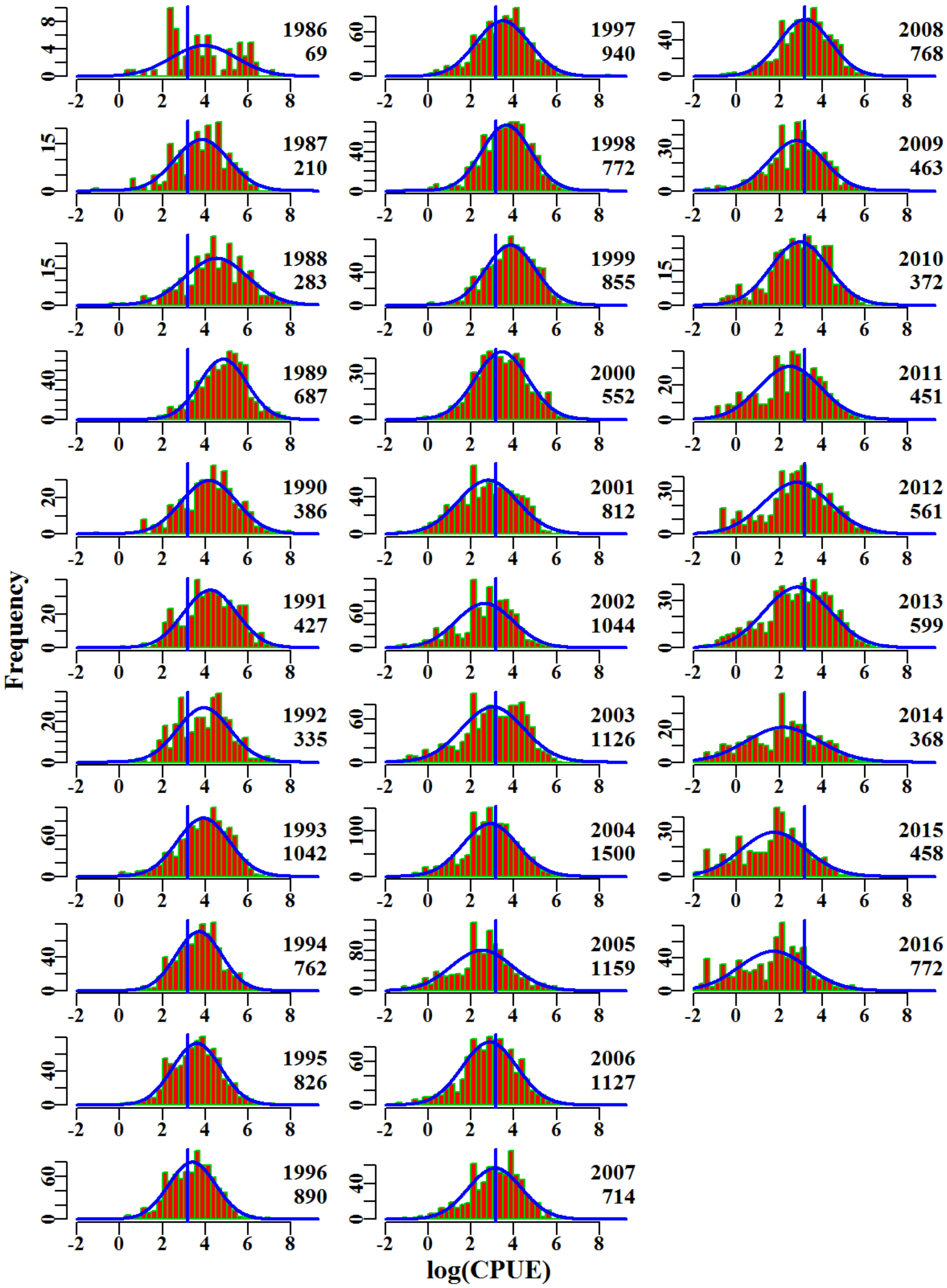


Figure 7.54. JackassMorwong30. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

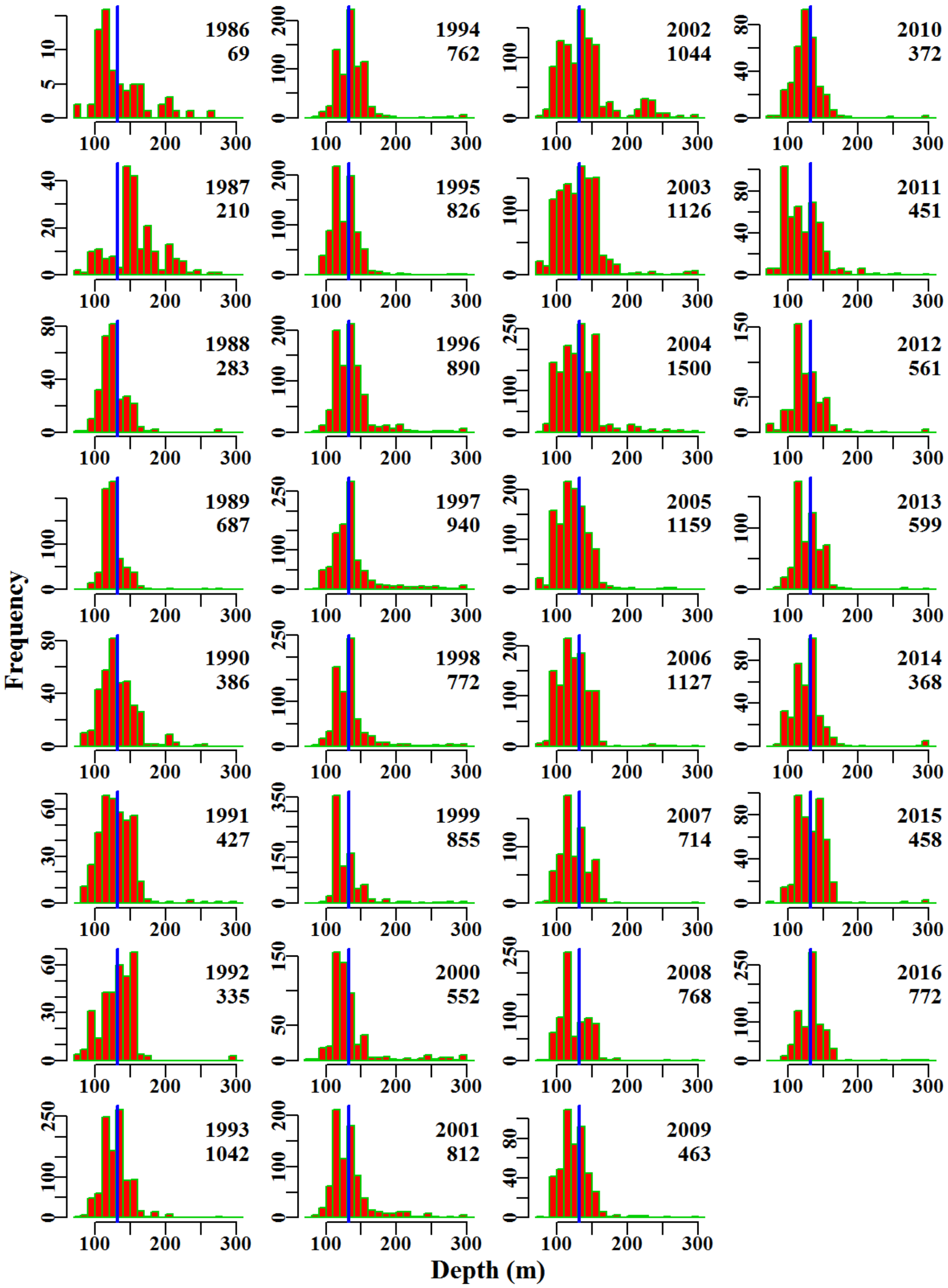


Figure 7.55. JackassMorwong30. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

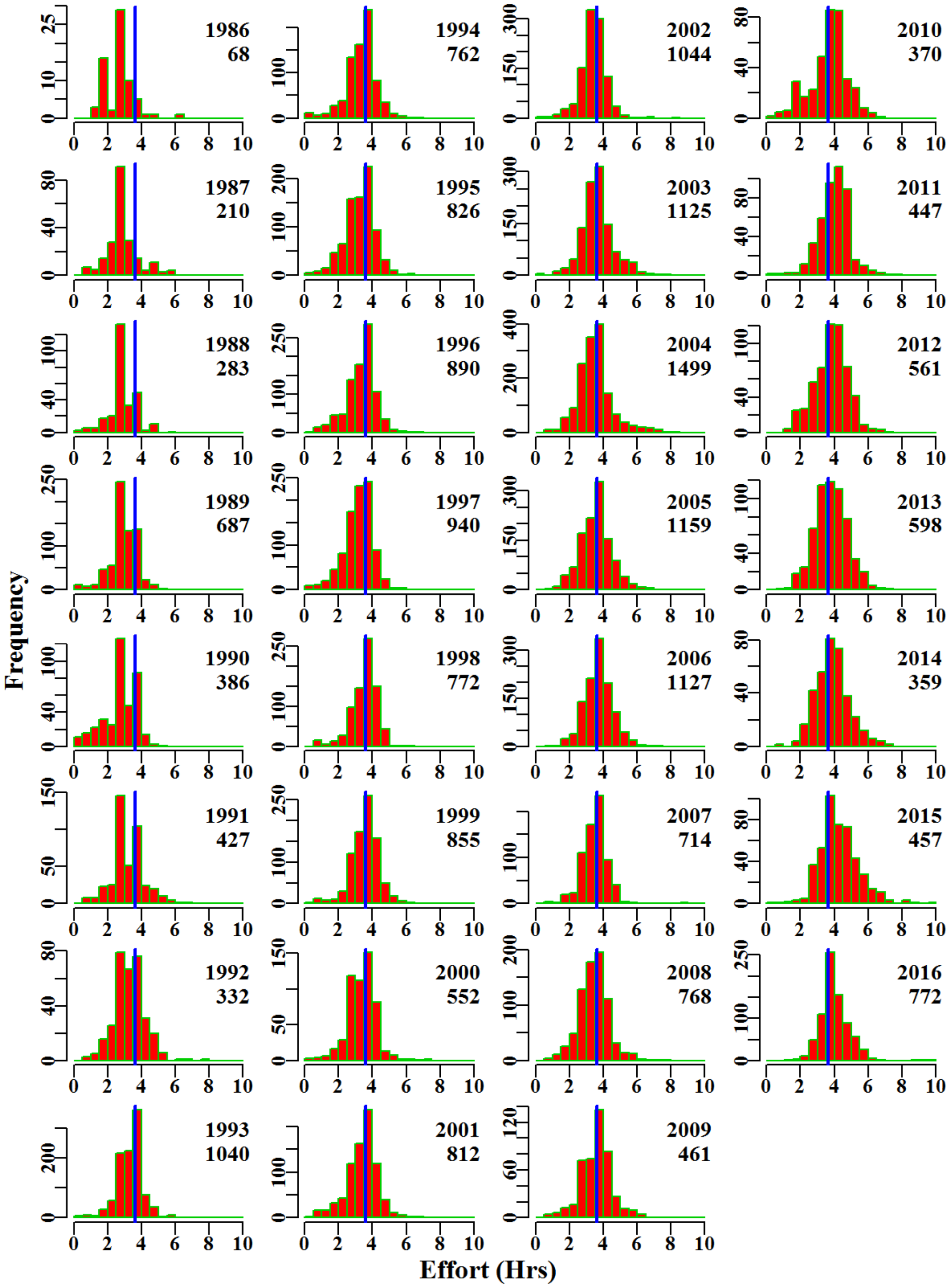


Figure 7.56. JackassMorwong30. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.11 Jackass Morwong 10 – 20

Jackass Morwong (MOR - 37377003 - *Nemadactylus macropterus*) was one of the 16 species first included in the quota system in 1992, which reflects its long history within the SESSF. The criteria used to select data from the Commonwealth logbook database (Table 7.40). A total of 8 statistical models were fitted sequentially to the available data, with the order of the non-interaction terms added based on the relative contribution of each term to model fit.

7.11.1 *Inferences*

The terms Year, Vessel, Month and Zone had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests that the assumed Normal distribution is valid, with small deviations at the upper tail of the distribution (Figure 7.60).

Most catch are reported in zone 10 in less than 200 m. Annual standardized CPUE has been below the long term average since about 1998 with some apparent periodicity (Figure 7.57).

7.11.2 *Action Items and Issues*

The structural adjustment altered the effect of the vessel factor on the standardized result. However, log(CPUE) has also changed in character from 2014 - 2016, with spikes of low catch rates arising.

Table 7.36. JackasssMorwong1020. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	982.8	5044	686.2	87	50.9	1.9981	0.000	28.043	0.041
1987	1087.7	4266	858.5	79	69.9	2.4229	0.029	20.649	0.024
1988	1483.5	5146	1024.7	79	65.2	2.2772	0.029	26.022	0.025
1989	1667.4	4325	929.4	65	72.2	2.1578	0.030	19.432	0.021
1990	1001.4	4127	600.6	59	49.5	1.8182	0.031	21.948	0.037
1991	1138.1	4436	661.8	55	54.3	1.6729	0.030	26.321	0.040
1992	758.3	2871	380.1	47	48.2	1.3362	0.034	17.665	0.046
1993	1015.0	3362	464.9	49	45.1	1.4226	0.033	21.998	0.047
1994	818.4	4467	473.2	49	38.5	1.2395	0.031	29.624	0.063
1995	789.5	4600	435.2	47	31.6	1.1395	0.031	33.568	0.077
1996	827.2	6218	544.8	51	28.9	1.0319	0.029	46.149	0.085
1997	1063.4	6030	672.1	53	38.4	1.1430	0.030	38.669	0.058
1998	876.4	4790	435.8	46	31.9	0.9215	0.031	36.795	0.084
1999	961.5	4428	447.8	50	36.2	0.9246	0.031	31.591	0.071
2000	945.2	5627	478.3	55	29.4	0.7910	0.030	41.006	0.086
2001	790.2	4808	252.5	47	18.5	0.5414	0.031	37.047	0.147
2002	811.2	5718	329.1	44	20.4	0.6070	0.030	46.133	0.140
2003	774.6	4584	237.0	47	17.5	0.4849	0.031	35.919	0.152
2004	765.5	4196	220.3	52	17.2	0.4788	0.032	31.464	0.143
2005	784.2	4378	262.6	39	19.4	0.5832	0.032	35.477	0.135
2006	811.3	3417	275.5	36	25.1	0.7082	0.034	27.429	0.100
2007	607.9	2437	212.4	20	31.3	0.6850	0.037	17.403	0.082
2008	700.4	3167	321.6	25	30.7	0.8695	0.035	23.937	0.074
2009	454.4	2448	228.5	19	28.2	0.7933	0.037	18.924	0.083
2010	380.0	2589	193.6	19	24.2	0.5418	0.037	20.810	0.107
2011	428.0	2400	170.9	18	24.1	0.5330	0.038	17.937	0.105
2012	395.6	2166	175.1	19	27.8	0.5246	0.038	14.905	0.085
2013	323.9	1410	97.6	15	25.1	0.4347	0.044	10.167	0.104
2014	216.6	1518	76.2	17	17.1	0.3249	0.042	11.627	0.152
2015	152.5	1096	42.3	20	14.3	0.2684	0.047	8.732	0.206
2016	183.4	1131	70.7	15	24.8	0.3243	0.049	7.603	0.108

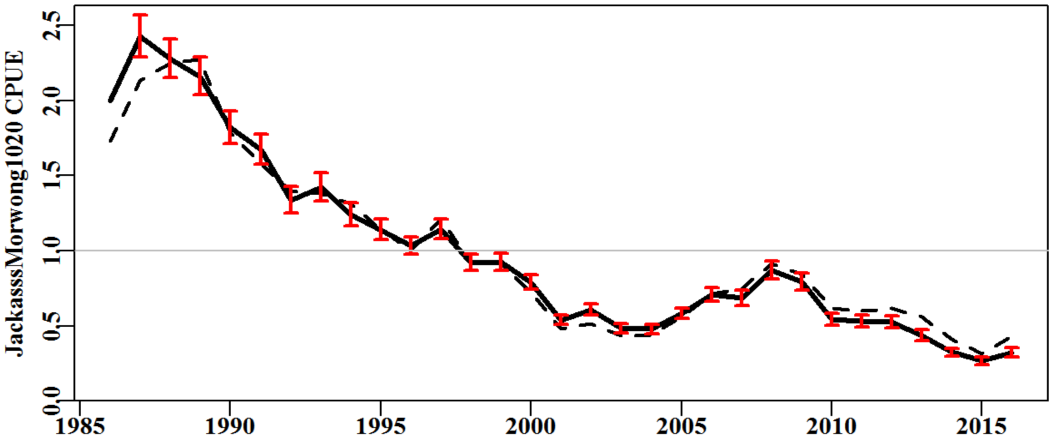


Figure 7.57. JackasssMorwong1020 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

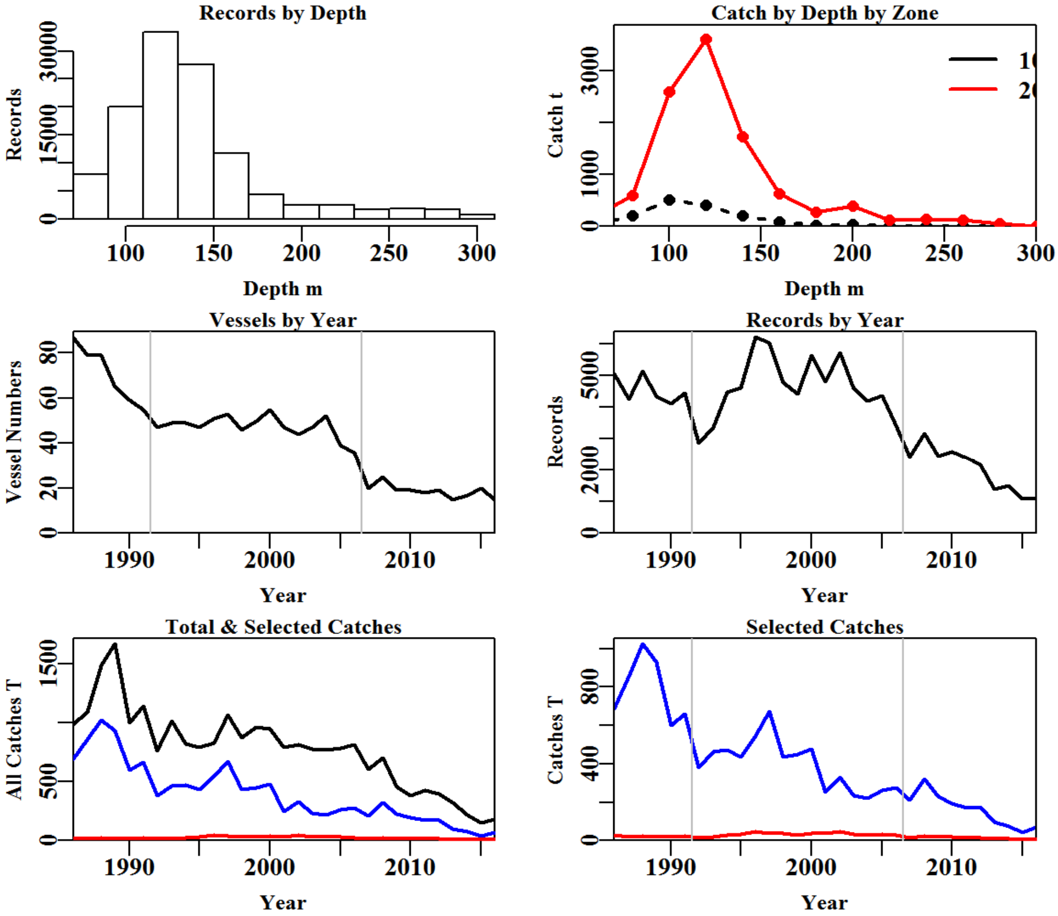


Figure 7.58. JackasssMorwong1020 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.37. JackasssMorwong1020 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	250941	230813	206077	202184	132542	117296	117200
Difference	0	20128	24736	3893	69642	15246	96

Table 7.38. The models used to analyse data for JackasssMorwong1020.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + Month
Model4	Year + Vessel + Month + Zone
Model5	Year + Vessel + Month + Zone + DepCat
Model6	Year + Vessel + Month + Zone + DepCat + DayNight
Model7	Year + Vessel + Month + Zone + DepCat + DayNight + Zone:Month
Model8	Year + Vessel + Month + Zone + DepCat + DayNight + Zone:DepCat

Table 7.39. JackasssMorwong1020. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	85332	242606	33020	117200	31	12.0	0.00
Vessel	71076	214169	61457	117200	209	22.2	10.20
Month	68027	208630	66996	117200	220	24.2	2.01
Zone	65708	204539	71087	117200	221	25.7	1.49
DepCat	63835	200435	75191	116158	233	26.5	0.85
DayNight	62417	197993	77634	116158	236	27.4	0.89
Zone:Month	61484	196372	79254	116158	247	28.0	0.59
Zone:DepCat	62108	197426	78200	116158	248	27.6	0.20

Table 7.40. JackasssMorwong1020. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	JackasssMorwong1020
csirocode	37377003
fishery	SET
depthrange	70 - 300
depthclass	20
zones	10, 20
methods	TW, TDO, TMO, OTT
years	1986 - 2016

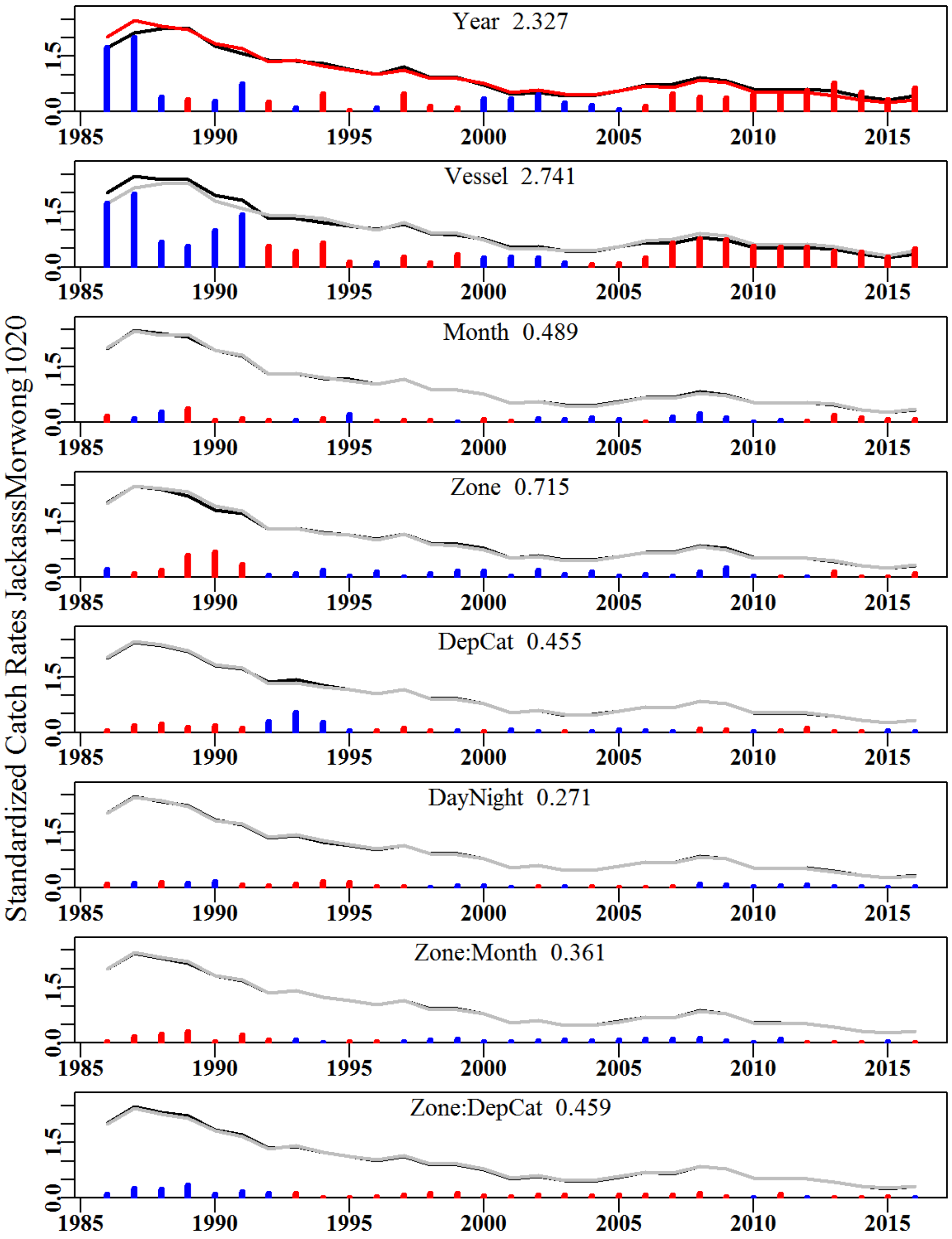


Figure 7.59. JackasssMorwong1020. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

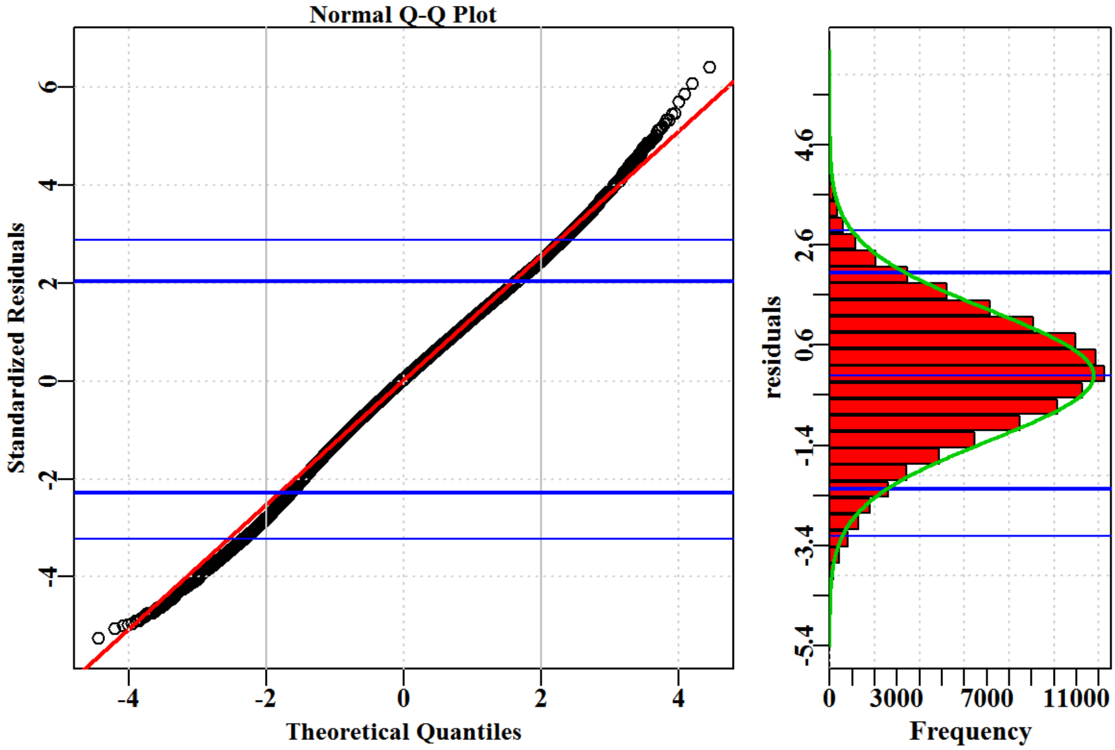


Figure 7.60. JackasssMorwong1020. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

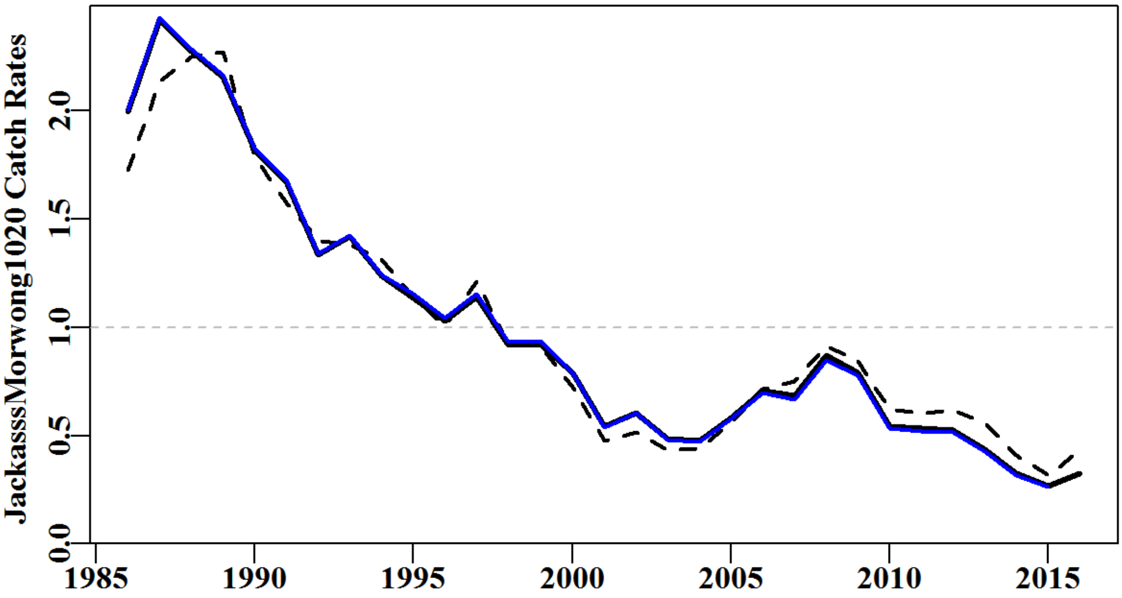


Figure 7.61. JackasssMorwong1020. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

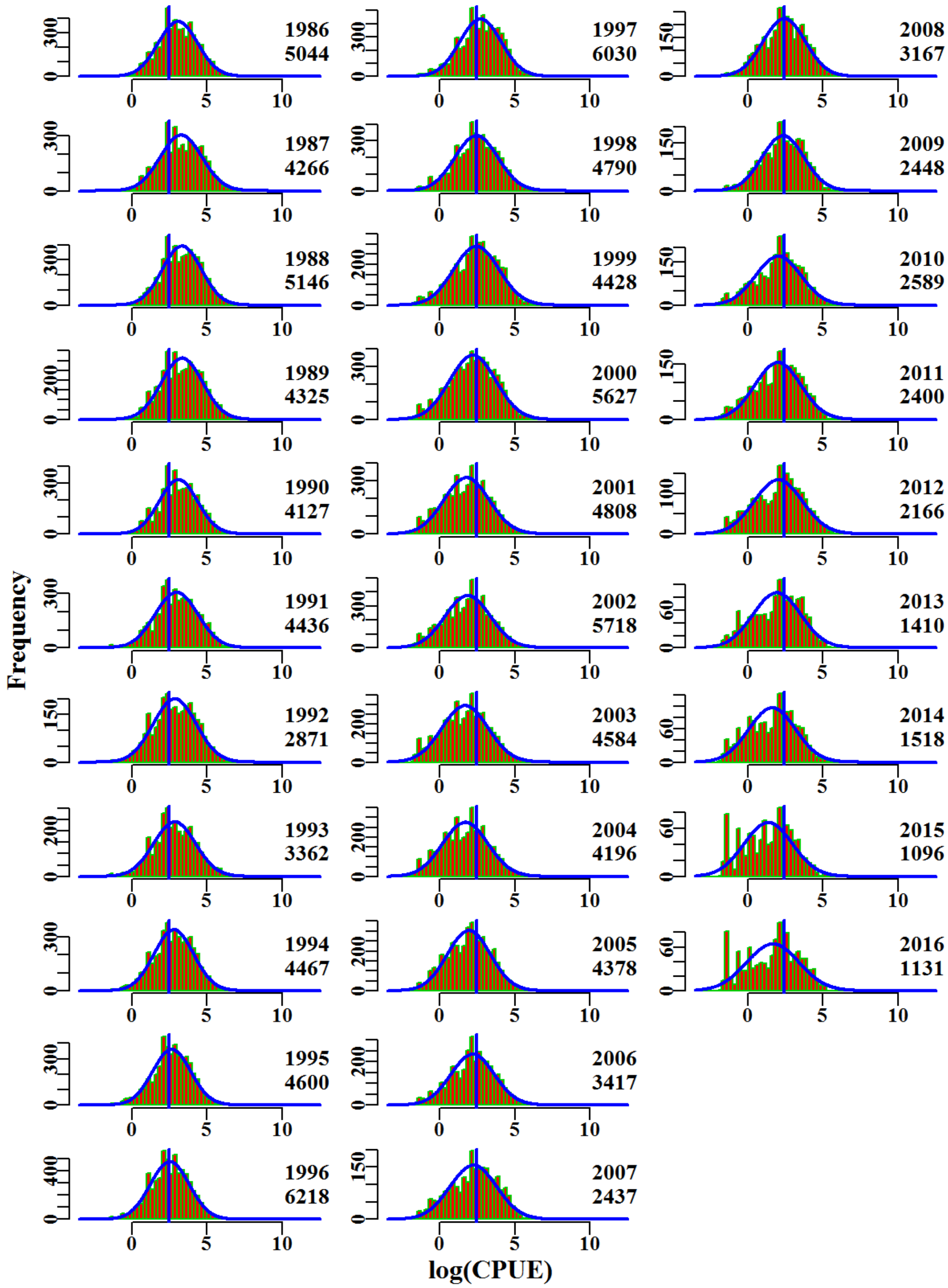


Figure 7.62. JackasssMorwong1020. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

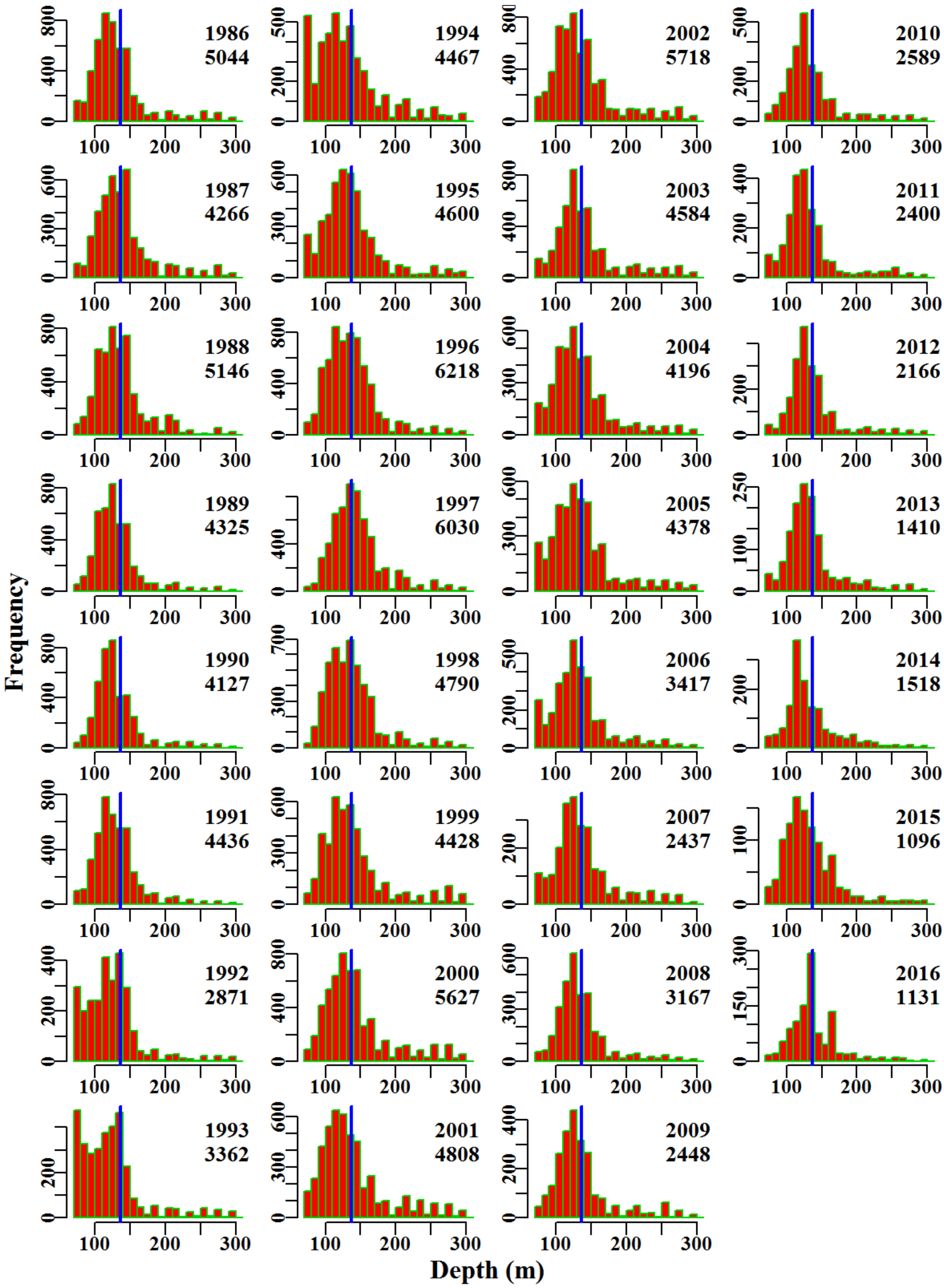


Figure 7.63. JackasssMorwong1020. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

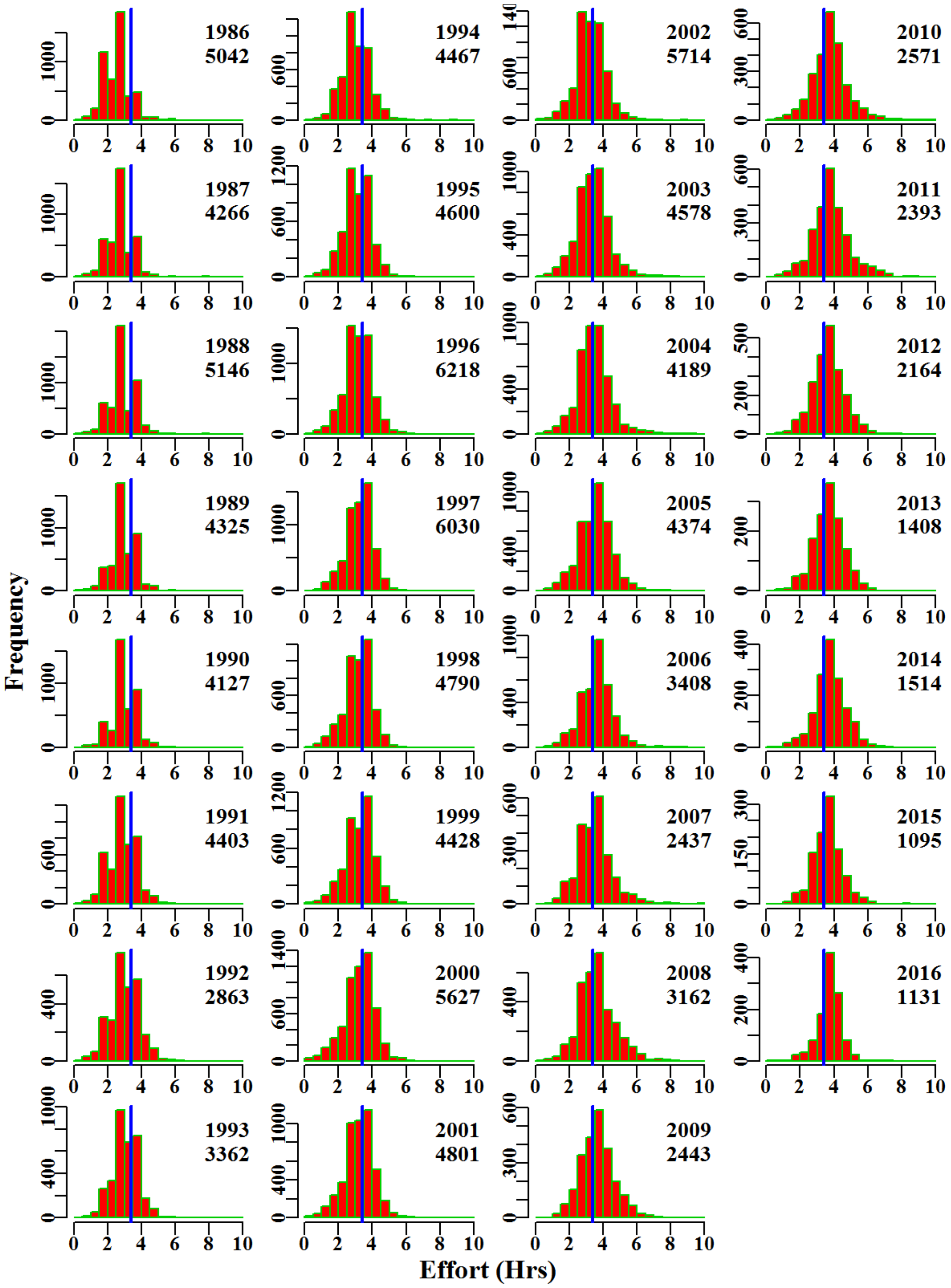


Figure 7.64. JackasssMorwong1020. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.12 Jackass Morwong 40 – 50

The fishery for Jackass Morwong (MOR - 37377003 - *Nemadactylus macropterus*) in zones 40 and 50 has been of variable character with a peak of catches between 2001 - 2006, dropping away rapidly following the structural adjustment. The criteria select data from the Commonwealth logbook database (Table 7.45). A total of 8 statistical models were fitted sequentially to the available data, with the order of the non-interaction terms added based on the relative contribution of each term to model fit.

7.12.1 *Inferences*

The terms Year, DepCat, Month and Vessel had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests that the assumed Normal distribution is valid, with small deviations at the lower tail of the distribution (Figure 7.68).

Most catch from zone 40 occurred at a shallower depth compared to zone 50. Since 2007, standardized CPUE has been below the long term average, with a declining trend to 2014 and a subsequent positive trend thereafter (Figure 7.65).

7.12.2 *Action Items and Issues*

The vessel factor changed its influence from 2001 onwards reflecting the increase in catches from 2001 and suggesting the fishery cahnged remarkably at that time. The reasons behind this change should be explained in more detail.

Table 7.41. JackasssMorwong4050. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	982.8	551	149.3	19	114.6	2.0291	0.000	1.928	0.013
1987	1087.7	350	58.5	21	60.8	1.5912	0.086	2.104	0.036
1988	1483.5	402	65.4	19	66.0	2.3679	0.087	1.803	0.028
1989	1667.4	346	83.2	21	74.4	1.7051	0.091	2.303	0.028
1990	1001.4	412	80.7	22	77.8	1.7361	0.093	2.333	0.029
1991	1138.1	281	40.4	26	40.0	1.1728	0.097	1.790	0.044
1992	758.3	252	28.9	14	33.1	0.9606	0.100	2.142	0.074
1993	1015.0	248	25.0	17	29.6	0.9162	0.101	2.247	0.090
1994	818.4	312	22.7	16	22.8	0.8959	0.094	2.755	0.121
1995	789.5	295	77.6	17	63.8	0.9195	0.095	2.405	0.031
1996	827.2	346	37.1	17	31.8	1.0178	0.093	2.869	0.077
1997	1063.4	489	53.9	20	26.8	0.8088	0.086	4.823	0.090
1998	876.4	267	54.6	19	42.4	0.8268	0.098	2.855	0.052
1999	961.5	383	77.2	17	42.8	0.7495	0.091	3.711	0.048
2000	945.2	430	118.9	28	79.6	1.1920	0.091	3.733	0.031
2001	790.2	920	276.8	25	104.8	1.2648	0.080	5.171	0.019
2002	811.2	860	251.7	22	94.6	1.2722	0.080	4.529	0.018
2003	774.6	655	171.7	24	85.5	1.0741	0.083	3.166	0.018
2004	765.5	681	176.7	25	77.0	1.1394	0.082	2.873	0.016
2005	784.2	722	190.7	21	78.2	1.2368	0.082	3.105	0.016
2006	811.3	818	183.2	19	58.1	0.9810	0.081	3.406	0.019
2007	607.9	594	115.4	15	44.9	0.8191	0.084	2.776	0.024
2008	700.4	473	101.9	16	55.1	0.8343	0.087	1.526	0.015
2009	454.4	413	59.2	13	34.9	0.6552	0.090	2.179	0.037
2010	380.0	410	38.3	13	20.8	0.4864	0.090	2.589	0.068
2011	428.0	622	82.9	14	27.5	0.5139	0.084	2.709	0.033
2012	395.6	345	34.7	14	23.2	0.3862	0.093	2.622	0.076
2013	323.9	466	36.2	13	15.9	0.3668	0.089	3.435	0.095
2014	216.6	252	10.1	13	8.8	0.2869	0.100	2.484	0.245
2015	152.5	155	7.0	9	8.4	0.3656	0.115	1.299	0.185
2016	183.4	255	25.0	11	18.1	0.4278	0.100	1.601	0.064

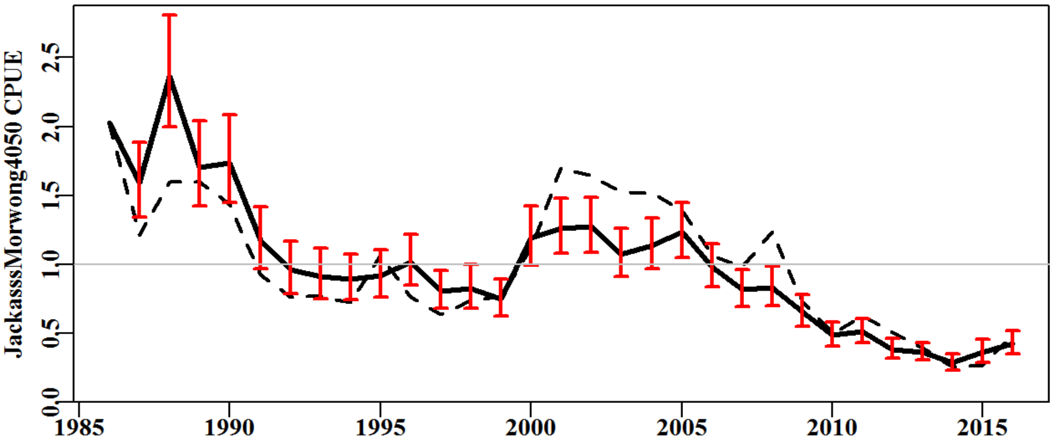


Figure 7.65. JackasssMorwong4050 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

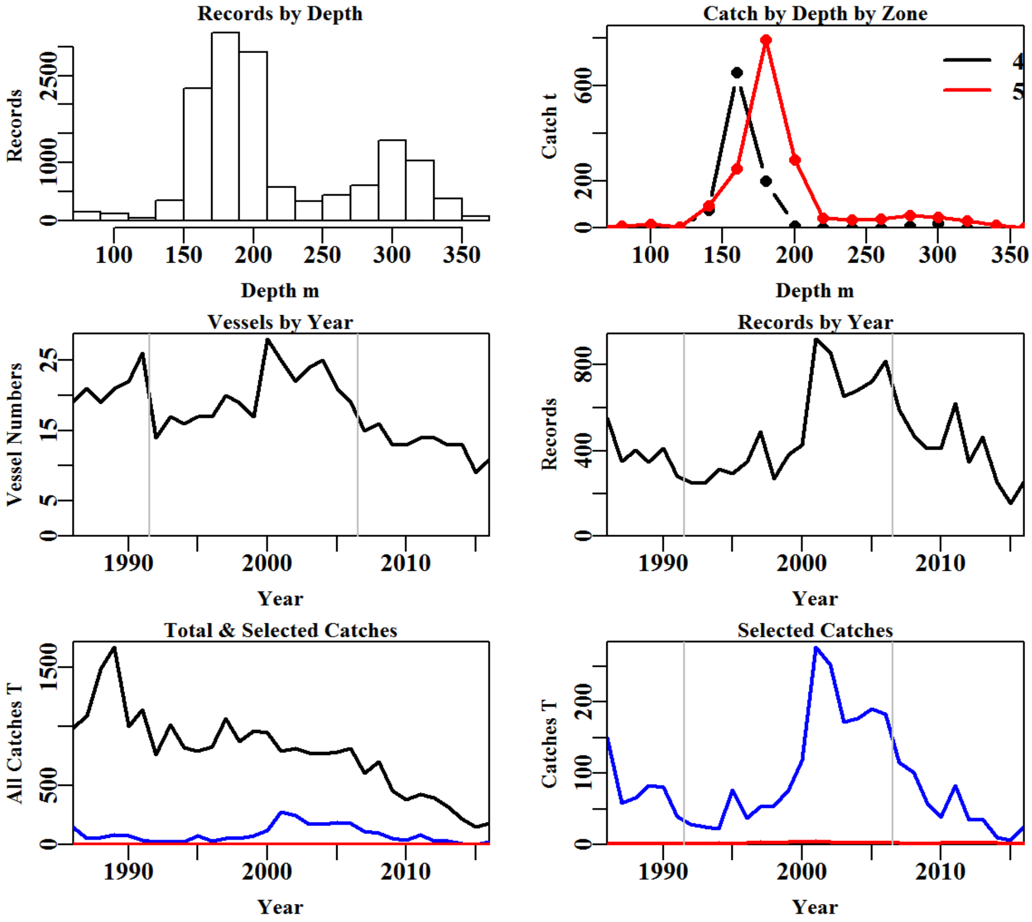


Figure 7.66. JackasssMorwong4050 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.42. JackasssMorwong4050 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	250941	230813	211445	207477	14408	14040	14005
Difference	0	20128	19368	3968	193069	368	35

Table 7.43. The models used to analyse data for JackasssMorwong4050.

	Model
Model1	Year
Model2	Year + DepCat
Model3	Year + DepCat + Month
Model4	Year + DepCat + Month + Vessel
Model5	Year + DepCat + Month + Vessel + DayNight
Model6	Year + DepCat + Month + Vessel + DayNight + Zone
Model7	Year + DepCat + Month + Vessel + DayNight + Zone + Zone:Month
Model8	Year + DepCat + Month + Vessel + DayNight + Zone + Zone:DepCat

Table 7.44. JackasssMorwong4050. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	8086	24837	3357	14005	31	11.7	0.00
DepCat	5746	20882	7312	13905	46	25.0	13.32
Month	4551	19131	9062	13905	57	31.3	6.23
Vessel	3868	17985	10208	13905	145	35.0	3.70
DayNight	3726	17795	10398	13905	148	35.6	0.67
Zone	3612	17647	10547	13905	149	36.2	0.53
Zone:Month	3467	17436	10758	13905	160	36.9	0.71
Zone:DepCat	3520	17496	10698	13905	163	36.7	0.48

Table 7.45. JackasssMorwong4050. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	JackasssMorwong4050
csirocode	37377003
fishery	SET
depthrange	70 - 360
depthclass	20
zones	40, 50
methods	TW, TDO, TMO, OTT
years	1986 - 2016

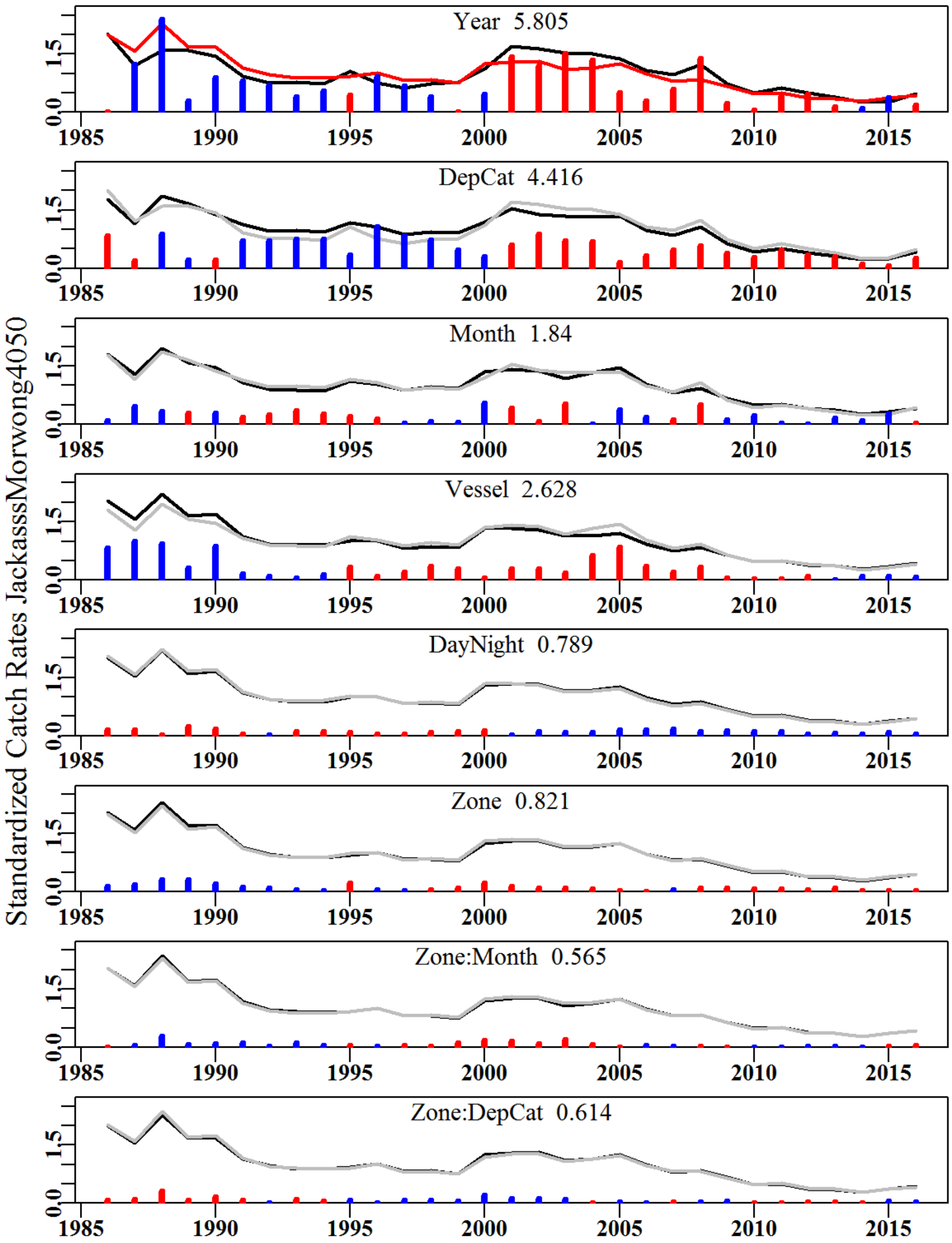


Figure 7.67. JackasssMorwong4050. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

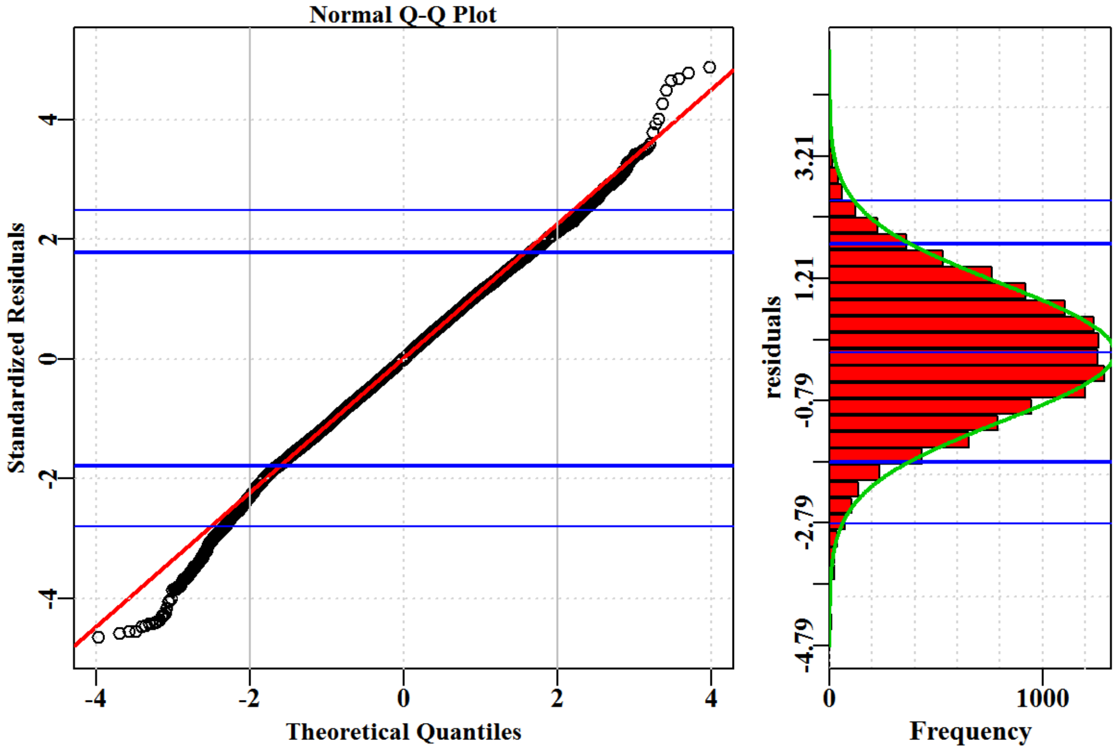


Figure 7.68. JackasssMorwong4050. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

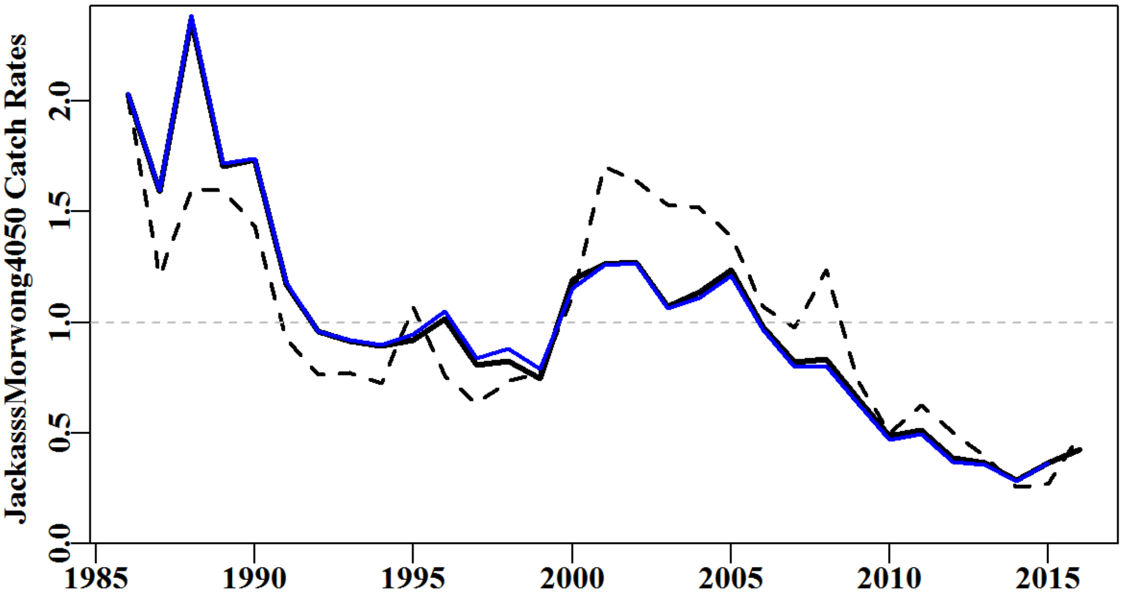


Figure 7.69. JackasssMorwong4050. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

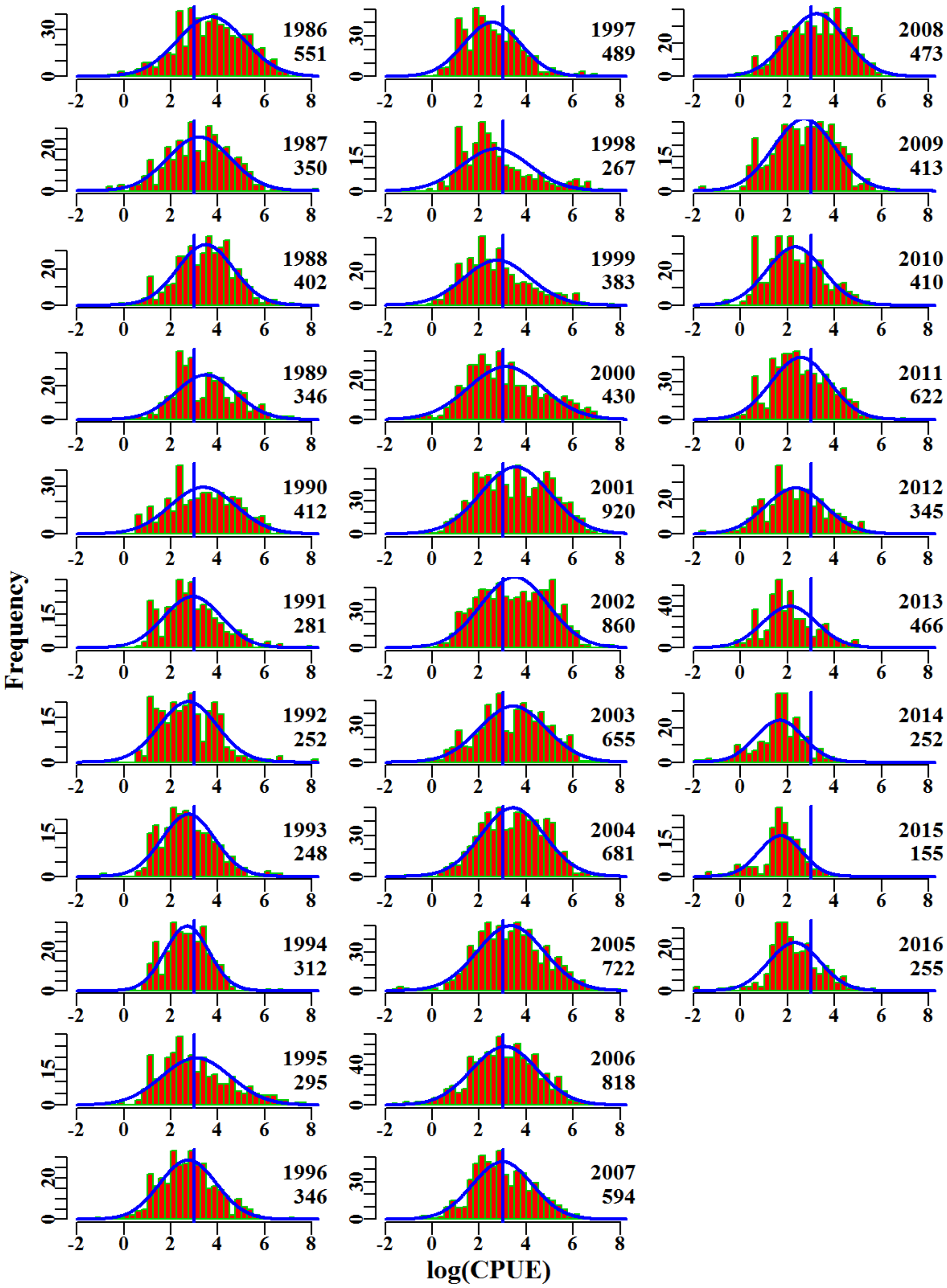


Figure 7.70. JackasssMorwong4050. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

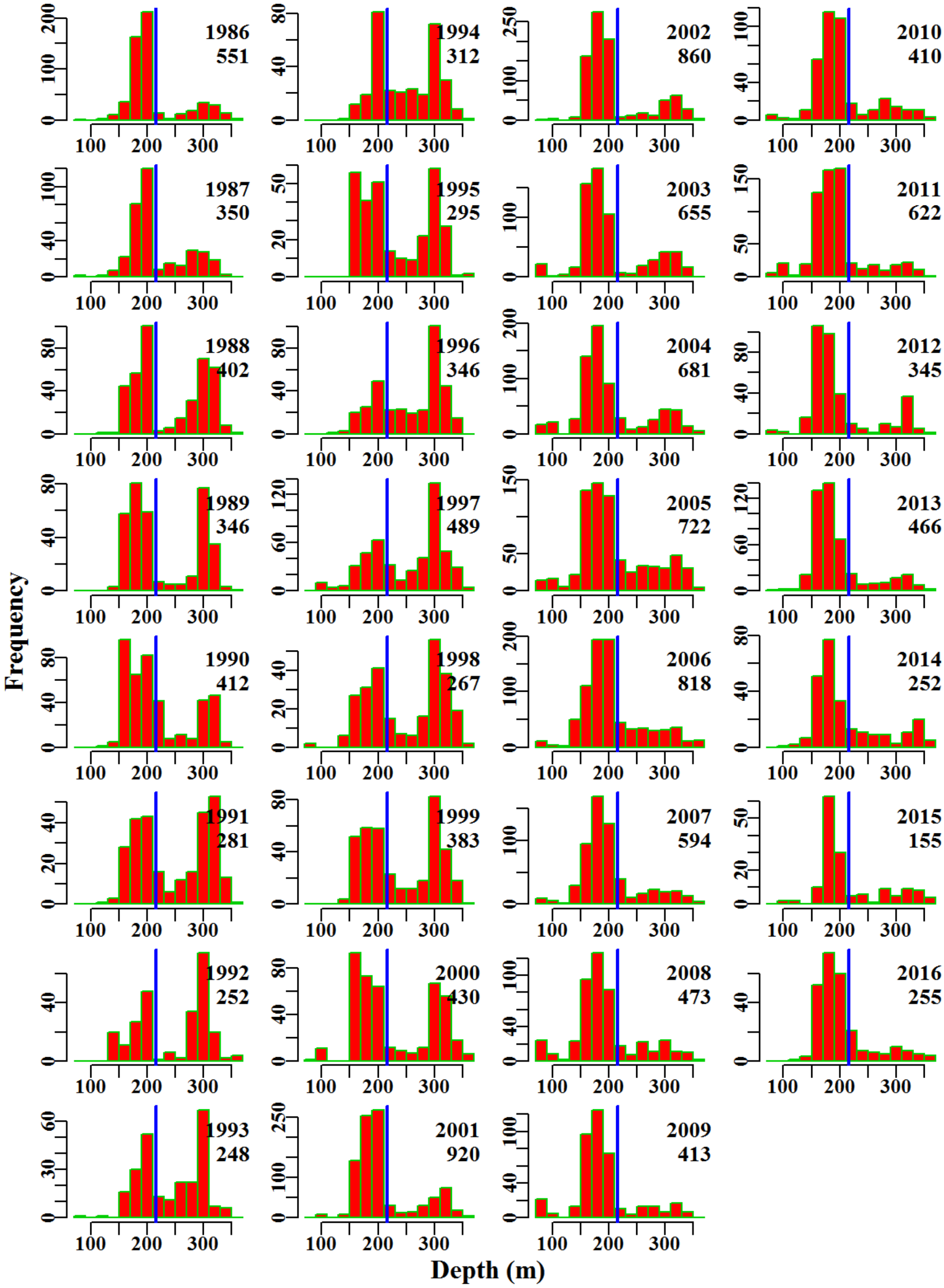


Figure 7.71. JackasssMorwong4050. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

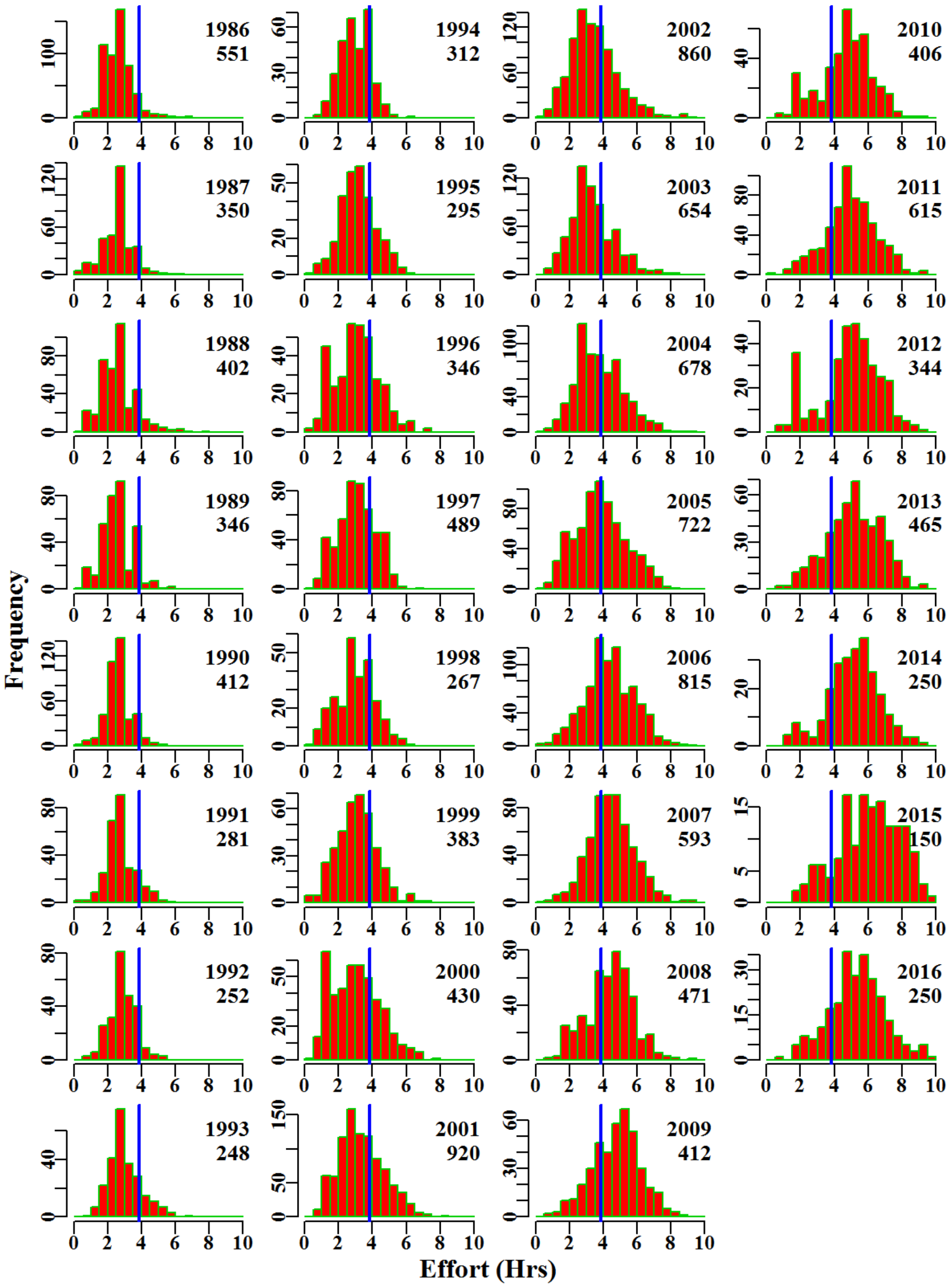


Figure 7.72. JackasssMorwong4050. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.13 Silver Warehou 40 – 50

Silver Warehou (TRS - 37445006 - *Seriolella punctata*) was one of the 16 species first included in the quota system in 1992, which reflects its long history within the SESSF. The criteria used to select data from the Commonwealth logbook database are described in (Table 7.50).

A total of 8 statistical models were fitted sequentially to the available data.

7.13.1 *Inferences*

The terms Year, Vessel, Month and DepCat had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests that the assumed Normal distribution is valid.

Annual standardized CPUE have declined since 2005, and since 2008 have been below the long term average (Figure 7.73). The vessel factor changed its action in 2000 to about 2006 after which it was less influential.

7.13.2 *Action Items and Issues*

After consideration of Silver Warehou catches in zones 40 - 50 by year and vessel, the period around 1999 - 2006 appears exceptional, or at least contains exceptional vessels, all of which left the fishery after the structural adjustment. This suggests that there have been transitional periods in the time-series of CPUE. This **urgently** needs more attention because this may imply that CPUE may no longer be acting as a valid index of relative abundance through time.

Table 7.46. SilverWarehou4050. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	1156.5	1120	643.6	23	200.8	1.4868	0.000	4.167	0.006
1987	782.2	725	491.0	26	279.7	1.6801	0.083	2.398	0.005
1988	1646.2	574	684.4	27	553.5	1.9444	0.088	2.280	0.003
1989	926.3	650	569.5	27	287.0	1.6381	0.090	2.663	0.005
1990	1346.6	569	298.7	26	196.7	1.0819	0.089	3.046	0.010
1991	1453.2	706	629.5	29	263.5	1.1604	0.085	3.190	0.005
1992	733.8	584	187.0	21	98.8	0.8789	0.088	3.340	0.018
1993	1815.8	1546	752.5	23	151.4	1.2186	0.073	7.028	0.009
1994	2309.5	1653	758.1	26	155.3	1.1201	0.071	7.765	0.010
1995	2002.9	1680	774.1	24	146.6	0.8975	0.071	8.978	0.012
1996	2188.2	1566	1020.8	26	208.2	1.0190	0.072	8.570	0.008
1997	2562.0	1882	1269.2	24	211.9	1.2090	0.070	9.457	0.007
1998	2166.0	1853	1197.6	22	220.9	1.4312	0.071	7.985	0.007
1999	2834.1	2747	1779.9	24	242.4	1.1807	0.068	11.412	0.006
2000	3401.6	3573	2603.0	30	323.5	1.1542	0.066	15.133	0.006
2001	2970.4	4190	2179.1	29	194.3	0.8715	0.066	20.814	0.010
2002	3841.4	4434	2949.9	27	248.4	0.9264	0.065	20.381	0.007
2003	2910.1	3419	2213.4	28	256.6	0.9629	0.067	15.028	0.007
2004	3202.1	4274	2548.6	25	164.2	1.0526	0.066	14.538	0.006
2005	2648.0	3080	2116.6	24	220.5	1.1524	0.067	11.838	0.006
2006	2191.2	2695	1686.5	21	187.4	1.0174	0.068	10.651	0.006
2007	1816.5	2787	1390.0	16	146.7	1.0292	0.068	10.396	0.007
2008	1381.2	2075	879.5	17	107.0	0.8184	0.070	9.171	0.010
2009	1285.3	2057	734.6	13	74.2	0.7104	0.070	9.452	0.013
2010	1189.4	2347	796.3	14	65.7	0.6460	0.069	11.578	0.015
2011	1108.8	2913	824.6	17	57.4	0.6221	0.068	11.607	0.014
2012	781.2	1905	560.4	15	57.3	0.4642	0.072	10.497	0.019
2013	584.1	1528	344.1	16	48.7	0.4354	0.074	8.306	0.024
2014	356.9	1545	244.4	14	29.2	0.4158	0.073	8.730	0.036
2015	368.4	1385	268.6	13	34.1	0.4499	0.075	6.689	0.025
2016	331.5	1105	172.2	13	25.2	0.3243	0.077	6.364	0.037

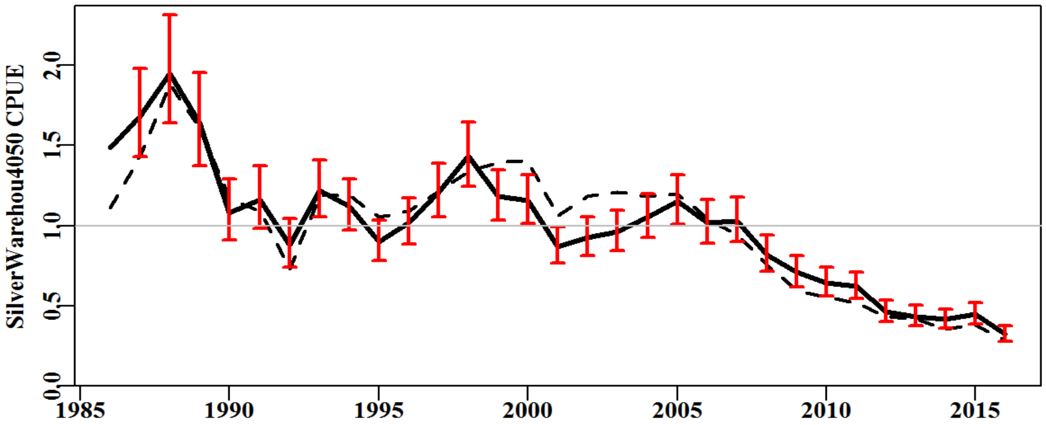


Figure 7.73. SilverWarehou4050 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

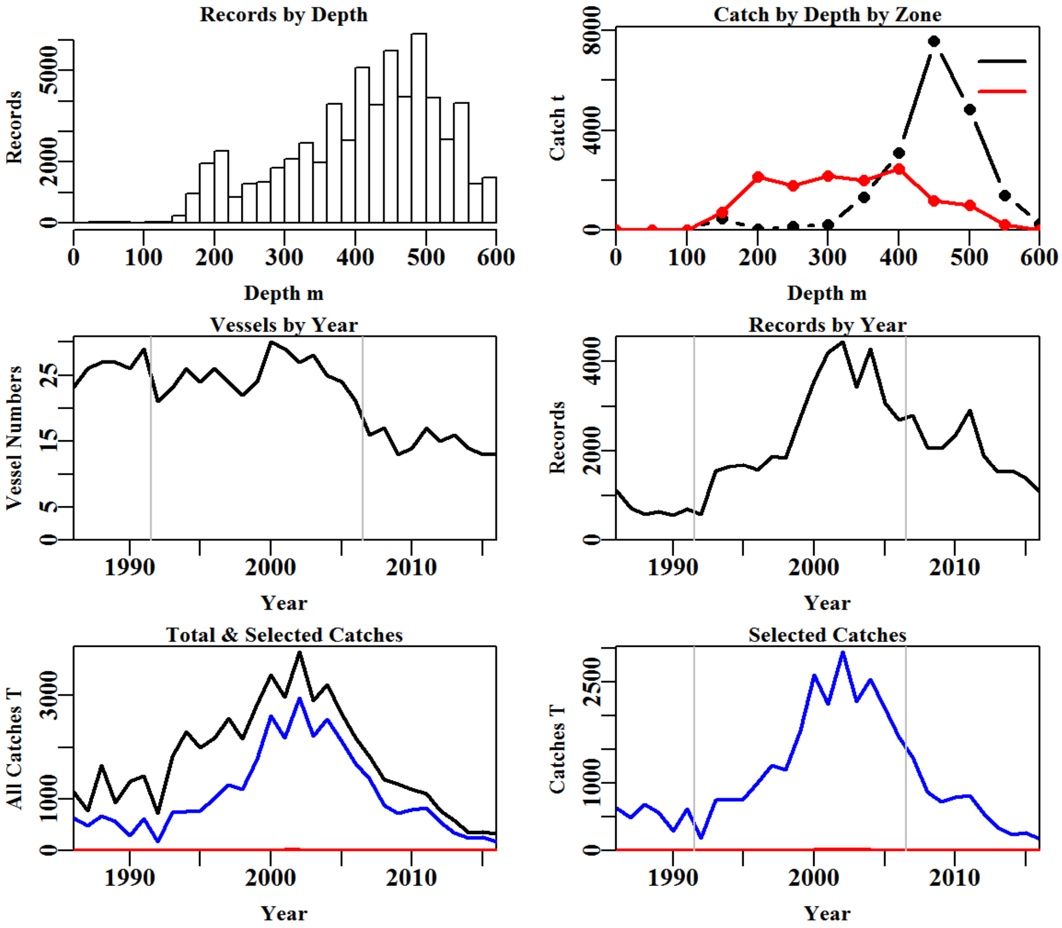


Figure 7.74. SilverWarehou4050 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.47. SilverWarehou4050 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	149803	146024	142739	141682	63478	63292	63167
Difference	0	3779	3285	1057	78204	186	125

Table 7.48. The models used to analyse data for SilverWarehou4050.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + Month
Model4	Year + Vessel + Month + DepCat
Model5	Year + Vessel + Month + DepCat + Zone
Model6	Year + Vessel + Month + DepCat + Zone + DayNight
Model7	Year + Vessel + Month + DepCat + Zone + DayNight + Zone:Month
Model8	Year + Vessel + Month + DepCat + Zone + DayNight + Zone:DepCat

Table 7.49. SilverWarehou4050. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	67236	182950	11701	63167	31	6.0	0.00
Vessel	59503	161358	33293	63167	131	16.9	10.97
Month	56551	153939	40713	63167	142	20.7	3.81
DepCat	55059	150158	44494	62753	154	22.1	1.36
Zone	54206	148126	46525	62753	155	23.2	1.05
DayNight	53908	147410	47242	62753	158	23.5	0.37
Zone:Month	53680	146824	47828	62753	169	23.8	0.29
Zone:DepCat	53712	146896	47756	62753	170	23.8	0.25

Table 7.50. SilverWarehou4050. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	SilverWarehou4050
csirocode	37445006
fishery	SET
depthrange	0 - 600
depthclass	50
zones	40, 50
methods	TW, TDO, OTT, TMO
years	1986 - 2016

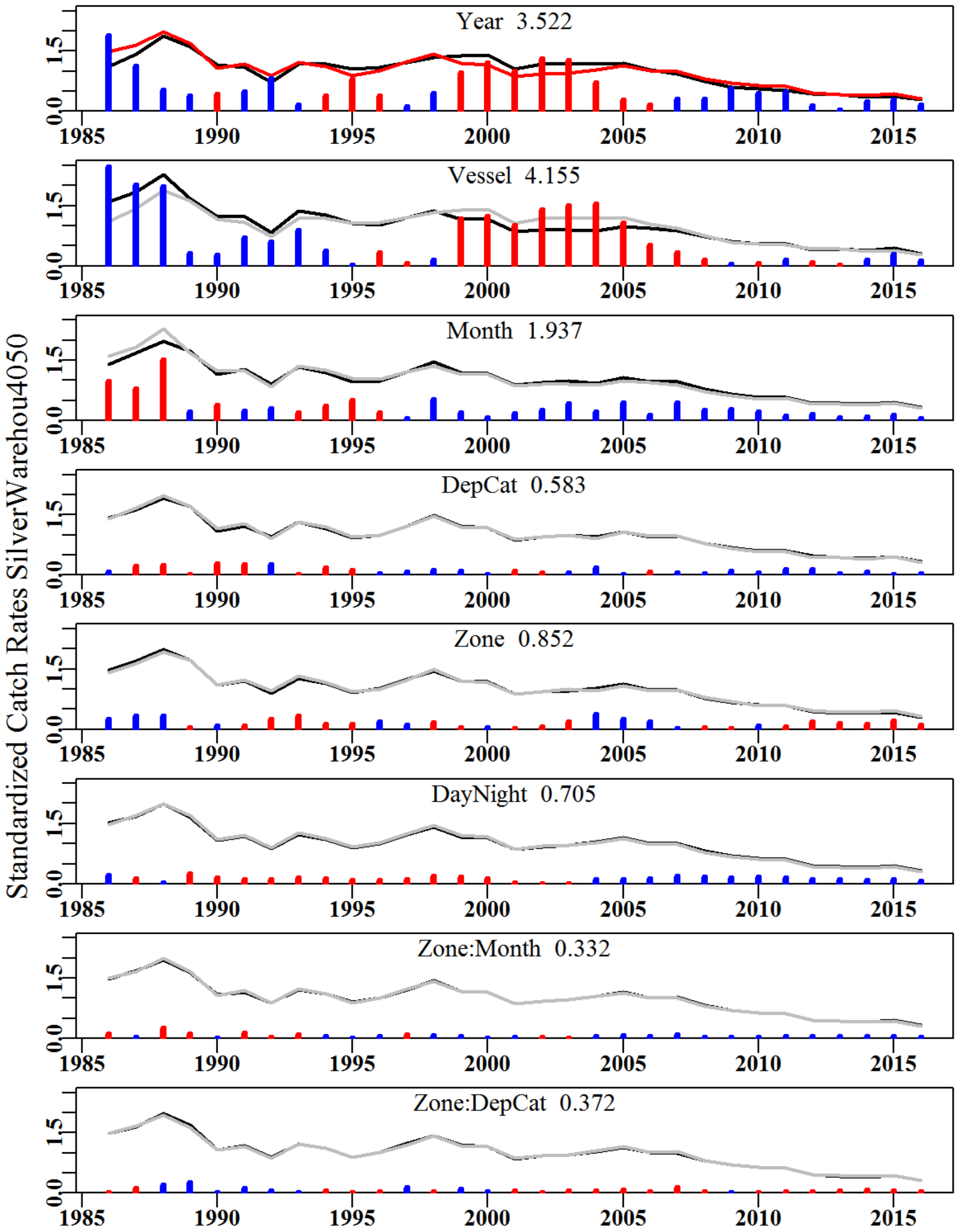


Figure 7.75. SilverWarehou4050. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

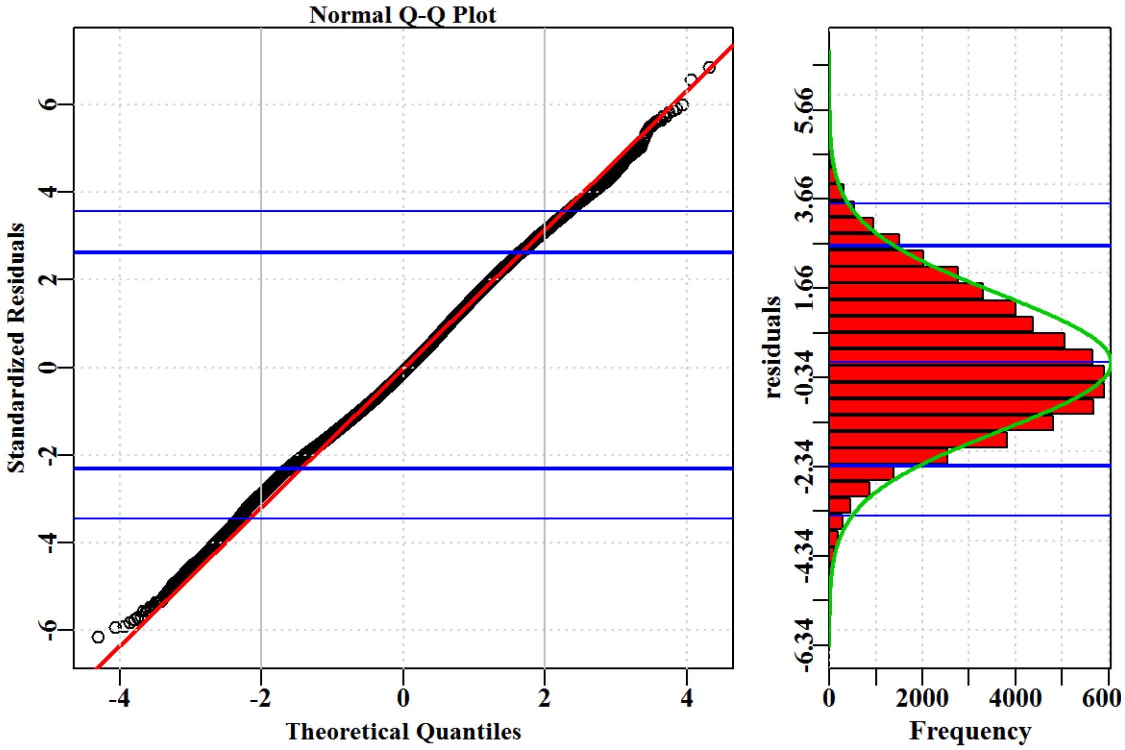


Figure 7.76. SilverWarehou4050. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

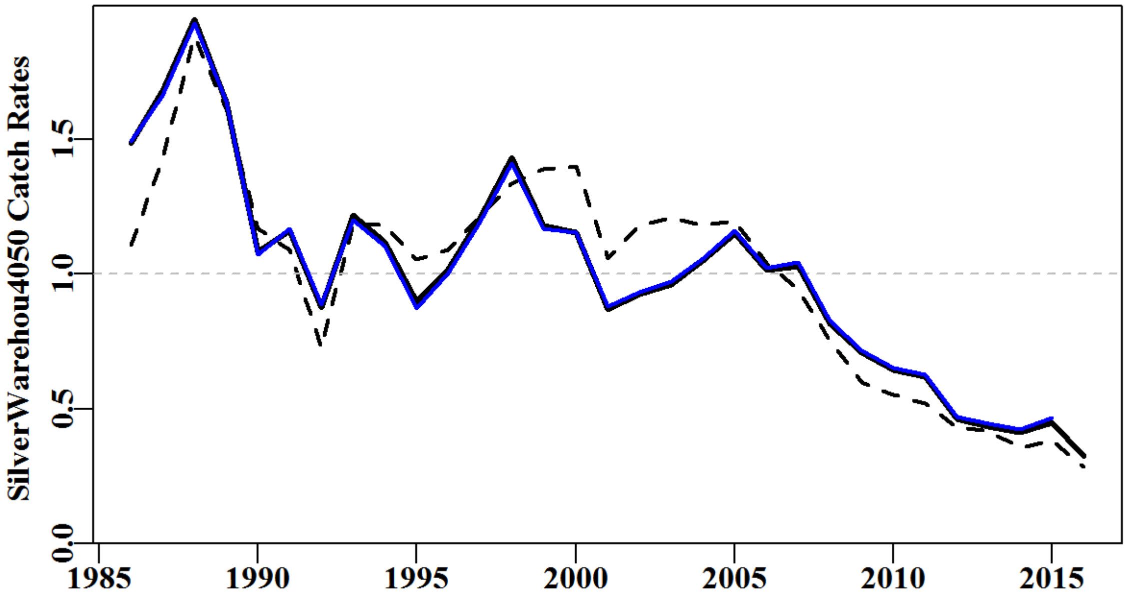


Figure 7.77. SilverWarehou4050. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

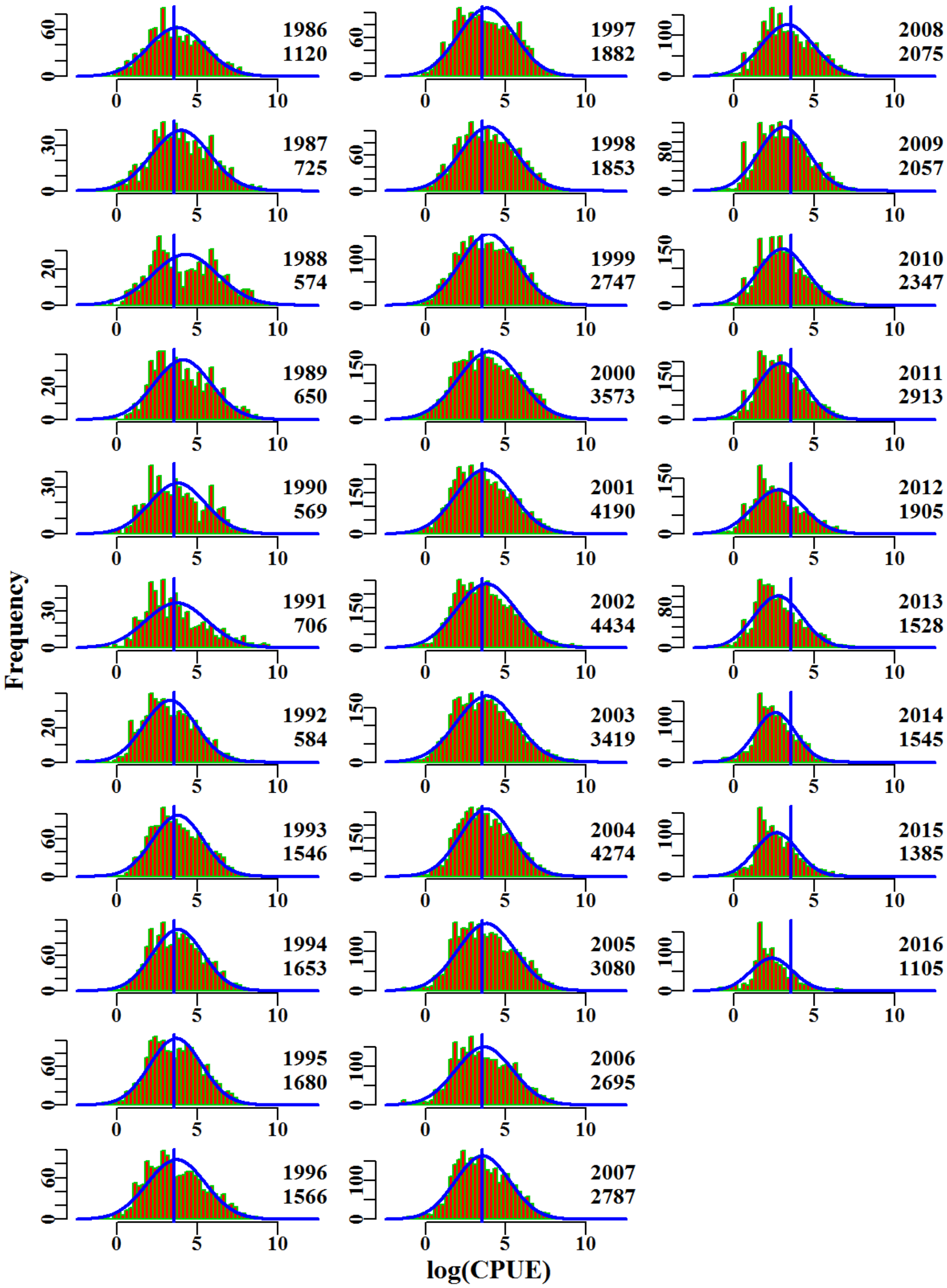


Figure 7.78. SilverWarehou4050. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

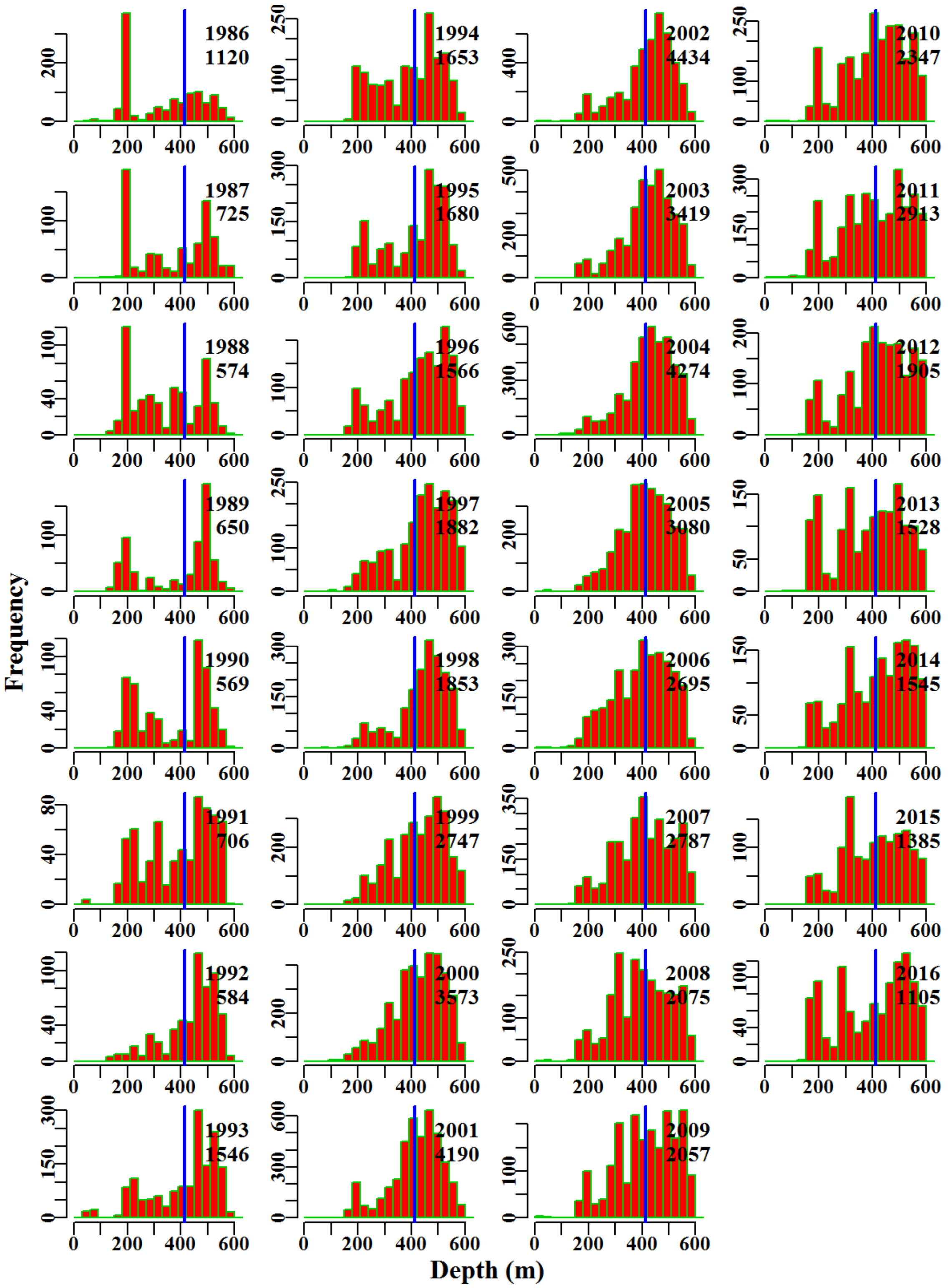


Figure 7.79. SilverWarehou4050. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

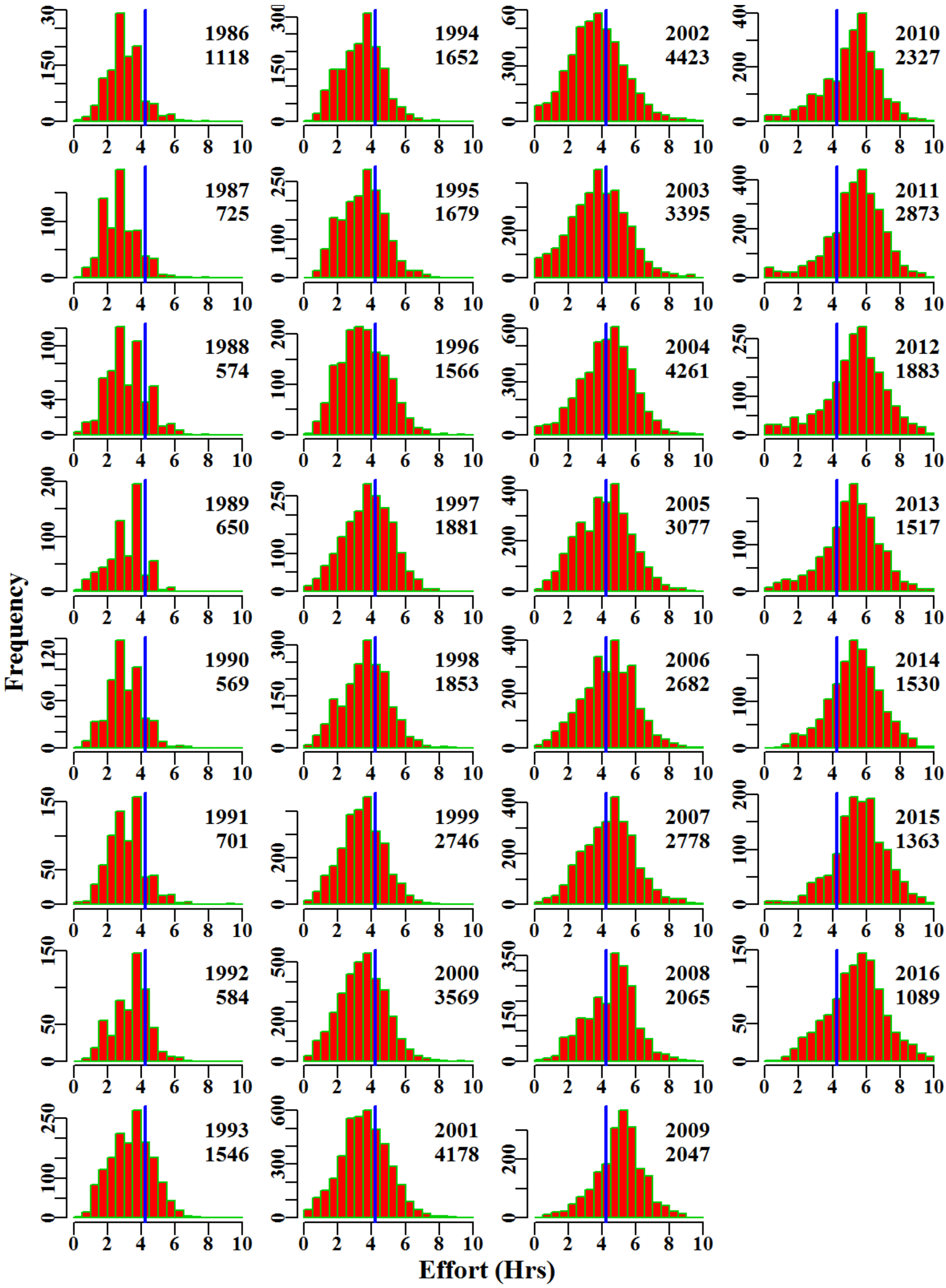


Figure 7.80. SilverWarehou4050. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.14 Silver Warehou 10 – 30

Silver Warehou (TRS - 37445006 - *Seriolella punctata*) was one of the 16 species first included in the quota system in 1992, which reflects its long history within the SESSF. The criteria used to select data from the Commonwealth logbook database are listed (Table 7.55).

A total of 8 statistical models were fitted sequentially to the available data.

7.14.1 *Inferences*

Most silver warehou in the east have been caught in zone 20 across the specified depth range between 1986 - 2016. Both the early catches and the CPUE exhibit high levels of variation and may be suspect before the introduction of quotas, prior to which they were mixed up with catches of Blue Warehou.

The terms Year, Vessel, Month and DepCat had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests that the assumed Normal distribution is valid.

Annual standardized CPUE has declined since 1994 and have been below average since 1999 (Figure 7.81).

7.14.2 *Action Items and Issues*

After consideration of Silver Warehou catches in zones 10 - 30 by year and vessel the period around 1992 - 2006 appears exceptional, or at least contains exceptional vessels. This suggests that there have been transitional periods in the time-series of CPUE. This **urgently** needs more attention because of the potential implications this has for the index of relative abundance through time.

Table 7.51. SilverWarehou1030. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	1156.5	1318	491.7	66	113.2	1.7934	0.000	6.906	0.014
1987	782.2	784	266.3	56	111.3	1.6692	0.078	4.512	0.017
1988	1646.2	1675	932.8	69	173.4	2.2483	0.066	8.495	0.009
1989	926.3	1399	337.9	63	62.4	1.8177	0.070	9.172	0.027
1990	1346.6	1414	992.3	59	258.0	2.3543	0.071	5.724	0.006
1991	1453.2	1584	578.0	64	116.2	1.4691	0.070	10.074	0.017
1992	733.8	1274	438.2	41	112.4	1.5379	0.073	7.425	0.017
1993	1815.8	2318	982.6	49	128.9	1.5330	0.066	14.864	0.015
1994	2309.5	2866	1542.0	46	186.0	1.7438	0.065	16.918	0.011
1995	2002.9	3335	1194.5	45	113.1	1.5602	0.064	22.696	0.019
1996	2188.2	4514	1116.6	53	72.4	1.1986	0.062	32.950	0.030
1997	2562.0	3883	1036.5	48	81.7	1.1622	0.064	26.113	0.025
1998	2166.0	2849	779.1	43	73.0	0.9729	0.065	21.304	0.027
1999	2834.1	2400	905.8	43	113.0	0.8536	0.067	17.189	0.019
2000	3401.6	3162	722.0	50	79.1	0.6872	0.065	21.639	0.030
2001	2970.4	3155	637.4	40	72.0	0.6517	0.065	21.681	0.034
2002	3841.4	3989	709.3	42	60.6	0.7255	0.064	27.942	0.039
2003	2910.1	3986	569.4	50	47.9	0.6942	0.064	28.456	0.050
2004	3202.1	3587	488.1	46	42.8	0.7770	0.064	25.791	0.053
2005	2648.0	3840	441.7	42	34.3	0.7114	0.064	30.863	0.070
2006	2191.2	2968	389.8	35	33.0	0.6189	0.066	24.421	0.063
2007	1816.5	1870	275.2	23	44.4	0.4938	0.070	14.458	0.053
2008	1381.2	2326	401.2	24	43.7	0.5694	0.068	19.606	0.049
2009	1285.3	2330	375.1	23	49.6	0.6487	0.068	17.466	0.047
2010	1189.4	2137	286.3	20	39.6	0.4940	0.069	15.677	0.055
2011	1108.8	2027	218.2	22	29.7	0.4125	0.069	16.394	0.075
2012	781.2	1863	190.2	20	32.8	0.3792	0.070	14.381	0.076
2013	584.1	1452	159.0	21	37.7	0.4805	0.073	11.527	0.073
2014	356.9	1348	89.3	22	21.7	0.3285	0.074	11.569	0.130
2015	368.4	1290	64.9	22	16.3	0.2264	0.074	11.584	0.179
2016	331.5	1341	100.2	22	19.5	0.1869	0.075	9.477	0.095

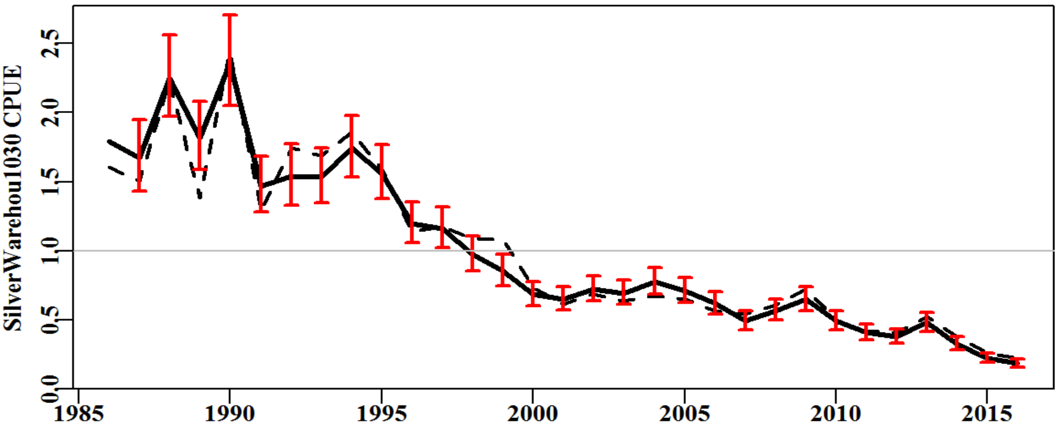


Figure 7.81. SilverWarehou1030 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

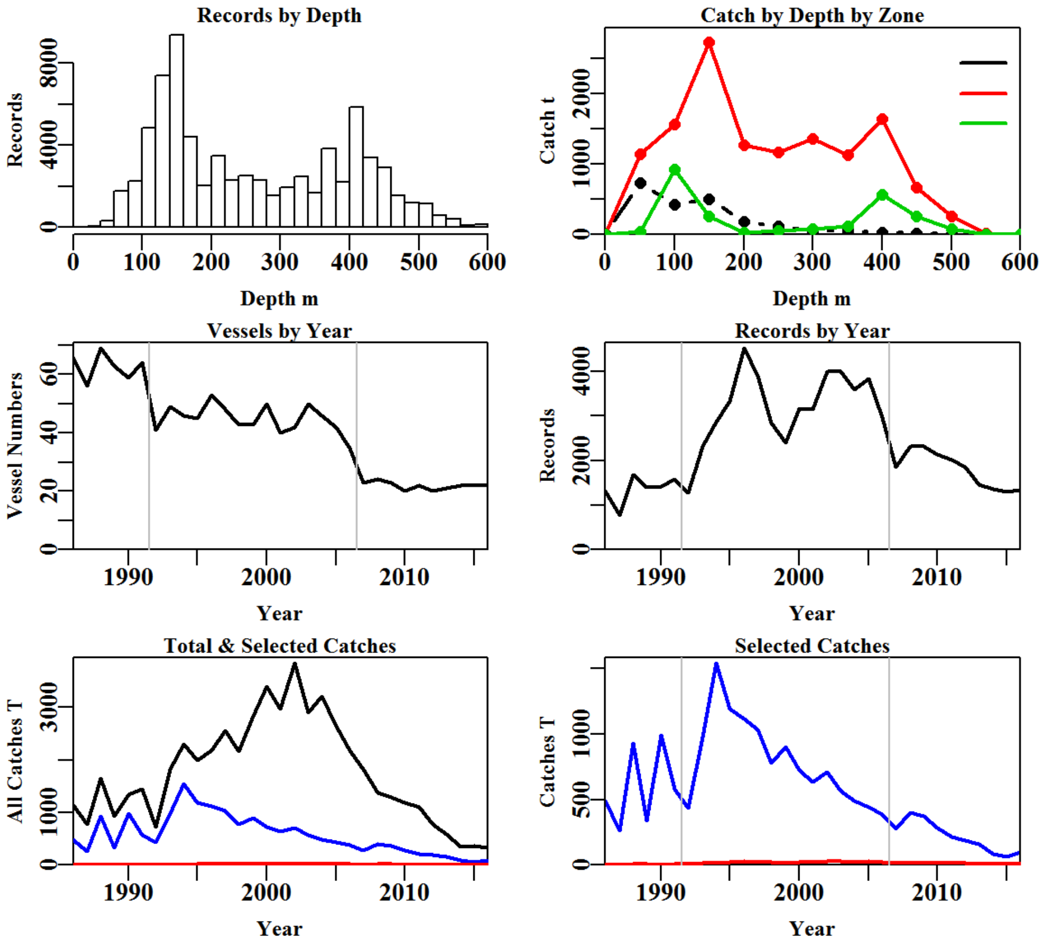


Figure 7.82. SilverWarehou1030 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.52. SilverWarehou1030 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	149803	146024	142739	141682	75805	74373	74284
Difference	0	3779	3285	1057	65877	1432	89

Table 7.53. The models used to analyse data for SilverWarehou1030.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + Month
Model4	Year + Vessel + Month + DepCat
Model5	Year + Vessel + Month + DepCat + Zone
Model6	Year + Vessel + Month + DepCat + Zone + DayNight
Model7	Year + Vessel + Month + DepCat + Zone + DayNight + Zone:Month
Model8	Year + Vessel + Month + DepCat + Zone + DayNight + Zone:DepCat

Table 7.54. SilverWarehou1030. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	82750	226113	20888	74284	31	8.4	0.00
Vessel	76511	206880	40121	74284	213	16.0	7.58
Month	72770	196661	50340	74284	224	20.1	4.14
DepCat	71234	192525	54476	73798	235	21.3	1.17
Zone	70978	191846	55155	73798	237	21.6	0.28
DayNight	70961	191788	55213	73798	240	21.6	0.02
Zone:Month	70005	189207	57794	73798	262	22.6	1.03
Zone:DepCat	70016	189229	57772	73798	263	22.6	1.02

Table 7.55. SilverWarehou1030. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	SilverWarehou1030
csirocode	37445006
fishery	SET
depthrange	0 - 600
depthclass	50
zones	10, 20, 30
methods	TW, TDO, OTT, TMO
years	1986 - 2016

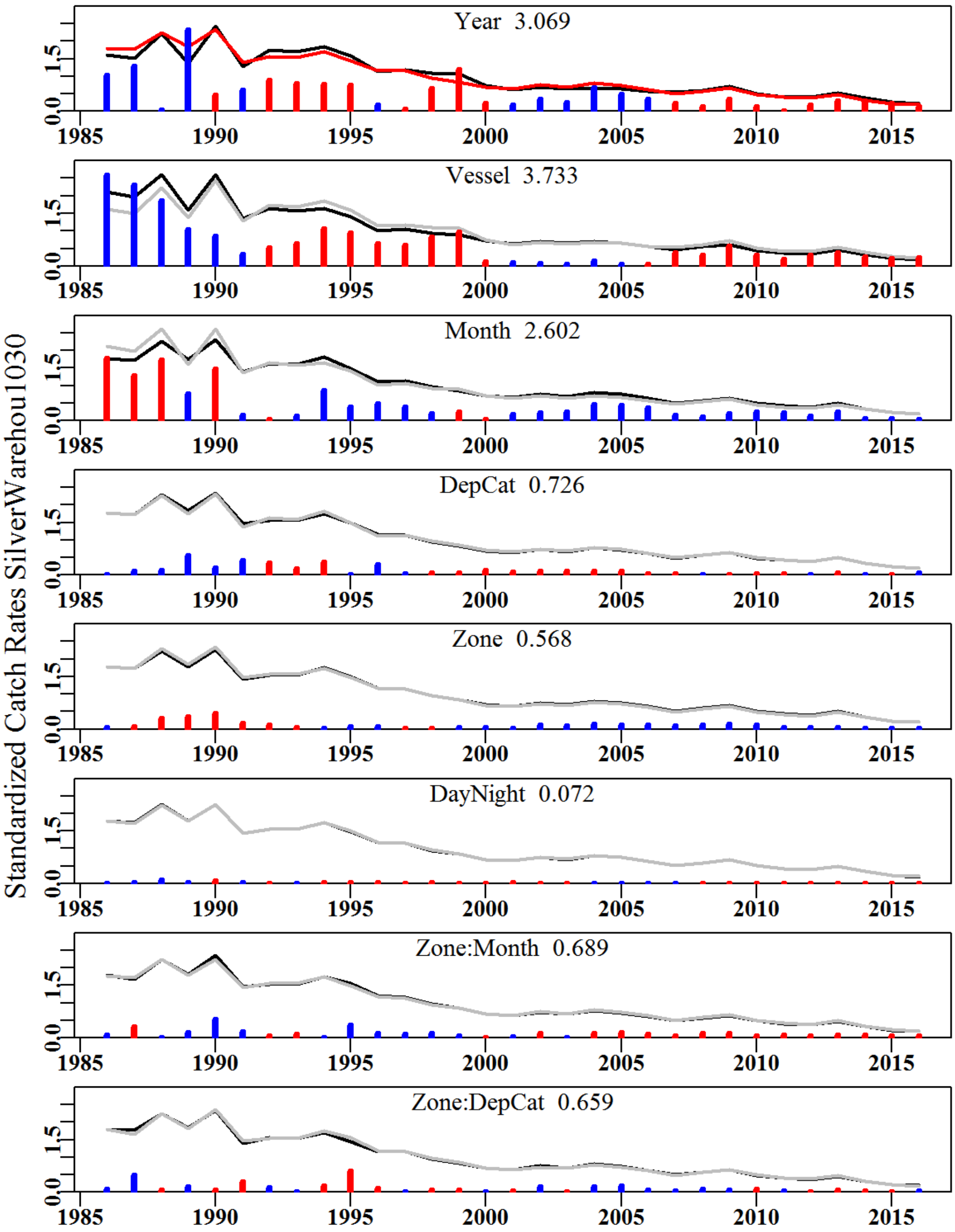


Figure 7.83. SilverWarehou1030. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

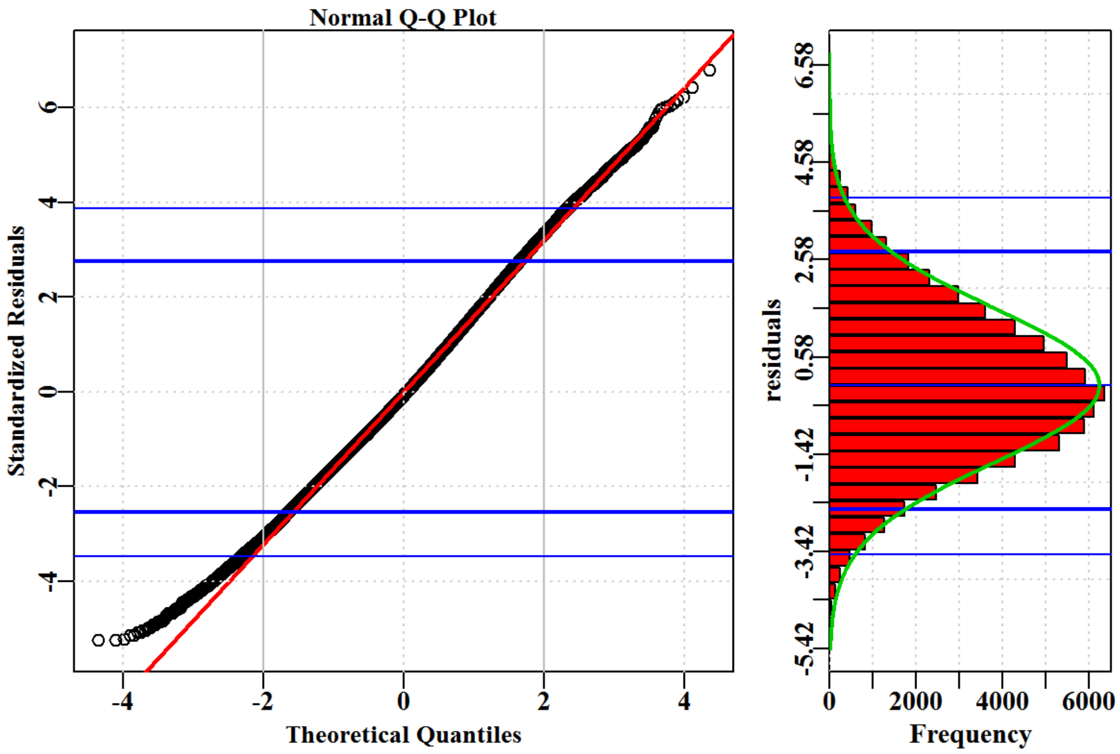


Figure 7.84. SilverWarehou1030. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

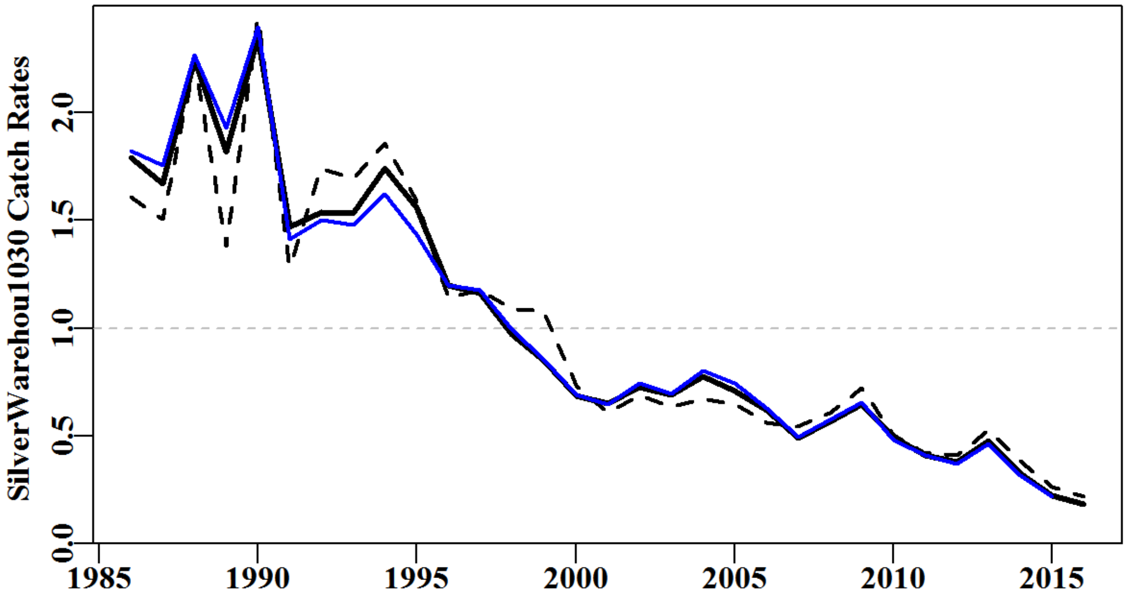


Figure 7.85. SilverWarehou1030. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

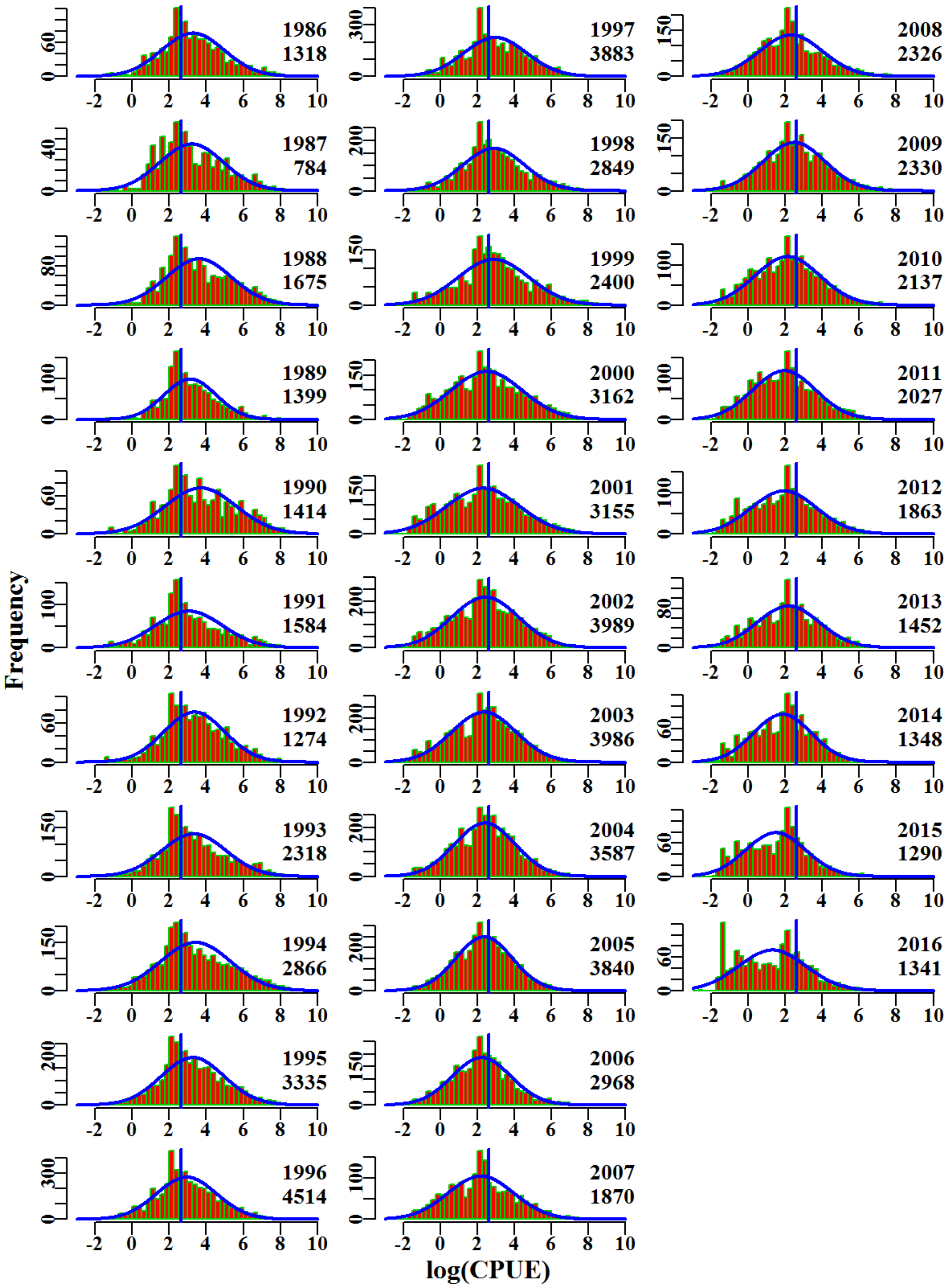


Figure 7.86. SilverWarehou1030. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

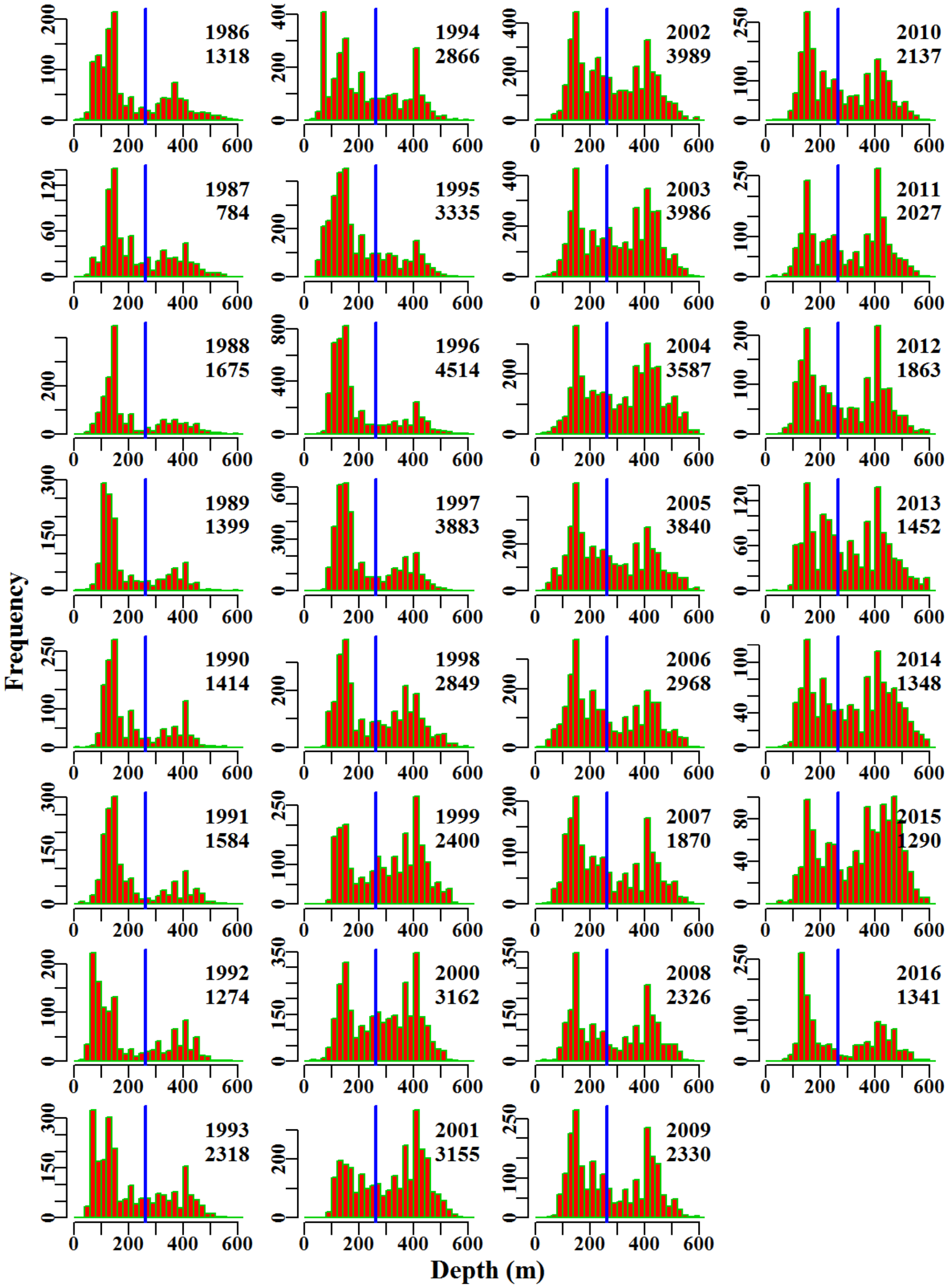


Figure 7.87. SilverWarehou1030. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

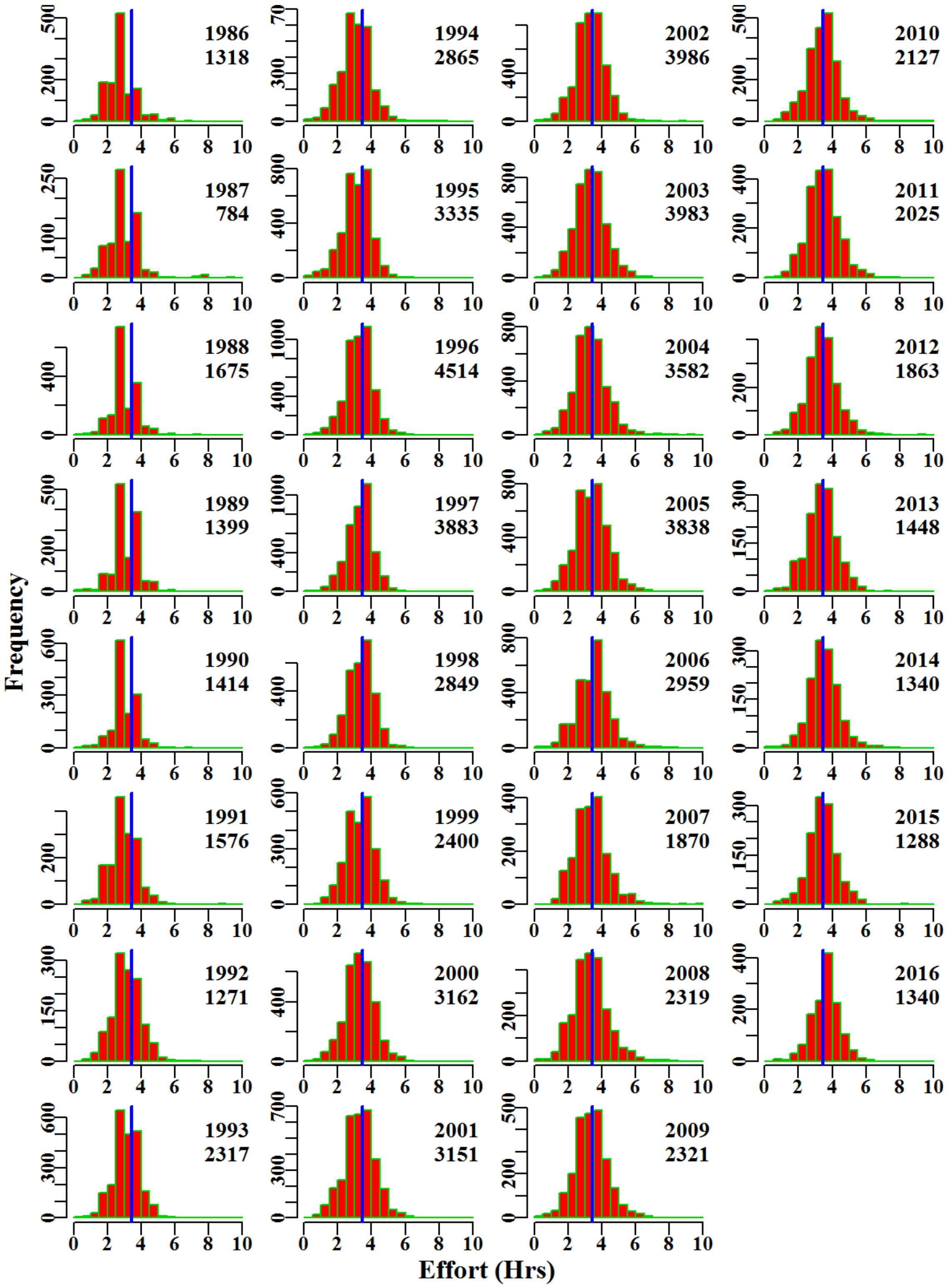


Figure 7.88. SilverWarehou1030. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.15 Flathead TW 30

Tiger Flathead (FLT - 37296001 - *Neoplatycephalus richardsoni*) was one of the 16 species first included in the quota system in 1992, which reflects its long history within the SESSF. The additional generic flathead group code was added as a result of a change in recording Tiger Flathead as 37296000 (Platycephalidae) in electronic logbooks since 2013. Trawl caught Tiger Flathead based on methods TW, TDO, OTT, TMO, in zones 30, and depths 0 to 300 within the SET fishery for the years 1986 - 2016 were analysed (Table 7.60). A total of 7 statistical models were fitted sequentially to the available data.

7.15.1 *Inferences*

The amount of flathead (*Neoplatycephalus richardsoni* and Platycephalidae) catch in shots <30 kg in zone 30 is small across the analysis period.

The terms Year, Vessel, DepCat, DayNight, Month and one interaction term (Month:DepCat) had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests a small departure of the assumed Normal distribution as depicted by the lower tail of the distribution.

The annual standardized CPUE trend was noisy and flat between 1986 - 2001, and after a transitional period between 2002 - 2006 during which catches surged, was noisy and flat from 2007 to 2016 (Figure 7.89). In more recent years catches have been increasing again.

7.15.2 *Action Items and Issues*

The number of records and corresponding catch in 1986 and 1987 are very low. Also, the depth distibution spread over a large range for these two years compared to all other years in the fishery. It is therefore recommended to removes these two years from the time series for analysis.

Table 7.56. FlatheadTW30. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Month:DepCat.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	1911.4	71	16.8	6	65.7	0.9210	0.000	0.571	0.034
1987	2471.7	90	5.2	9	18.2	0.5779	0.192	1.045	0.203
1988	2482.8	199	40.3	9	50.9	0.9341	0.172	1.452	0.036
1989	2609.0	516	48.4	19	29.4	0.7119	0.165	3.790	0.078
1990	2041.7	253	24.6	27	34.9	0.7193	0.167	1.925	0.078
1991	2236.2	316	33.4	29	28.3	0.6842	0.163	2.824	0.085
1992	2377.4	268	33.6	15	37.6	0.6355	0.167	1.428	0.042
1993	1881.0	901	92.1	24	30.2	0.6036	0.159	6.401	0.070
1994	1710.9	611	64.4	17	31.7	0.6315	0.160	4.706	0.073
1995	1805.8	693	71.3	17	31.4	0.6982	0.160	6.217	0.087
1996	1880.2	713	61.4	17	26.7	0.6463	0.160	6.916	0.113
1997	2356.2	880	104.6	14	42.7	0.8077	0.159	5.300	0.051
1998	2306.7	704	118.5	14	55.7	0.9612	0.159	2.968	0.025
1999	3118.7	770	175.1	17	68.3	1.0567	0.159	3.464	0.020
2000	2947.8	514	83.6	21	49.9	0.8721	0.161	2.505	0.030
2001	2600.5	931	102.5	17	31.5	0.7368	0.158	5.009	0.049
2002	2876.8	1367	212.2	15	46.7	1.3601	0.157	5.452	0.026
2003	3232.4	1451	239.3	21	47.3	1.3900	0.156	3.920	0.016
2004	3227.4	1920	477.1	15	80.1	1.8622	0.156	3.784	0.008
2005	2846.8	1538	388.1	18	77.1	1.6803	0.156	3.906	0.010
2006	2586.0	1314	287.9	13	60.2	1.3565	0.157	2.395	0.008
2007	2648.4	820	173.0	8	64.6	1.1021	0.159	1.852	0.011
2008	2913.1	872	173.7	11	61.1	1.0278	0.158	2.644	0.015
2009	2460.9	600	100.2	10	49.6	1.0106	0.160	1.461	0.015
2010	2502.3	535	104.1	10	55.4	0.9973	0.161	2.080	0.020
2011	2466.6	623	131.3	9	64.6	0.9506	0.160	1.513	0.012
2012	2780.8	754	160.7	9	59.0	1.1881	0.159	1.186	0.007
2013	1941.1	833	191.3	11	65.4	1.1648	0.159	2.406	0.013
2014	2370.1	766	183.6	11	67.3	1.3236	0.159	1.238	0.007
2015	2668.8	1167	292.6	13	69.2	1.2759	0.158	2.088	0.007
2016	2900.7	1567	332.0	12	59.6	1.1120	0.157	6.772	0.020

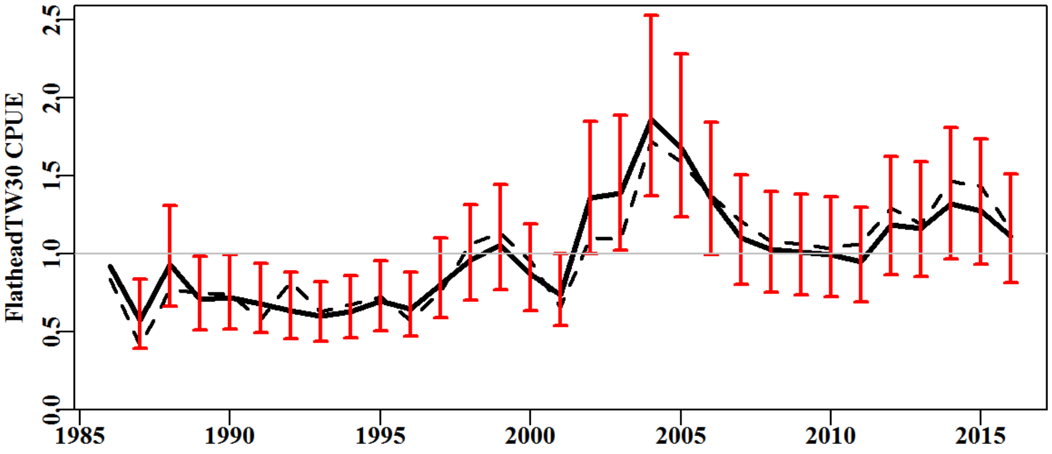


Figure 7.89. FlatheadTW30 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

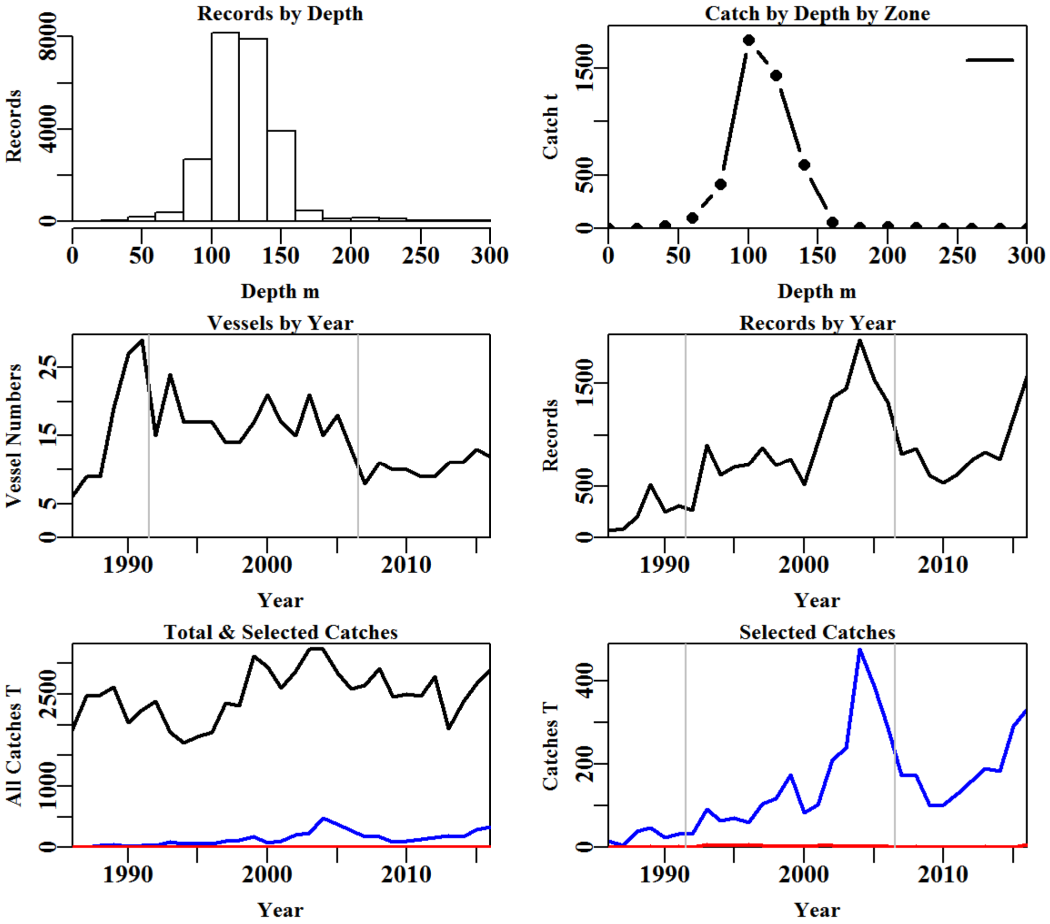


Figure 7.90. FlatheadTW30 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.57. FlatheadTW30 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	598651	510715	502362	494318	24925	24560	24557
Difference	0	87936	8353	8044	469393	365	3

Table 7.58. The models used to analyse data for FlatheadTW30.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + DayNight
Model5	Year + Vessel + DepCat + DayNight + Month
Model6	Year + Vessel + DepCat + DayNight + Month + Month:DepCat
Model7	Year + Vessel + DepCat + DayNight + Month + DayNight:Month

Table 7.59. FlatheadTW30. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Month:DepCat.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	3582	28342	2432	24557	31	7.8	0.00
Vessel	1780	26137	4636	24557	124	14.6	6.85
DepCat	532	24520	6254	24265	139	19.0	4.34
DayNight	236	24217	6556	24265	142	20.0	0.99
Month	-27	23934	6839	24265	153	20.9	0.90
Month:DepCat	-624	23080	7693	24265	295	23.2	2.37
DayNight:Month	-74	23841	6933	24265	177	21.1	0.23

Table 7.60. FlatheadTW30. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	FlatheadTW30
csirocode	37296001, 37296000
fishery	SET
depthrange	0 - 300
depthclass	20
zones	30
methods	TW, TDO, OTT, TMO
years	1986 - 2016

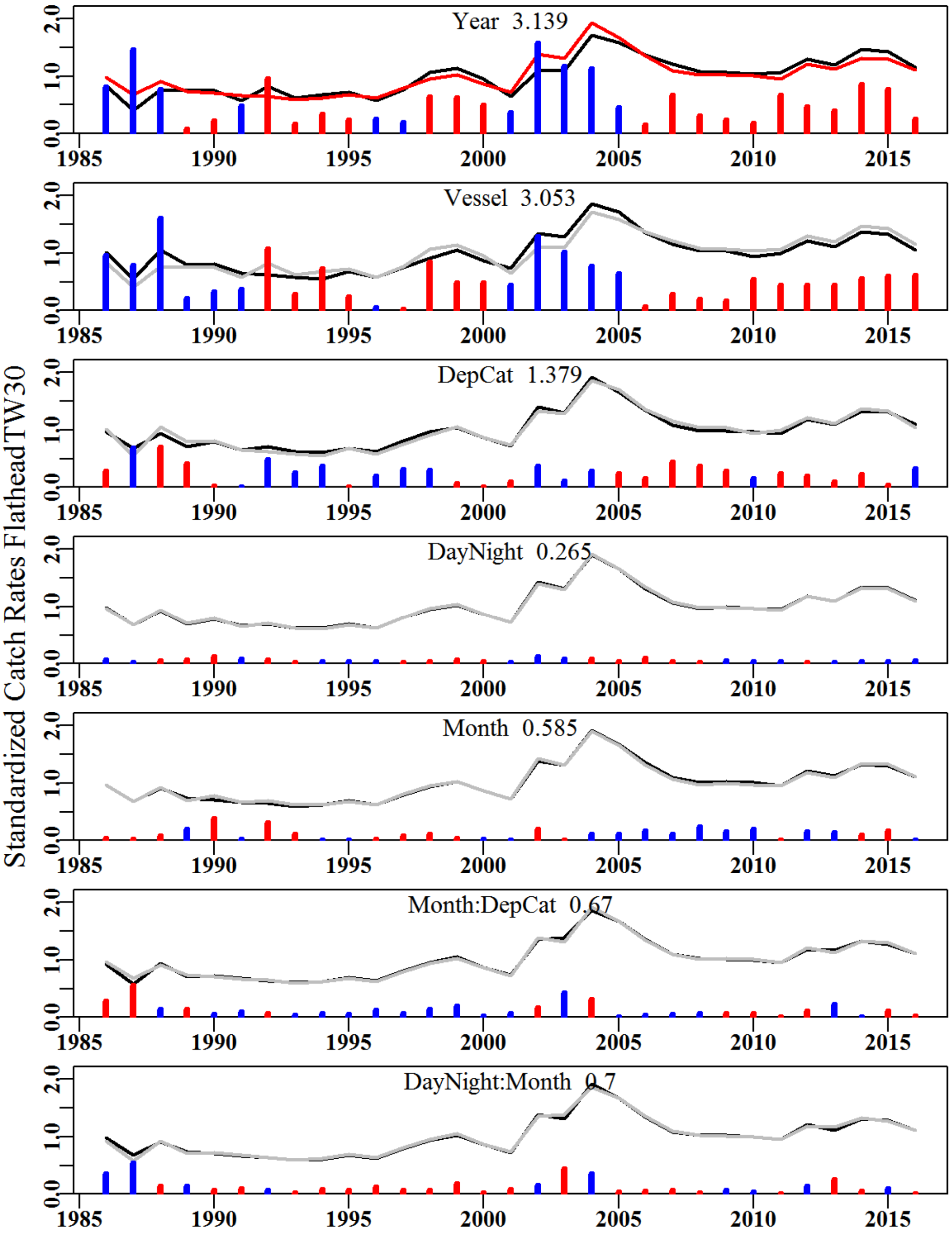


Figure 7.91. FlatheadTW30. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

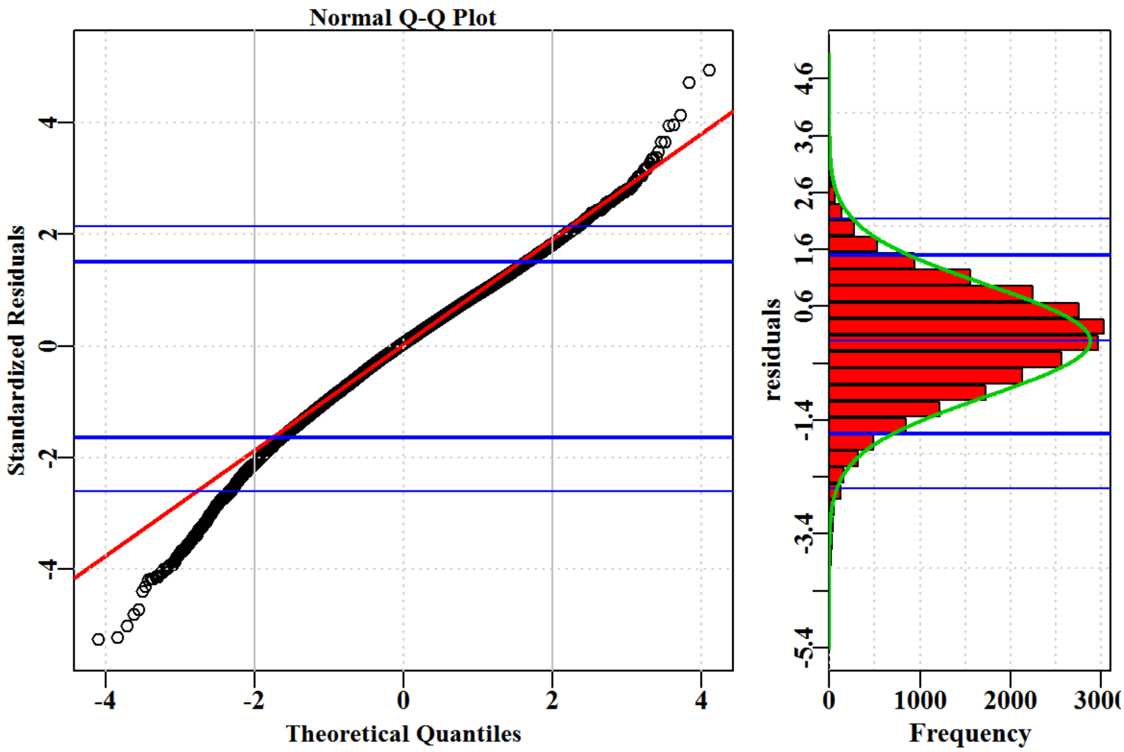


Figure 7.92. FlatheadTW30. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

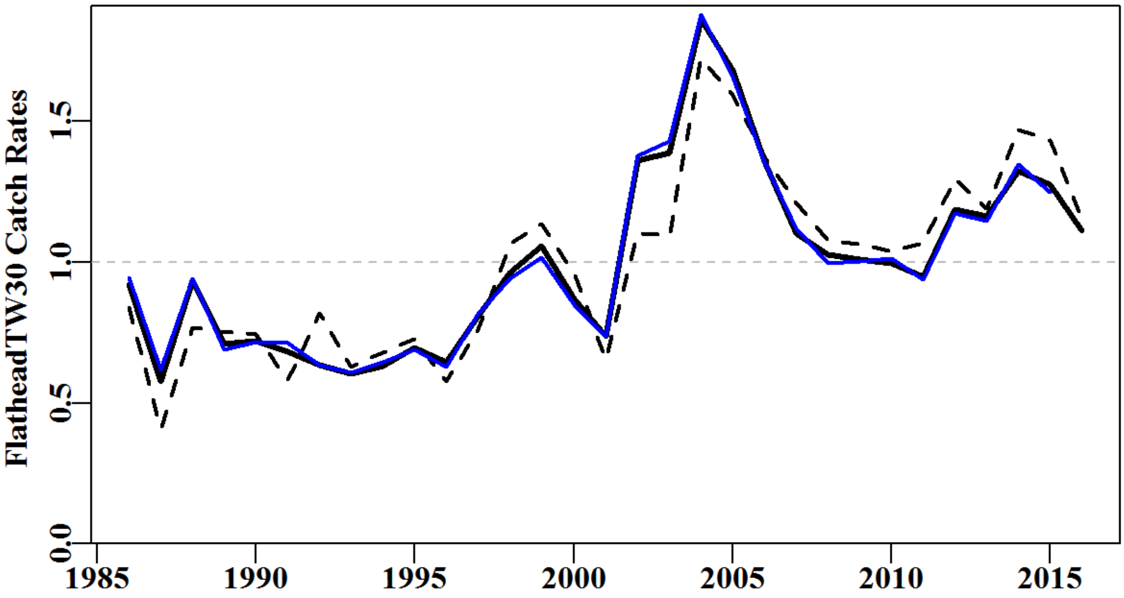


Figure 7.93. FlatheadTW30. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

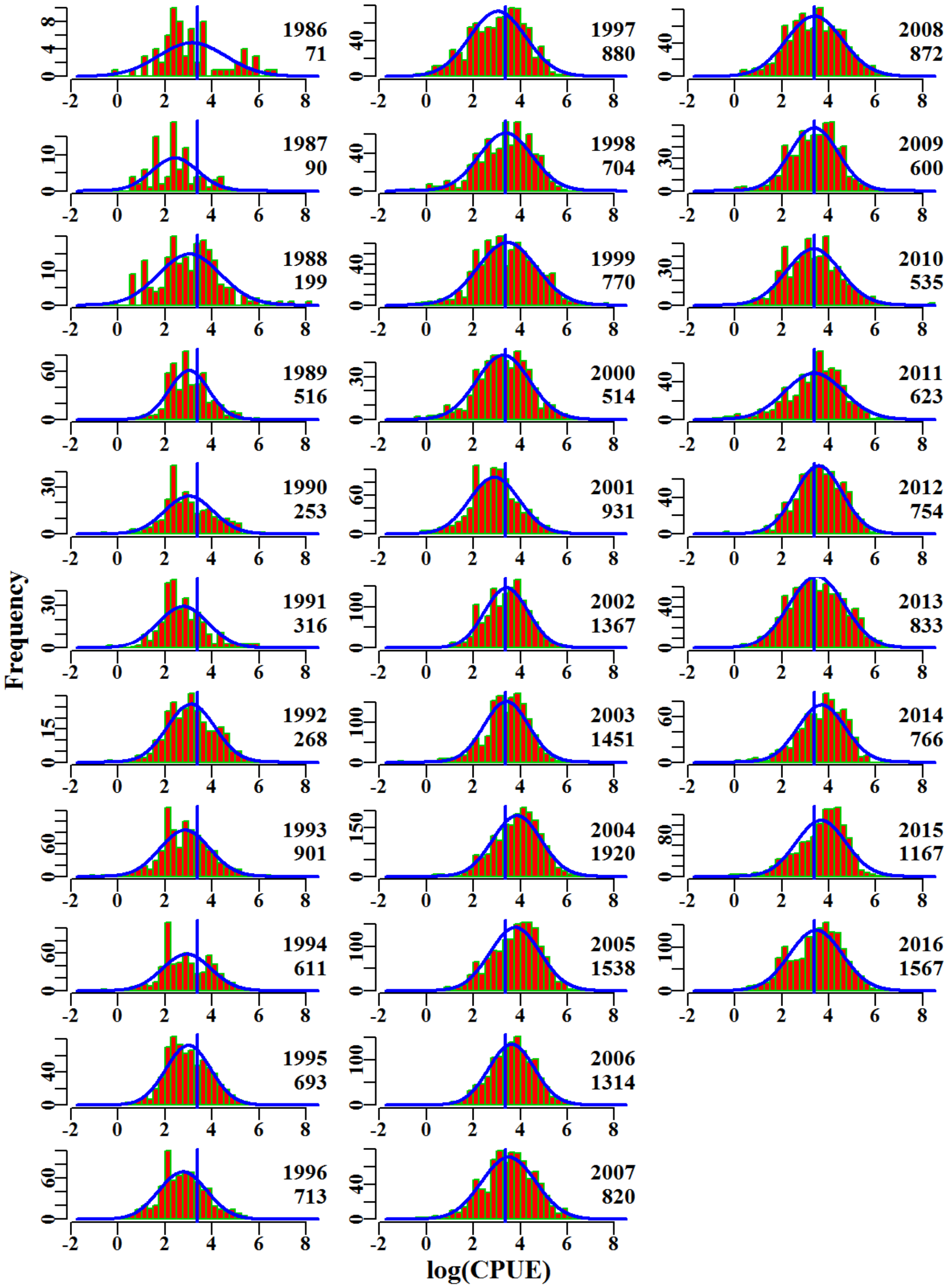


Figure 7.94. FlatheadTW30. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

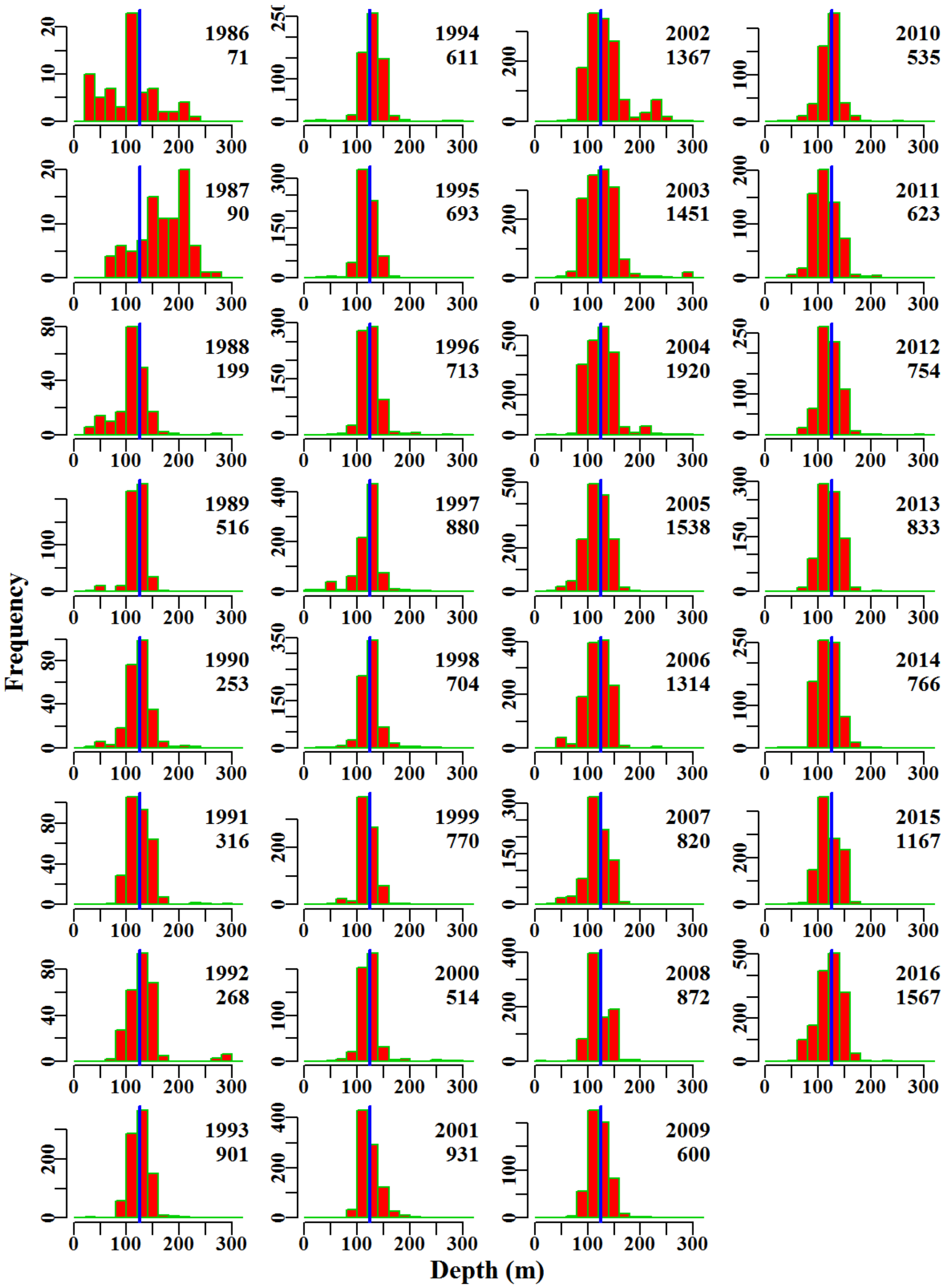


Figure 7.95. FlatheadTW30. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

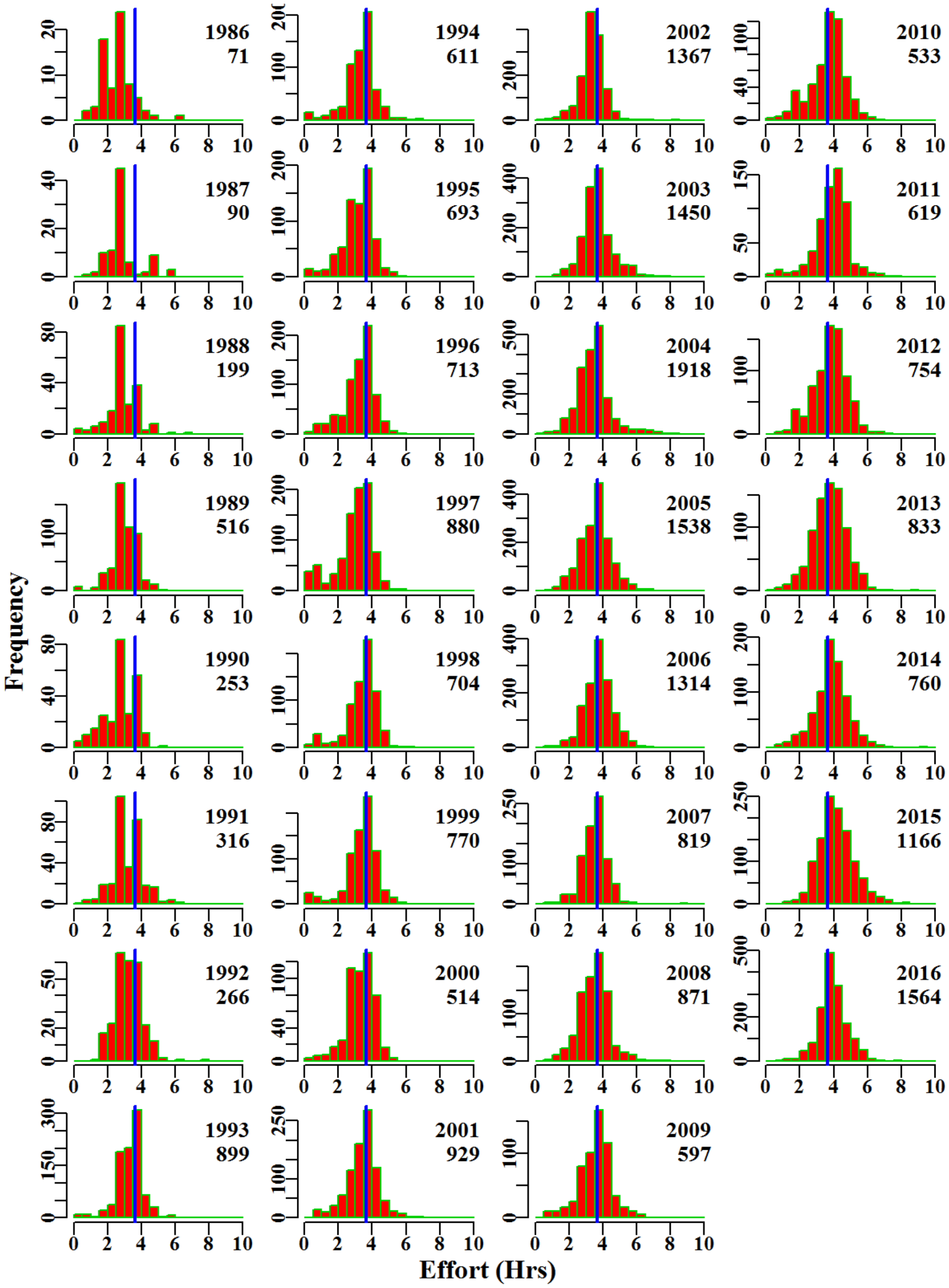


Figure 7.96. FlatheadTW30. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.16 Flathead TW 10 – 20

Tiger Flathead (FLT - 37296001 - *Neoplatycephalus richardsoni*) is one of the 16 species first included in the quota system in 1992. The additional generic flathead group code was added as a result of a change in recording Tiger Flathead as 37296000 (Platycephalidae) in electronic logbooks since 2013. The criteria used to select data from the Commonwealth logbook database (Table 7.65). A total of 8 statistical models were fitted sequentially to the available data.

7.16.1 *Inferences*

The amount of Flathead (*Neoplatycephalus richardsoni* and Platycephalidae) catch in shots <30 kg in zone 10 and 20 is small across the analysis period. Most Flathead were caught in zone 10 followed by 20.

The terms Year, Vessel and DepCat had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests a small departure of the assumed Normal distribution as depicted by the lower tail of the distribution (Figure 7.100).

Annual standardized CPUE appears cyclical above and below average and has remained above average since 2015 (Figure 7.97). The structural adjustment had a profound effect upon the influence of the vessel factor reducing the standardized trend well below the nominal geometric mean cpue.

7.16.2 *Actions Items and Issues*

After consideration of Tiger Flathead catches in the east by year and vessel for the period around 1992 - 2006 appears to be different from catches by vessel from 2007. This suggests that there have been transitional periods in the time-series of CPUE. This **urgently** needs more attention because of the potential implications this has for the index of relative abundance through time.

Table 7.61. FlatheadTW1020. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:DepCat.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	1911.4	10507	968.8	95	30.9	0.7878	0.000	68.003	0.070
1987	2471.7	8360	1011.4	88	40.7	1.0437	0.016	46.624	0.046
1988	2482.8	9471	1177.0	86	41.2	1.1229	0.015	50.432	0.043
1989	2609.0	9154	1214.7	74	43.6	1.1335	0.016	49.576	0.041
1990	2041.7	7883	1224.5	64	51.8	1.3715	0.016	29.056	0.024
1991	2236.2	7926	1147.2	57	51.4	1.2824	0.017	32.076	0.028
1992	2377.4	6961	905.0	54	43.8	1.0230	0.017	30.230	0.033
1993	1881.0	8816	994.2	57	38.6	1.0286	0.016	39.422	0.040
1994	1710.9	10254	900.3	55	29.9	0.7558	0.016	63.003	0.070
1995	1805.8	10286	990.9	54	31.6	0.7957	0.016	66.107	0.067
1996	1880.2	11070	957.4	59	29.2	0.7111	0.016	76.363	0.080
1997	2356.2	10396	996.7	61	31.1	0.7127	0.016	66.384	0.067
1998	2306.7	9995	999.7	52	32.5	0.7537	0.016	63.491	0.064
1999	3118.7	10398	1129.7	57	36.2	0.9116	0.016	57.195	0.051
2000	2947.8	12945	1646.3	60	51.7	0.9992	0.015	63.689	0.039
2001	2600.5	11733	1316.4	52	39.6	0.9655	0.015	53.347	0.041
2002	2876.8	12421	1451.9	49	39.2	1.0496	0.015	55.762	0.038
2003	3232.4	12952	1595.8	52	41.3	1.0355	0.015	59.555	0.037
2004	3227.4	12296	1344.3	52	36.2	0.8997	0.015	63.986	0.048
2005	2846.8	10729	1156.0	49	34.1	0.7743	0.016	63.230	0.055
2006	2586.0	9140	1148.9	46	40.3	0.9388	0.016	44.141	0.038
2007	2648.4	6336	1076.5	25	55.1	1.1416	0.018	22.021	0.020
2008	2913.1	7300	1330.8	27	56.4	1.1996	0.018	26.739	0.020
2009	2460.9	6311	1060.7	26	51.6	1.1079	0.018	22.526	0.021
2010	2502.3	6876	1124.4	25	49.0	1.0679	0.018	25.378	0.023
2011	2466.6	6777	1096.5	24	52.0	1.0506	0.018	24.333	0.022
2012	2780.8	6887	1162.5	25	54.3	1.1560	0.018	26.102	0.022
2013	1941.1	5643	689.5	24	37.4	0.8790	0.019	25.953	0.038
2014	2370.1	6361	945.9	25	46.0	1.0302	0.018	22.842	0.024
2015	2668.8	6387	987.7	30	48.3	1.1608	0.018	15.844	0.016
2016	2900.7	5451	845.7	27	50.4	1.1098	0.019	14.734	0.017

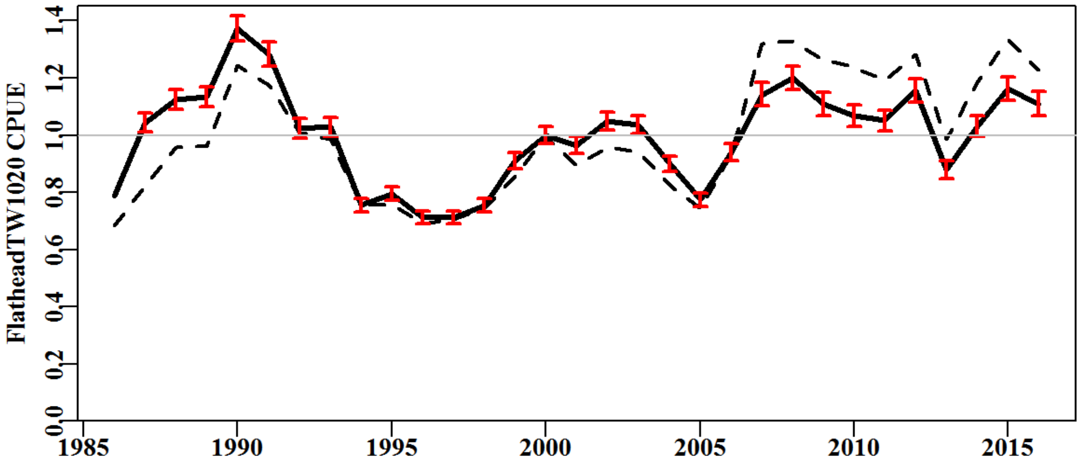


Figure 7.97. FlatheadTW1020 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

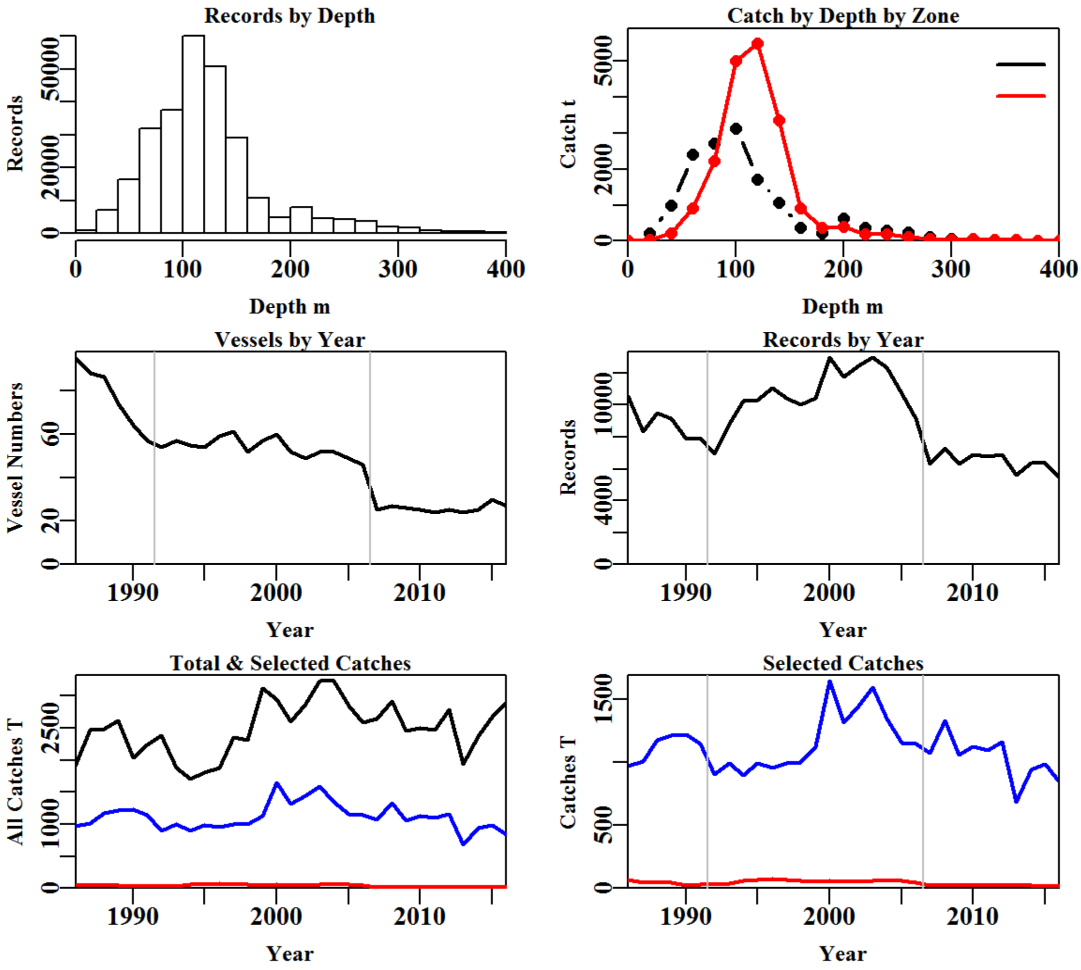


Figure 7.98. FlatheadTW1020 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.62. FlatheadTW1020 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	598651	510715	508758	500619	349350	278330	278022
Difference	0	87936	1957	8139	151269	71020	308

Table 7.63. The models used to analyse data for FlatheadTW1020.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + Month
Model5	Year + Vessel + DepCat + Month + DayNight
Model6	Year + Vessel + DepCat + Month + DayNight + Zone
Model7	Year + Vessel + DepCat + Month + DayNight + Zone + Zone:Month
Model8	Year + Vessel + DepCat + Month + DayNight + Zone + Zone:DepCat

Table 7.64. FlatheadTW1020. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:DepCat.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	46610	328693	11881	278022	31	3.5	0.00
Vessel	15561	293564	47011	278022	219	13.7	10.26
DepCat	6859	282321	58253	275862	237	16.4	2.69
Month	5925	281345	59230	275862	248	16.7	0.29
DayNight	5562	280969	59606	275862	251	16.8	0.11
Zone	5507	280911	59664	275862	252	16.8	0.02
Zone:Month	3261	278611	61964	275862	263	17.5	0.68
Zone:DepCat	2631	277957	62617	275862	272	17.7	0.87

Table 7.65. FlatheadTW1020. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	FlatheadTW1020
csirocode	37296001, 37296000
fishery	SET
depthrange	0 - 400
depthclass	20
zones	10, 20
methods	TW, TDO, OTT, TMO
years	1986 - 2016

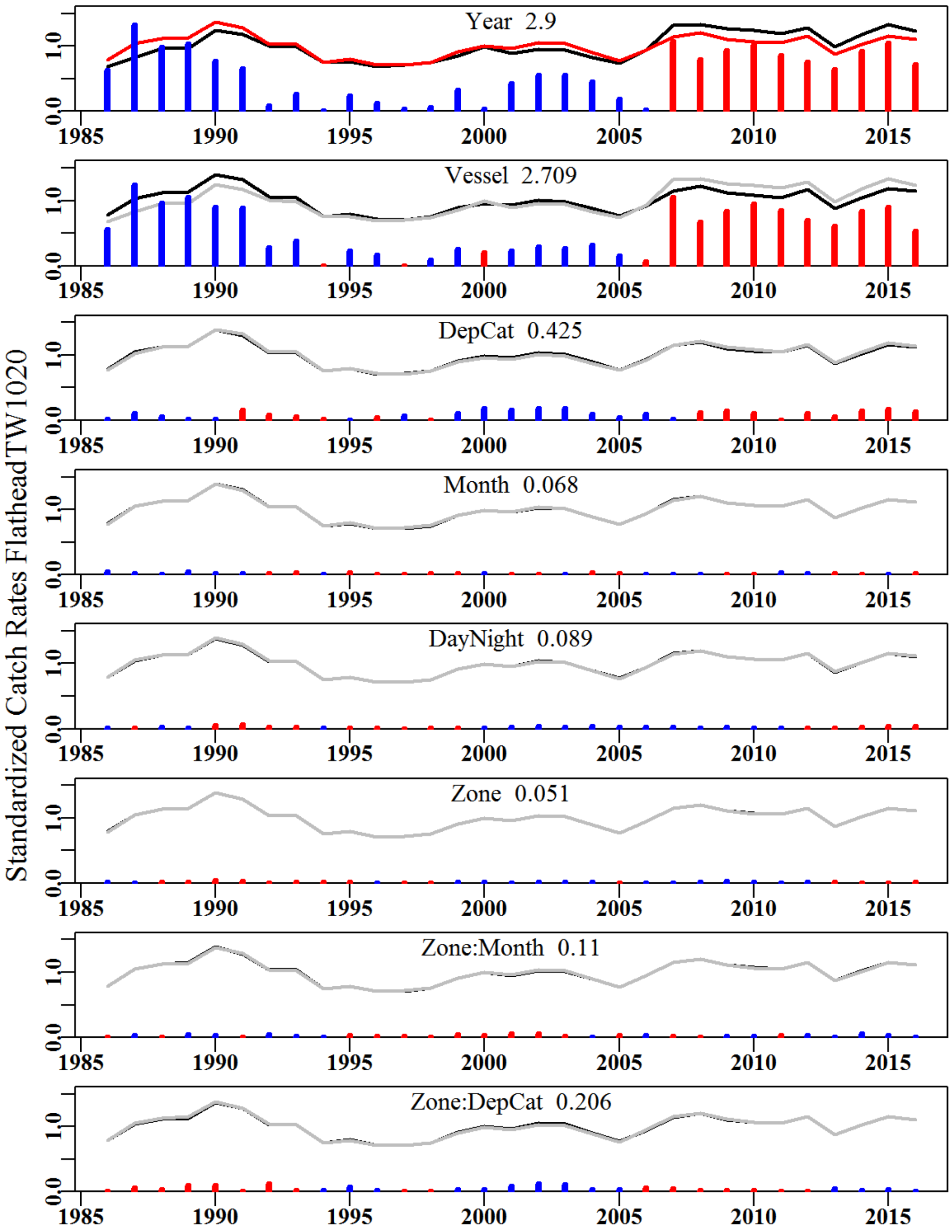


Figure 7.99. FlatheadTW1020. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

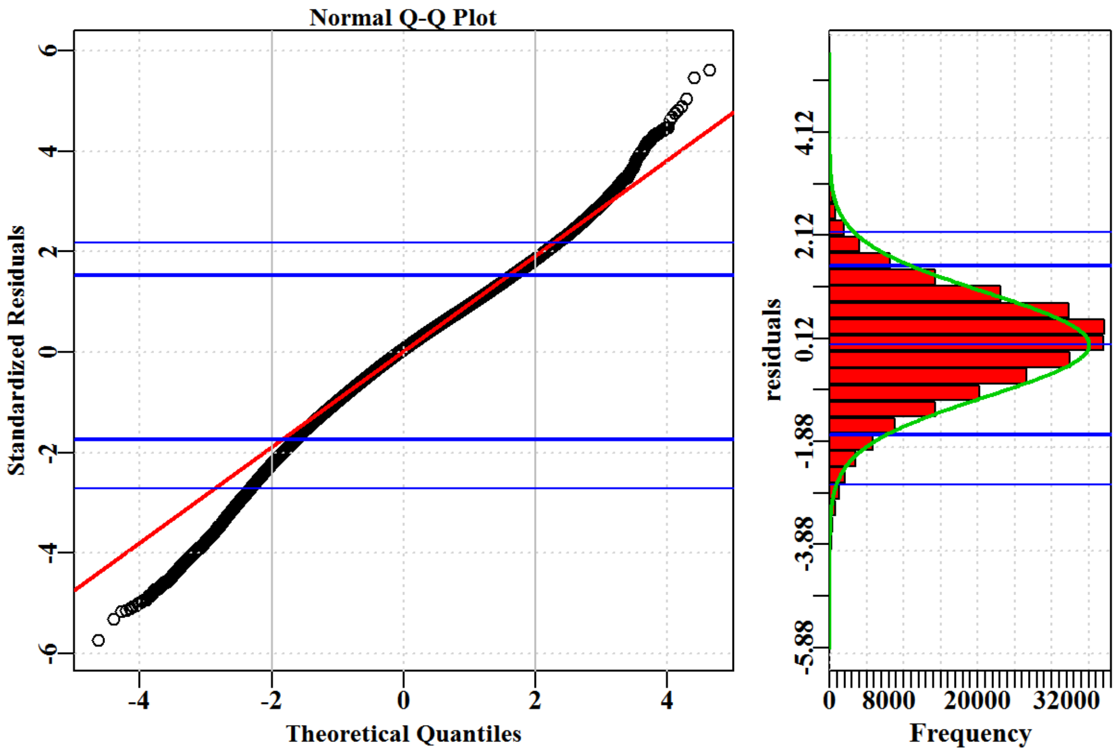


Figure 7.100. FlatheadTW1020. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

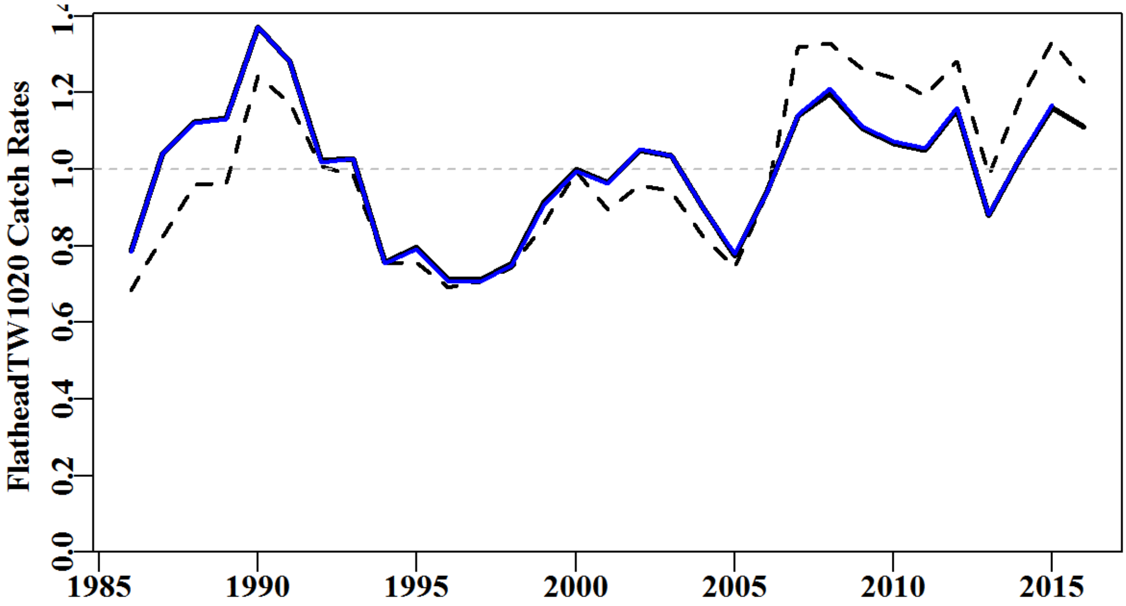


Figure 7.101. FlatheadTW1020. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

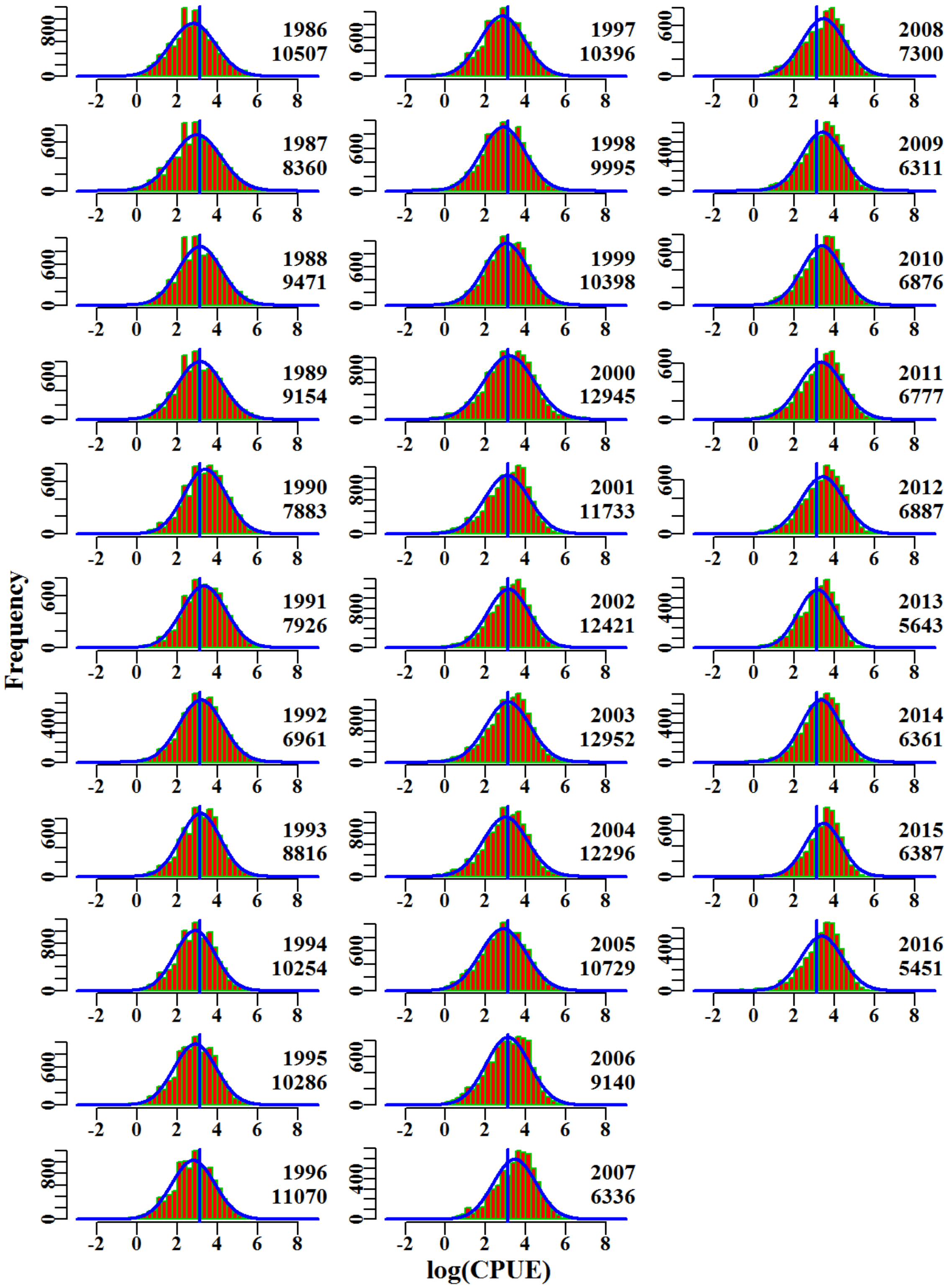


Figure 7.102. FlatheadTW1020. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

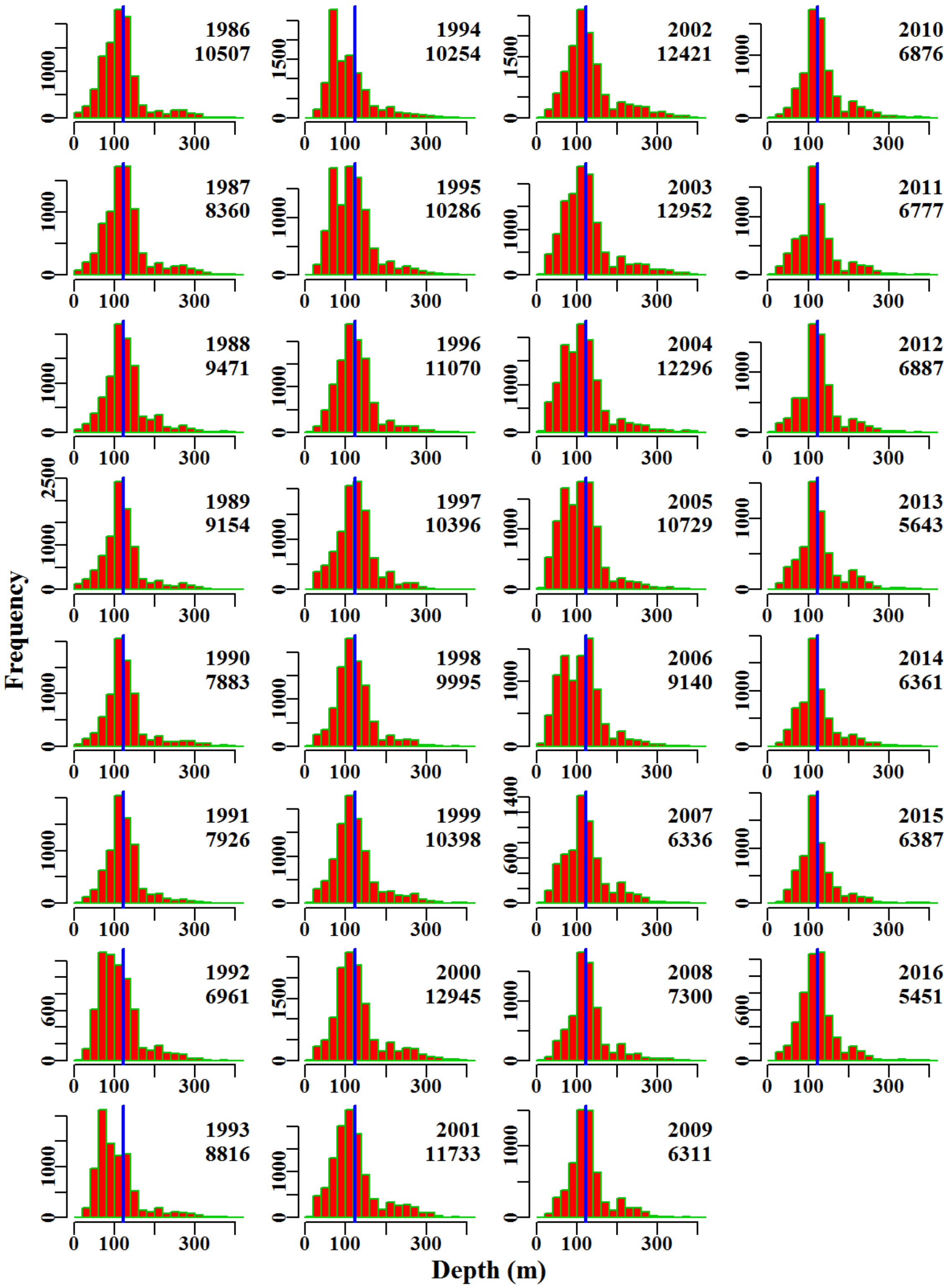


Figure 7.103. FlatheadTW1020. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

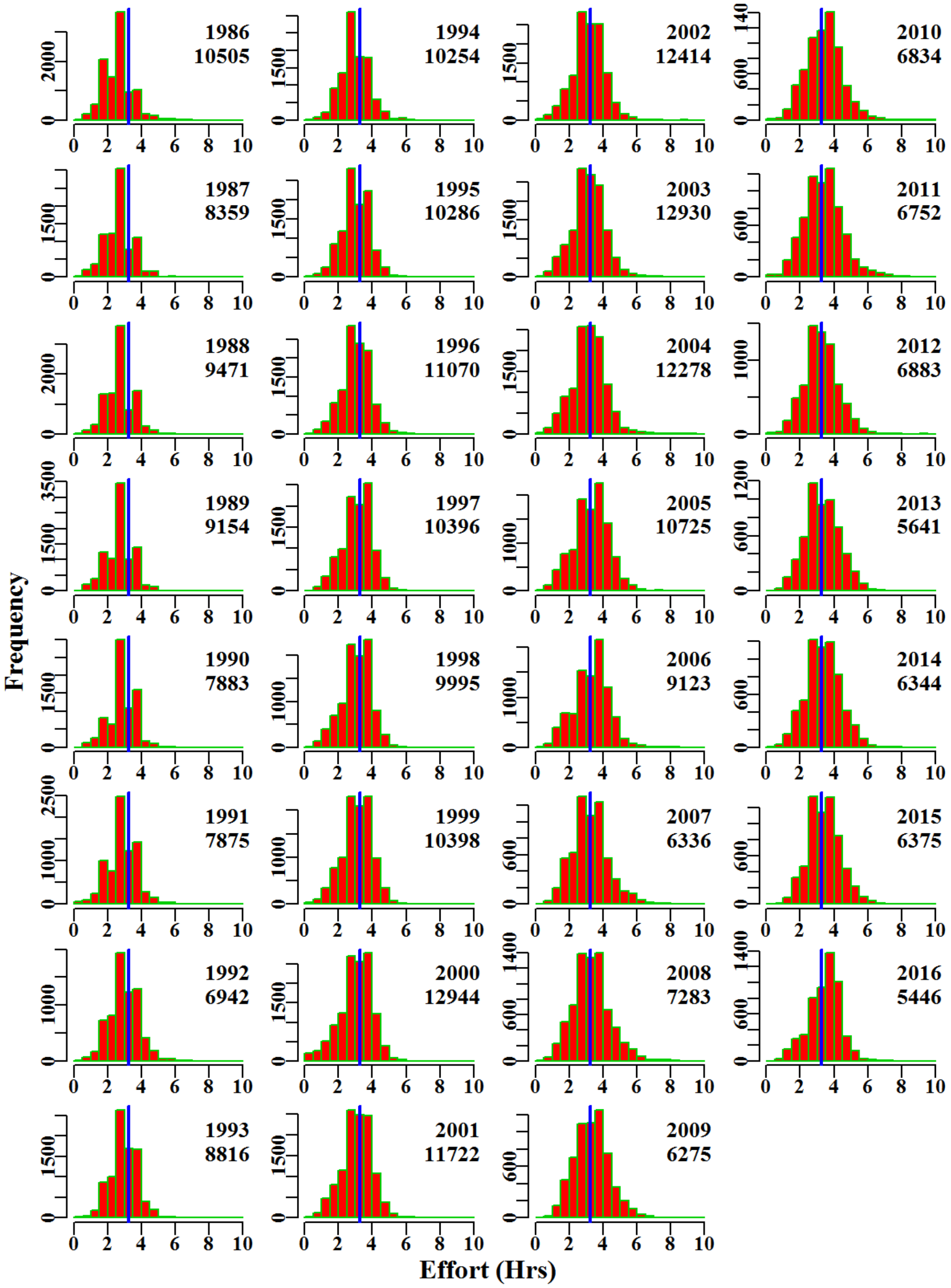


Figure 7.104. FlatheadTW1020. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.17 FlatheadDS2060

Tiger Flathead (FLT - 37296001 - *Neoplatycephalus richardsoni*) taken by Danish seine were analysed separately. The additional generic flathead group code was added as a result of a change in recording Tiger Flathead as 37296000 (Platycephalidae) in electronic logbooks since 2013. The criteria used to select data from the Commonwealth logbook database (Table 7.70). The CPUE was defined as catch/shot. A total of 8 statistical models were fitted sequentially to the available data, with the order of the non-interaction terms added based on the relative contribution of each term to model fit.

7.17.1 *Inferences*

Flathead (*Neoplatycephalus richardsoni* and Platycephalidae) taken by Danish Seine are caught in shallower depths in zone 60 compared to zone 20 (Figure 7.106), with a shift to deeper waters becoming apparent from 1997 onwards which may be related to which vessels were fishing.

The terms Year, DepCat, Month, Vessel, DayNight and one interaction term (Zone:Month) had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests a departure of the assumed Normal distribution as depicted by the lower tail of the distribution.

Some vessels have remained in this fishery since 1986 with significant catches, while other vessels have left following the structural adjustment in 2007 and not returned. Annual standardized CPUE appears cyclical above and below average and has remained above average since 2015 (Figure 7.105).

7.17.2 *Action Items and Issues*

It is recommended that an exploration of the fishery dynamics be evaluated to determine whether the CPUE values are being influenced by the species being targeted within individual shots (e.g. is there interference between shots catching mostly flathead comapred to shots catching mostly School Whiting?). This will be important for determining whether estimated annual indices adequately reflect stock abundance.

Table 7.66. FlatheadDS2060. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/shot), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	1911.4	5988	774.2	26	183.8	1.0467	0.000	31.641	0.041
1987	2471.7	5922	1373.2	23	336.8	1.4604	0.023	28.323	0.021
1988	2482.8	6171	1104.2	25	262.7	1.5557	0.022	25.018	0.023
1989	2609.0	5602	1147.2	27	289.4	1.4447	0.023	29.263	0.026
1990	2041.7	4778	588.8	25	150.6	1.0006	0.024	31.522	0.054
1991	2236.2	4741	777.4	28	215.8	1.3321	0.024	26.643	0.034
1992	2377.4	6674	1218.4	23	233.9	1.4242	0.022	28.867	0.024
1993	1881.0	6162	557.3	25	114.6	0.8982	0.023	41.900	0.075
1994	1710.9	7330	649.5	25	125.5	0.7720	0.022	41.557	0.064
1995	1805.8	5660	658.2	21	192.4	0.7869	0.023	27.413	0.042
1996	1880.2	7615	748.3	22	137.3	0.7376	0.022	45.519	0.061
1997	2356.2	8408	1149.9	20	193.6	0.9530	0.022	38.526	0.034
1998	2306.7	9876	1134.4	21	147.9	0.8060	0.021	48.421	0.043
1999	3118.7	8750	1702.1	23	269.1	1.1675	0.022	25.685	0.015
2000	2947.8	7354	1092.5	19	199.9	0.8619	0.022	32.650	0.030
2001	2600.5	7858	1084.5	19	196.9	0.8068	0.022	32.792	0.030
2002	2876.8	8218	1144.1	22	181.8	0.9543	0.022	31.619	0.028
2003	3232.4	9006	1210.2	23	168.6	0.9998	0.022	30.090	0.025
2004	3227.4	7784	1253.0	22	193.7	0.9831	0.022	25.558	0.020
2005	2846.8	7212	1125.8	22	183.9	0.9997	0.023	23.401	0.021
2006	2586.0	5563	968.1	21	232.4	0.9840	0.024	16.140	0.017
2007	2648.4	5551	1182.1	15	294.1	1.1890	0.024	15.157	0.013
2008	2913.1	6214	1283.5	15	280.3	1.0685	0.024	18.241	0.014
2009	2460.9	5499	1168.9	15	318.4	1.1048	0.024	18.171	0.016
2010	2502.3	6050	1167.4	15	273.9	0.9897	0.024	15.650	0.013
2011	2466.6	6889	1122.3	14	207.9	0.9221	0.023	20.987	0.019
2012	2780.8	7214	1382.3	14	298.8	0.8738	0.023	19.580	0.014
2013	1941.1	7265	937.0	14	168.8	0.6485	0.023	31.034	0.033
2014	2370.1	8374	1165.2	14	186.2	0.7089	0.023	33.164	0.028
2015	2668.8	8680	1324.3	15	196.3	0.7479	0.023	39.676	0.030
2016	2900.7	9293	1469.7	16	204.8	0.7719	0.022	41.165	0.028

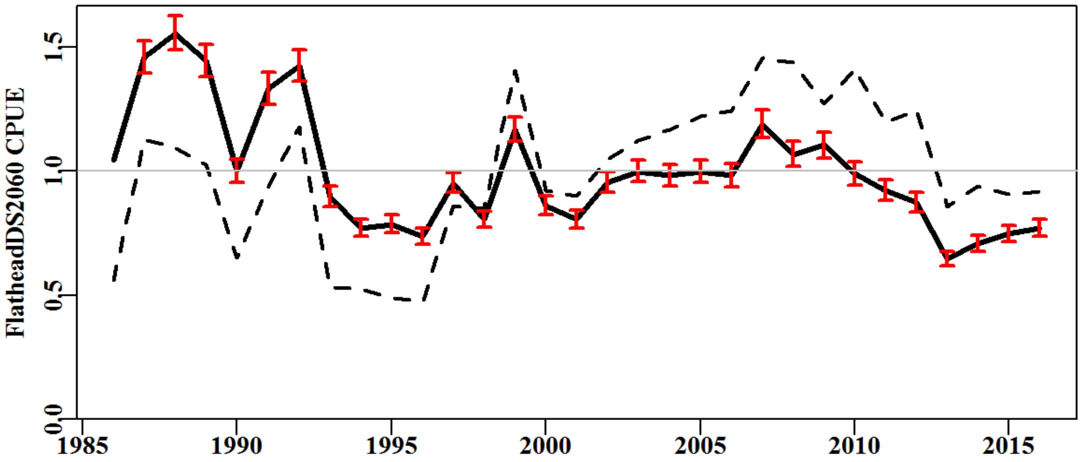


Figure 7.105. FlatheadDS2060 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

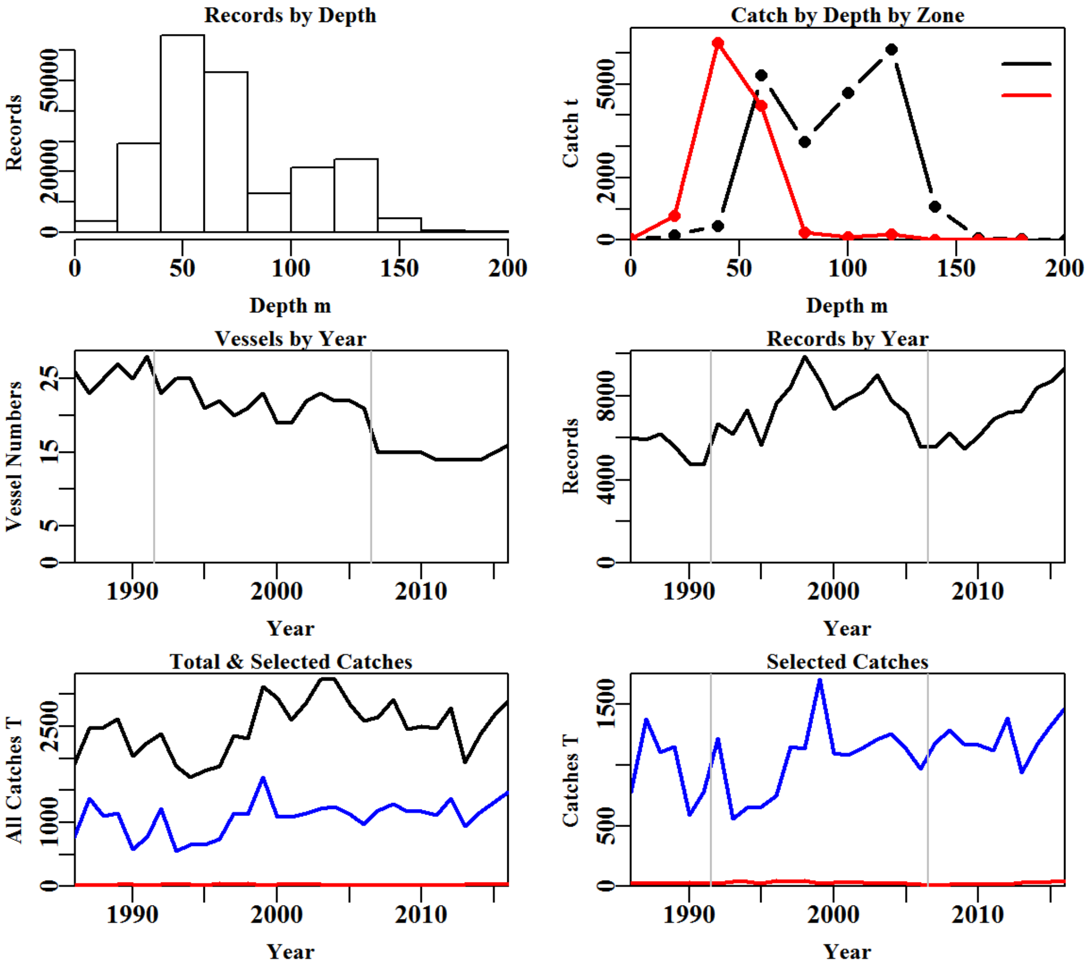


Figure 7.106. FlatheadDS2060 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.67. FlatheadDS2060 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	598651	587235	551784	543785	344786	219580	217701
Difference	0	11416	35451	7999	198999	125206	1879

Table 7.68. The models used to analyse data for FlatheadDS2060.

	Model
Model1	Year
Model2	Year + DepCat
Model3	Year + DepCat + Month
Model4	Year + DepCat + Month + Vessel
Model5	Year + DepCat + Month + Vessel + DayNight
Model6	Year + DepCat + Month + Vessel + DayNight + Zone
Model7	Year + DepCat + Month + Vessel + DayNight + Zone + Zone:Month
Model8	Year + DepCat + Month + Vessel + DayNight + Zone + Zone:DepCat

Table 7.69. FlatheadDS2060. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	169265	473593	21405	217701	31	4.3	0.00
DepCat	103143	346807	148191	214495	41	28.9	24.60
Month	92533	330036	164962	214495	52	32.3	3.43
Vessel	80768	312267	182731	214495	105	36.0	3.63
DayNight	76095	305529	189469	214495	108	37.4	1.38
Zone	73827	302312	192687	214495	109	38.0	0.66
Zone:Month	69605	296390	198609	214495	120	39.2	1.21
Zone:DepCat	72884	300961	194038	214495	118	38.3	0.27

Table 7.70. FlatheadDS2060. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	FlatheadDS2060
csirocode	37296001, 37296000
fishery	SET
depthrange	0 - 200
depthclass	20
zones	20, 60
methods	DS
years	1986 - 2016

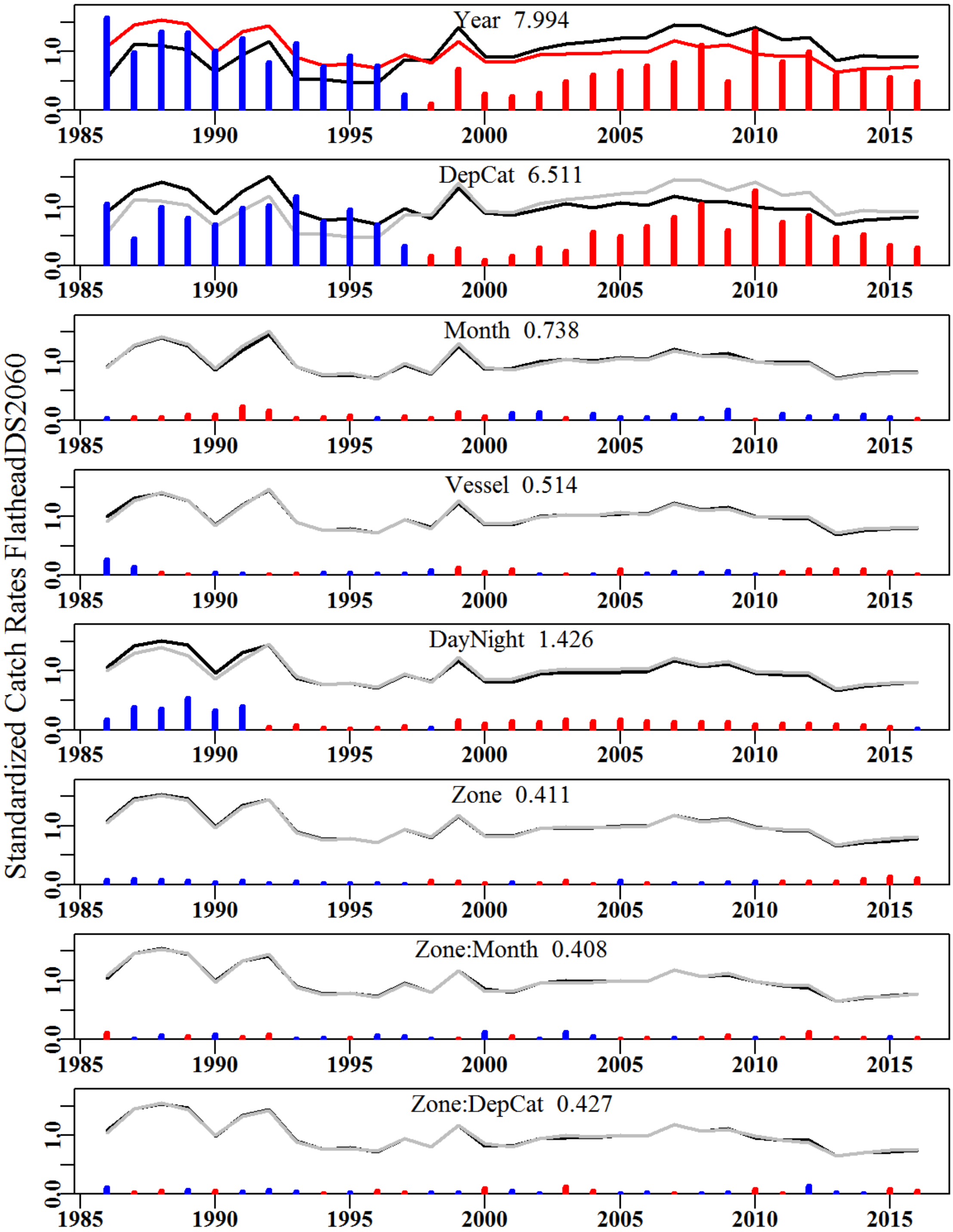


Figure 7.107. FlatheadDS2060. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

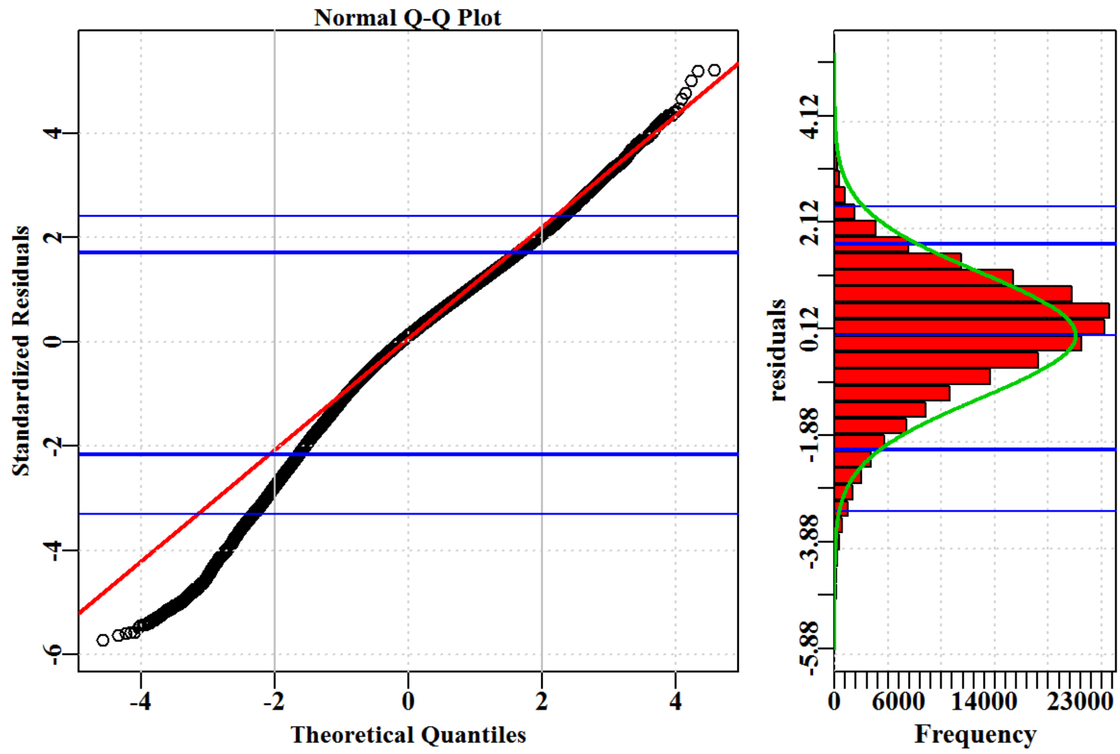


Figure 7.108. FlatheadDS2060. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

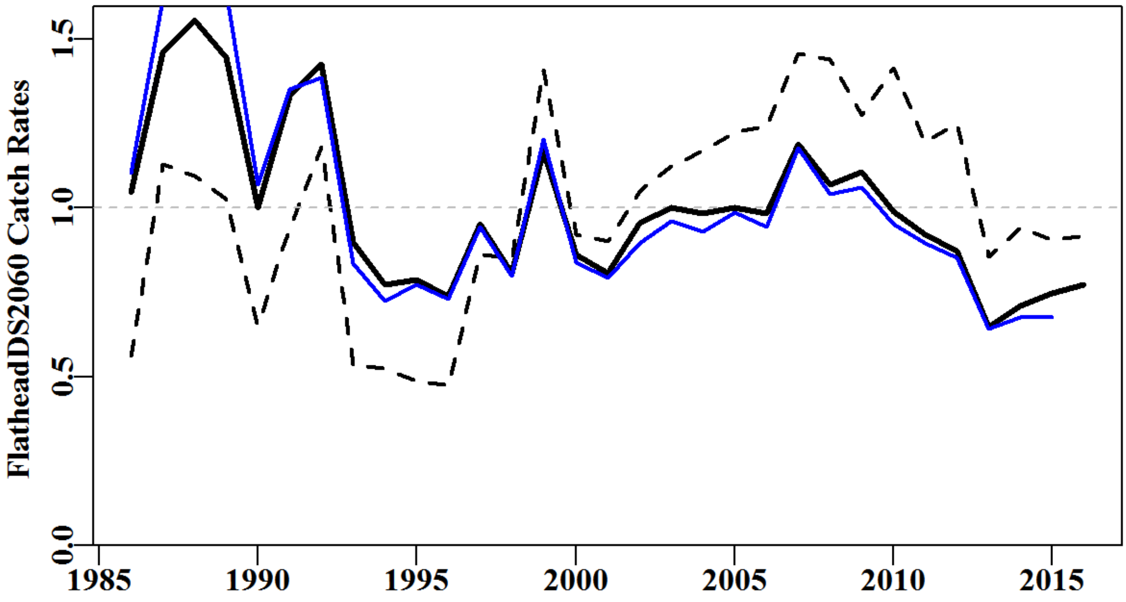


Figure 7.109. FlatheadDS2060. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

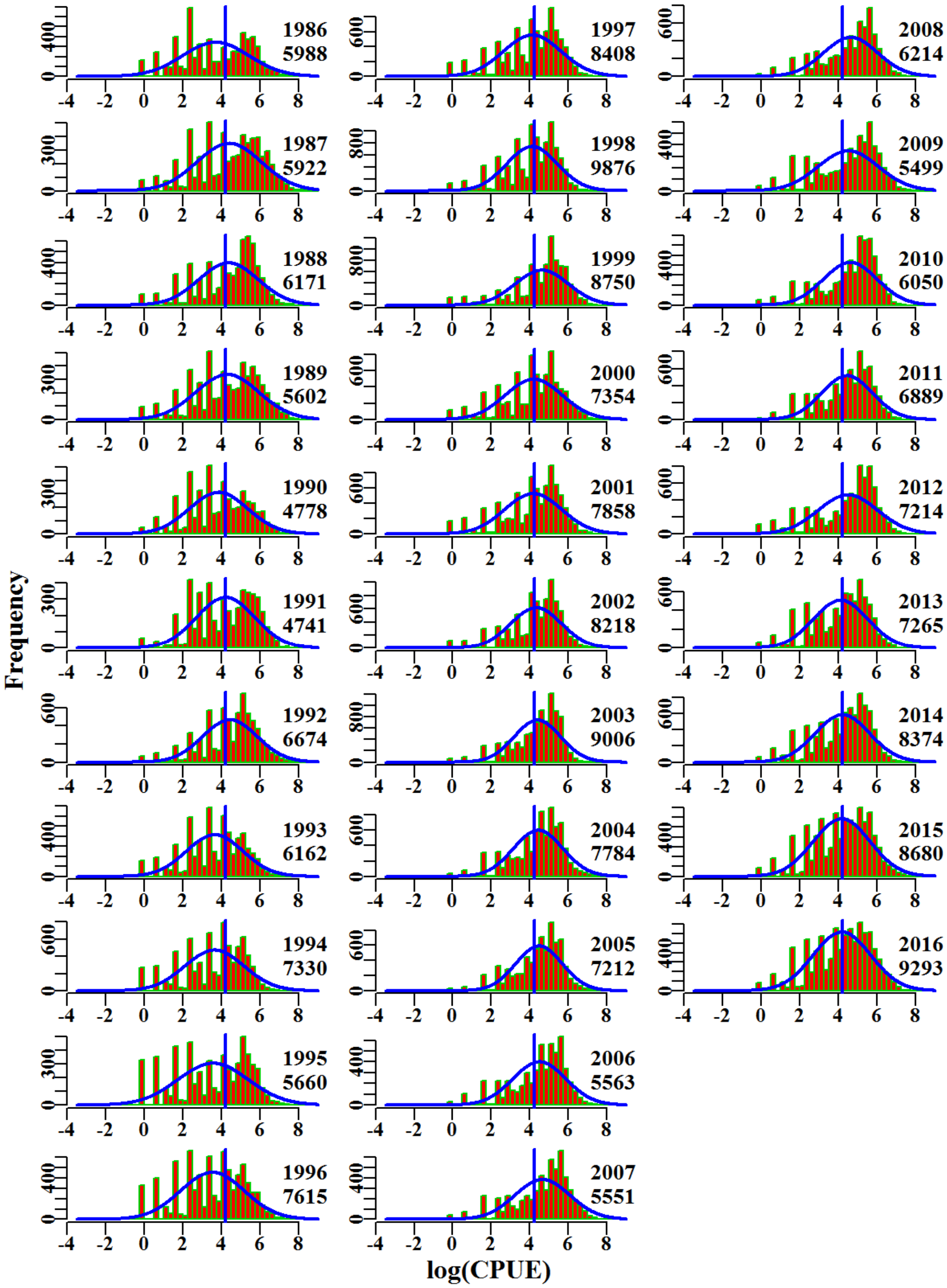


Figure 7.110. FlatheadDS2060. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

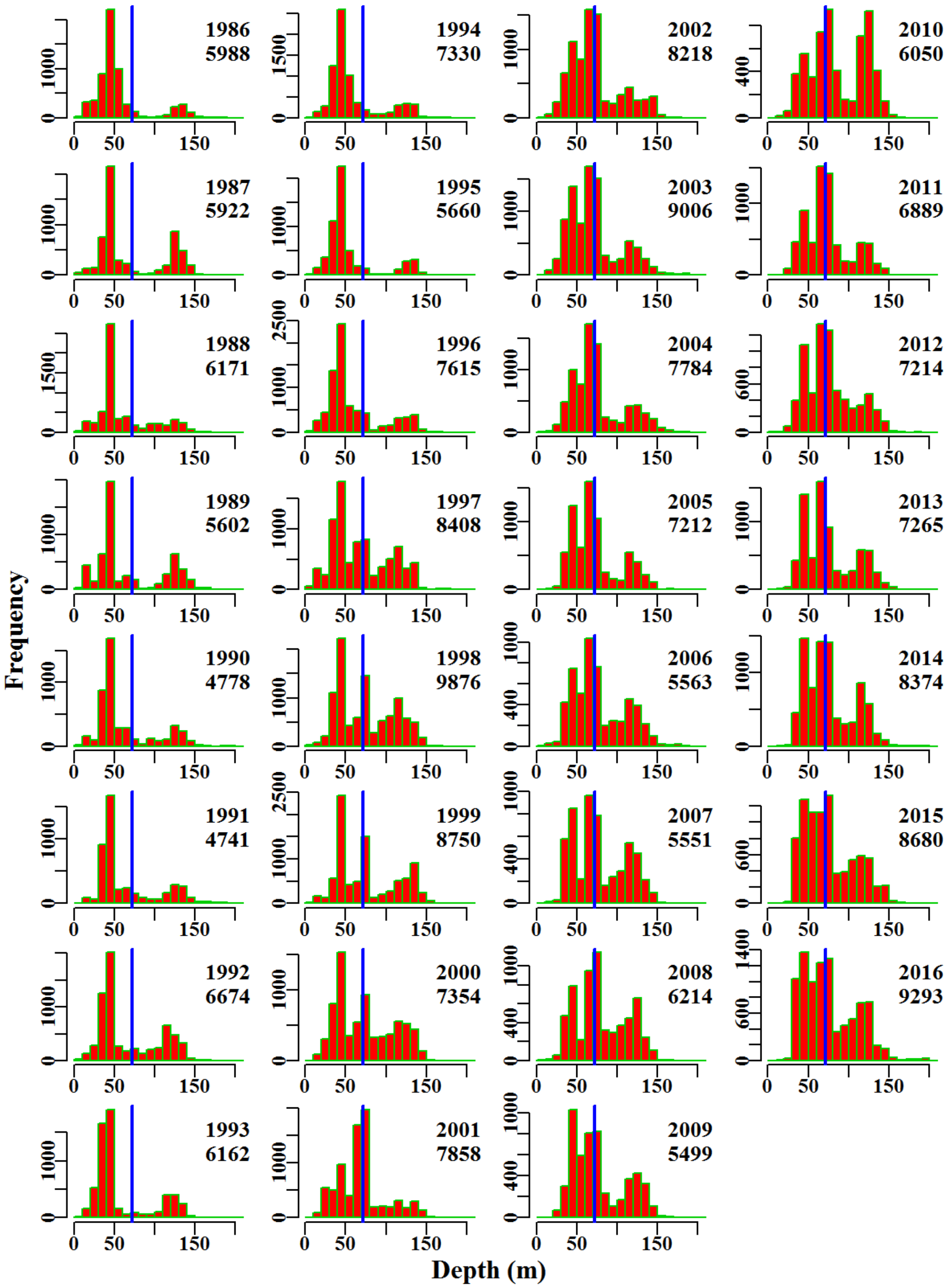


Figure 7.111. FlatheadDS2060. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.18 Redfish 10 – 20

Redfish (RED - 37258003 - *Centroberyx affinis*) is one of the 16 species first included in the quota system in 1992. Redfish caught by trawl based on methods TW, TDO, TMO, OTT, in zones 10, 20, and depths 0 to 400 within the SET fishery for the years 1986 - 2016 were used in the analysis (Table 7.75). A total of 8 statistical models were fitted sequentially to the available data.

7.18.1 *Inferences*

Most trawl caught Redifsh has occurred in zone 10 across the analysis period. The total annual redfish catch of 38 t in 2016 was less compared to the previous year (52 t) and the lowest recorded in the series (between 1986 - 2016). Large scale changes in CPUE have occurred through time coincident with large increases and decreases in catches. Annual standardized CPUE has declined since 1993 (Figure 7.112).

The terms Year, Vessel and DepCat had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests that the assumed Normal distribution is valid.

7.18.2 *Action Items and Issues*

After consideration of redfish catches in zones 10 and 20 by year and vessel, the period around 1993 - 2006 appears to be different to other years. This suggests that there have been transitional periods in the time-series of CPUE. This **urgently** needs more attention because of the potential implications this has for the index of relative abundance through time.

Table 7.71. Redfish1020. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:DepCat.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	1687.5	5338	1598.2	87	119.2	1.8113	0.000	23.189	0.015
1987	1252.7	3931	1185.4	79	120.5	1.5509	0.034	18.015	0.015
1988	1125.5	3972	1078.8	75	95.2	1.7370	0.034	17.757	0.016
1989	714.3	2723	644.4	72	80.0	1.2838	0.038	15.676	0.024
1990	931.4	2593	794.8	58	105.0	1.6201	0.039	11.844	0.015
1991	1570.6	3352	1238.0	52	140.5	1.7909	0.037	15.101	0.012
1992	1636.7	3207	1523.7	48	197.4	2.2476	0.038	14.361	0.009
1993	1921.3	3785	1767.6	53	205.7	2.7011	0.036	16.183	0.009
1994	1487.7	5477	1340.8	53	111.8	1.9919	0.034	28.374	0.021
1995	1240.6	5697	1195.7	52	82.5	1.2850	0.033	34.543	0.029
1996	1344.0	5805	1305.1	56	90.3	1.1629	0.033	33.987	0.026
1997	1397.3	4406	1354.0	58	139.1	1.2168	0.035	25.700	0.019
1998	1553.7	4309	1528.0	49	187.1	1.4331	0.035	23.686	0.016
1999	1116.5	3943	1091.8	53	145.7	1.2014	0.036	21.228	0.019
2000	758.5	4668	737.1	53	80.5	0.8027	0.035	29.017	0.039
2001	742.3	4576	725.5	47	76.7	0.7616	0.035	29.042	0.040
2002	807.1	5215	774.5	49	69.7	0.7096	0.034	32.828	0.042
2003	615.6	4119	555.9	51	62.6	0.6066	0.036	27.665	0.050
2004	475.2	3965	449.4	50	52.1	0.5403	0.036	27.119	0.060
2005	483.5	3796	453.2	46	47.3	0.6014	0.037	26.873	0.059
2006	325.5	2589	302.7	42	46.0	0.5597	0.040	19.924	0.066
2007	216.3	1880	209.0	23	46.8	0.5545	0.045	13.478	0.064
2008	183.8	1932	179.8	25	35.2	0.4904	0.045	15.482	0.086
2009	160.5	1619	154.3	23	33.4	0.4193	0.048	12.878	0.083
2010	152.8	1871	147.5	24	28.6	0.4076	0.046	16.190	0.110
2011	87.3	1408	84.1	22	21.9	0.2974	0.050	10.905	0.130
2012	66.4	1354	62.3	21	18.2	0.2090	0.050	11.216	0.180
2013	62.7	1137	60.4	20	20.0	0.2654	0.053	9.879	0.163
2014	86.9	1416	82.9	22	25.9	0.3562	0.049	11.944	0.144
2015	52.2	1197	50.0	22	17.4	0.2191	0.053	10.131	0.203
2016	38.4	782	24.3	21	11.7	0.1651	0.063	6.324	0.260

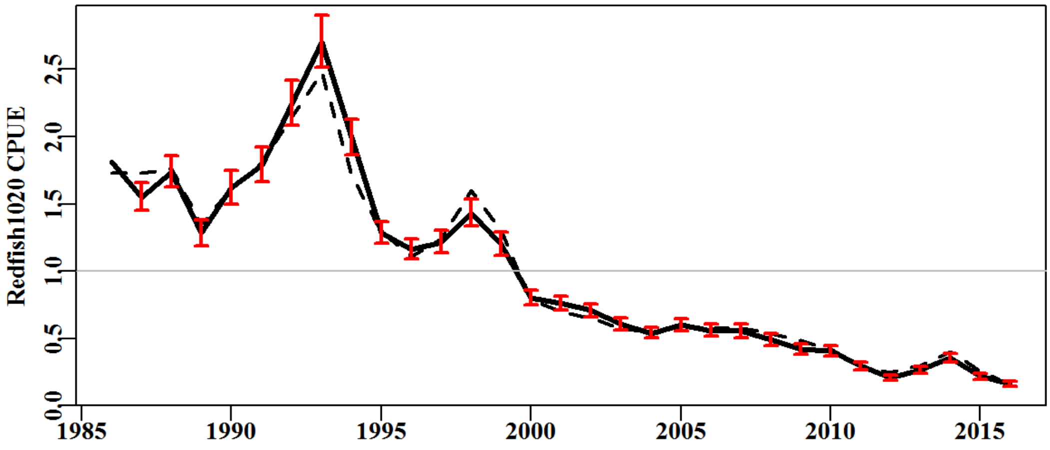


Figure 7.112. Redfish1020 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

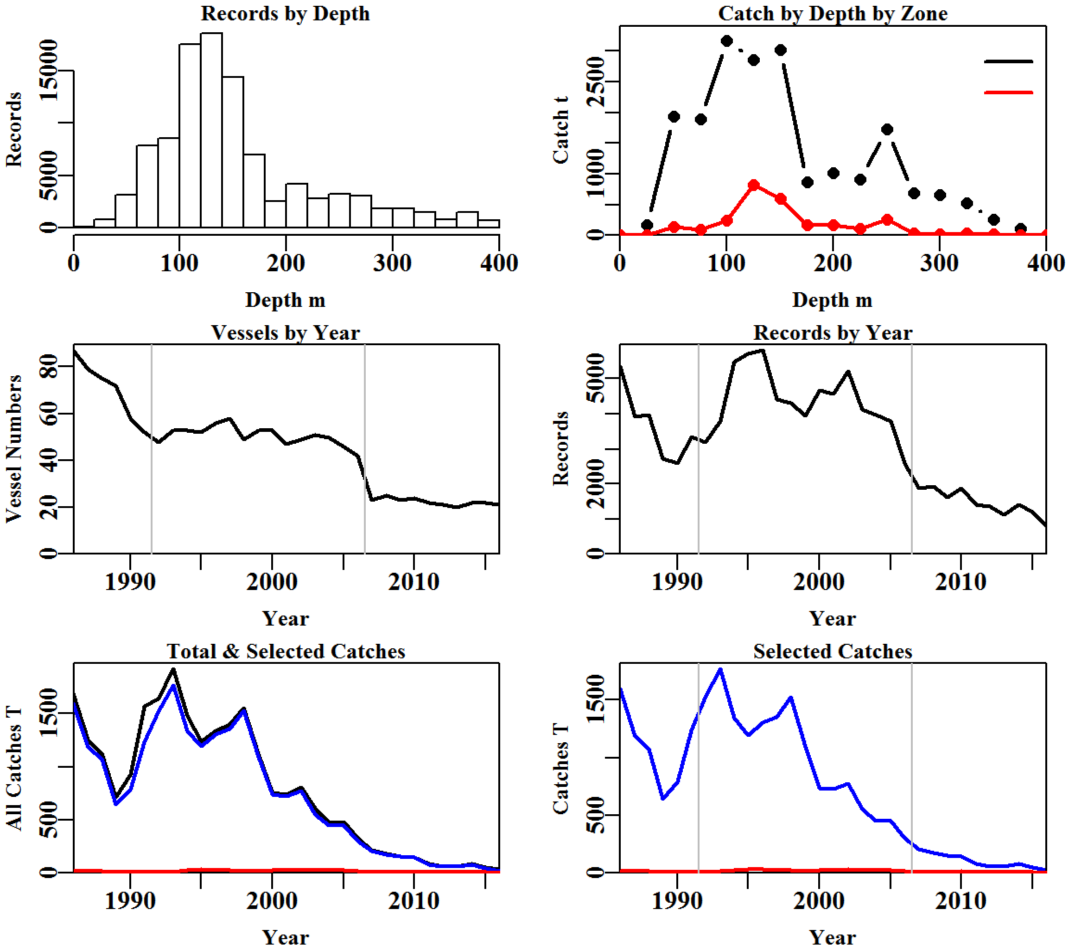


Figure 7.113. Redfish1020 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.72. Redfish1020 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	118227	112455	110011	109008	103157	102110	102062
Difference	0	5772	2444	1003	5851	1047	48

Table 7.73. The models used to analyse data for Redfish1020.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + Zone
Model5	Year + Vessel + DepCat + Zone + DayNight
Model6	Year + Vessel + DepCat + Zone + DayNight + Month
Model7	Year + Vessel + DepCat + Zone + DayNight + Month + Zone:Month
Model8	Year + Vessel + DepCat + Zone + DayNight + Month + Zone:DepCat

Table 7.74. Redfish1020. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:DepCat.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	110895	302331	36754	102062	31	10.8	0.00
Vessel	93494	254152	84932	102062	189	24.9	14.10
DepCat	87632	239703	99381	101505	205	28.7	3.83
Zone	86358	236707	102377	101505	206	29.6	0.89
DayNight	85702	235169	103915	101505	209	30.1	0.46
Month	85350	234305	104779	101505	220	30.3	0.25
Zone:Month	85223	233961	105123	101505	231	30.4	0.09
Zone:DepCat	84953	233315	105769	101505	236	30.6	0.28

Table 7.75. Redfish1020. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	Redfish1020
csirocode	37258003
fishery	SET
depthrange	0 - 400
depthclass	25
zones	10, 20
methods	TW, TDO, TMO, OTT
years	1986 - 2016

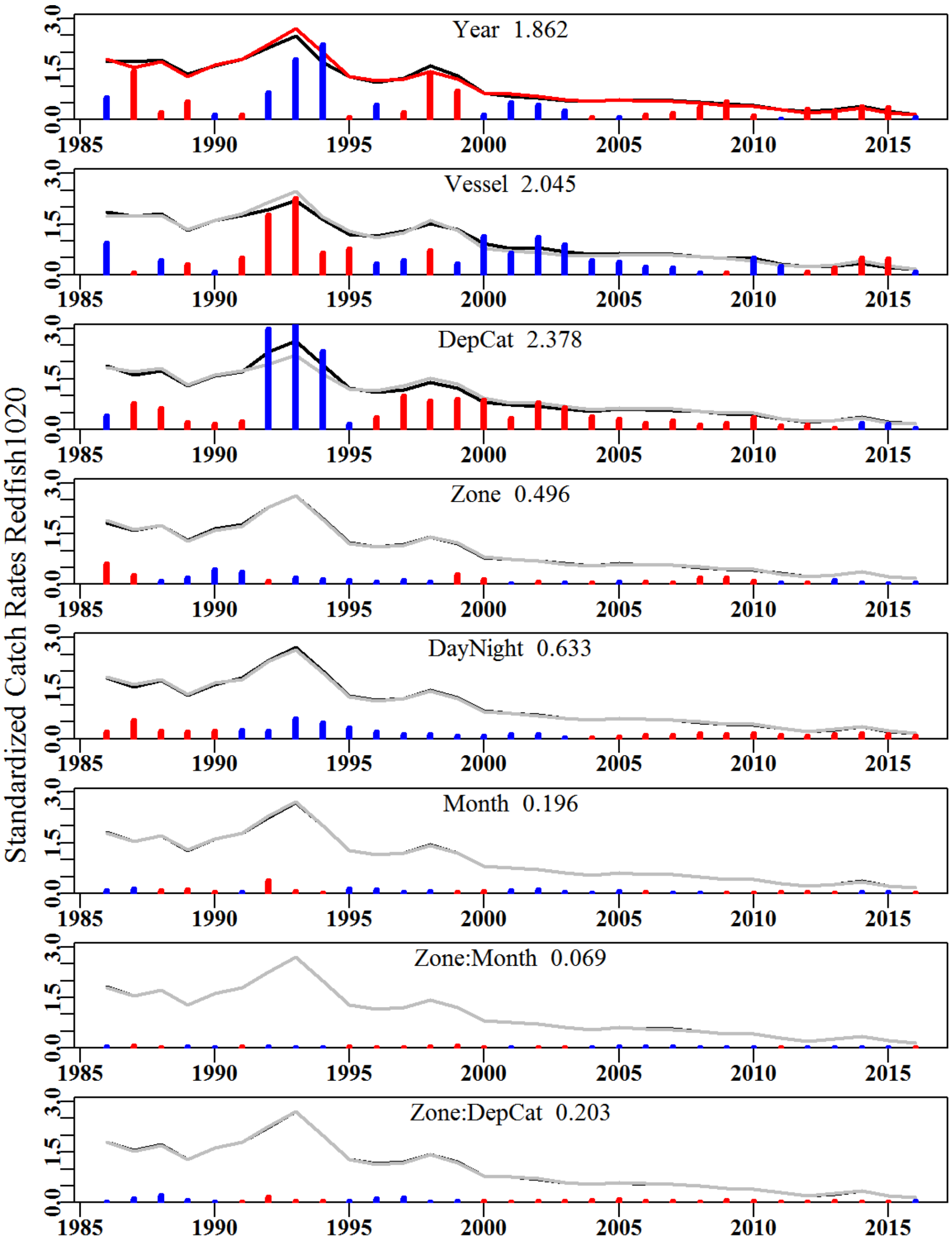


Figure 7.114. Redfish1020. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

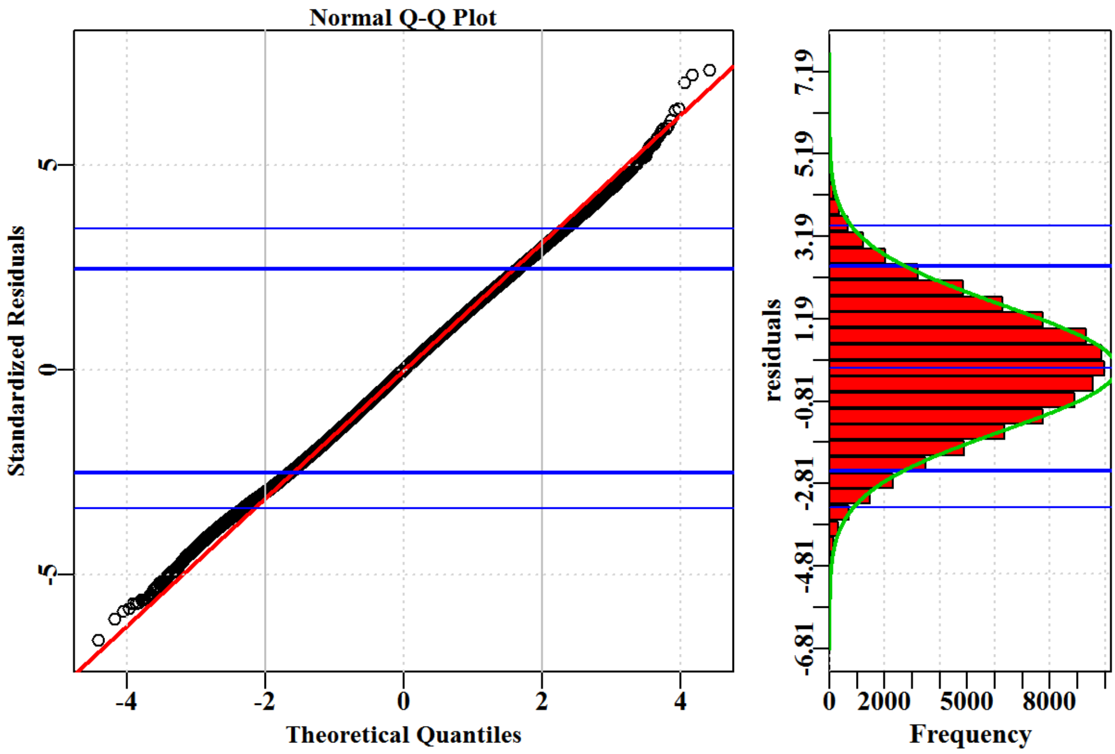


Figure 7.115. Redfish1020. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

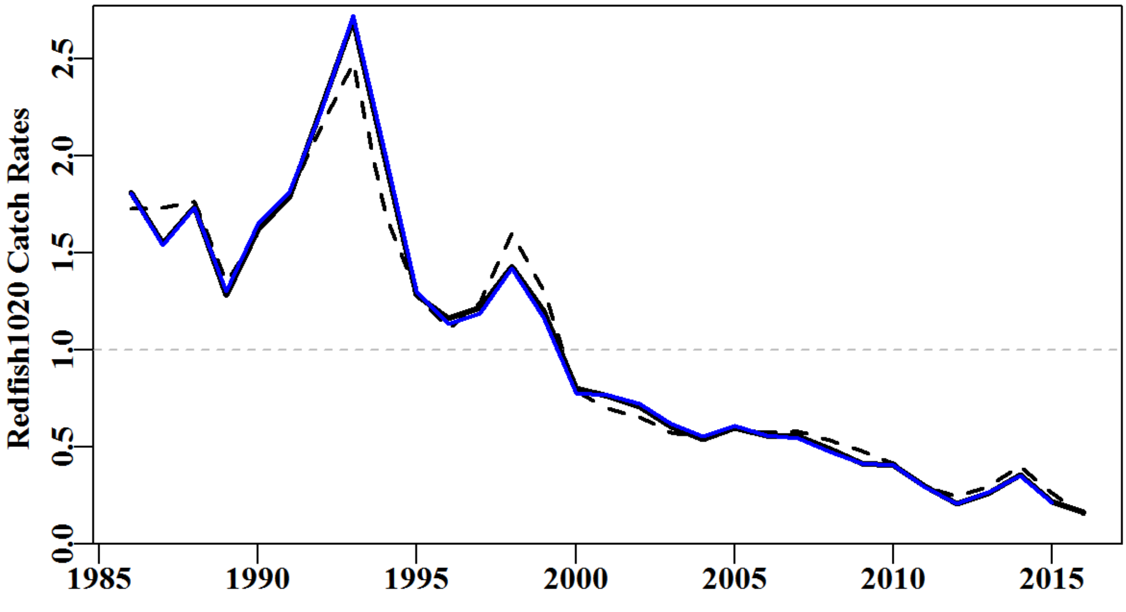


Figure 7.116. Redfish1020. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

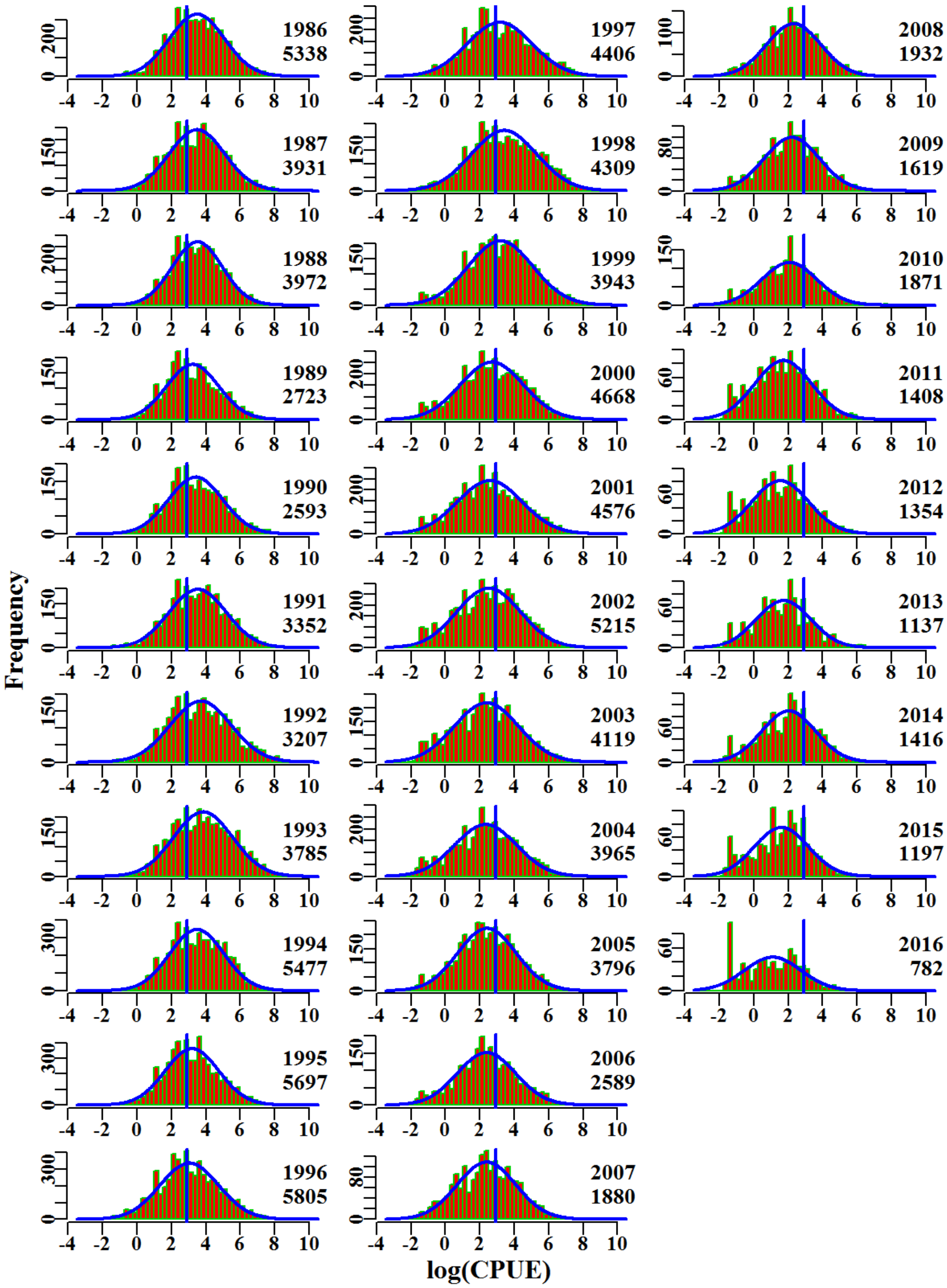


Figure 7.117. Redfish1020. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

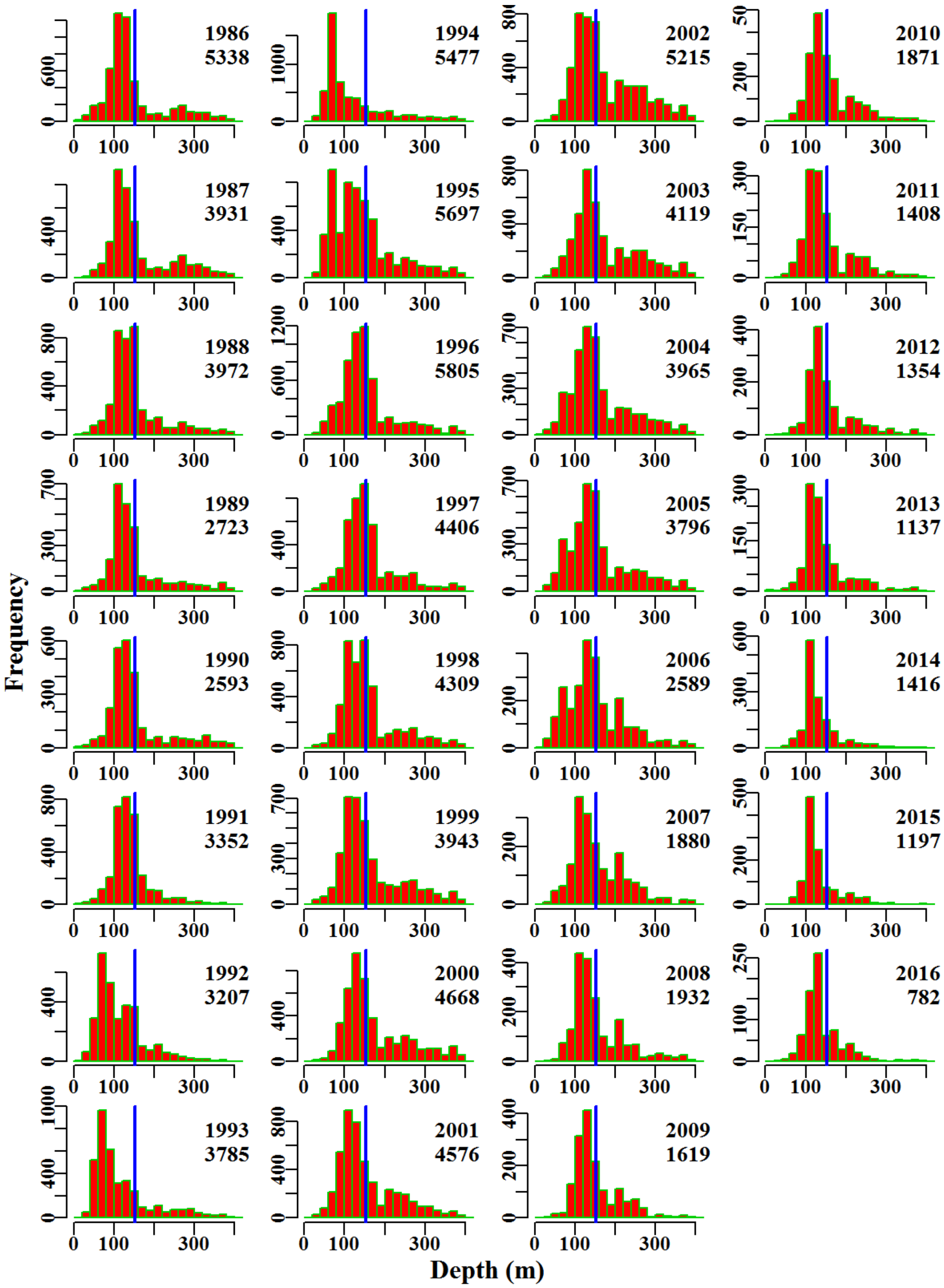


Figure 7.118. Redfish1020. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

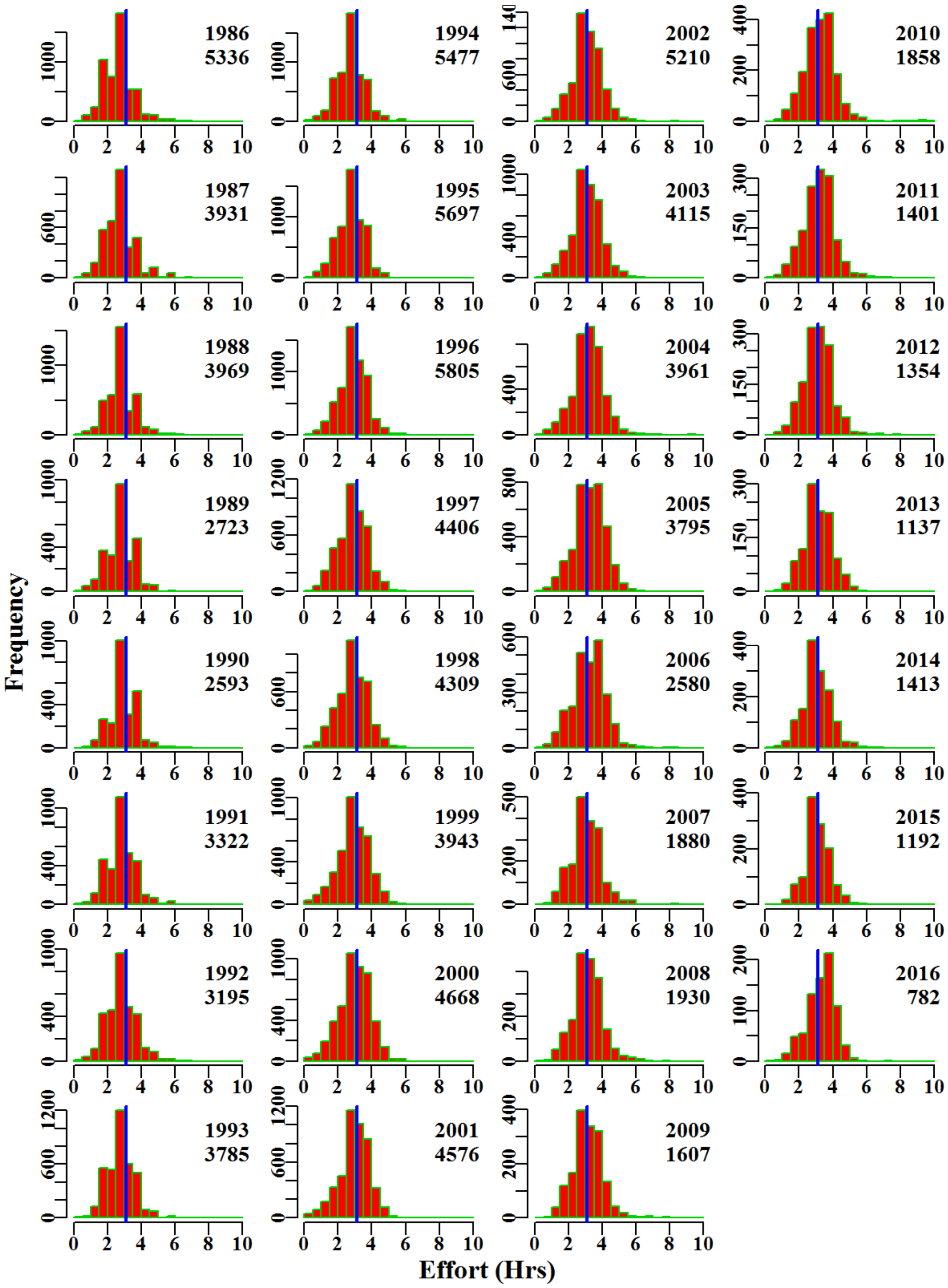


Figure 7.119. Redfish1020. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.19 Blue-Eye Trevalla TW 2030

Blue-Eye Trevalla (TBE - 37445001 - *Hyperoglyphe antarctica*) was one of the 16 species first included in the quota system in 1992, which reflects its long history within the SESSF. Trawl caught Blue-Eye Trevalla based on methods TW, TDO, in zones 20, 30, and depths 0 to 1000 within the SET fishery for the years 1986 - 2016 were used in the analysis. Recently, Ocean Blue-Eye Trevalla (37445014 - *Schedophilus labyrinthicus*) was also included in this analysis. Schedophilus labyrinthicusThese constitute the criteria used to select data from the Commonwealth logbook database (Table 7.80). A total of 8 statistical models were fitted sequentially to the available data.

7.19.1 *Inferences*

Catches average about 30 t per year and appear to change relative to availability rather than the influence of the trawl fishery on the stock. Over the period when CPUE was lower than average (about 1996 - 2006) there was an increase in small shots of < 30kg (Figure 7.121), which is suggestive of either low availability of high levels of small fish.

The terms Year, Vessel and Zone had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests a departure from that the assumed Normal distribution as depicted by the tails of the distribution (Figure 7.123).

Annual standardized CPUE have been below average since about 1996 and relatively flat trend (Figure 7.120). Very few vessels now contribute signifianct catches by trawl and the catch rate distributions are no longer even approximately normal.

7.19.2 *Action Items and Issues*

Given the on-going low catches, and the recent even lower catches, the major changes in the fleet contributing to the fishery, the dramatically changing caharater os the CPUE data itself, and the recent disjunction between the nominal catch rates and the stanadardized catch rates it is questionable whether this time-series of CPUE is indicative in any useful way of the relative abundance of Blue-Eye Trevalla. Whether this analysis should be continued should be considered.

Table 7.76. BlueEyeTW2030. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:DepCat.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	38.0	166	9.1	17	21.9	2.2855	0.000	1.453	0.159
1987	15.5	190	10.0	14	17.6	2.1760	0.137	1.769	0.176
1988	105.2	307	19.4	21	22.7	2.6812	0.130	3.404	0.175
1989	88.1	313	33.3	32	38.2	2.9974	0.132	2.849	0.086
1990	79.3	264	39.8	36	88.9	3.9460	0.135	1.604	0.040
1991	76.0	474	29.2	37	20.8	2.0527	0.127	5.537	0.190
1992	49.3	313	14.2	23	17.4	1.5299	0.134	3.321	0.233
1993	59.7	731	37.7	31	19.7	1.2530	0.124	7.161	0.190
1994	110.0	854	89.0	33	41.5	1.4195	0.123	7.892	0.089
1995	58.6	486	28.3	29	17.5	0.9509	0.128	6.045	0.214
1996	71.7	644	35.4	29	16.4	0.7697	0.126	6.625	0.187
1997	471.5	602	19.9	31	10.7	0.7094	0.128	6.481	0.326
1998	476.0	471	18.7	24	11.3	0.8220	0.130	5.166	0.277
1999	575.0	631	41.7	27	9.2	0.8433	0.127	6.515	0.156
2000	671.4	657	37.7	35	8.0	0.5245	0.125	5.629	0.149
2001	648.3	700	25.2	24	4.6	0.4611	0.125	6.049	0.240
2002	843.9	700	33.7	28	12.0	0.4566	0.127	5.842	0.173
2003	605.3	722	14.1	25	6.3	0.4562	0.126	5.455	0.388
2004	612.3	623	15.2	28	11.6	0.4501	0.128	4.492	0.296
2005	755.2	502	17.9	26	16.7	0.4549	0.131	3.189	0.178
2006	573.7	327	36.8	17	67.2	0.5571	0.135	2.097	0.057
2007	937.1	247	10.6	11	9.8	0.4543	0.141	1.652	0.156
2008	398.9	434	13.7	15	26.8	0.4166	0.134	2.776	0.203
2009	521.0	246	22.8	14	85.1	0.4027	0.142	1.329	0.058
2010	437.4	197	11.5	13	35.2	0.2784	0.147	0.996	0.086
2011	554.2	227	7.8	12	13.1	0.2839	0.144	1.259	0.161
2012	463.8	150	1.3	11	2.6	0.2564	0.154	0.925	0.694
2013	398.4	147	4.1	11	25.5	0.2283	0.156	0.923	0.225
2014	460.5	120	20.6	11	337.4	0.3079	0.163	0.554	0.027
2015	305.4	189	22.4	14	368.1	0.3153	0.152	0.847	0.038
2016	332.7	140	9.5	12	82.5	0.2594	0.159	0.775	0.082

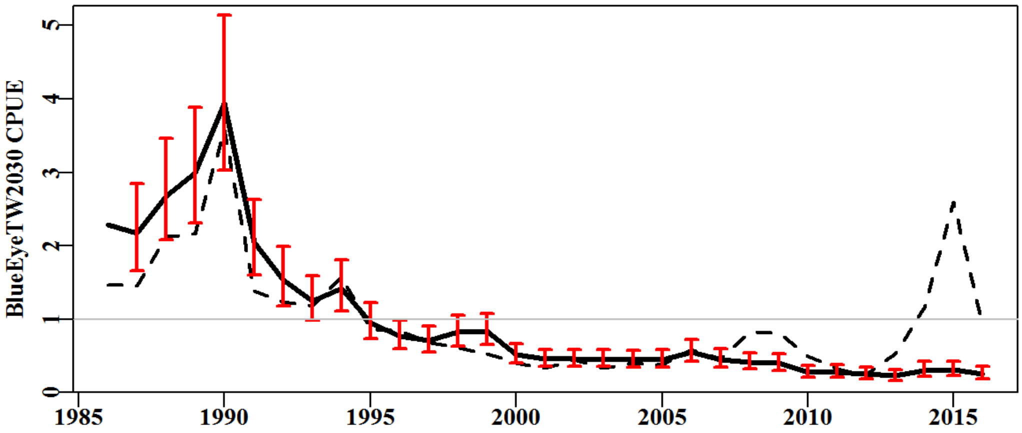


Figure 7.120. BlueEyeTW2030 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

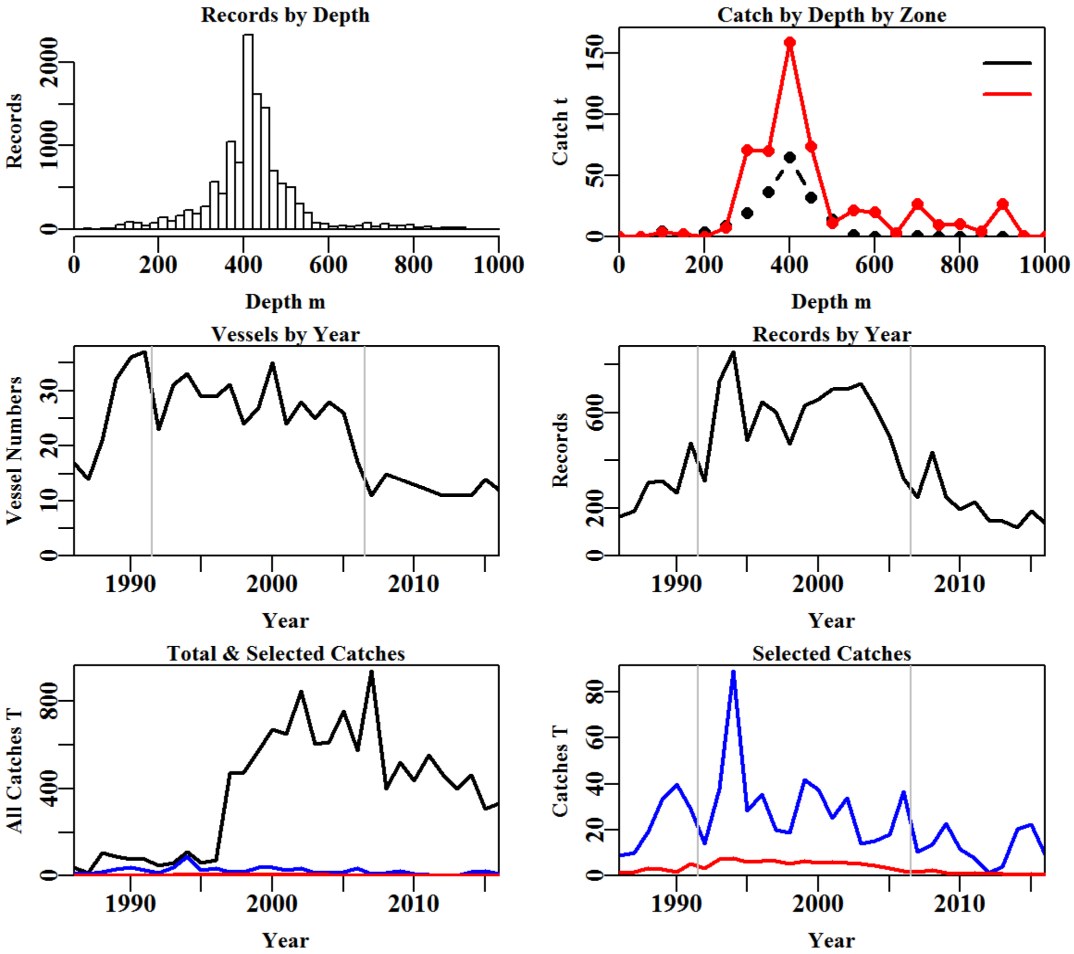


Figure 7.121. BlueEyeTW2030 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.77. BlueEyeTW2030 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	53480	34190	34138	34027	14553	12778	12774
Difference	0	19290	52	111	19474	1775	4

Table 7.78. The models used to analyse data for BlueEyeTW2030.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + Zone
Model4	Year + Vessel + Zone + DepCat
Model5	Year + Vessel + Zone + DepCat + Month
Model6	Year + Vessel + Zone + DepCat + Month + DayNight
Model7	Year + Vessel + Zone + DepCat + Month + DayNight + Zone:DepCat
Model8	Year + Vessel + Zone + DepCat + Month + DayNight + Zone:Month

Table 7.79. BlueEyeTW2030. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:DepCat.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	11885	32232	5130	12774	31	13.5	0.00
Vessel	4787	18138	19224	12774	154	50.9	37.34
Zone	4383	17571	19791	12774	155	52.4	1.53
DepCat	4265	17280	20081	12695	175	52.6	0.19
Month	4231	17205	20157	12695	186	52.8	0.17
DayNight	4201	17156	20205	12695	189	52.9	0.12
Zone:DepCat	4046	16897	20465	12695	208	53.5	0.64
Zone:Month	4172	17087	20275	12695	200	53.0	0.15

Table 7.80. BlueEyeTW2030. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	BlueEyeTW2030
csirocode	37445001, 37445014
fishery	SET
depthrange	0 - 1000
depthclass	50
zones	20, 30
methods	TW, TDO
years	1986 - 2016

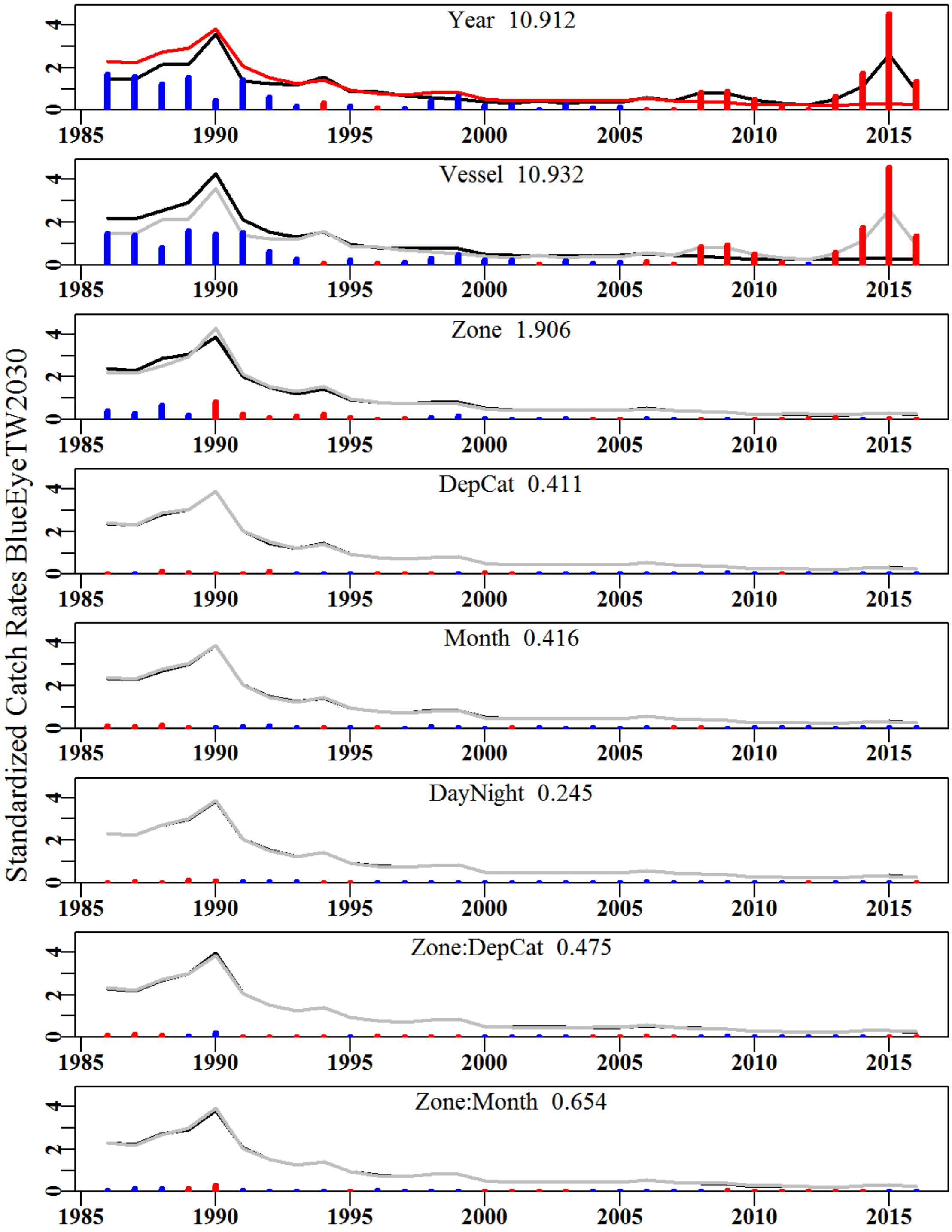


Figure 7.122. BlueEyeTW2030. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

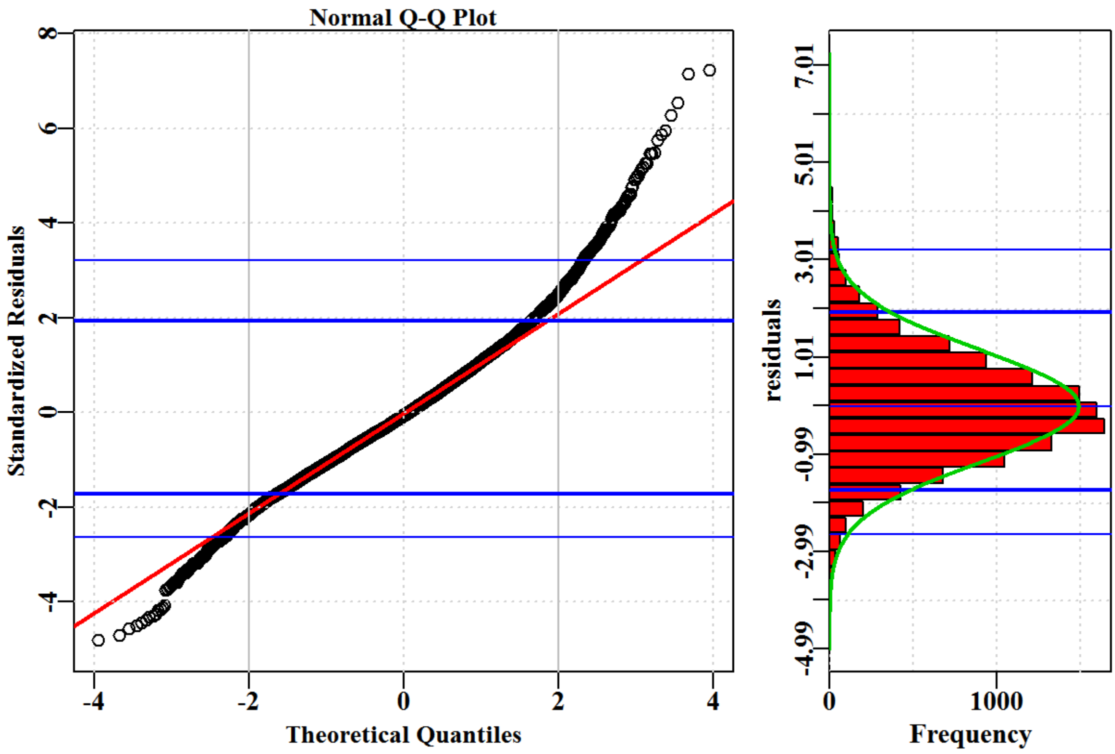


Figure 7.123. BlueEyeTW2030. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

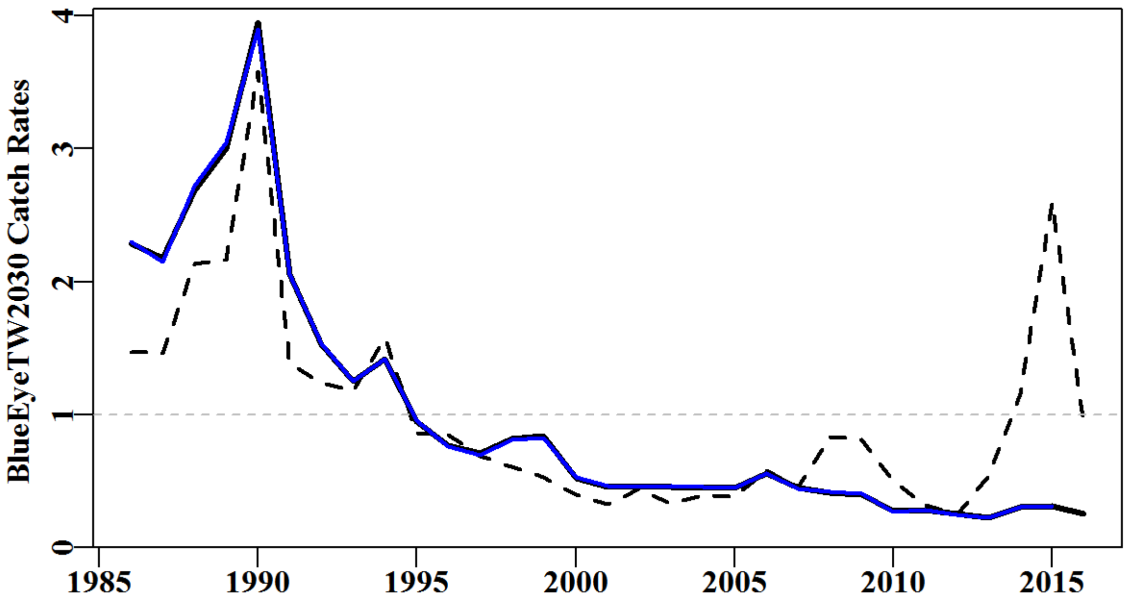


Figure 7.124. BlueEyeTW2030. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

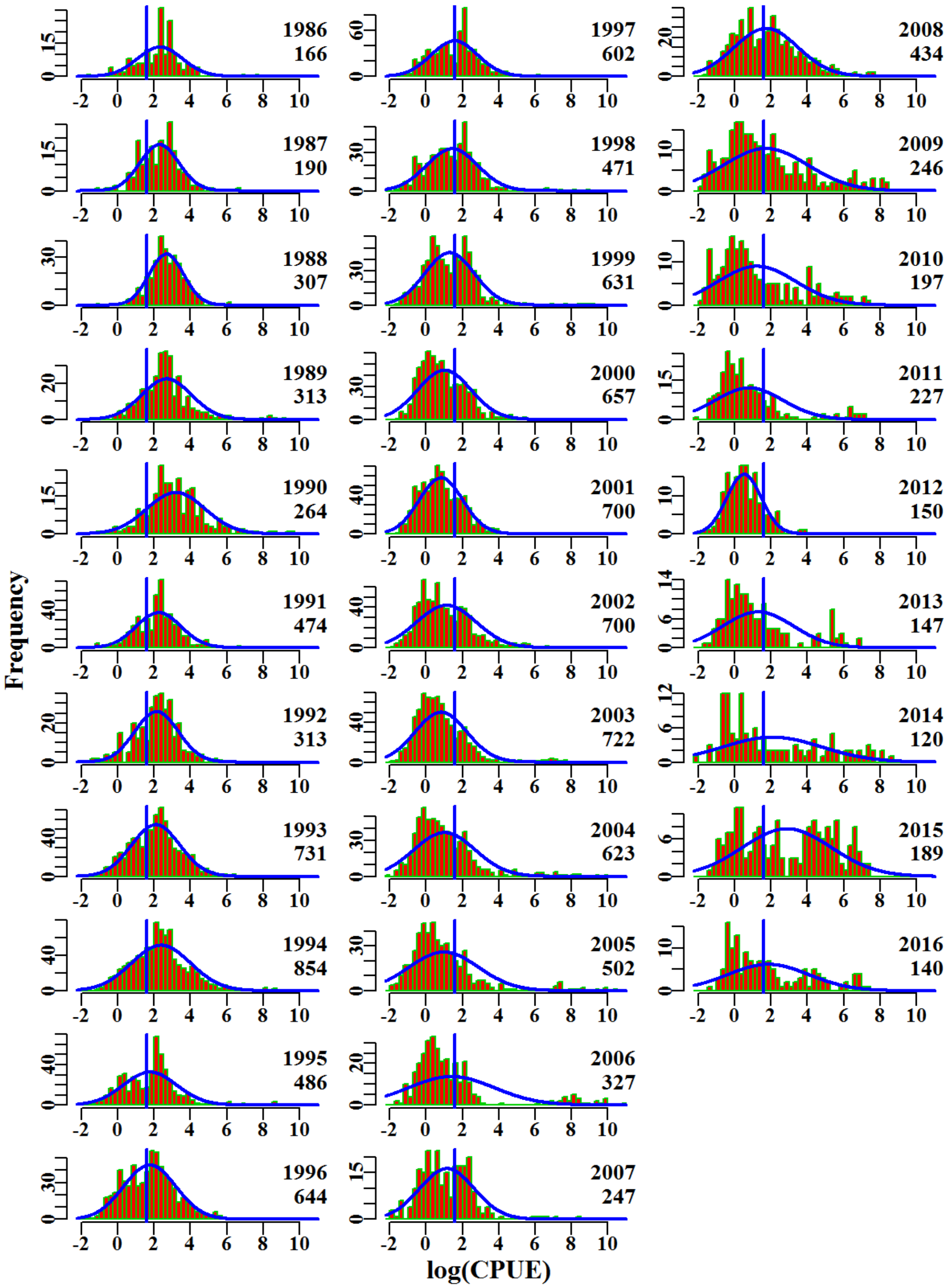


Figure 7.125. BlueEyeTW2030. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

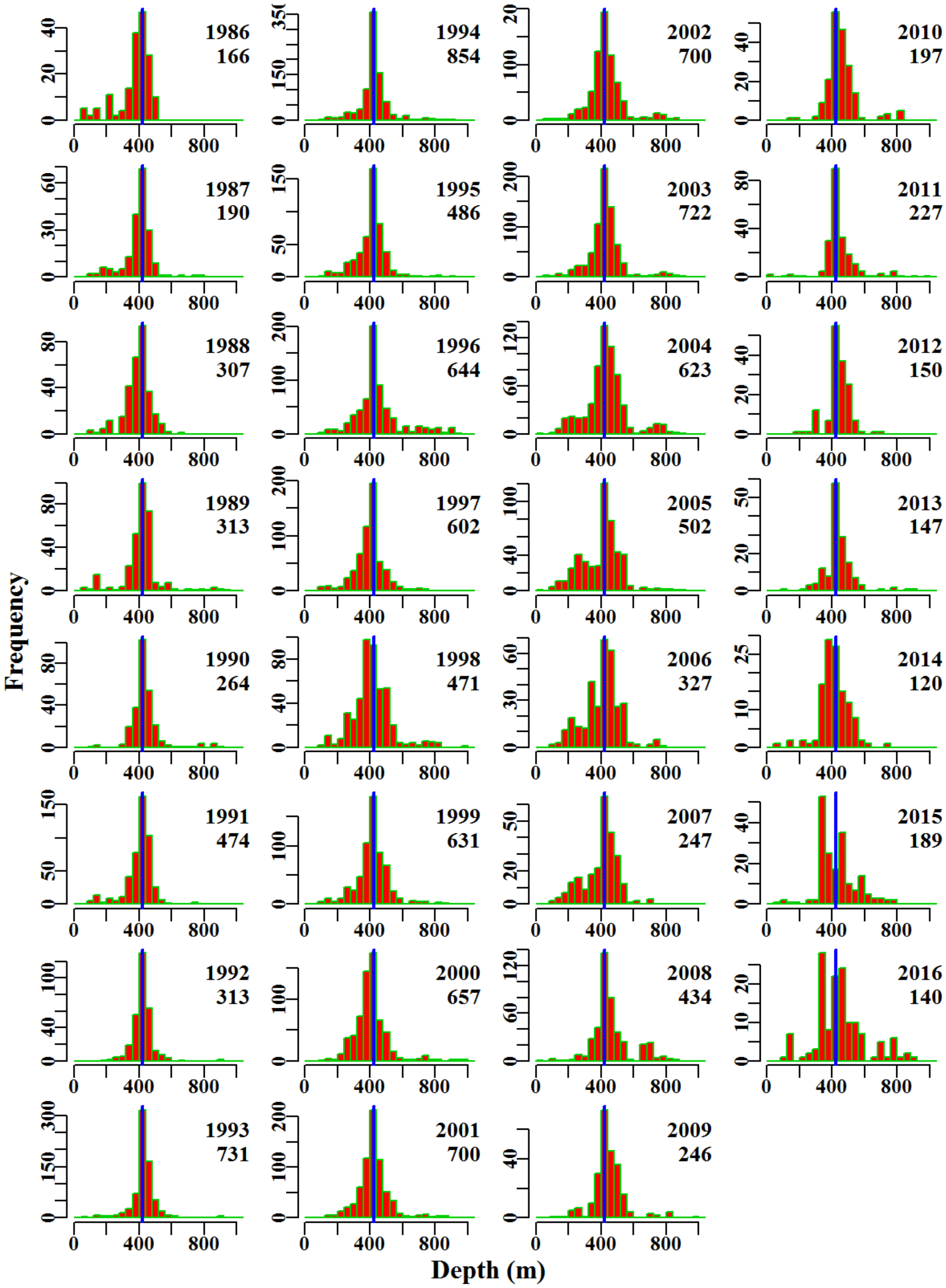


Figure 7.126. BlueEyeTW2030. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

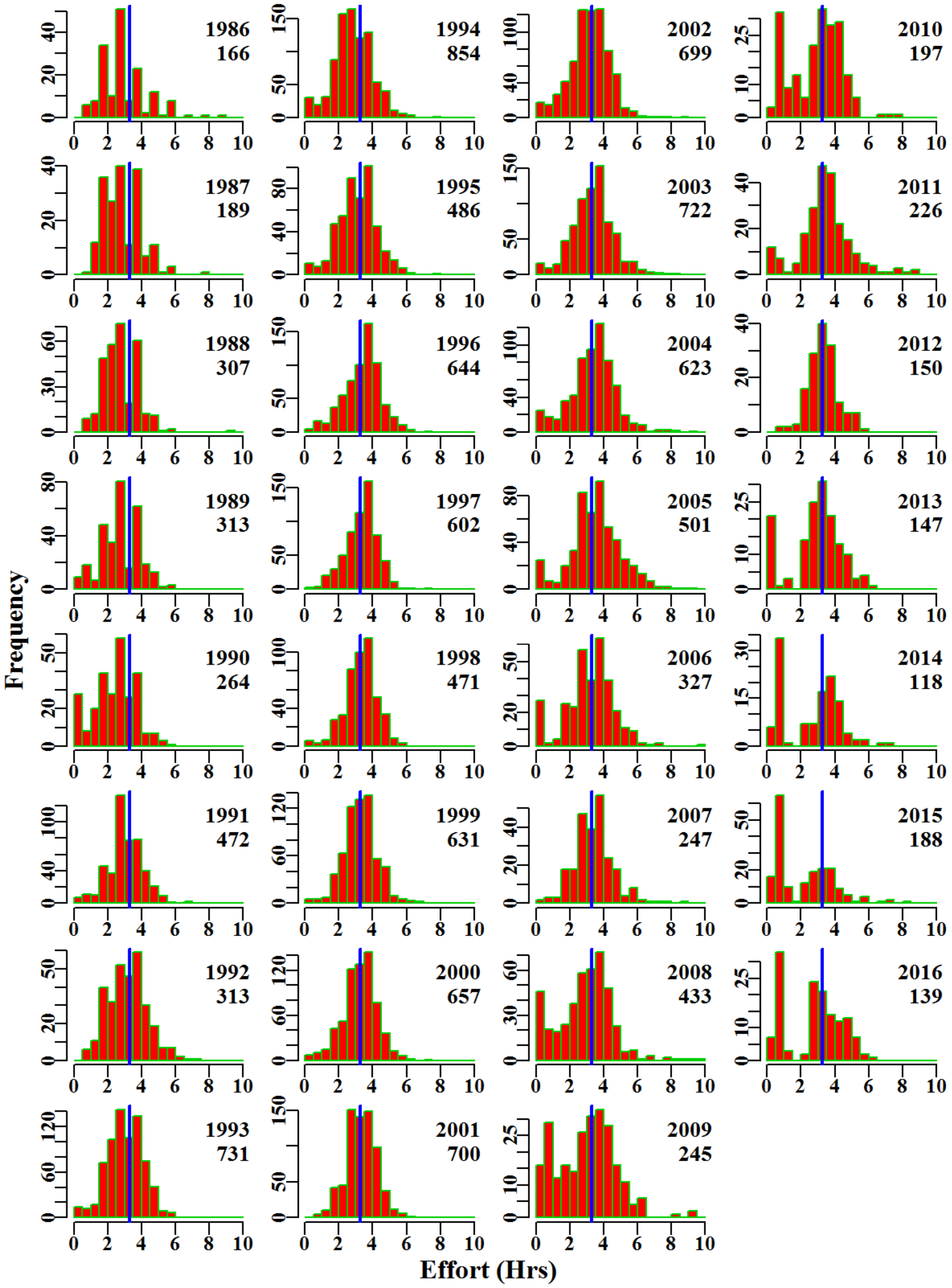


Figure 7.127. BlueEyeTW2030. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.20 Blue-Eye Trevalla TW 4050

Blue-Eye Trevalla (TBE - 37445001 - *Hyperoglyphe antarctica*) was one of the 16 species first included in the quota system in 1992, which reflects its long history within the SESSF. Recently, Ocean Blue-Eye Trevalla (37445014 - *Schedophilus labyrinthicus*) was also included in this analysis. The criteria used to select data from the Commonwealth logbook database (Table 7.85). A total of 8 statistical models were fitted sequentially to the available data.

7.20.1 *Inferences*

Catches appear to change relative to availability rather than the influence of the fishery on the stock. Over the period when CPUE was lower than average (about 1992 - 2006) there was an increase in small shots of < 30kg (Figure 7.129), which suggests these are merely bycatch to the usual fishing practices.

The terms Year, Vessel and DepCat had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests a departure from that the assumed Normal distribution as depicted by the tails of the distribution (Figure 7.131).

Annual standardized CPUE have been below average since about 1996 and relatively flat trend (Figure 7.128). CPUE before the introduction of quotas in 1992 are consistent from 1988 - 1991 but are double that following the introduction of quota. Very few vessels now contribute significant catches.

7.20.2 *Action Items and Issues*

If this analysis is to continue then the early CPUE data rom 1988 - 1991 should be explored in more detail to ensure it is representative of the fishery and does not contain systematic errors. After introducing quota the CPUE distributions became more consistent through time, although relatively low numbers of observations are now contributing to a change in their character in the latest years

Table 7.81. BlueEyeTW4050. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:DepCat

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	38.0	194	16.0	18	26.9	1.0426	0.000	1.602	0.100
1987	15.5	56	3.1	14	19.8	0.8048	0.178	0.356	0.113
1988	105.2	142	76.4	15	474.9	2.5044	0.157	0.716	0.009
1989	88.1	238	44.0	24	93.5	2.1722	0.138	2.149	0.049
1990	79.3	157	30.9	16	64.9	2.1839	0.159	1.850	0.060
1991	76.0	128	18.7	18	34.5	1.7521	0.159	1.149	0.061
1992	49.3	129	28.6	15	620.9	2.1979	0.157	0.908	0.032
1993	59.7	289	18.1	19	16.3	0.9763	0.140	3.992	0.220
1994	110.0	348	16.3	19	14.0	0.9963	0.136	5.148	0.316
1995	58.6	500	26.4	21	12.4	0.8922	0.133	6.678	0.253
1996	71.7	523	30.2	24	18.0	0.9396	0.133	6.277	0.208
1997	471.5	788	82.4	18	22.3	0.9502	0.130	7.718	0.094
1998	476.0	780	58.9	19	14.6	1.1264	0.132	8.776	0.149
1999	575.0	877	46.3	19	15.7	1.1438	0.130	9.412	0.203
2000	671.4	1109	44.7	25	13.1	0.9943	0.129	11.202	0.250
2001	648.3	969	43.5	26	15.0	0.9593	0.131	10.861	0.249
2002	843.9	803	32.3	26	13.6	0.7992	0.131	8.787	0.272
2003	605.3	391	11.0	25	8.5	0.6955	0.138	3.814	0.346
2004	612.3	852	31.3	24	9.9	0.6172	0.131	7.231	0.231
2005	755.2	508	12.8	22	7.5	0.5871	0.135	4.382	0.344
2006	573.7	533	16.3	17	7.3	0.5853	0.134	4.049	0.249
2007	937.1	538	26.2	16	12.8	0.6261	0.134	3.700	0.141
2008	398.9	324	16.4	14	14.8	0.8243	0.140	2.695	0.165
2009	521.0	343	15.8	13	10.6	0.7785	0.139	2.543	0.161
2010	437.4	427	31.0	14	15.6	0.7901	0.136	2.835	0.091
2011	554.2	381	14.7	14	6.5	0.6120	0.138	3.033	0.206
2012	463.8	261	9.0	11	4.4	0.4496	0.146	1.773	0.197
2013	398.4	205	18.7	15	10.8	0.5923	0.148	1.609	0.086
2014	460.5	216	8.7	13	6.6	0.5411	0.148	2.118	0.243
2015	305.4	106	2.7	9	5.3	0.3209	0.170	0.745	0.281
2016	332.7	92	3.3	13	7.1	0.5442	0.172	0.842	0.255

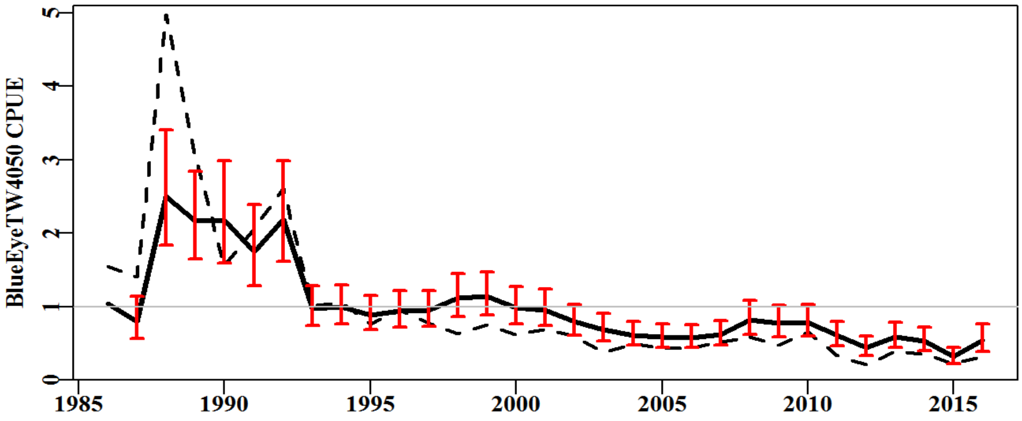


Figure 7.128. BlueEyeTW4050 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

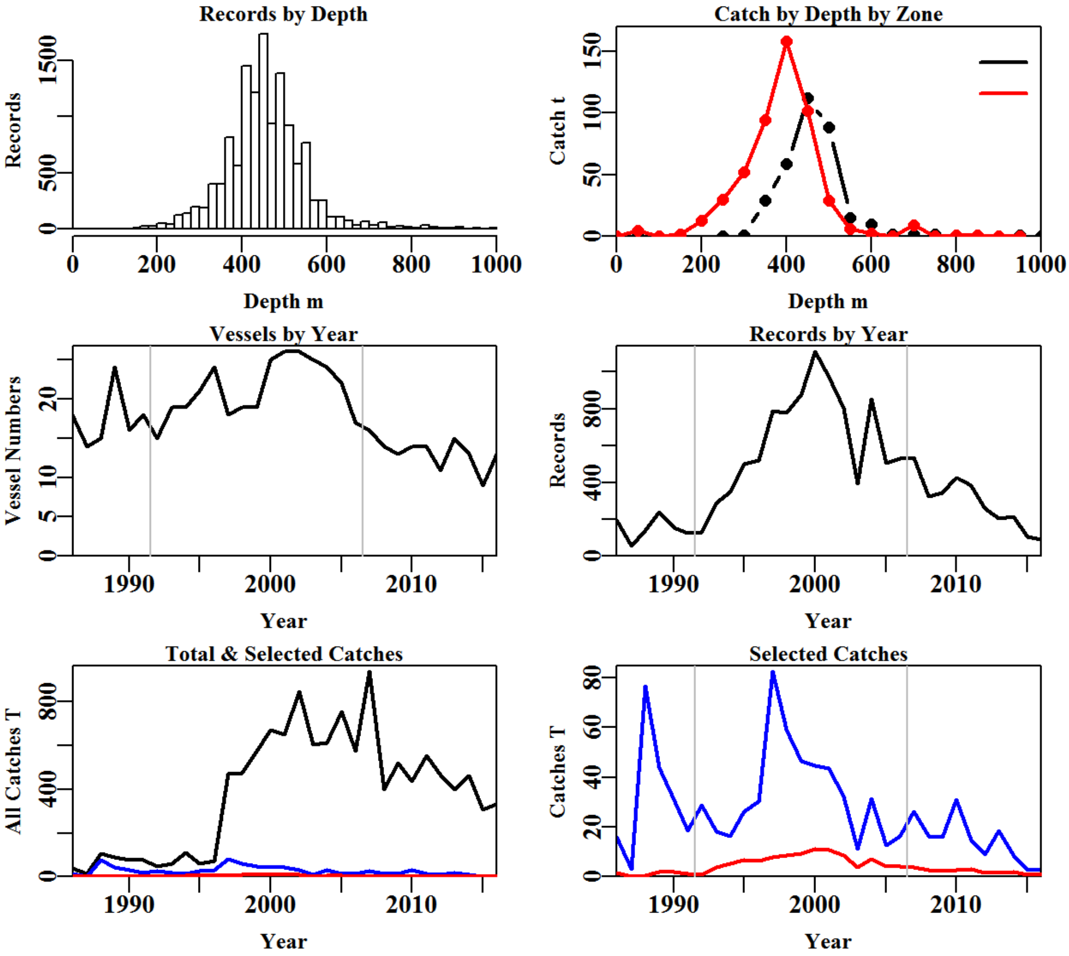


Figure 7.129. BlueEyeTW4050 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.82. BlueEyeTW4050 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	53480	34190	34138	34027	14148	13231	13207
Difference	0	19290	52	111	19879	917	24

Table 7.83. The models used to analyse data for BlueEyeTW4050.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + Zone
Model5	Year + Vessel + DepCat + Zone + DayNight
Model6	Year + Vessel + DepCat + Zone + DayNight + Month
Model7	Year + Vessel + DepCat + Zone + DayNight + Month + Zone:DepCat
Model8	Year + Vessel + DepCat + Zone + DayNight + Month + Zone:Month

Table 7.84. BlueEyeTW4050. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:DepCat.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	8616	25240	3335	13207	31	11.5	0.00
Vessel	3271	16624	11952	13207	116	41.3	29.84
DepCat	2890	16039	12537	13142	136	42.9	1.62
Zone	2824	15956	12620	13142	137	43.2	0.29
DayNight	2711	15812	12763	13142	140	43.7	0.50
Month	2618	15674	12901	13142	151	44.2	0.44
Zone:DepCat	2601	15614	12961	13142	168	44.3	0.14
Zone:Month	2618	15648	12927	13142	162	44.2	0.05

Table 7.85. BlueEyeTW4050. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	BlueEyeTW4050
csirocode	37445001, 37445014
fishery	SET
depthrange	0 - 1000
depthclass	50
zones	40, 50
methods	TW, TDO
years	1986 - 2016

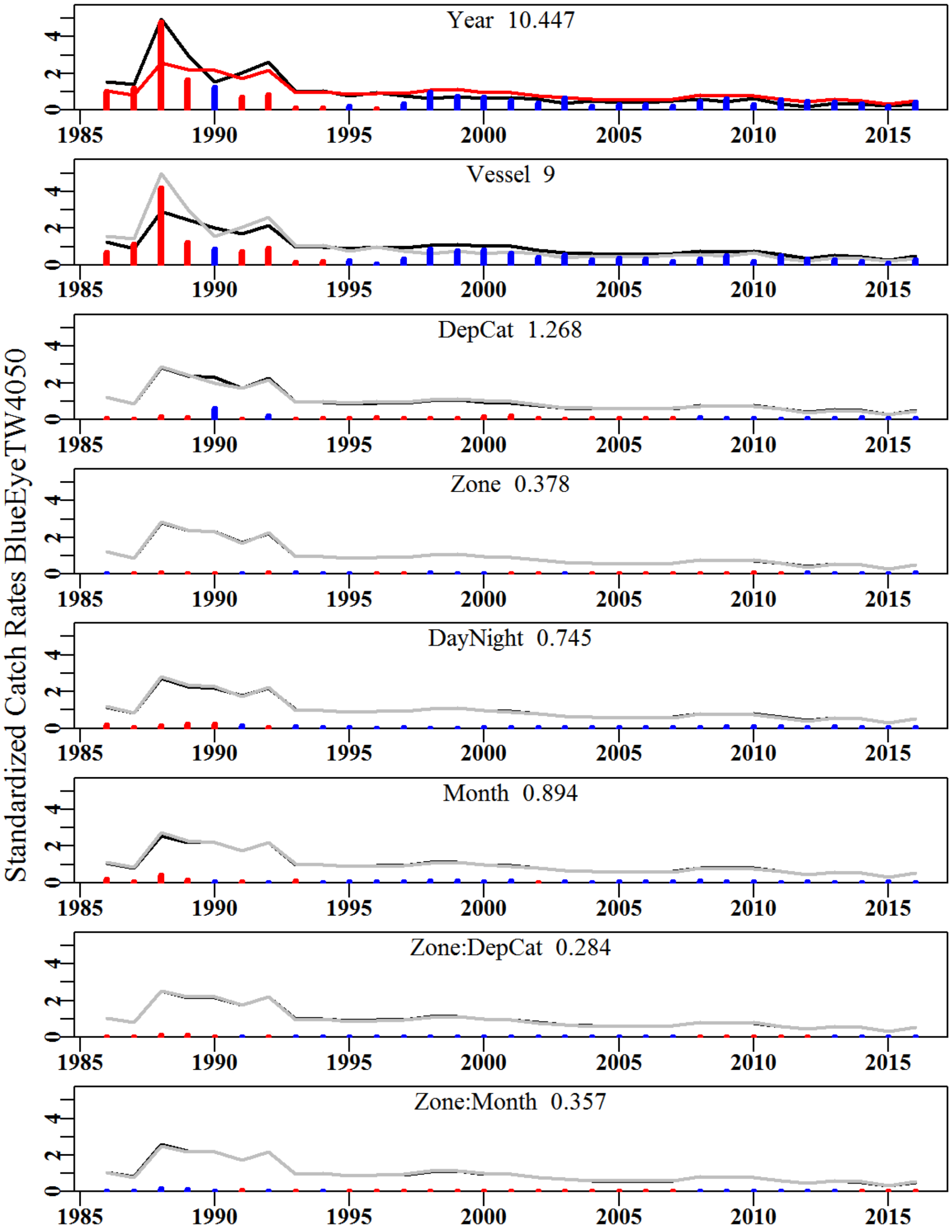


Figure 7.130. BlueEyeTW4050. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

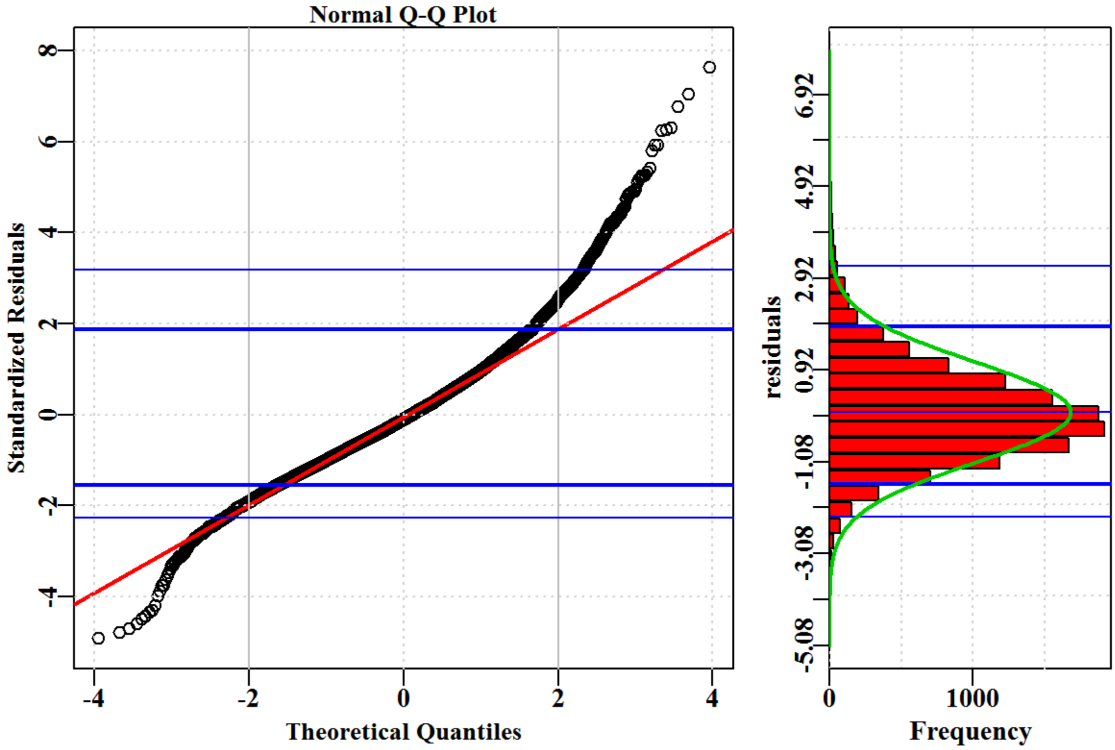


Figure 7.131. BlueEyeTW4050. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

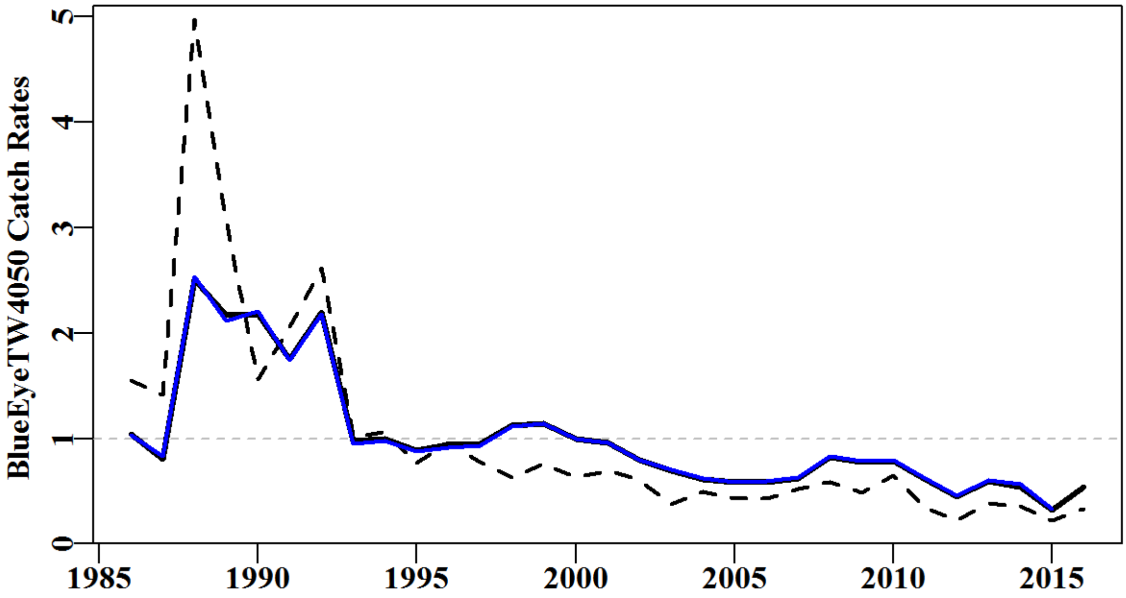


Figure 7.132. BlueEyeTW4050. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

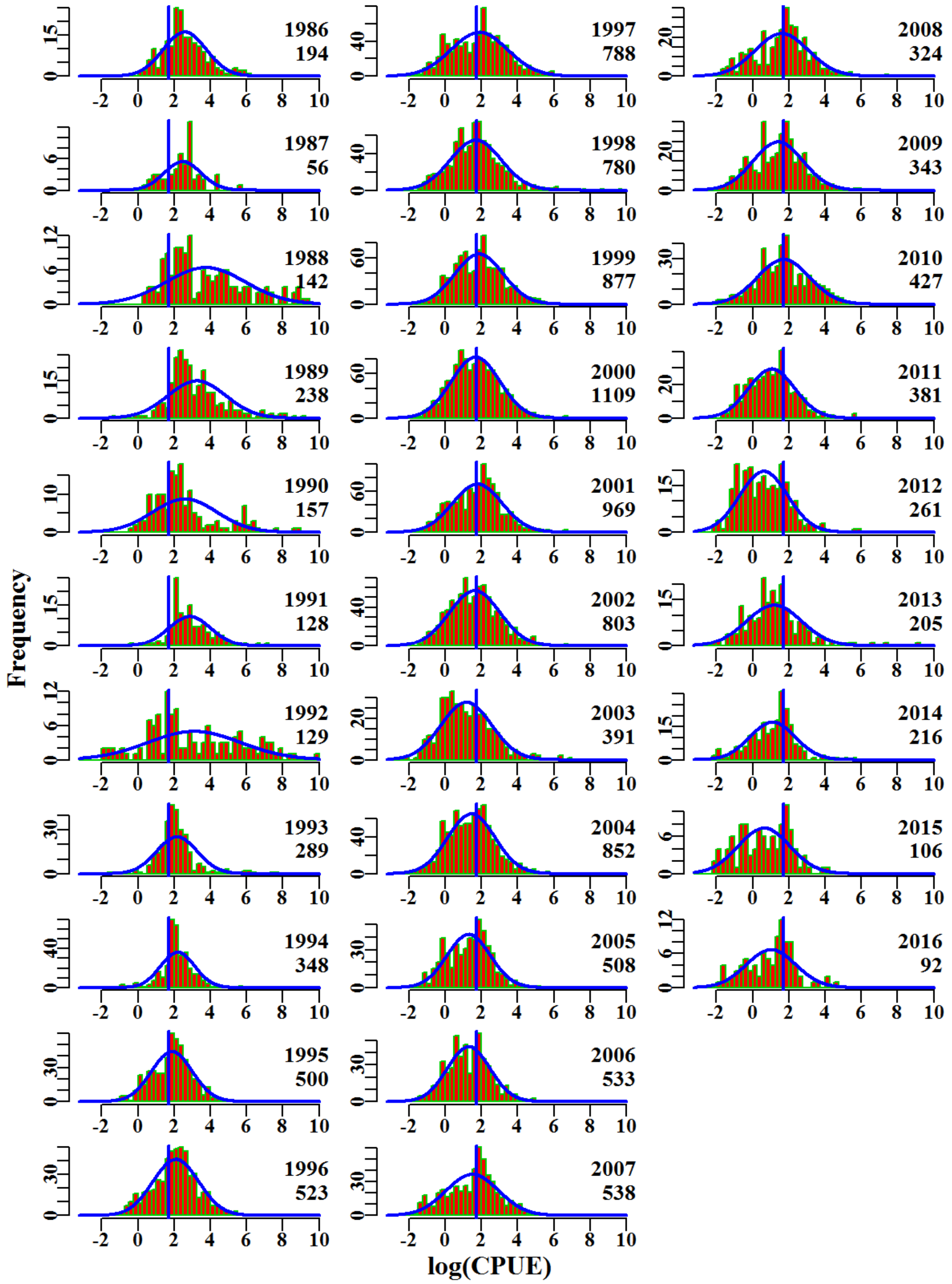


Figure 7.133. BlueEyeTW4050. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

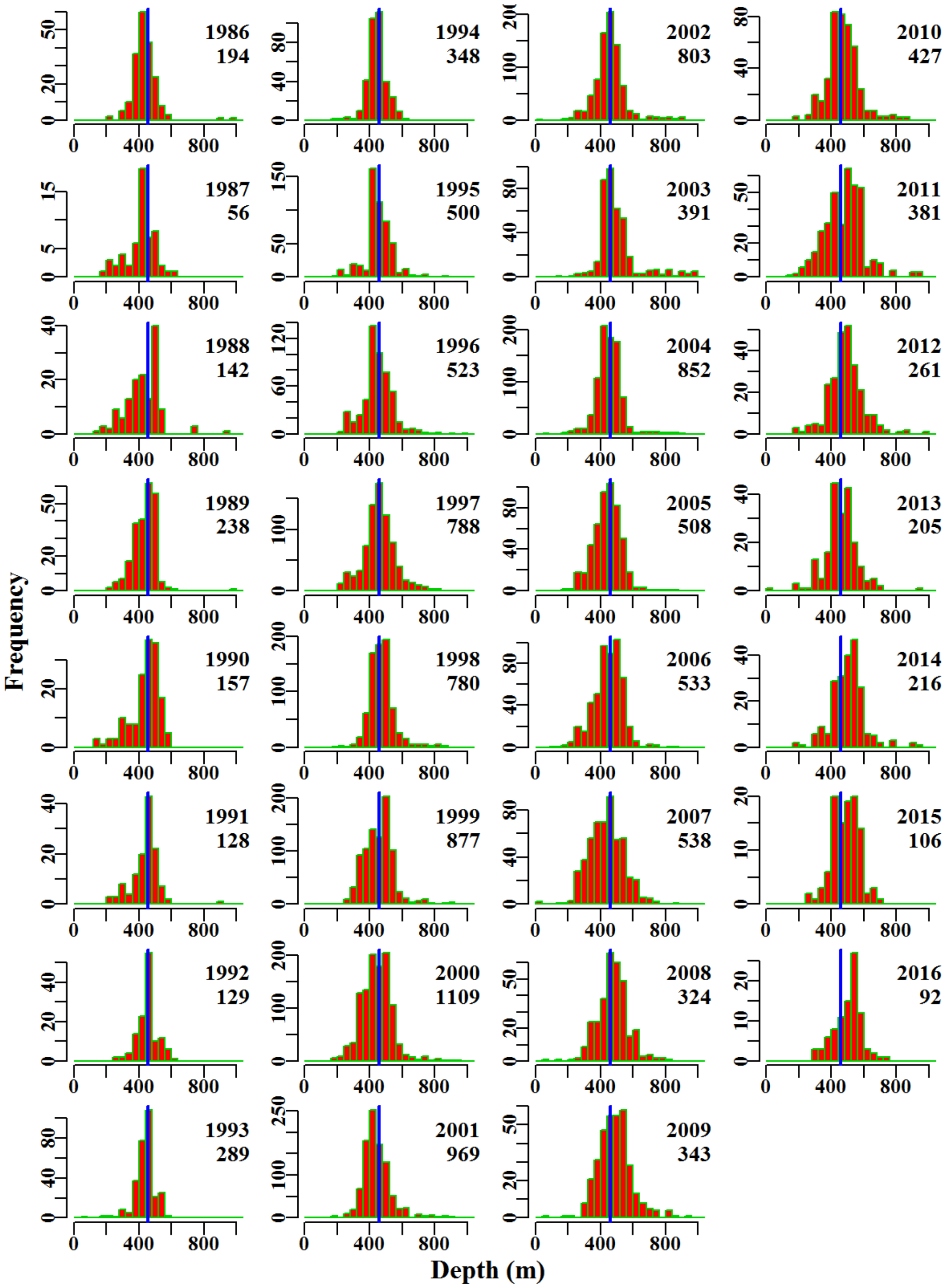


Figure 7.134. BlueEyeTW4050. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

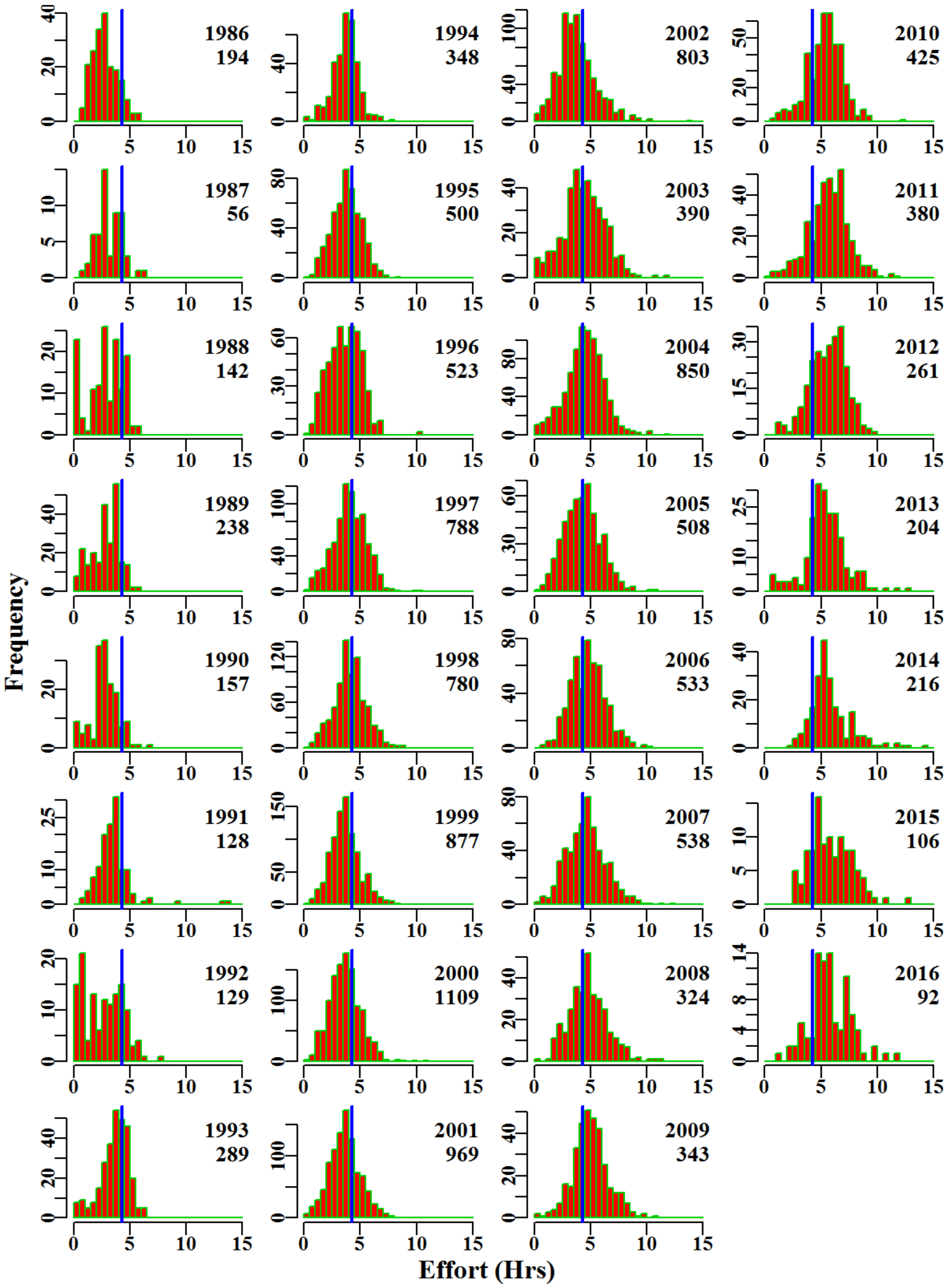


Figure 7.135. BlueEyeTW4050. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.21 Blue-Grenadier Non-Spawning

Blue Grenadier (GRE - 37227001 - *Macroronus novaezelandiae*) caught by methods TW, TDO, in zones 10, 20, 30, 40, 50, 60, and depths 100 to 1000 within the SET fishery for the years 1986 - 2016 were used in the analysis (Table 7.90).

A total of 8 statistical models were fitted sequentially to the available data.

7.21.1 *Inferences*

Blue grenadier (non-spawning) were mostly caught in zone 10 and 50, followed by zone 40 and 60 across the analysis period.

The terms Year, Vessel, DayNight, DepCat, Zone and Month had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests only a tiny departure from that of the assumed Normal distribution with a tiny proportion of records in the upper tail of the distribution departing from normality.

Annual standardized CPUE have been below average between 1993 - 2013, with two apparent cycles, each peaking in 1998 and 2008 respectively. Since 2013, these annual indices were above average (Figure 7.136).

7.21.2 *Action Items and Issues*

No issues identified.

Table 7.86. BlueGrenadierNS. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	1205.5	3189	1183.3	92	141.8	1.5670	0.000	12.975	0.011
1987	1462.5	3569	1437.4	91	135.2	2.0034	0.034	14.612	0.010
1988	1530.1	3961	1470.2	102	129.0	2.1745	0.034	17.944	0.012
1989	1854.7	4309	1813.5	99	151.1	2.1841	0.034	18.030	0.010
1990	1710.8	3577	1625.1	92	156.7	2.1759	0.036	12.588	0.008
1991	2780.7	4307	2392.3	86	208.3	1.5535	0.034	15.985	0.007
1992	1760.8	3235	1505.8	62	178.0	1.2582	0.037	12.493	0.008
1993	1670.0	4203	1619.0	63	125.3	0.9537	0.035	19.171	0.012
1994	1341.2	4491	1309.6	66	93.9	0.8610	0.035	22.709	0.017
1995	1020.1	5075	1015.2	61	58.5	0.5964	0.034	32.575	0.032
1996	1092.7	5370	1055.3	73	56.2	0.5383	0.034	38.256	0.036
1997	1032.0	6194	994.6	73	43.7	0.5597	0.033	45.879	0.046
1998	1489.3	6598	1452.4	65	74.7	0.9037	0.033	41.174	0.028
1999	2113.3	8046	2052.0	65	89.7	0.9482	0.032	47.127	0.023
2000	1768.0	7680	1751.2	73	73.4	0.6850	0.033	49.627	0.028
2001	1062.1	7344	1023.1	60	40.3	0.3943	0.033	56.314	0.055
2002	1151.4	6347	1124.7	57	54.7	0.3931	0.034	41.014	0.036
2003	707.7	5676	669.6	56	33.7	0.3279	0.034	36.443	0.054
2004	1444.5	6393	1204.7	56	56.1	0.5516	0.034	23.445	0.019
2005	1626.5	5346	1174.7	54	65.8	0.6642	0.034	18.427	0.016
2006	1486.6	4362	1308.8	42	84.4	0.8858	0.035	11.087	0.008
2007	1312.0	3659	1203.7	27	86.5	0.7877	0.037	10.335	0.009
2008	1312.5	3406	1274.4	26	110.9	0.8706	0.037	9.052	0.007
2009	1150.9	3443	1128.4	23	89.0	0.8069	0.037	9.795	0.009
2010	1167.6	3314	1136.1	25	81.9	0.8031	0.037	8.203	0.007
2011	923.1	3969	897.7	26	49.4	0.6530	0.036	9.699	0.011
2012	645.7	3210	613.6	29	40.8	0.5220	0.038	10.238	0.017
2013	774.5	3059	743.8	26	58.1	0.9293	0.038	7.226	0.010
2014	994.1	3044	922.8	28	78.7	1.1405	0.038	6.173	0.007
2015	1069.7	2965	1050.3	29	106.0	1.2430	0.038	8.140	0.008
2016	982.5	2520	963.7	24	111.6	1.0642	0.040	5.510	0.006

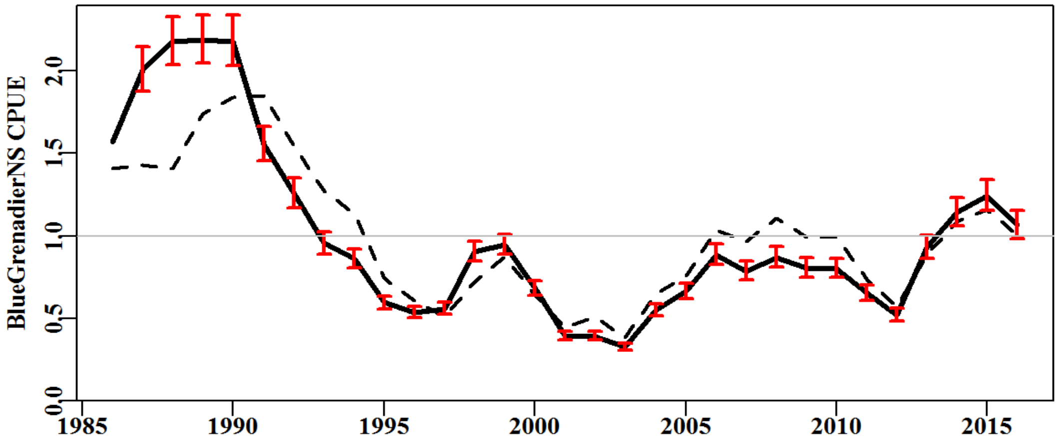


Figure 7.136. BlueGrenadierNS standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

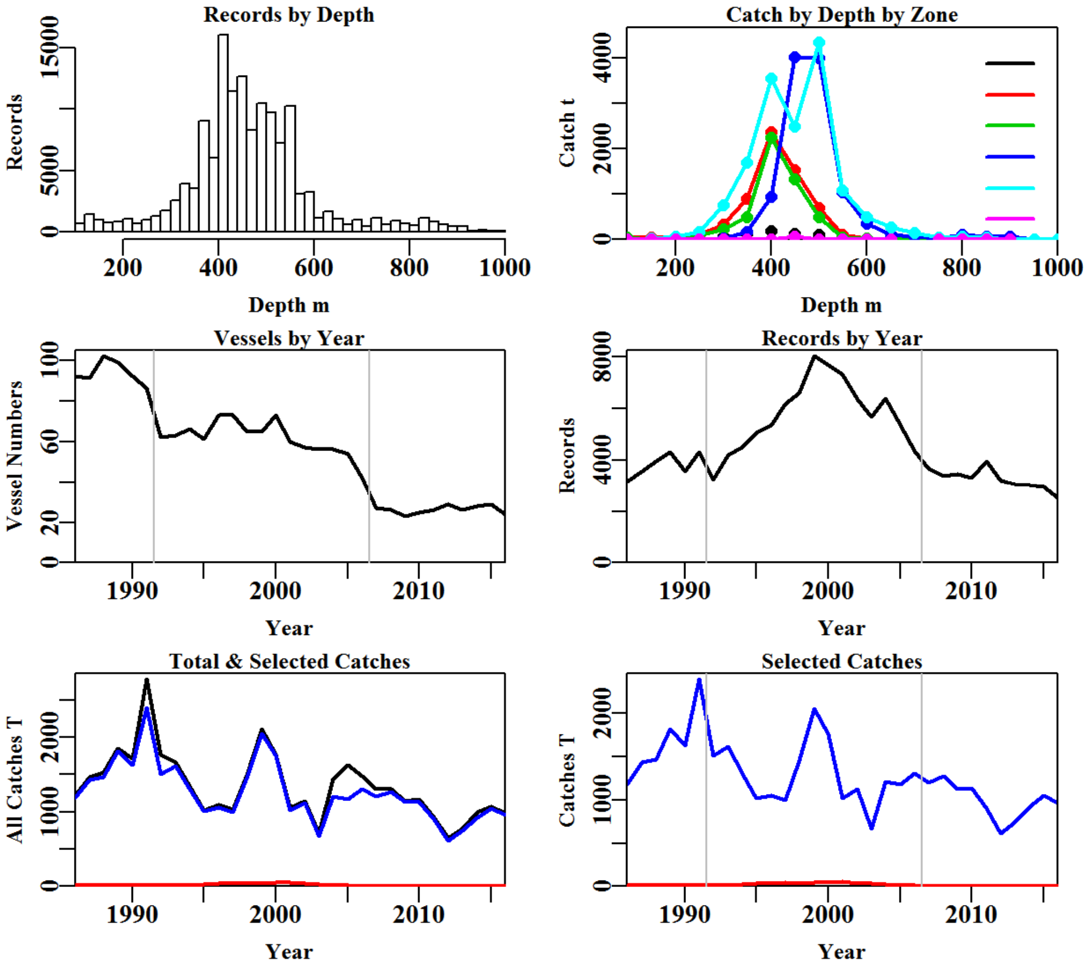


Figure 7.137. BlueGrenadierNS fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.87. BlueGrenadierNS data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	160014	149272	148577	147158	143403	141963	141861
Difference	0	10742	695	1419	3755	1440	102

Table 7.88. The models used to analyse data for BlueGrenadierNS.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DayNight
Model4	Year + Vessel + DayNight + DepCat
Model5	Year + Vessel + DayNight + DepCat + Zone
Model6	Year + Vessel + DayNight + DepCat + Zone + Month
Model7	Year + Vessel + DayNight + DepCat + Zone + Month + Zone:DepCat
Model8	Year + Vessel + DayNight + DepCat + Zone + Month + Zone:Month

Table 7.89. BlueGrenadierNS. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	130387	355501	25576	141861	31	6.7	0.00
Vessel	105953	298402	82674	141861	233	21.6	14.87
DayNight	97048	280235	100841	141861	236	26.3	4.77
DepCat	87630	261556	119520	140995	253	30.8	4.43
Zone	83451	253900	127176	140995	258	32.8	2.02
Month	79078	246107	134970	140995	269	34.9	2.06
Zone:DepCat	77523	243117	137959	140995	353	35.6	0.75
Zone:Month	75778	240237	140840	140995	321	36.4	1.53

Table 7.90. BlueGrenadierNS. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	BlueGrenadierNS
csirocode	37227001
fishery	SET
depthrange	100 - 1000
depthclass	50
zones	10, 20, 30, 40, 50, 60
methods	TW, TDO
years	1986 - 2016

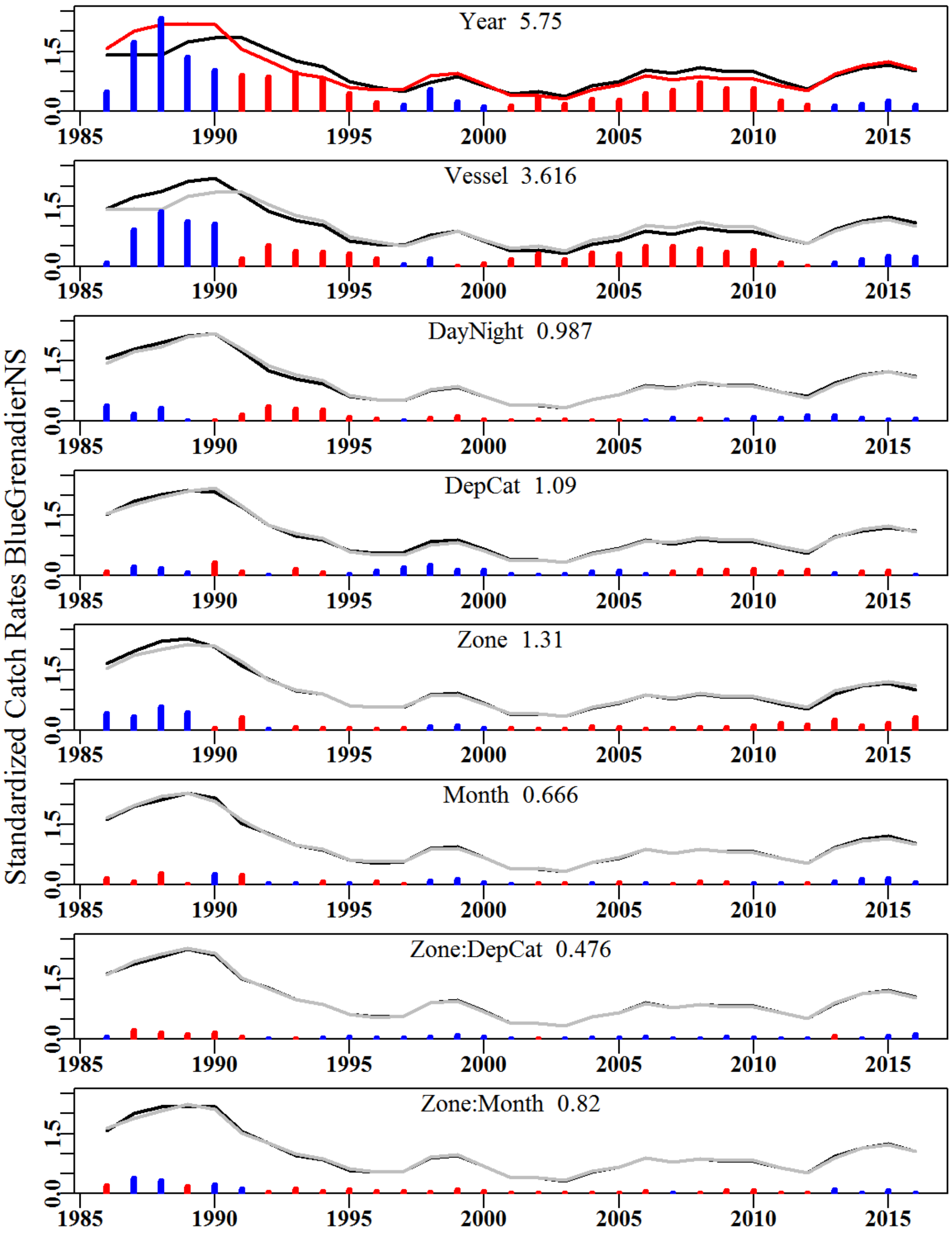


Figure 7.138. BlueGrenadierNS. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

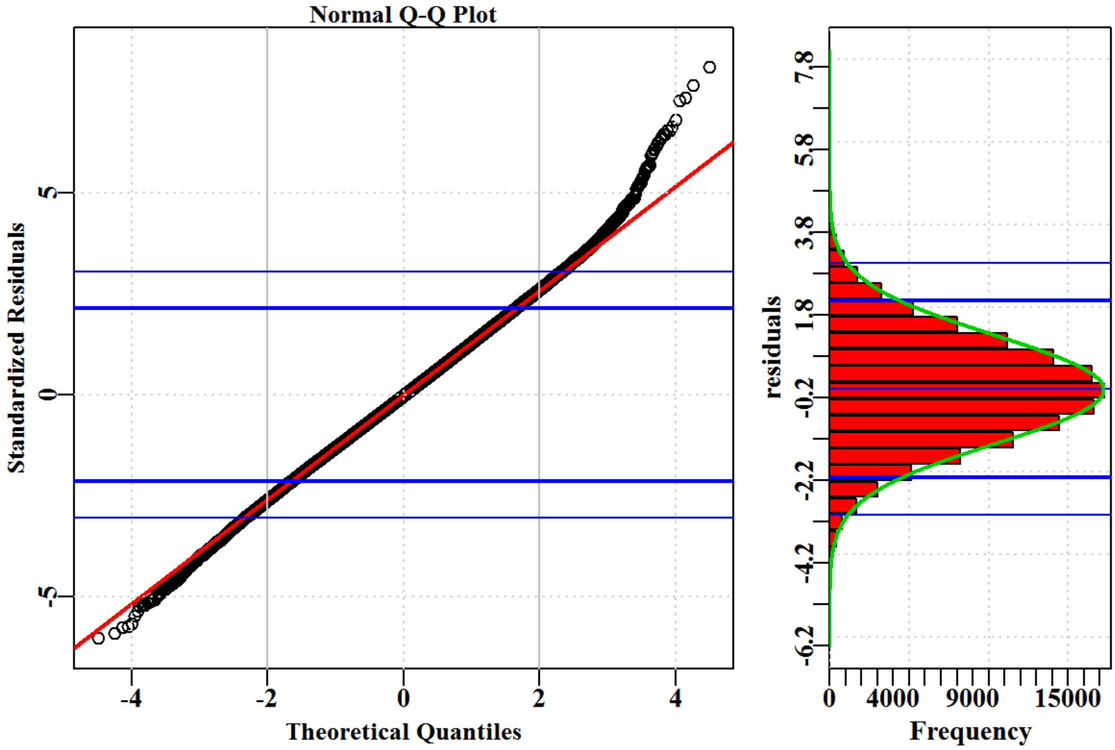


Figure 7.139. BlueGrenadierNS. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

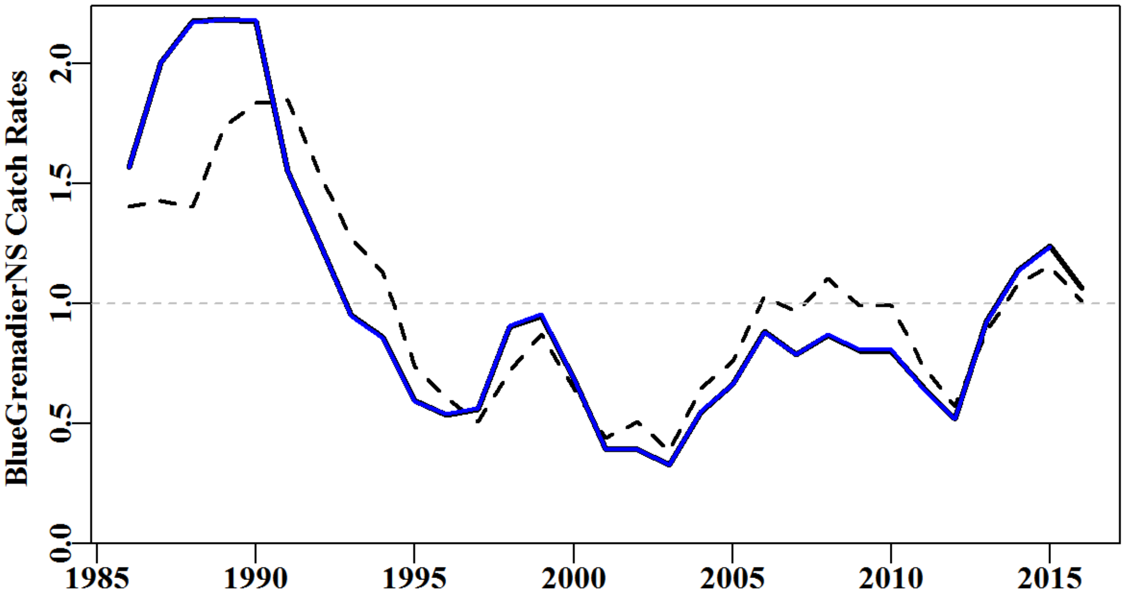


Figure 7.140. BlueGrenadierNS. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

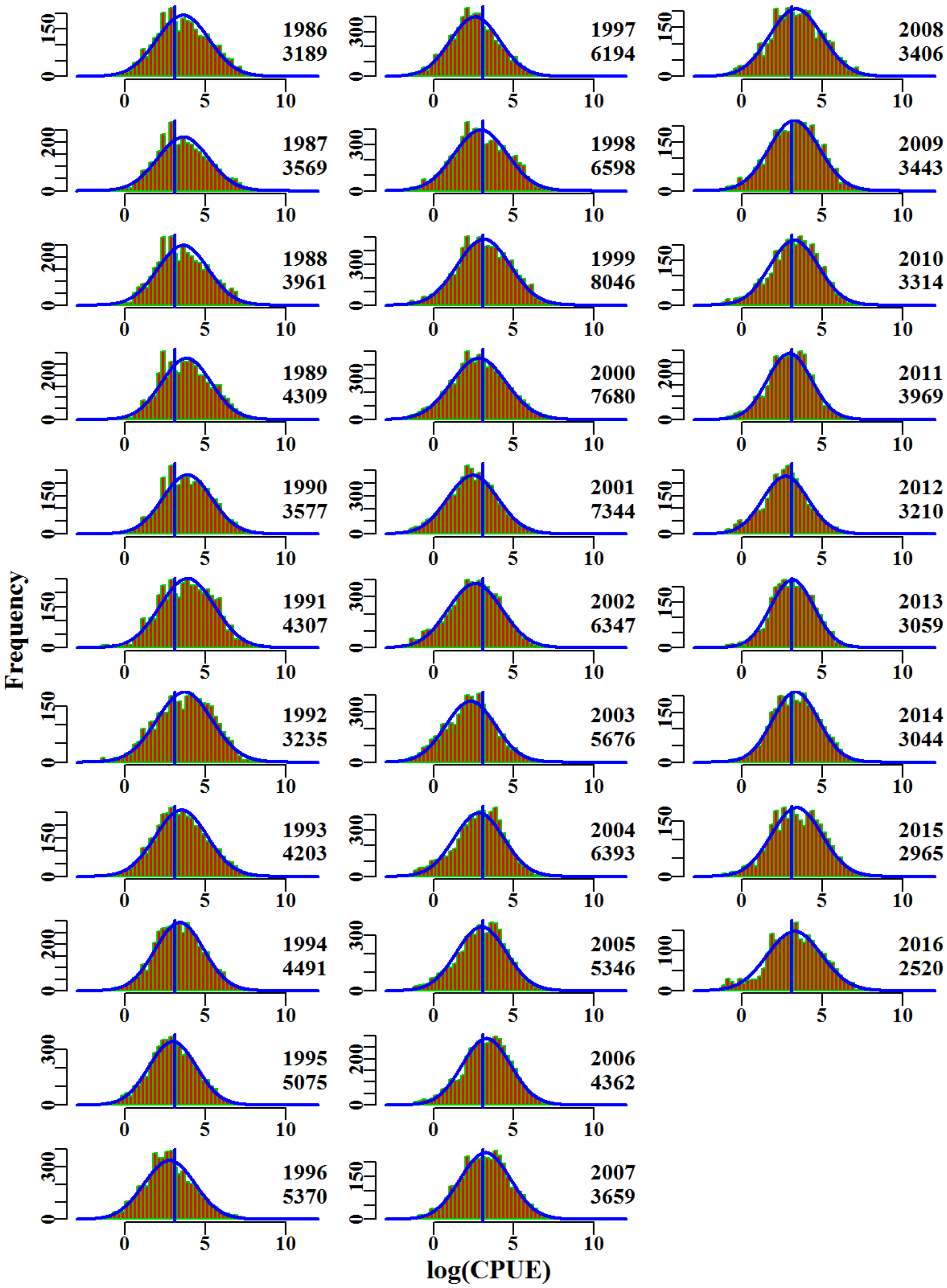


Figure 7.141. BlueGrenadierNS. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

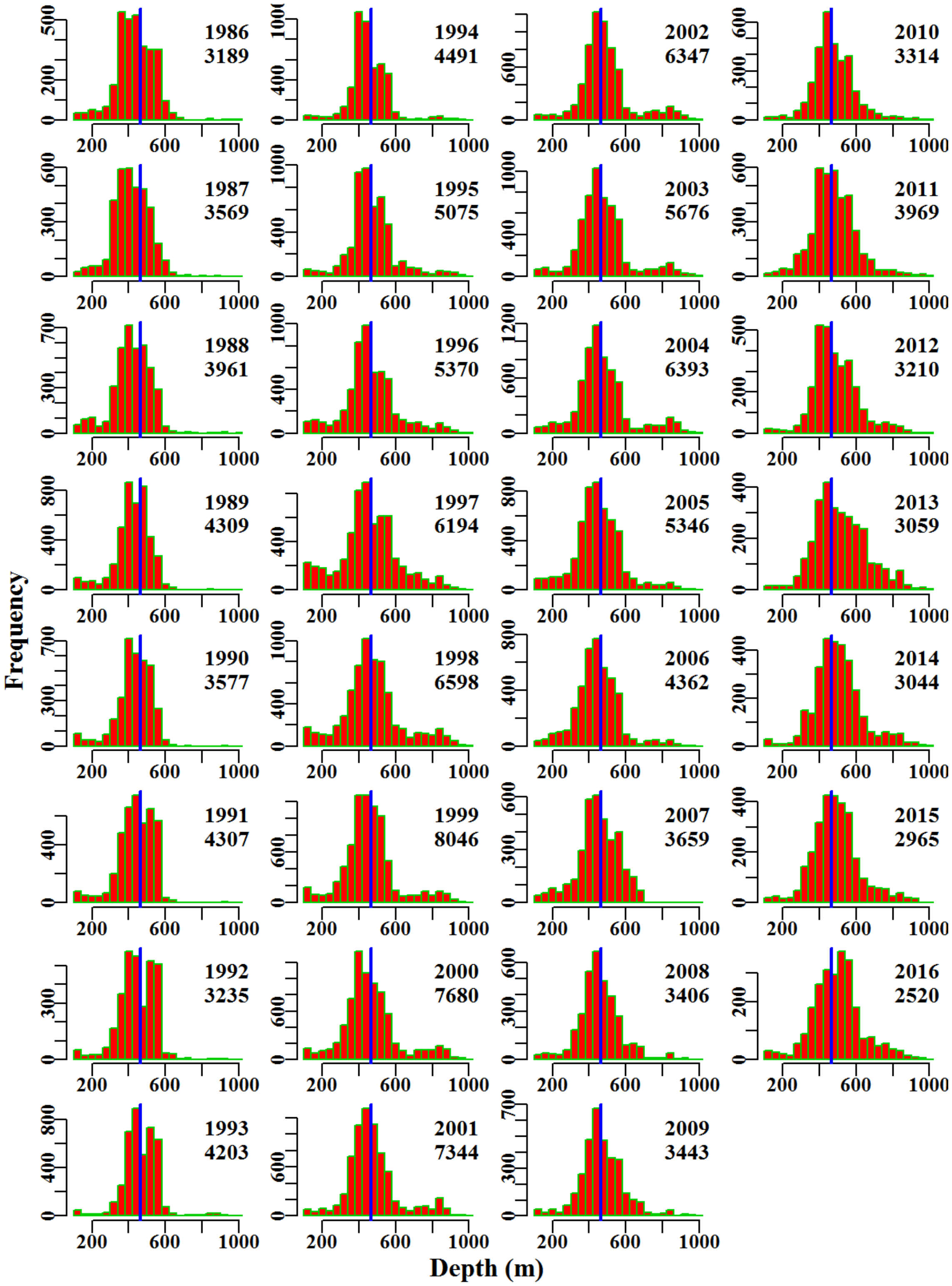


Figure 7.142. BlueGrenadierNS. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

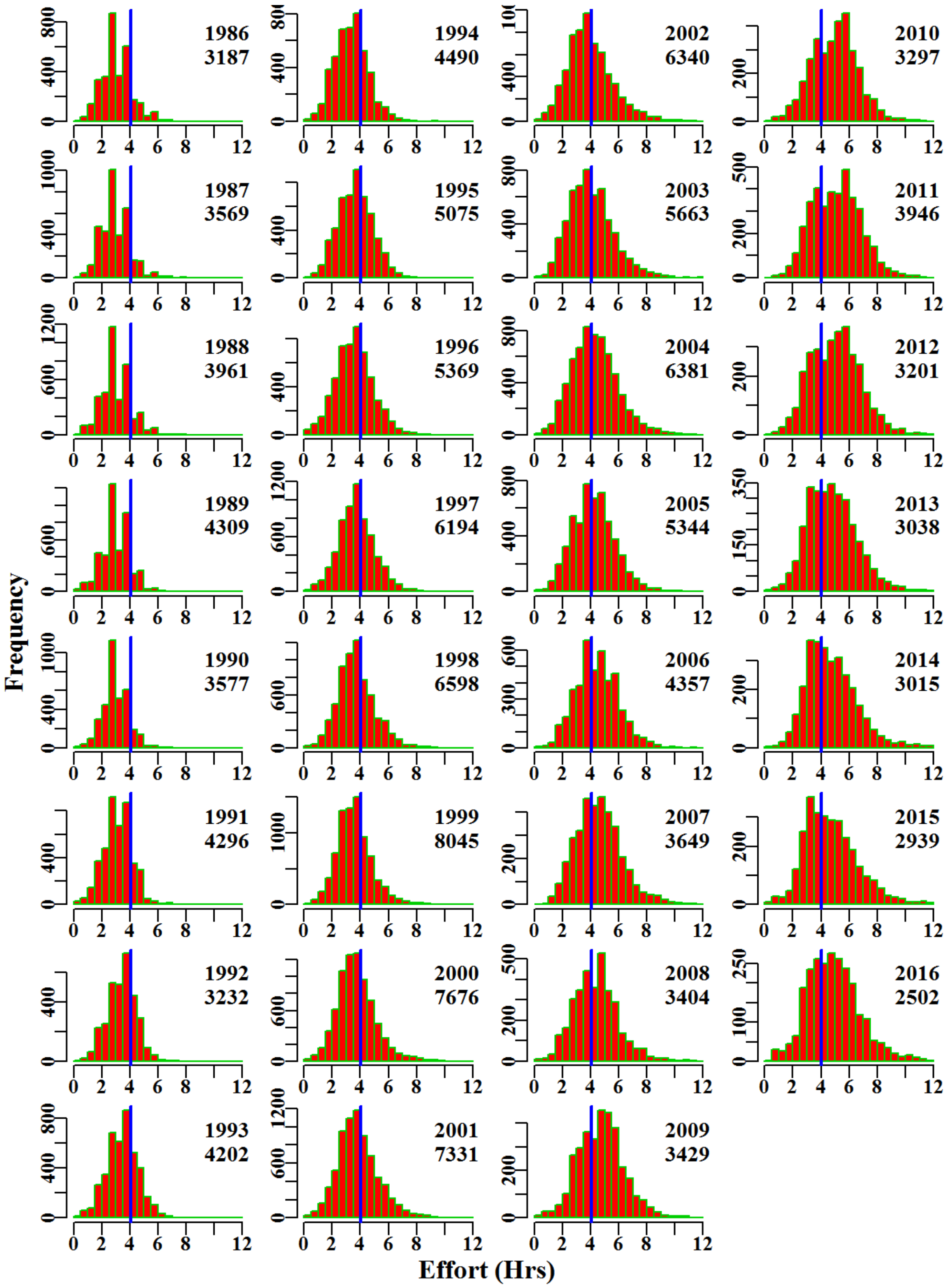


Figure 7.143. BlueGrenadierNS. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.22 Pink Ling 10 – 30

Pink Ling (LIG - 37228002 - *Genypterus blacodes*) caught by trawl based on methods TW, TDO, in zones 10, 20, 30, and depths 250 to 600 within the SET fishery for the years 1986 - 2016 were used in the analysis (Table 7.95).

A total of 8 statistical models were fitted sequentially to the available data.

7.22.1 *Inferences*

Pink Ling were mostly caught in zone 20, followed by zone 10 and 30 across the analysis period.

The terms Year, Vessel, DepCat and Month had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics.

Annual standardized CPUE have been below average since 2001, corresponding to a relatively flat trend (Figure 7.144). The structural adjustment had a major effect upon the influence of the vessel factor from 2006 or 2007 onwards.

7.22.2 *Action Items and Issues*

A detailed consideration be given to the change in vessel effects following the structural adjustment to ensure that the time-series of Pink Ling CPUE was not broken by this management intervention.

Table 7.91. PinkLing1030. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:DepCat.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	679.0	4512	498.3	80	44.9	1.1499	0.000	24.980	0.050
1987	765.1	4260	492.3	77	46.0	1.2227	0.022	22.714	0.046
1988	583.1	3613	400.1	77	40.5	1.1739	0.024	18.002	0.045
1989	678.9	3879	422.1	77	39.9	1.0159	0.023	20.261	0.048
1990	674.5	2794	413.1	68	52.3	1.4691	0.026	11.283	0.027
1991	736.8	2938	370.3	72	46.2	1.4363	0.026	13.494	0.036
1992	568.3	2437	331.3	58	45.7	1.1225	0.027	11.381	0.034
1993	892.8	3525	504.5	59	50.1	1.0684	0.025	17.396	0.034
1994	895.4	4066	470.3	63	42.6	1.0954	0.024	21.312	0.045
1995	1208.9	4361	586.7	57	49.2	1.3730	0.023	22.197	0.038
1996	1233.3	4268	667.6	63	56.1	1.3682	0.023	17.606	0.026
1997	1696.8	4808	732.7	62	52.1	1.3949	0.023	19.978	0.027
1998	1592.4	4909	730.5	57	53.1	1.3787	0.023	22.609	0.031
1999	1651.6	5964	832.7	59	48.7	1.2527	0.022	28.287	0.034
2000	1507.5	5112	660.3	63	46.3	1.1022	0.023	24.561	0.037
2001	1393.0	4569	485.6	53	38.0	0.8585	0.024	24.340	0.050
2002	1330.3	3902	360.6	52	35.3	0.7520	0.025	22.760	0.063
2003	1353.1	4310	445.8	57	38.7	0.7829	0.024	19.660	0.044
2004	1522.9	3359	347.2	54	37.2	0.7036	0.026	14.451	0.042
2005	1203.3	3454	329.9	51	32.4	0.6572	0.026	14.071	0.043
2006	1069.2	2593	323.1	38	42.0	0.7912	0.027	6.942	0.021
2007	875.9	1652	204.3	23	42.2	0.7504	0.032	4.627	0.023
2008	980.3	2382	329.0	24	46.6	0.8980	0.029	5.368	0.016
2009	775.0	1947	212.4	27	34.6	0.6396	0.030	5.226	0.025
2010	906.2	1991	271.1	23	48.2	0.7924	0.030	5.215	0.019
2011	1081.9	2201	294.9	22	47.3	0.8331	0.029	5.123	0.017
2012	1030.9	1972	273.3	24	49.8	0.8924	0.030	5.180	0.019
2013	752.9	1582	185.9	22	41.0	0.7378	0.032	4.594	0.025
2014	861.2	1648	235.3	24	49.1	0.8322	0.031	5.071	0.022
2015	721.8	1657	189.4	24	41.0	0.7213	0.032	5.325	0.028
2016	729.8	1546	194.1	25	41.4	0.7336	0.033	5.205	0.027

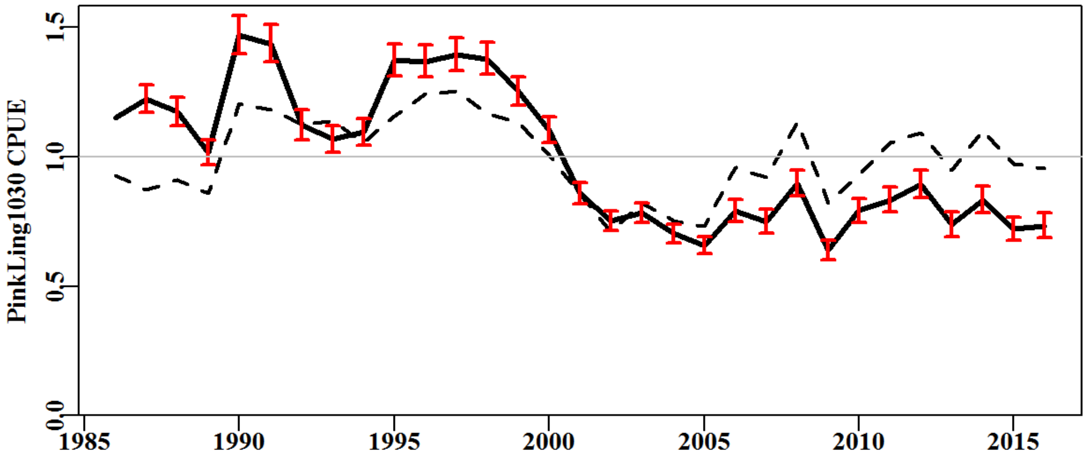


Figure 7.144. PinkLing1030 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

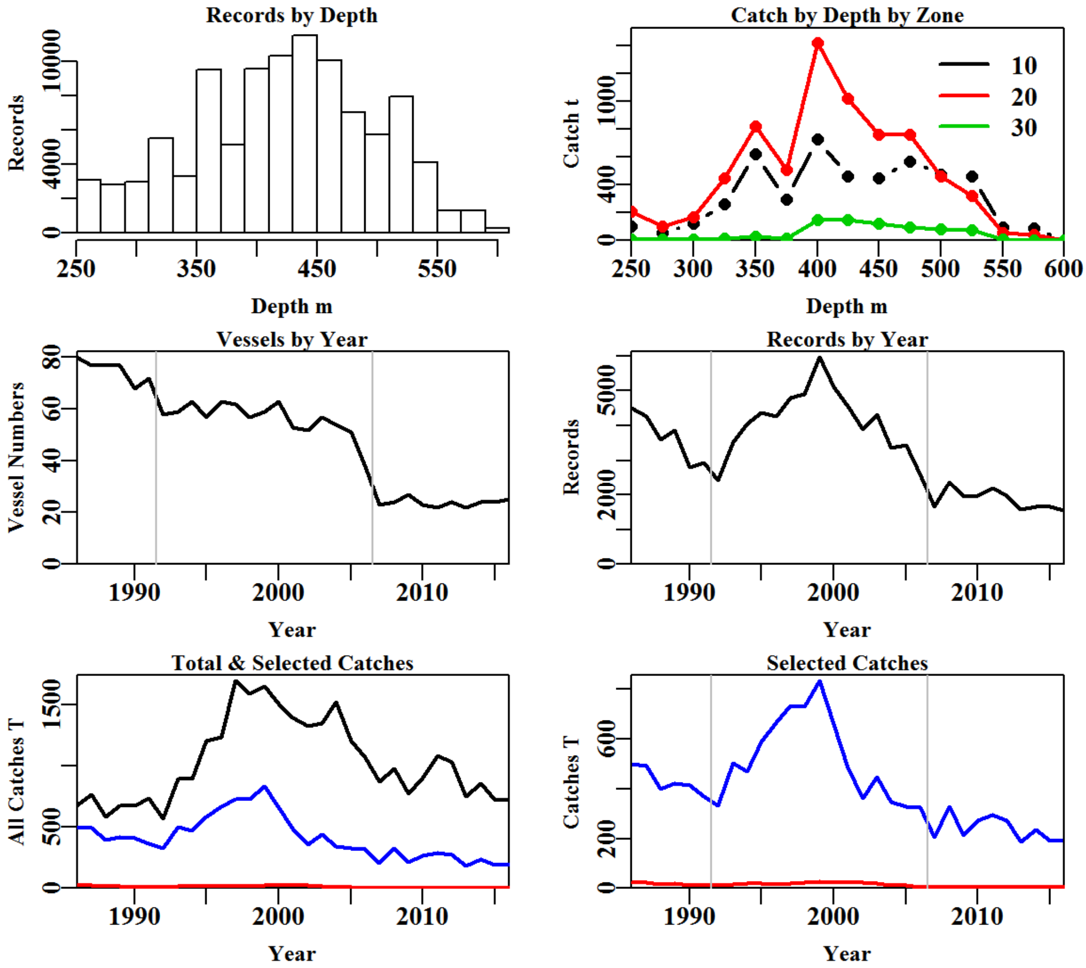


Figure 7.145. PinkLing1030 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.92. PinkLing1030 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	299423	274873	185316	183381	104388	102245	102211
Difference	0	24550	89557	1935	78993	2143	34

Table 7.93. The models used to analyse data for PinkLing1030.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + Month
Model5	Year + Vessel + DepCat + Month + Zone
Model6	Year + Vessel + DepCat + Month + Zone + DayNight
Model7	Year + Vessel + DepCat + Month + Zone + DayNight + Zone:DepCat
Model8	Year + Vessel + DepCat + Month + Zone + DayNight + Zone:Month

Table 7.94. PinkLing1030. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:DepCat.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	34287	142863	2770	102211	31	1.9	0.00
Vessel	16859	120030	25603	102211	217	17.4	15.53
DepCat	4826	105773	39861	101313	231	25.7	8.28
Month	809	101639	43994	101313	242	28.6	2.90
Zone	232	101058	44575	101313	244	29.0	0.41
DayNight	85	100905	44728	101313	247	29.1	0.11
Zone:DepCat	-1066	99710	45924	101313	275	29.9	0.82
Zone:Month	-988	99798	45835	101313	269	29.9	0.76

Table 7.95. PinkLing1030. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	PinkLing1030
csirocode	37228002
fishery	SET
depthrange	250 - 600
depthclass	25
zones	10, 20, 30
methods	TW, TDO
years	1986 - 2016

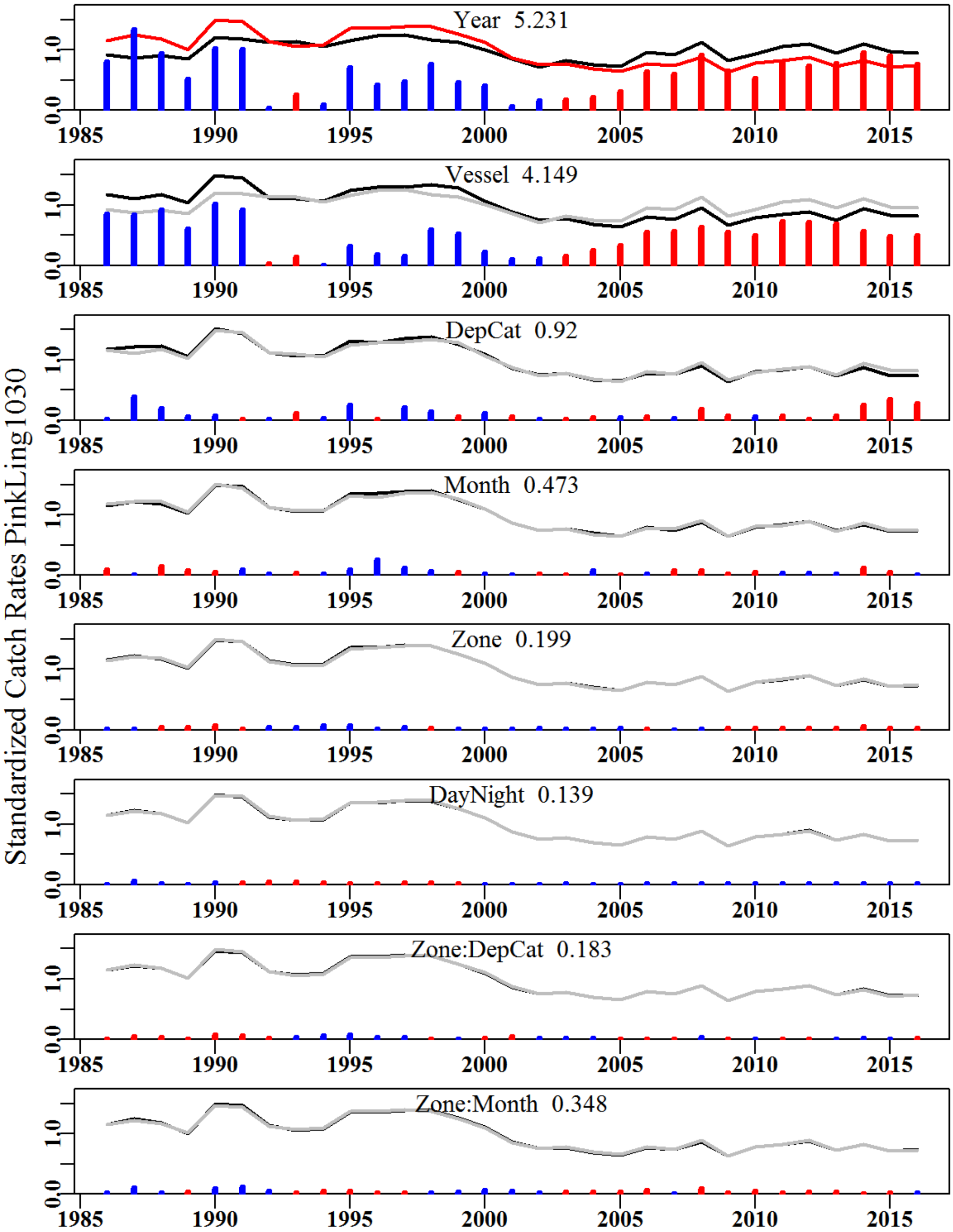


Figure 7.146. PinkLing1030. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

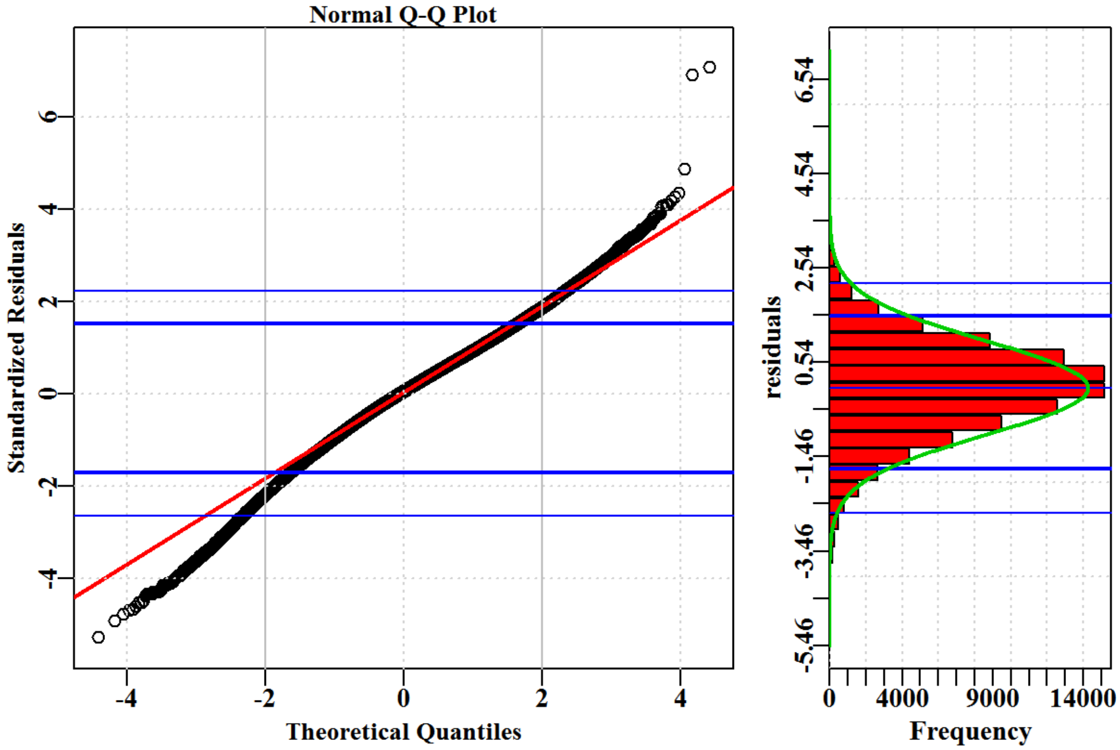


Figure 7.147. PinkLing1030. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

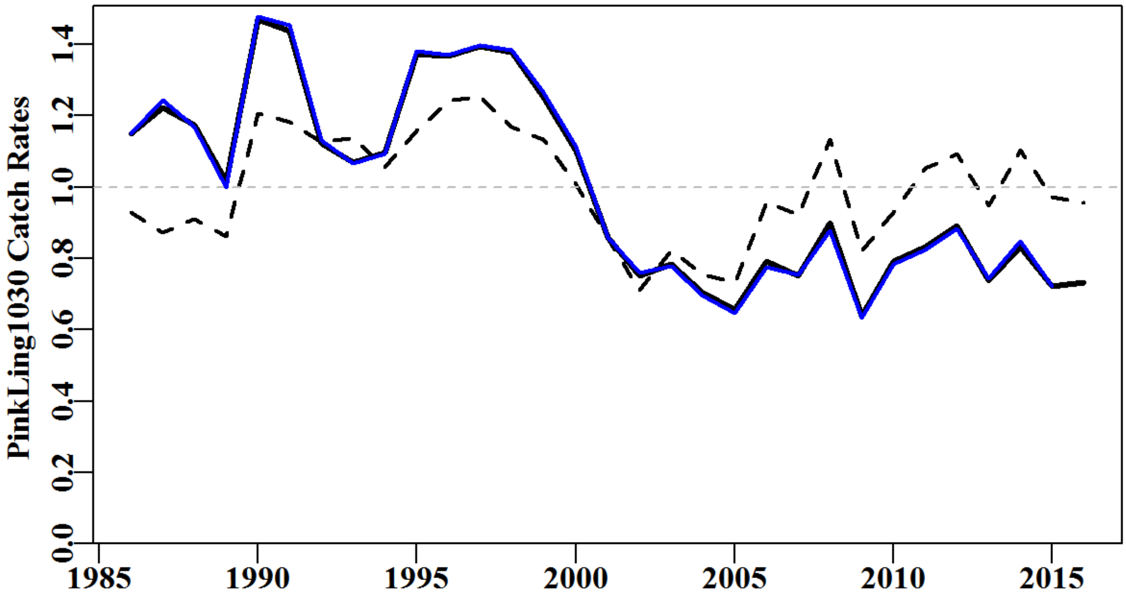


Figure 7.148. PinkLing1030. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

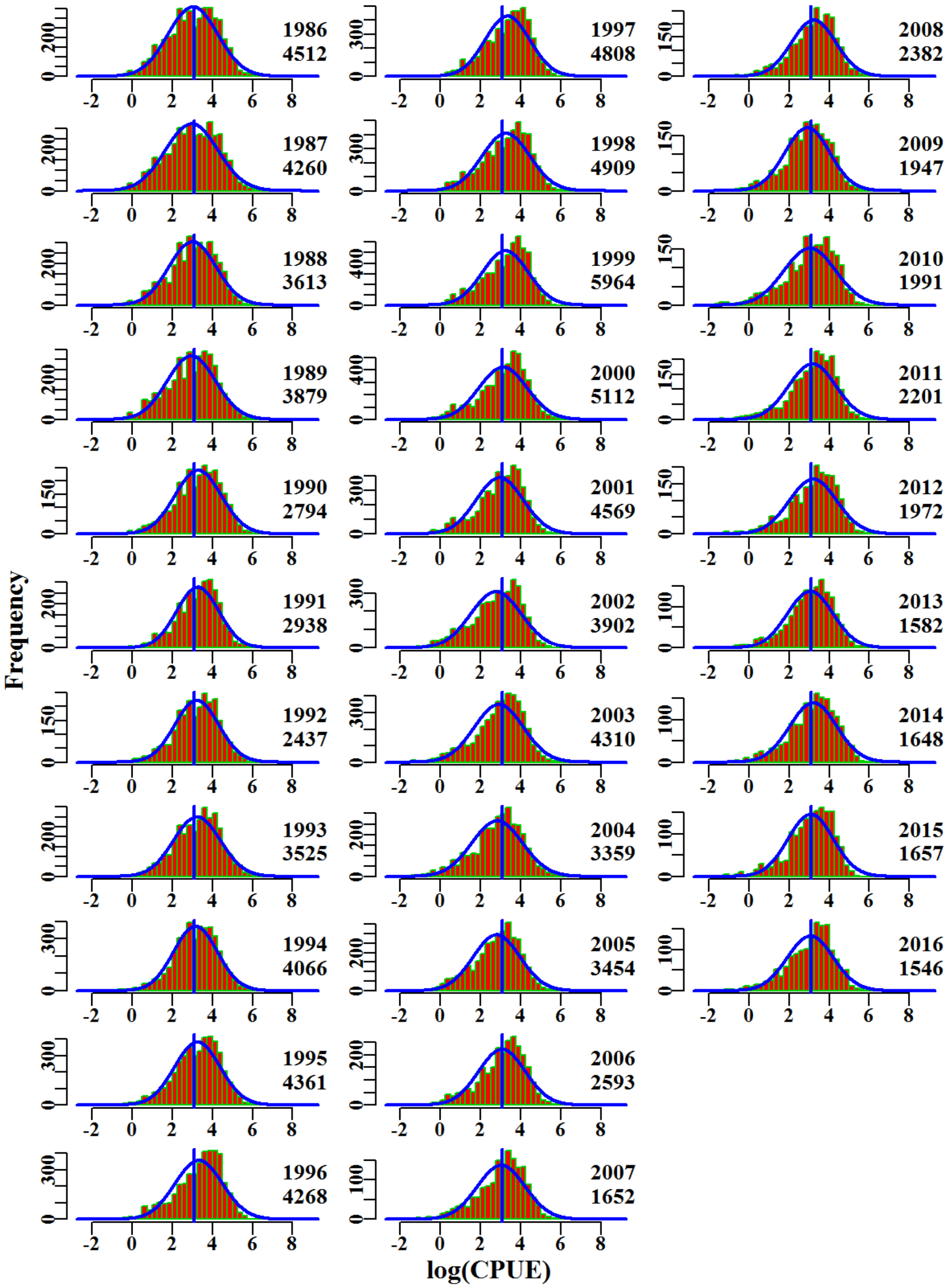


Figure 7.149. PinkLing1030. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

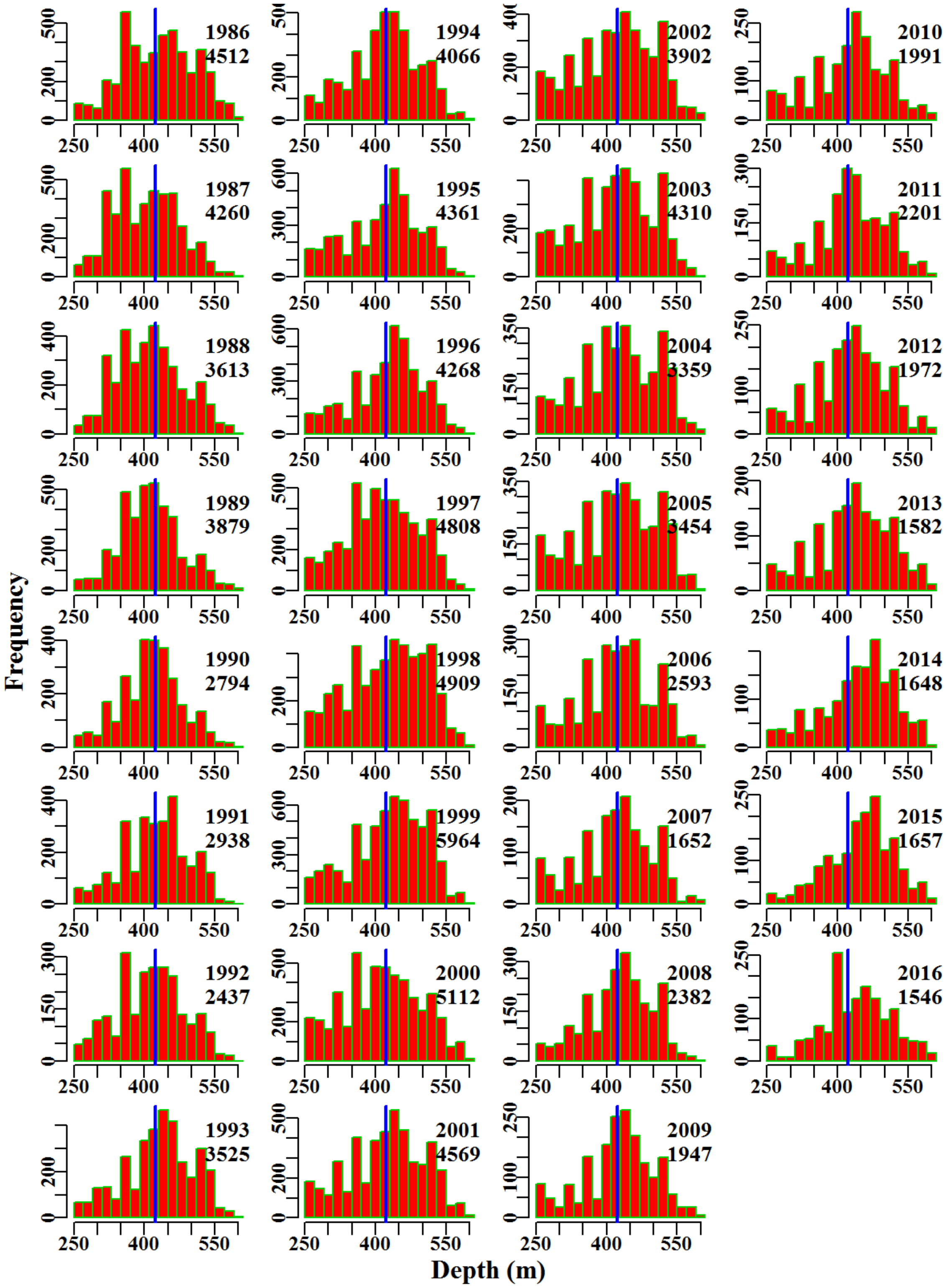


Figure 7.150. PinkLing1030. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

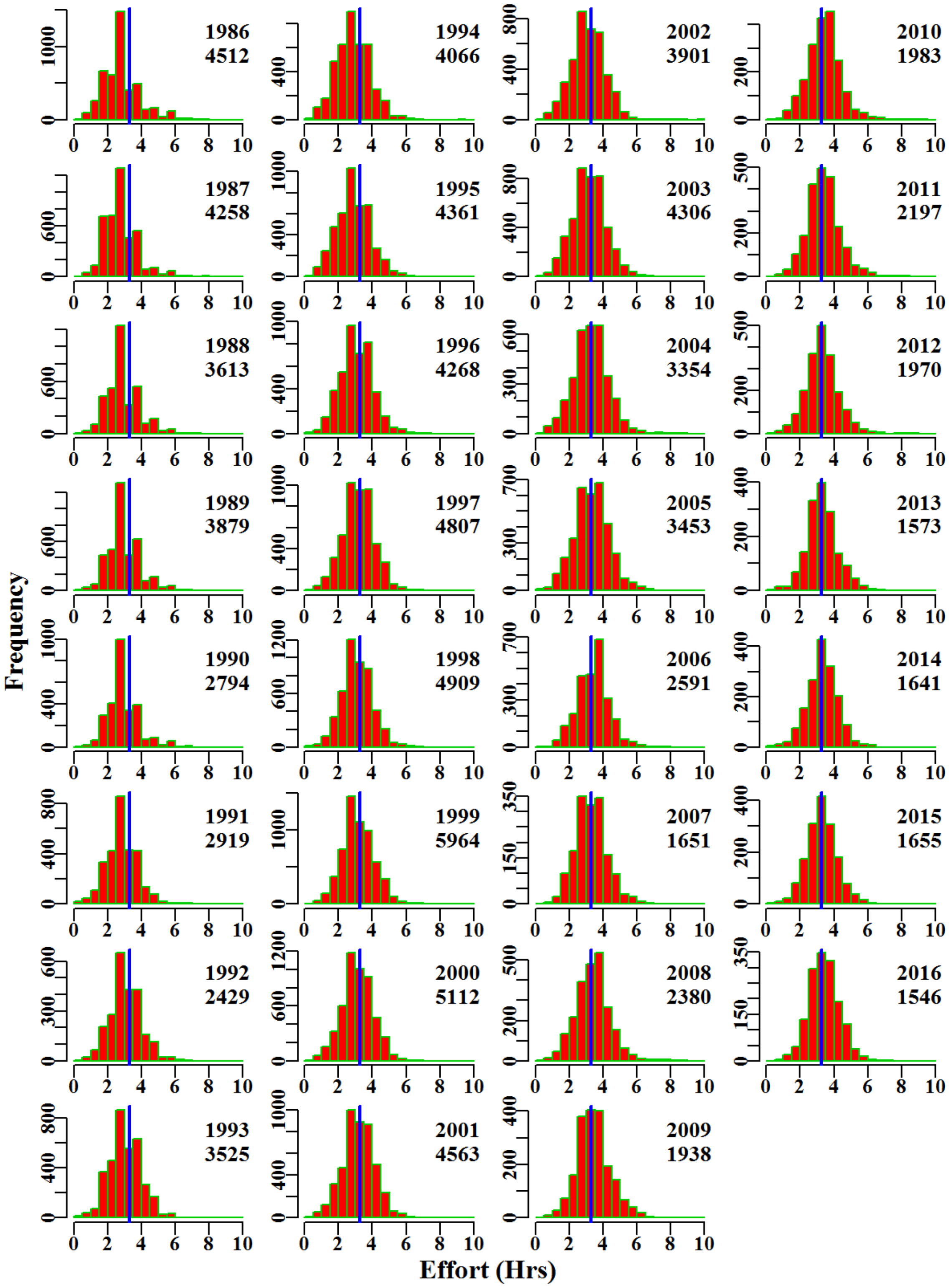


Figure 7.151. PinkLing1030. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.23 Pink Ling 40 – 50

Pink Ling (LIG - 37228002 - *Genypterus blacodes*) caught by trawl based on methods TW, TDO, in zones 40, 50, and depths 200 to 800 within the SET fishery for the years 1986 - 2016 were used in the analysis (Table 7.100).

A total of 8 statistical models were fitted sequentially to the available data.

7.23.1 *Inferences*

The majority of catch of this slope species occurred in zone 40. The terms Year, DepCat, Vessel, Month and Zone had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics.

Annual standardized CPUE reached a minimum in 2005 and have been increasing since then and have been at the long term average from 2013 - 2016 (Figure 7.152).

7.23.2 *Action Items and Issues*

Further work on the effect of the structural adjustment is required for Pink Ling in zones 40 and 50.

Table 7.96. PinkLing4050. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	679.0	1265	112.9	23	27.8	1.2006	0.000	6.366	0.056
1987	765.1	1310	206.3	28	51.9	1.3547	0.037	5.770	0.028
1988	583.1	1026	95.7	32	28.0	1.0585	0.040	6.742	0.070
1989	678.9	1469	183.1	34	36.2	1.0846	0.038	8.720	0.048
1990	674.5	1524	147.4	32	28.3	0.9738	0.039	11.993	0.081
1991	736.8	1896	198.9	37	25.9	1.0437	0.037	11.985	0.060
1992	568.3	1632	102.1	24	17.0	0.7759	0.038	12.691	0.124
1993	892.8	2253	235.5	24	26.6	1.0532	0.037	15.774	0.067
1994	895.4	2110	247.8	24	30.9	1.2840	0.036	12.143	0.049
1995	1208.9	3515	426.8	25	31.9	1.3327	0.034	22.065	0.052
1996	1233.3	3403	448.0	26	33.0	1.4014	0.035	22.411	0.050
1997	1696.8	3732	577.4	24	37.3	1.4687	0.034	21.195	0.037
1998	1592.4	3709	558.5	21	38.3	1.4493	0.035	19.130	0.034
1999	1651.6	3794	427.9	24	30.4	1.1420	0.034	23.876	0.056
2000	1507.5	4656	509.3	30	28.6	0.9957	0.034	31.276	0.061
2001	1393.0	5100	502.4	28	24.5	0.8818	0.034	36.957	0.074
2002	1330.3	4633	429.6	27	21.5	0.7635	0.034	36.669	0.085
2003	1353.1	3822	360.2	27	20.5	0.7668	0.034	26.324	0.073
2004	1522.9	3901	306.2	25	17.7	0.7198	0.035	17.758	0.058
2005	1203.3	2663	195.7	23	15.6	0.5997	0.036	11.350	0.058
2006	1069.2	2322	210.0	21	17.9	0.6336	0.036	6.803	0.032
2007	875.9	2532	287.3	16	21.7	0.6936	0.036	7.741	0.027
2008	980.3	1795	214.2	17	24.6	0.8894	0.038	4.396	0.021
2009	775.0	1976	260.6	13	24.5	0.8644	0.037	4.177	0.016
2010	906.2	2337	272.2	14	21.0	0.8442	0.036	4.838	0.018
2011	1081.9	2792	356.9	16	21.5	0.8427	0.036	5.266	0.015
2012	1030.9	2342	345.0	14	25.7	0.8849	0.037	4.565	0.013
2013	752.9	1780	282.7	17	28.0	0.9964	0.038	3.646	0.013
2014	861.2	1948	285.1	15	24.8	0.9804	0.038	3.537	0.012
2015	721.8	1636	237.8	13	25.1	0.9570	0.039	2.655	0.011
2016	729.8	1583	233.3	13	27.9	1.0629	0.039	3.466	0.015

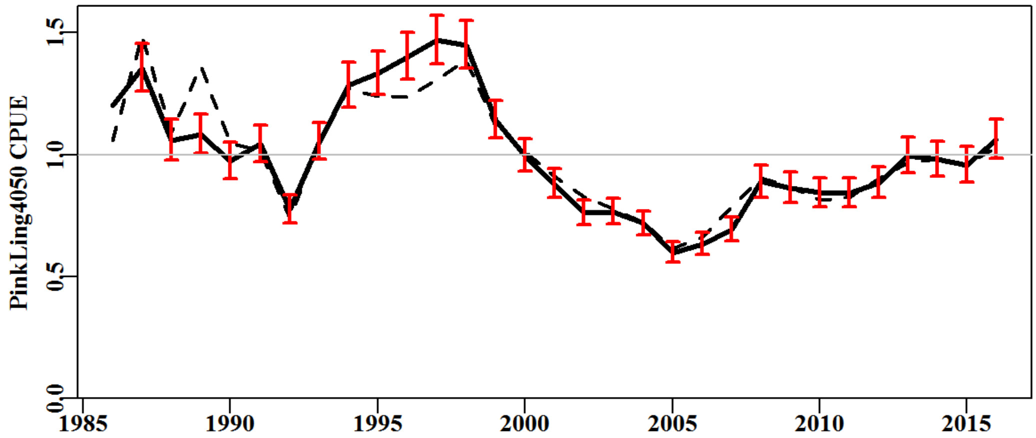


Figure 7.152. PinkLing4050 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

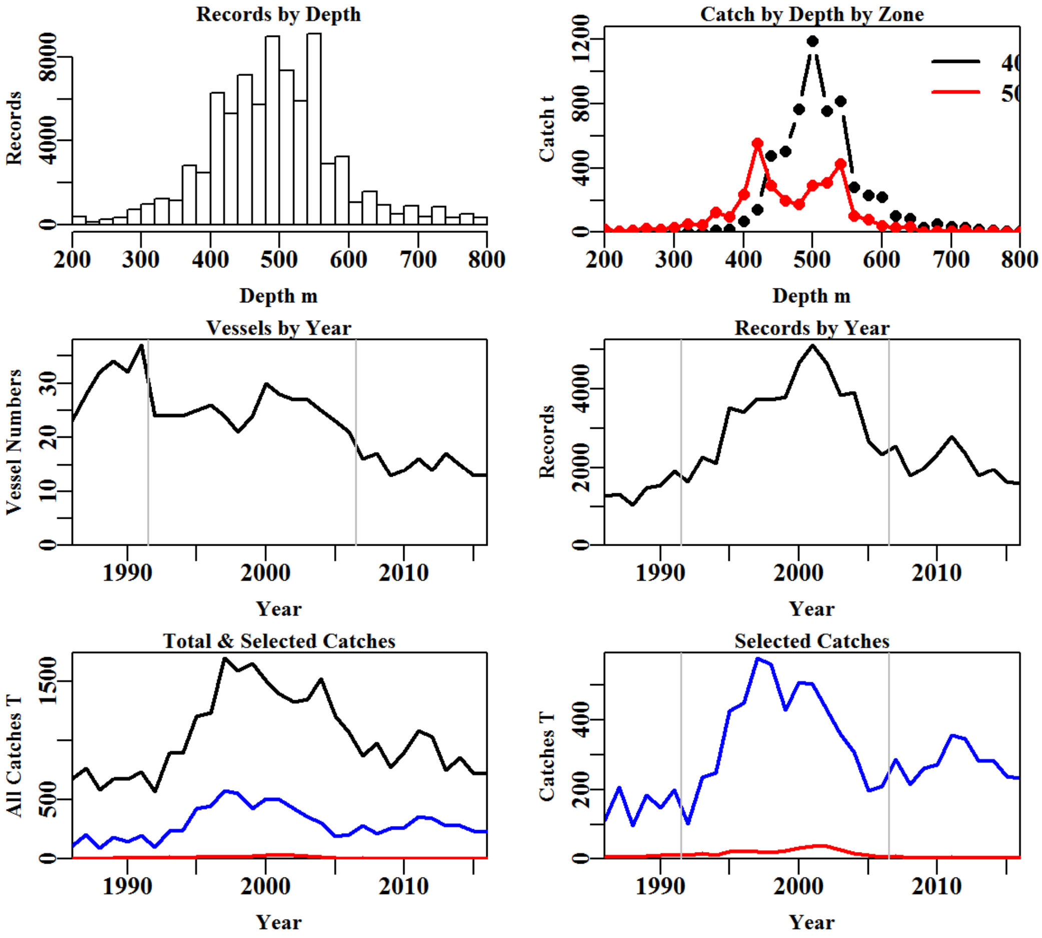


Figure 7.153. PinkLing4050 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.97. PinkLing4050 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	299423	274873	205323	203267	81359	80540	80456
Difference	0	24550	69550	2056	121908	819	84

Table 7.98. The models used to analyse data for PinkLing4050.

	Model
Model1	Year
Model2	Year + DepCat
Model3	Year + DepCat + Vessel
Model4	Year + DepCat + Vessel + Month
Model5	Year + DepCat + Vessel + Month + Zone
Model6	Year + DepCat + Vessel + Month + Zone + DayNight
Model7	Year + DepCat + Vessel + Month + Zone + DayNight + Zone:DepCat
Model8	Year + DepCat + Vessel + Month + Zone + DayNight + Zone:Month

Table 7.99. PinkLing4050. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	150	80544	3901	80456	31	4.6	0.00
DepCat	-11505	69131	15315	79952	61	17.4	12.81
Vessel	-18303	63340	21105	79952	159	24.2	6.83
Month	-21115	61135	23311	79952	170	26.8	2.63
Zone	-22280	60249	24197	79952	171	27.9	1.06
DayNight	-22311	60221	24225	79952	174	27.9	0.03
Zone:DepCat	-23163	59538	24908	79952	204	28.7	0.79
Zone:Month	-23828	59072	25373	79952	185	29.3	1.36

Table 7.100. PinkLing4050. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	PinkLing4050
csirocode	37228002
fishery	SET
depthrange	200 - 800
depthclass	20
zones	40, 50
methods	TW, TDO
years	1986 - 2016

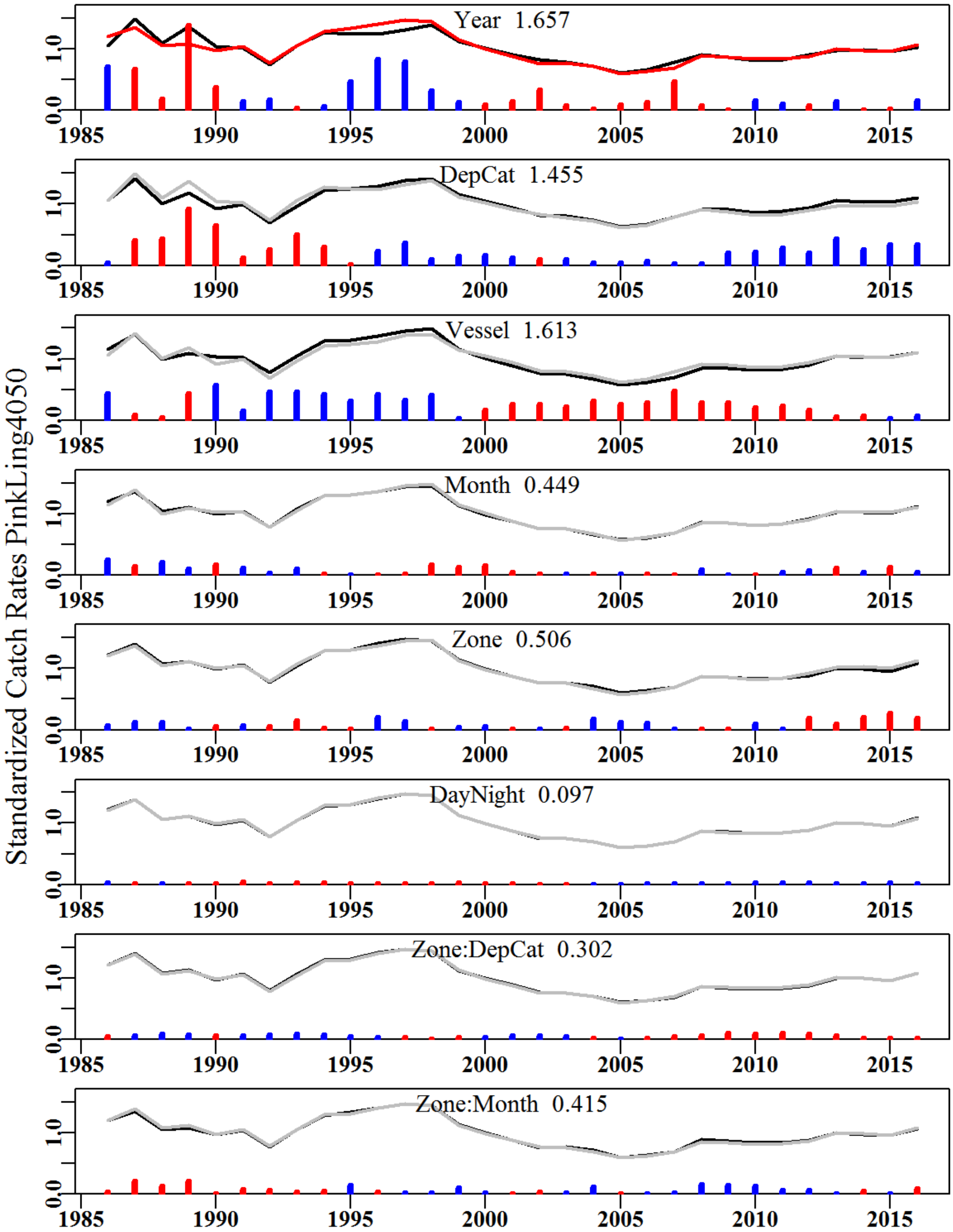


Figure 7.154. PinkLing4050. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

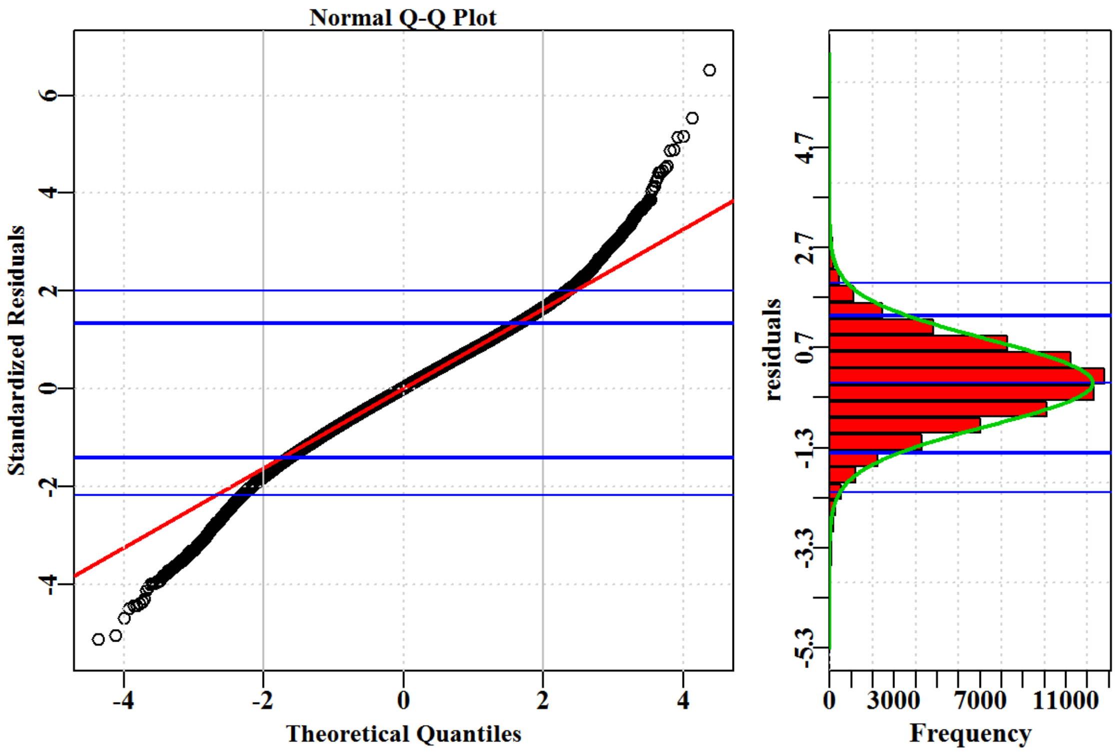


Figure 7.155. PinkLing4050. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

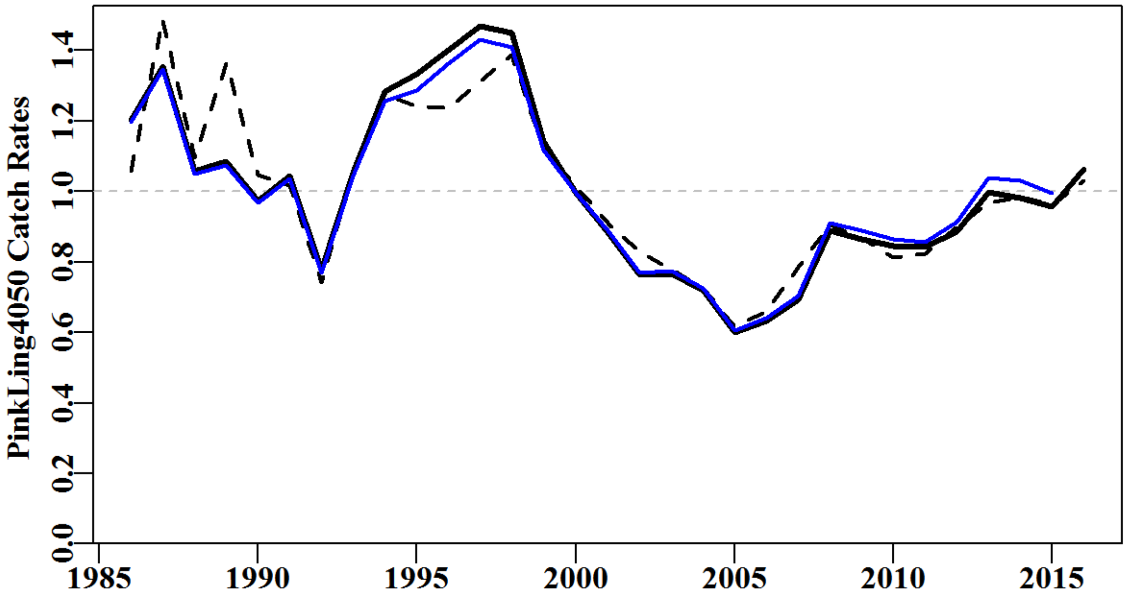


Figure 7.156. PinkLing4050. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

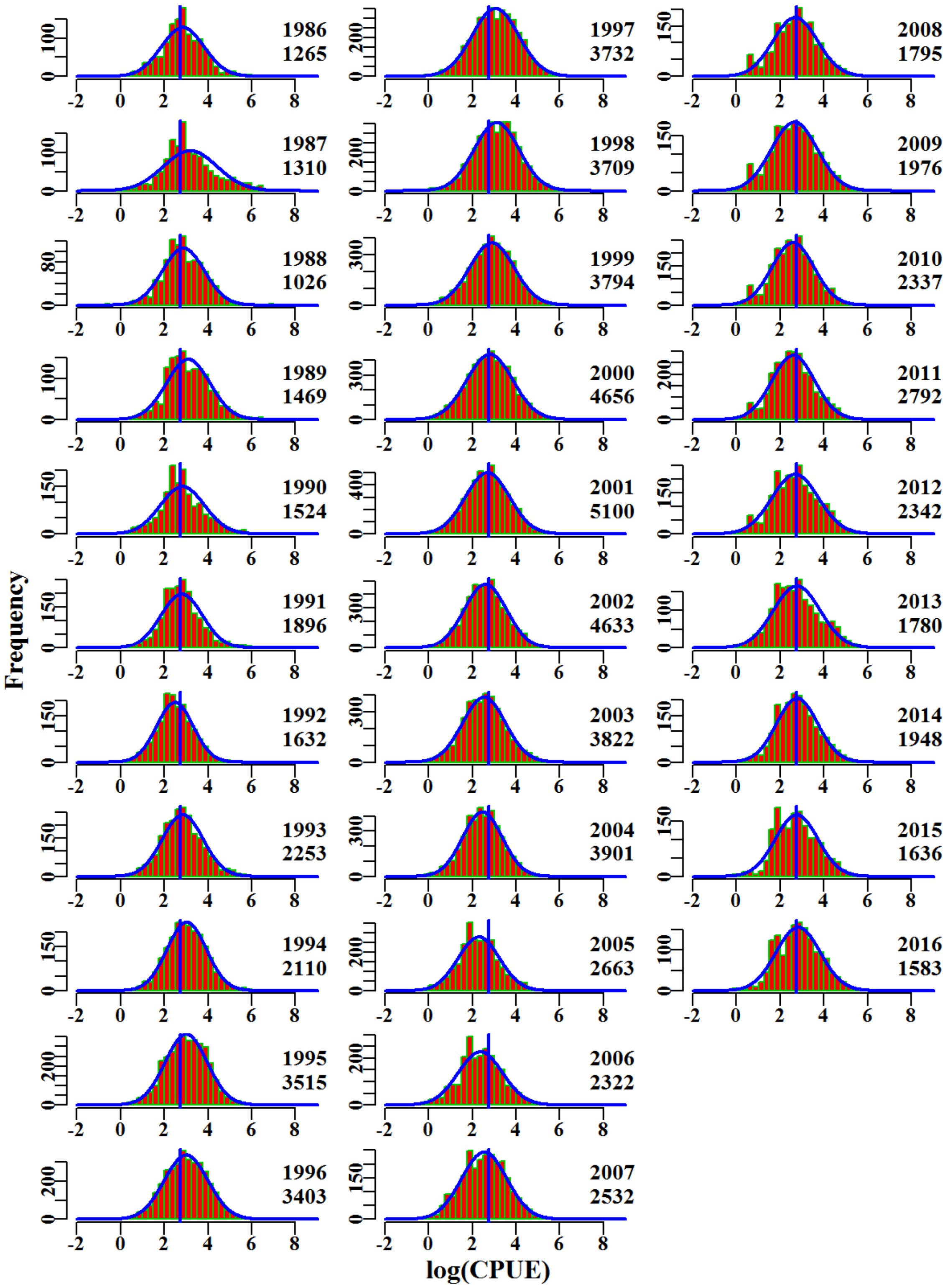


Figure 7.157. PinkLing4050. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

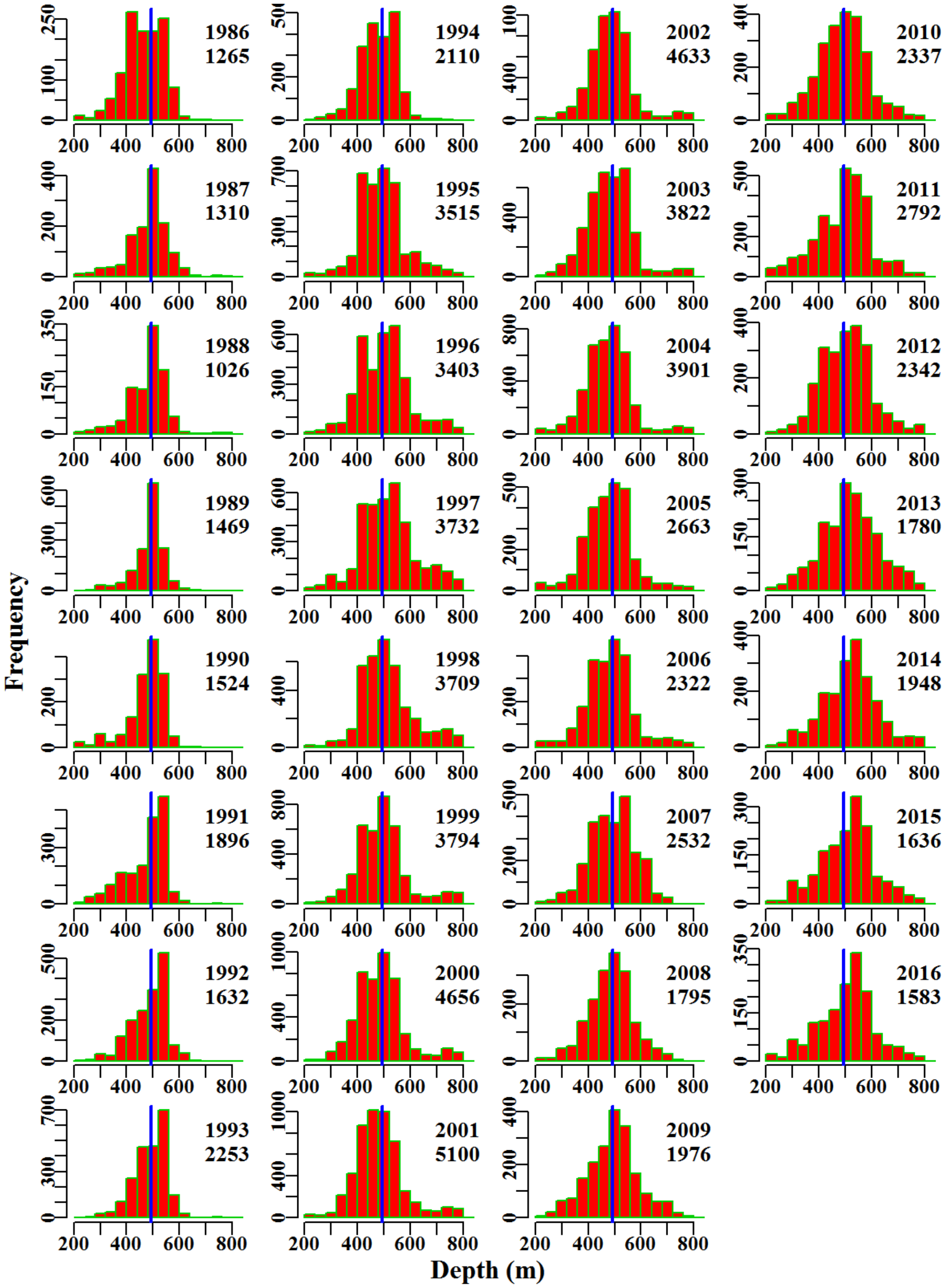


Figure 7.158. PinkLing4050. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

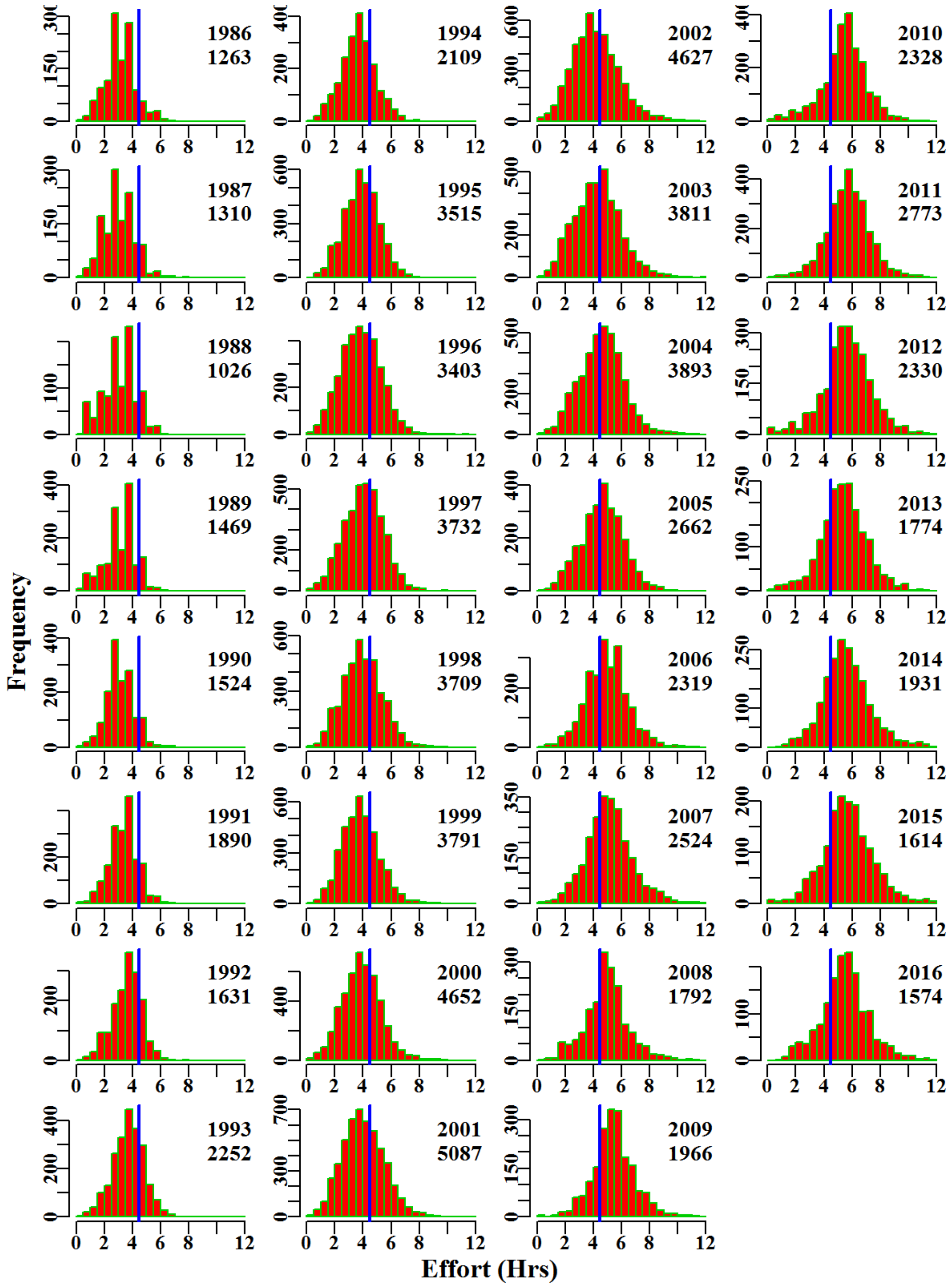


Figure 7.159. PinkLing4050. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.24 Ocean Perch Offshore 1020

Offshore Ocean Perch (REG - 37287001 - *Helicolenus percoides*) caught by trawl based on methods TW, TDO, in zones 10, 20, and depths 200 to 700 within the SET fishery for the years 1986 - 2016 were used in the analysis (Table 7.105).

A total of 8 statistical models were fitted sequentially to the available data.

7.24.1 *Inferences*

The majority of catch of this species occurred in zone 10 followed by zone 20. Over the period when CPUE was lower than average (about 1996 - 2006) there was an increase in small shots of < 30kg (Figure 7.161), which is suggestive or either low availability of high levels of small fish.

The terms Year, Month, Vessel and DepCat had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics.

Annual standardized CPUE have been below average and relatively flat between 1995 and 2006. The trend from 2007 has also been relatively flat and mostly just above average (Figure 7.160).

7.24.2

No issues identified.

Table 7.101. OceanPerchOffshore1020. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	262.4	3479	207.4	77	21.5	1.0266	0.000	27.367	0.132
1987	198.4	3140	132.8	70	15.8	0.9553	0.026	27.720	0.209
1988	188.4	2808	150.8	73	18.6	1.0652	0.027	23.405	0.155
1989	209.2	3036	160.0	67	19.6	1.0232	0.027	24.607	0.154
1990	181.7	1970	115.9	57	20.6	1.3651	0.030	15.900	0.137
1991	223.6	2093	139.0	53	24.4	1.4258	0.029	17.070	0.123
1992	169.7	1855	114.4	48	20.4	1.2053	0.030	16.217	0.142
1993	259.6	2924	199.2	53	21.7	1.2093	0.027	25.211	0.127
1994	257.3	3014	181.0	49	22.0	1.1237	0.027	26.439	0.146
1995	240.0	3146	150.3	50	18.1	0.9986	0.027	31.983	0.213
1996	263.9	3411	176.8	53	17.8	0.8884	0.026	31.516	0.178
1997	298.8	3725	193.8	54	17.3	0.9394	0.026	35.631	0.184
1998	295.0	3850	194.6	49	17.3	0.8353	0.026	36.582	0.188
1999	295.8	4406	219.1	52	16.8	0.9306	0.025	42.934	0.196
2000	270.2	4180	180.9	54	14.9	0.7768	0.026	40.694	0.225
2001	281.6	4063	184.8	43	16.7	0.8937	0.026	38.441	0.208
2002	255.3	3648	150.7	45	15.9	0.8367	0.027	32.918	0.218
2003	322.7	3960	185.0	53	17.3	0.8888	0.026	35.123	0.190
2004	316.3	3129	150.5	46	17.9	0.8953	0.028	25.970	0.173
2005	316.8	3089	170.1	46	20.0	1.0078	0.028	26.438	0.155
2006	237.6	2326	113.2	39	15.6	0.8721	0.030	23.197	0.205
2007	180.6	1528	94.9	22	20.1	1.1101	0.033	14.186	0.149
2008	184.3	1843	101.8	23	17.5	1.0140	0.032	16.411	0.161
2009	173.9	1694	99.6	23	19.7	1.0032	0.033	15.900	0.160
2010	195.6	1759	118.1	21	22.5	0.9869	0.032	14.677	0.124
2011	186.9	1874	116.7	22	23.2	0.9012	0.032	15.544	0.133
2012	183.9	1693	114.1	22	26.0	0.9541	0.033	13.394	0.117
2013	171.2	1280	102.4	20	30.1	1.0052	0.035	9.212	0.090
2014	174.4	1523	115.9	21	29.9	1.0121	0.033	10.421	0.090
2015	150.8	1409	105.1	22	31.6	0.8670	0.035	9.158	0.087
2016	132.1	1164	95.0	23	30.9	0.9830	0.037	7.238	0.076

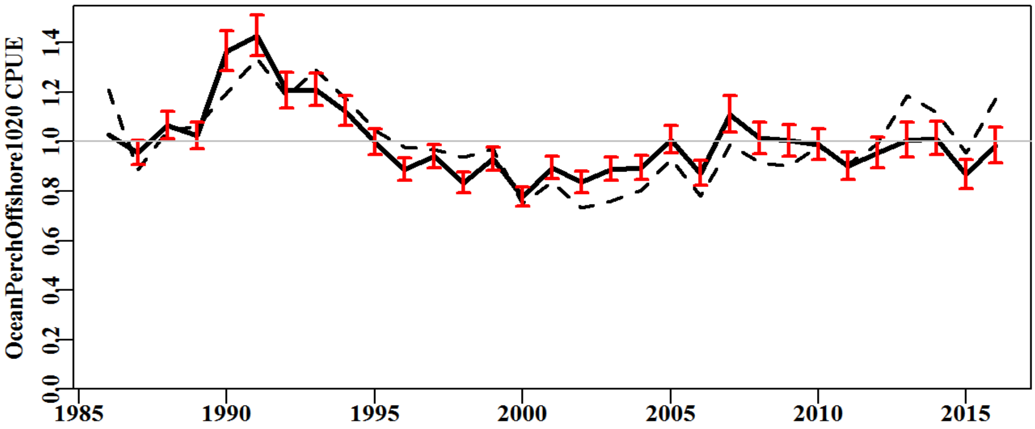


Figure 7.160. OceanPerchOffshore1020 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

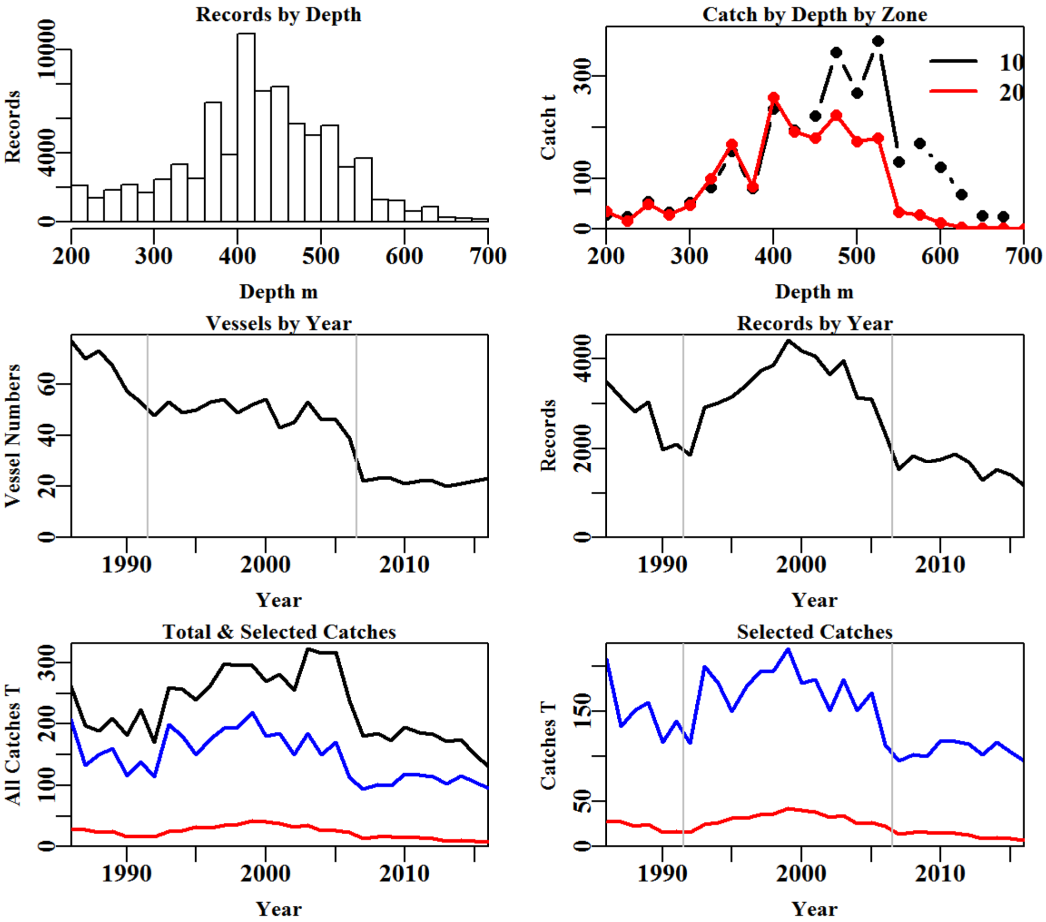


Figure 7.161. OceanPerchOffshore1020 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.102. OceanPerchOffshore1020 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	165571	151043	123583	122180	83778	83057	83019
Difference	0	14528	27460	1403	38402	721	38

Table 7.103. The models used to analyse data for OceanPerchOffshore1020.

	Model
Model1	Year
Model2	Year + Month
Model3	Year + Month + Vessel
Model4	Year + Month + Vessel + DepCat
Model5	Year + Month + Vessel + DepCat + DayNight
Model6	Year + Month + Vessel + DepCat + DayNight + Zone
Model7	Year + Month + Vessel + DepCat + DayNight + Zone + Zone:Month
Model8	Year + Month + Vessel + DepCat + DayNight + Zone + Zone:DepCat

Table 7.104. OceanPerchOffshore1020. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	25747	113121	2239	83019	31	1.9	0.00
Month	24392	111259	4101	83019	42	3.5	1.60
Vessel	10939	94249	21111	83019	203	18.1	14.59
DepCat	584	82725	32636	82587	223	27.6	9.54
DayNight	54	82190	33171	82587	226	28.1	0.47
Zone	16	82150	33211	82587	227	28.1	0.03
Zone:Month	-2054	80095	35265	82587	238	29.9	1.79
Zone:DepCat	-351	81746	33614	82587	247	28.5	0.34

Table 7.105. OceanPerchOffshore1020. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	OceanPerchOffshore1020
csirocode	37287001
fishery	SET
depthrange	200 - 700
depthclass	25
zones	10, 20
methods	TW, TDO
years	1986 - 2016

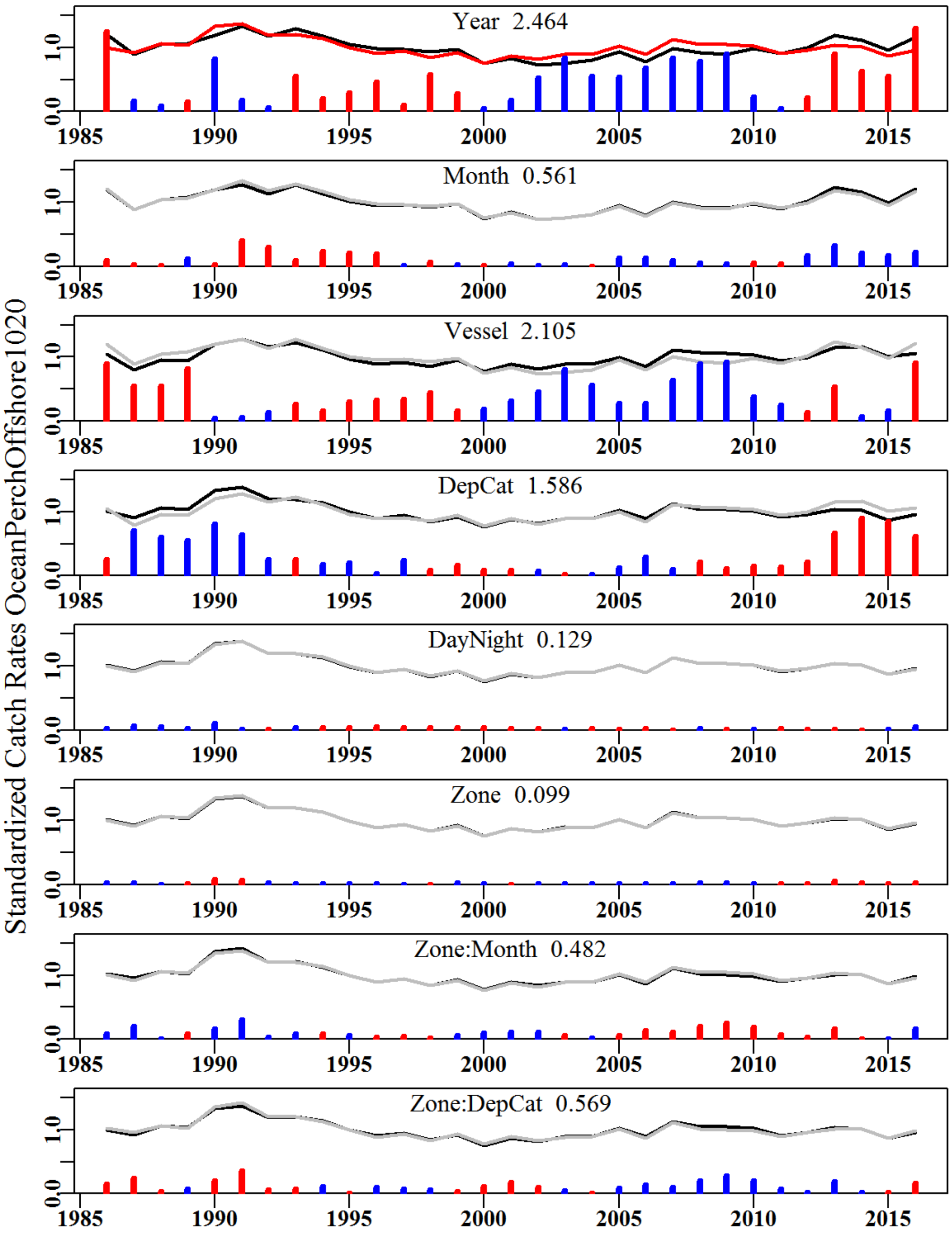


Figure 7.162. OceanPerchOffshore1020. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

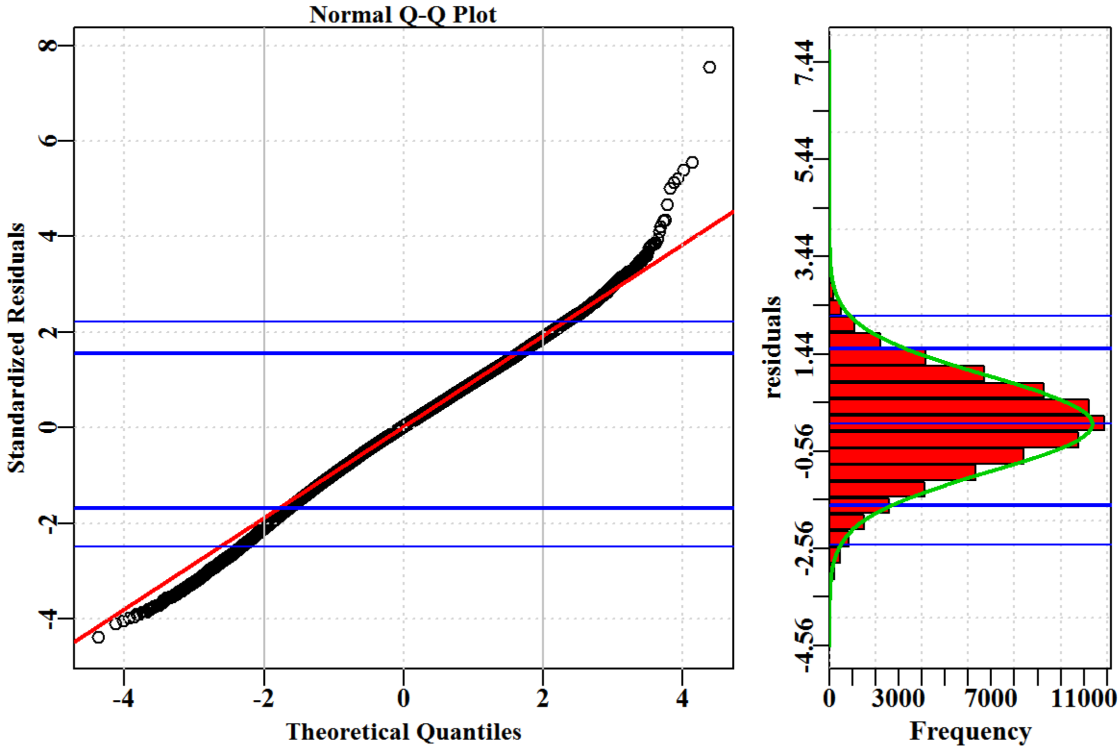


Figure 7.163. OceanPerchOffshore1020. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

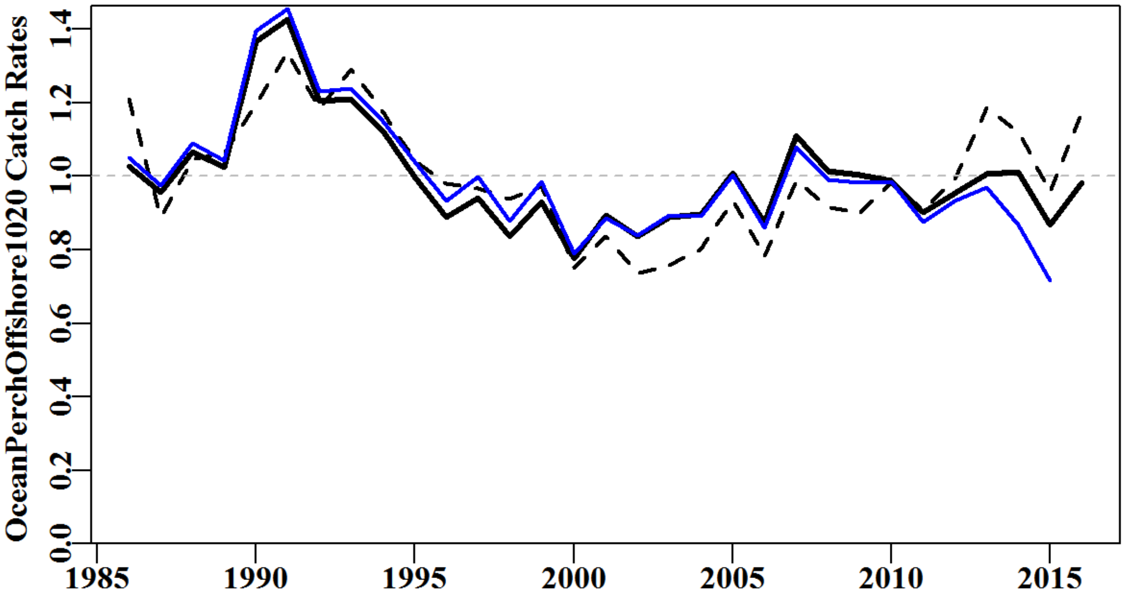


Figure 7.164. OceanPerchOffshore1020. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

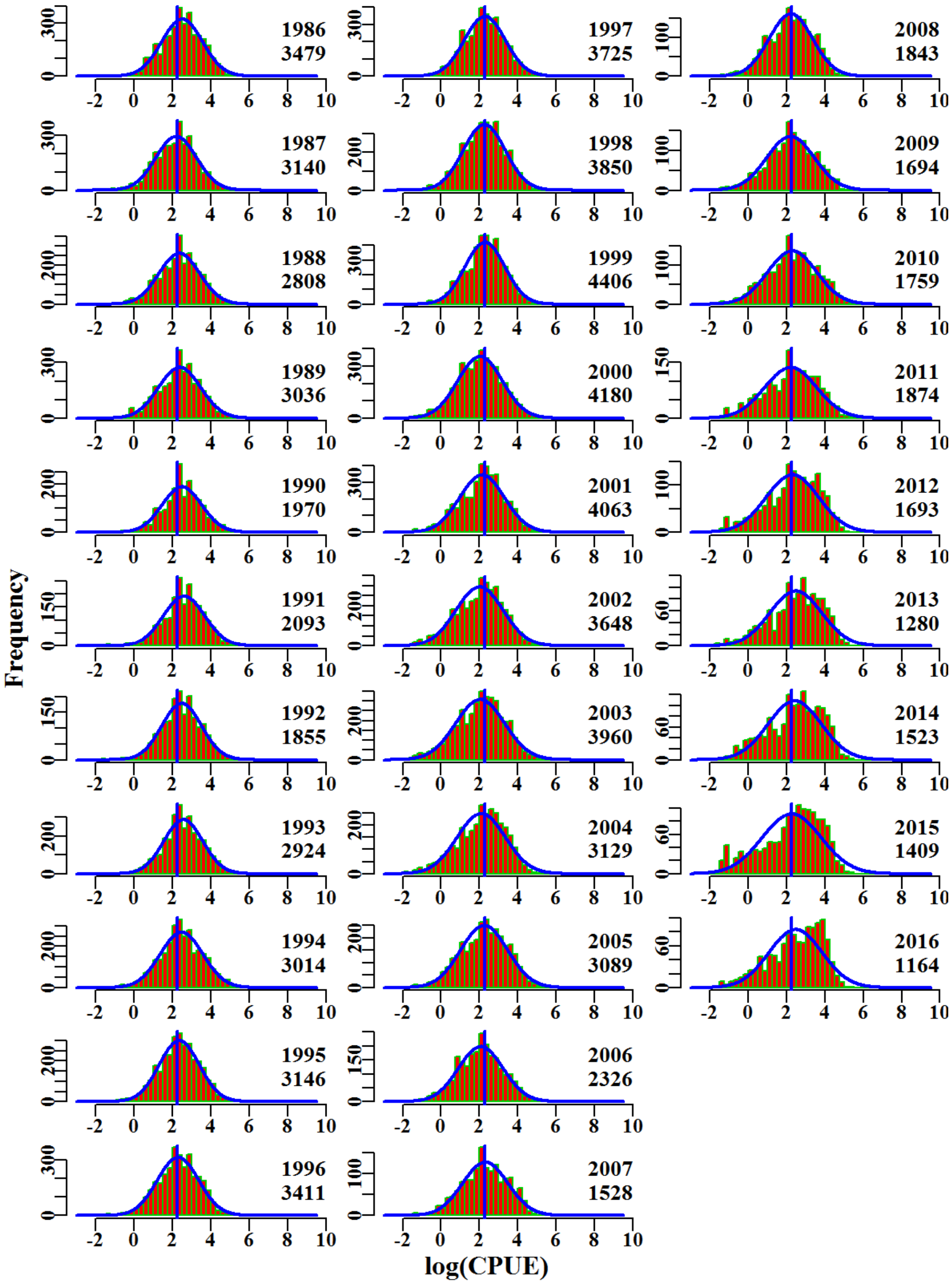


Figure 7.165. OceanPerchOffshore1020. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

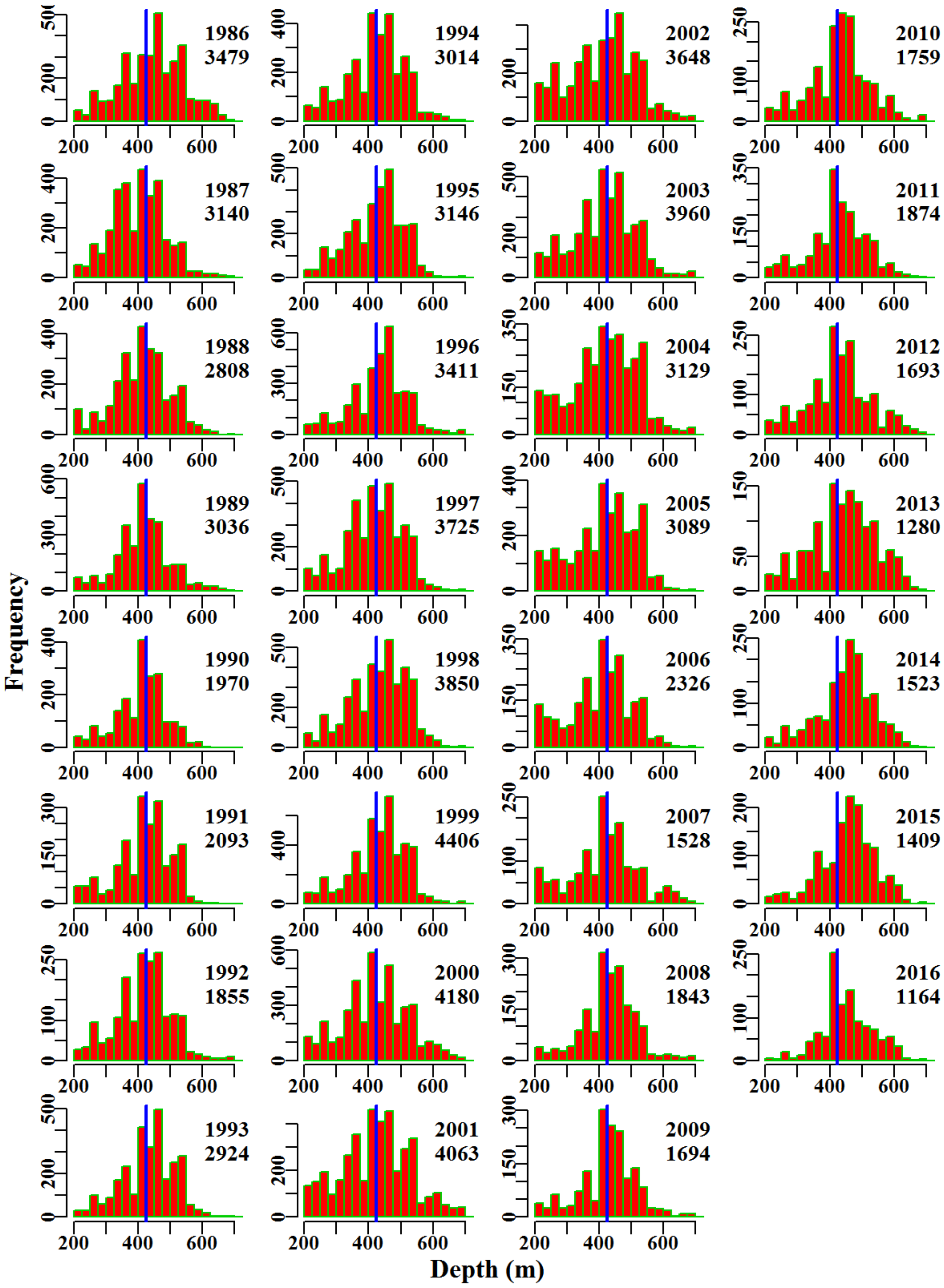


Figure 7.166. OceanPerchOffshore1020. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

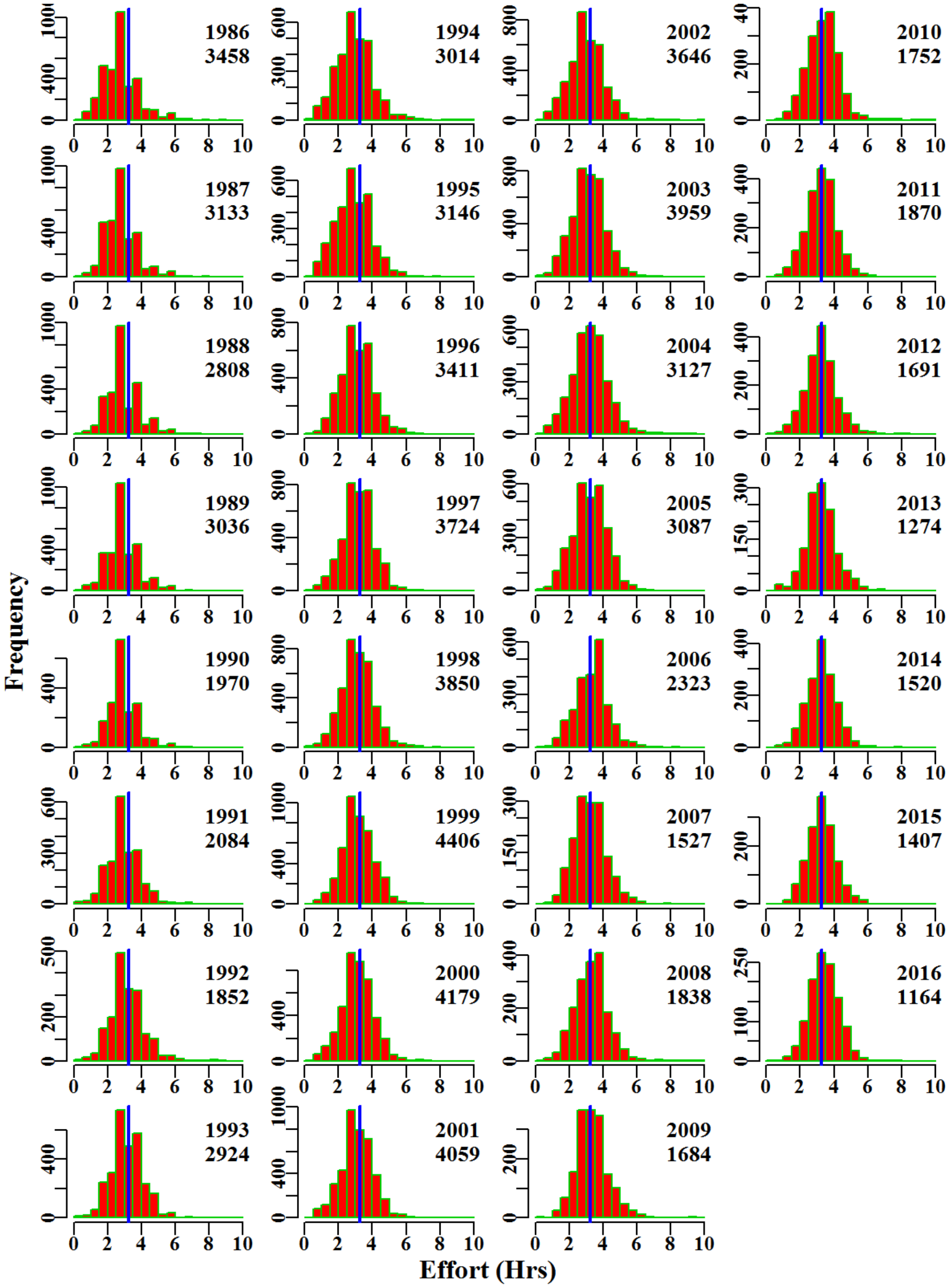


Figure 7.167. OceanPerchOffshore1020. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.25 Ocean Perch Offshore 1050

Offshore Ocean Perch (REG - 37287001 - *Helicolenus percoides*) caught by trawl based on methods TW, TDO, in zones 10, 20, 30, 40, 50, and depths 200 to 700 within the SET fishery for the years 1986 - 2016 were used in the analysis (Table 7.110).

A total of 8 statistical models were fitted sequentially to the available data.

7.25.1 *Inferences*

The majority of catch of this species occurred in zone 10 followed by zone 20 while catches in zones 30, 40, and 50 remain relatively minor. Over the period when CPUE was lower than average (about 1996 - 2006) there was an increase in small shots of < 30kg (Figure 7.169), which is suggestive or either low availability of high levels of small fish.

The terms Year, Month, Vessel and DepCat had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics.

Annual standardized CPUE have been below average and relatively flat between 1995 and 2006. The trend from 2007 has also been relatively flat and mostly just above average (Figure 7.168).

7.25.2 *Action Items and Issues*

The generally lower CPUE for Offshore Ocean Perch in zones 30, 40, and 50 suggest it is not a major target species in those zones. It is recommended that the Tier 4 for Offshore Ocean Perch continue using the analysis presented in Offshore Ocean Perch for zones 10 and 20 as catch rates in those zones would seem to be more indicative of the main location for the stock.

Table 7.106. OceanPerchOffshore1050. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	262.4	3728	220.7	92	20.9	1.1027	0.000	29.823	0.135
1987	198.4	3414	145.1	93	15.7	1.0153	0.024	30.086	0.207
1988	188.4	3098	161.4	93	18.4	1.1442	0.025	26.361	0.163
1989	209.2	3422	173.7	86	18.8	1.1134	0.024	29.626	0.171
1990	181.7	2437	144.2	80	18.9	1.4078	0.027	22.323	0.155
1991	223.6	2888	172.1	87	21.3	1.4409	0.026	27.032	0.157
1992	169.7	2380	130.5	70	17.7	1.1804	0.027	22.547	0.173
1993	259.6	3669	224.0	69	19.2	1.2212	0.024	35.466	0.158
1994	257.3	3797	209.4	66	19.1	1.1671	0.024	38.340	0.183
1995	240.0	4454	191.7	69	15.2	1.0835	0.023	50.949	0.266
1996	263.9	4867	215.0	76	14.5	0.9605	0.023	53.357	0.248
1997	298.8	5621	248.1	72	13.8	1.0023	0.023	60.051	0.242
1998	295.0	5340	241.0	67	14.6	0.9285	0.023	55.736	0.231
1999	295.8	5786	259.3	73	14.9	0.9657	0.023	61.921	0.239
2000	270.2	5702	218.0	80	12.9	0.8283	0.023	59.267	0.272
2001	281.6	5973	229.2	68	13.4	0.8903	0.023	63.130	0.275
2002	255.3	5619	195.7	69	12.5	0.8511	0.023	57.239	0.293
2003	322.7	5800	232.1	66	13.4	0.9237	0.023	57.591	0.248
2004	316.3	5124	203.0	68	12.9	0.9412	0.024	50.304	0.248
2005	316.8	4564	204.1	64	14.9	0.9619	0.024	43.032	0.211
2006	237.6	3382	139.4	53	12.3	0.8569	0.026	35.610	0.256
2007	180.6	2631	122.2	33	13.5	0.9812	0.027	26.333	0.215
2008	184.3	2691	125.3	32	13.7	0.9827	0.027	26.058	0.208
2009	173.9	2758	130.0	32	13.7	0.9572	0.027	28.067	0.216
2010	195.6	2937	151.8	32	14.3	0.9785	0.027	30.224	0.199
2011	186.9	3144	147.8	30	14.6	0.8258	0.026	30.286	0.205
2012	183.9	2833	137.4	30	16.5	0.8026	0.027	24.646	0.179
2013	171.2	2322	126.6	29	17.3	0.8512	0.028	19.660	0.155
2014	174.4	2406	137.0	30	18.7	0.9136	0.028	20.576	0.150
2015	150.8	2179	124.4	31	19.8	0.8036	0.029	17.135	0.138
2016	132.1	1738	110.7	30	21.3	0.9167	0.031	12.575	0.114

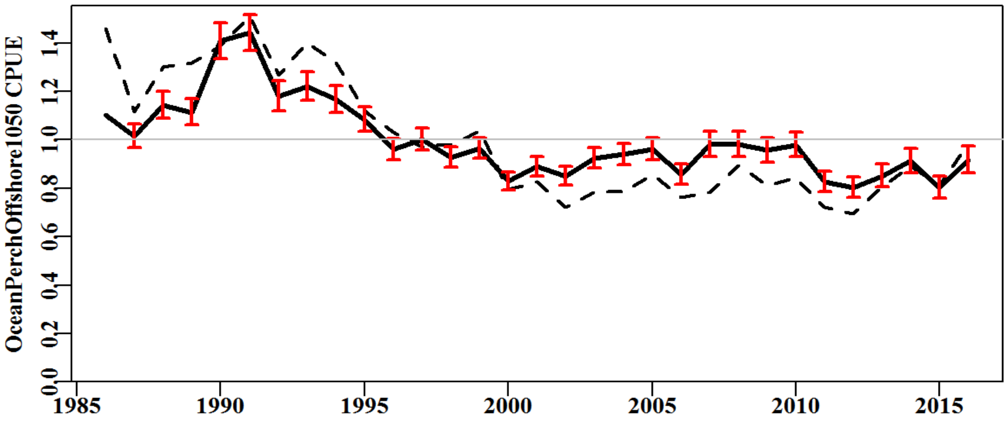


Figure 7.168. OceanPerchOffshore1050 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

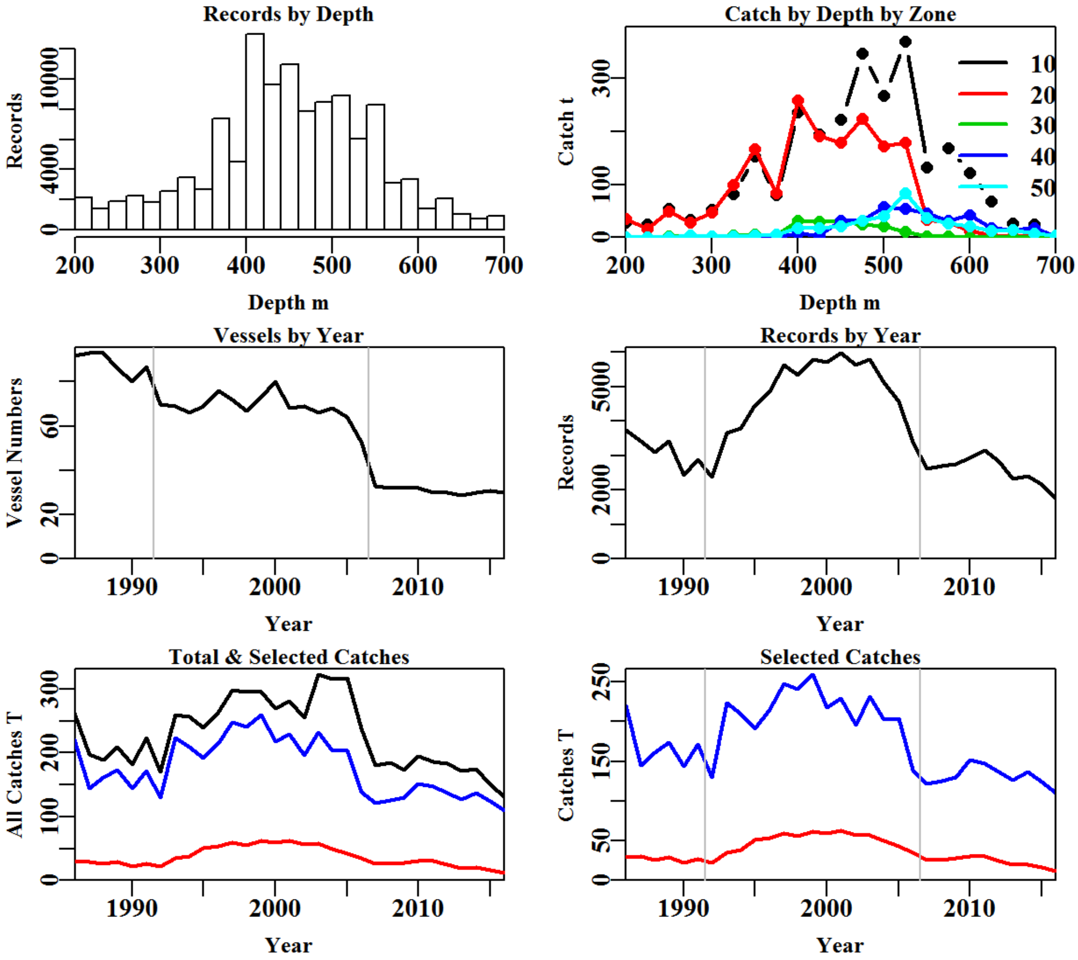


Figure 7.169. OceanPerchOffshore1050 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.107. OceanPerchOffshore1050 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	165571	151043	123583	122180	118058	116762	116704
Difference	0	14528	27460	1403	4122	1296	58

Table 7.108. The models used to analyse data for OceanPerchOffshore1050.

	Model
Model1	Year
Model2	Year + Month
Model3	Year + Month + Vessel
Model4	Year + Month + Vessel + DepCat
Model5	Year + Month + Vessel + DepCat + DayNight
Model6	Year + Month + Vessel + DepCat + DayNight + Zone
Model7	Year + Month + Vessel + DepCat + DayNight + Zone + Zone:Month
Model8	Year + Month + Vessel + DepCat + DayNight + Zone + Zone:DepCat

Table 7.109. OceanPerchOffshore1050. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	37254	160506	5948	116704	31	3.5	0.00
Month	36748	159781	6674	116704	42	4.0	0.43
Vessel	9338	125890	40565	116704	248	24.2	20.23
DepCat	667	116124	50331	115992	268	29.5	5.32
DayNight	-575	114880	51574	115992	271	30.3	0.75
Zone	-7643	108082	58372	115992	275	34.4	4.12
Zone:Month	-10297	105557	60897	115992	319	35.9	1.51
Zone:DepCat	-9187	106506	59948	115992	355	35.3	0.91

Table 7.110. OceanPerchOffshore1050. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	OceanPerchOffshore1050
csirocode	37287001
fishery	SET
depthrange	200 - 700
depthclass	25
zones	10, 20, 30, 40, 50
methods	TW, TDO
years	1986 - 2016

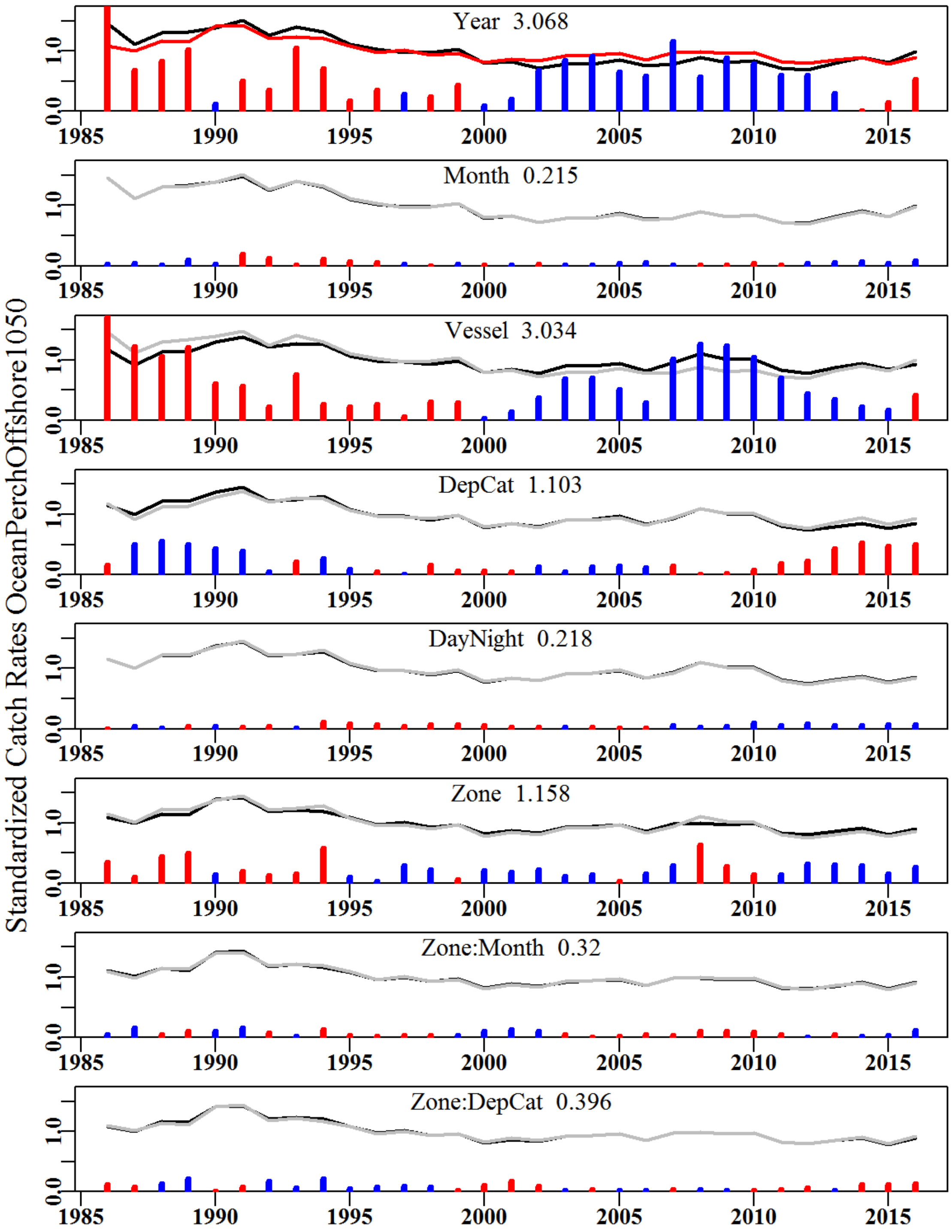


Figure 7.170. OceanPerchOffshore1050. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

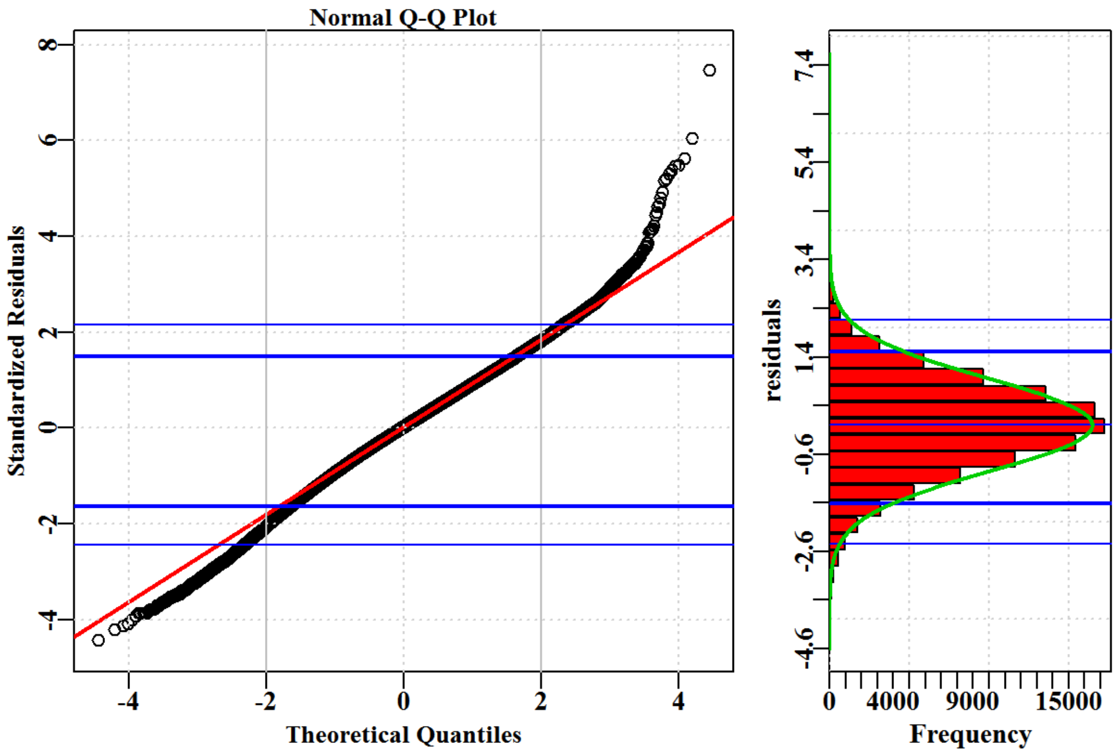


Figure 7.171. OceanPerchOffshore1050. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

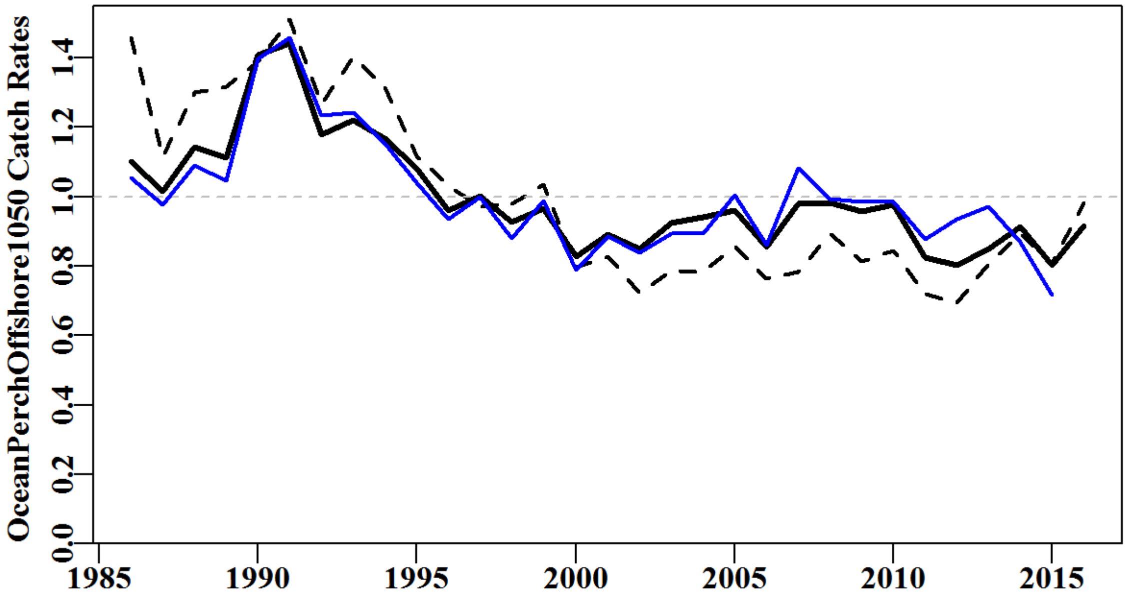


Figure 7.172. OceanPerchOffshore1050. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

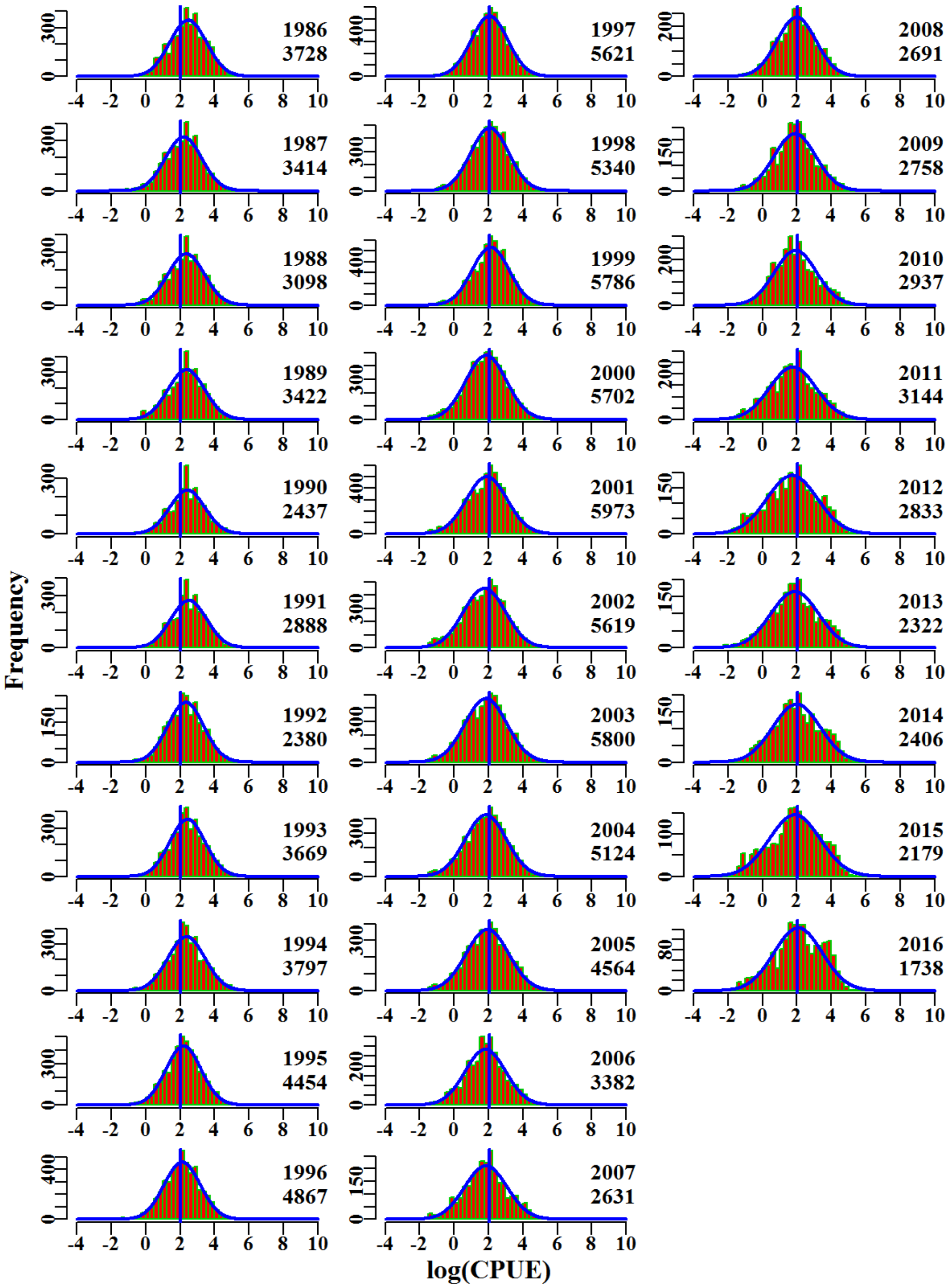


Figure 7.173. OceanPerchOffshore1050. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

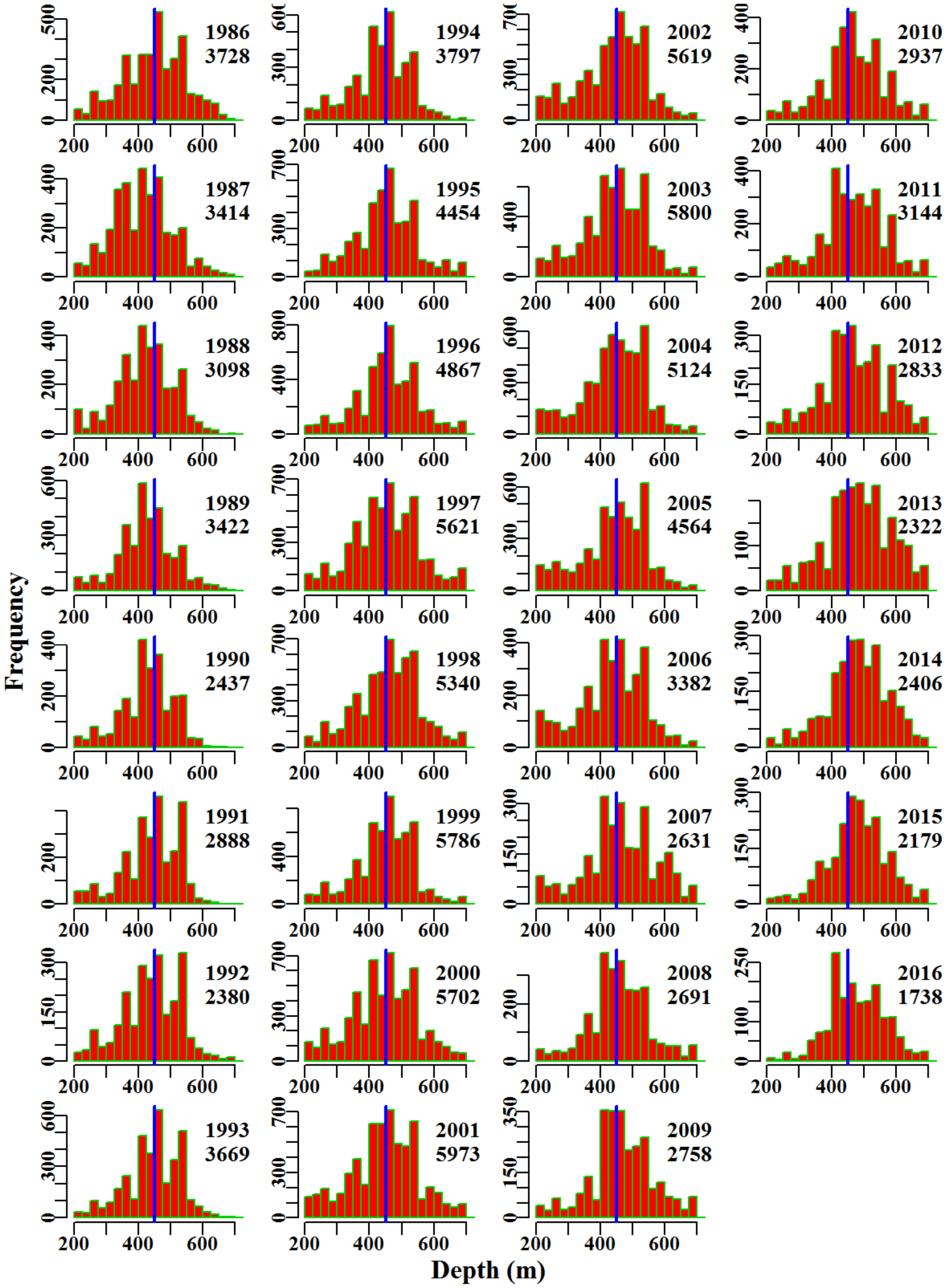


Figure 7.174. OceanPerchOffshore1050. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

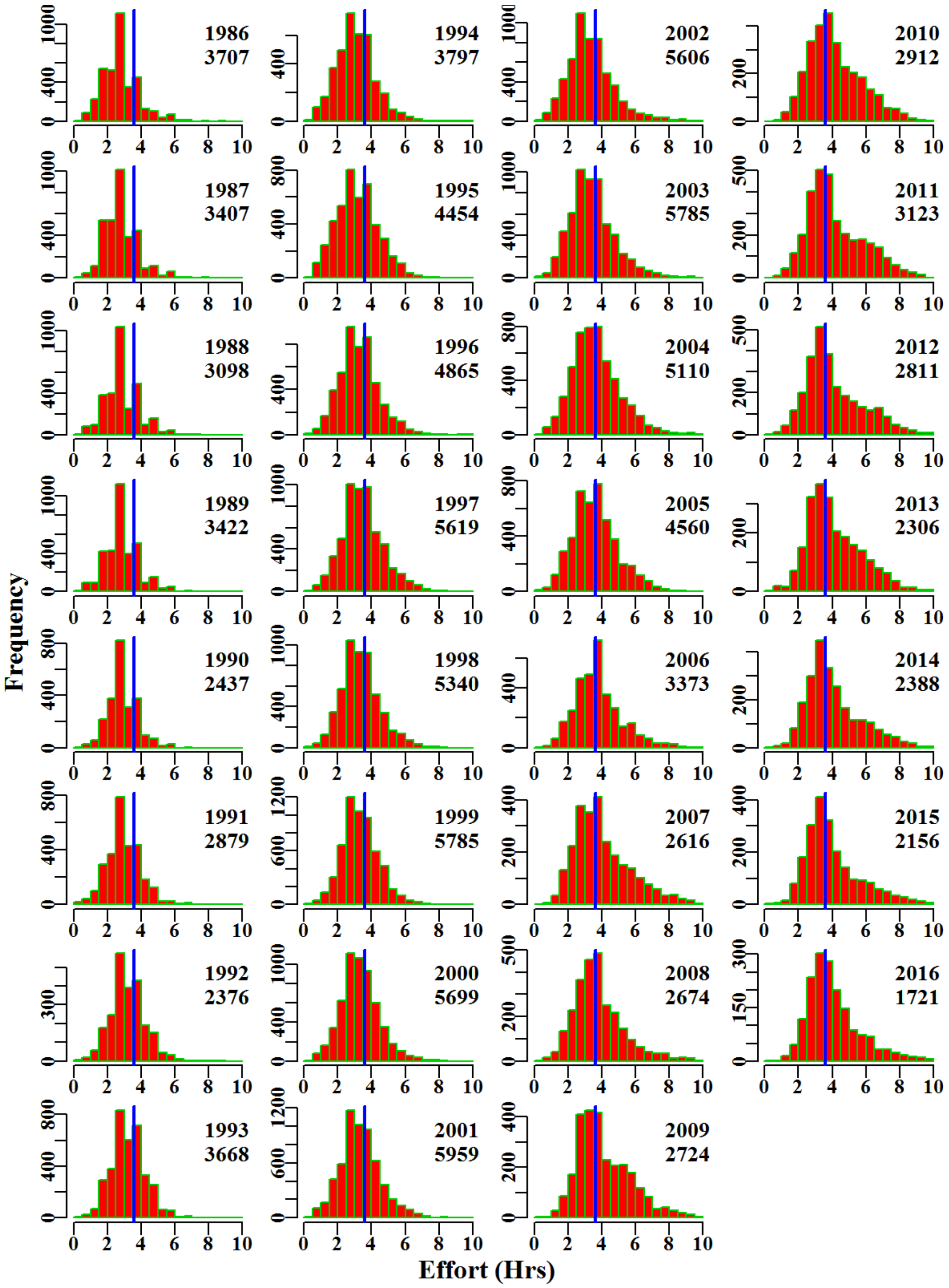


Figure 7.175. OceanPerchOffshore1050. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.25.3 *Comparison of Zones 10:20 and 10:50*

Table 7.111. The reported log-book catches and records by zone, with catches first and then records for each zone in sequence. The difference between the analyses is only die to the inclusion of the catches reported in zones 30, 40, and 50.

	10	10	20	20	30	30	40	40	50	50
1986	156.950	2760	50.413	719	0.147	4	8.165	77	4.985	168
1987	94.025	2376	38.772	764	0.436	13	5.283	67	6.599	194
1988	94.863	1827	55.902	981	2.848	51	3.503	62	4.300	177
1989	100.226	1995	59.778	1041	2.157	48	5.915	115	5.661	223
1990	55.256	1064	60.687	906	13.943	58	6.390	91	7.891	318
1991	79.671	1089	59.320	1004	7.824	194	8.872	157	16.444	444
1992	75.749	1045	38.630	810	1.167	47	7.235	144	7.696	334
1993	126.667	1530	72.519	1394	3.908	111	11.677	252	9.207	382
1994	114.476	1596	66.479	1418	6.452	227	14.400	261	7.621	295
1995	97.604	1941	52.737	1205	6.091	225	25.020	668	10.282	415
1996	110.921	2081	65.887	1330	7.249	229	16.032	543	14.928	684
1997	121.677	2229	72.096	1496	8.896	319	23.764	759	21.640	818
1998	131.125	2409	63.504	1441	4.364	134	19.065	661	22.983	695
1999	125.123	2468	93.942	1938	12.433	314	14.531	539	13.316	527
2000	108.316	2184	72.584	1996	8.670	241	14.885	712	13.550	569
2001	98.060	1892	86.756	2171	17.421	598	14.780	740	12.216	572
2002	82.483	1806	68.181	1842	13.202	398	16.694	880	15.127	693
2003	92.328	1703	92.678	2257	12.740	339	19.616	823	14.688	678
2004	70.068	1292	80.391	1837	13.132	368	13.321	604	26.118	1023
2005	94.501	1433	75.579	1656	9.201	309	10.226	541	14.589	625
2006	60.269	987	52.899	1339	5.834	161	8.396	396	11.960	499
2007	59.531	647	35.369	881	3.226	126	15.226	605	8.850	372
2008	48.429	705	53.407	1138	5.274	214	10.084	374	8.141	260
2009	51.897	636	47.711	1058	6.808	195	14.326	548	9.209	321
2010	69.944	777	48.163	982	5.141	149	14.499	498	14.099	531
2011	63.714	715	52.981	1159	4.452	182	11.856	596	14.830	492
2012	72.231	724	41.910	969	4.011	190	10.383	626	8.853	324
2013	58.327	518	44.063	762	4.275	184	7.563	397	12.361	461
2014	68.110	586	47.830	937	1.409	62	9.026	412	10.590	409
2015	61.381	535	43.674	874	4.528	140	6.404	346	8.414	284
2016	62.938	527	32.077	637	1.921	85	6.820	290	6.984	199

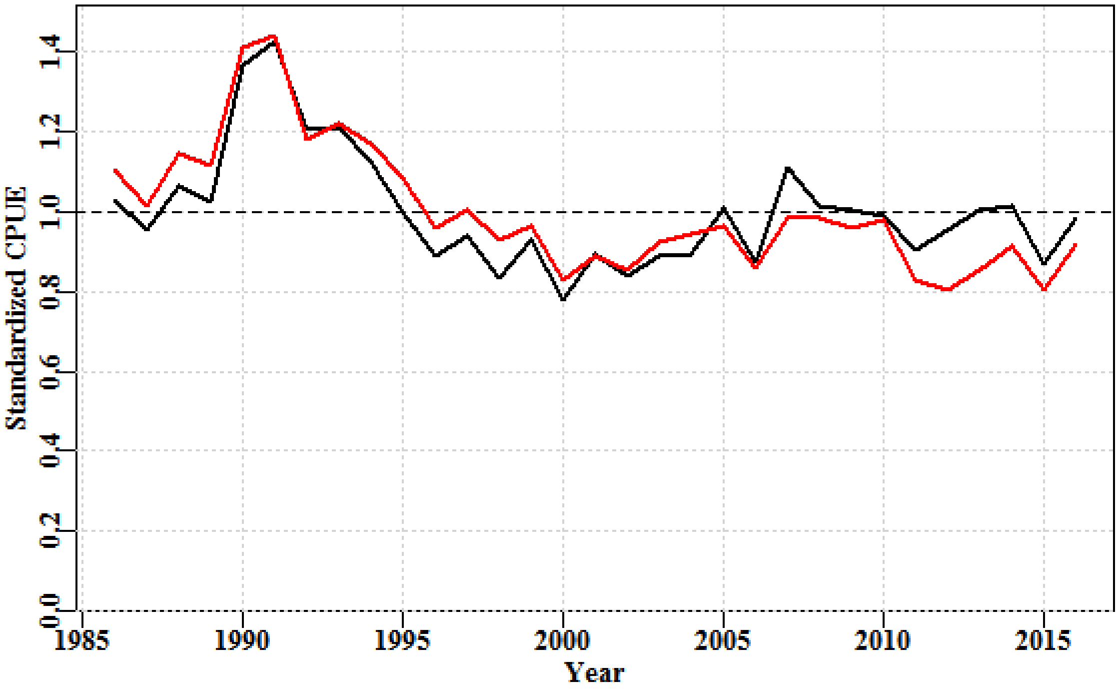


Figure 7.176. A comparison of the optimum standardization for Offshore Ocean Perch when using just Zones 10 and 20 and when including records from zones 30, 40, and 50.

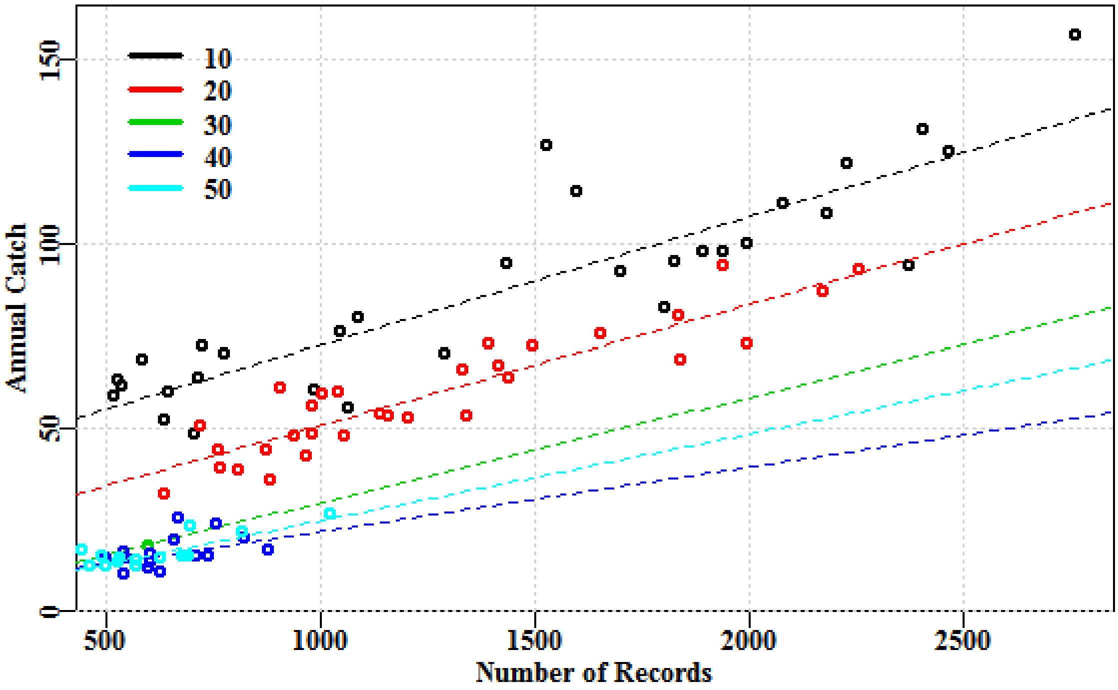


Figure 7.177. A plot of the different reported Catch vs reported number of records for each zone from 10 to 50 for Offshoure Ocean Perch. The dotted lines are the linear regressions in each case illustrating the different average ratio CPUE for each zone and that fact that CPUE in zones 30 - 50 is generally lower for the same effort than in zones 10 and 20.

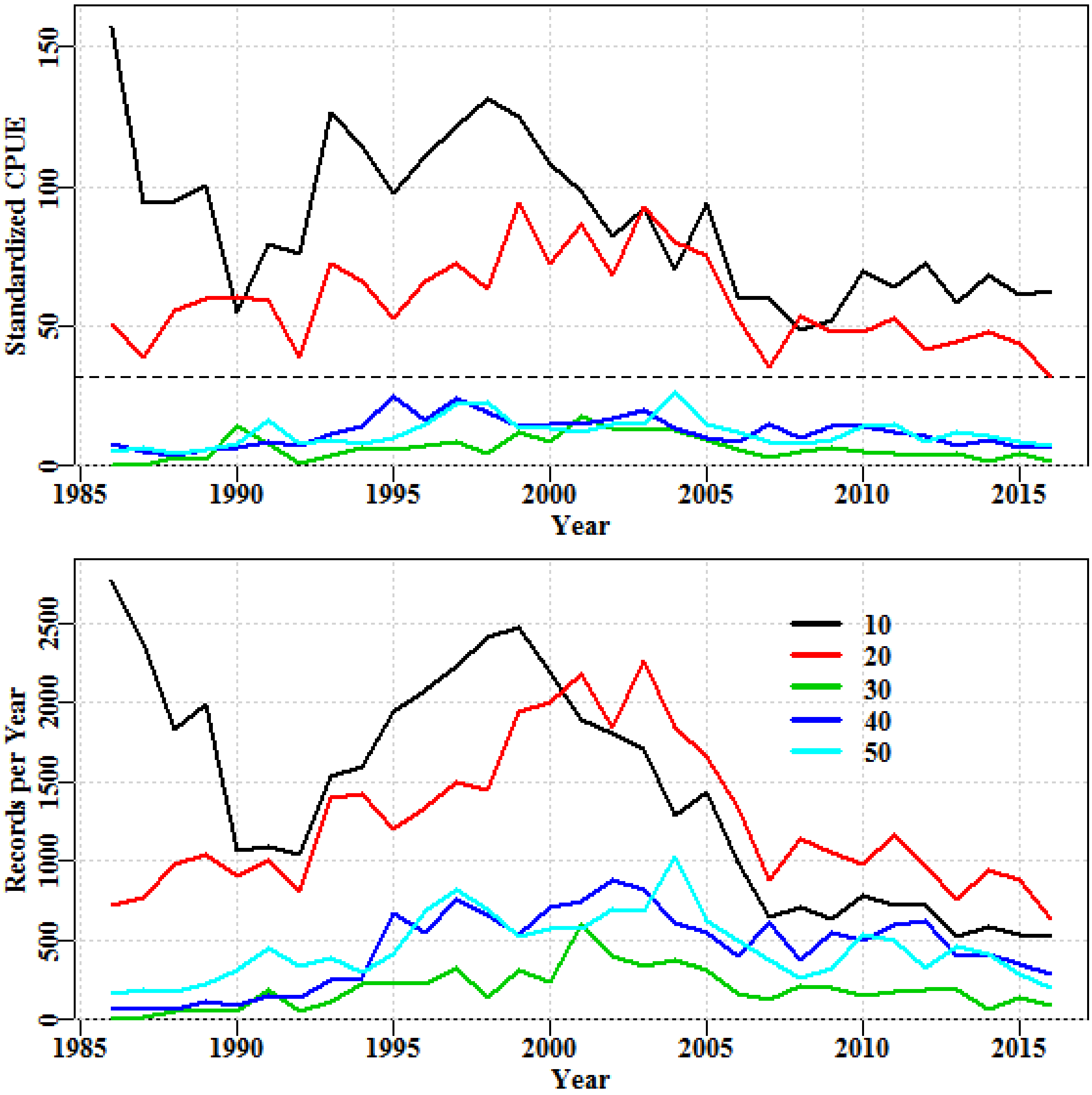


Figure 7.178. Catch and Records by Zone through time illustrating that catches in 30 to 50 have never been as great as those in zones 10 and 20 although the number of records can be relatively high.

7.26 Ocean Perch Inshore 1020

Inshore Ocean Perch (REG - 37287001 - *Helicolenus percoides*) caught by trawl based on methods TW, TDO, in zones 10, 20, and depths 0 to 200 within the SET fishery for the years 1986 - 2016 were analysed (Table 7.116). A total of 8 statistical models were fitted sequentially to the available data.

7.26.1 *Inferences*

The majority of catch of this species occurred in zone 10 followed by zone 20. Small shots <30 kg appear throughout the analysis period. There was an increase in small shots of < 30kg over the 1992 - 2006 period, which is suggestive or either low availability of high levels of small fish (Figure 7.180). There are very high levels of discards of this species so the CPUE is not likely to be characteristic of the stock status.

The terms Year, Month, Vessel and DepCat had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests a small departure from that the assumed Normal distribution as depicted by both tails of the distribution (Figure 7.182).

Annual standardized CPUE are relatively flat and just above average in the last 10 years based on upper 95% confidence limit (Figure 7.179).

7.26.2 *Action Items and Issues*

As the discarding rate continues to be very high ~90% of all catches) it is recommended that this analysis not be conducted as it may mistakenly be assumed to be informative of the stock's relative biomass through time.

Table 7.112. OceanPerchInshore1020. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:DepCat.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	262.4	339	15.2	50	11.9	0.8834	0.000	3.789	0.249
1987	198.4	406	12.0	58	10.6	1.0393	0.092	4.068	0.340
1988	188.4	518	16.5	59	11.7	1.1850	0.089	5.674	0.343
1989	209.2	443	15.4	52	12.5	1.1399	0.093	4.877	0.317
1990	181.7	450	15.6	45	12.0	1.2327	0.094	4.629	0.296
1991	223.6	498	20.4	43	16.6	1.3190	0.093	5.095	0.250
1992	169.7	266	14.2	29	19.4	1.7146	0.105	2.675	0.189
1993	259.6	465	25.0	38	20.8	1.9280	0.096	3.943	0.158
1994	257.3	558	23.3	35	15.8	1.7708	0.093	6.282	0.269
1995	240.0	600	21.2	35	13.4	1.3245	0.091	7.790	0.367
1996	263.9	688	21.3	39	11.2	1.1934	0.090	8.906	0.418
1997	298.8	572	16.4	40	10.7	1.1185	0.093	6.673	0.408
1998	295.0	646	15.6	41	9.5	0.9838	0.091	8.414	0.538
1999	295.8	674	15.9	40	8.9	0.8794	0.091	8.605	0.541
2000	270.2	1328	30.6	39	8.8	1.0420	0.086	15.361	0.502
2001	281.6	1047	23.5	34	8.7	1.0156	0.088	10.764	0.458
2002	255.3	1423	25.2	36	6.6	0.7284	0.087	12.298	0.488
2003	322.7	1086	17.6	40	6.0	0.5654	0.088	9.570	0.544
2004	316.3	962	15.5	41	6.3	0.5755	0.089	7.617	0.493
2005	316.8	898	19.8	41	7.6	0.6479	0.090	8.296	0.418
2006	237.6	602	9.3	35	4.8	0.5437	0.093	4.939	0.529
2007	180.6	395	8.7	21	9.4	0.7823	0.100	4.425	0.506
2008	184.3	330	8.0	21	9.0	0.9631	0.103	3.549	0.445
2009	173.9	289	6.7	21	7.9	0.8240	0.107	3.178	0.476
2010	195.6	308	7.1	21	8.4	0.8580	0.105	3.451	0.483
2011	186.9	275	6.4	19	8.5	0.9978	0.108	2.708	0.421
2012	183.9	392	8.1	20	7.8	0.8243	0.100	3.689	0.457
2013	171.2	221	4.9	14	7.6	0.9903	0.110	2.839	0.577
2014	174.4	153	3.1	15	6.5	0.6967	0.121	1.724	0.557
2015	150.8	124	2.7	15	6.9	0.4232	0.128	1.061	0.394
2016	132.1	88	2.3	13	8.2	0.8095	0.148	0.876	0.377

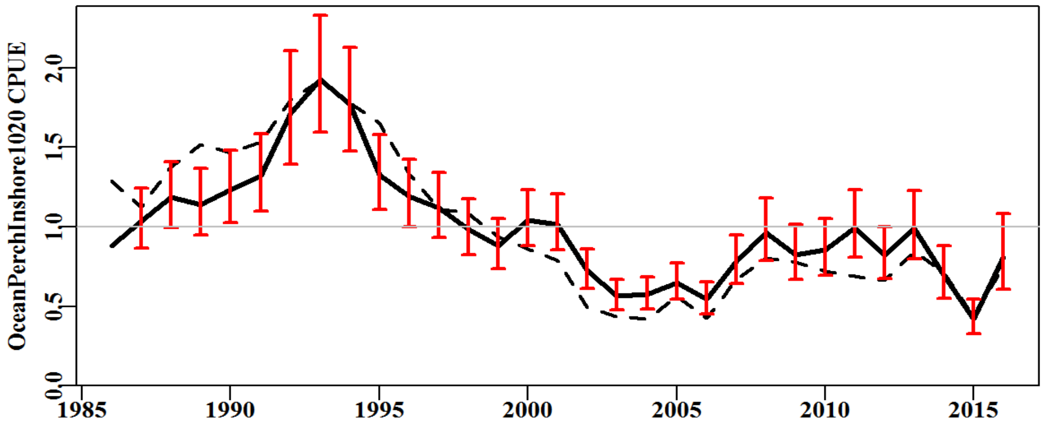


Figure 7.179. OceanPerchInshore1020 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

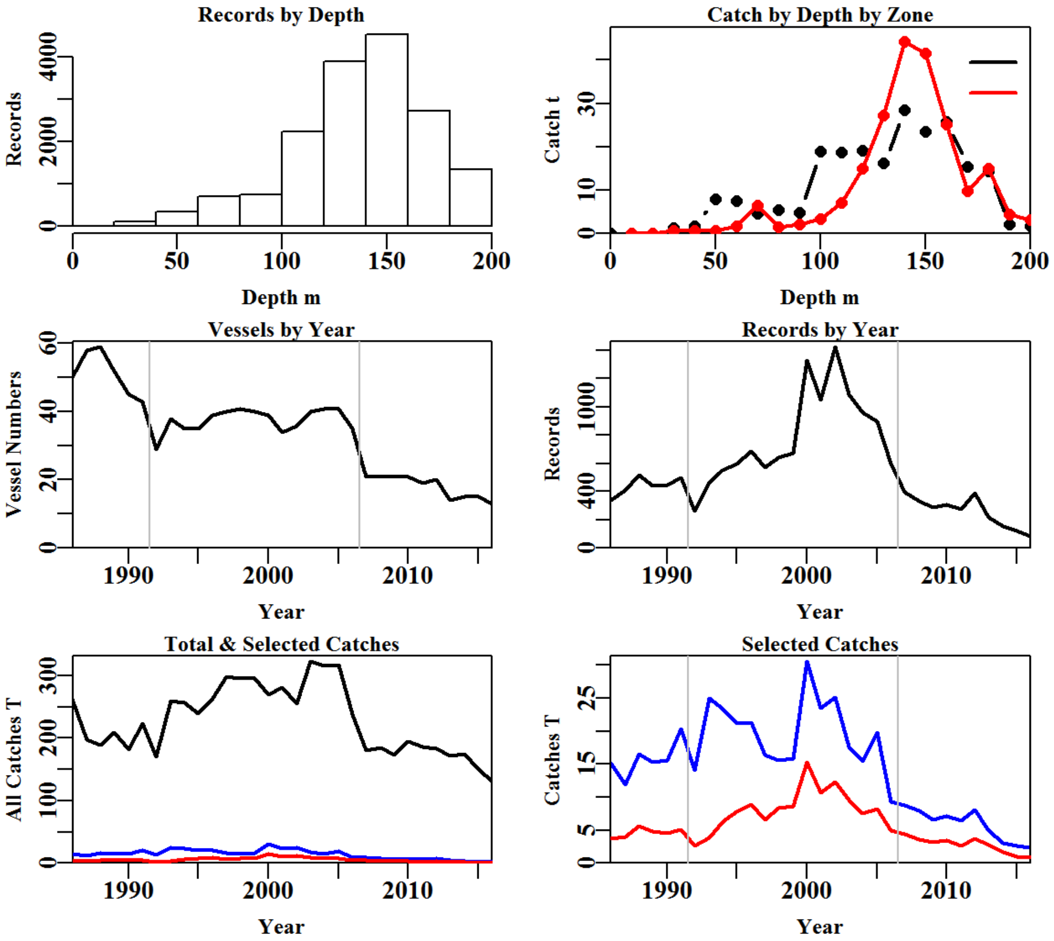


Figure 7.180. OceanPerchInshore1020 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.113. OceanPerchInshore1020 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	165571	151043	24300	24145	17343	17065	17044
Difference	0	14528	126743	155	6802	278	21

Table 7.114. The models used to analyse data for OceanPerchInshore1020

	Model
Model1	Year
Model2	Year + Month
Model3	Year + Month + Vessel
Model4	Year + Month + Vessel + DepCat
Model5	Year + Month + Vessel + DepCat + DayNight
Model6	Year + Month + Vessel + DepCat + DayNight + Zone
Model7	Year + Month + Vessel + DepCat + DayNight + Zone + Zone:Month
Model8	Year + Month + Vessel + DepCat + DayNight + Zone + Zone:DepCat

Table 7.115. OceanPerchInshore1020. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:DepCat.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	6056	24228	3868	17044	31	13.6	0.00
Month	5793	23826	4269	17044	42	15.0	1.38
Vessel	2490	19288	8807	17044	191	30.6	15.58
DepCat	1528	17758	10337	16612	210	34.2	3.67
DayNight	1467	17686	10409	16612	213	34.5	0.25
Zone	1389	17602	10494	16612	214	34.8	0.31
Zone:Month	1391	17580	10515	16612	225	34.8	0.04
Zone:DepCat	1283	17449	10646	16612	233	35.3	0.49

Table 7.116. OceanPerchInshore1020. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	OceanPerchInshore1020
csirocode	37287001
fishery	SET
depthrange	0 - 200
depthclass	10
zones	10, 20
methods	TW, TDO
years	1986 - 2016

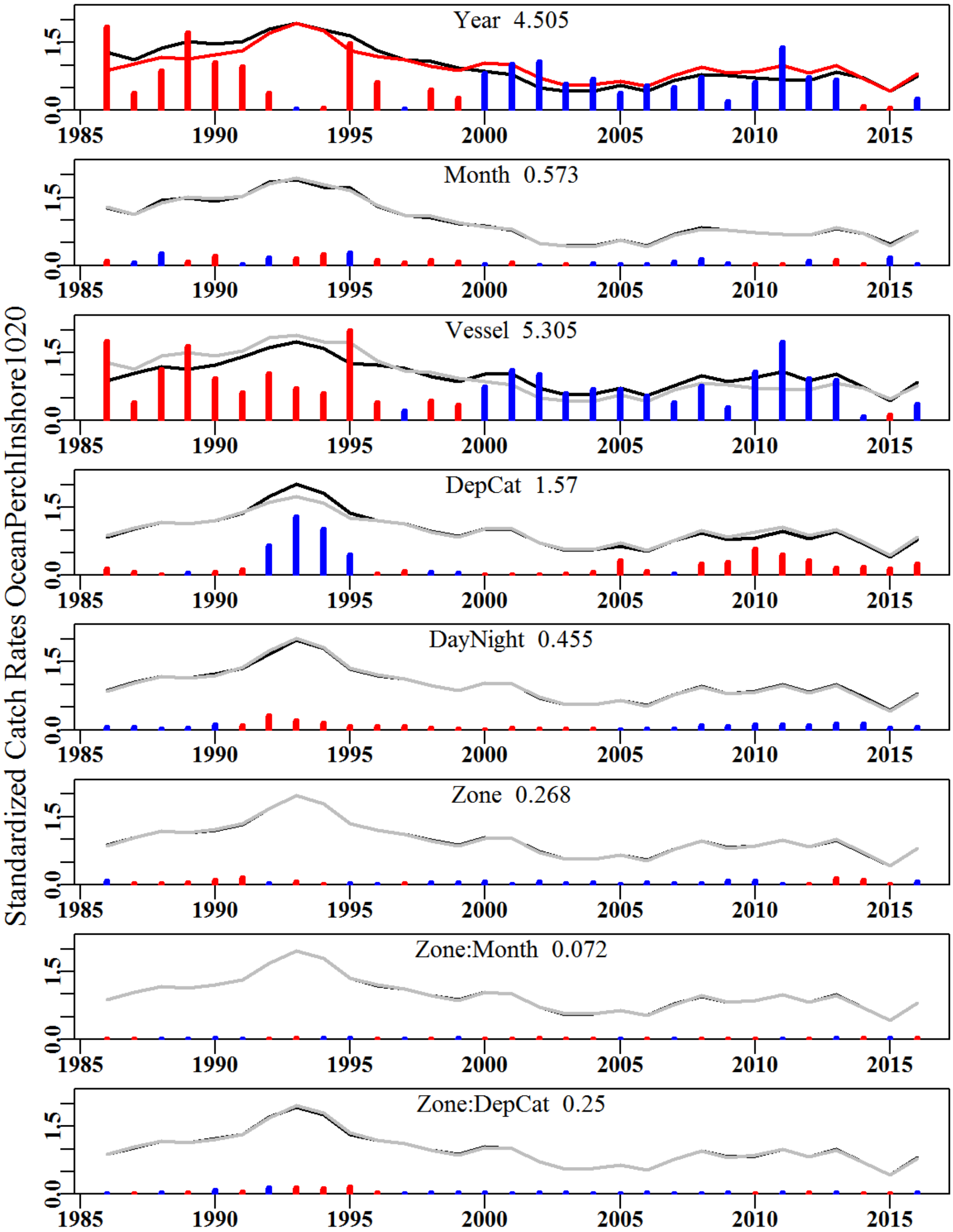


Figure 7.181. OceanPerchInshore1020. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

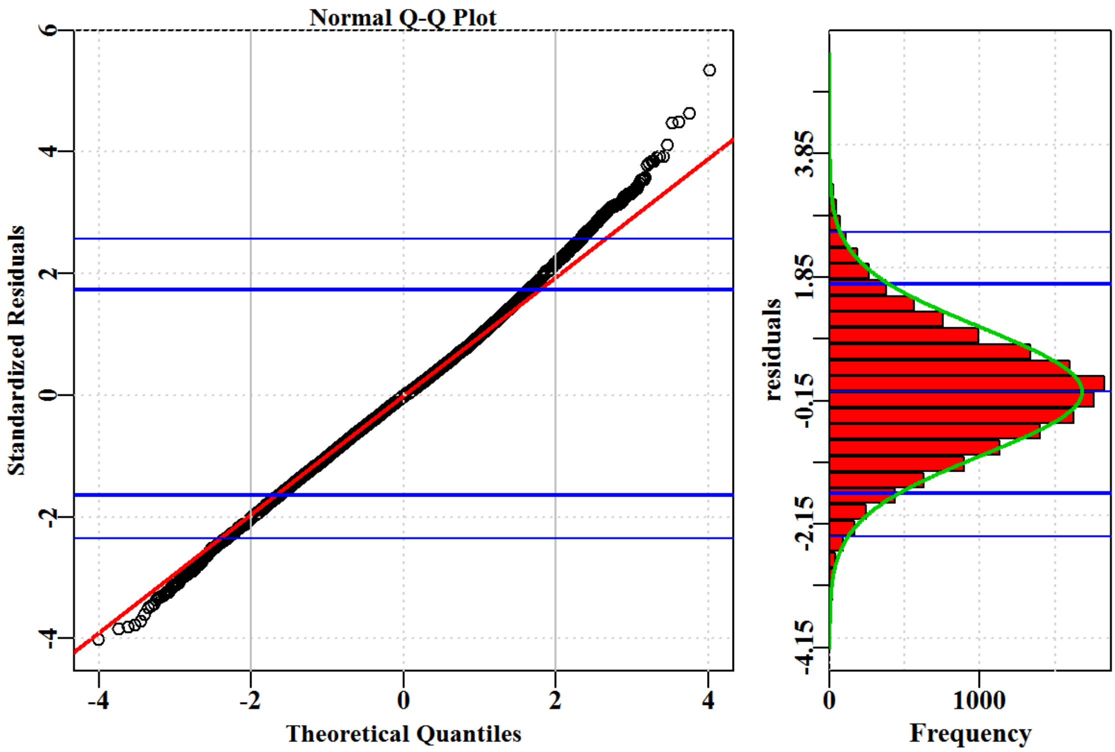


Figure 7.182. OceanPerchInshore1020. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

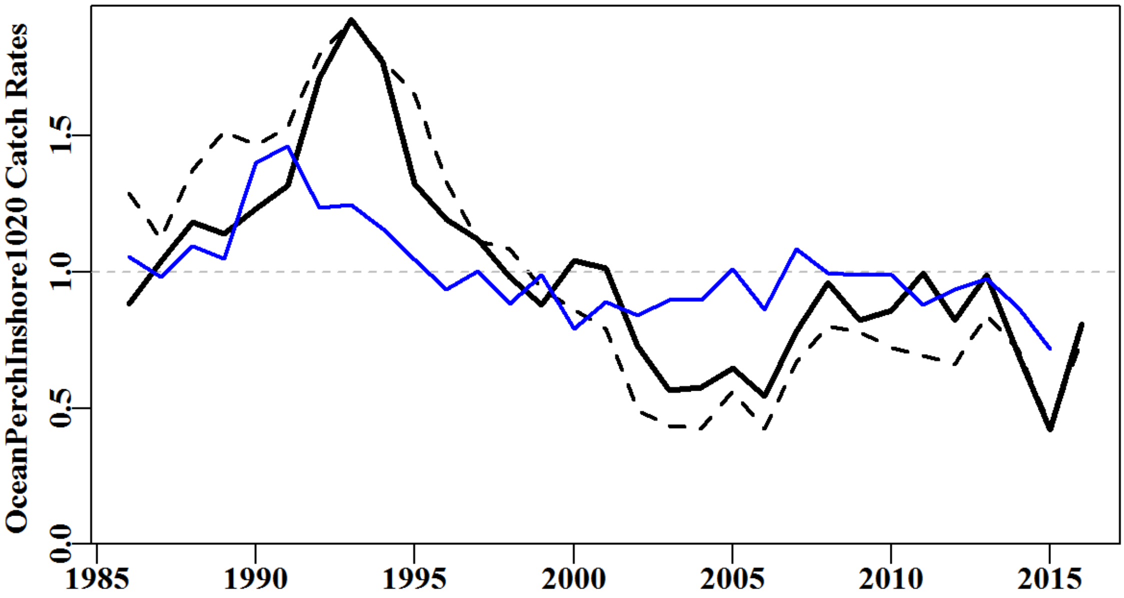


Figure 7.183. OceanPerchInshore1020. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

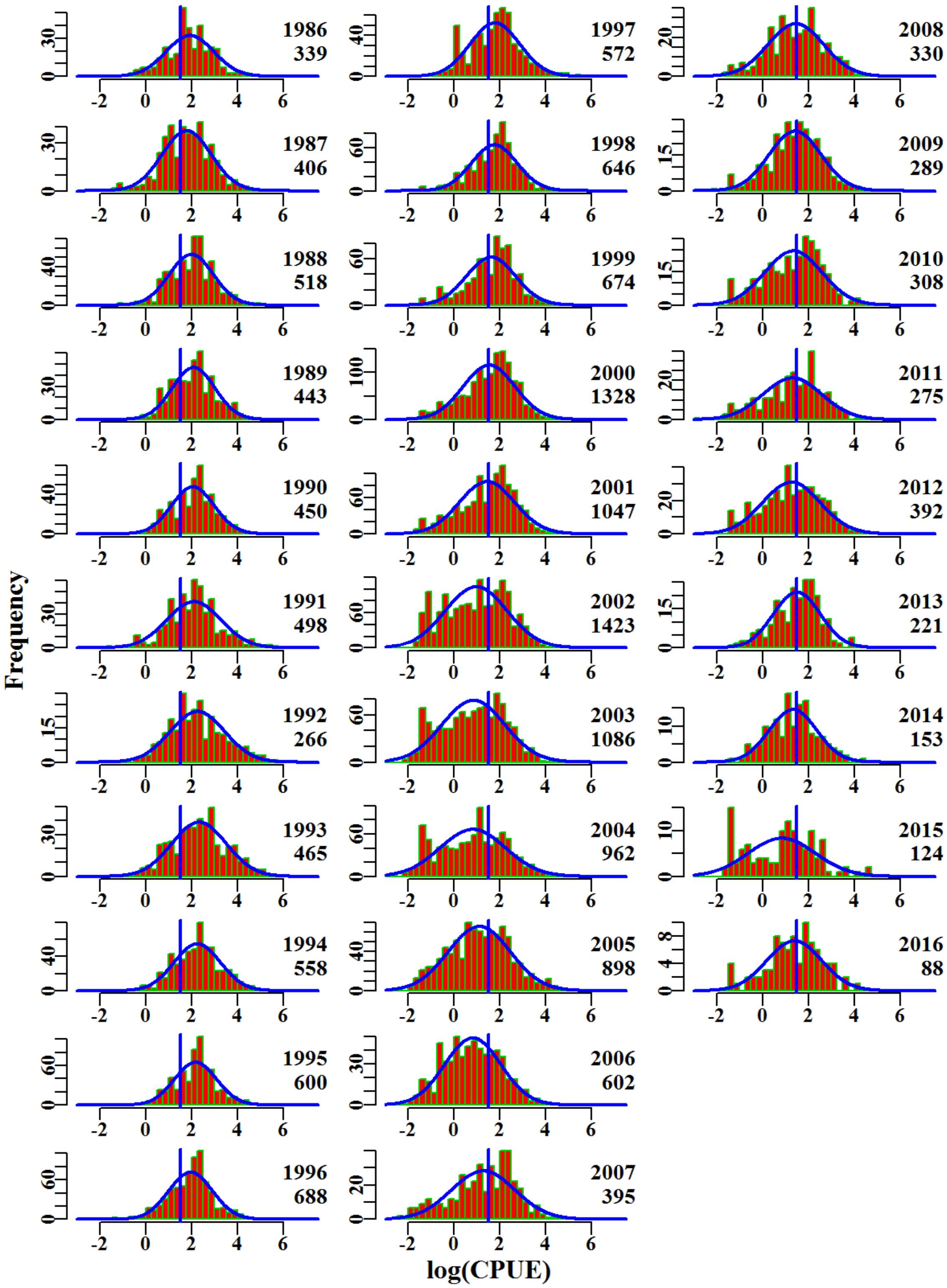


Figure 7.184. OceanPerchInshore1020. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

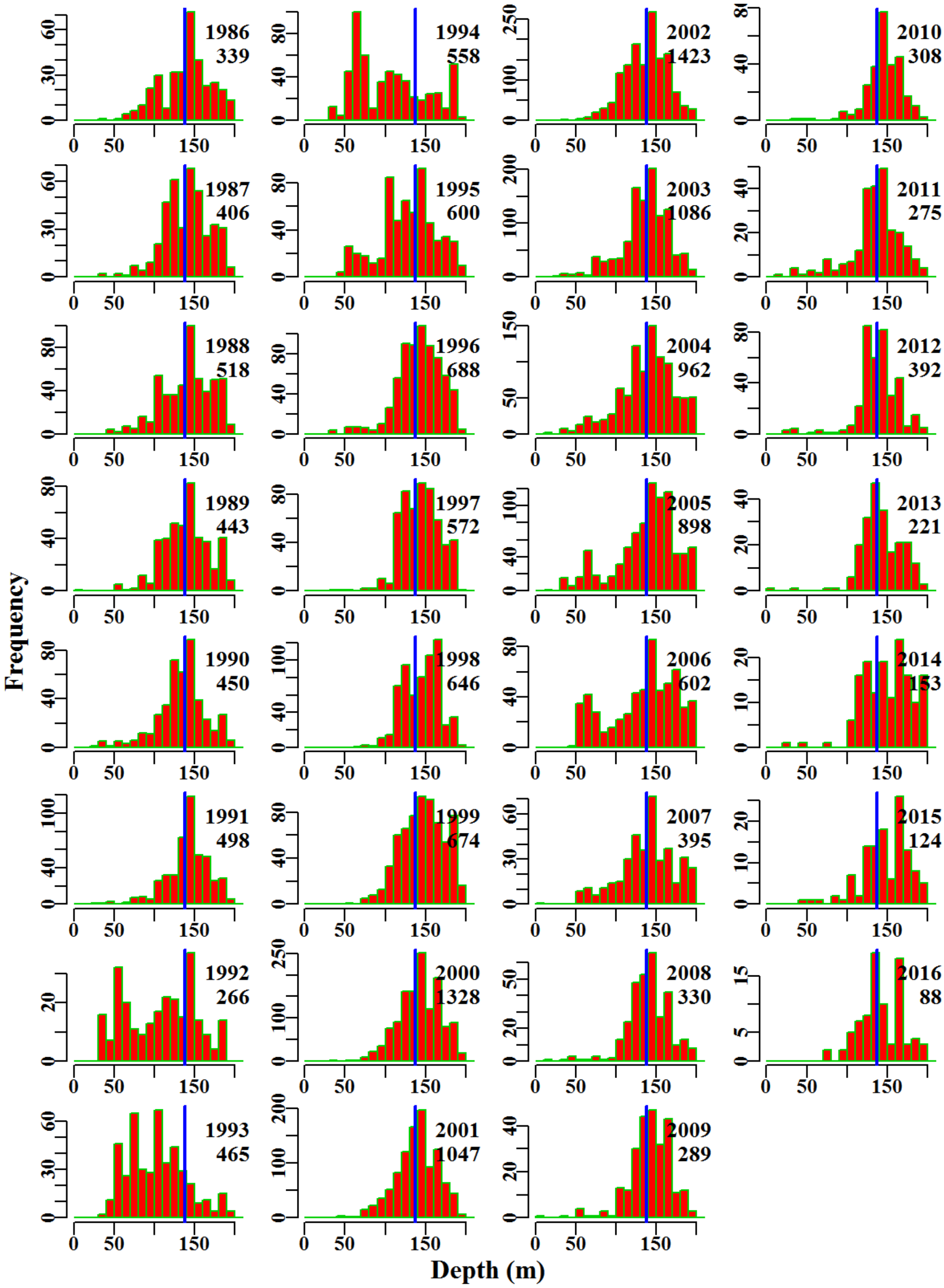


Figure 7.185. OceanPerchInshore1020. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

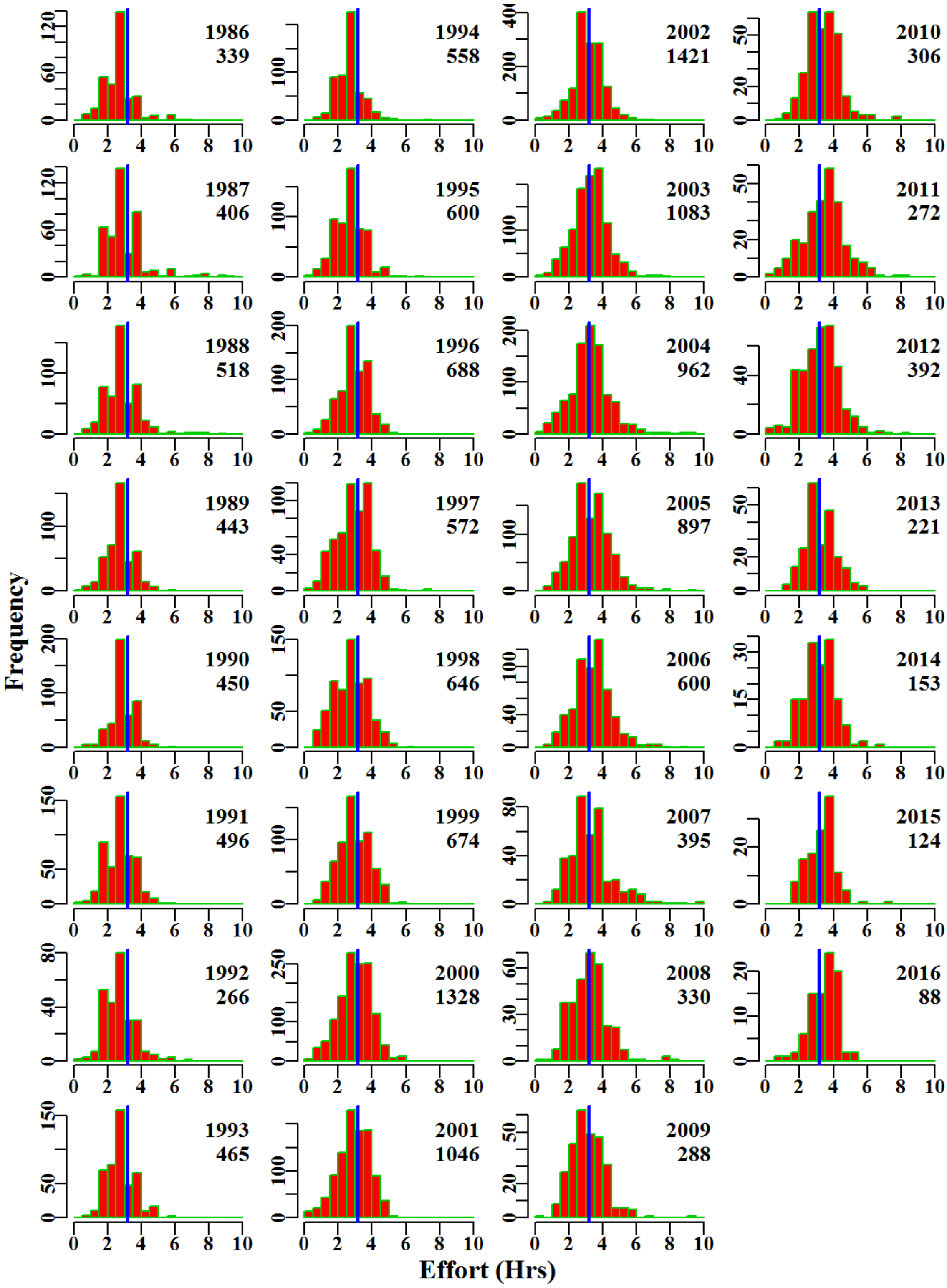


Figure 7.186. OceanPerchInshore1020. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.27 Ocean Jackets 1050

Ocean Jackets (LTC - 37465006 - *Nelusetta ayraudi* and Leather Jackets LTH – 37465000). Trawl caught Ocean Jackets based on methods TW, TDO, in zones 10, 20, 30, 40, 50, and depths 0 to 300 within the SET fishery for the years 1986 - 2016 were analysed (Table 7.121). A total of 8 statistical models were fitted sequentially to the available data.

7.27.1 *Inferences*

The majority of catch of this species occurred in zone 10 followed by zone 20, with minimal catches in the rermaining zones. Small shots <30 kg appear through out the analysis period. There was an increase in small shots of < 30kg over the 1992 - 2006 period, which is suggestive or either low availability of high levels of small fish (Figure 7.188).

The terms Year and Vessel had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics.

Annual standardized CPUE are relatively flat and below average between 1986-2004 reflecting the releatively low catches at the time. It increased rapidly along with catches from 2003 - 2007 after which it has continued relatively high (declining slightly from 2007 - 2016) (Figure 7.187).

7.27.2 *Action Items and Issues*

No issues identified.

Table 7.117. OceanJackets1050. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:DepCat.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	56.4	2472	44.7	75	7.3	0.6343	0.000	26.985	0.604
1987	53.4	1445	28.2	61	7.7	0.6748	0.037	16.329	0.580
1988	66.3	1911	45.7	66	8.8	0.8126	0.034	22.773	0.498
1989	71.7	1808	32.8	65	6.9	0.6988	0.035	20.249	0.618
1990	91.0	1548	33.2	46	7.7	0.6876	0.037	16.552	0.499
1991	170.5	1329	24.8	46	6.7	0.5964	0.039	15.288	0.617
1992	88.9	1207	24.9	41	6.8	0.6141	0.040	14.746	0.592
1993	71.9	1342	29.2	42	6.8	0.6626	0.039	17.052	0.583
1994	74.4	1449	34.9	45	8.3	0.7472	0.038	19.351	0.555
1995	140.2	2222	59.1	41	9.0	0.7365	0.035	27.483	0.465
1996	199.6	2571	72.2	54	9.9	0.7613	0.034	30.350	0.420
1997	177.4	2007	52.5	51	9.5	0.6962	0.035	22.001	0.419
1998	189.9	2488	68.0	44	9.4	0.6918	0.034	27.312	0.402
1999	202.8	2681	88.2	52	10.6	0.8126	0.033	31.109	0.353
2000	198.8	2981	73.2	53	7.7	0.6522	0.033	37.436	0.512
2001	222.6	3190	64.2	55	6.5	0.5804	0.033	37.870	0.589
2002	378.5	4878	199.4	61	10.8	0.6911	0.031	52.369	0.263
2003	482.3	5505	187.4	58	9.8	0.6582	0.030	54.479	0.291
2004	692.6	6232	313.4	60	16.0	1.0762	0.030	56.735	0.181
2005	890.6	5165	342.9	54	21.1	1.2349	0.031	39.556	0.115
2006	741.5	4636	301.7	50	21.1	1.3698	0.031	35.267	0.117
2007	564.8	3095	285.5	27	31.3	1.6412	0.034	19.909	0.070
2008	490.4	3554	318.3	29	28.8	1.5562	0.033	23.243	0.073
2009	610.0	3260	376.1	28	36.5	1.7449	0.033	19.844	0.053
2010	483.9	3259	300.2	29	30.4	1.4375	0.033	20.895	0.070
2011	487.4	3224	277.2	29	29.9	1.3593	0.033	21.340	0.077
2012	519.7	3443	343.8	30	33.5	1.5608	0.033	21.750	0.063
2013	488.5	2845	265.4	28	28.7	1.5580	0.034	16.611	0.063
2014	512.0	3375	273.1	28	24.4	1.3980	0.033	21.540	0.079
2015	414.9	3078	248.4	31	25.7	1.3463	0.034	20.054	0.081
2016	467.1	2297	199.9	28	26.5	1.3080	0.036	15.697	0.079

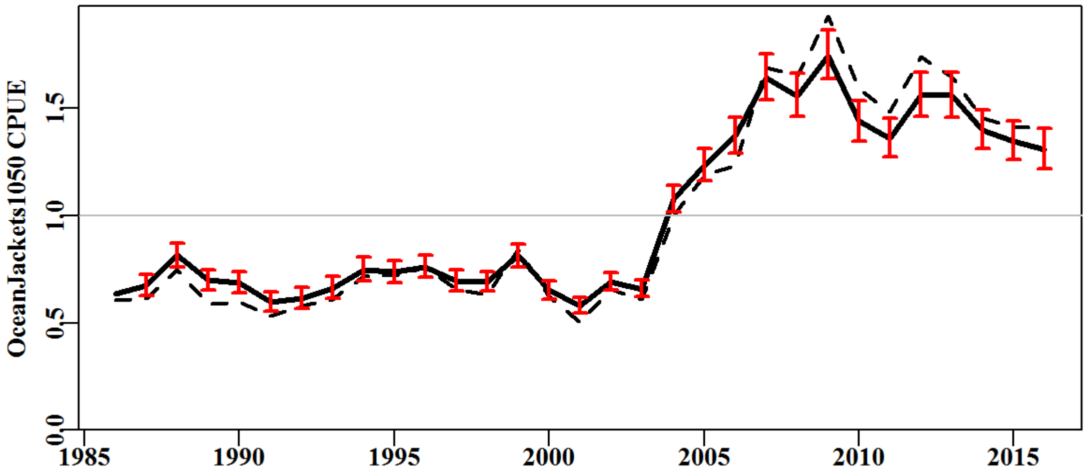


Figure 7.187. OceanJackets1050 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

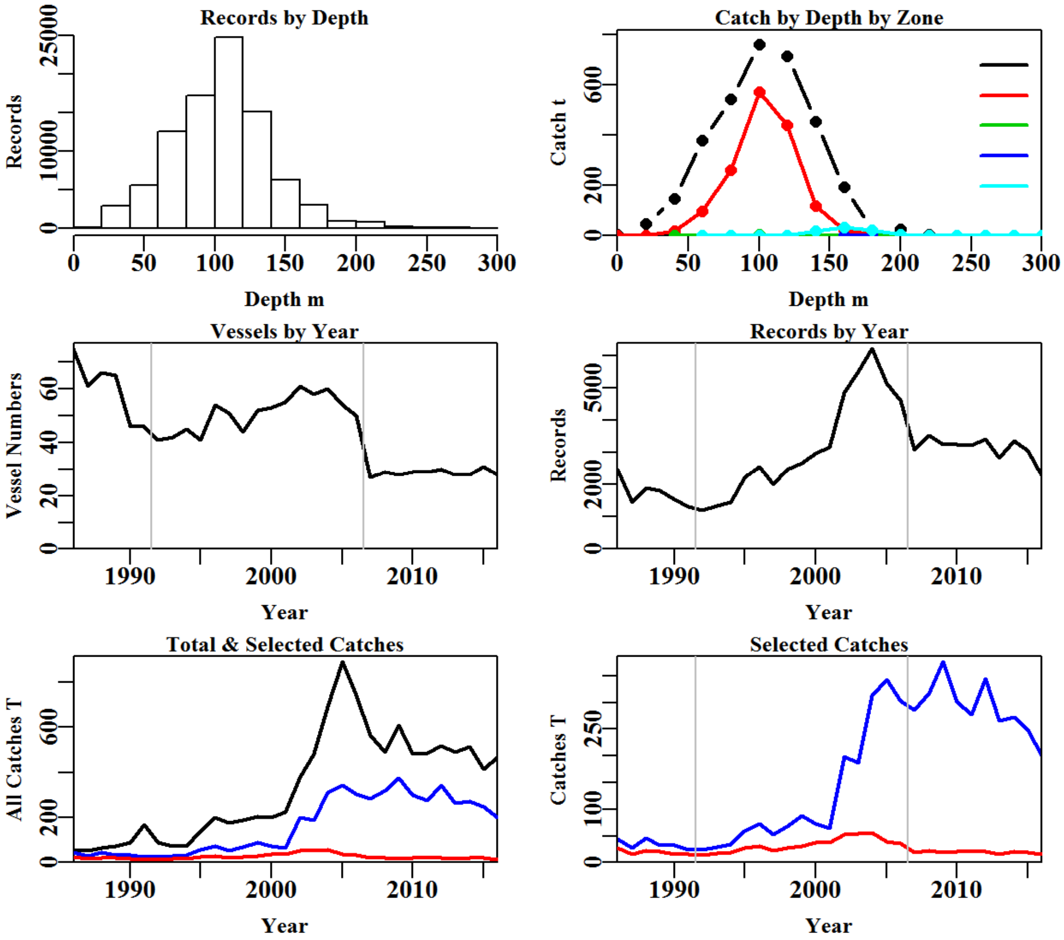


Figure 7.188. OceanJackets1050 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.118. OceanJackets1050 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	170570	161348	160583	156719	95717	90647	90497
Difference	0	9222	765	3864	61002	5070	150

Table 7.119. The models used to analyse data for OceanJackets1050.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + Month
Model5	Year + Vessel + DepCat + Month + Zone
Model6	Year + Vessel + DepCat + Month + Zone + DayNight
Model7	Year + Vessel + DepCat + Month + Zone + DayNight + Zone:Month
Model8	Year + Vessel + DepCat + Month + Zone + DayNight + Zone:DepCat

Table 7.120. OceanJackets1050. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:DepCat.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	20817	113824	16664	90497	31	12.7	0.00
Vessel	7662	98049	32439	90497	204	24.7	11.95
DepCat	7064	96769	33719	89892	219	25.2	0.51
Month	6249	95872	34617	89892	230	25.9	0.68
Zone	5485	95052	35437	89892	234	26.5	0.63
DayNight	5320	94871	35618	89892	237	26.7	0.14
Zone:Month	5127	94585	35903	89892	276	26.8	0.19
Zone:DepCat	4309	93735	36754	89892	273	27.5	0.85

Table 7.121. OceanJackets1050. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	OceanJackets1050
csirocode	37465006, 37465000
fishery	SET
depthrange	0 - 300
depthclass	20
zones	10, 20, 30, 40, 50
methods	TW, TDO
years	1986 - 2016

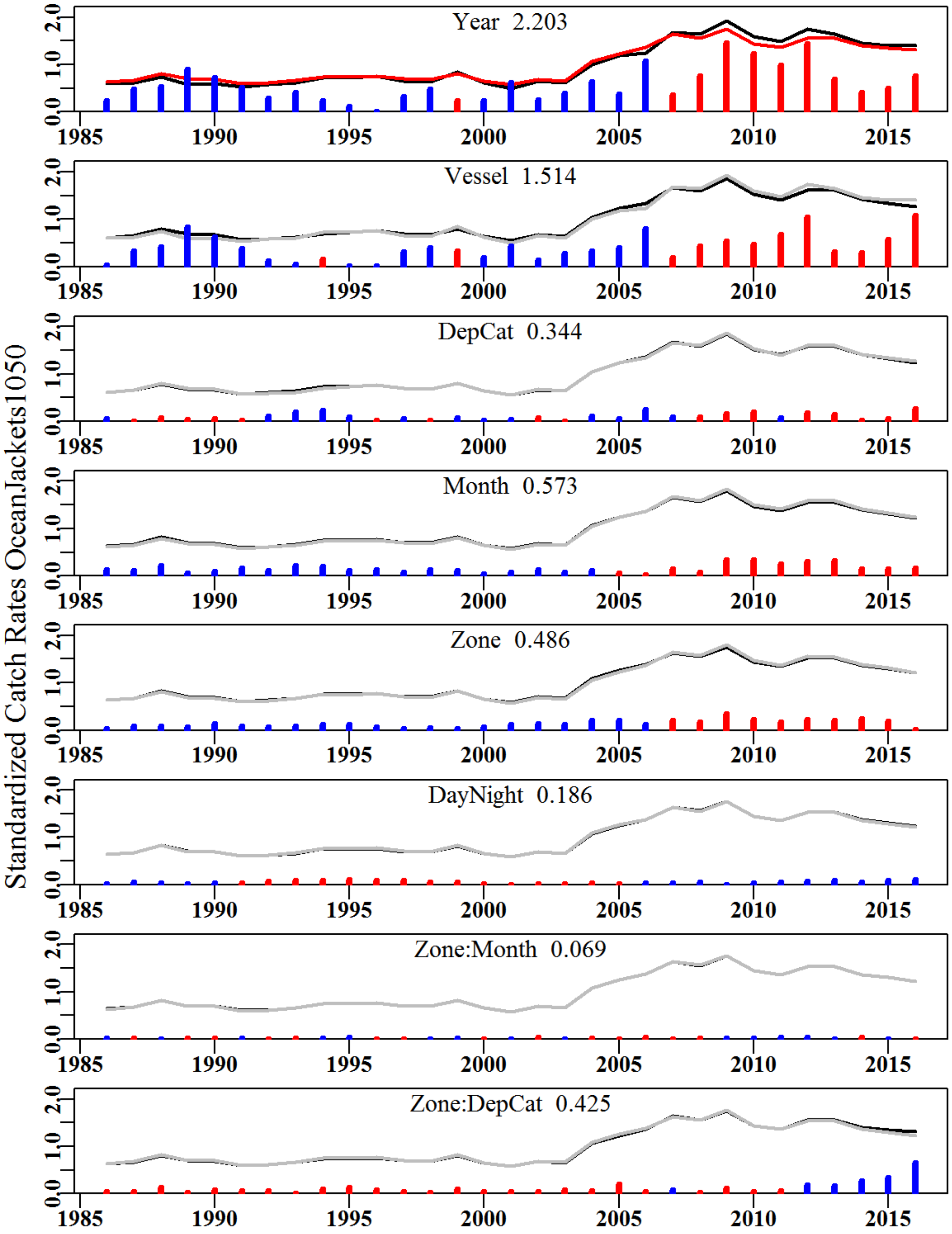


Figure 7.189. OceanJackets1050. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

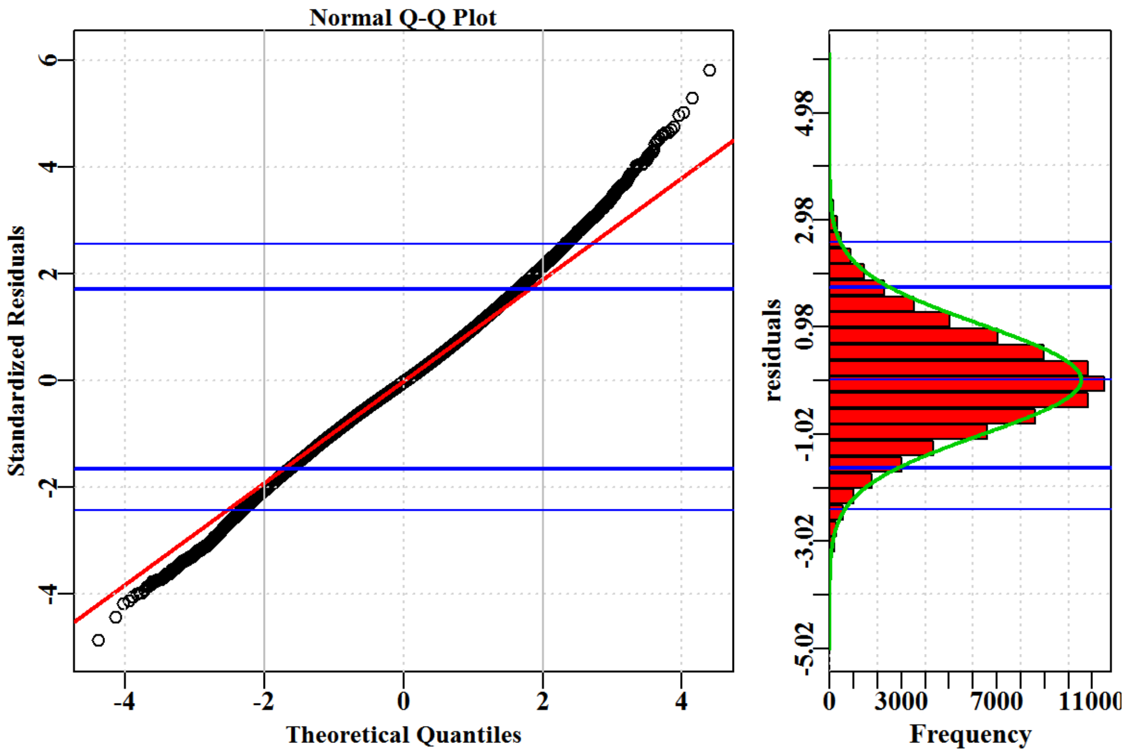


Figure 7.190. OceanJackets1050. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

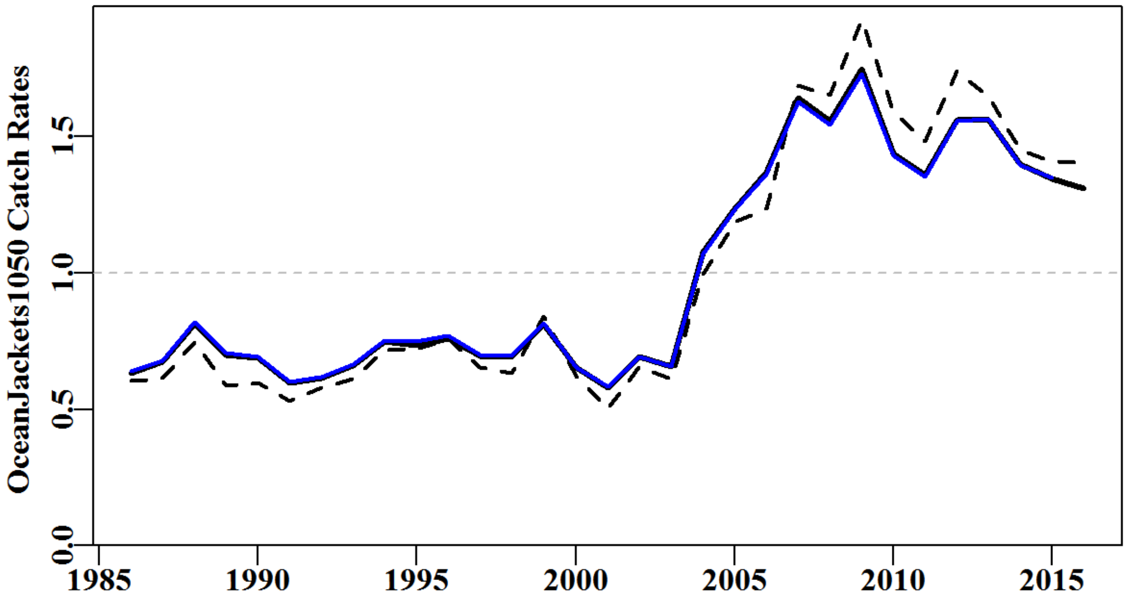


Figure 7.191. OceanJackets1050. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

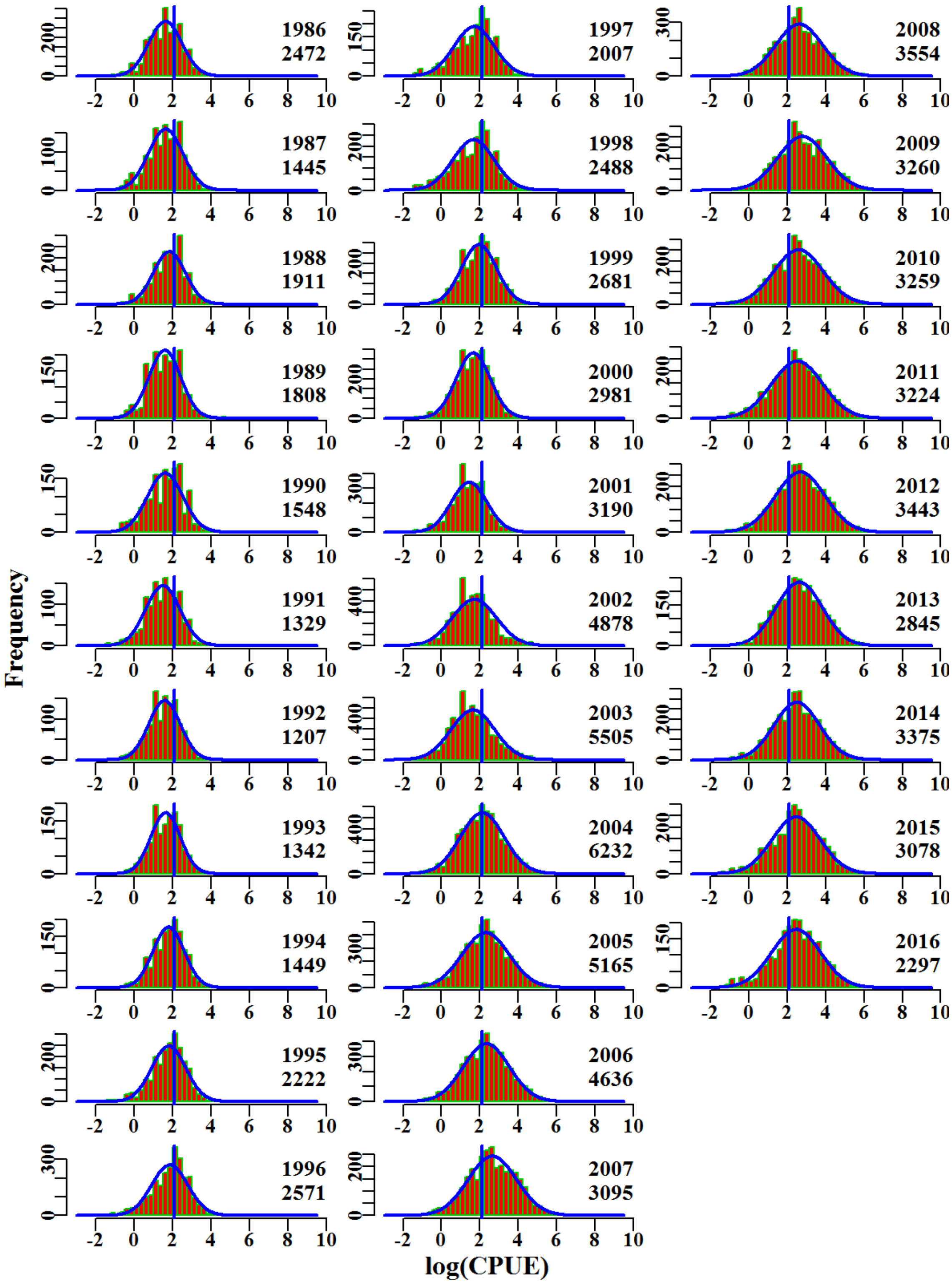


Figure 7.192. OceanJackets1050. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

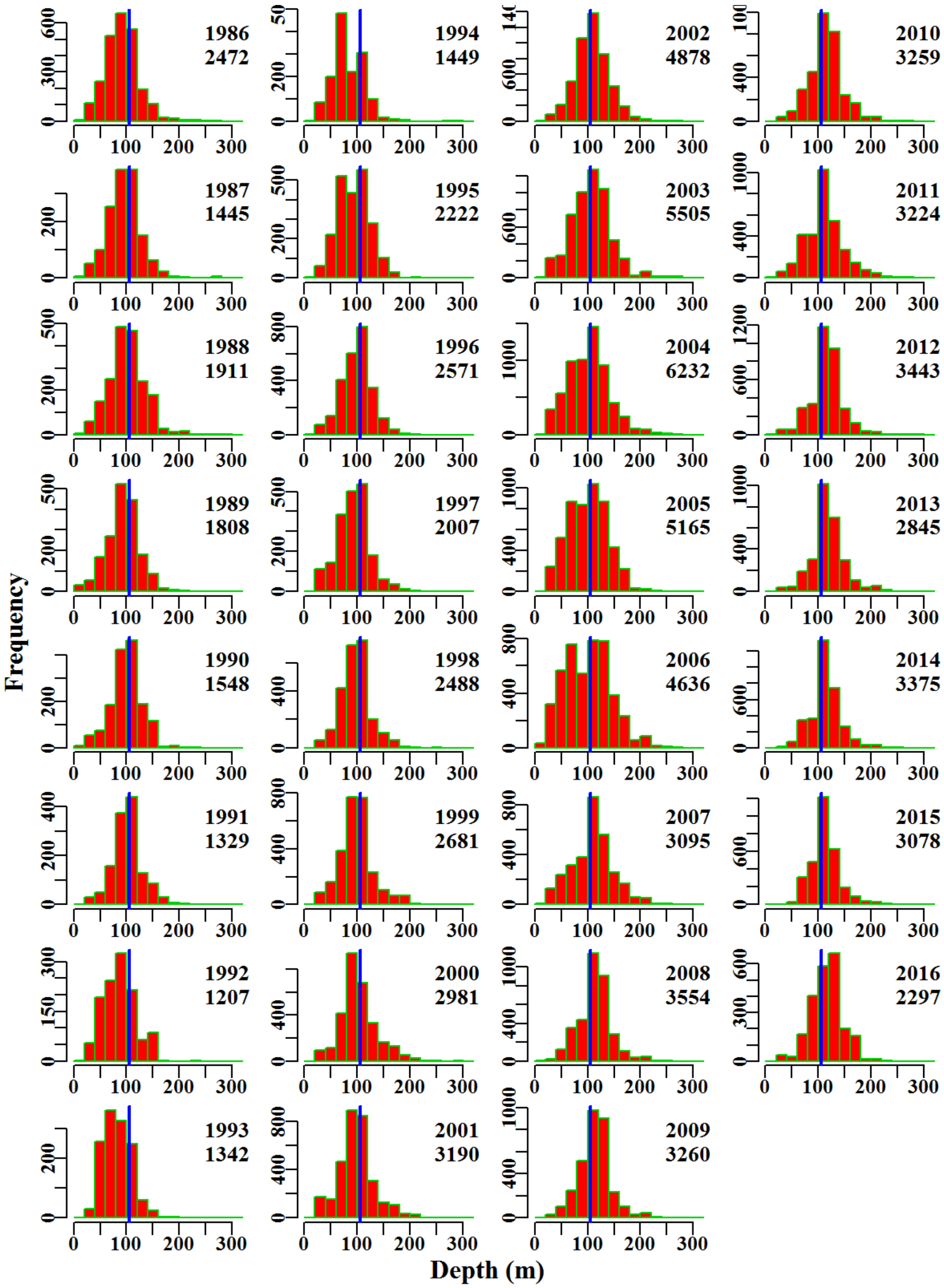


Figure 7.193. OceanJackets1050. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

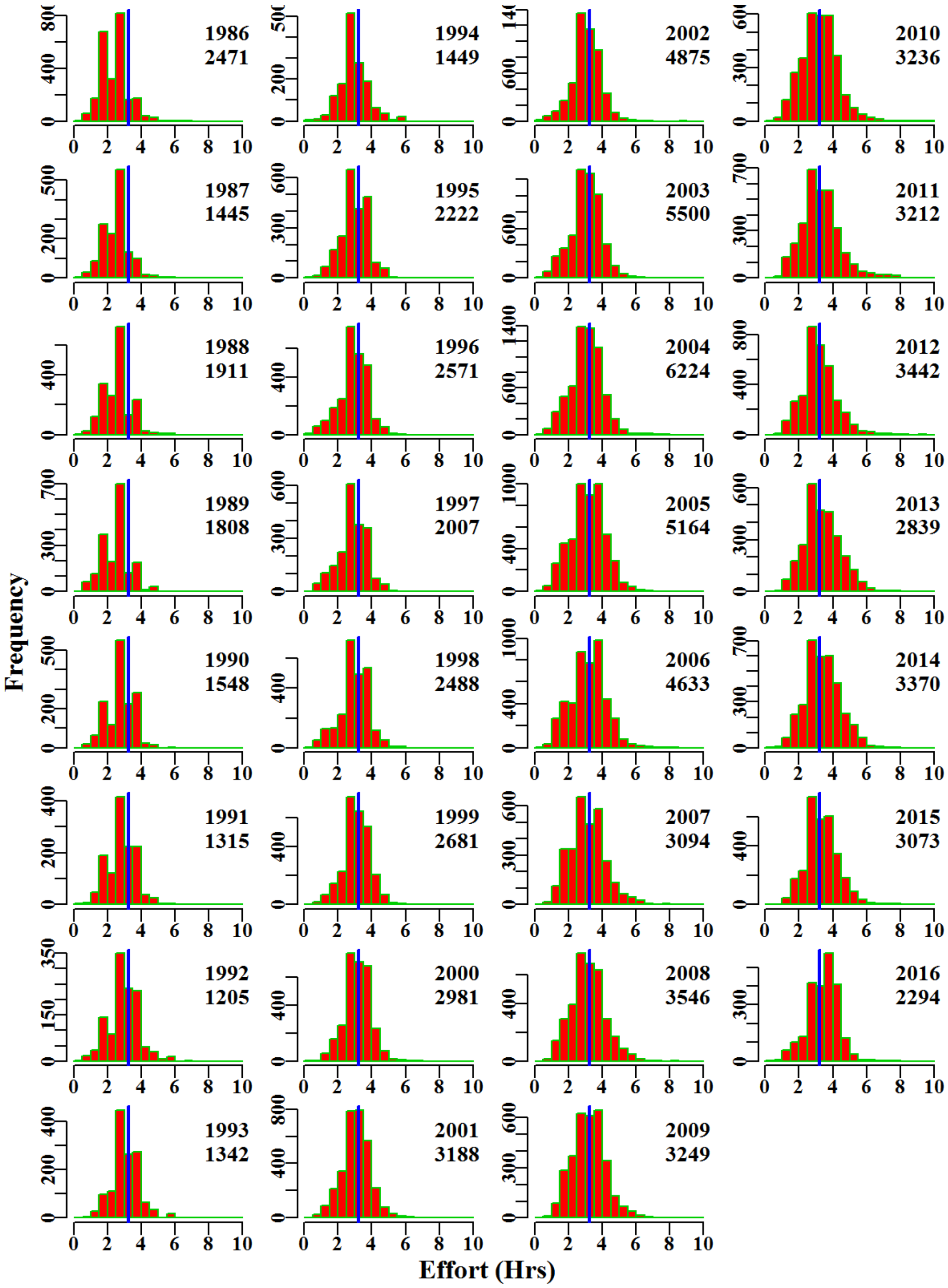


Figure 7.194. OceanJackets1050. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.28 Ocean Jackets GAB

Ocean Jackets (LTC - 37465006 - *Nelusetta ayraudi* and Leather Jackets LTH – 37465000). Trawl caught Ocean Jackets based on methods TW, TDO, in zones 82, 83, and depths 0 to 300 within the GAB fishery for the years 1986 - 2016 were analysed (Table 7.126). A total of 8 statistical models were fitted sequentially to the available data.

7.28.1 *Inferences*

The majority of catch of this species occurred in zone 83 followed by zone 82 in the GAB. A large spike of catches occurred from 2002 - 2006, which declined rapidly following the structural adjustment, although this may not have caused the decline in the GAB.

The terms Year, DayNight, Vessel DepCat and Month had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests a small departure from that the assumed Normal distribution as depicted by both tails of the distribution (Figure 7.198).

Annual standardized CPUE are noisy and flat across the 1986 - 2016 period (Figure 7.195) but catches and numbers of records were low from 1986 - 1989.

7.28.2 *Action Items and Issues*

No issues identified.

Table 7.122. OceanJacketsGAB. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	56.4	141	8.5	1	15.6	1.2385	0.000	2.550	0.300
1987	53.4	212	22.6	3	23.2	1.0304	0.106	2.330	0.103
1988	66.3	245	15.6	7	20.7	1.2315	0.187	1.613	0.103
1989	71.7	576	34.7	7	17.9	1.2415	0.184	4.303	0.124
1990	91.0	920	51.4	11	15.7	0.8282	0.182	8.755	0.170
1991	170.5	1252	139.8	8	26.8	1.0554	0.181	6.495	0.046
1992	88.9	954	59.5	7	14.1	0.9023	0.181	9.684	0.163
1993	71.9	819	38.8	4	9.9	0.6127	0.181	9.462	0.244
1994	74.4	745	36.7	5	10.6	0.5404	0.182	7.580	0.207
1995	140.2	1316	78.8	5	13.0	0.7032	0.181	12.907	0.164
1996	199.6	1725	123.5	6	15.0	0.8203	0.180	15.119	0.122
1997	177.4	2135	121.1	9	11.9	0.6783	0.180	21.690	0.179
1998	189.9	1799	116.4	9	13.9	0.7362	0.180	16.305	0.140
1999	202.8	1585	109.0	7	13.6	0.8377	0.181	12.255	0.112
2000	198.8	1552	122.3	5	17.4	0.8618	0.181	11.172	0.091
2001	222.6	1993	146.2	6	15.5	0.8941	0.181	12.521	0.086
2002	378.5	1798	148.4	6	16.3	0.9497	0.181	12.040	0.081
2003	482.3	2837	279.6	9	19.4	1.0851	0.180	11.501	0.041
2004	692.6	3433	364.4	9	20.9	1.1856	0.180	13.313	0.037
2005	890.6	4317	522.9	10	23.8	1.2570	0.180	14.612	0.028
2006	741.5	3609	408.4	11	21.4	0.9743	0.180	11.970	0.029
2007	564.8	2647	254.9	8	19.7	0.8726	0.181	10.759	0.042
2008	490.4	2351	146.4	6	12.9	0.7490	0.181	14.857	0.102
2009	610.0	2160	220.0	4	20.8	1.0394	0.181	11.249	0.051
2010	483.9	1792	168.2	4	18.9	1.1794	0.181	5.282	0.031
2011	487.4	1857	191.0	4	21.1	1.2000	0.181	5.501	0.029
2012	519.7	1716	154.8	5	17.3	1.1433	0.181	3.205	0.021
2013	488.5	2216	204.4	6	17.4	1.2582	0.181	1.018	0.005
2014	512.0	2016	206.9	6	18.3	1.3062	0.181	0.332	0.002
2015	414.9	1570	148.6	3	18.4	1.2608	0.181	0.894	0.006
2016	467.1	1654	203.1	4	23.8	1.3269	0.181	4.774	0.024

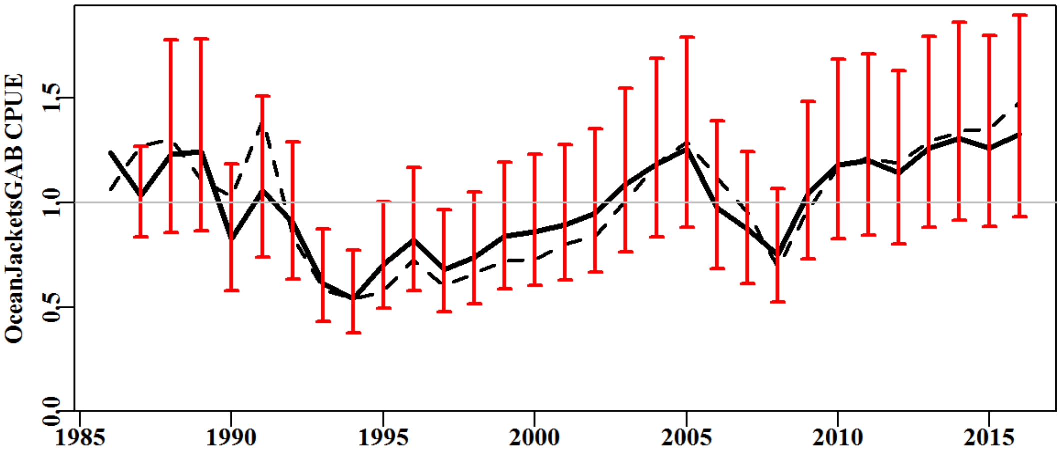


Figure 7.195. OceanJacketsGAB standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

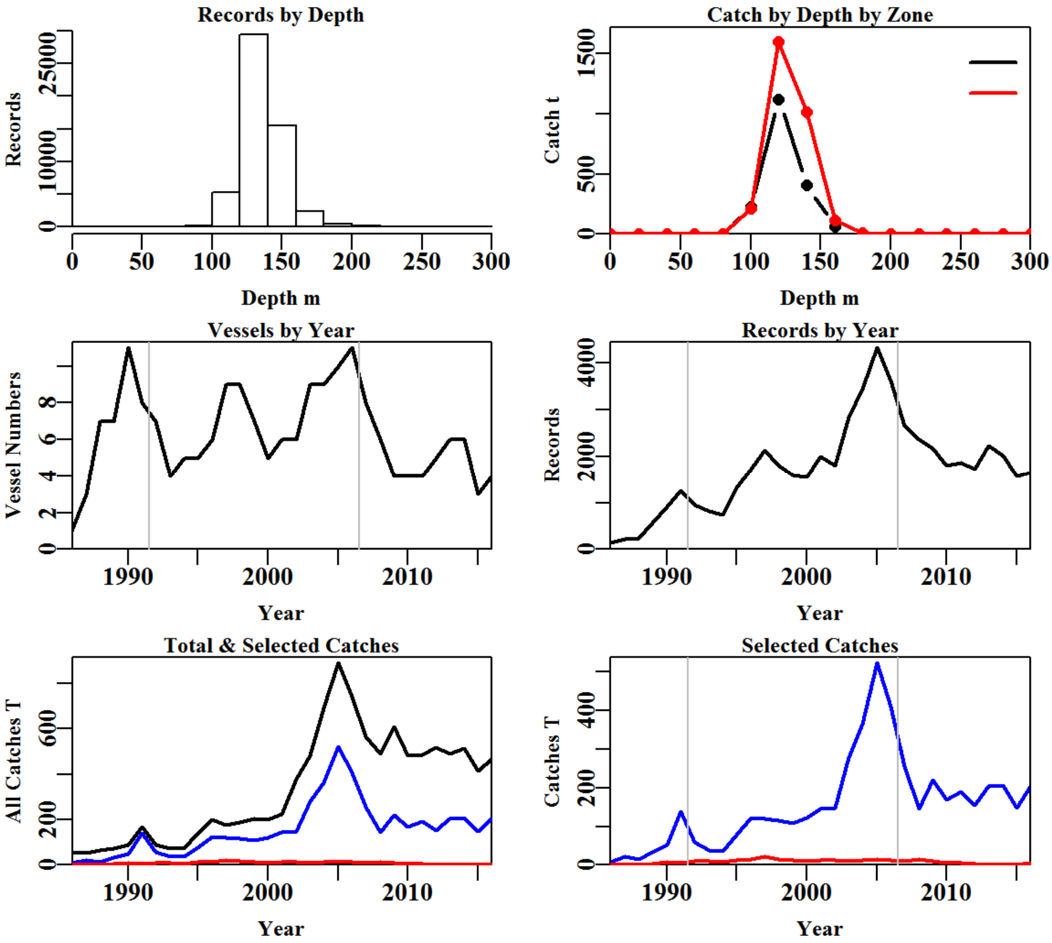


Figure 7.196. OceanJacketsGAB fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.123. OceanJacketsGAB data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	170570	162024	161249	157385	55697	53957	53942
Difference	0	8546	775	3864	101688	1740	15

Table 7.124. The models used to analyse data for OceanJacketsGAB.

	Model
Model1	Year
Model2	Year + DayNight
Model3	Year + DayNight + Vessel
Model4	Year + DayNight + Vessel + DepCat
Model5	Year + DayNight + Vessel + DepCat + Month
Model6	Year + DayNight + Vessel + DepCat + Month + Zone
Model7	Year + DayNight + Vessel + DepCat + Month + Zone + Zone:Month
Model8	Year + DayNight + Vessel + DepCat + Month + Zone + Zone:DepCat

Table 7.125. OceanJacketsGAB. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	2105	56024	4257	53942	31	7.0	0.00
DayNight	-3813	50198	10084	53942	34	16.7	9.67
Vessel	-6410	47771	12511	53942	72	20.7	3.97
DepCat	-9173	44941	15341	53517	87	24.8	4.14
Month	-10408	43897	16385	53517	98	26.5	1.73
Zone	-10417	43888	16393	53517	99	26.5	0.01
Zone:Month	-10624	43701	16581	53517	110	26.8	0.30
Zone:DepCat	-10413	43867	16415	53517	114	26.6	0.02

Table 7.126. OceanJacketsGAB. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	OceanJacketsGAB
csirocode	37465006, 37465000
fishery	GAB
depthrange	0 - 300
depthclass	20
zones	82, 83
methods	TW, TDO
years	1986 - 2016

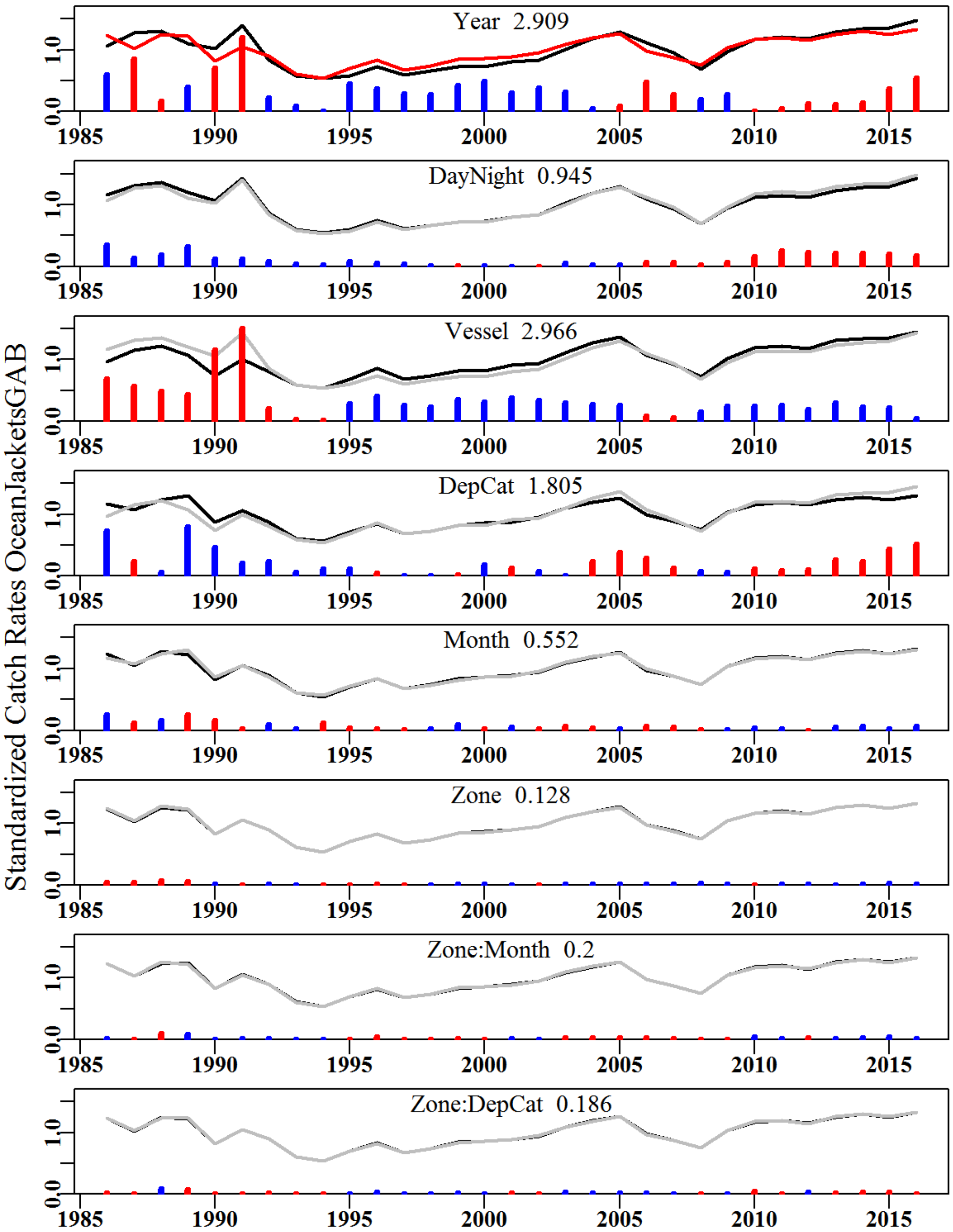


Figure 7.197. OceanJacketsGAB. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

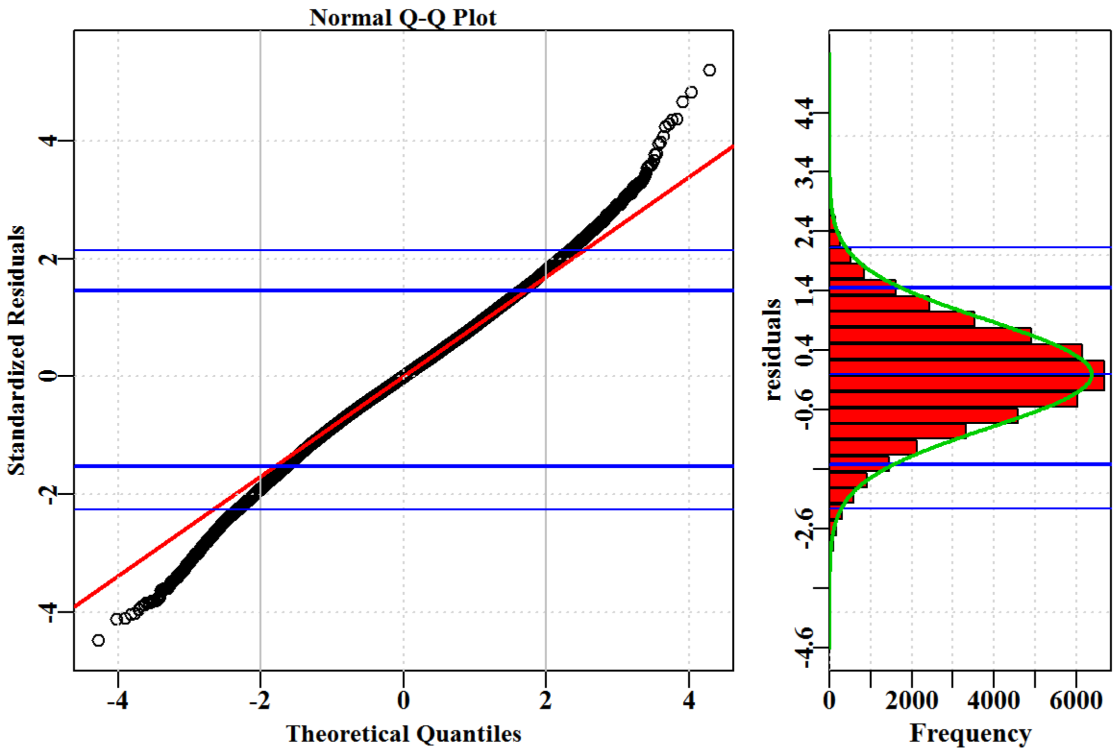


Figure 7.198. OceanJacketsGAB. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

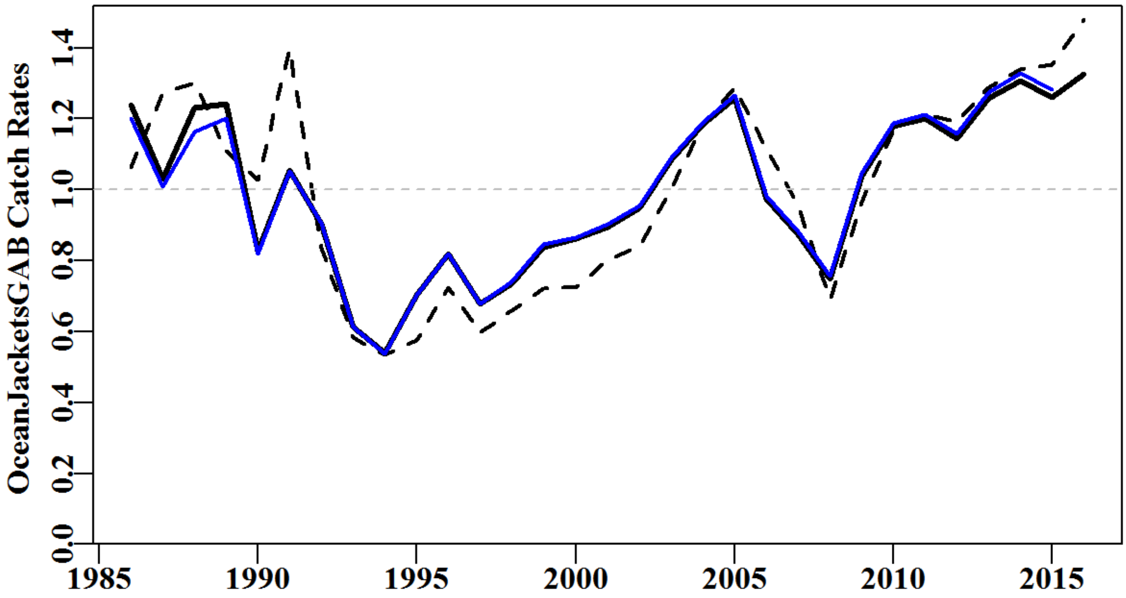


Figure 7.199. OceanJacketsGAB. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

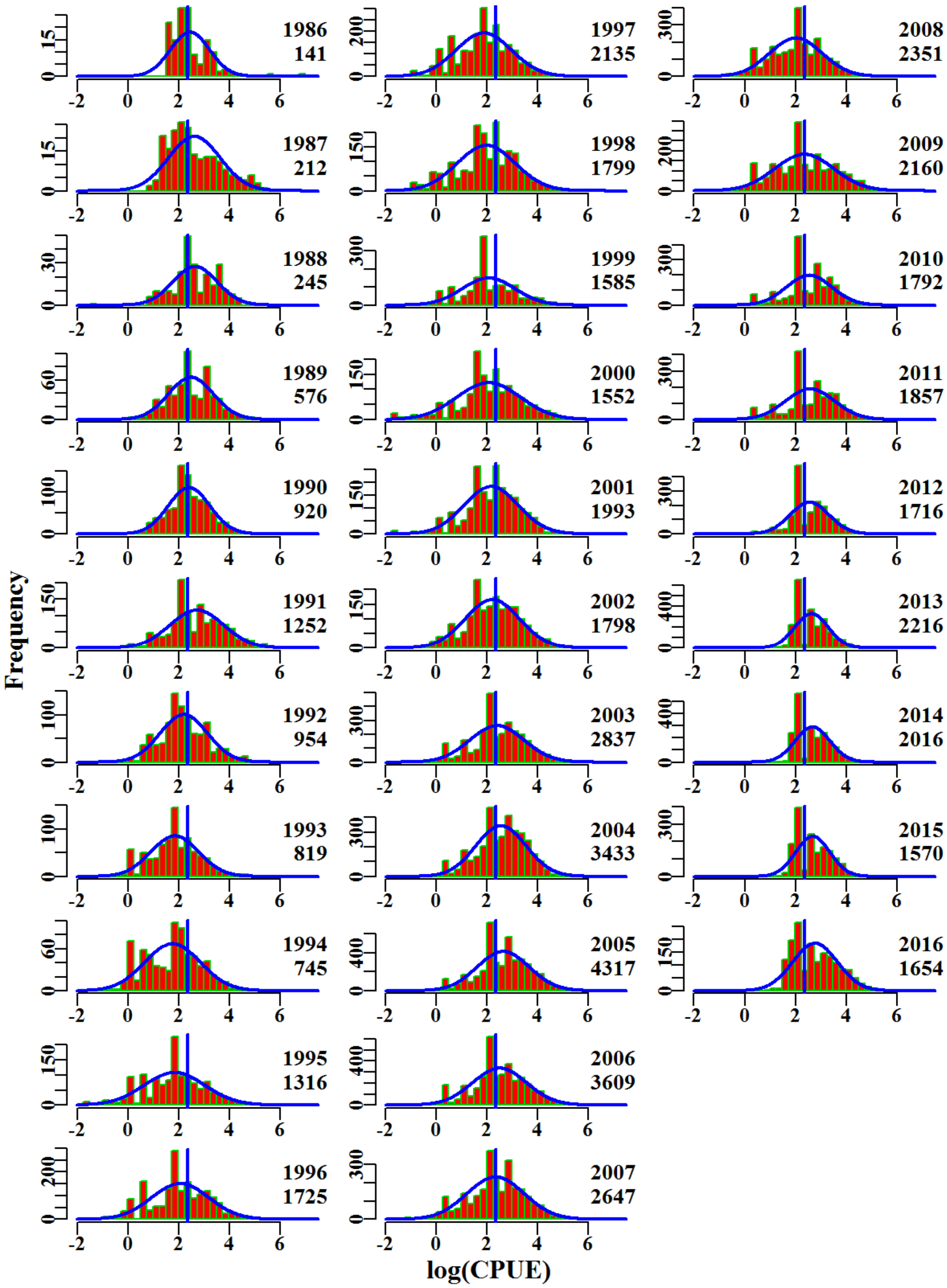


Figure 7.200. OceanJacketsGAB. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

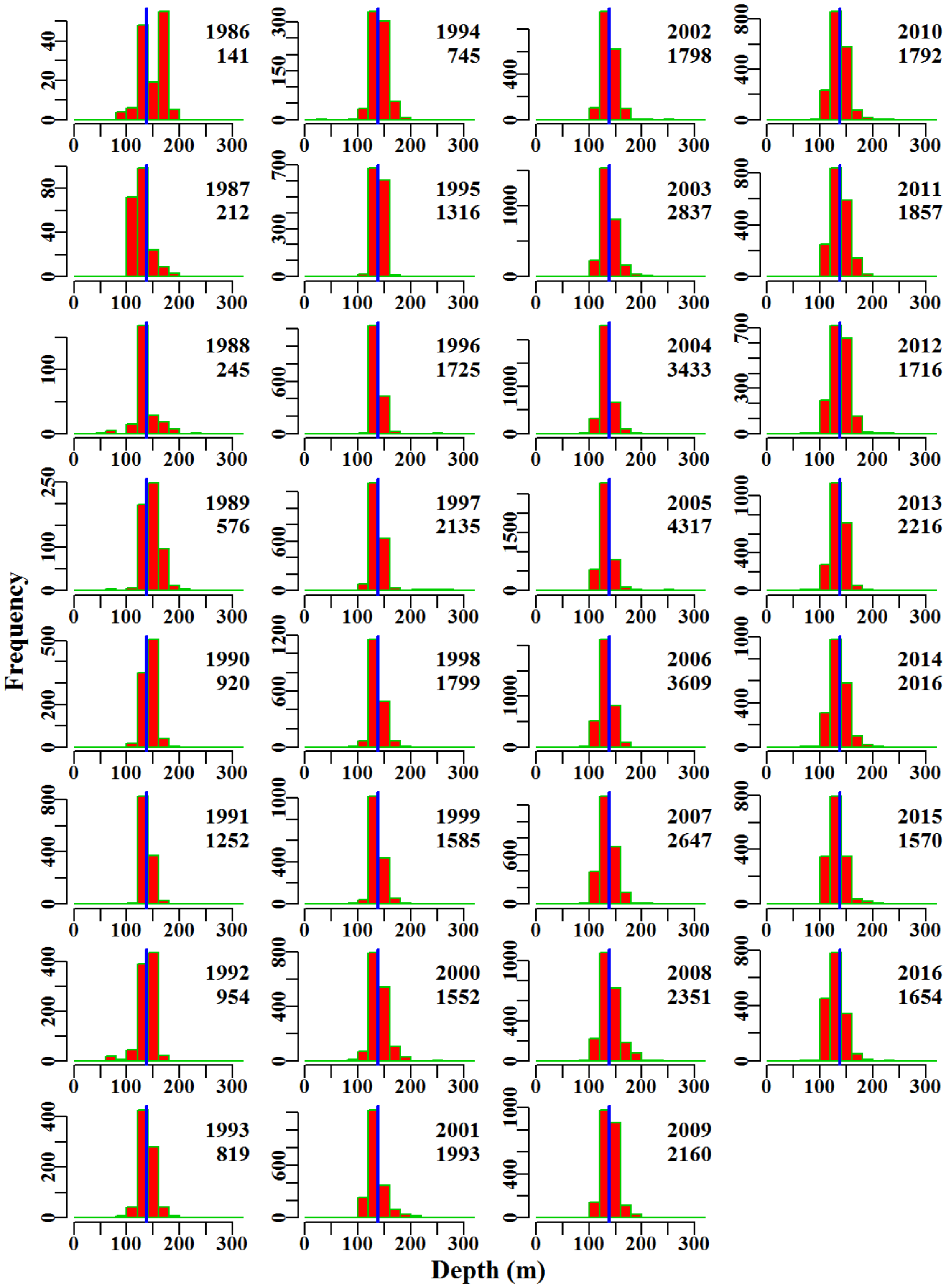


Figure 7.201. OceanJacketsGAB. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

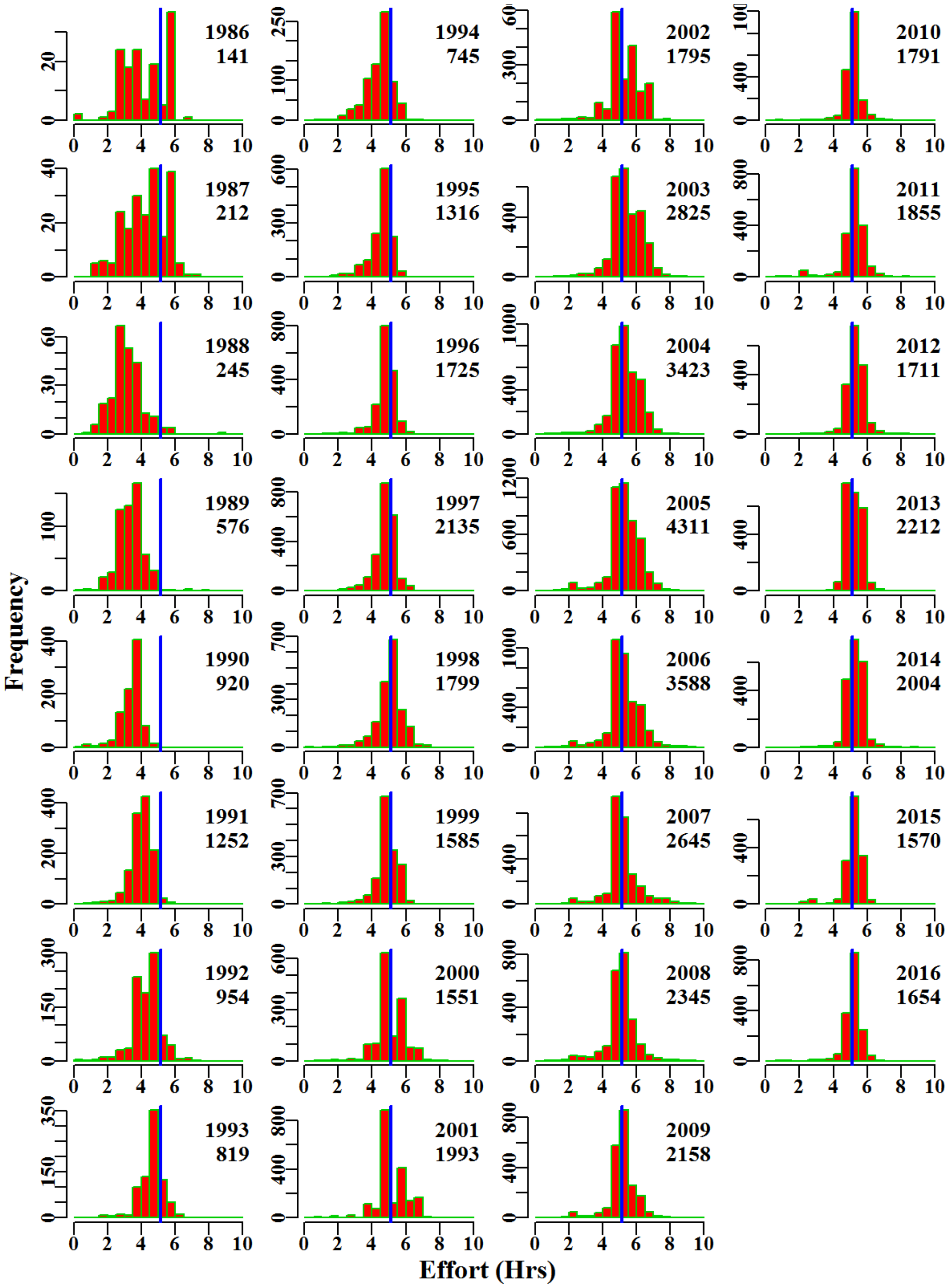


Figure 7.202. OceanJacketsGAB. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.29 Western Gemfish 4050

For Western Gemfish (GEM - 37439002 - *Rexea solandri*) in zones 40 and 50. Trawl caught Western Gemfish based on methods TW, TDO, OTT, in zones 40, 50, and depths 100 to 700 within the SET fishery for the years 1986 - 2016 were analysed (Table 7.131).

A total of 8 statistical models were fitted sequentially to the available data.

7.29.1 *Inferences*

The majority of catch of this species occurred in zone 50 with minimal catches in zone 40.

The terms Year, DepCat, DayNight and Vessel had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests a small departure of the assumed Normal distribution as depicted by the upper tail of the distribution (Figure 7.206).

Annual standardized CPUE are noisy and flat since 1992 and consistenly below average since 2001 (Figure 7.203).

7.29.2 *Action Items and Issues*

No issues identified.

Table 7.127. gemfish4050. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	307.7	1681	306.8	24	63.5	2.4034	0.000	5.837	0.019
1987	250.2	1212	248.4	26	68.2	2.2873	0.045	4.464	0.018
1988	223.4	1208	221.1	27	63.2	2.2959	0.048	6.723	0.030
1989	156.7	1076	156.6	28	50.0	1.9223	0.050	6.139	0.039
1990	135.2	1037	134.7	25	43.3	1.4701	0.053	8.594	0.064
1991	268.5	1363	248.6	25	57.3	1.4151	0.050	7.145	0.029
1992	89.7	664	80.9	15	43.0	0.9841	0.058	4.244	0.052
1993	101.8	711	101.4	16	40.0	0.9433	0.058	5.646	0.056
1994	96.0	826	95.1	18	33.4	1.0161	0.055	5.739	0.060
1995	84.0	963	83.9	21	29.0	0.8944	0.053	8.403	0.100
1996	142.9	1132	142.6	26	44.1	0.9644	0.051	9.811	0.069
1997	152.9	1375	152.4	21	42.5	0.8569	0.049	11.475	0.075
1998	122.4	1256	121.9	20	40.2	0.9290	0.050	10.304	0.084
1999	176.9	1688	176.1	18	37.4	0.8714	0.048	14.426	0.082
2000	231.9	1909	229.2	27	57.1	0.9636	0.048	14.963	0.065
2001	168.5	1669	168.2	26	44.9	0.7690	0.049	13.782	0.082
2002	85.9	1398	85.2	23	19.8	0.5844	0.050	13.114	0.154
2003	122.7	1050	121.7	23	40.8	0.6769	0.053	7.707	0.063
2004	107.1	1214	105.2	22	25.3	0.6497	0.053	8.154	0.077
2005	116.1	1056	114.7	18	33.1	0.6738	0.054	5.770	0.050
2006	104.7	884	101.7	17	25.4	0.5572	0.056	4.497	0.044
2007	60.0	695	57.5	14	19.9	0.5284	0.059	3.725	0.065
2008	55.4	752	53.0	14	14.9	0.6122	0.058	4.754	0.090
2009	60.0	928	56.3	12	12.9	0.6785	0.055	6.122	0.109
2010	90.1	1370	86.4	14	13.0	0.7303	0.051	8.030	0.093
2011	55.2	1072	53.9	12	10.1	0.7138	0.053	6.942	0.129
2012	49.6	738	47.2	13	13.2	0.6799	0.059	4.277	0.091
2013	42.2	575	38.5	14	13.3	0.6027	0.063	3.116	0.081
2014	70.5	672	69.0	14	25.0	0.8524	0.060	2.136	0.031
2015	48.7	655	46.3	12	17.1	0.6812	0.062	2.064	0.045
2016	53.3	659	50.6	13	17.7	0.7922	0.061	2.164	0.043

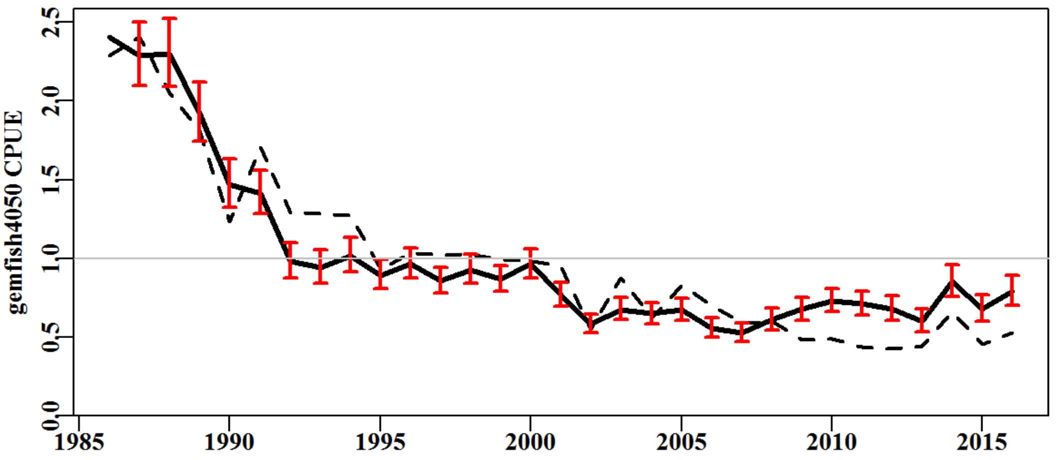


Figure 7.203. gemfish4050 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

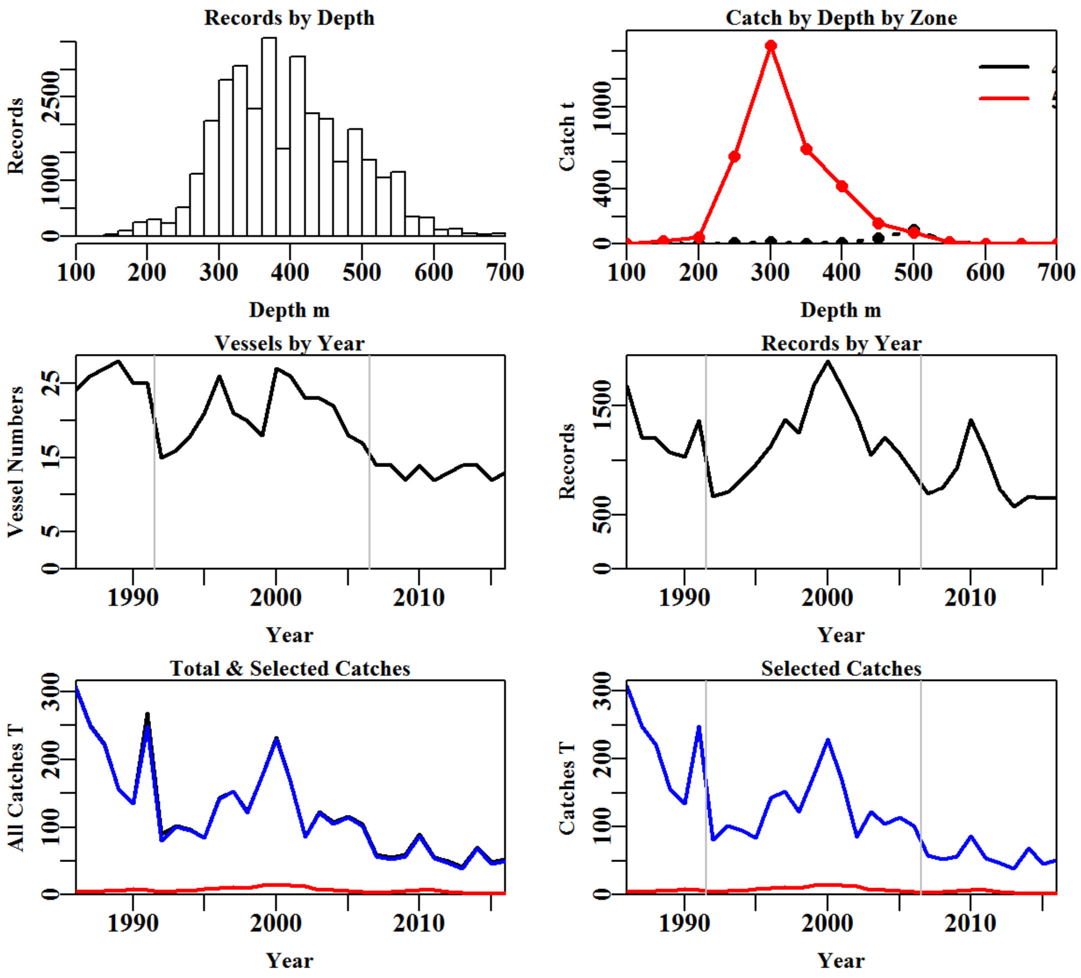


Figure 7.204. gemfish4050 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.128. gemfish4050 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	36142	34735	34545	33808	33808	33531	33488
Difference	0	1407	190	737	0	277	43

Table 7.129. The models used to analyse data for gemfish4050.

	Model
Model1	Year
Model2	Year + DepCat
Model3	Year + DepCat + Vessel
Model4	Year + DepCat + Vessel + Zone
Model5	Year + DepCat + Vessel + Zone + DayNight
Model6	Year + DepCat + Vessel + Zone + DayNight + Month
Model7	Year + DepCat + Vessel + Zone + DayNight + Month + Zone:Month
Model8	Year + DepCat + Vessel + Zone + DayNight + Month + Zone:DepCat

Table 7.130. gemfish4050. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	22766	65967	8443	33488	31	11.3	0.00
DepCat	13931	50517	23893	33356	43	31.8	20.54
Vessel	8835	43126	31284	33356	133	41.6	9.82
Zone	8771	43042	31369	33356	134	41.7	0.11
DayNight	8186	42285	32125	33356	137	42.8	1.02
Month	7821	41798	32613	33356	148	43.4	0.64
Zone:Month	7549	41431	32979	33356	159	43.9	0.48
Zone:DepCat	7718	41641	32769	33356	159	43.6	0.19

Table 7.131. gemfish4050. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	gemfish4050
csirocode	37439002, 91439002, 92439002
fishery	SET
depthrange	100 - 700
depthclass	50
zones	40, 50
methods	TW, TDO, OTT
years	1986 - 2016

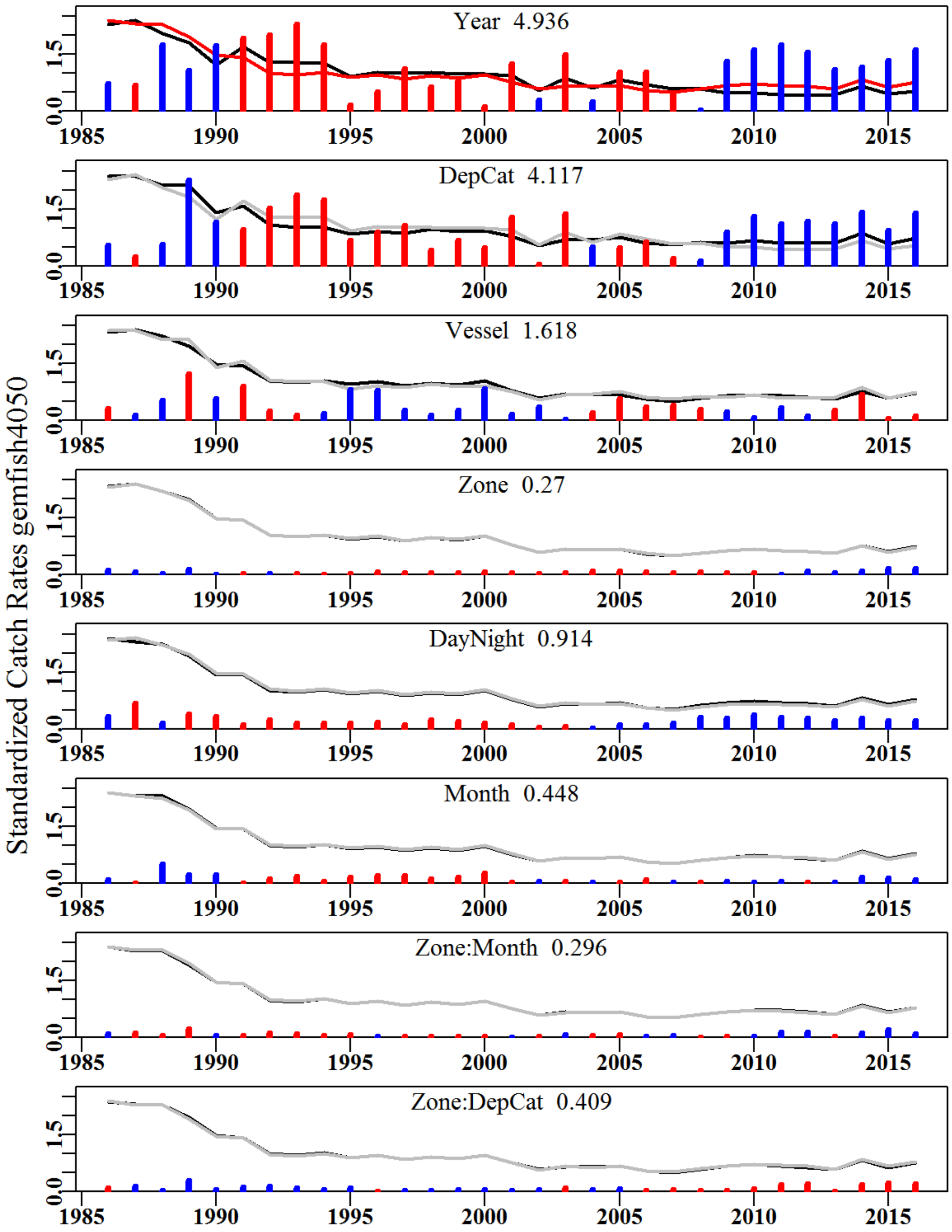


Figure 7.205. gemfish4050. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

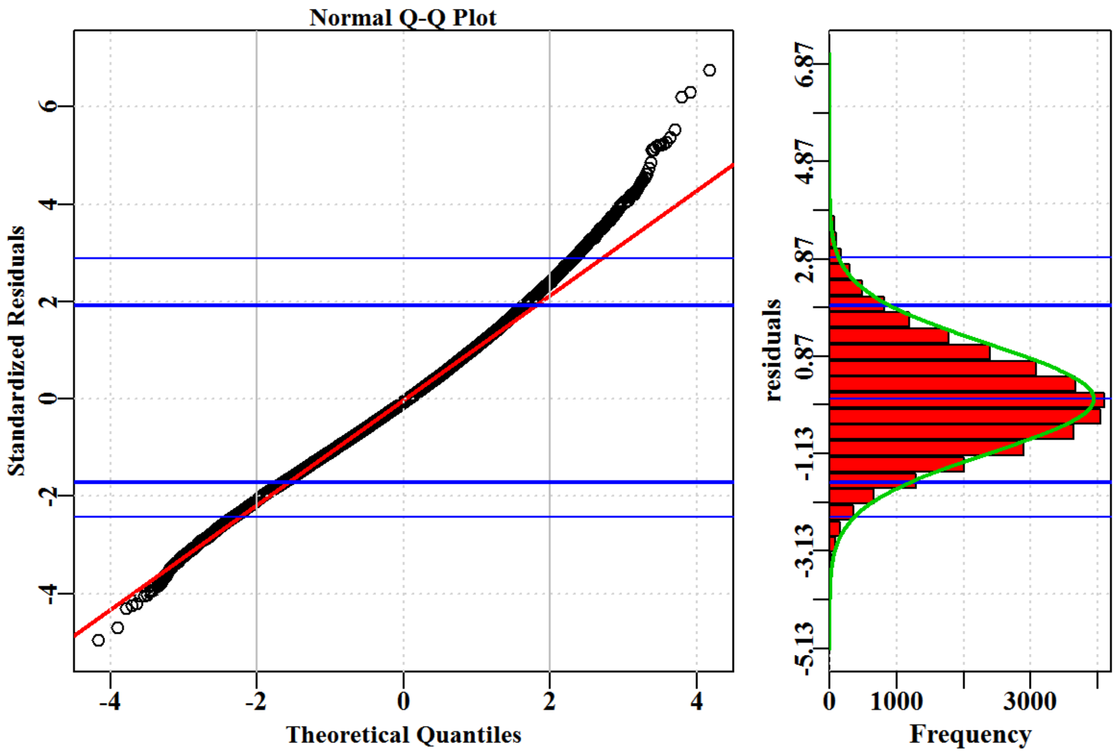


Figure 7.206. gemfish4050. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

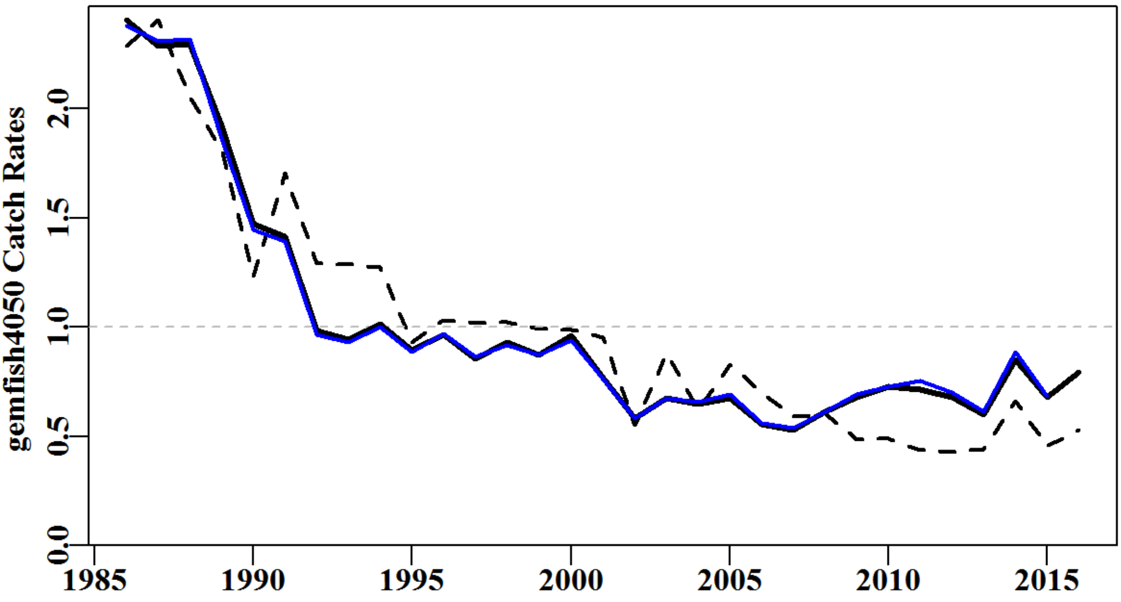


Figure 7.207. gemfish4050. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

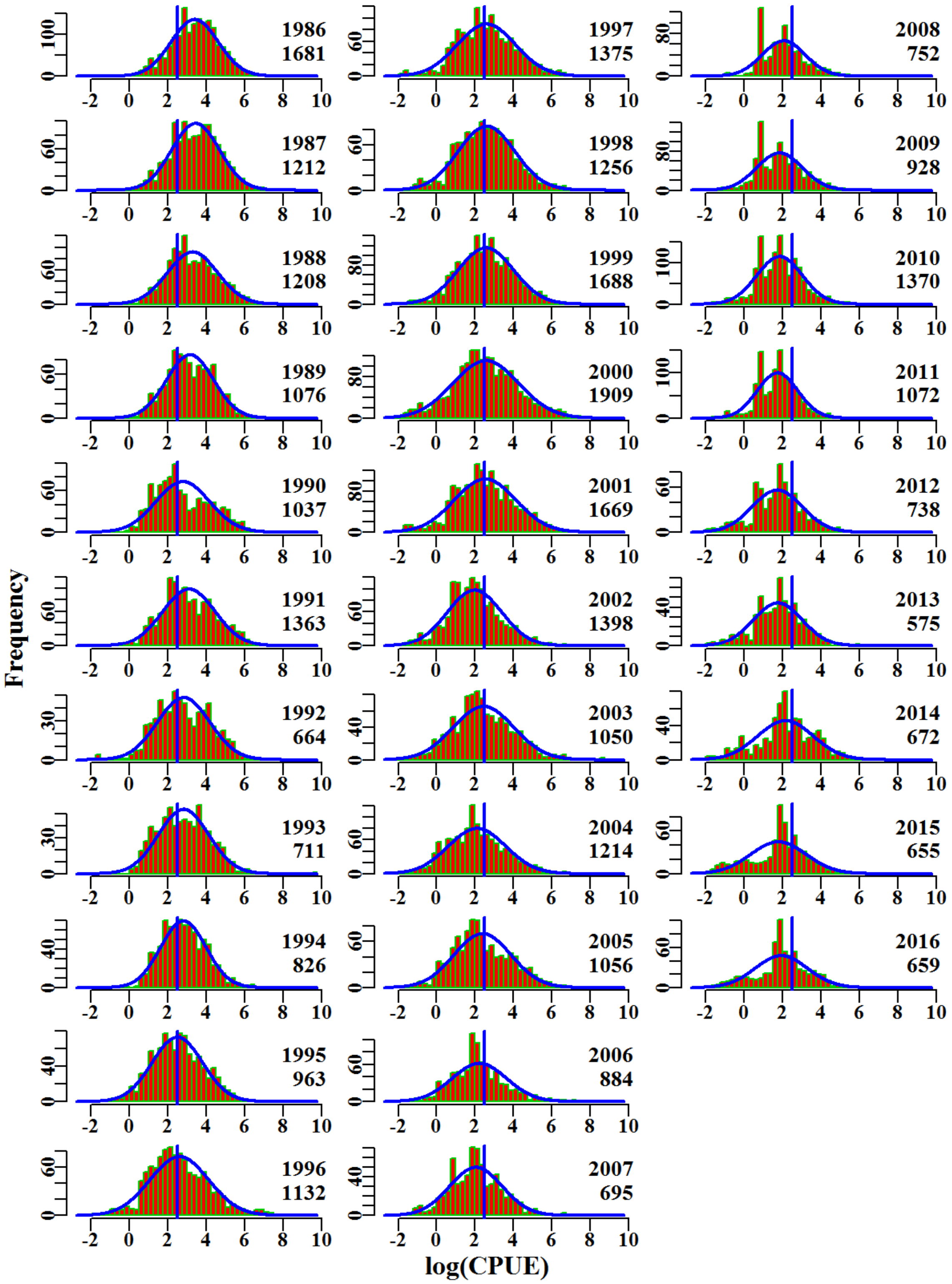


Figure 7.208. gemfish4050. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

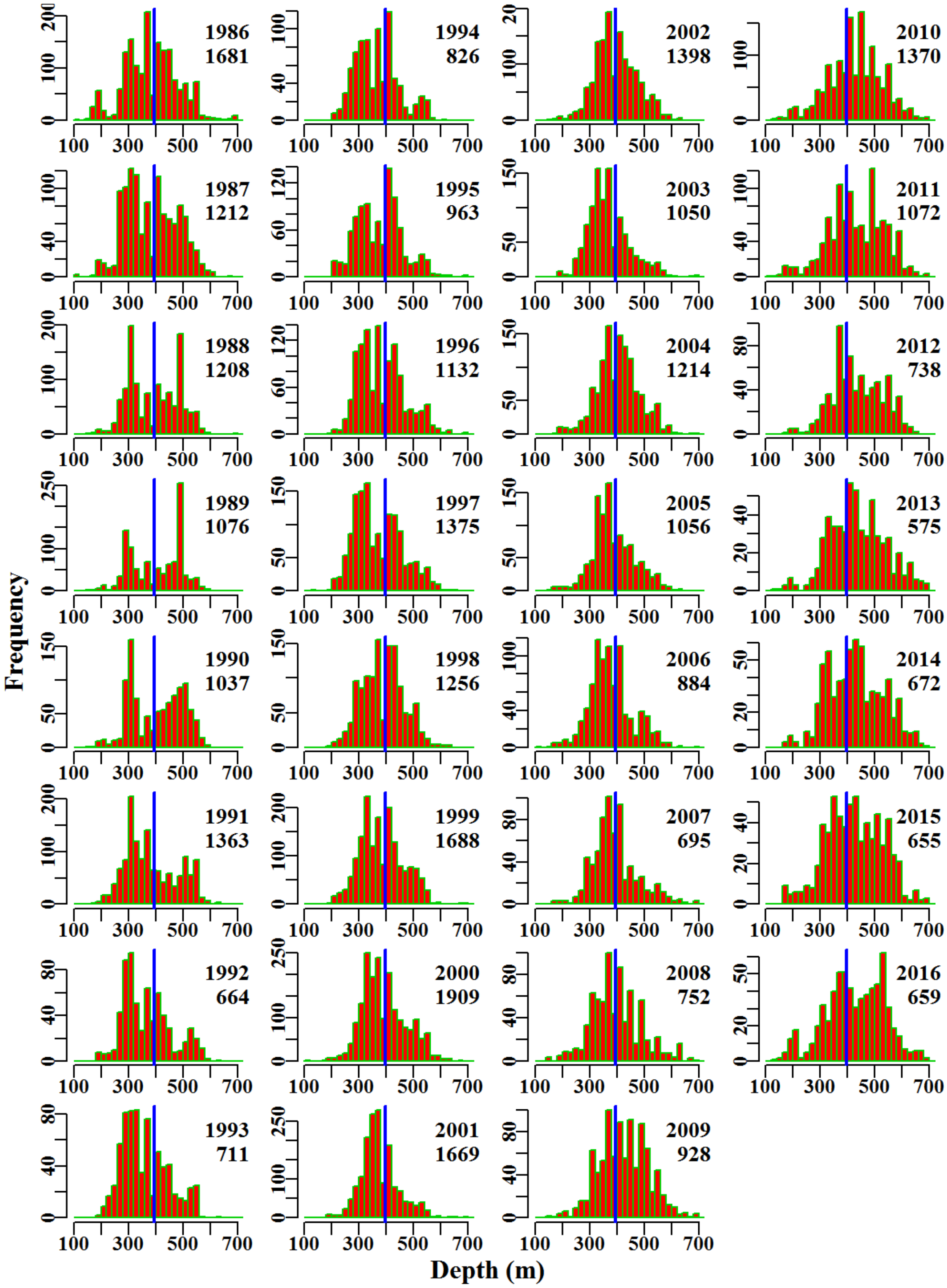


Figure 7.209. gemfish4050. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

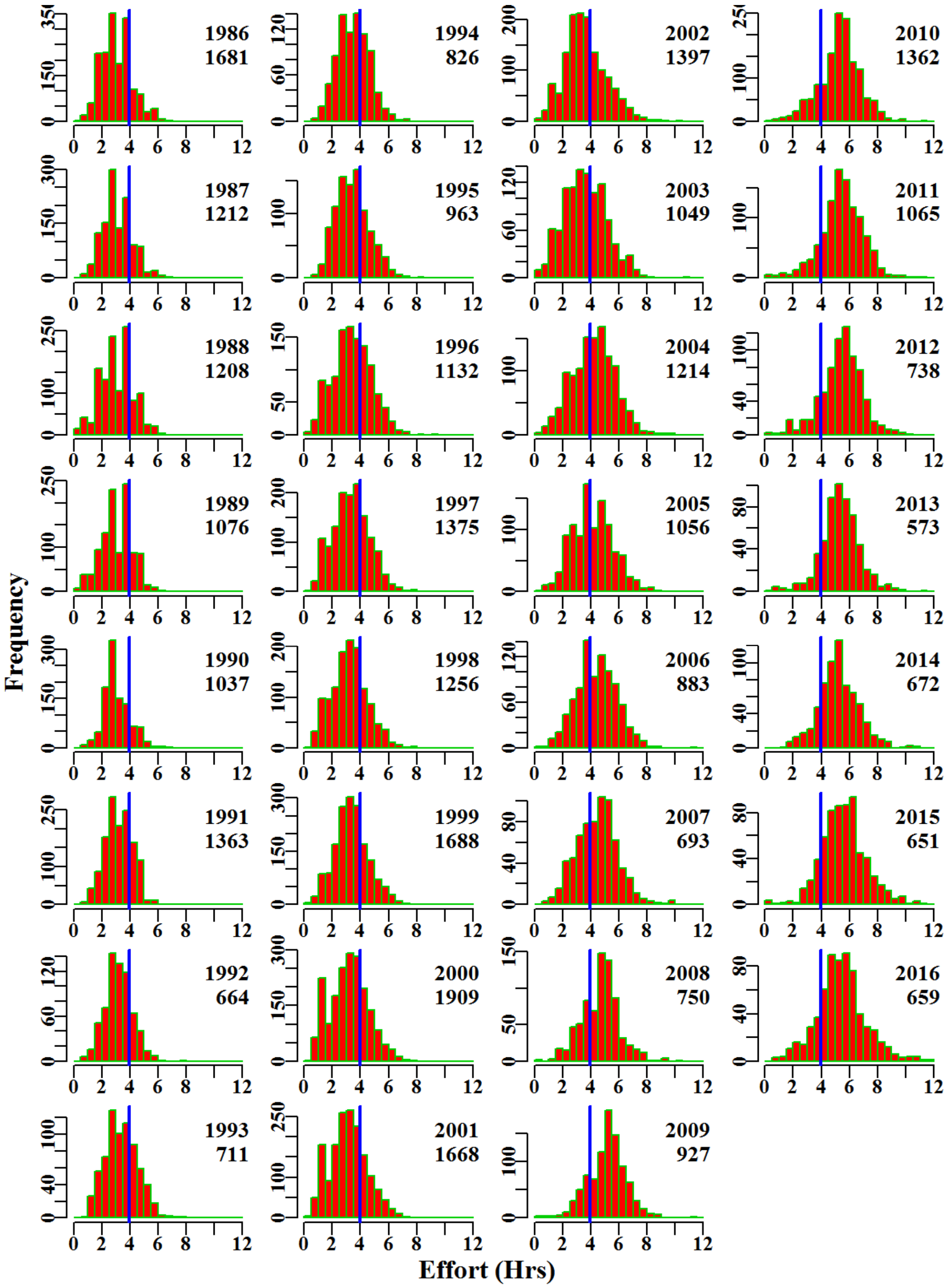


Figure 7.210. gemfish4050. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.30 Western Gemfish 4050GAB

For Western Gemfish (GEM - 37439002 - *Rexea solandri*) in zones 40 and 50 and the GAB, initial data selection was conducted according to the detials given in Table 7.136.

A total of 8 statistical models were fitted sequentially to the available data.

7.30.1 *Inferences*

The majority of catch of this species occurred in zone 50 followed by zone 82 and minimal catches in the remaning zones.

The terms Year, DepCat, Vessel, Zone and DayNight had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests the assumed Normal distribution is valid with a slight departure as depicted by the tails of the distribution (Figure 7.214).

Annual standardized CPUE have been consistenly below average and flat since 1999 (Figure 7.211). However, the CPUE from 1986 - 1994 is more representative of zone 50 than of the GAB. Given recent evidence that the stocks of Western Gemfish in the GAB and most of Zone 50 are different biological stocks it is doubtful that these data should be combined.

7.30.2 *Action Items and Issues*

This analysis is recommended to be abandoned as misleading through it combining the data from two biological stocks.

Table 7.132. gemfish4050GAB. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	308.9	1704	306.6	25	62.1	2.3353	0.000	6.489	0.021
1987	263.8	1286	261.8	29	67.7	2.1813	0.046	5.264	0.020
1988	260.2	1403	255.4	36	63.4	2.0843	0.048	8.098	0.032
1989	185.3	1400	184.8	37	45.5	1.6170	0.049	8.829	0.048
1990	146.2	1245	145.6	35	37.9	1.3985	0.053	10.824	0.074
1991	300.0	1570	279.6	32	56.1	1.3582	0.050	9.022	0.032
1992	105.7	800	96.9	21	41.3	1.0164	0.057	5.424	0.056
1993	108.7	896	108.3	20	35.2	0.8492	0.056	7.403	0.068
1994	110.8	1040	109.9	24	33.2	0.8733	0.054	7.406	0.067
1995	106.9	1287	106.8	26	27.0	0.8436	0.051	11.493	0.108
1996	162.9	1580	161.8	32	30.6	0.9665	0.049	15.871	0.098
1997	214.8	2094	214.2	28	32.7	0.8621	0.047	19.388	0.091
1998	208.1	1966	207.3	26	35.8	1.0082	0.048	16.479	0.080
1999	323.9	2338	323.0	24	42.8	1.0082	0.047	17.989	0.056
2000	264.1	2335	261.4	31	52.7	0.8652	0.047	17.759	0.068
2001	259.9	2335	258.7	30	47.1	0.8080	0.047	17.421	0.067
2002	129.7	1751	128.5	28	20.4	0.6226	0.049	15.406	0.120
2003	207.5	1613	201.1	33	34.1	0.6747	0.050	11.075	0.055
2004	488.2	1950	480.4	30	47.8	0.7275	0.050	11.082	0.023
2005	389.6	1874	379.1	27	50.6	0.7292	0.050	8.591	0.023
2006	463.3	1620	437.3	26	56.3	0.6807	0.051	6.635	0.015
2007	426.7	1407	416.9	20	62.9	0.6252	0.052	6.000	0.014
2008	169.0	1247	157.2	19	19.6	0.6682	0.053	7.719	0.049
2009	113.5	1271	105.0	16	13.6	0.6942	0.053	8.274	0.079
2010	139.6	1706	128.8	18	12.8	0.7546	0.050	10.101	0.078
2011	87.3	1294	75.2	16	10.4	0.7543	0.053	8.327	0.111
2012	108.2	1072	102.9	18	16.0	0.8113	0.056	5.711	0.055
2013	55.9	712	47.9	20	13.2	0.6937	0.061	3.206	0.067
2014	97.7	841	89.1	17	24.4	0.9125	0.058	2.337	0.026
2015	57.0	718	50.2	14	16.5	0.7369	0.062	2.259	0.045
2016	55.8	679	51.2	15	17.2	0.8390	0.062	2.314	0.045

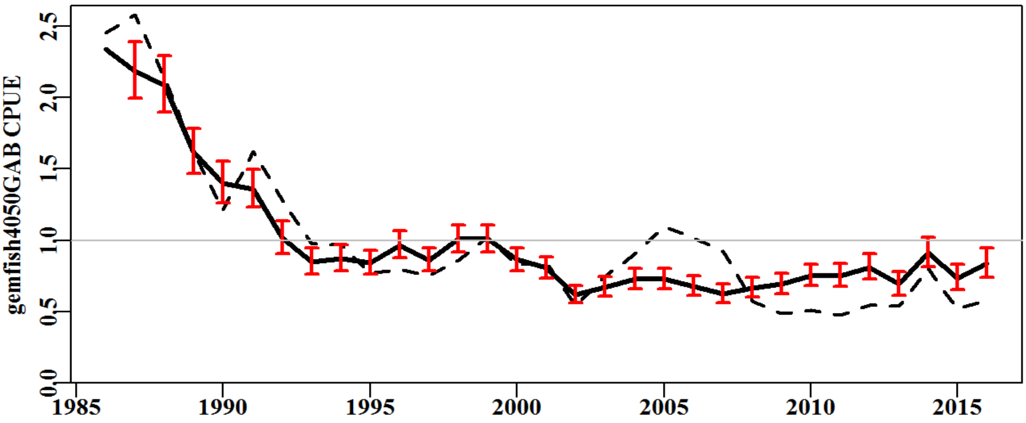


Figure 7.211. gemfish4050GAB standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

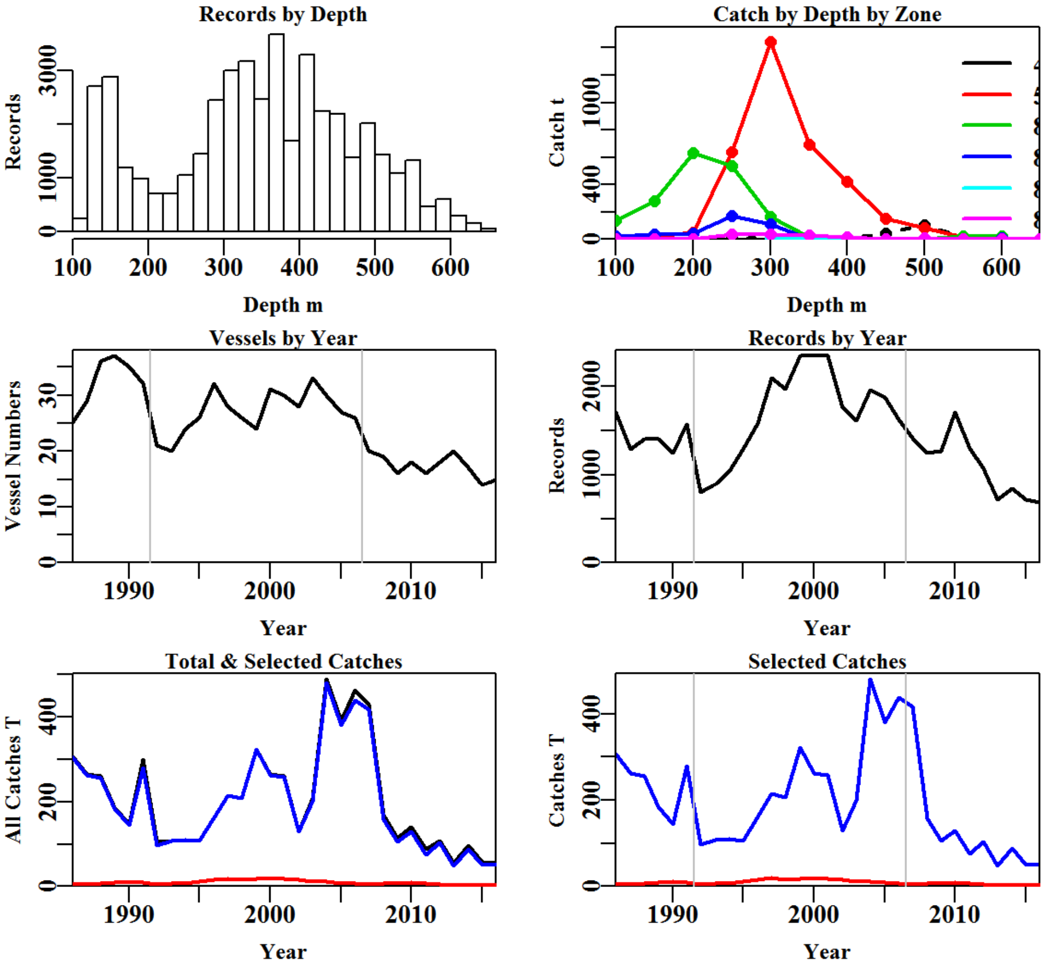


Figure 7.212. gemfish4050GAB fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.133. gemfish4050GAB data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	50641	49585	48981	47868	47868	45079	45034
Difference	0	1056	604	1113	0	2789	45

Table 7.134. The models used to analyse data for gemfish4050GAB.

	Model
Model1	Year
Model2	Year + DepCat
Model3	Year + DepCat + Vessel
Model4	Year + DepCat + Vessel + Zone
Model5	Year + DepCat + Vessel + Zone + DayNight
Model6	Year + DepCat + Vessel + Zone + DayNight + Month
Model7	Year + DepCat + Vessel + Zone + DayNight + Month + Zone:Month
Model8	Year + DepCat + Vessel + Zone + DayNight + Month + Zone:DepCat

Table 7.135. gemfish4050GAB. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	37997	104563	8804	45034	31	7.7	0.00
DepCat	24616	77498	35869	44846	42	31.4	23.66
Vessel	16719	64665	48702	44846	153	42.6	11.22
Zone	15945	63544	49823	44846	158	43.6	0.99
DayNight	14937	62124	51243	44846	161	44.8	1.26
Month	14747	61831	51536	44846	172	45.1	0.25
Zone:Month	13695	60252	53115	44846	226	46.4	1.34
Zone:DepCat	14254	61013	52354	44846	224	45.7	0.66

Table 7.136. gemfish4050GAB. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	gemfish4050GAB
csirocode	37439002, 91439002, 92439002
fishery	SET_GAB
depthrange	100 - 650
depthclass	50
zones	40, 50, 82, 83, 84, 85
methods	TW, TDO, OTT
years	1986 - 2016

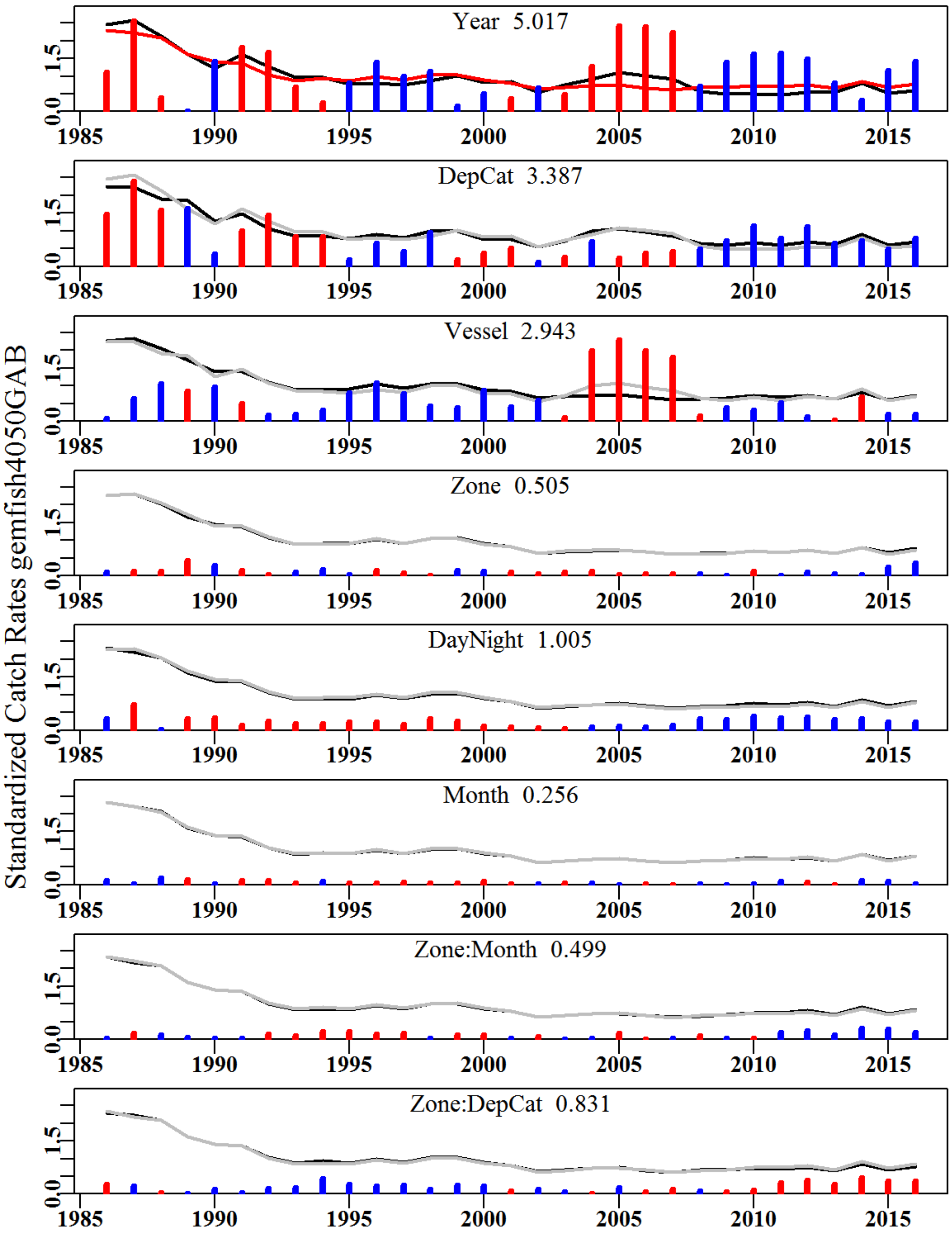


Figure 7.213. gemfish4050GAB. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

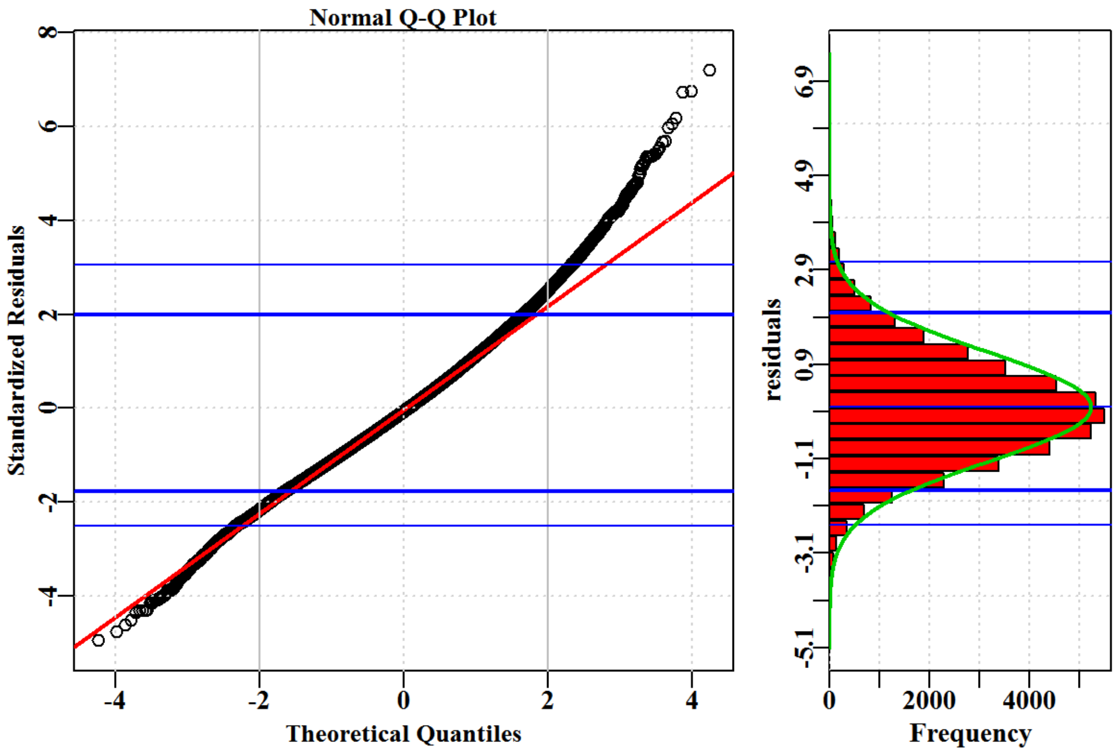


Figure 7.214. gemfish4050GAB. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

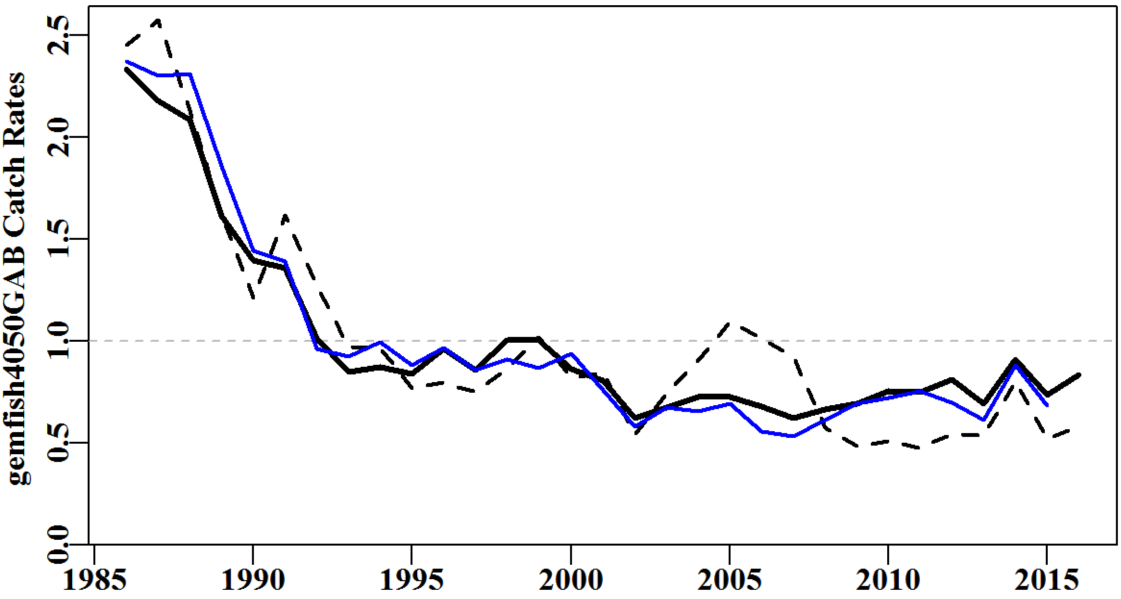


Figure 7.215. gemfish4050GAB. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

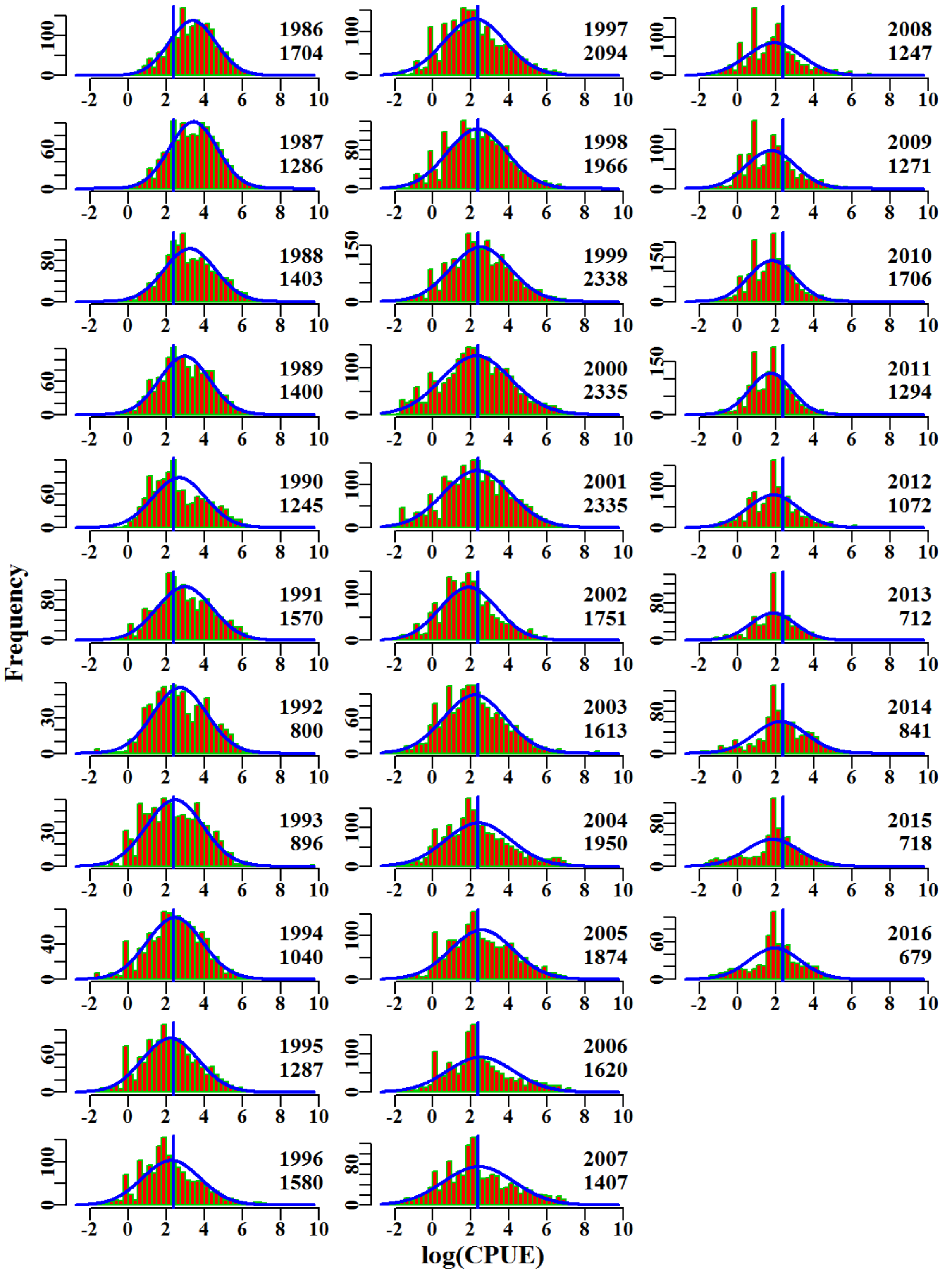


Figure 7.216. gemfish4050GAB. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

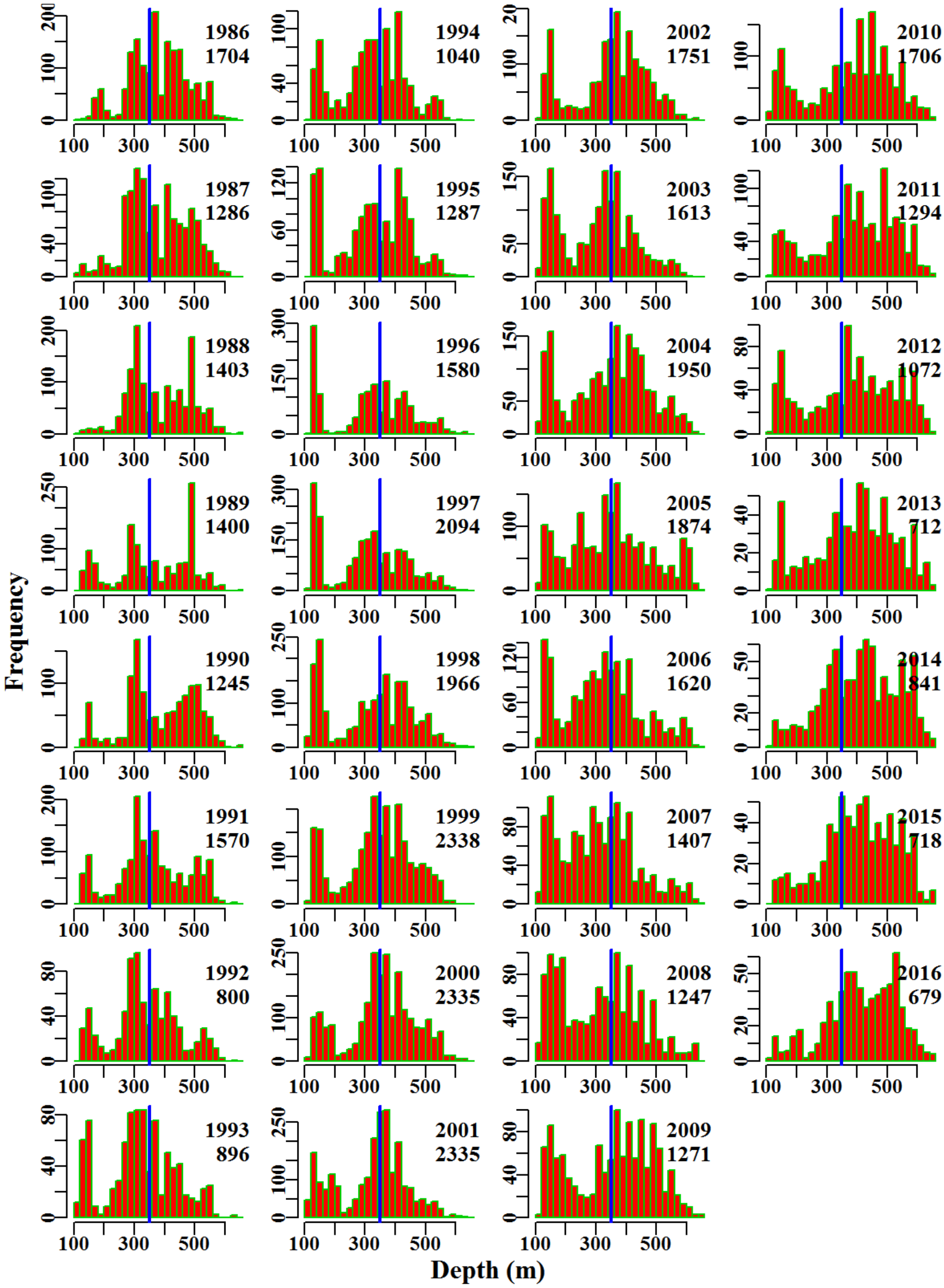


Figure 7.217. gemfish4050GAB. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

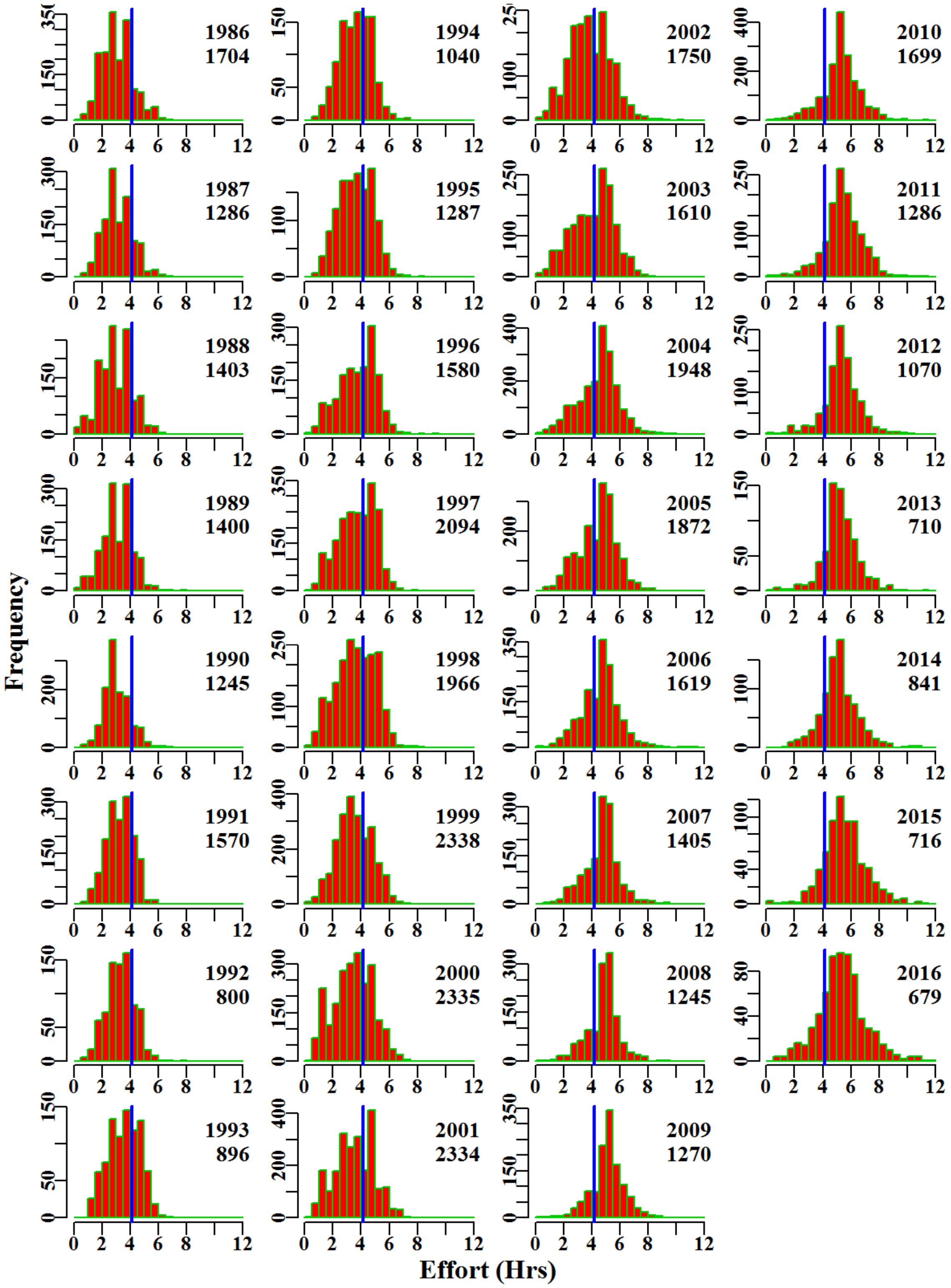


Figure 7.218. gemfish4050GAB. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.31 Western Gemfish GAB

For Western Gemfish (GEM - 37439002 - *Rexea solandri*) in zones from the GAB, initial data selection was conducted according to the detials given in Table 7.141.

A total of 8 statistical models were fitted sequentially to the available data.

7.31.1 *Inferences*

The majority of catch of this species occurred in zone 82 followed by zone 83 with minimal catches in the reamining GAB zones. There was a small number of records (30) and coresponding catch (0.7 t) in 2016 across these zones. There were very high catches between 2004-2007 due to a single exceptional vessel.

The terms Year and Vessel had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics.

Annual standardized CPUE are noisy and flat across the years analysed (Figure 7.219), with the effect of the exceptional vessel being accounted for in the standardization.

7.31.2 *Action Items and Issues*

No issues identified.

Table 7.137. gemfishGAB. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1995	181.7	325	22.5	5	13.2	0.7532	0.000	3.098	0.138
1996	382.2	450	19.2	7	7.1	0.9684	0.093	6.064	0.315
1997	572.0	720	61.8	9	12.8	0.9579	0.089	7.928	0.128
1998	404.8	709	85.3	8	24.7	1.4410	0.091	6.175	0.072
1999	448.7	654	146.9	7	58.8	1.7487	0.093	3.598	0.024
2000	336.5	427	32.2	6	14.6	0.6078	0.099	2.800	0.087
2001	331.5	671	90.5	7	43.0	1.0211	0.092	3.634	0.040
2002	195.9	351	43.2	6	20.7	0.9117	0.103	2.283	0.053
2003	268.0	562	79.3	10	20.5	0.8469	0.097	3.333	0.042
2004	569.0	738	375.3	10	114.3	1.1081	0.097	2.957	0.008
2005	511.8	818	264.3	10	83.4	0.9854	0.098	2.821	0.011
2006	544.9	736	335.8	11	132.1	0.9472	0.097	2.138	0.006
2007	599.1	715	359.7	9	173.0	0.8290	0.096	2.284	0.006
2008	294.9	499	104.5	7	28.7	0.8709	0.097	2.984	0.029
2009	194.9	350	49.0	4	15.1	0.7961	0.104	2.171	0.044
2010	220.7	345	42.7	4	11.7	0.8306	0.105	2.100	0.049
2011	147.7	229	21.5	4	12.4	0.8789	0.116	1.421	0.066
2012	168.6	334	55.8	5	23.0	1.2702	0.107	1.435	0.026
2013	103.8	149	9.7	6	11.5	1.1804	0.133	0.174	0.018
2014	130.3	176	20.2	5	20.7	1.1777	0.134	0.246	0.012
2015	86.6	68	4.1	2	10.5	1.1211	0.174	0.206	0.050
2016	74.6	30	0.7	3	7.4	0.7475	0.246	0.196	0.273

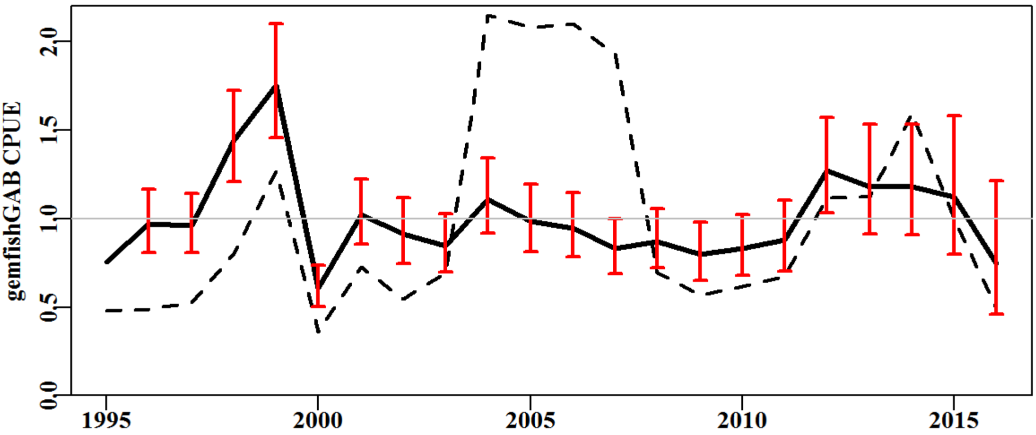


Figure 7.219. gemfishGAB standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

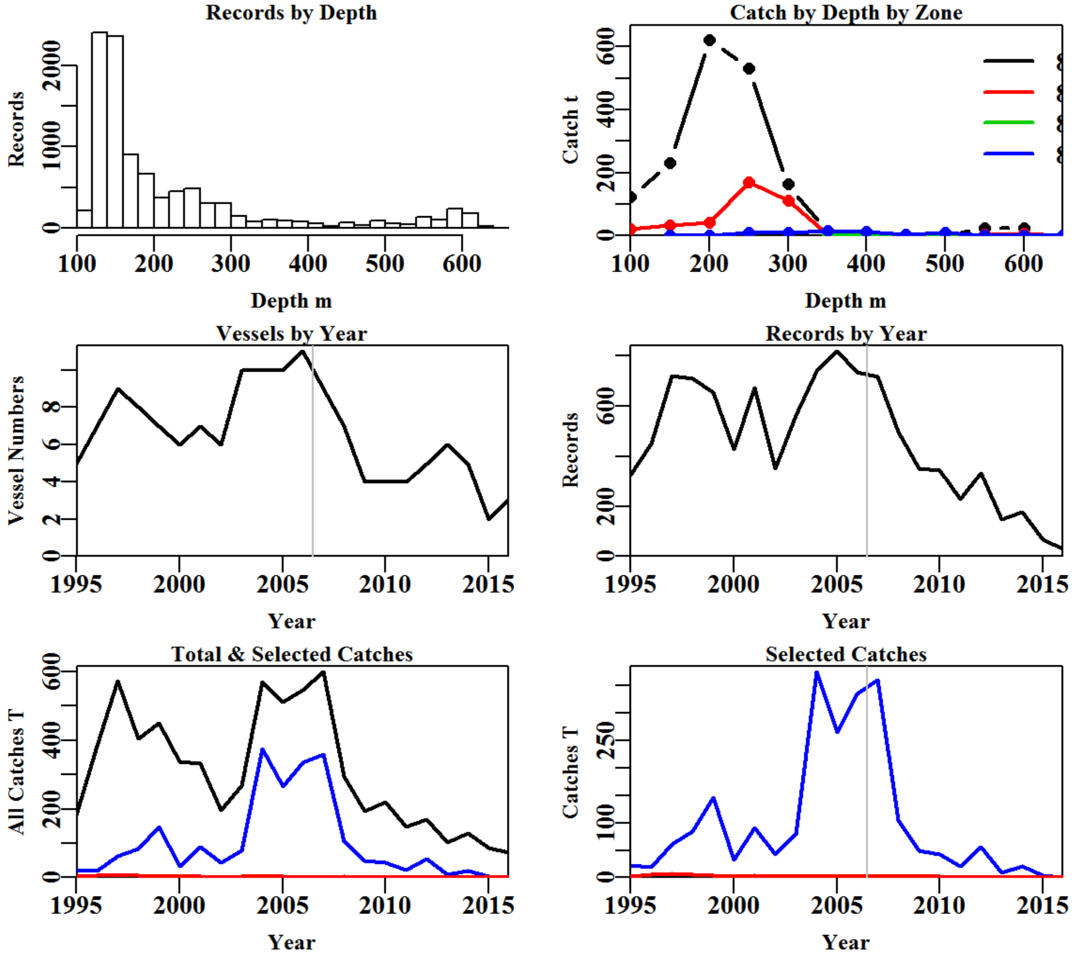


Figure 7.220. gemfishGAB fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.138. gemfishGAB data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	128016	121833	120276	81841	11858	10070	10056
Difference	0	6183	1557	38435	69983	1788	14

Table 7.139. The models used to analyse data for gemfishGAB.

	Model
Model1	Year
Model2	Year + DepCat
Model3	Year + DepCat + Vessel
Model4	Year + DepCat + Vessel + Zone
Model5	Year + DepCat + Vessel + Zone + DayNight
Model6	Year + DepCat + Vessel + Zone + DayNight + Month
Model7	Year + DepCat + Vessel + Zone + DayNight + Month + Zone:Month
Model8	Year + DepCat + Vessel + Zone + DayNight + Month + Zone:DepCat

Table 7.140. gemfishGAB. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	11111	30227	3406	10056	22	9.9	0.00
DepCat	7412	20853	12779	10014	33	37.6	27.69
Vessel	5844	17750	15883	10014	56	46.8	9.16
Zone	5444	17044	16589	10014	59	48.9	2.10
DayNight	5080	16427	17206	10014	62	50.7	1.84
Month	4804	15945	17688	10014	73	52.1	1.39
Zone:Month	4510	15384	18249	10014	105	53.6	1.53
Zone:DepCat	4725	15734	17899	10014	100	52.6	0.50

Table 7.141. gemfishGAB. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	gemfishGAB
csirocode	37439002, 91439002, 92439002
fishery	GAB
depthrange	100 - 650
depthclass	50
zones	82, 83, 84, 85
methods	TW, TDO, OTT
years	1995 - 2016

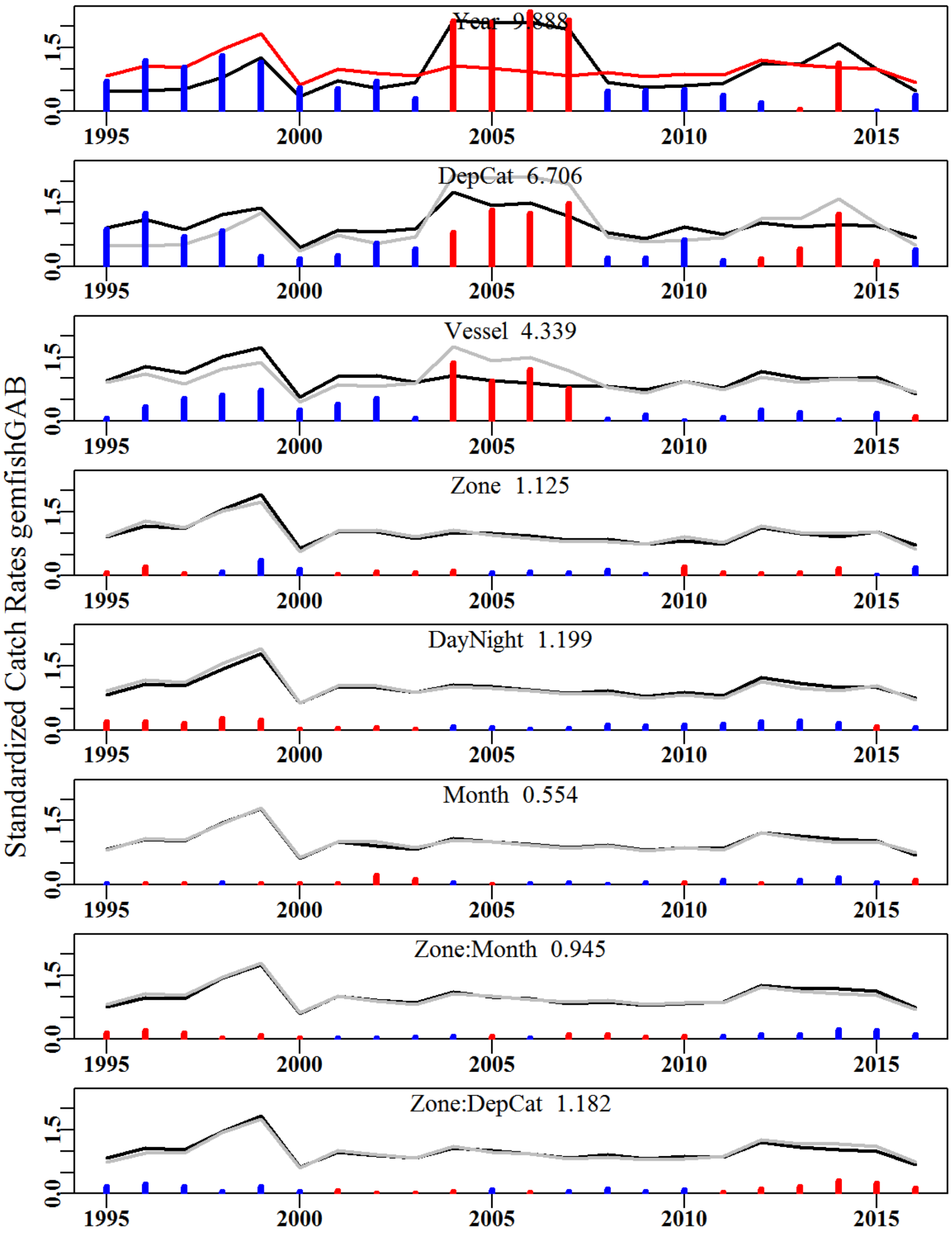


Figure 7.221. gemfishGAB. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

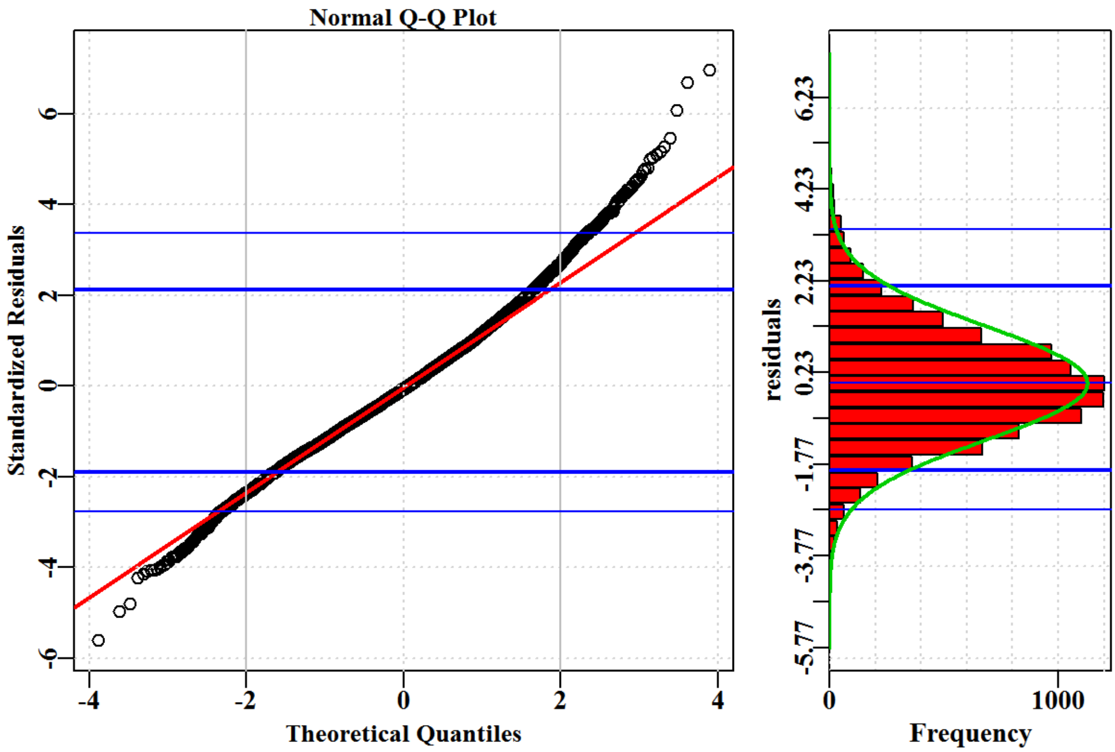


Figure 7.222. gemfishGAB. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

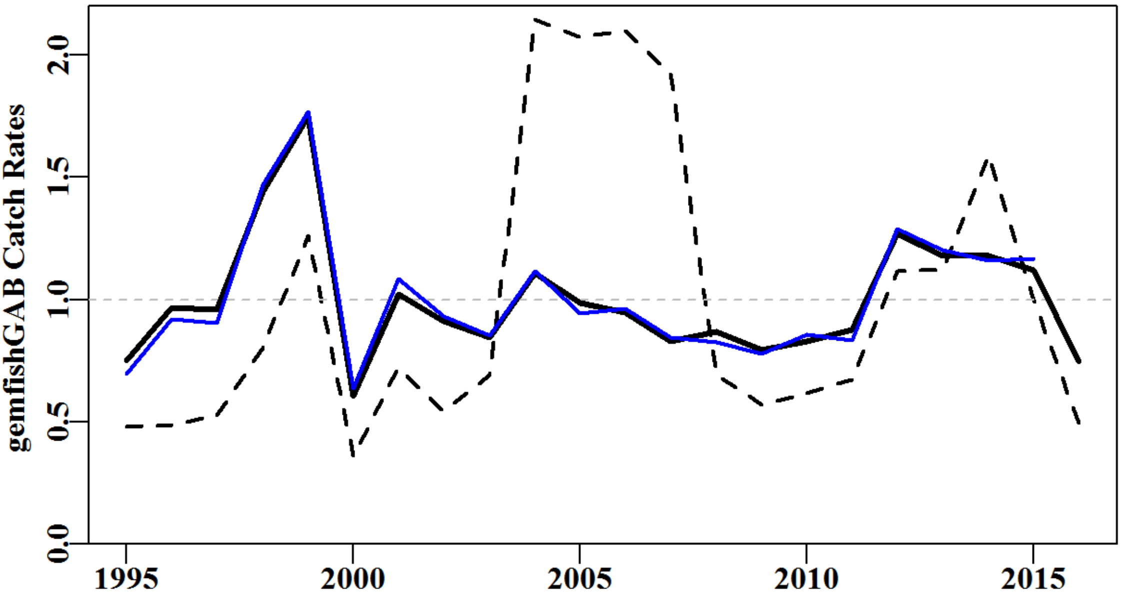


Figure 7.223. gemfishGAB. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

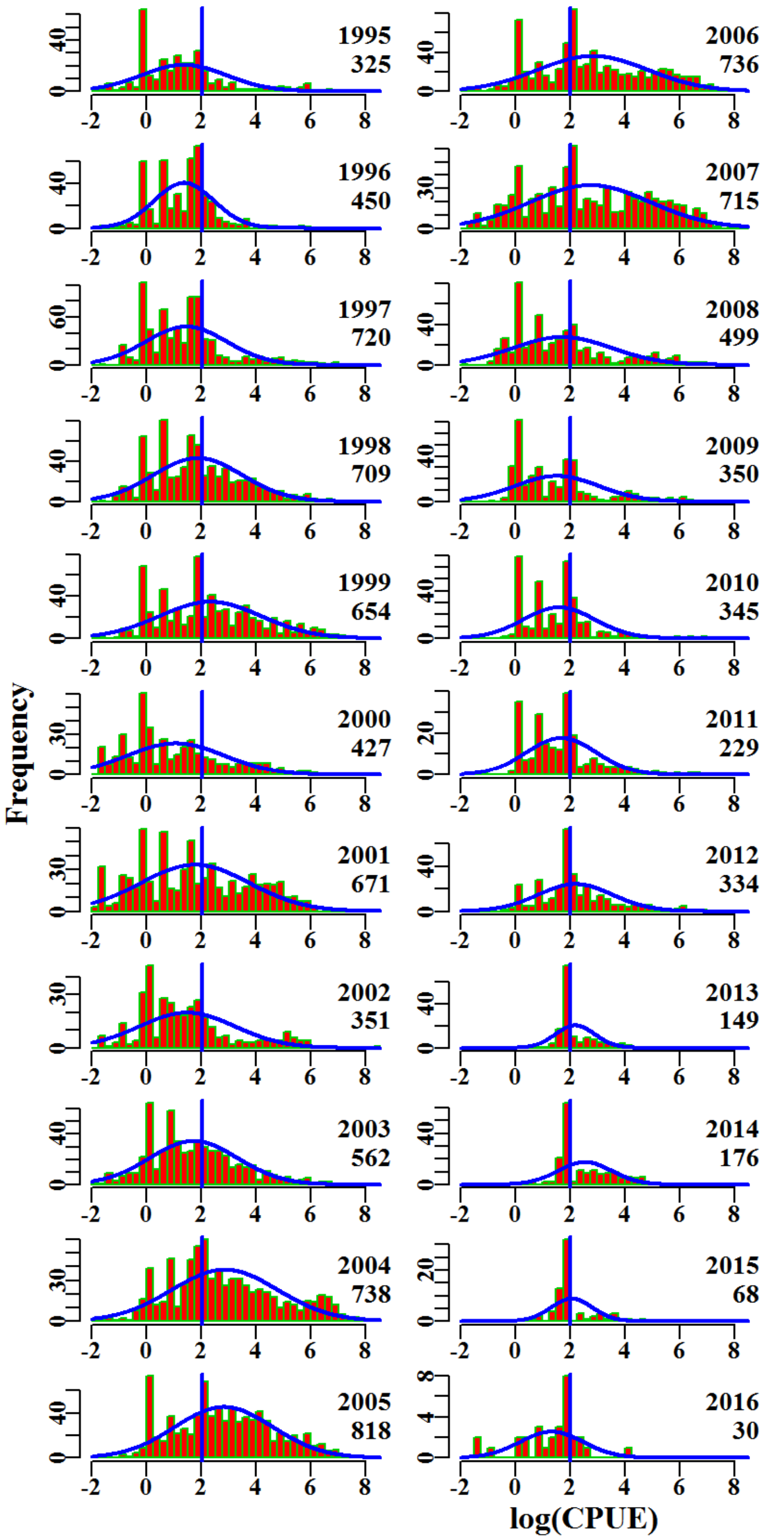


Figure 7.224. gemfishGAB. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

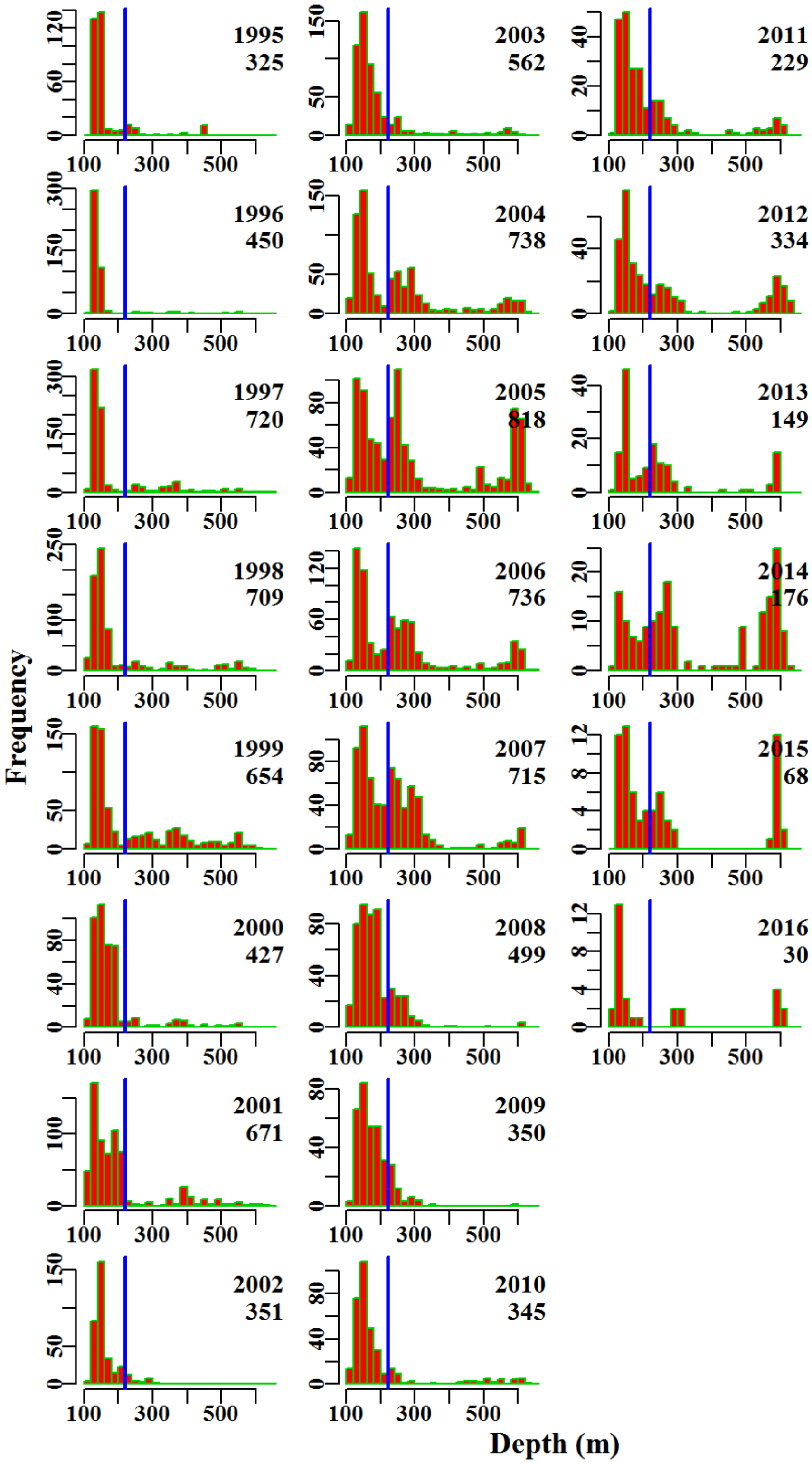


Figure 7.225. gemfishGAB. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

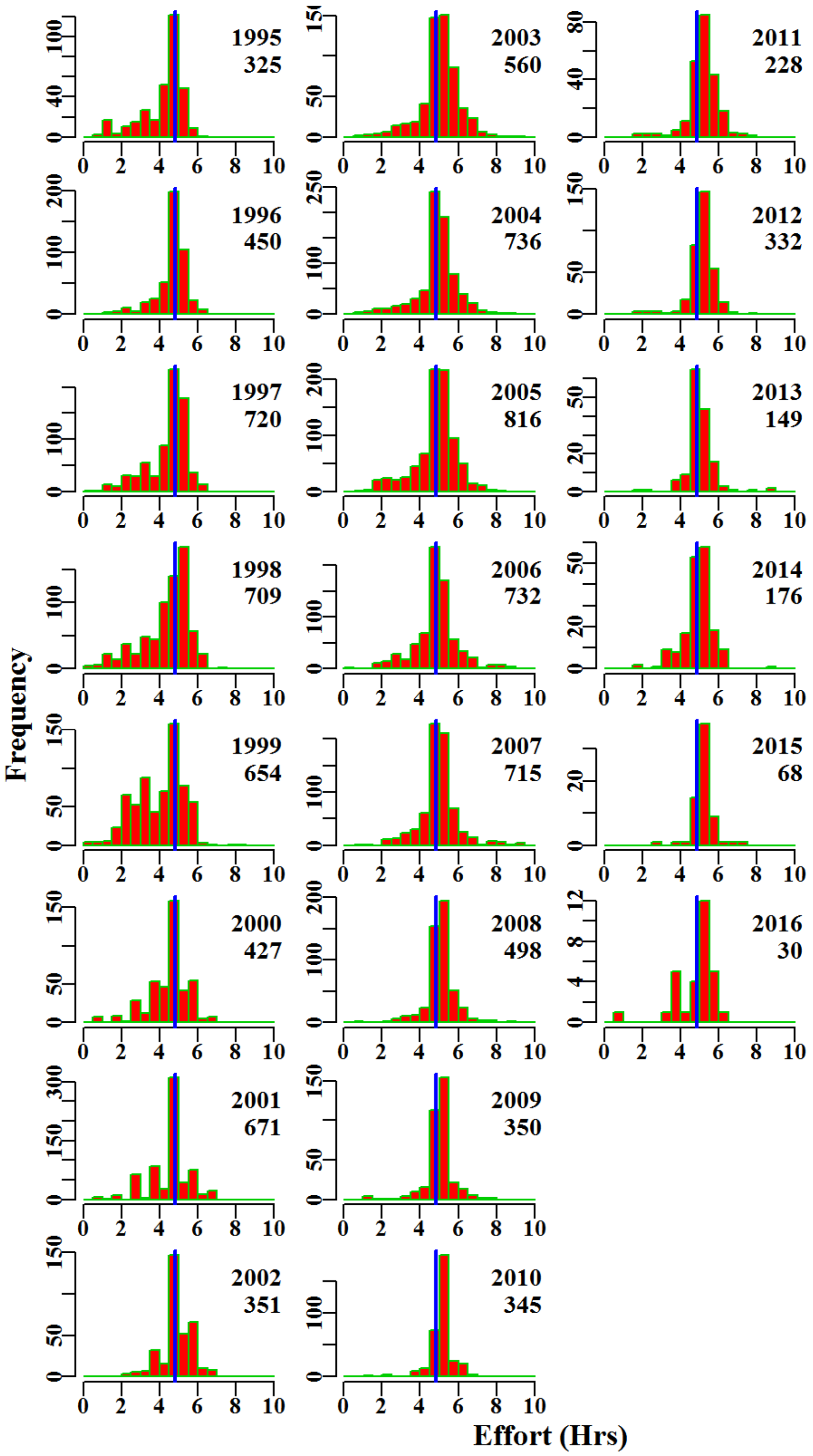


Figure 7.226. gemfishGAB. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.32 Blue Warehouse 10 – 30

For Blue Warehou (TRT - 37445005 - *Seriolella brama*) in zones 10 to 30, initial data selection was conducted according to the detials given in Table 7.146.

A total of 8 statistical models were fitted sequentially to the available data.

7.32.1 *Inferences*

The majority of catch of this species occurred in zone 20 followed by zones 30 and 10. Large catches continued from about 1988 - 1998 and have since dropped to trivial levels and have been below 10 t since 2011.

The terms Year and Vessel had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests a small departure of the assumed Normal distribution as depicted by the tails of the distribution (Figure 7.230).

Annual standardized CPUE trend is flat since 2001 and consistenly well below average since 1999 (Figure 7.227).

7.32.2 *Action Items and Issues*

No issues identified.

Table 7.142. bluewarehou1030. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	211.9	701	138.8	40	69.8	2.1152	0.000	3.563	0.026
1987	405.9	457	168.2	40	84.9	2.5428	0.105	2.506	0.015
1988	544.0	775	334.0	33	121.7	3.1298	0.095	3.571	0.011
1989	776.0	1178	664.7	41	181.5	4.0950	0.093	4.040	0.006
1990	881.4	826	508.3	42	183.0	3.7078	0.097	3.188	0.006
1991	1284.2	1567	465.2	54	99.8	2.0710	0.092	9.024	0.019
1992	934.4	1351	407.1	40	95.8	1.7193	0.093	8.297	0.020
1993	829.6	2192	431.5	45	61.1	1.3447	0.090	14.379	0.033
1994	944.8	2443	473.2	43	63.8	1.2794	0.089	16.853	0.036
1995	815.4	2643	464.3	44	59.0	1.1493	0.089	20.044	0.043
1996	724.4	3550	531.1	49	53.8	1.2663	0.087	26.146	0.049
1997	935.2	2481	404.3	42	57.1	1.2306	0.090	16.432	0.041
1998	903.2	2555	457.2	39	65.3	1.1234	0.089	17.202	0.038
1999	591.1	1642	131.6	39	27.2	0.6048	0.092	12.443	0.095
2000	470.5	2221	185.6	41	25.1	0.5196	0.090	15.442	0.083
2001	285.5	1475	57.3	33	11.0	0.3048	0.094	10.251	0.179
2002	290.5	1858	63.0	36	8.2	0.2318	0.092	12.457	0.198
2003	234.0	1324	42.1	38	6.1	0.1785	0.095	8.345	0.198
2004	232.4	1249	52.1	38	11.5	0.2429	0.097	8.496	0.163
2005	289.1	830	21.3	33	5.5	0.1704	0.101	4.701	0.221
2006	379.5	776	25.7	28	8.3	0.1937	0.103	4.652	0.181
2007	177.8	584	16.8	14	6.0	0.2016	0.107	3.843	0.229
2008	163.3	738	27.4	18	8.9	0.2783	0.103	5.486	0.200
2009	135.2	447	36.9	15	21.9	0.3455	0.112	2.887	0.078
2010	129.3	372	12.0	15	7.6	0.2128	0.118	2.272	0.189
2011	103.3	435	9.8	13	5.0	0.1757	0.114	2.650	0.270
2012	52.3	356	9.9	14	5.9	0.1439	0.119	1.961	0.198
2013	68.0	166	3.7	17	5.6	0.1338	0.147	0.942	0.256
2014	15.3	89	1.8	12	3.6	0.0894	0.184	0.377	0.211
2015	5.4	55	1.6	9	8.0	0.1031	0.223	0.302	0.190
2016	18.8	192	7.1	14	8.6	0.0946	0.143	0.992	0.139

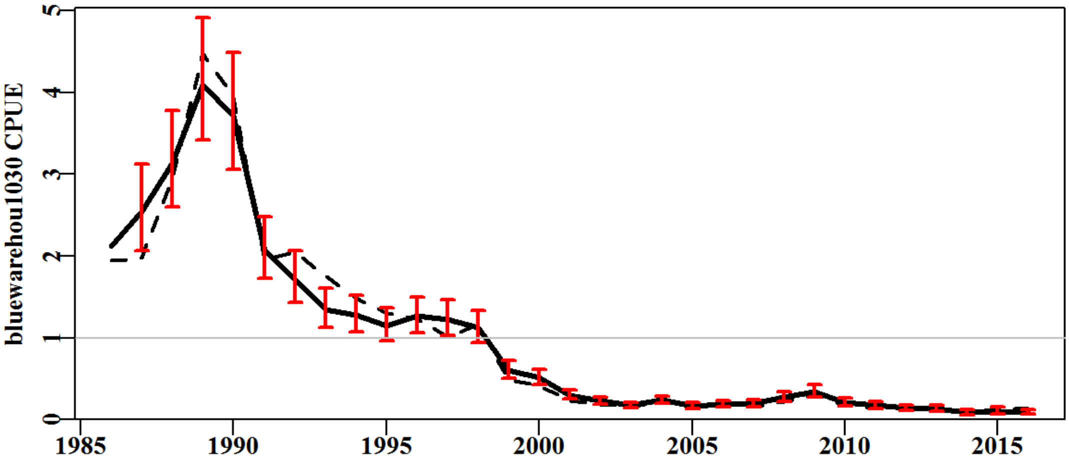


Figure 7.227. bluewarehou1030 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

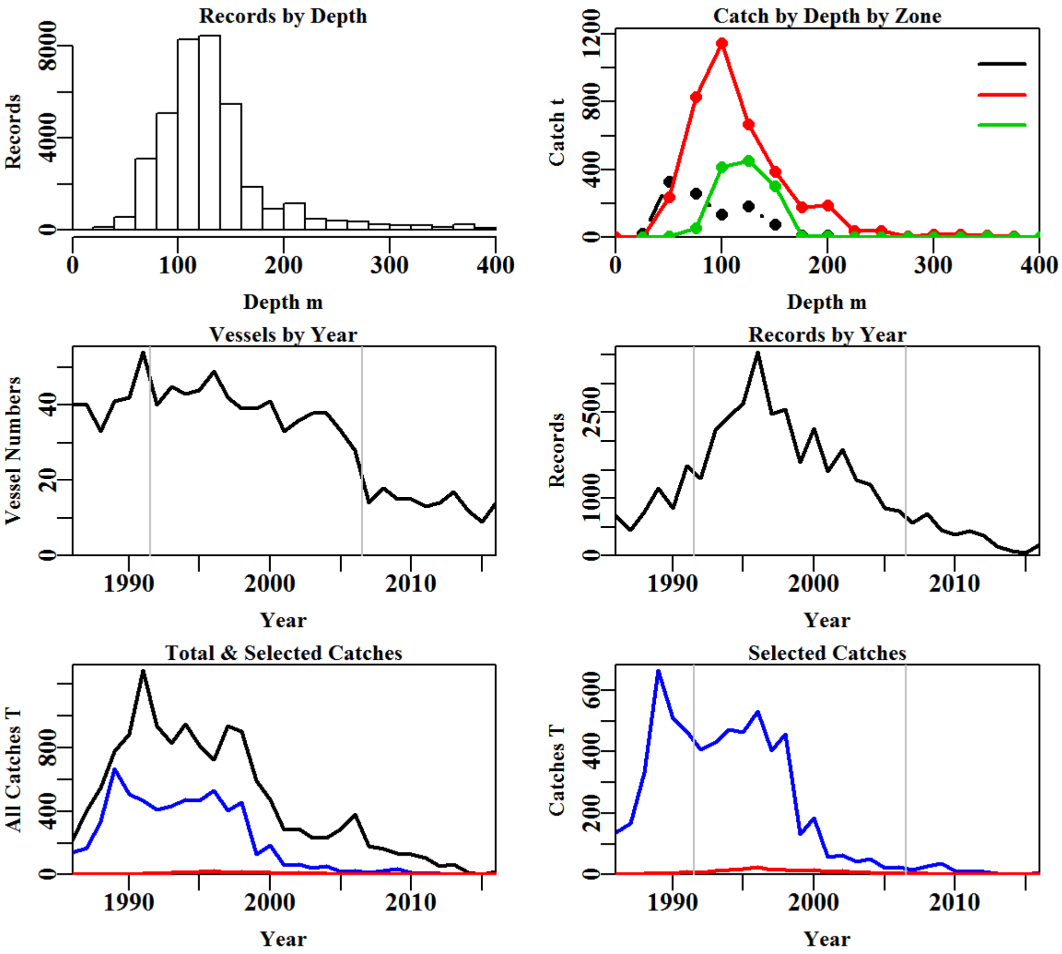


Figure 7.228. bluewarehou1030 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.143. bluewarehou1030 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	65987	59374	56929	56607	40130	37585	37528
Difference	0	6613	2445	322	16477	2545	57

Table 7.144. The models used to analyse data for bluewarehou1030.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + Month
Model5	Year + Vessel + DepCat + Month + Zone
Model6	Year + Vessel + DepCat + Month + Zone + DayNight
Model7	Year + Vessel + DepCat + Month + Zone + DayNight + Zone:Month
Model8	Year + Vessel + DepCat + Month + Zone + DayNight + Zone:DepCat

Table 7.145. bluewarehou1030. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	37629	102117	39084	37528	31	27.6	0.00
Vessel	32919	89280	51921	37528	197	36.4	8.82
DepCat	32240	87524	53677	37301	213	37.3	0.83
Month	32053	87035	54165	37301	224	37.6	0.33
Zone	31620	86021	55180	37301	226	38.3	0.72
DayNight	31532	85806	55394	37301	229	38.5	0.15
Zone:Month	31265	85093	56107	37301	251	38.9	0.47
Zone:DepCat	31292	85119	56082	37301	259	38.9	0.44

Table 7.146. bluewarehou1030. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	bluewarehou1030
csirocode	37445005, 91445005, 92445005
fishery	SET
depthrange	0 - 400
depthclass	25
zones	10, 20, 30
methods	TW, TDO, OTT
years	1986 - 2016

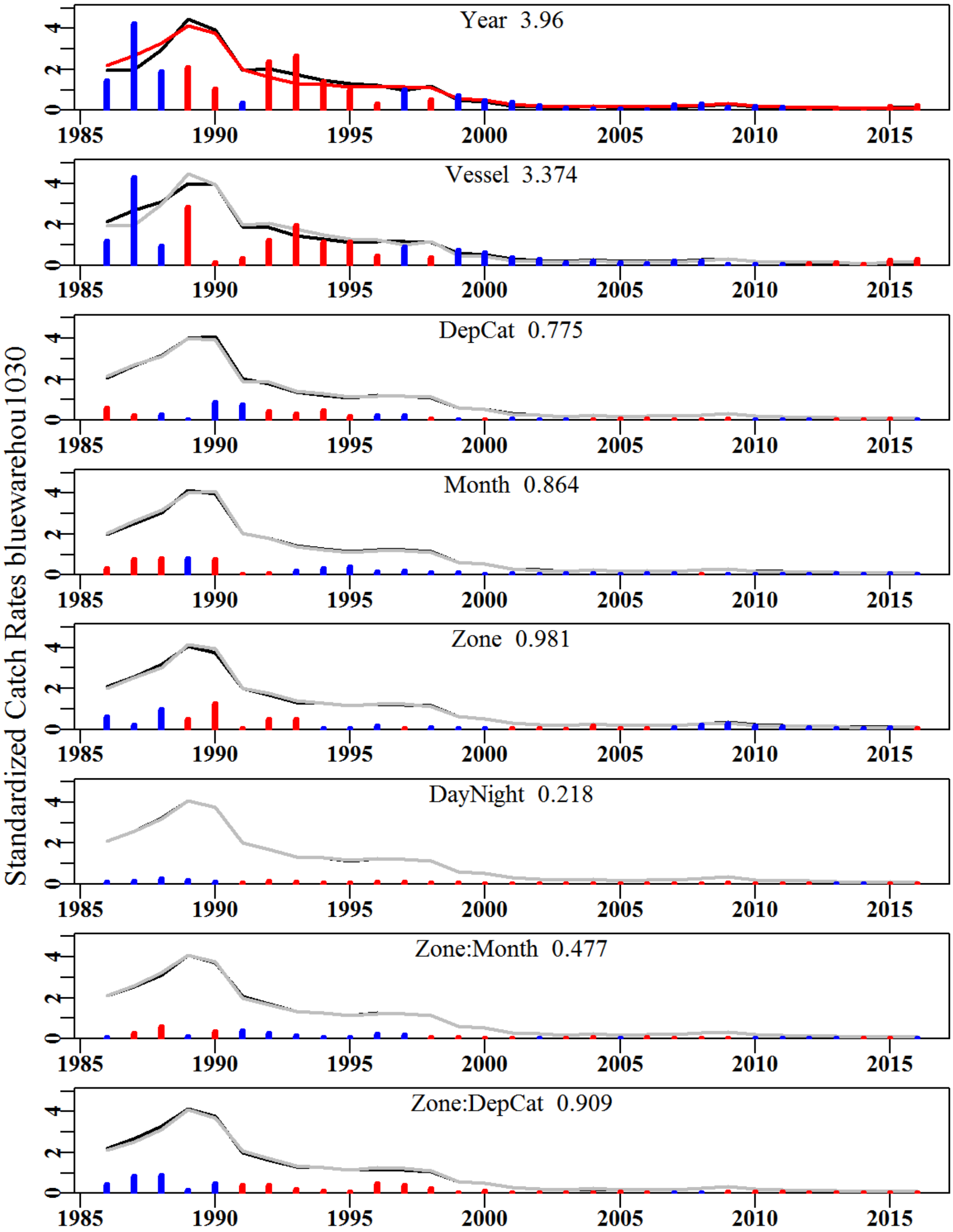


Figure 7.229. bluewarehou1030. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

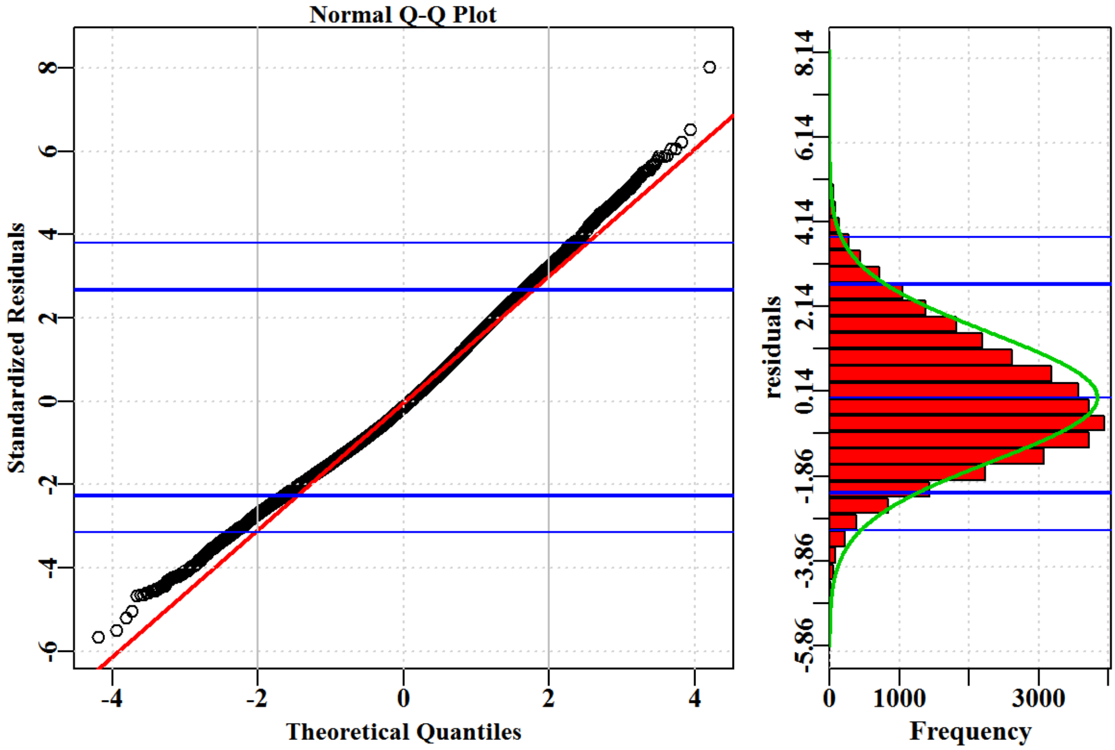


Figure 7.230. bluewarehou1030. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

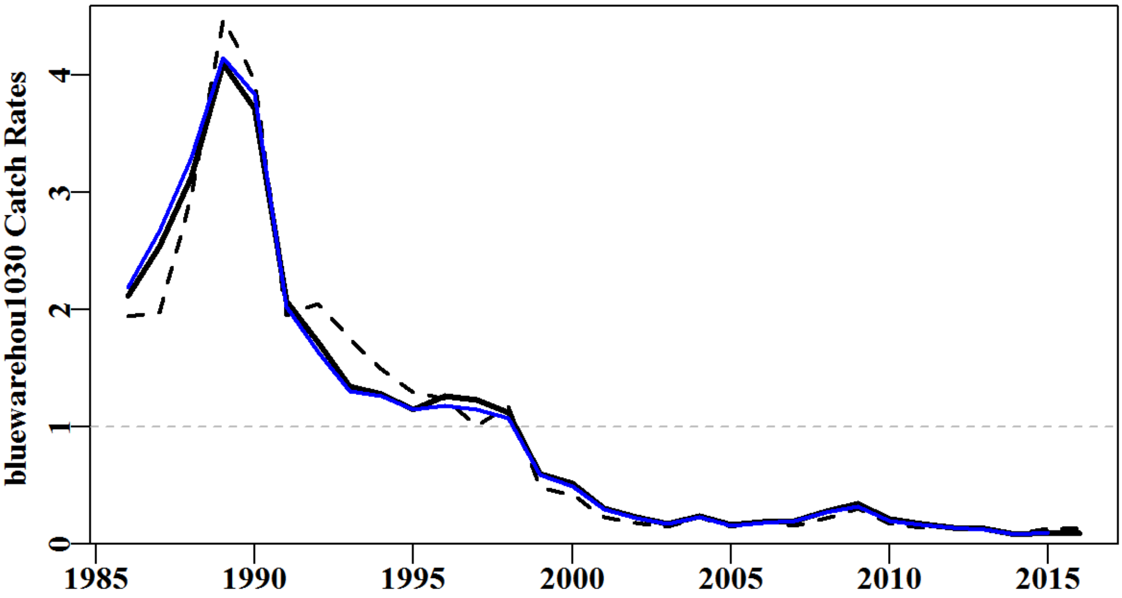


Figure 7.231. bluewarehou1030. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

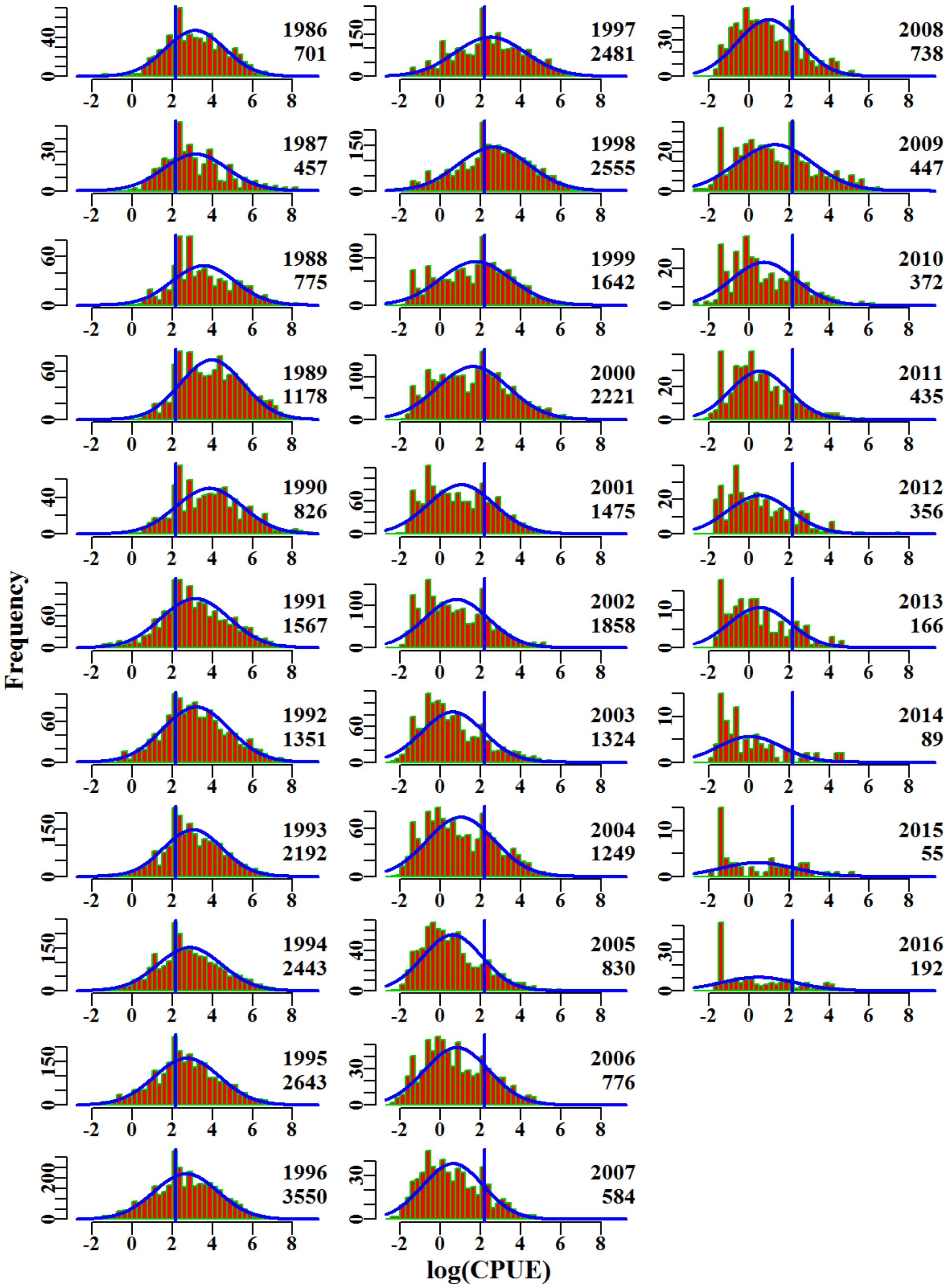


Figure 7.232. bluewarehou1030. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

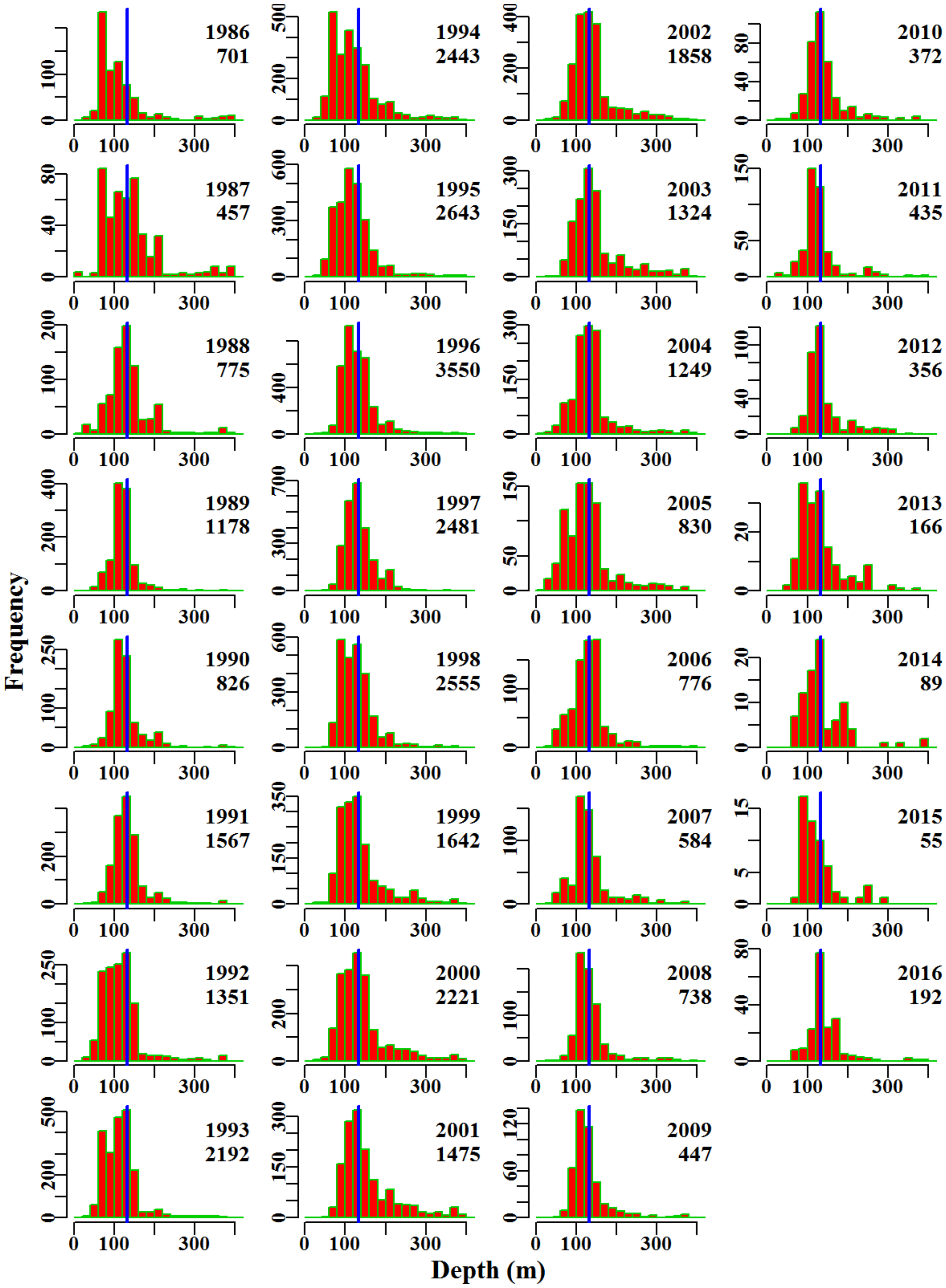


Figure 7.233. bluewarehou1030. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

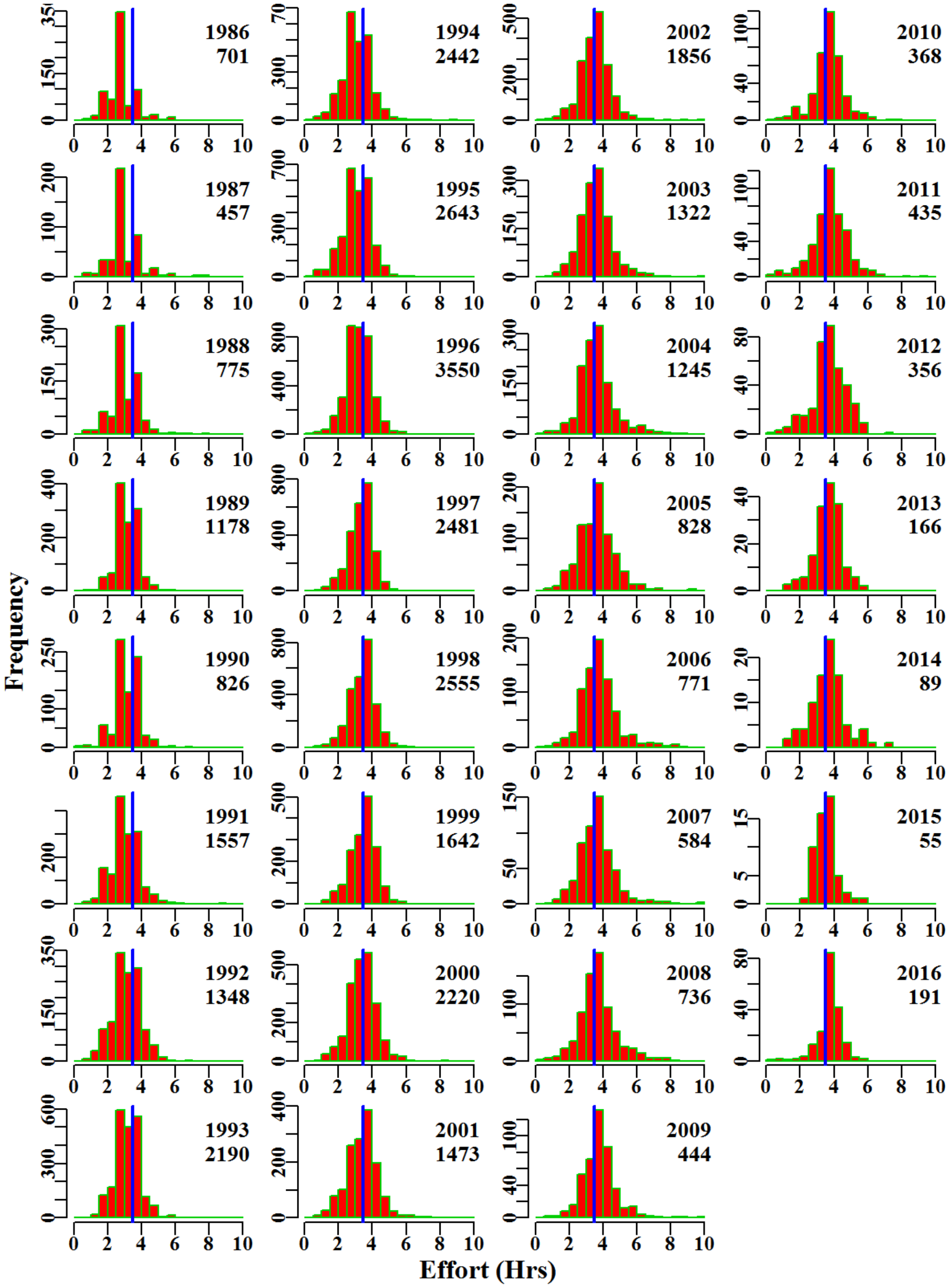


Figure 7.234. bluewarehou1030. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.33 Blue Warehou 40 – 50

For Blue Warehou (TRT - 37445005 - *Seriolella brama*) in zones 40 and 50, initial data selection was conducted according to the detials given in Table 7.151. A total of 8 statistical models were fitted sequentially to the available data.

7.33.1 *Inferences*

The majority of catch of this species occurred in zone 50 and minimal catches occurred in the remaining zone (40). There were small record numbers (18 and 42) and coresponding catch (0.6 t and 2.6 t) in 2015 and 2016 respectively. This also corresponds to the lowest catches across the years analysed.

The terms Year, Vessel, Month and DepCat had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests a small departure from the assumed Normal distribution as depicted by the lower tail of the distribution (Figure 7.238).

Annual standardized CPUE trend is flat since 1992 and mostly below average (Figure 7.235). Catch rates prior to the introduction of quotas are highly variable both within years and between years. At that time Blue Warehou data was mixed with Silver warehou data so this early data is less trustworthy. Data are now so sparse that the analysis results can no longer be trusted to represent the stock.

7.33.2 *Action Items and Issues*

Exploration of the early CPUE data could be made to examine whether there are obvious or consistent errors leading to mean CPUE values 4 times greater than the long term average.

Table 7.147. bluewarehou4050. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	211.9	159	71.4	14	162.6	3.5640	0.000	0.759	0.011
1987	405.9	183	215.6	10	635.9	3.5863	0.243	0.334	0.002
1988	544.0	180	198.0	12	566.8	1.5857	0.251	0.700	0.004
1989	776.0	56	81.3	13	562.1	4.1659	0.311	0.235	0.003
1990	881.4	444	298.3	14	334.5	1.5990	0.236	2.280	0.008
1991	1284.2	597	647.5	18	846.3	2.6435	0.234	1.060	0.002
1992	934.4	538	430.1	17	470.8	1.4336	0.236	1.733	0.004
1993	829.6	495	362.9	21	411.4	1.1020	0.237	1.700	0.005
1994	944.8	824	449.9	21	247.5	1.2163	0.232	2.525	0.006
1995	815.4	825	325.1	22	155.1	0.8258	0.230	4.180	0.013
1996	724.4	700	183.6	24	88.5	0.5595	0.232	4.278	0.023
1997	935.2	431	243.5	23	351.8	0.5854	0.237	3.068	0.013
1998	903.2	582	354.5	19	459.4	0.9116	0.236	2.728	0.008
1999	591.1	688	174.4	19	124.2	0.5016	0.235	4.505	0.026
2000	470.5	652	203.6	24	157.3	0.4083	0.235	3.746	0.018
2001	285.5	686	194.2	23	98.5	0.4299	0.234	4.249	0.022
2002	290.5	531	218.1	23	181.9	0.5574	0.236	3.007	0.014
2003	234.0	362	175.4	19	191.9	0.5008	0.242	2.421	0.014
2004	232.4	437	159.3	21	132.6	0.5420	0.239	2.276	0.014
2005	289.1	461	257.8	18	329.5	0.8637	0.239	1.775	0.007
2006	379.5	695	337.5	16	213.0	0.5964	0.236	3.757	0.011
2007	177.8	466	148.6	16	116.8	0.5004	0.239	2.570	0.017
2008	163.3	353	117.8	12	88.3	0.4050	0.242	2.056	0.017
2009	135.2	308	89.0	11	70.1	0.3012	0.244	1.337	0.015
2010	129.3	407	105.3	12	52.7	0.3487	0.239	1.833	0.017
2011	103.3	519	77.9	14	31.1	0.3125	0.238	2.235	0.029
2012	52.3	262	32.8	14	25.4	0.1805	0.249	1.659	0.051
2013	68.0	305	57.9	13	37.1	0.2455	0.245	1.546	0.027
2014	15.3	60	11.6	9	48.9	0.1856	0.306	0.457	0.039
2015	5.4	18	0.6	5	5.8	0.0780	0.440	0.051	0.088
2016	18.8	42	2.6	8	11.6	0.2642	0.336	0.243	0.094

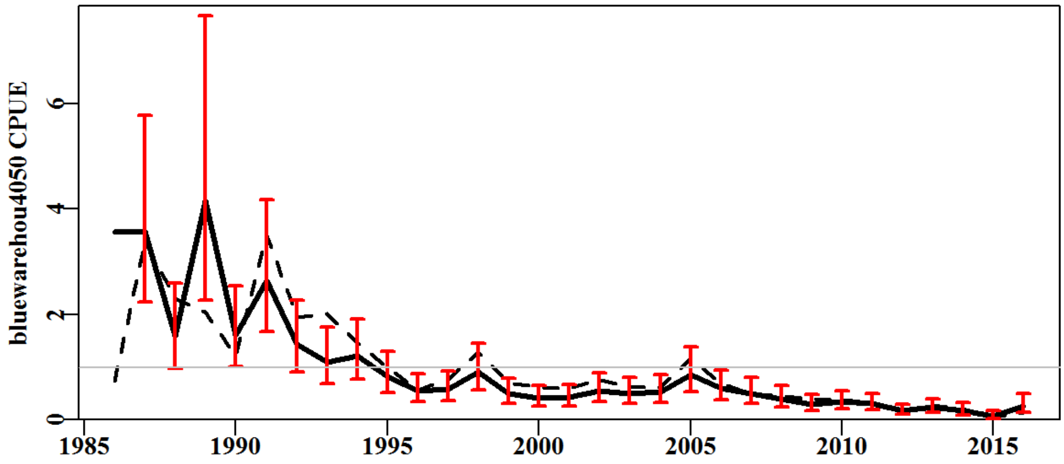


Figure 7.235. bluewarehou4050 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

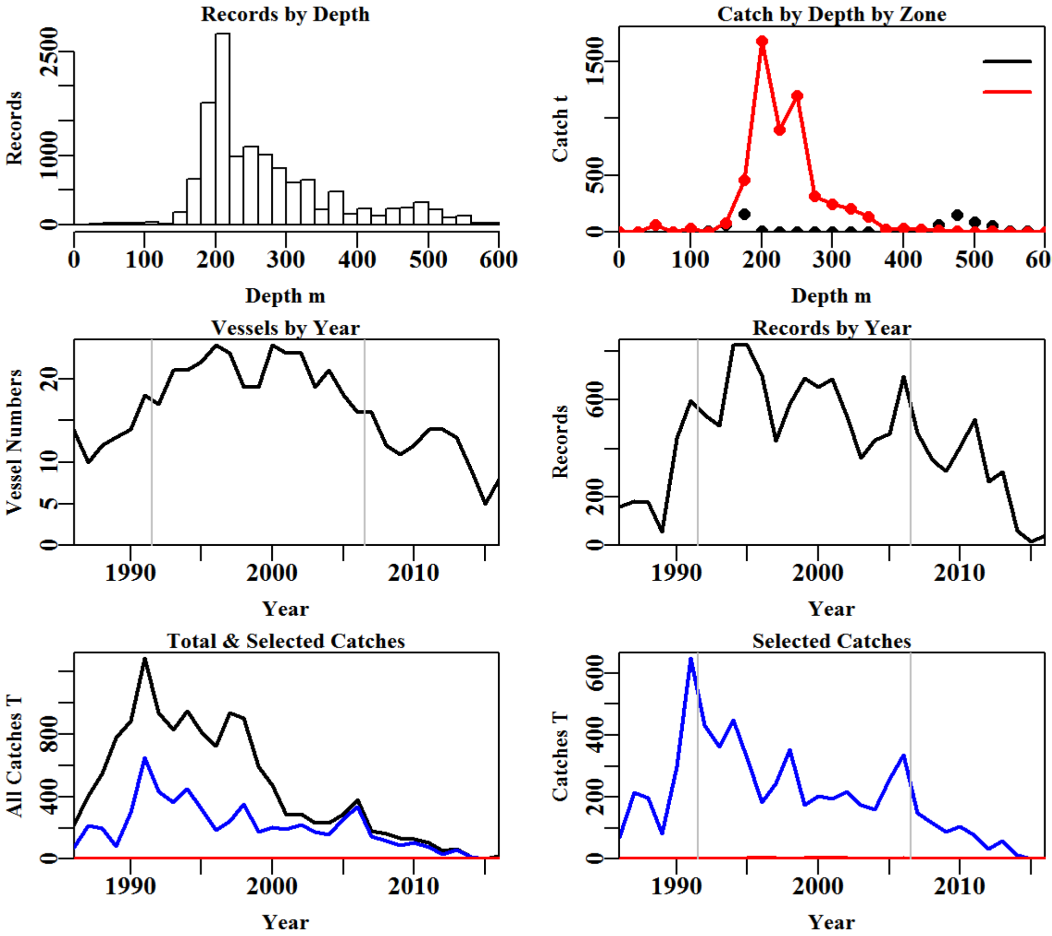


Figure 7.236. bluewarehou4050 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.148. bluewarehou4050 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	65987	59374	59240	58890	13773	13287	13266
Difference	0	6613	134	350	45117	486	21

Table 7.149. The models used to analyse data for bluewarehou4050

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + Month
Model4	Year + Vessel + Month + DepCat
Model5	Year + Vessel + Month + DepCat + Zone
Model6	Year + Vessel + Month + DepCat + Zone + DayNight
Model7	Year + Vessel + Month + DepCat + Zone + DayNight + Zone:Month
Model8	Year + Vessel + Month + DepCat + Zone + DayNight + Zone:DepCat

Table 7.150. bluewarehou4050. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	14720	40052	5975	13266	31	12.8	0.00
Vessel	13574	36285	9742	13266	113	20.5	7.71
Month	12541	33510	12517	13266	124	26.5	6.02
DepCat	11759	31457	14570	13202	148	30.4	3.90
Zone	11756	31447	14580	13202	149	30.4	0.02
DayNight	11704	31309	14718	13202	152	30.7	0.29
Zone:Month	11669	31174	14853	13202	163	31.0	0.24
Zone:DepCat	11703	31205	14822	13202	173	30.8	0.12

Table 7.151. bluewarehou4050. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	bluewarehou4050
csirocode	37445005, 91445005, 92445005
fishery	SET
depthrange	0 - 600
depthclass	25
zones	40, 50
methods	TW, TDO, OTT
years	1986 - 2016

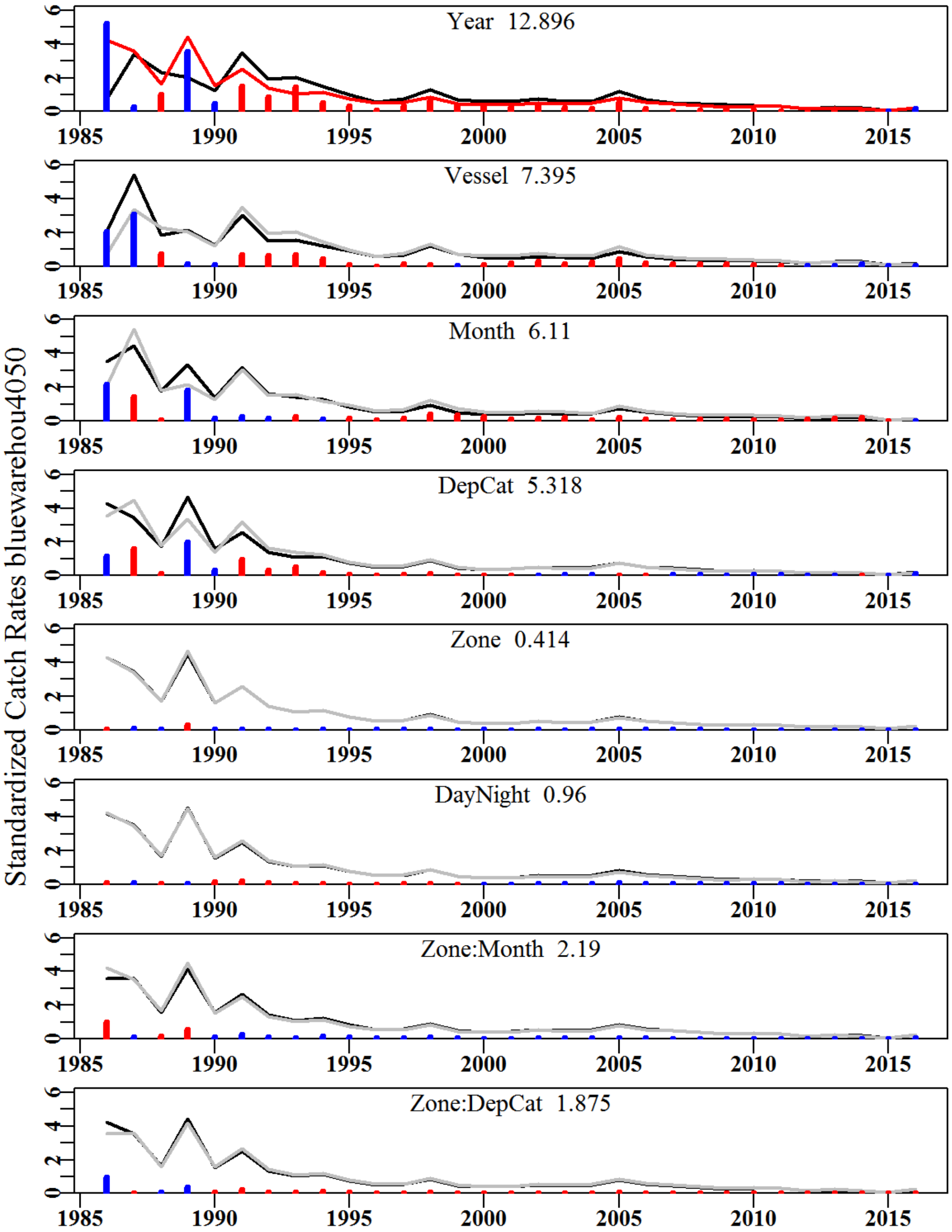


Figure 7.237. bluewarehou4050. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

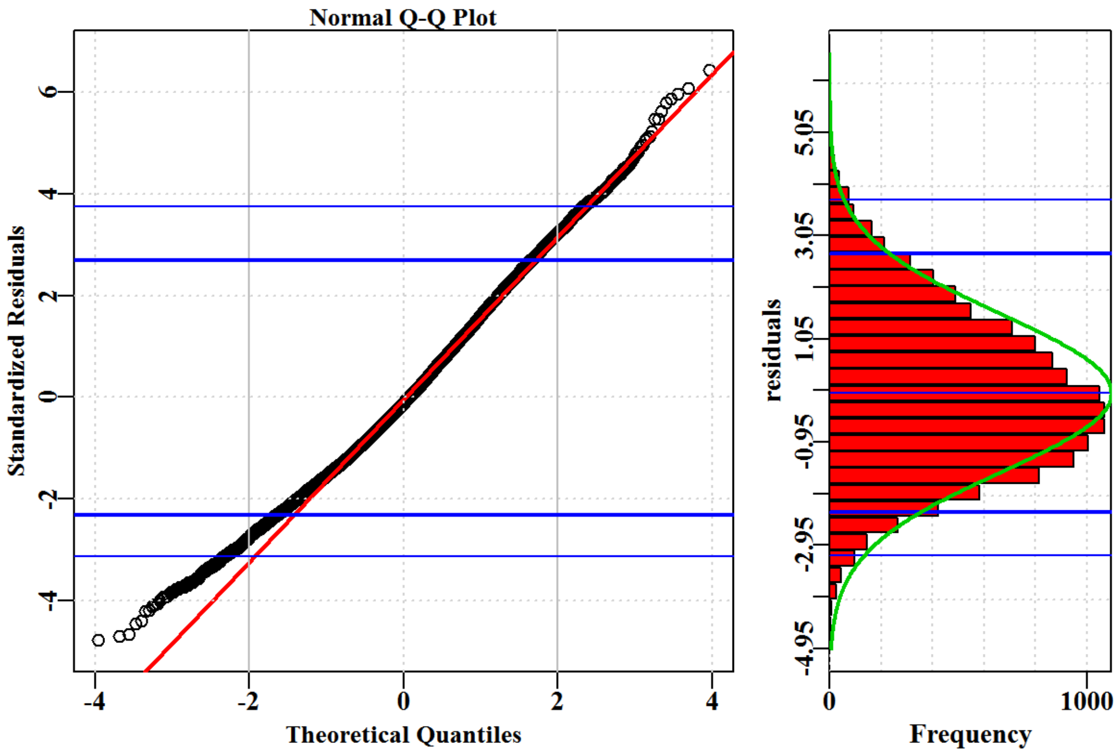


Figure 7.238. bluewarehou4050. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

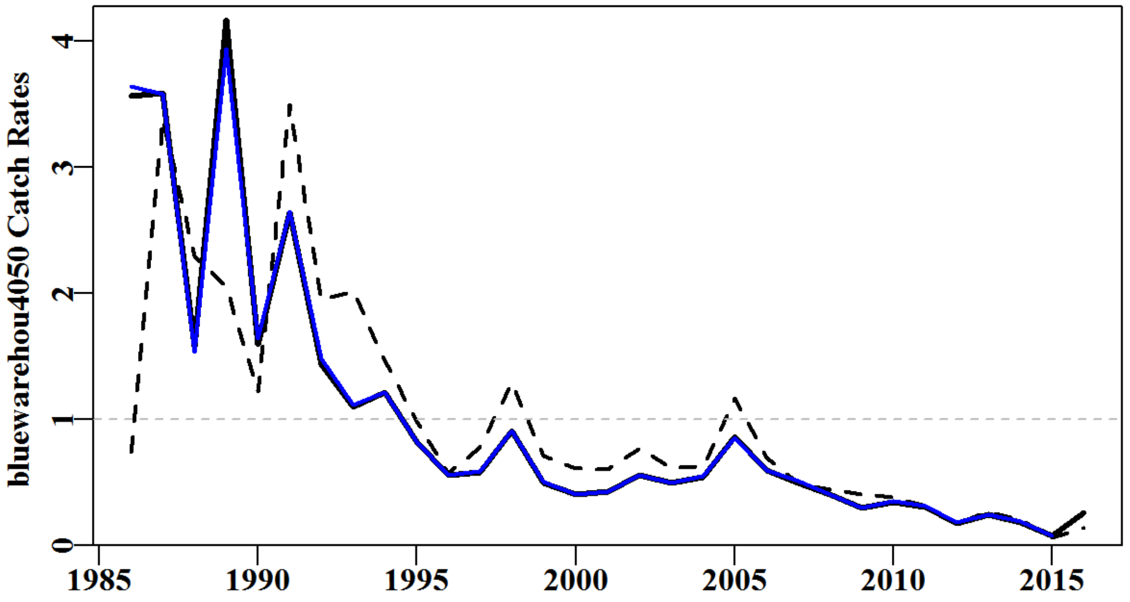


Figure 7.239. bluewarehou4050. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

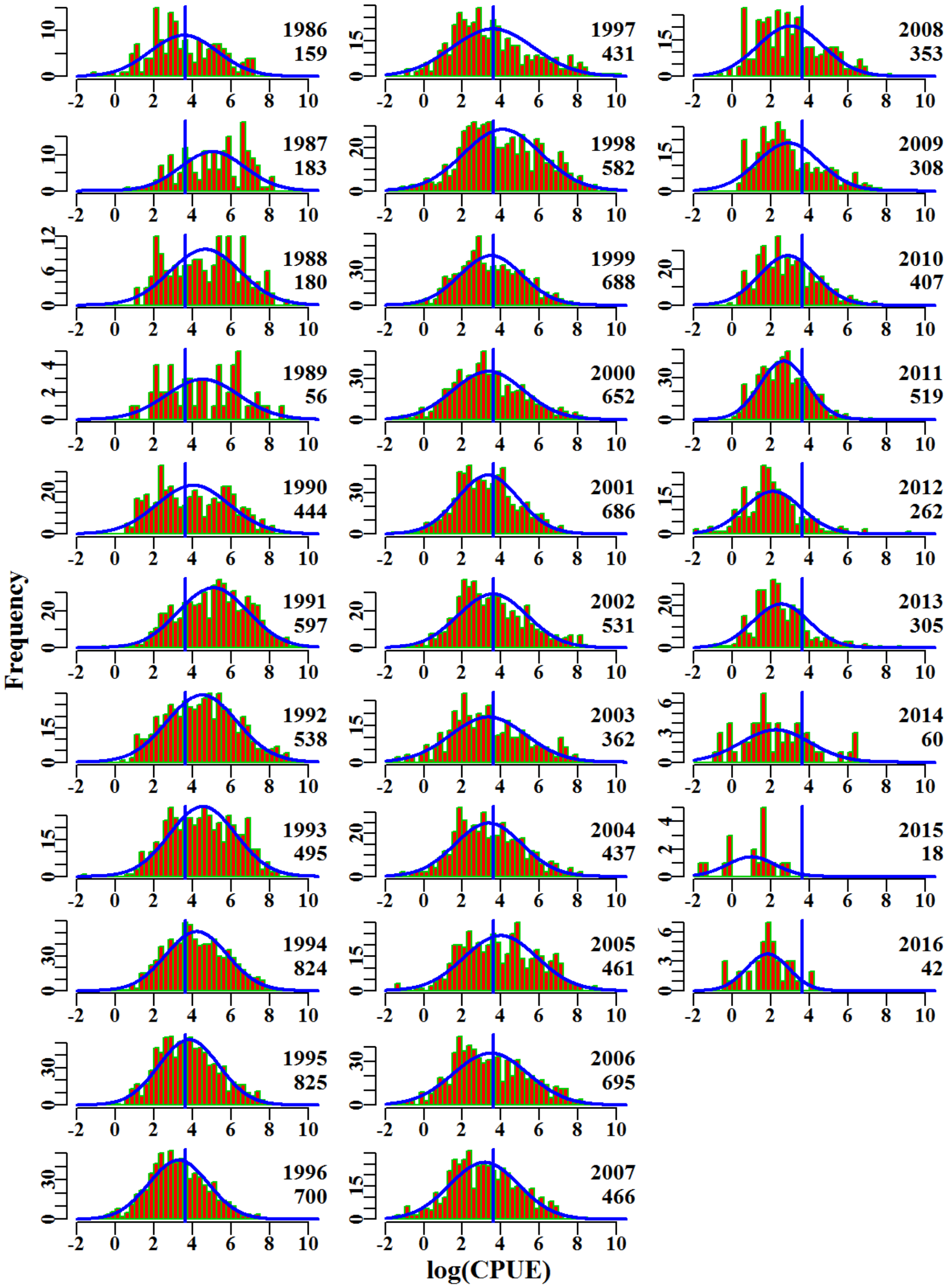


Figure 7.240. bluewarehou4050. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

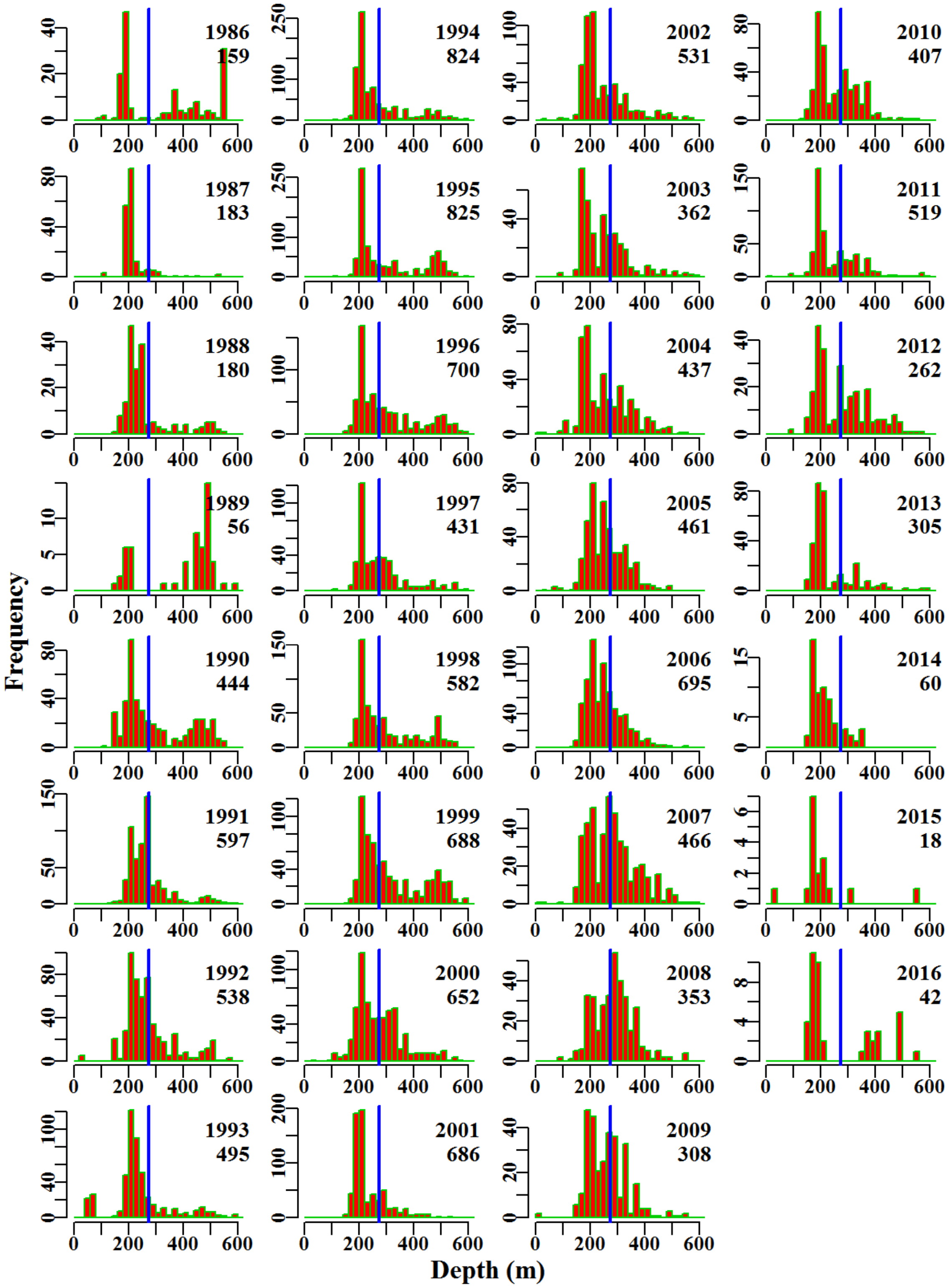


Figure 7.241. bluewarehou4050. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

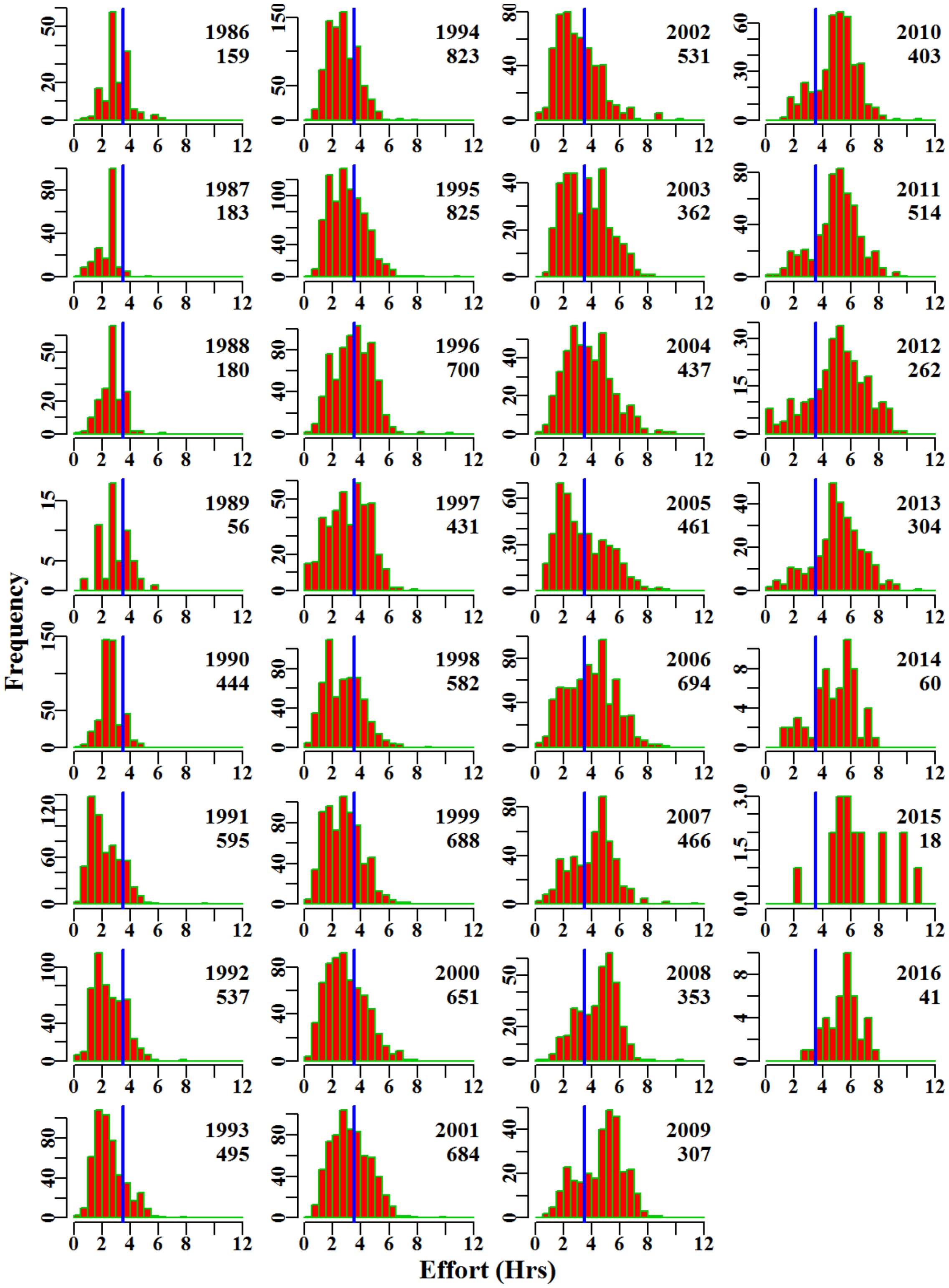


Figure 7.242. bluewarehou4050. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.34 Deepwater Flathead

The initial data selection for Deepwater Flathead (FLD - 37296002 - *Platycephaus conatus*) in the GAB was conducted according to the detials given in Table 7.156.

A total of 9 statistical models were fitted sequentially to the available data.

7.34.1 *Inferences*

The majority of catch of this species occurred in longitude 129-130 (degrees longitude take the place of zones to provide more detail).

The terms Year, Vessel, Zone, Month, DepCat, DayNight and three interaction terms (Zone:Month, Zone:Vessel and Zone:DepCat) had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics.

Annual standardized CPUE has been cyclical in the early years following the ups and downs of catches (prior to 2007) and relatively flat and mostly below average since 2007 (Figure 7.243).

7.34.2 *Action Items and Issues*

No issues identified.

Table 7.152. deepwaterflathead. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:DepCat.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1987	80.3	229	44.3	3	62.5	0.5122	0.000	0.195	0.004
1988	317.2	532	260.6	4	196.0	1.0345	0.056	0.732	0.003
1989	402.6	944	345.6	6	100.3	1.0106	0.053	0.803	0.002
1990	430.2	1297	393.9	6	90.8	0.9908	0.052	0.900	0.002
1991	621.0	1465	513.5	8	85.5	0.9546	0.051	0.819	0.002
1992	524.1	958	499.5	3	117.9	1.2092	0.052	0.345	0.001
1993	593.1	881	580.7	5	149.5	1.6221	0.053	0.570	0.001
1994	1285.9	1683	1233.7	6	173.4	2.0087	0.050	0.327	0.000
1995	1585.1	1849	1552.3	5	176.6	1.9122	0.050	0.030	0.000
1996	1499.2	2726	1450.5	6	110.2	1.2718	0.049	0.405	0.000
1997	1030.0	2684	944.5	7	72.0	0.8838	0.049	1.340	0.001
1998	690.4	2401	669.2	7	57.0	0.6808	0.050	3.280	0.005
1999	571.0	2040	541.3	7	53.6	0.8029	0.051	1.530	0.003
2000	845.6	2378	773.9	5	67.5	0.8810	0.050	1.857	0.002
2001	973.1	2411	910.5	5	75.6	1.0569	0.050	1.207	0.001
2002	1708.9	3113	1613.1	8	103.5	1.4587	0.050	0.900	0.001
2003	2260.6	4468	2156.6	10	93.8	1.4548	0.050	0.387	0.000
2004	2155.2	5349	2054.2	9	74.5	1.1476	0.050	0.923	0.000
2005	1426.0	5014	1238.5	10	49.5	0.7277	0.050	1.642	0.001
2006	1014.2	4151	947.2	10	45.9	0.6689	0.050	1.667	0.002
2007	1039.9	3659	908.2	6	50.8	0.7463	0.050	2.978	0.003
2008	813.2	3086	766.5	4	50.6	0.8925	0.050	2.089	0.003
2009	849.4	3193	824.6	4	52.3	0.7856	0.050	2.793	0.003
2010	966.8	2803	927.0	4	67.8	0.9961	0.050	1.300	0.001
2011	963.2	3269	789.3	4	47.1	0.7965	0.050	1.490	0.002
2012	1019.8	3448	842.3	4	48.3	0.7981	0.050	1.724	0.002
2013	874.7	3232	649.3	4	39.1	0.7017	0.050	2.080	0.003
2014	588.6	2572	485.3	4	37.5	0.6437	0.051	2.314	0.005
2015	593.9	2248	472.0	3	42.2	0.7181	0.051	1.574	0.003
2016	276.6	1022	201.1	3	39.6	0.6315	0.054	0.744	0.004

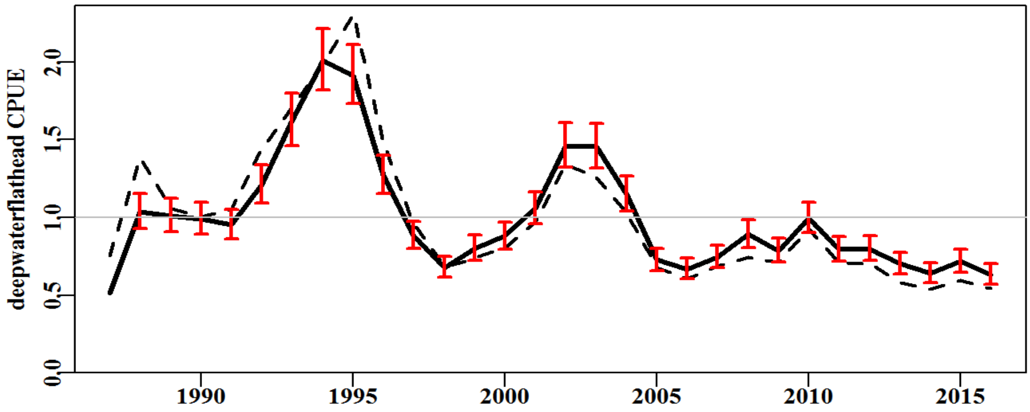


Figure 7.243. deepwaterflathead standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

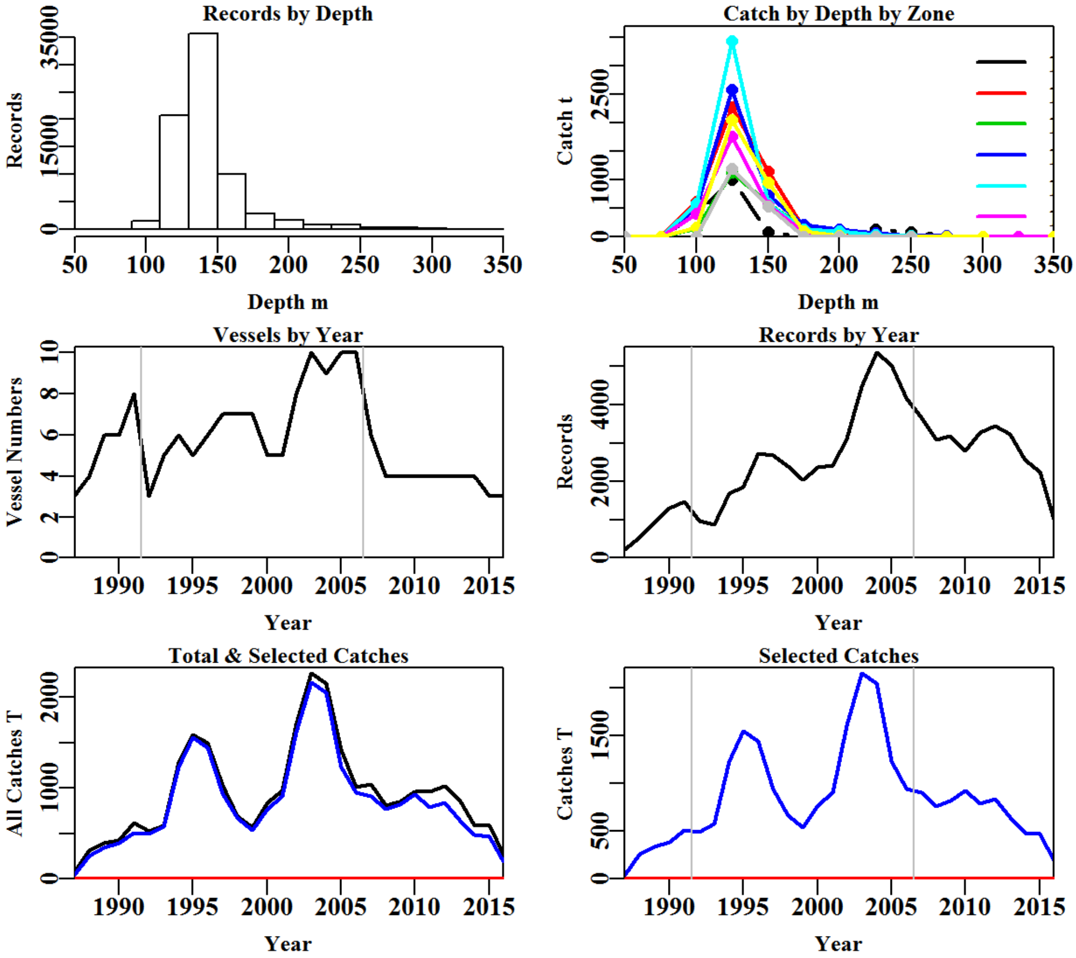


Figure 7.244. deepwaterflathead fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.153. deepwaterflathead data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

0	0	0	0	0
0	0	0	0	0

Table 7.154. The models used to analyse data for deepwaterflathead.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + Zone
Model4	Year + Vessel + Zone + Month
Model5	Year + Vessel + Zone + Month + DepCat
Model6	Year + Vessel + Zone + Month + DepCat + DayNight
Model7	Year + Vessel + Zone + Month + DepCat + DayNight + Zone:Month
Model8	Year + Vessel + Zone + Month + DepCat + DayNight + Zone:Vessel
Model9	Year + Vessel + Zone + Month + DepCat + DayNight + Zone:DepCat

Table 7.155. deepwaterflathead. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:DepCat.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	-34870	47172	9415	75105	30	16.6	0.00
Vessel	-40072	43993	12594	75105	49	22.2	5.60
Zone	-46348	40459	16128	75105	56	28.4	6.24
Month	-49666	38699	17888	75105	67	31.6	3.10
DepCat	-51156	37927	18661	75105	79	32.9	1.36
DayNight	-53121	36944	19643	75105	82	34.6	1.73
Zone:Month	-54465	36215	20373	75105	159	35.9	1.23
Zone:Vessel	-55155	35836	20751	75105	209	36.5	1.85
Zone:DepCat	-55344	35797	20790	75105	155	36.6	1.97

Table 7.156. deepwaterflathead. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	deepwaterflathead
csirocode	37296002
fishery	GAB
depthrange	50 - 350
depthclass	25
zones	82, 83, 84, 85
methods	TW, TDO, OTT, PTB
years	1986 - 2016

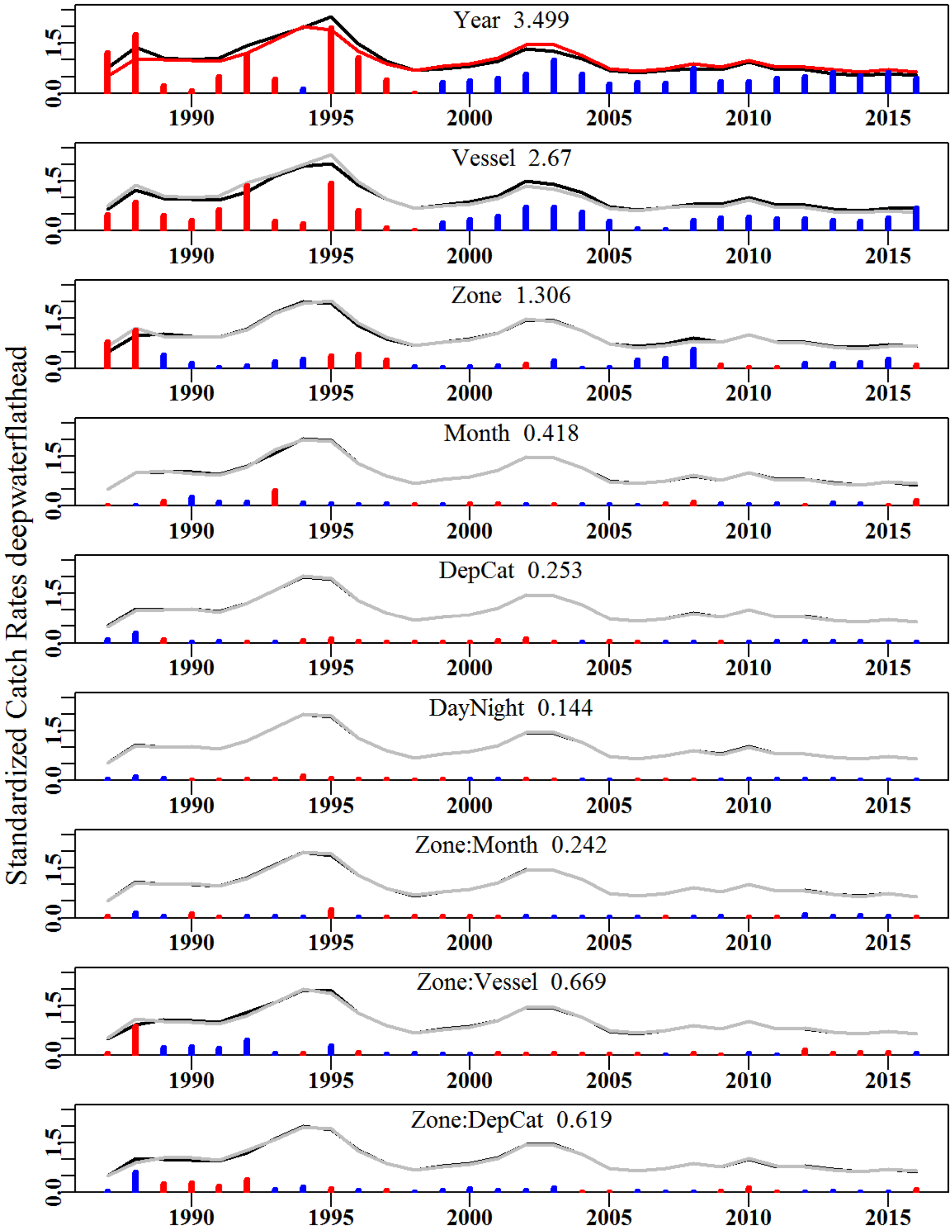


Figure 7.245. deepwaterflathead. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

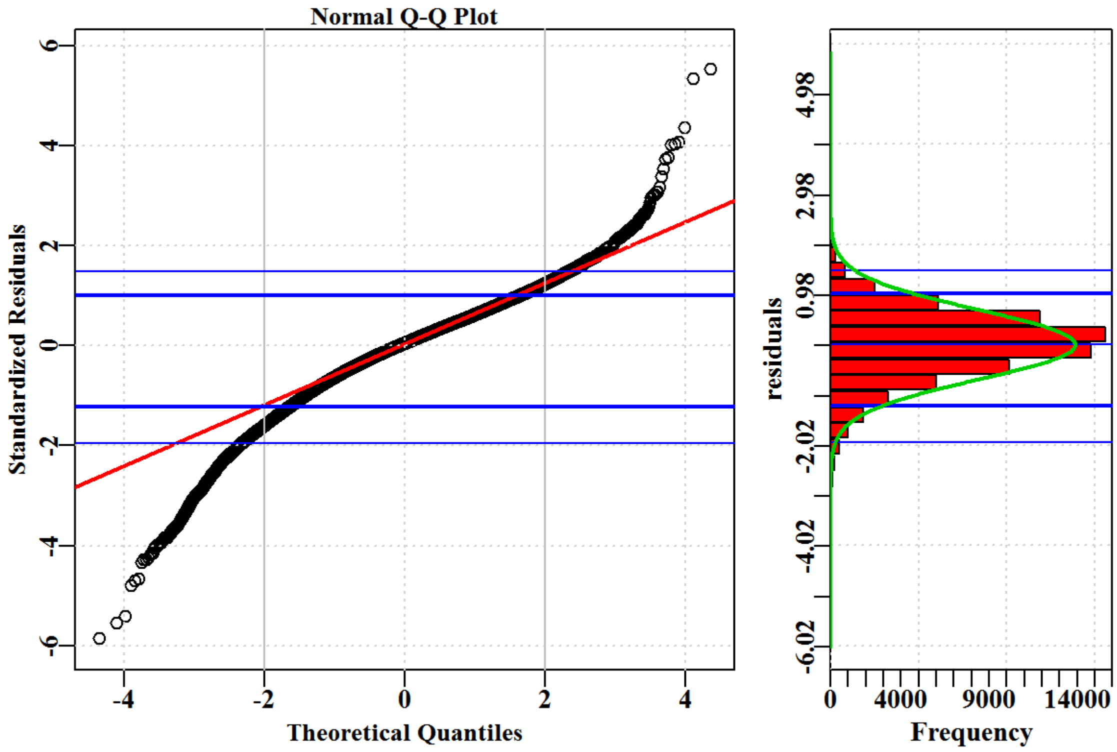


Figure 7.246. deepwaterflathead. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

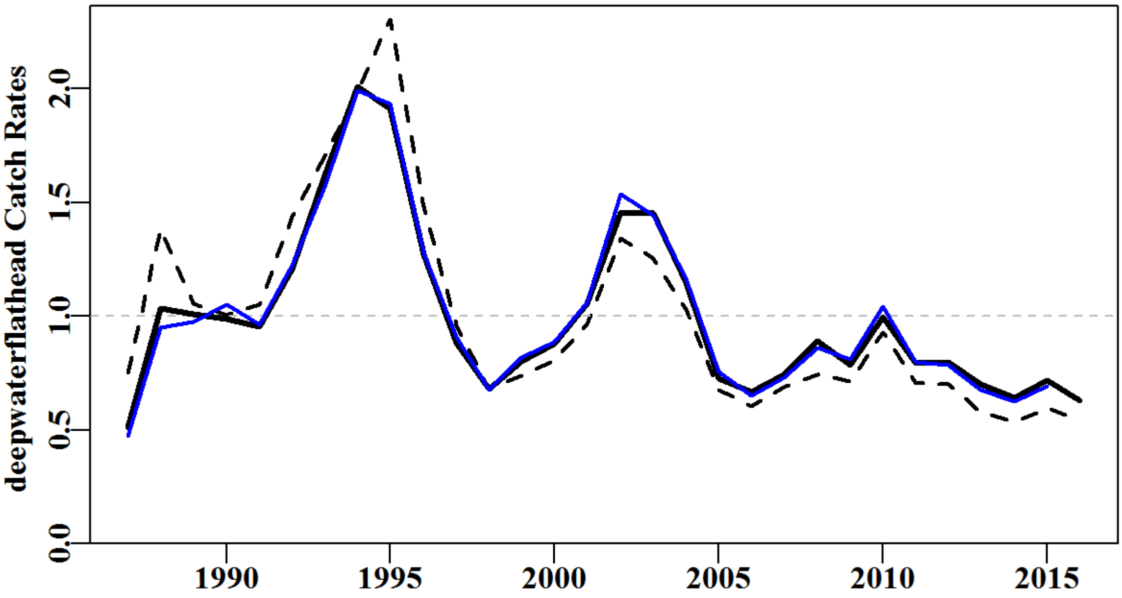


Figure 7.247. deepwaterflathead. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

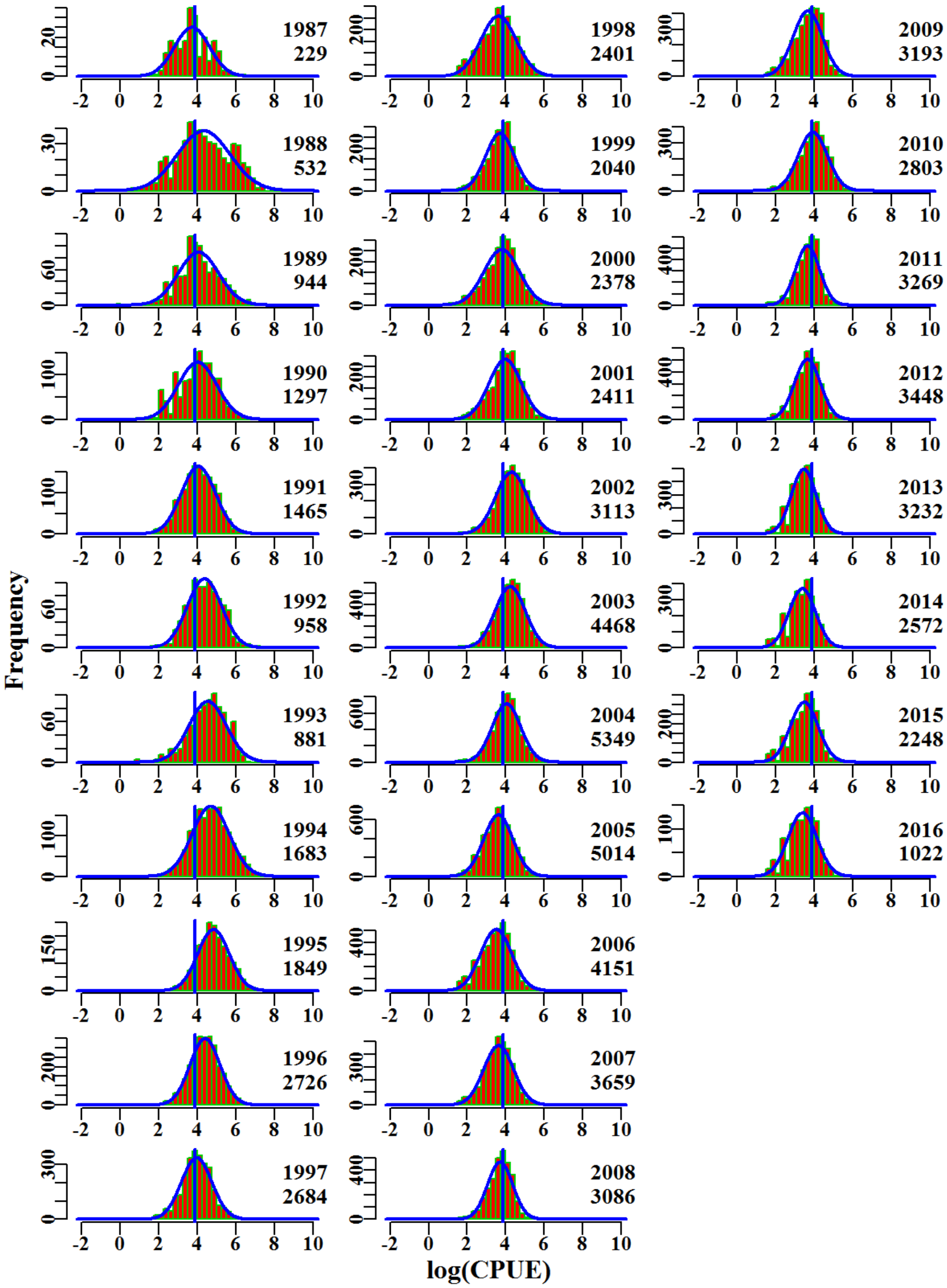


Figure 7.248. deepwaterflathead. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

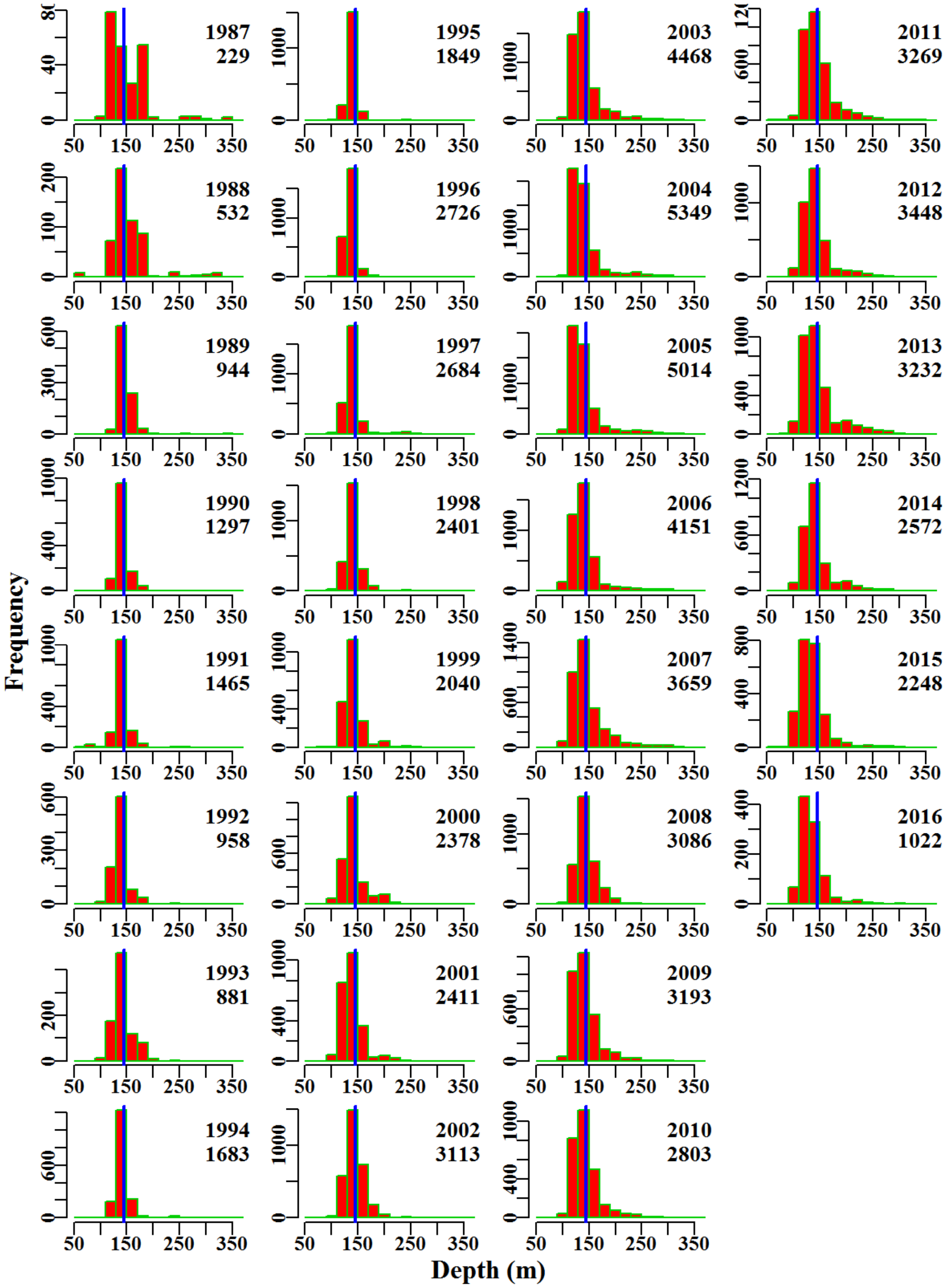


Figure 7.249. deepwaterflathead. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

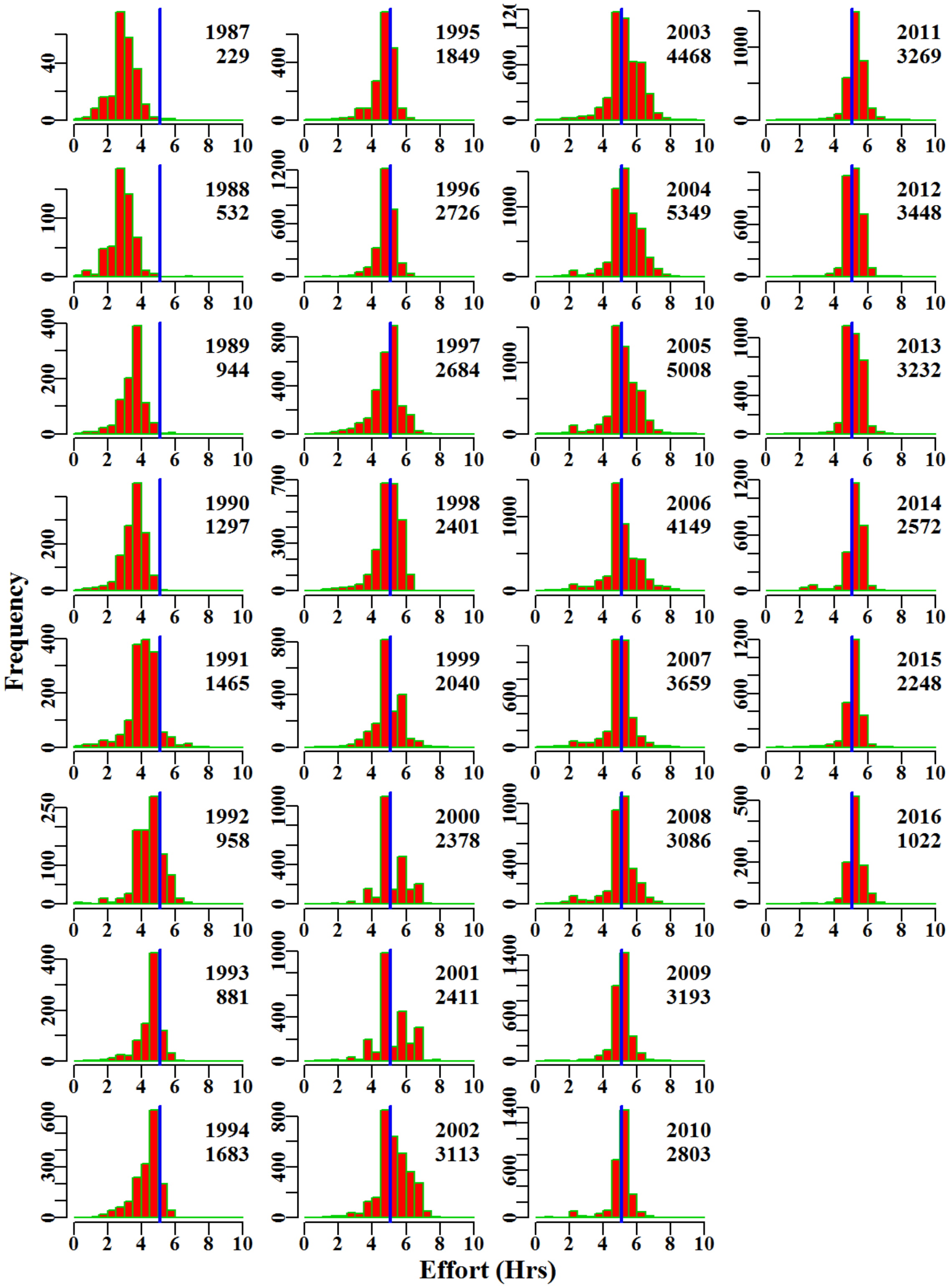


Figure 7.250. deepwaterflathead. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.35 Bight Redfish

Initial data selection for Bight Redfish (FLD - 37258004 - *Centroberyx gerrardi*) in the GAB was conducted according to the detials given in Table 7.161.

A total of 9 statistical models were fitted sequentially to the available data.

7.35.1 *Inferences*

The majority of catch of this species occurred in zone 126, again with degree longitude taking the place of zones to provide more detail.

The terms Year, DayNight, Zone, Month, Vessel and interaction two terms (Zone:Month, Zone:DepCat) had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics.

Annual standardized CPUE trend is flat since 1992 and oscillating between above and below average (Figure 7.251), and this is despite major changes in the distribution of the log(CPUE) from 2012 - 2016. The number of vessels involved in the fishery are now low (< 10 since 2006), so the interpretation of CPUE should also consider which vessels are fishing and where.

7.35.2 *Action Items and Issues*

No issues identified.

Table 7.157. bightredfish. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:DepCat.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1987	47.4	152	24.6	3	51.6	2.5674	0.000	0.090	0.004
1988	88.0	404	68.1	4	60.9	2.4495	0.113	0.885	0.013
1989	173.6	737	148.2	6	62.1	1.5389	0.108	2.017	0.014
1990	290.1	1045	252.8	8	75.1	1.4148	0.106	2.220	0.009
1991	274.0	1015	220.9	7	58.7	1.2900	0.105	3.790	0.017
1992	132.1	719	117.0	3	39.7	0.9531	0.107	3.816	0.033
1993	108.7	688	105.9	5	37.2	0.9130	0.108	4.561	0.043
1994	163.6	1274	159.0	6	35.8	0.6201	0.104	7.128	0.045
1995	176.9	1396	175.4	5	30.2	0.7377	0.104	7.773	0.044
1996	334.1	2029	328.7	6	37.8	0.8981	0.102	10.358	0.032
1997	375.9	1922	366.0	7	46.2	0.9407	0.103	9.838	0.027
1998	442.2	1794	434.0	7	57.1	1.1052	0.103	8.723	0.020
1999	328.3	1495	327.2	7	52.0	0.9718	0.105	5.404	0.017
2000	397.5	1715	390.3	5	64.5	0.8610	0.104	6.689	0.017
2001	228.9	1641	227.7	5	34.9	0.6735	0.105	7.421	0.033
2002	374.5	2123	369.8	8	37.2	0.7199	0.104	9.152	0.025
2003	853.2	3144	845.0	10	57.8	0.9791	0.103	8.796	0.010
2004	882.2	3782	754.4	9	42.7	0.9395	0.103	15.491	0.021
2005	755.9	3532	718.2	10	43.0	0.8933	0.103	13.678	0.019
2006	952.8	3294	930.1	9	72.1	0.9899	0.103	10.318	0.011
2007	749.7	2744	683.8	6	67.8	0.9154	0.104	11.605	0.017
2008	654.9	2427	643.1	4	68.0	0.9791	0.104	9.294	0.014
2009	458.1	2307	453.4	4	48.4	0.9132	0.104	11.703	0.026
2010	283.2	1858	280.8	4	34.8	0.7238	0.105	10.622	0.038
2011	327.9	2184	321.2	4	30.7	0.7246	0.104	10.872	0.034
2012	266.2	1881	259.5	4	26.7	0.6486	0.105	14.511	0.056
2013	198.0	1519	191.4	4	22.9	0.5936	0.106	12.283	0.064
2014	238.1	1428	235.6	4	32.1	0.6419	0.106	8.433	0.036
2015	173.6	1193	170.5	3	29.8	0.6311	0.107	5.431	0.032
2016	142.3	1043	140.6	4	27.9	0.7719	0.108	6.270	0.045

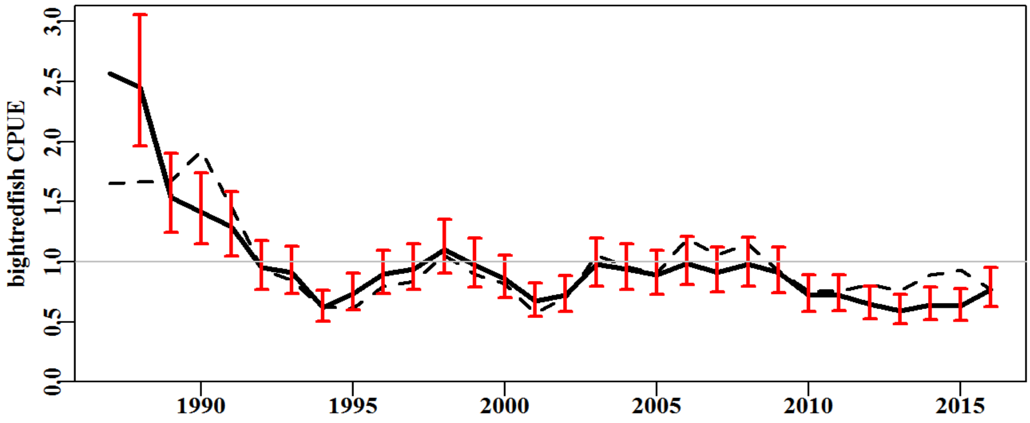


Figure 7.251. bightredfish standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

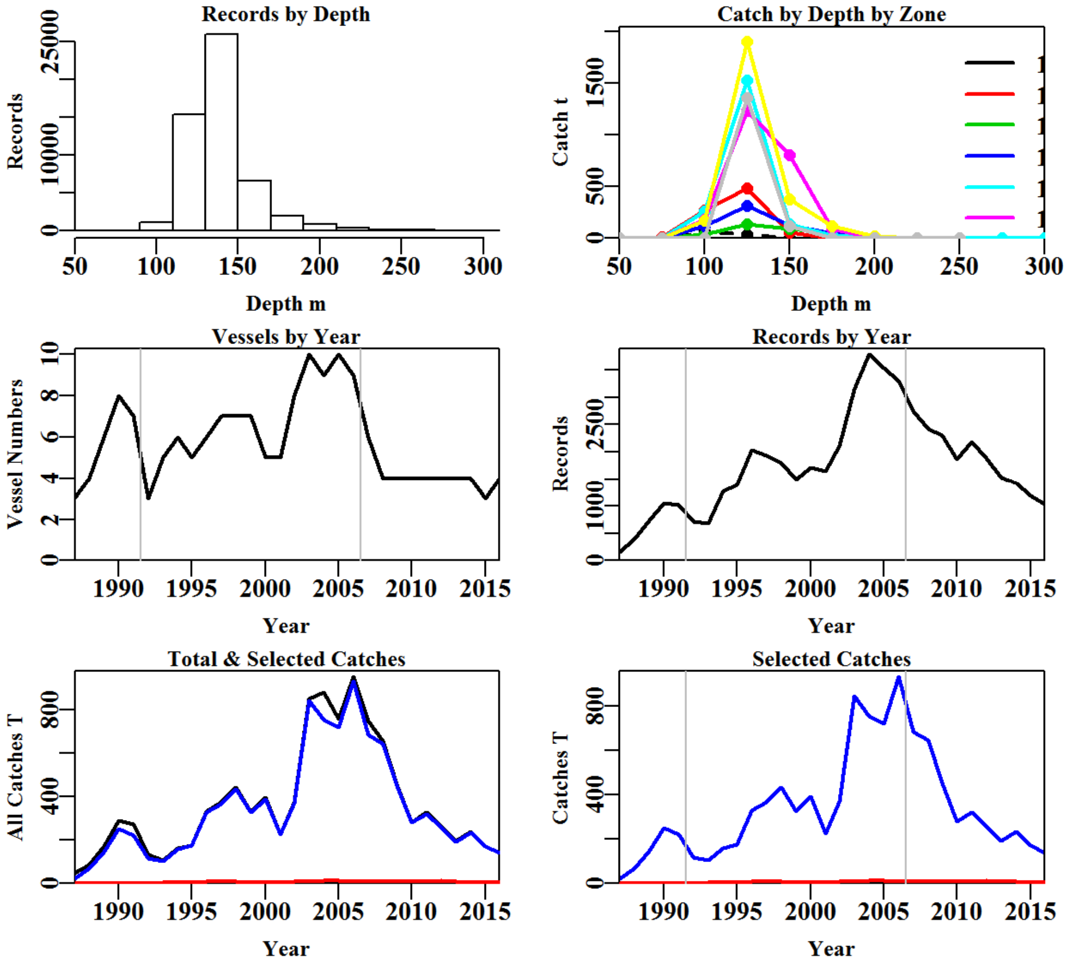


Figure 7.252. bightredfish fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.158. bightredfish data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

0	0	0	0	0
0	0	0	0	0

Table 7.159. The models used to analyse data for bightredfish.

	Model
Model1	Year
Model2	Year + DayNight
Model3	Year + DayNight + Zone
Model4	Year + DayNight + Zone + Month
Model5	Year + DayNight + Zone + Month + Vessel
Model6	Year + DayNight + Zone + Month + Vessel + DepCat
Model7	Year + DayNight + Zone + Month + Vessel + DepCat + Zone:Month
Model8	Year + DayNight + Zone + Month + Vessel + DepCat + Zone:Vessel
Model9	Year + DayNight + Zone + Month + Vessel + DepCat + Zone:DepCat

Table 7.160. bightredfish. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:DepCat.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	32620	97355	3016	52134	30	3.0	0.00
DayNight	27096	87558	12813	52134	33	12.7	9.76
Zone	21789	79061	21309	52134	40	21.2	8.46
Month	17553	72861	27509	52134	51	27.3	6.17
Vessel	16254	71017	29354	52134	70	29.2	1.81
DepCat	16068	70736	29635	52134	80	29.4	0.27
Zone:Month	15176	69330	31040	52134	157	30.7	1.30
Zone:Vessel	15478	69600	30770	52134	207	30.4	0.96
Zone:DepCat	14674	68709	31661	52134	141	31.4	1.94

Table 7.161. bightredfish. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	bightredfish
csirocode	37258004
fishery	GAB
depthrange	50 - 300
depthclass	25
zones	82, 83
methods	TW, TDO, OTT, PTB
years	1986 - 2016

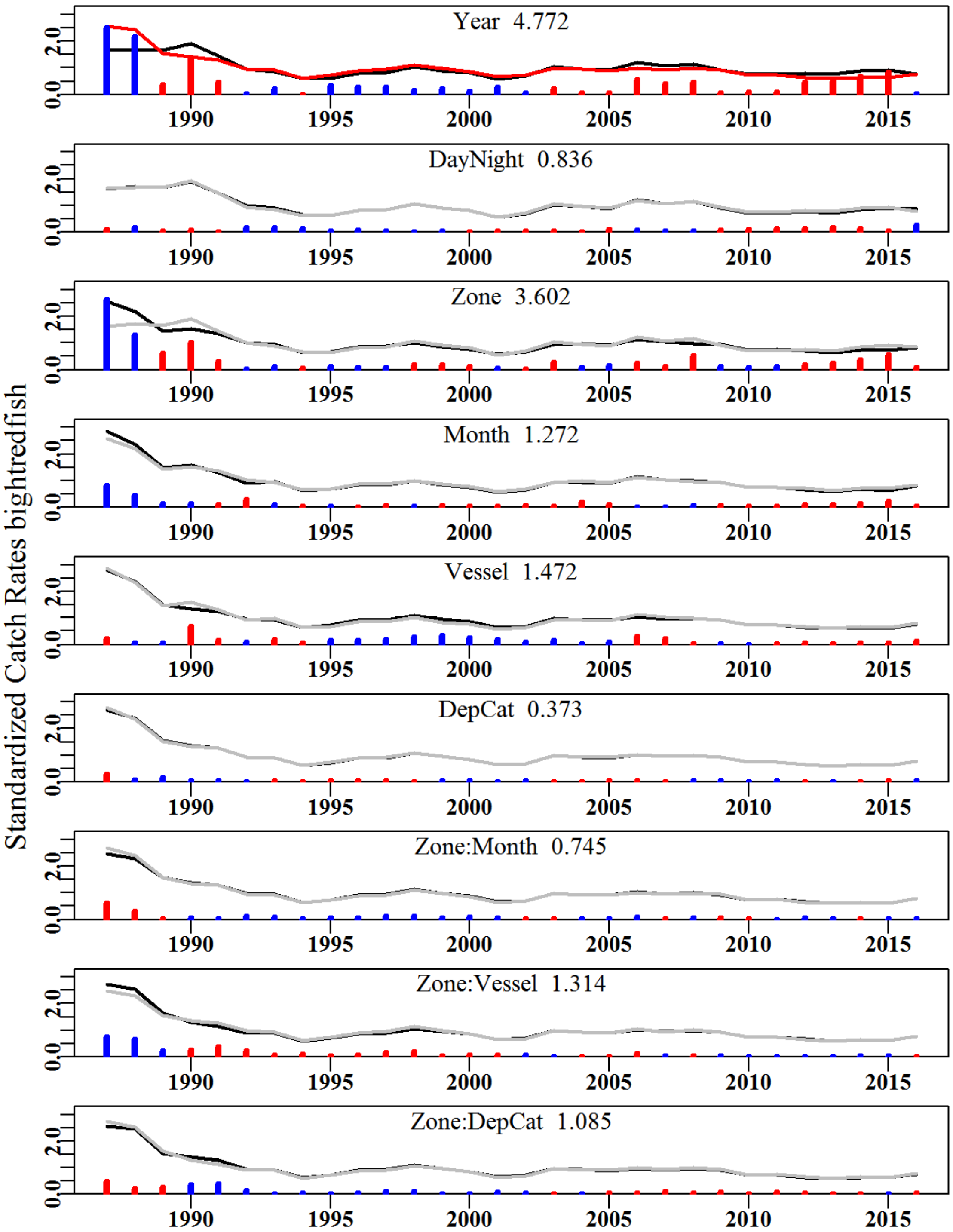


Figure 7.253. bightredfish. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

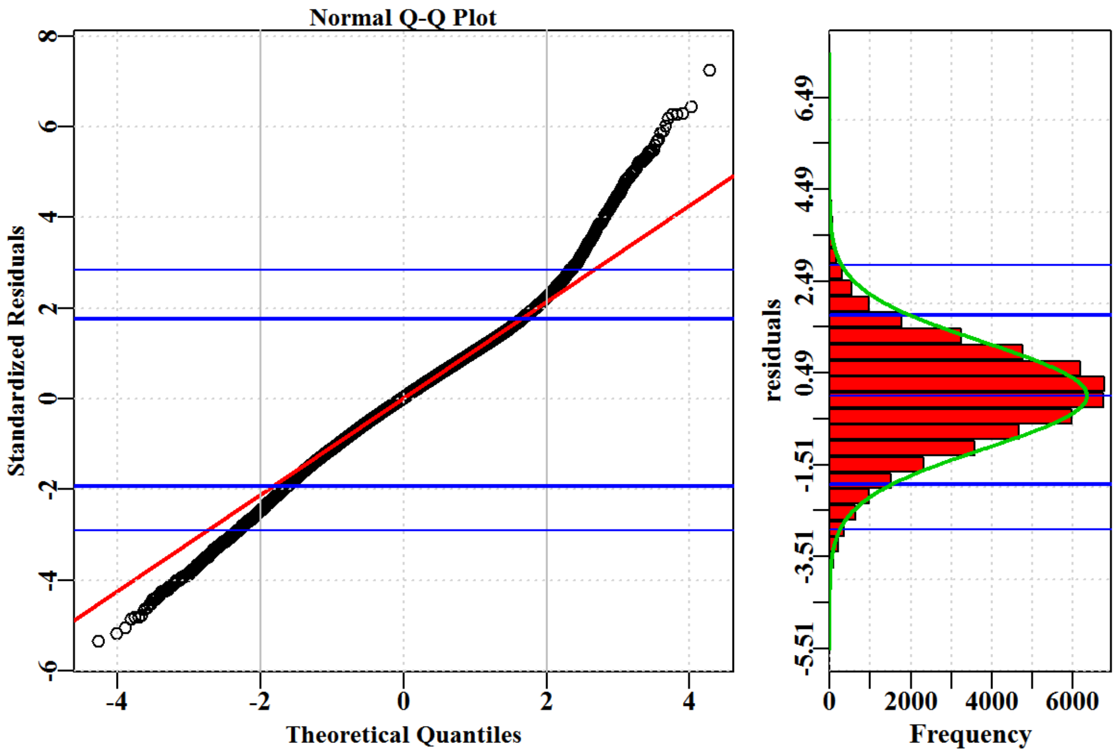


Figure 7.254. bightredfish. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

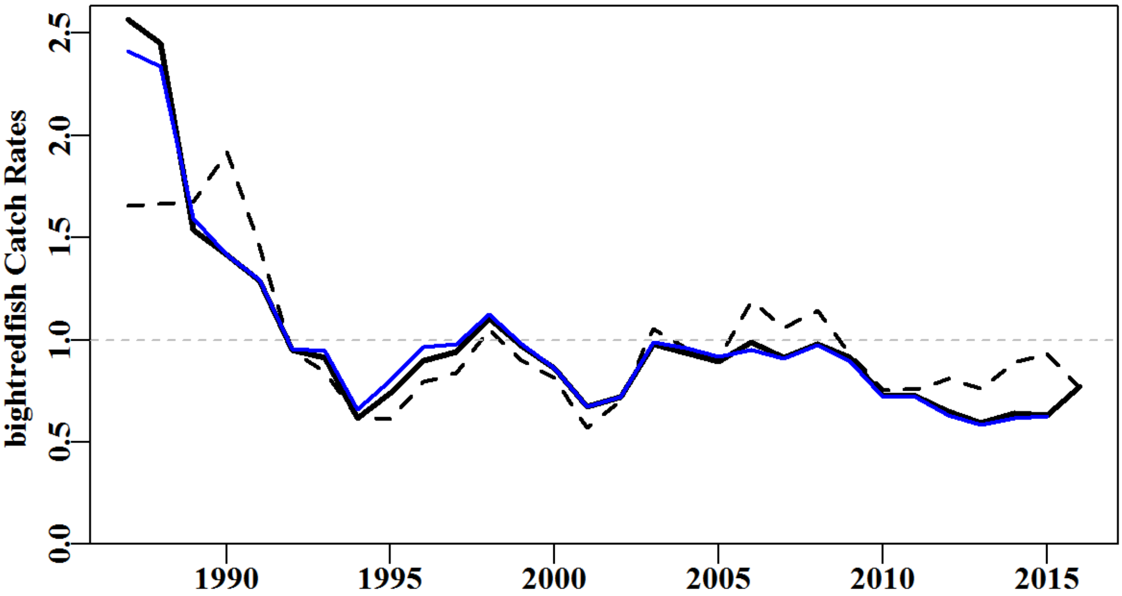


Figure 7.255. bightredfish. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

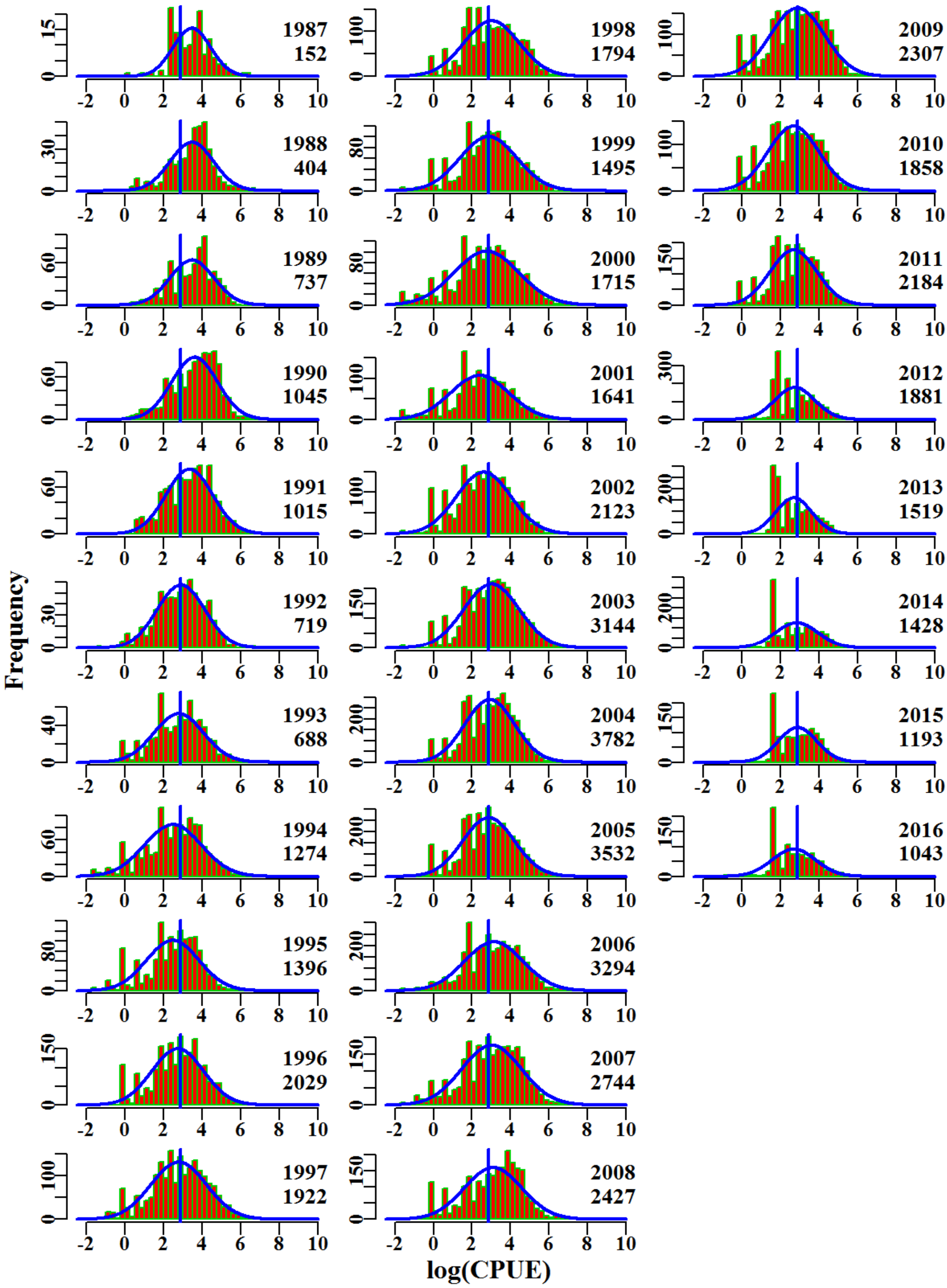


Figure 7.256. bightredfish. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

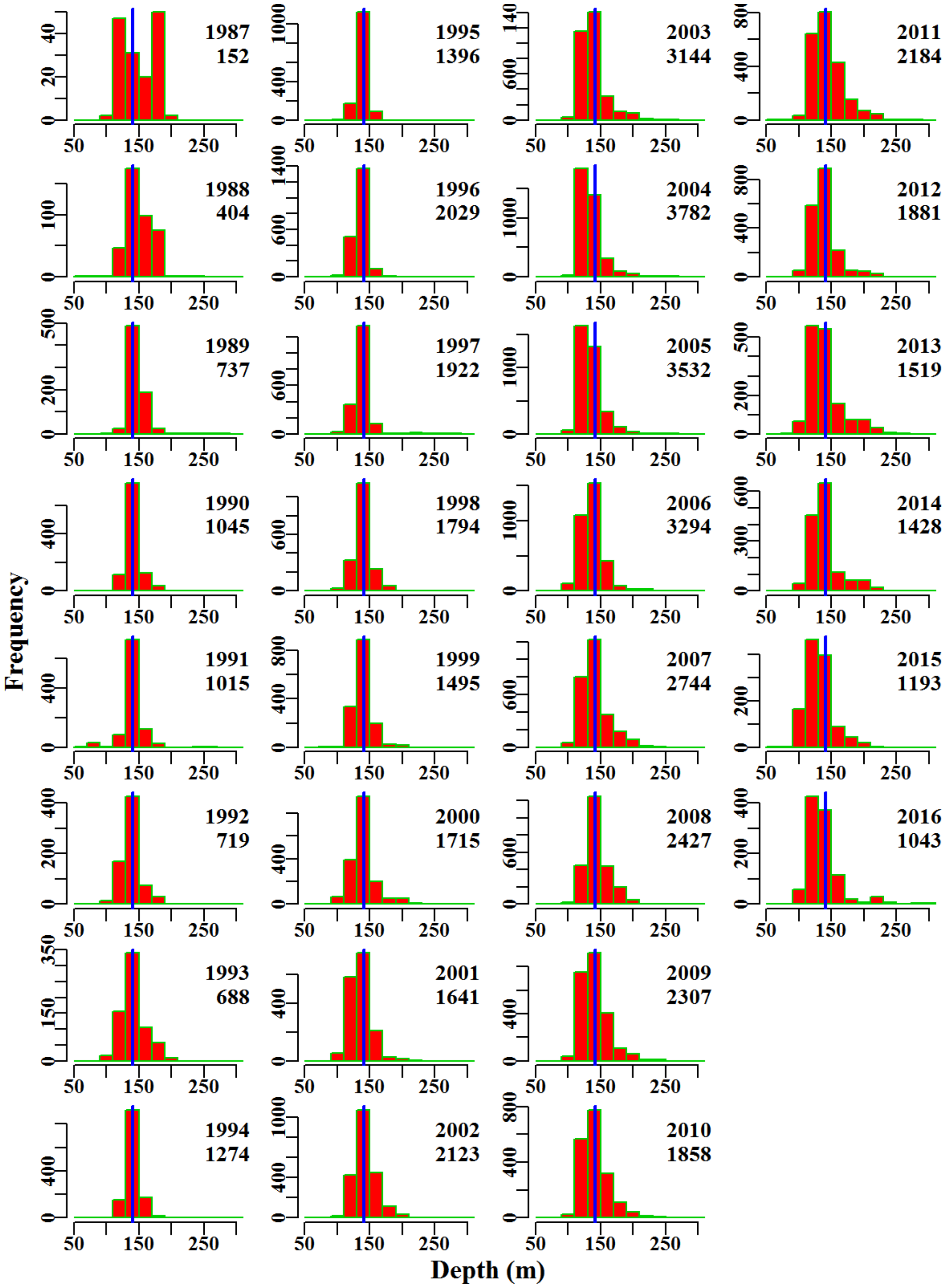


Figure 7.257. bightredfish. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

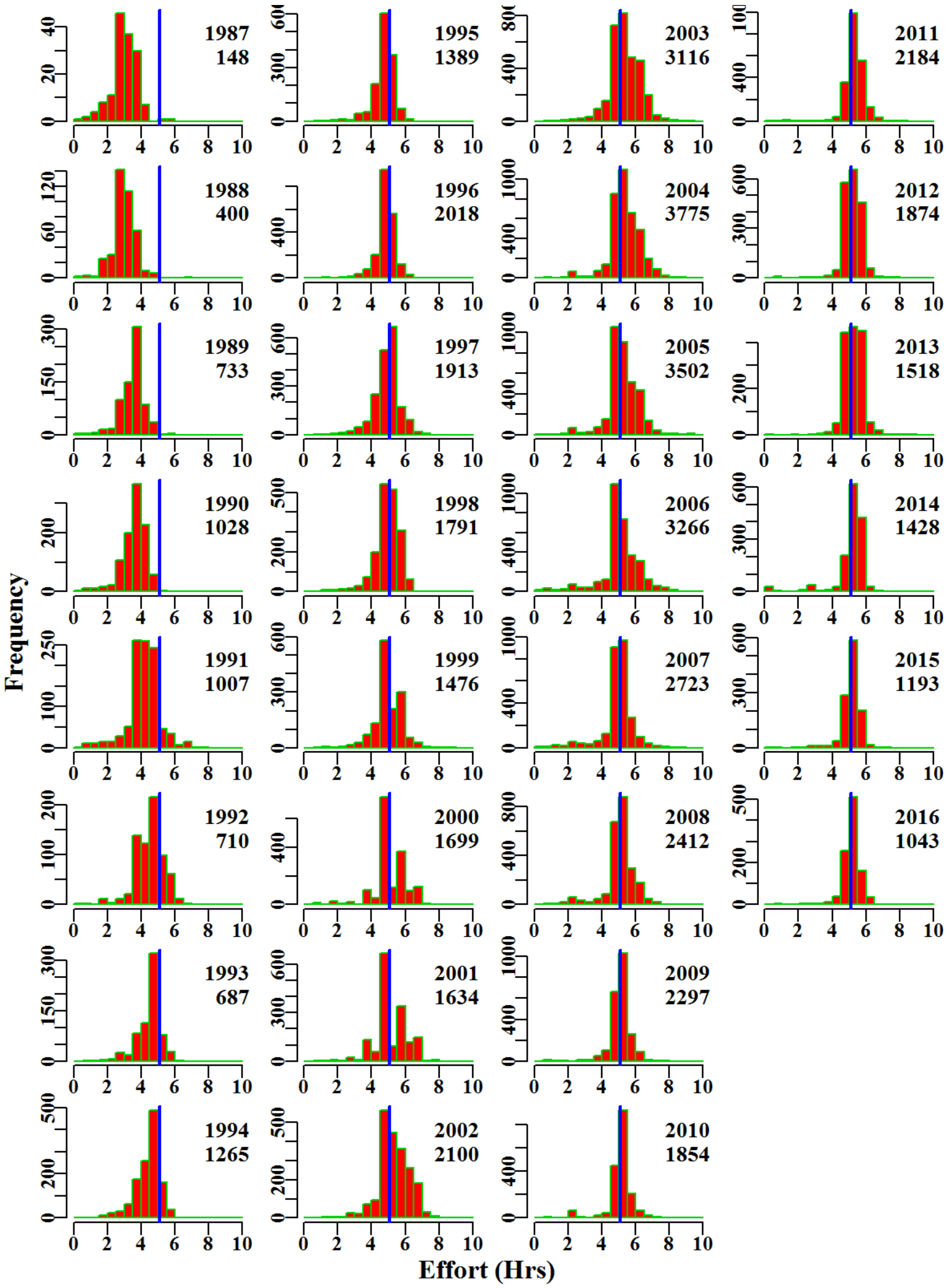


Figure 7.258. bightredfish. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.36 Ribaldo 10-50

Initial data selection for Ribaldo (RBD - 37224002 - *Mora moro*) in the SET was conducted according to the details given in Table 7.166.

A total of 8 statistical models were fitted sequentially to the available data.

7.36.1 *Inferences*

The majority of catch of this species occurred in zone 40, 50, 20 and 30 and minimal catches in zone 10. There were increases in catches <30 kg during the 1995-2005 period.

The terms Year, Vessel, DepCat, Zone and interaction two terms (Zone:Month, Zone:DepCat) had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests a departure from the assumed Normal distribution as depicted by the tails of the distribution (Figure 7.262).

The number of records by depth was highly variable and sometimes bimodal from 1986 - 1994, after which the number of records increased and the distributions became more consistent through time. The number of vessels contributing to the fishery also increased markedly after 2003. It is questionable whether the earlier years of CPUE are representative of the whole stock.

Annual standardized CPUE trend is noisy and relatively flat since 1996 and mostly below average (Figure 7.259).

7.36.2 *Action Items and Issues*

It is recommended that the geographical distribution of catches be explored to determine how representative of the entire stock's distribution the early years are.

Table 7.162. ribaldo. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	4.1	72	3.5	11	24.3	2.2237	0.000	0.655	0.186
1987	7.9	158	7.3	14	16.5	1.3211	0.137	1.509	0.207
1988	10.9	123	8.0	22	25.7	2.0485	0.152	0.855	0.106
1989	11.3	136	7.7	14	30.2	1.8648	0.150	1.114	0.144
1990	3.7	58	2.3	11	14.0	1.4433	0.171	0.648	0.287
1991	7.8	145	5.2	22	11.9	1.4266	0.150	1.697	0.329
1992	13.3	226	11.7	26	16.1	1.4183	0.141	1.982	0.170
1993	22.8	330	19.8	37	18.8	1.2075	0.141	3.424	0.173
1994	41.9	423	23.6	30	18.5	1.3283	0.139	4.945	0.209
1995	90.3	1147	86.3	26	18.8	1.4528	0.135	10.384	0.120
1996	82.3	1492	77.0	32	15.0	1.1043	0.135	15.009	0.195
1997	103.1	1714	96.6	30	14.0	0.9551	0.134	16.038	0.166
1998	99.9	1666	92.0	33	13.6	0.9099	0.135	16.791	0.183
1999	72.1	1133	59.7	32	12.6	0.8171	0.135	13.630	0.228
2000	66.8	1174	53.8	41	10.5	0.7549	0.135	12.940	0.240
2001	82.5	1129	52.6	37	9.9	0.6992	0.135	12.191	0.232
2002	157.8	1142	57.2	30	10.0	0.6417	0.135	11.296	0.197
2003	180.8	1307	66.0	35	10.0	0.6202	0.135	12.136	0.184
2004	181.1	1257	66.4	33	11.1	0.6778	0.135	7.662	0.115
2005	90.4	671	30.0	32	9.6	0.5957	0.137	3.993	0.133
2006	122.6	637	32.1	34	11.4	0.6224	0.137	3.335	0.104
2007	78.3	404	15.6	24	8.7	0.4358	0.140	2.568	0.165
2008	78.5	367	17.6	24	9.9	0.5702	0.141	2.377	0.135
2009	105.0	572	33.4	20	12.0	0.6462	0.138	3.243	0.097
2010	91.9	681	37.1	22	11.6	0.6719	0.137	5.114	0.138
2011	93.9	863	44.5	20	9.8	0.6727	0.136	4.633	0.104
2012	107.2	759	42.4	19	11.6	0.6791	0.137	3.942	0.093
2013	122.7	932	69.1	23	14.5	0.8295	0.136	4.061	0.059
2014	138.2	856	59.9	22	12.6	0.8125	0.136	4.388	0.073
2015	99.8	744	51.0	25	13.3	0.8086	0.137	3.530	0.069
2016	66.5	602	40.3	20	12.5	0.7404	0.138	3.282	0.081

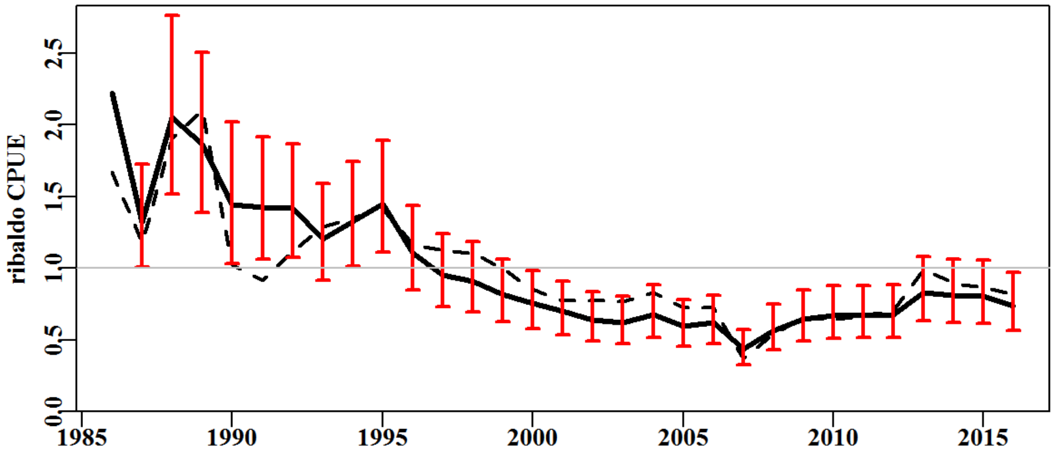


Figure 7.259. ribaldo standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

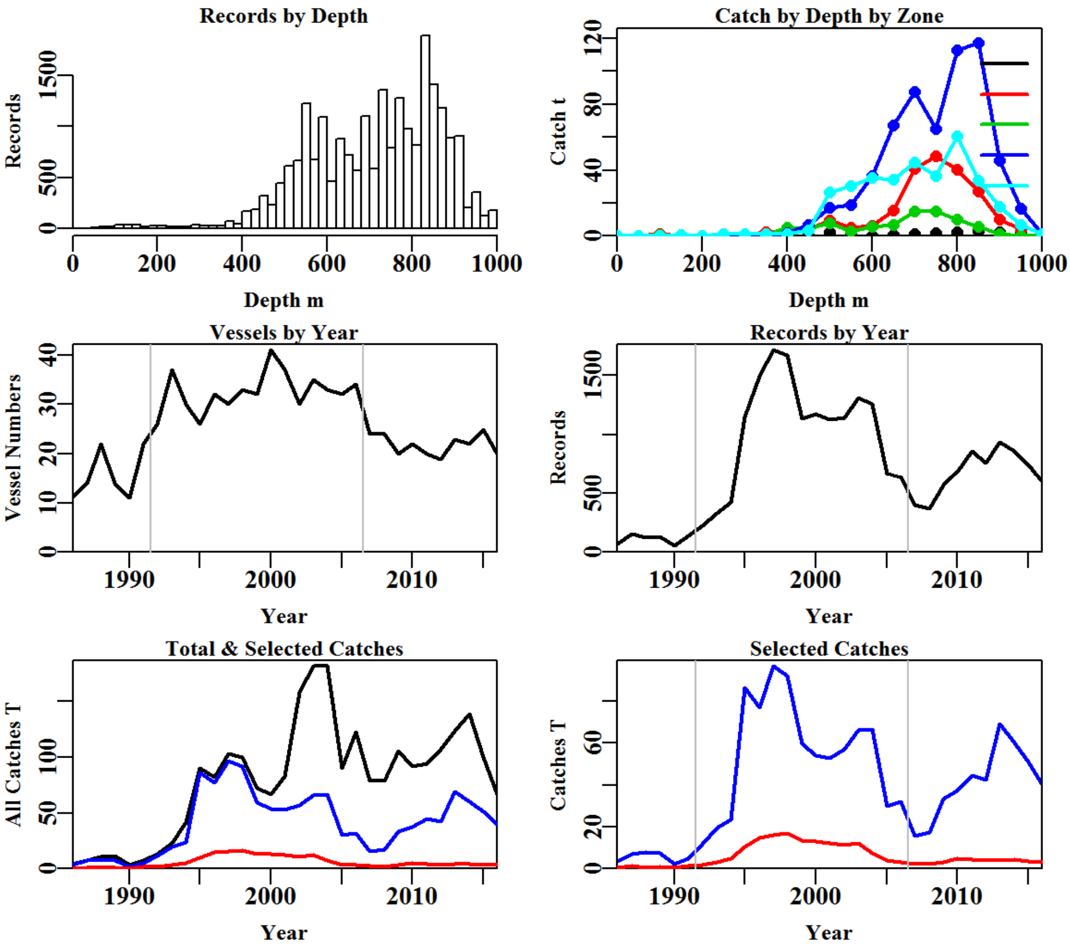


Figure 7.260. ribaldo fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.163. ribaldo data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	33035	26026	25268	25098	23137	22930	22920
Difference	0	7009	758	170	1961	207	10

Table 7.164. The models used to analyse data for ribald.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + Zone
Model5	Year + Vessel + DepCat + Zone + DayNight
Model6	Year + Vessel + DepCat + Zone + DayNight + Month
Model7	Year + Vessel + DepCat + Zone + DayNight + Month + Zone:Month
Model8	Year + Vessel + DepCat + Zone + DayNight + Month + Zone:DepCat

Table 7.165. ribaldo. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	-1687	21236	1664	22920	31	7.1	0.00
Vessel	-3774	19171	3728	22920	160	15.7	8.55
DepCat	-6851	16534	6365	22712	180	26.3	10.60
Zone	-7557	16022	6877	22712	184	28.6	2.27
DayNight	-7678	15932	6967	22712	187	29.0	0.39
Month	-7737	15876	7023	22712	198	29.2	0.22
Zone:Month	-8313	15418	7481	22712	242	31.1	1.91
Zone:DepCat	-8098	15523	7376	22712	273	30.5	1.34

Table 7.166. ribaldo. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	ribaldo
csirocode	37224002
fishery	SET
depthrange	0 - 1000
depthclass	50
zones	10, 20, 30, 40, 50
methods	TW, TDO, OTT, PTB, TMO
years	1986 - 2016

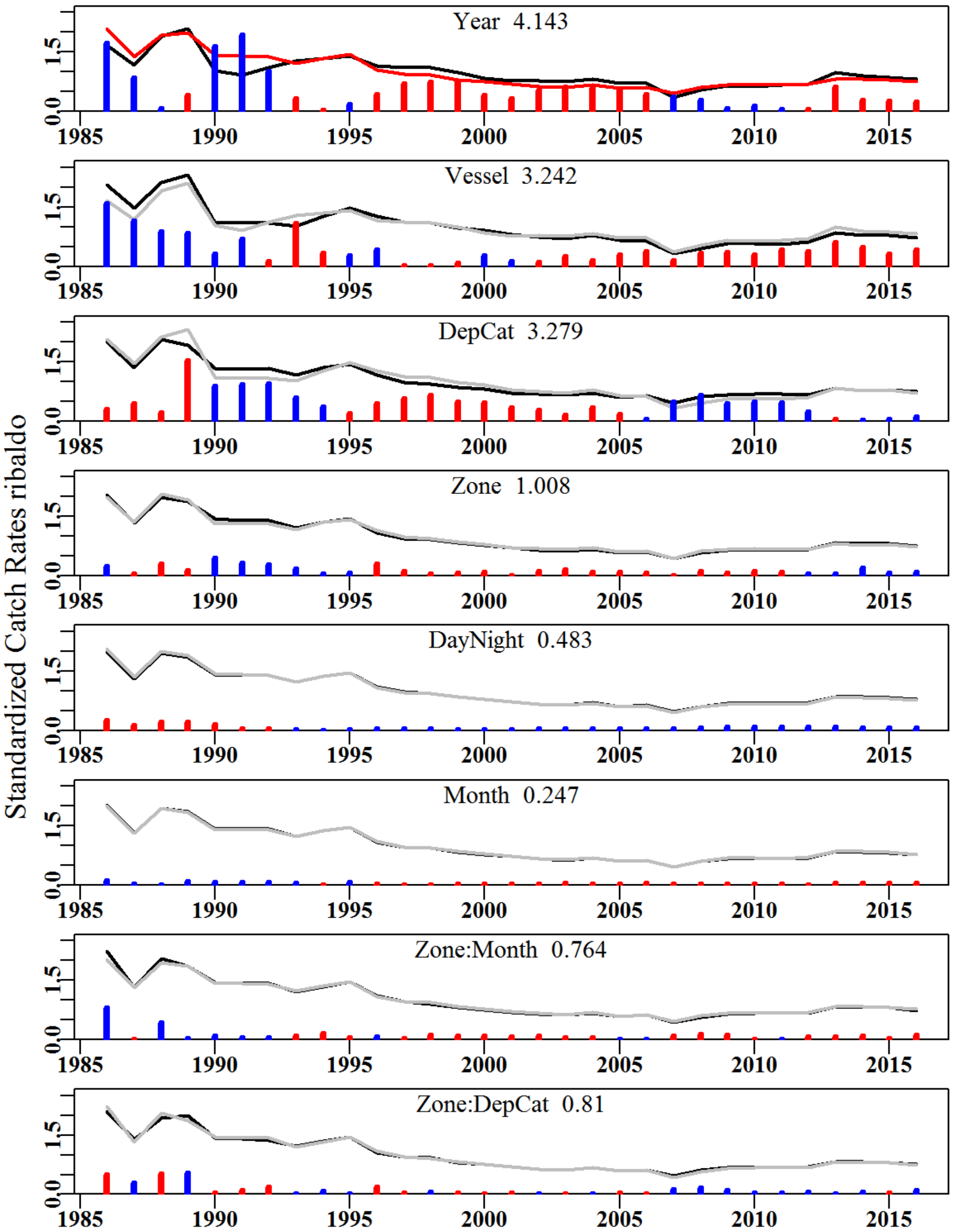


Figure 7.261. ribaldo. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

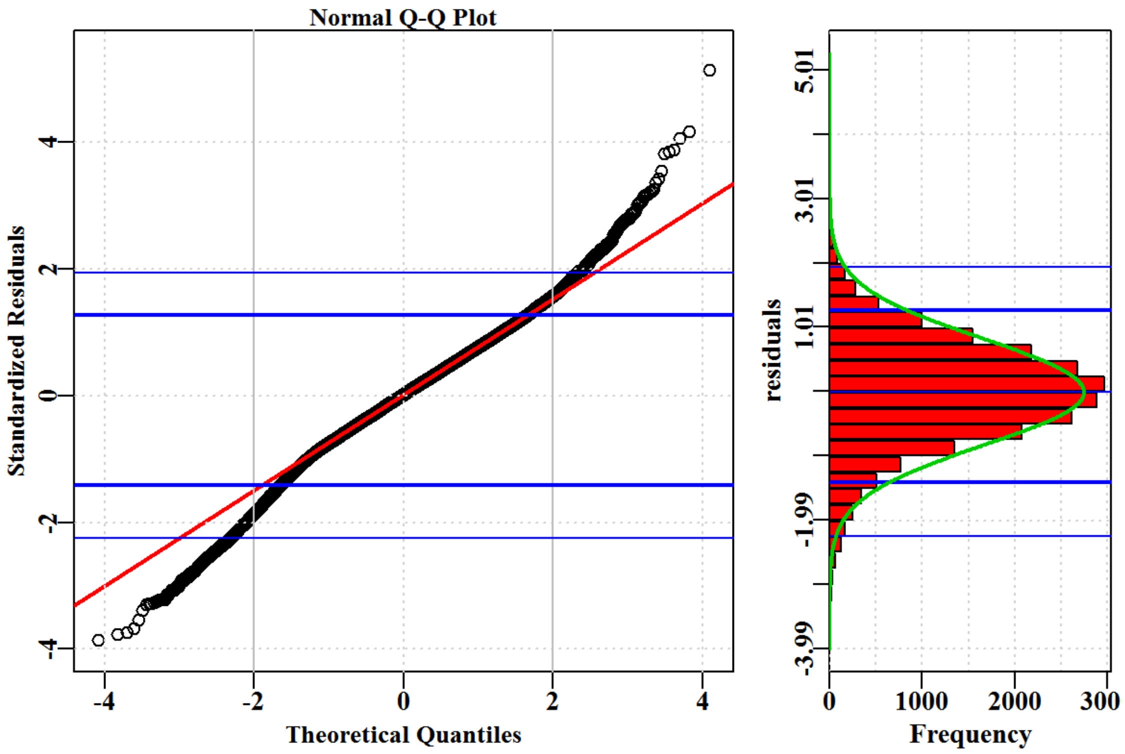


Figure 7.262. ribaldo. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

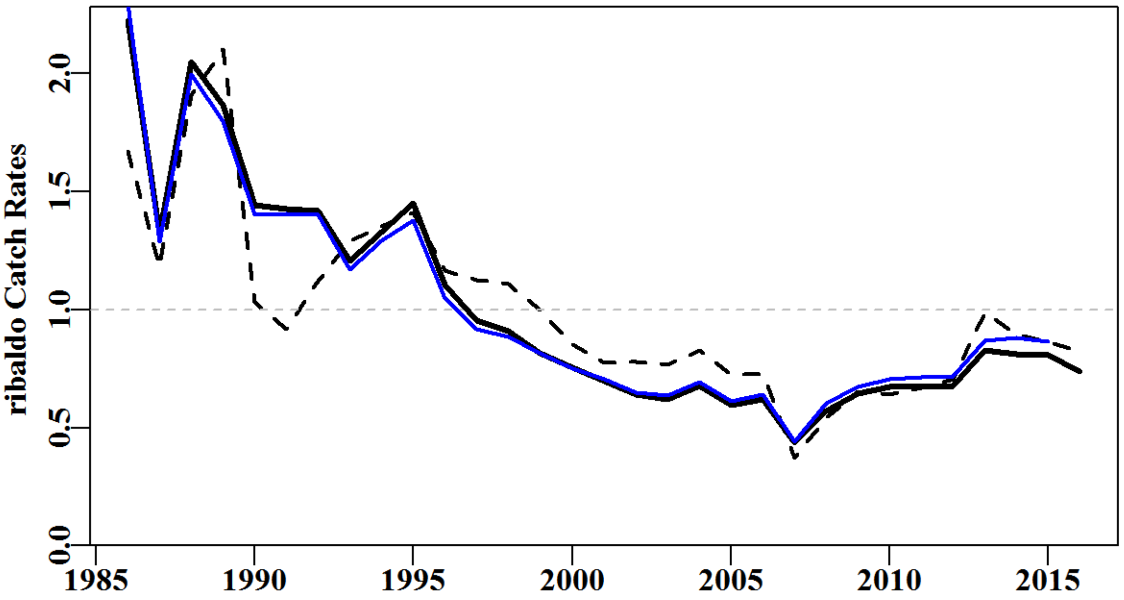


Figure 7.263. ribaldo. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

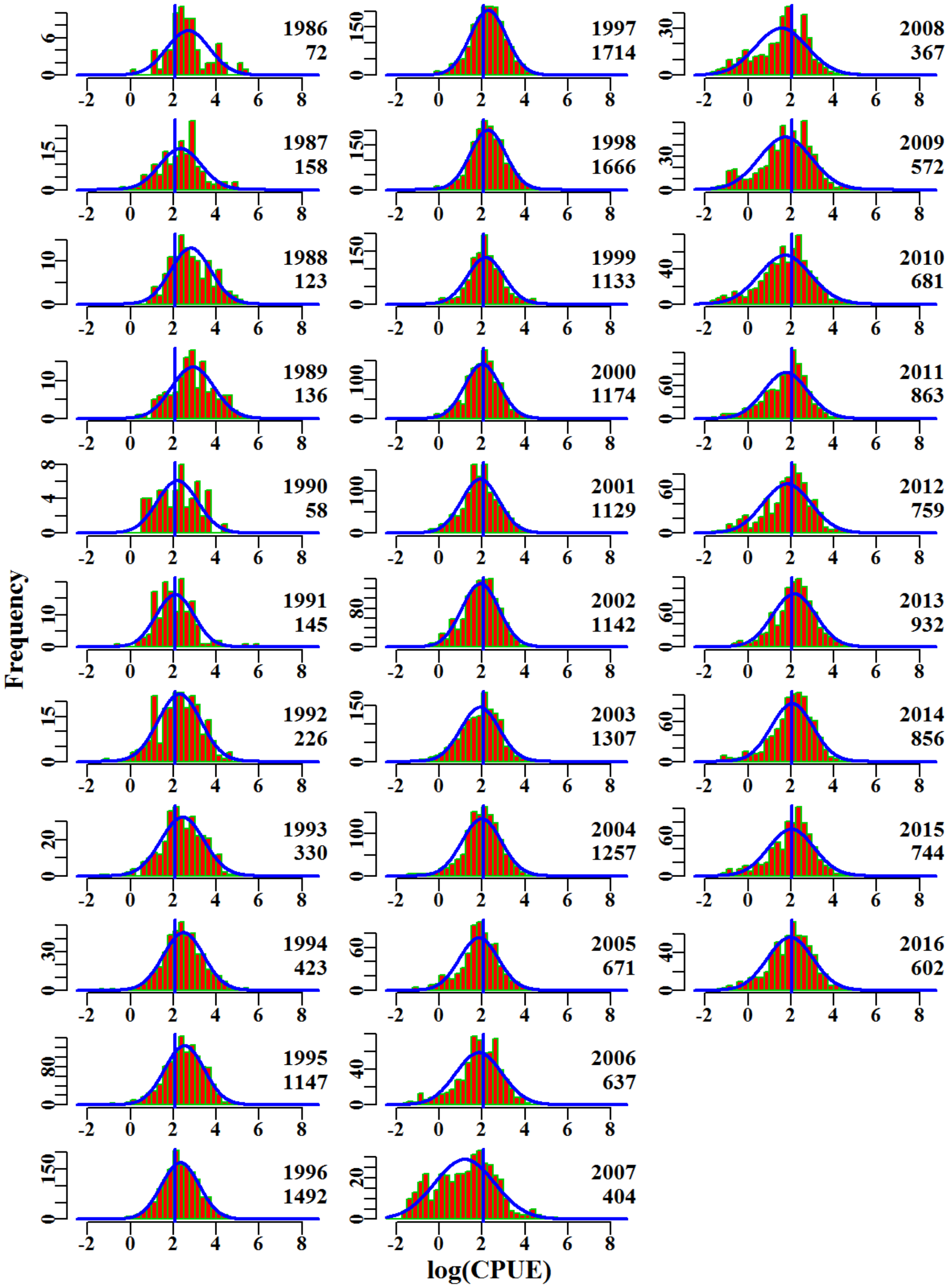


Figure 7.264. ribaldo. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

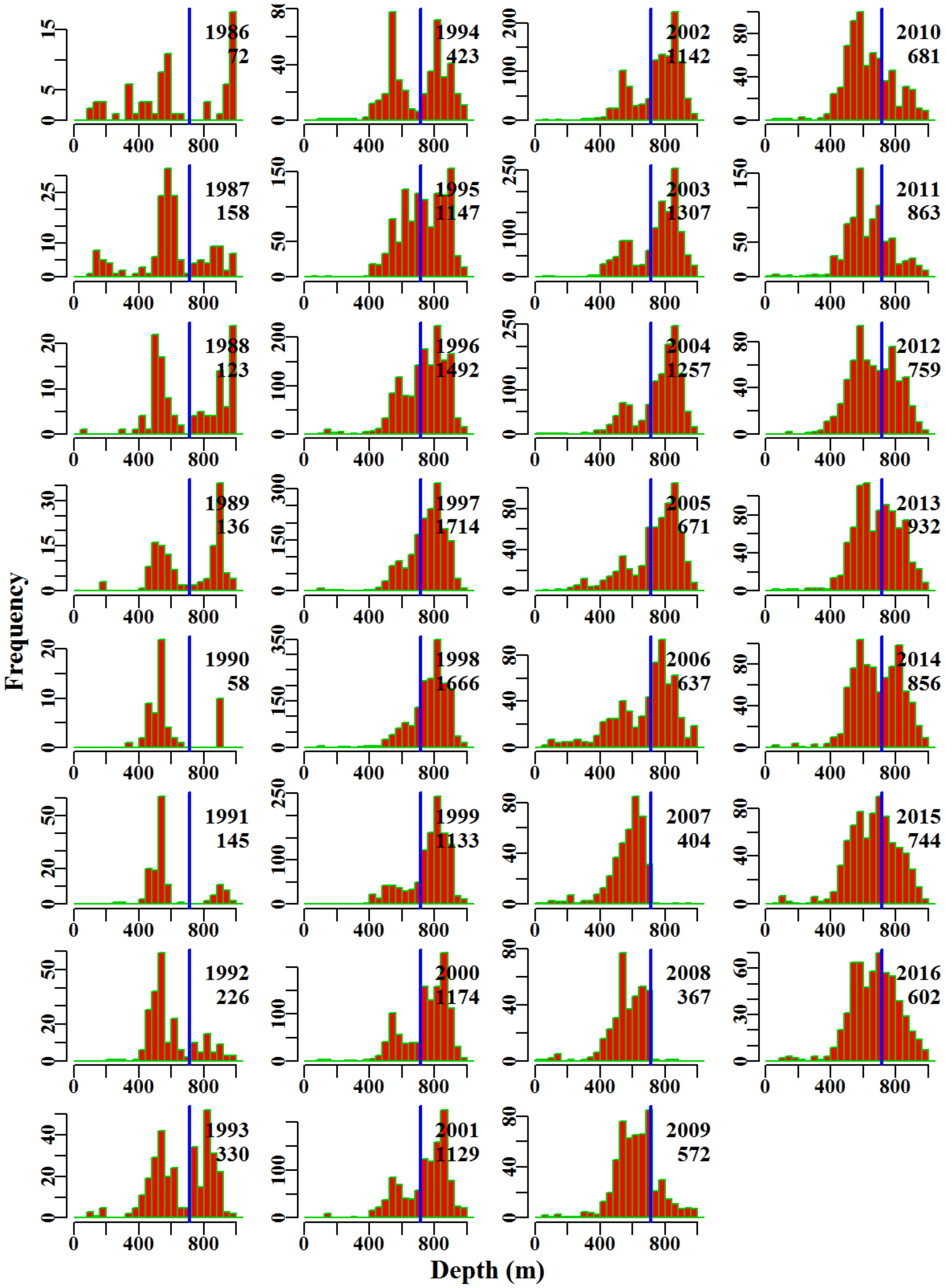


Figure 7.265. ribaldo. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

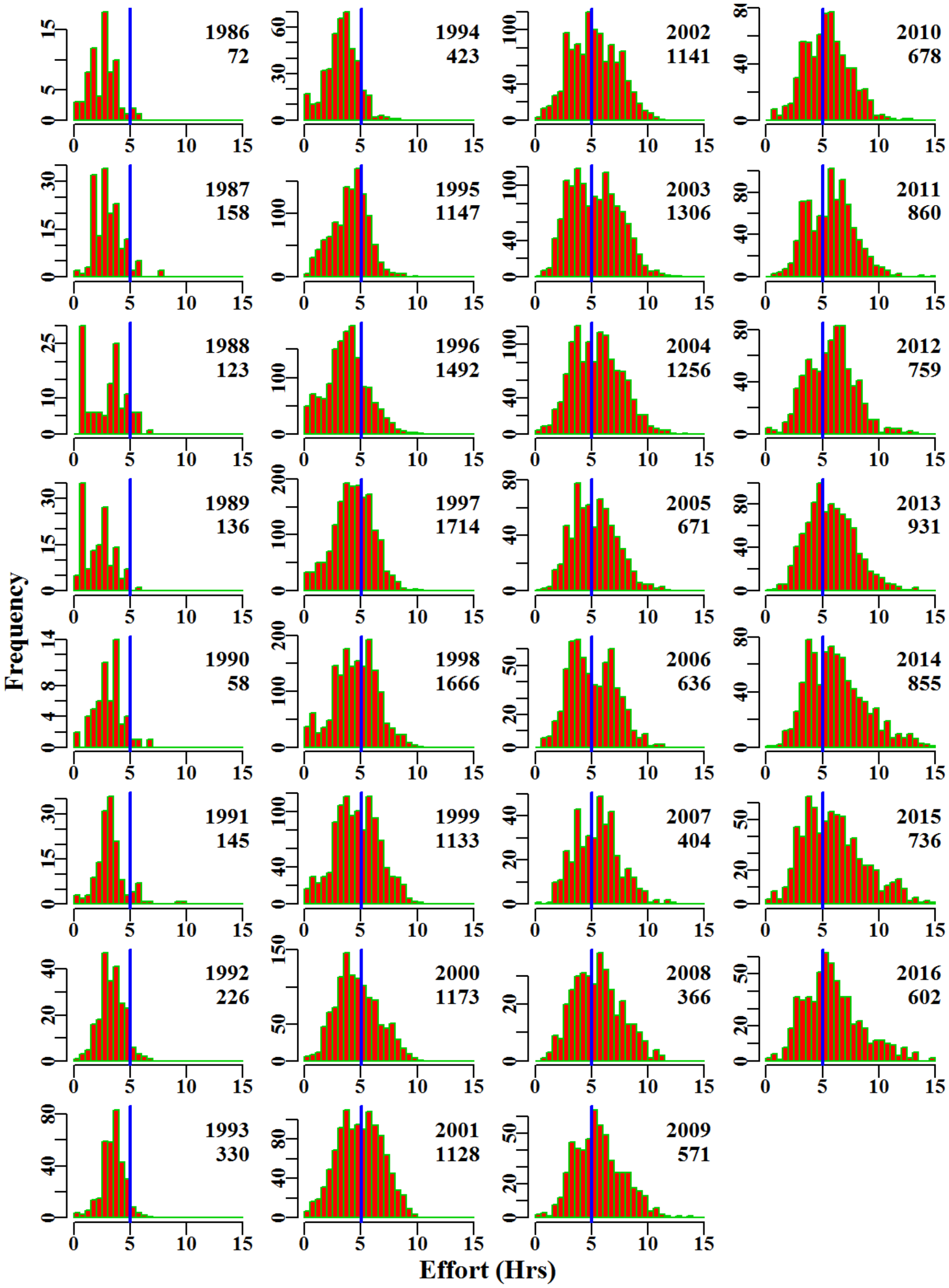


Figure 7.266. ribaldo. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.37 RibaldoAL

Initial data selection for Ribaldo (RBD - 37224002 - *Mora moro*) in the SEN and GHT was conducted according to the details given in Table 7.171.

A total of 7 statistical models were fitted sequentially to the available data.

7.37.1 *Inferences*

The majority of catch of this species occurred in zone 20, 30 and 40.

The terms Year, Vessel, DepCat, Zone and interaction term (Zone:Month) had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. Few vessels have ever contributed to this fishery and the early years are only made up from the catches of low vessel numbers.

Annual standardized CPUE trend is noisy and relatively flat since about 2005 and mostly below average (Figure 7.267).

7.37.2 *Action Items and Issues*

The first two or three years of data need to be examined to determine how representative these data are of the whole stock. It may also benefit from being converted to catch-per-hook rather than catch-per-shot.

Table 7.167. RibaldoAL. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/shot), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
2001	82.5	63	15.7	2	268.8	1.0621	0.000	0.205	0.013
2002	157.8	259	95.5	4	455.9	2.5251	0.188	0.878	0.009
2003	180.8	337	102.9	7	359.2	1.9125	0.184	1.553	0.015
2004	181.1	715	96.7	11	131.4	1.7025	0.179	5.369	0.056
2005	90.4	309	37.2	7	128.1	1.0578	0.185	2.417	0.065
2006	122.6	605	65.4	8	123.5	1.0365	0.179	3.488	0.053
2007	78.3	393	28.1	6	72.7	0.6230	0.182	2.617	0.093
2008	78.5	401	56.8	6	168.8	0.7447	0.180	2.130	0.038
2009	105.0	432	68.3	6	220.0	0.7332	0.178	2.256	0.033
2010	91.9	381	51.7	5	175.7	0.6918	0.180	1.811	0.035
2011	93.9	356	46.5	5	165.1	0.8209	0.181	1.872	0.040
2012	107.2	295	58.8	6	282.8	0.7754	0.183	1.228	0.021
2013	122.7	275	49.8	5	241.2	0.6283	0.185	1.143	0.023
2014	138.2	267	66.3	5	504.1	0.6713	0.185	0.853	0.013
2015	99.8	198	35.1	3	265.2	0.6068	0.189	0.865	0.025
2016	66.5	240	24.5	3	138.1	0.4081	0.188	1.361	0.056

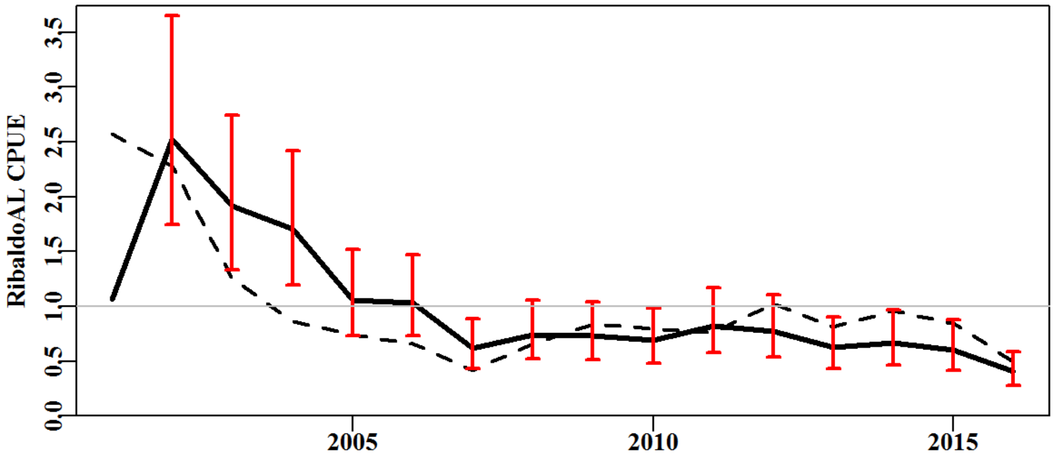


Figure 7.267. RibaldoAL standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

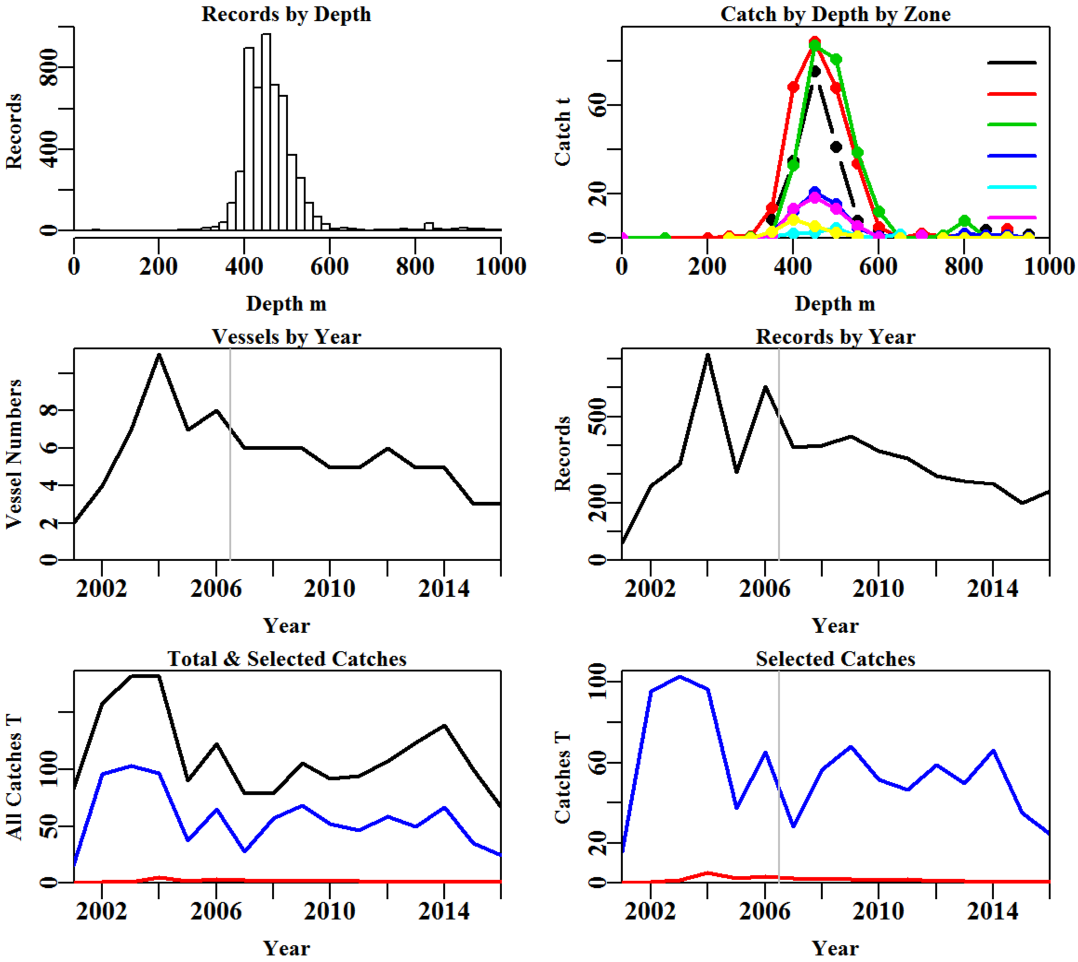


Figure 7.268. RibaldoAL fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.168. RibaldoAL data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	33035	32830	32047	20470	19571	5552	5526
Difference	0	205	783	11577	899	14019	26

Table 7.169. The models used to analyse data for RibaldoAL.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + Zone
Model5	Year + Vessel + DepCat + Zone + Month
Model6	Year + Vessel + DepCat + Zone + Month + Zone:Month
Model7	Year + Vessel + DepCat + Zone + Month + Zone:DepCat

Table 7.170. RibaldoAL. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	5406	14614	728	5526	16	4.5	0.00
Vessel	3373	10068	5274	5526	29	34.0	29.56
DepCat	2941	9235	6107	5503	46	39.0	4.99
Zone	2848	9061	6281	5503	52	40.1	1.08
Month	2807	8958	6384	5503	63	40.7	0.56
Zone:Month	2679	8547	6795	5503	128	42.7	2.04
Zone:DepCat	2791	8723	6619	5503	128	41.5	0.86

Table 7.171. RibaldoAL. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	RibaldoAL
csirocode	37224002
fishery	SEN_GHT
depthrange	0 - 1000
depthclass	50
zones	20, 30, 40, 50, 83, 84, 85
methods	AL
years	2001 - 2016

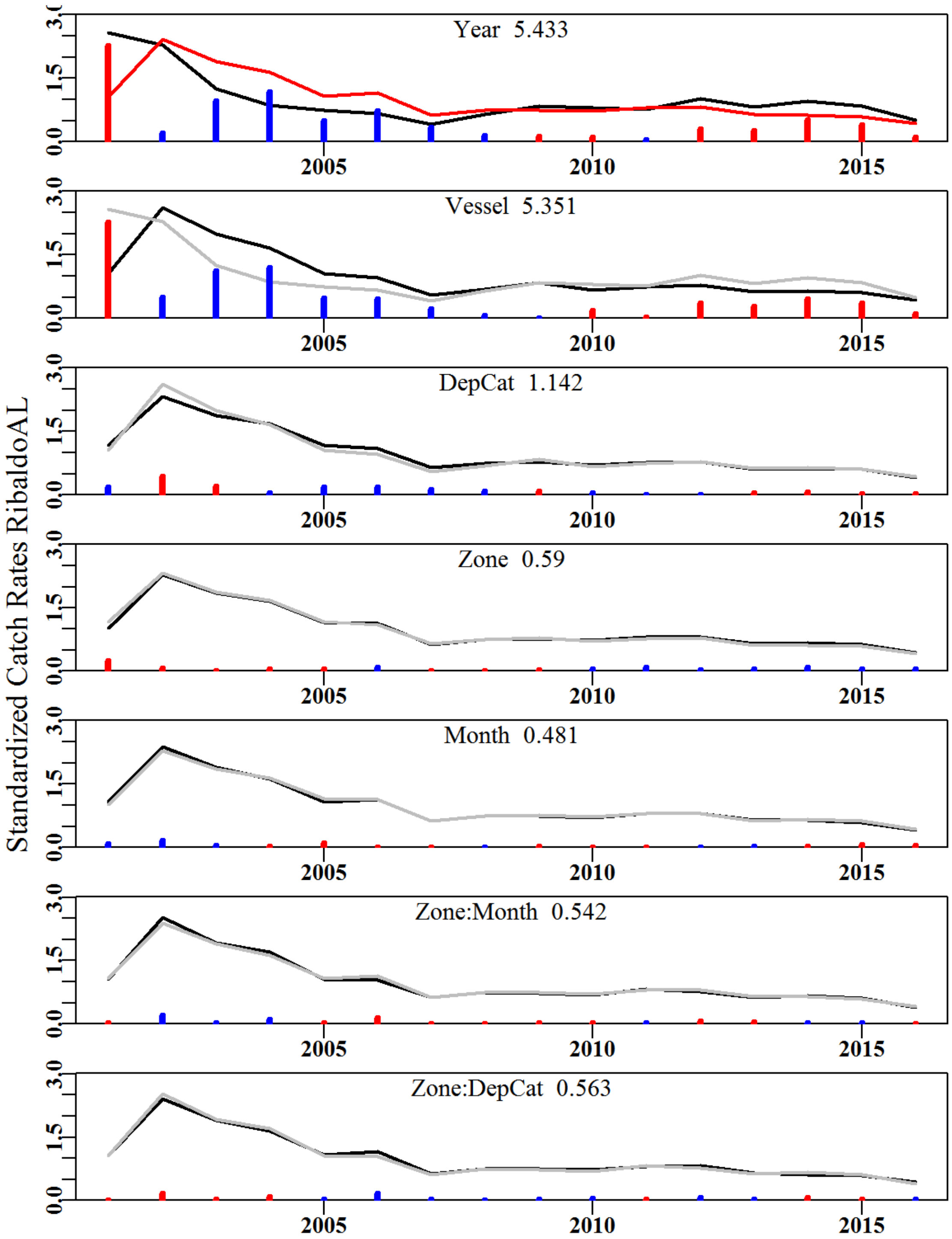


Figure 7.269. RibaldoAL. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

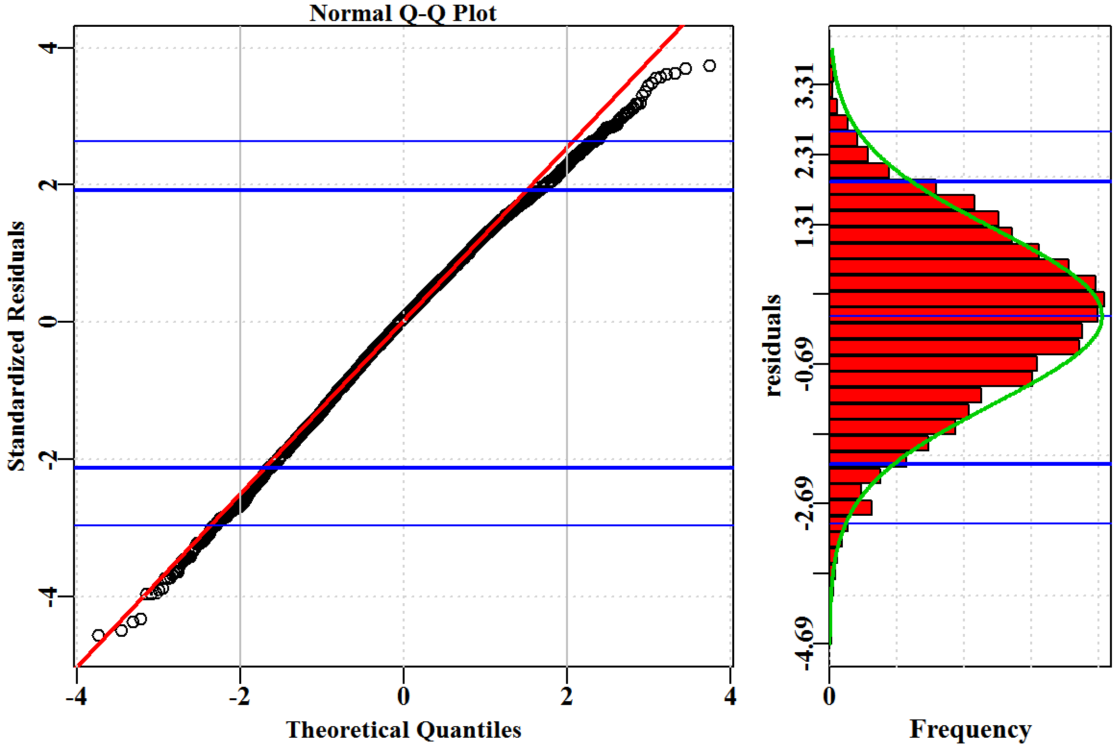


Figure 7.270. RibaldoAL. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

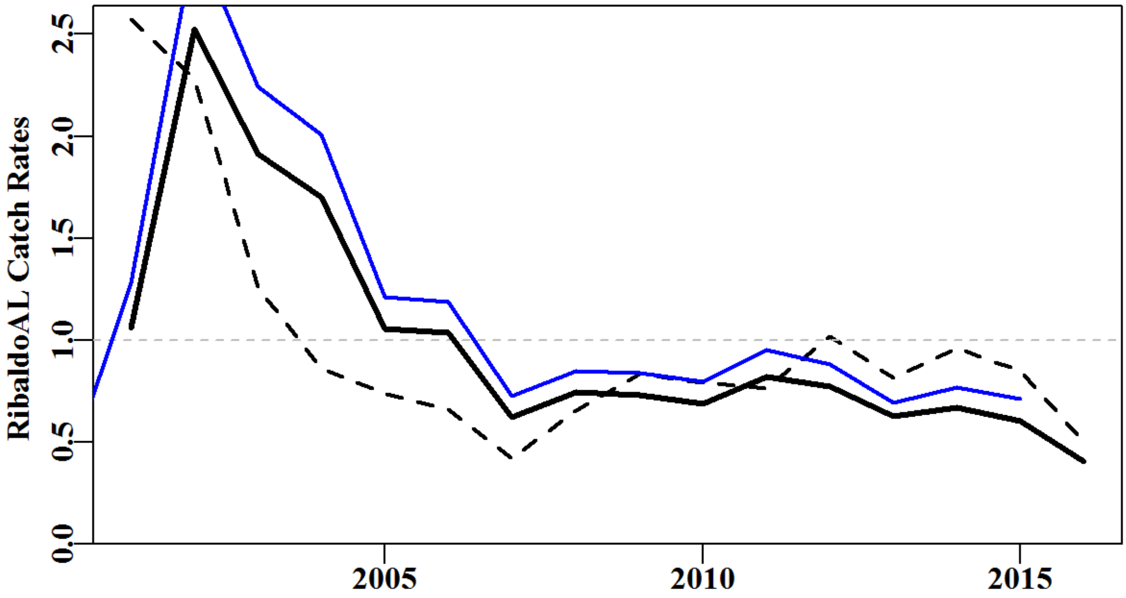


Figure 7.271. RibaldoAL. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

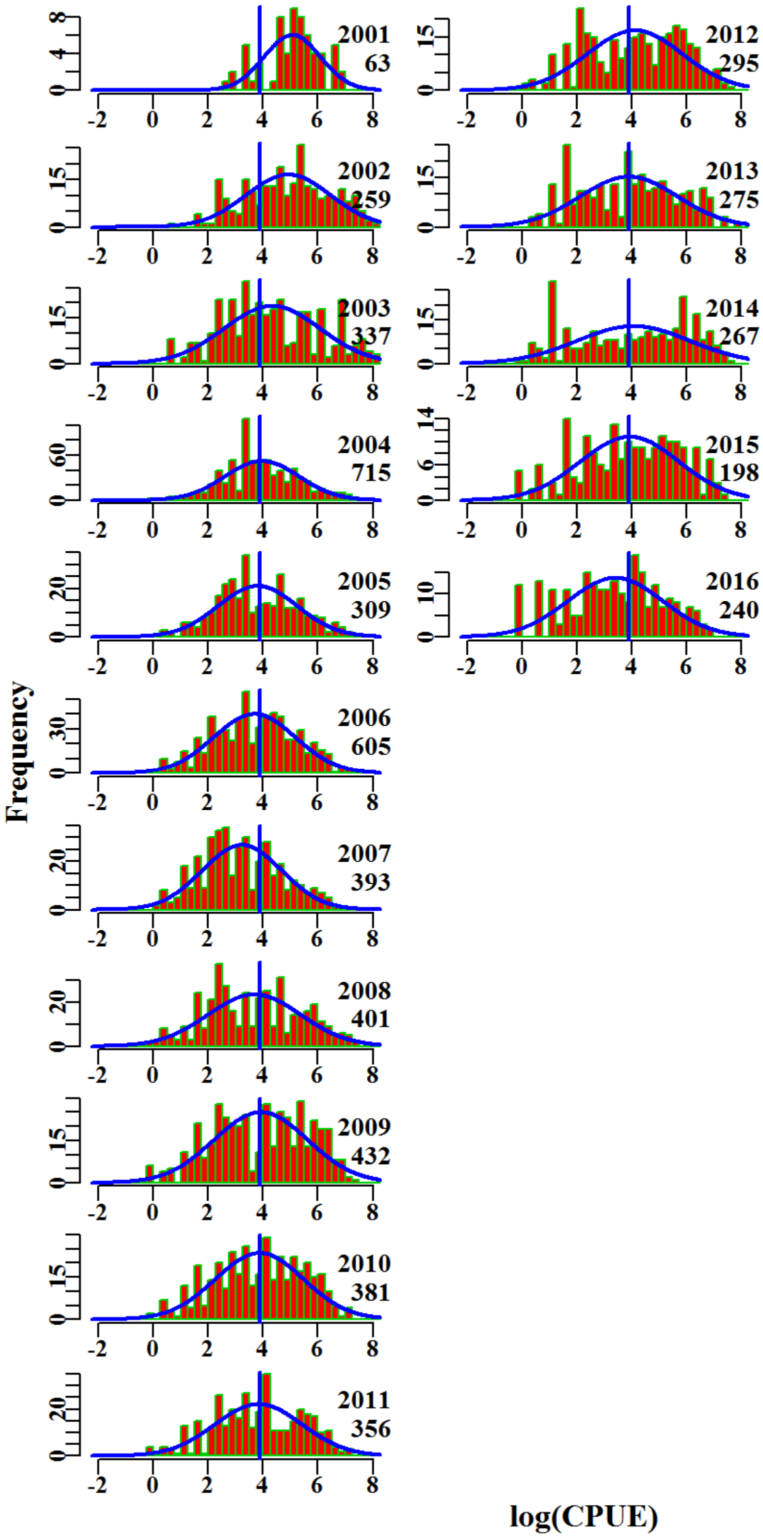


Figure 7.272. RibaldoAL. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

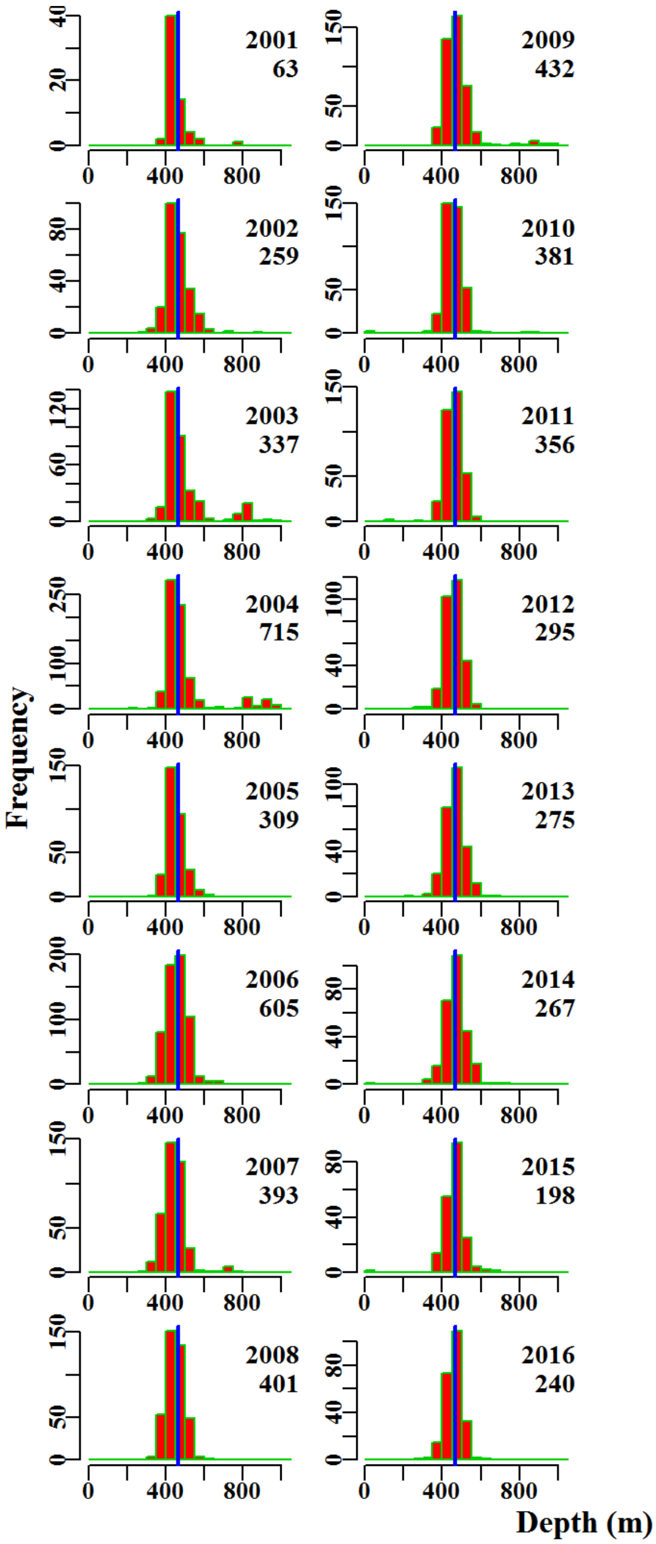


Figure 7.273. RibaldoAL. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.38 Silver Trevally 1020

Initial data selection for Silver Trevally (TRE - 37337062 - *Pseudocaranx dentex*) in the SET was conducted according to the details given in Table 7.176.

A total of 8 statistical models were fitted sequentially to the available data.

7.38.1 *Inferences*

The majority of catch of this species occurred in zone 10, followed by 20.

The terms Year, Vessel and DepCat had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests that the assumed Normal distribution is valid with only a slight departure as depicted at the lower tail of the distribution.

Annual standardized CPUE trend is noisy and relatively flat since about 1992 and has remained below average since 2011 (Figure 7.274). A major change from the nominal geometric mean occurs from 2013 onwards and this is mainly due to changes in the vessels operating, the depths in which they fish, and the reduced amount of fish being caught. The number of vessels actively contributing to this fishery has now reduced to low numbers and this may also be related to the recent major deviation from the nominal catch rate.

7.38.2 *Action Items and Issues*

Further exploration of the reasons behind the recent deviation of the standardized time-series from the nominal geometric mean are required to provide a more detailed explanation for these changed dynamics.

Table 7.172. SilverTrevally1020. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	469.5	1976	306.3	74	49.4	1.0783	0.000	14.045	0.046
1987	198.5	1259	134.9	64	43.5	1.2716	0.057	9.150	0.068
1988	278.5	1582	244.0	56	51.3	1.4561	0.052	12.162	0.050
1989	376.2	2196	332.8	62	60.5	1.8540	0.048	13.717	0.041
1990	450.4	2101	349.0	53	60.4	2.1796	0.050	11.667	0.033
1991	340.7	2225	251.7	50	43.6	1.8920	0.050	14.256	0.057
1992	296.5	1711	255.6	45	41.3	1.1545	0.053	11.867	0.046
1993	377.7	2279	282.0	49	42.4	1.1616	0.050	16.189	0.057
1994	392.8	3299	360.9	48	38.8	0.9864	0.047	24.750	0.069
1995	413.4	3342	379.2	48	44.0	1.1059	0.046	25.146	0.066
1996	340.6	3233	315.3	54	39.4	1.0019	0.047	24.840	0.079
1997	328.8	2868	297.5	56	53.6	0.9853	0.048	20.250	0.068
1998	210.1	2281	177.5	46	38.9	0.7520	0.049	17.808	0.100
1999	166.1	1856	115.1	45	32.3	0.7339	0.052	13.486	0.117
2000	154.8	2009	122.6	49	26.2	0.5709	0.051	14.720	0.120
2001	270.2	3236	227.9	45	36.3	0.6879	0.046	21.733	0.095
2002	232.8	2777	209.1	44	37.8	0.6467	0.048	17.735	0.085
2003	337.9	2761	282.0	49	59.7	0.6910	0.048	16.735	0.059
2004	458.2	3339	367.8	45	64.3	0.8478	0.047	19.451	0.053
2005	291.1	2324	242.1	43	58.8	0.7378	0.050	13.862	0.057
2006	247.3	1687	209.2	39	82.6	0.8024	0.053	9.316	0.045
2007	172.7	836	115.6	22	88.7	0.7804	0.064	4.422	0.038
2008	128.4	1065	95.9	23	48.8	0.8978	0.060	6.909	0.072
2009	164.1	1152	136.0	23	57.4	0.9029	0.059	6.765	0.050
2010	240.2	1264	192.0	24	97.7	1.1495	0.058	6.444	0.034
2011	193.5	1125	179.5	20	112.9	0.9841	0.059	5.679	0.032
2012	139.7	966	131.6	21	99.2	0.7756	0.062	5.132	0.039
2013	122.8	723	112.9	20	97.7	0.8267	0.067	3.935	0.035
2014	106.9	891	98.7	20	63.1	0.6307	0.063	5.207	0.053
2015	79.5	574	73.4	22	69.9	0.6597	0.073	2.925	0.040
2016	52.3	338	39.6	18	114.7	0.7950	0.089	1.643	0.042

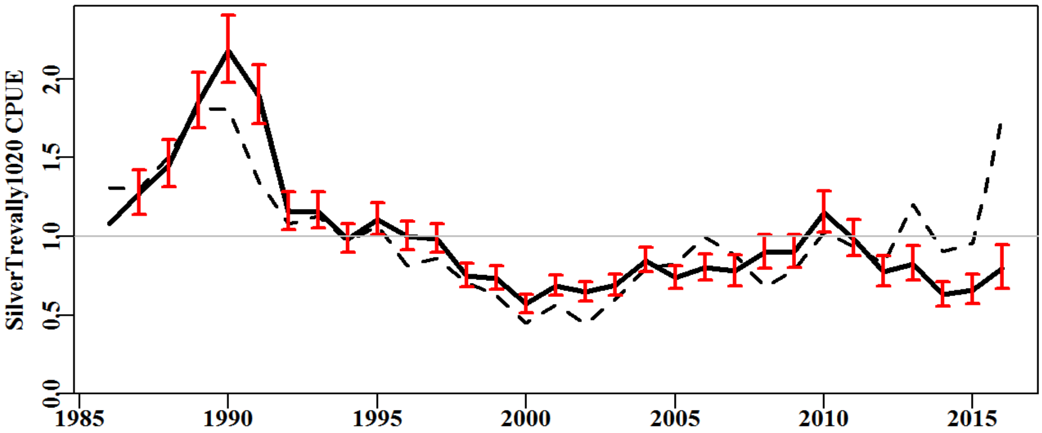


Figure 7.274. SilverTrevally1020 standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

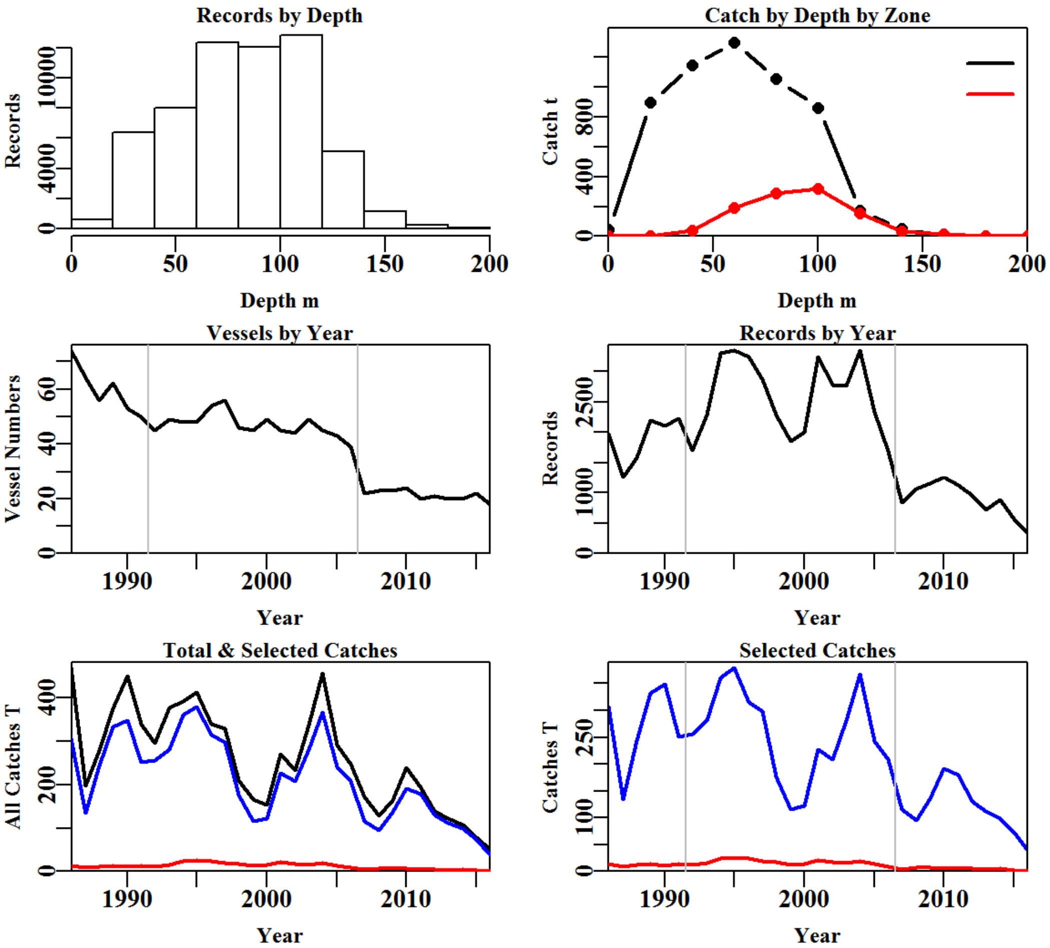


Figure 7.275. SilverTrevally1020 fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.173. SilverTrevally1020 data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	75222	71633	70601	69745	60670	59331	59275
Difference	0	3589	1032	856	9075	1339	56

Table 7.174. The models used to analyse data for SilverTrevally1020.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + Month
Model5	Year + Vessel + DepCat + Month + DayNight
Model6	Year + Vessel + DepCat + Month + DayNight + Zone
Model7	Year + Vessel + DepCat + Month + DayNight + Zone + Zone:Month
Model8	Year + Vessel + DepCat + Month + DayNight + Zone + Zone:DepCat

Table 7.175. SilverTrevally1020. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	62315	169429	7919	59275	31	4.4	0.00
Vessel	48365	133192	44155	59275	188	24.7	20.24
DepCat	44761	125052	52296	58819	198	28.6	3.91
Month	44051	123505	53843	58819	209	29.4	0.87
DayNight	43226	121773	55574	58819	212	30.4	0.99
Zone	43197	121708	55639	58819	213	30.5	0.04
Zone:Month	43055	121369	55979	58819	224	30.6	0.18
Zone:DepCat	43169	121613	55735	58819	222	30.5	0.04

Table 7.176. SilverTrevally1020. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	SilverTrevally1020
csirocode	37337062
fishery	SET
depthrange	0 - 200
depthclass	20
zones	10, 20
methods	TW, TDO, OTT, PTB, TMO
years	1986 - 2016

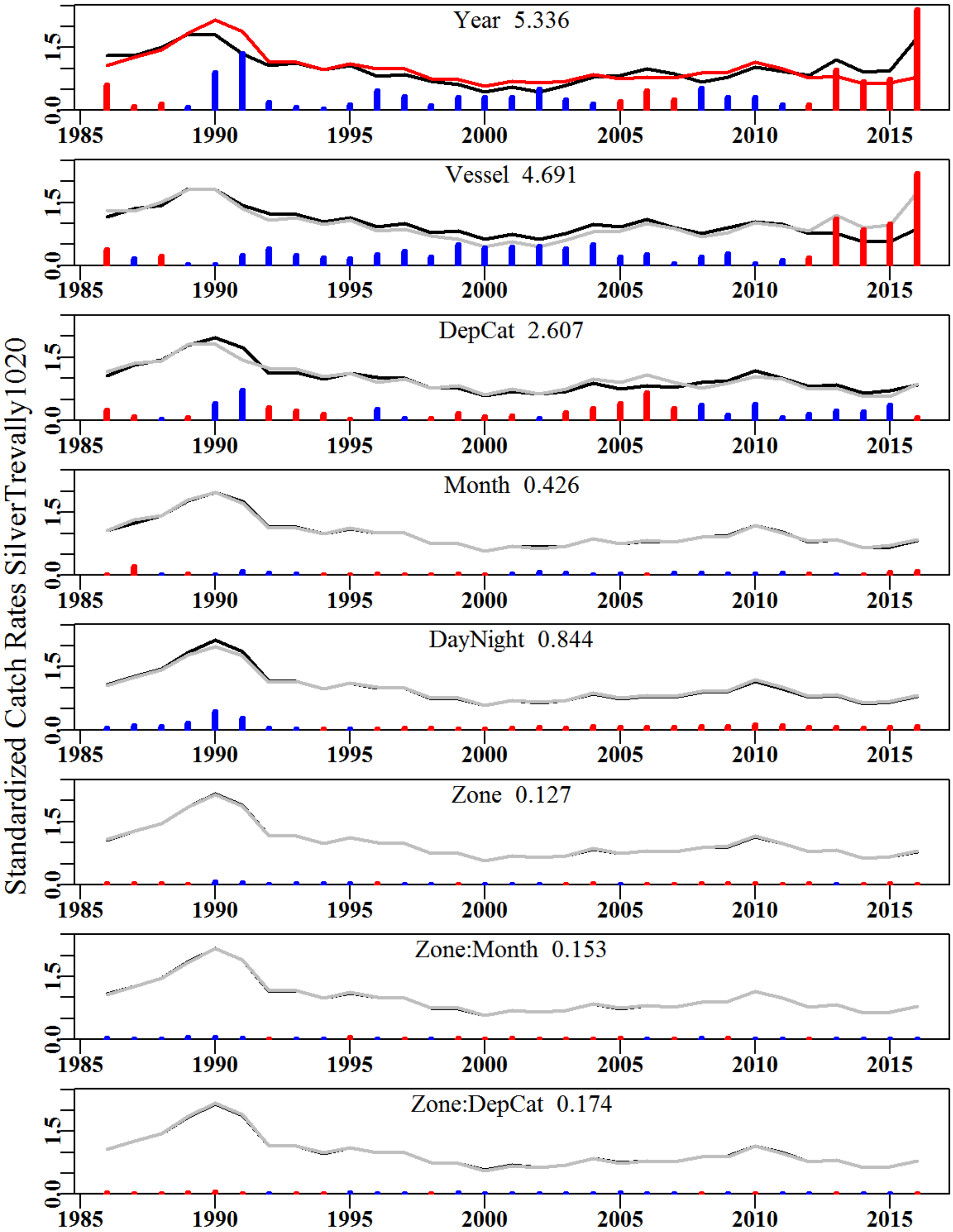


Figure 7.276. SilverTrevally1020. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

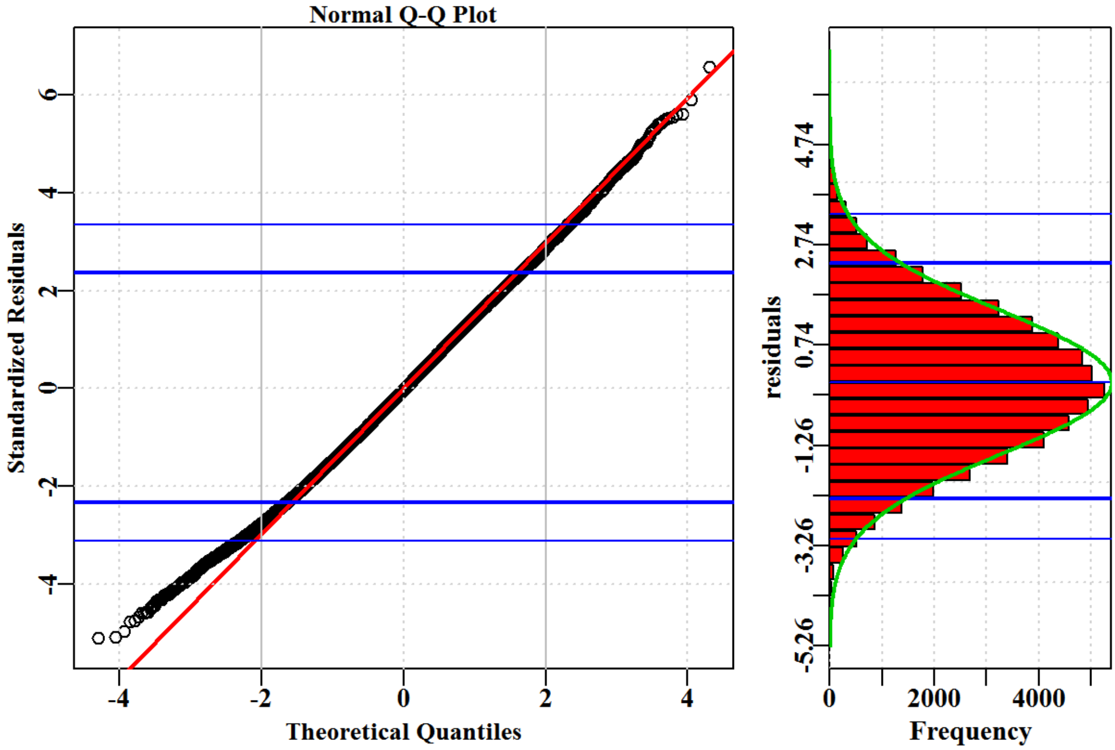


Figure 7.277. SilverTrevally1020. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

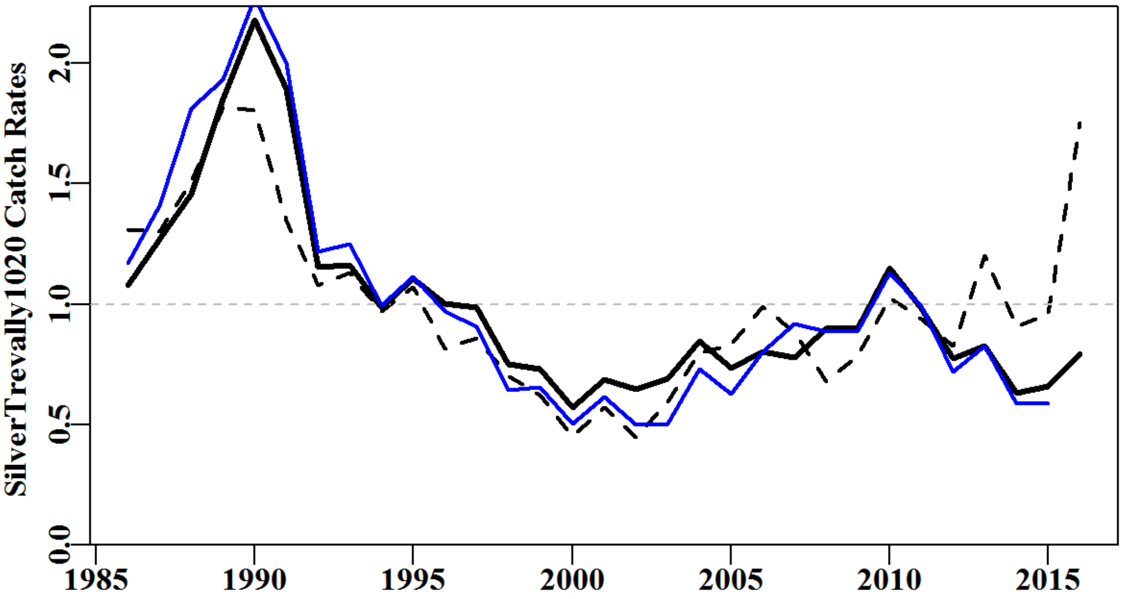


Figure 7.278. SilverTrevally1020. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

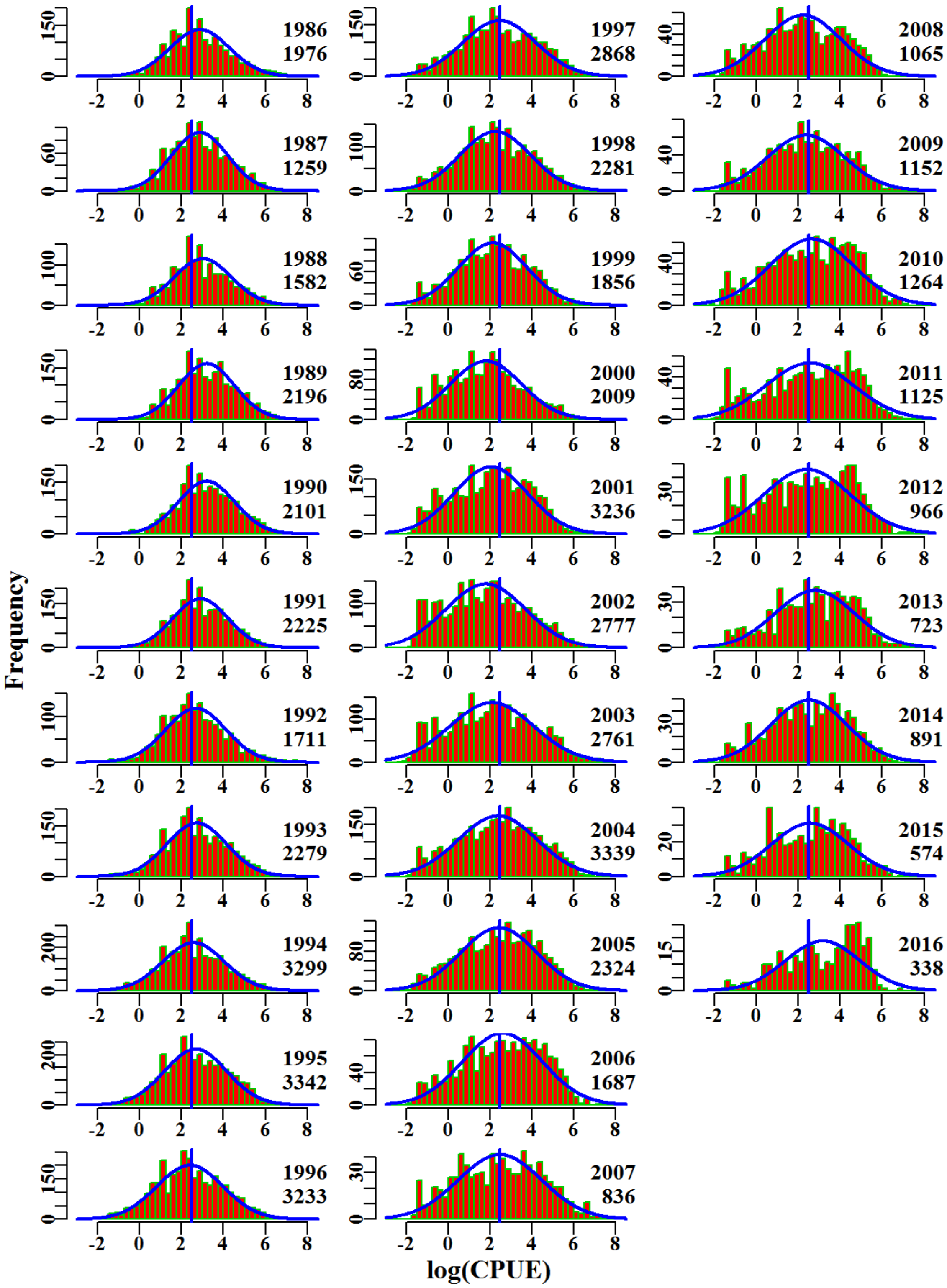


Figure 7.279. SilverTrevally1020. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

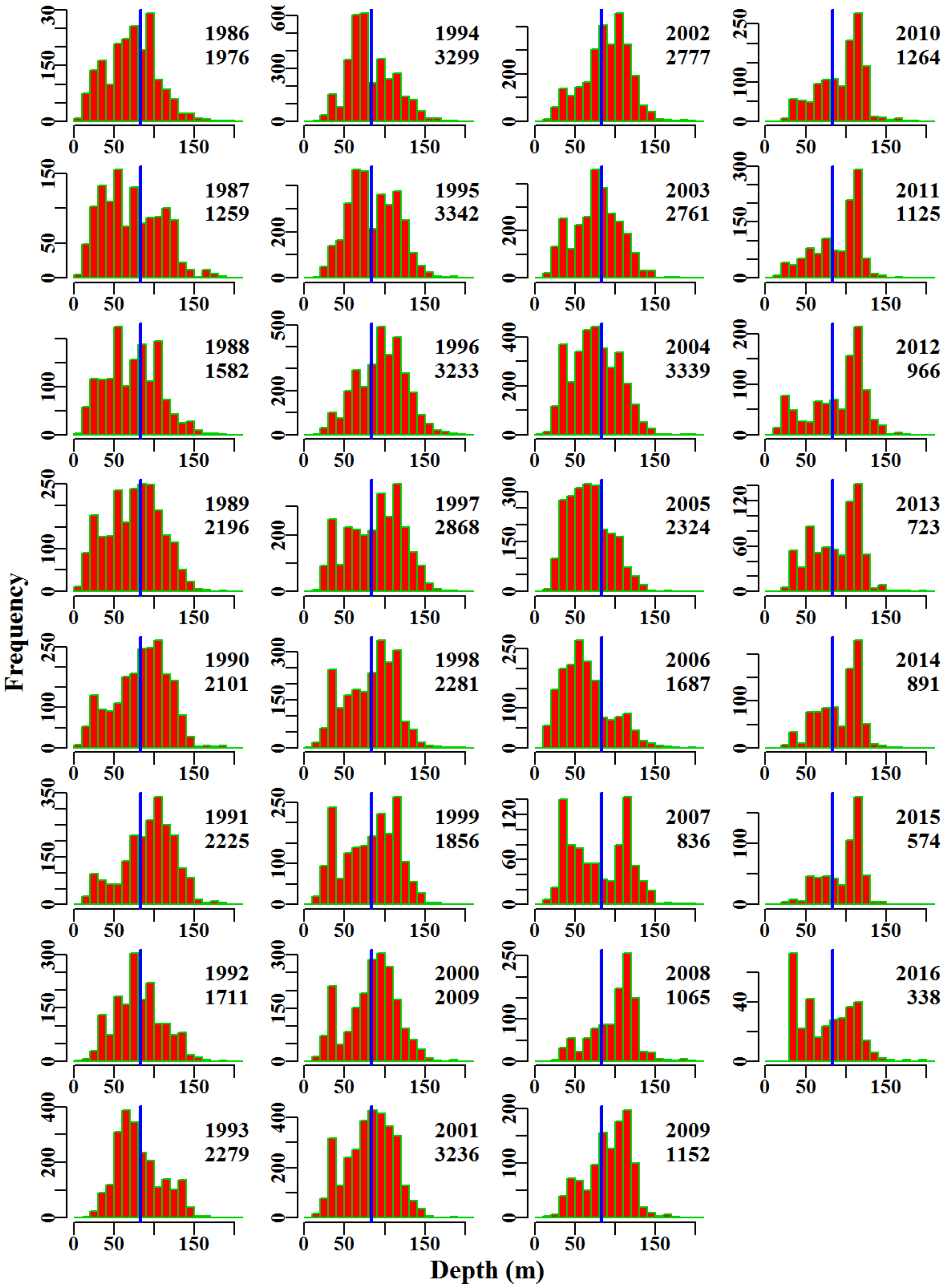


Figure 7.280. SilverTrevally1020. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

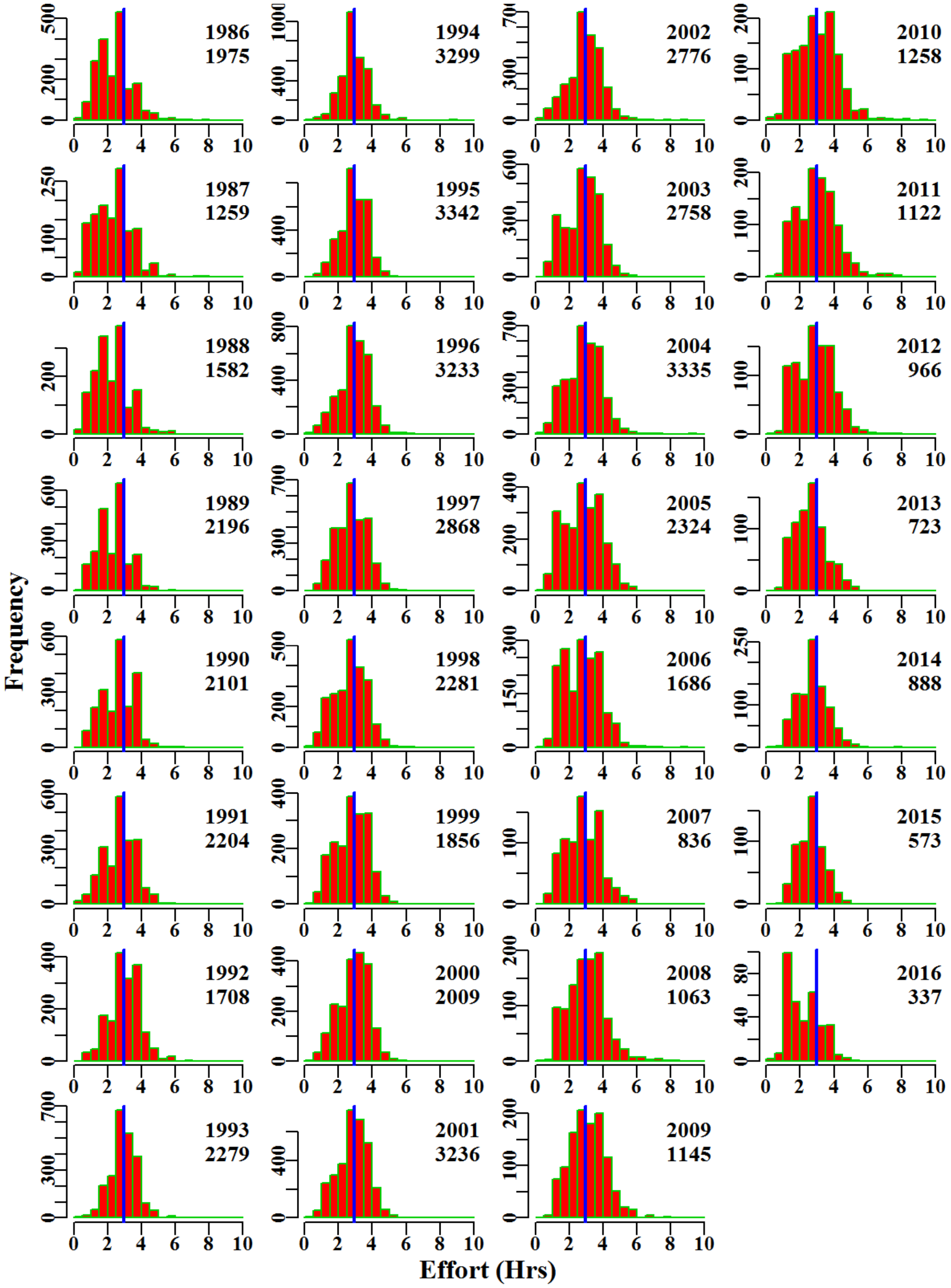


Figure 7.281. SilverTrevally1020. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.39 Silver Trevally 1020 - No MPA

Initial data selection for Silver Trevally (TRE - 37337062 - *Pseudocaranx dentex*) in the SET was conducted according to the details given in Table 7.181 and then records reported as State waters, which includes the Bateman's Bay MPA were excluded.

A total of 8 statistical models were fitted sequentially to the available data.

7.39.1 *Inferences*

The majority of catch of this species occurred in zone 10, followed by 20.

The terms Year, Vessel, DepCat and Month had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests that the assumed Normal distribution is valid with a slight departure as depicted at the lower tail of the distribution (Figure 7.285).

Annual standardized CPUE trend is noisy and relatively flat since about 2012 and below average (Figure 7.282). A deviation similar to that in the 'include MPA' scenario is apparent where the standardized trend deviates markedly from the nominal geometric mean trend from 2013 - 2016 and for the same reasons of changes in vessels fishing, low numbers of significantly contributing vessels, changes in the depth distribution of fishing and lower catches and numbers of records.

7.39.2 *Action Items and Issues*

Further exploration of the reasons behind the recent deviation of the standardized time-series from the nominal geometric mean are required to provide a more detailed explanation for these changed dynamics.

Table 7.177. SilverTrevally1020nompa. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	469.5	1708	270.5	73	48.3	1.2323	0.000	12.471	0.046
1987	198.5	1028	113.0	61	45.2	1.4631	0.062	7.327	0.065
1988	278.5	1220	220.8	51	59.4	1.9122	0.057	9.409	0.043
1989	376.2	1761	271.2	61	56.3	2.0484	0.052	11.919	0.044
1990	450.4	1753	273.6	51	55.1	2.3734	0.053	10.176	0.037
1991	340.7	1868	204.0	49	42.2	2.1099	0.054	12.052	0.059
1992	296.5	1272	166.6	45	35.6	1.3488	0.059	9.362	0.056
1993	377.7	1235	130.7	47	34.0	1.3781	0.059	9.851	0.075
1994	392.8	1810	137.5	46	24.9	1.0398	0.055	15.062	0.110
1995	413.4	1497	129.4	43	27.8	1.1425	0.057	13.437	0.104
1996	340.6	1804	122.8	47	21.8	0.9235	0.056	15.794	0.129
1997	328.8	1389	82.2	48	18.8	0.8721	0.059	12.249	0.149
1998	210.1	962	45.9	40	16.7	0.6358	0.063	8.560	0.186
1999	166.1	818	39.3	39	16.6	0.6545	0.067	6.598	0.168
2000	154.8	1000	42.9	41	12.5	0.4767	0.063	7.714	0.180
2001	270.2	1541	82.5	42	18.1	0.5537	0.056	10.486	0.127
2002	232.8	1479	68.4	40	14.5	0.4462	0.058	9.519	0.139
2003	337.9	1123	57.7	45	19.3	0.4417	0.061	6.854	0.119
2004	458.2	1345	84.5	42	23.8	0.6144	0.059	8.687	0.103
2005	291.1	673	59.6	40	32.1	0.5430	0.070	3.983	0.067
2006	247.3	493	48.8	32	44.7	0.7567	0.078	3.207	0.066
2007	172.7	463	47.1	20	48.3	0.8291	0.081	2.553	0.054
2008	128.4	818	69.7	23	43.1	0.8473	0.067	5.653	0.081
2009	164.1	836	94.2	23	54.4	0.8733	0.066	5.072	0.054
2010	240.2	967	135.6	24	81.0	1.1019	0.064	5.145	0.038
2011	193.5	863	140.6	20	112.2	0.9912	0.066	4.359	0.031
2012	139.7	665	88.1	21	66.8	0.7017	0.071	3.929	0.045
2013	122.8	508	72.2	20	72.7	0.8302	0.077	2.882	0.040
2014	106.9	603	58.2	20	47.9	0.5911	0.073	3.674	0.063
2015	79.5	438	52.8	21	65.8	0.6593	0.082	2.269	0.043
2016	52.3	188	17.4	17	63.3	0.6081	0.114	1.205	0.069

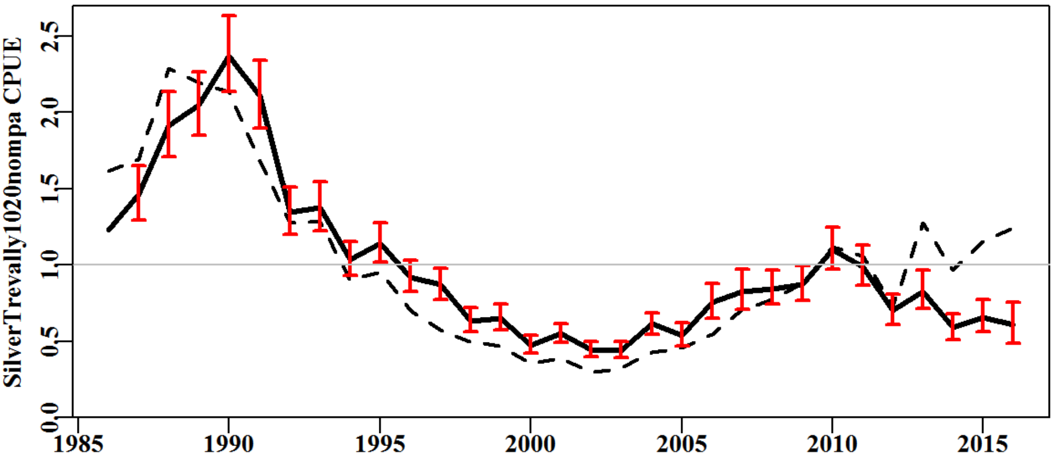


Figure 7.282. SilverTrevally1020nompa standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

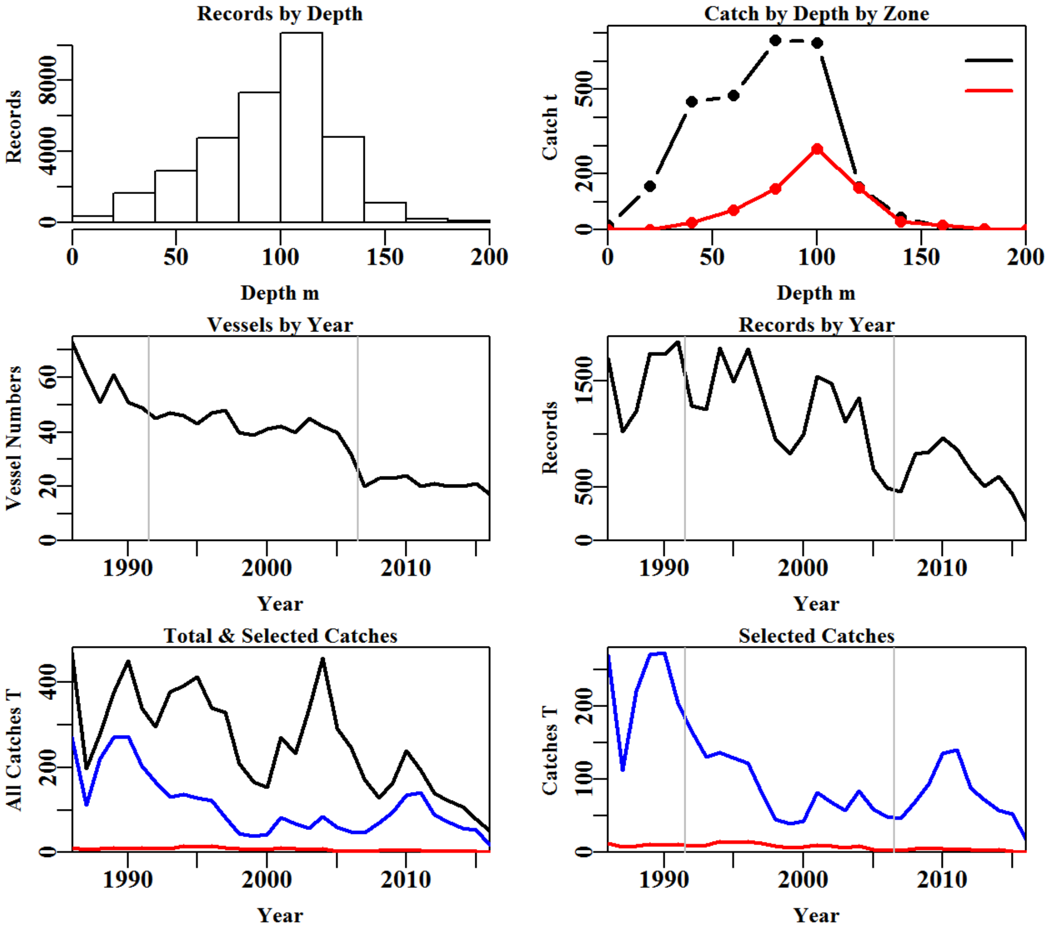


Figure 7.283. SilverTrevally1020nompa fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.178. SilverTrevally1020nompa data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery	NoMPA
Records	75222	71633	70601	69745	60670	59331	59275	34128
Difference	0	3589	1032	856	9075	1339	56	25147

Table 7.179. The models used to analyse data for SilverTrevally1020nompa.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + Month
Model5	Year + Vessel + DepCat + Month + DayNight
Model6	Year + Vessel + DepCat + Month + DayNight + Zone
Model7	Year + Vessel + DepCat + Month + DayNight + Zone + Zone:Month
Model8	Year + Vessel + DepCat + Month + DayNight + Zone + Zone:DepCat

Table 7.180. SilverTrevally1020nompa. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	32388	87999	13226	34128	31	13.0	0.00
Vessel	25247	70743	30483	34128	185	29.7	16.74
DepCat	24251	68519	32706	33881	195	31.2	1.50
Month	23548	67069	34157	33881	206	32.7	1.43
DayNight	23060	66097	35128	33881	209	33.6	0.97
Zone	22993	65964	35262	33881	210	33.8	0.13
Zone:Month	22900	65740	35485	33881	221	34.0	0.20
Zone:DepCat	22979	65900	35325	33881	219	33.8	0.05

Table 7.181. SilverTrevally1020nompa. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	SilverTrevally1020nompa
csirocode	37337062
fishery	SET
depthrange	0 - 200
depthclass	20
zones	10, 20
methods	TW, TDO, OTT, PTB, TMO
years	1986 - 2016

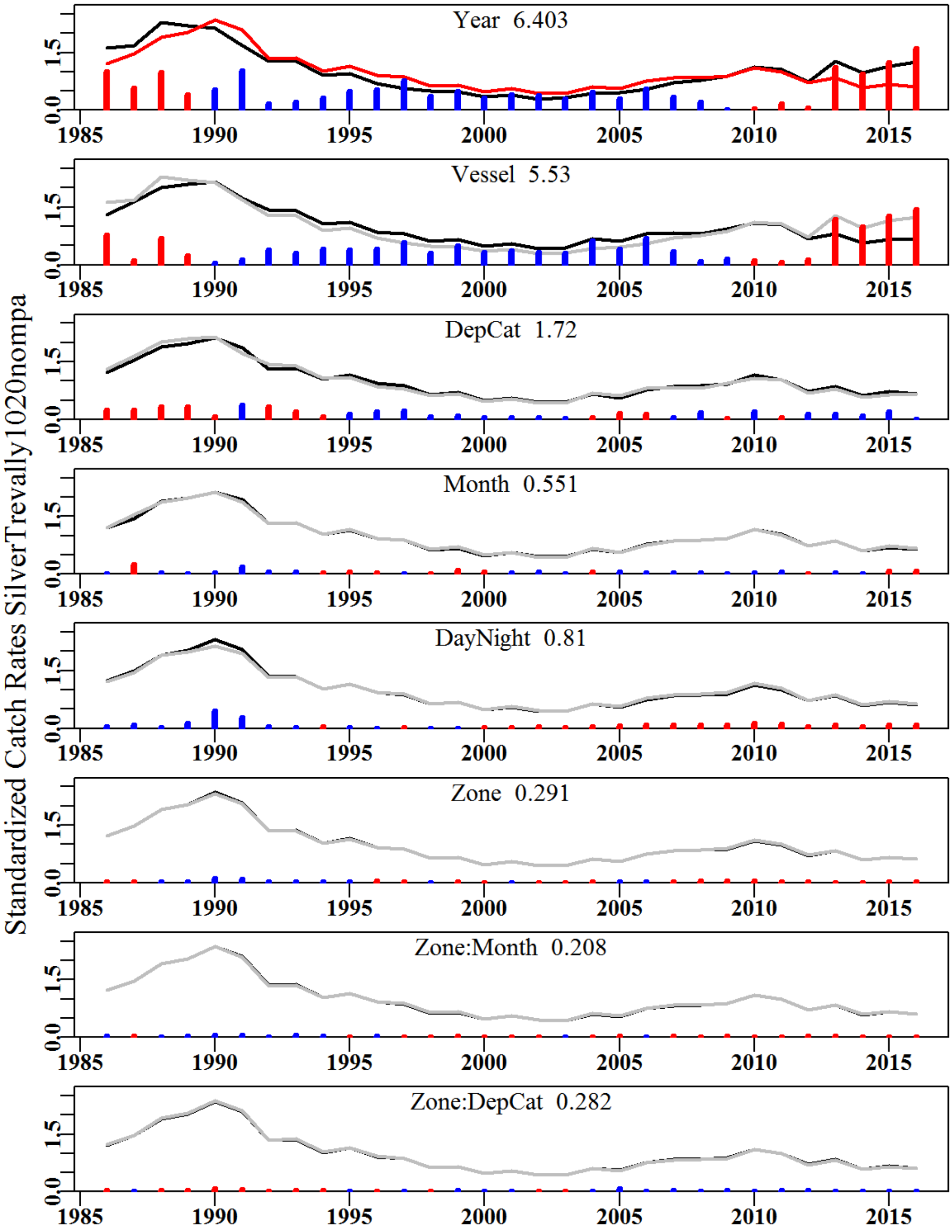


Figure 7.284. SilverTrevally1020nompa. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

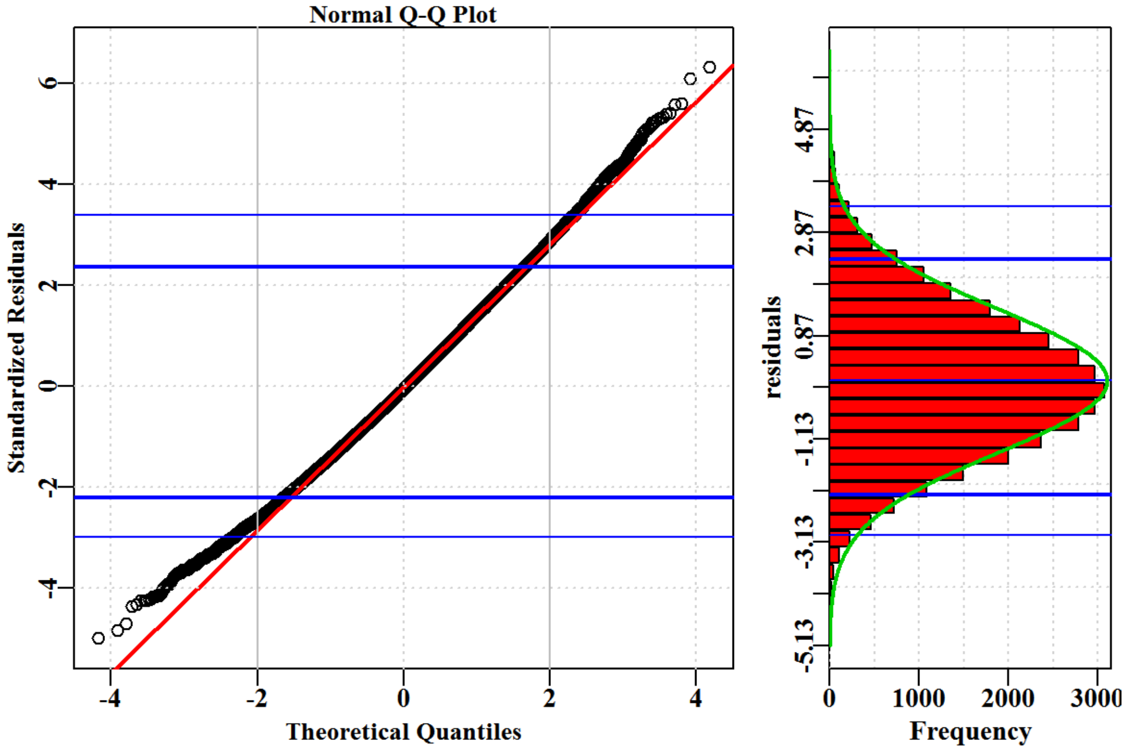


Figure 7.285. SilverTrevally1020nompa. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

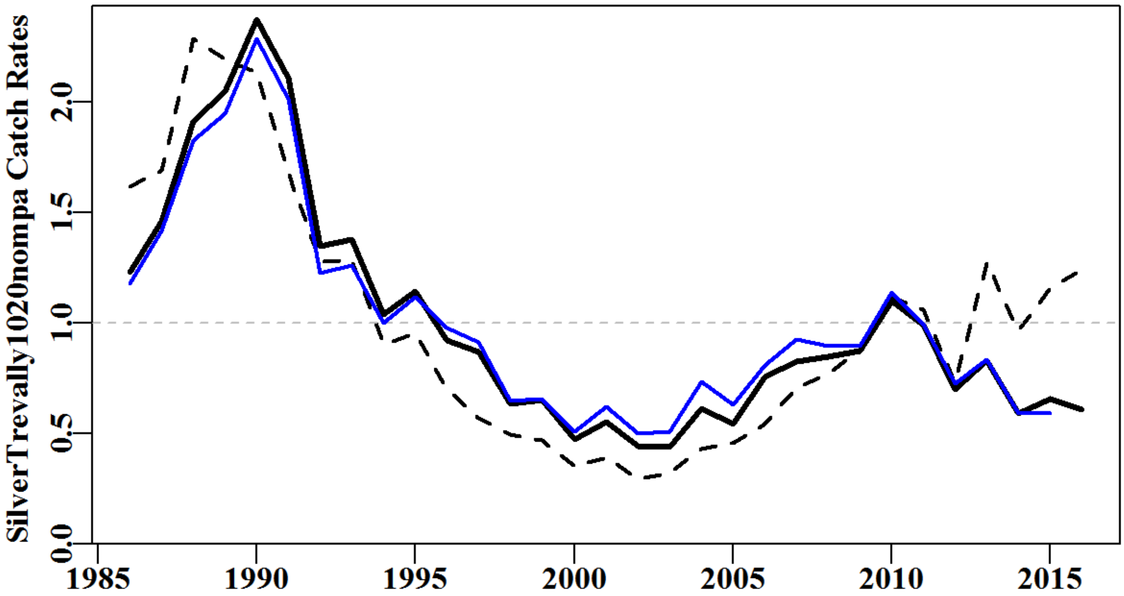


Figure 7.286. SilverTrevally1020nompa. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

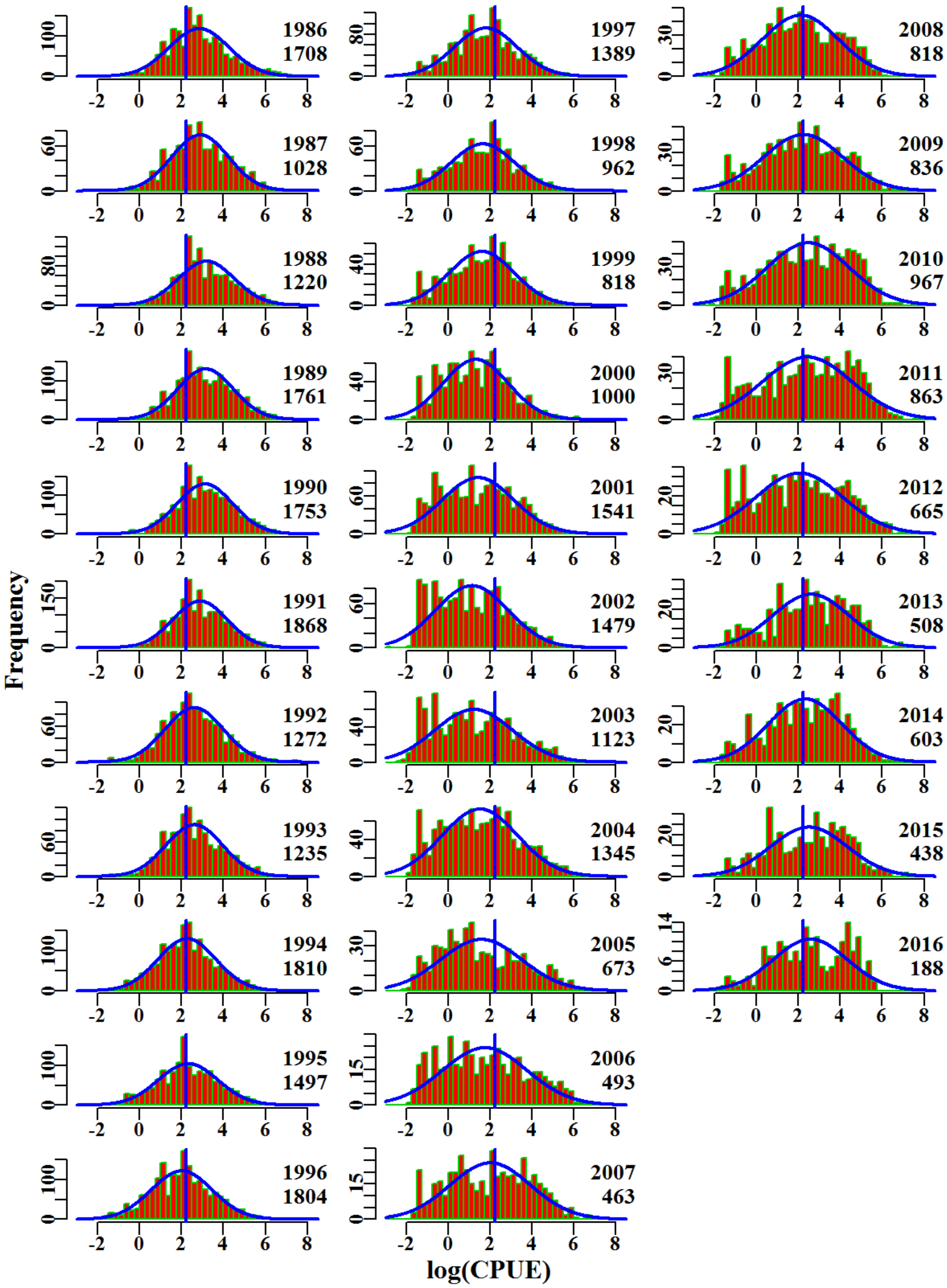


Figure 7.287. SilverTrevally1020nompa. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

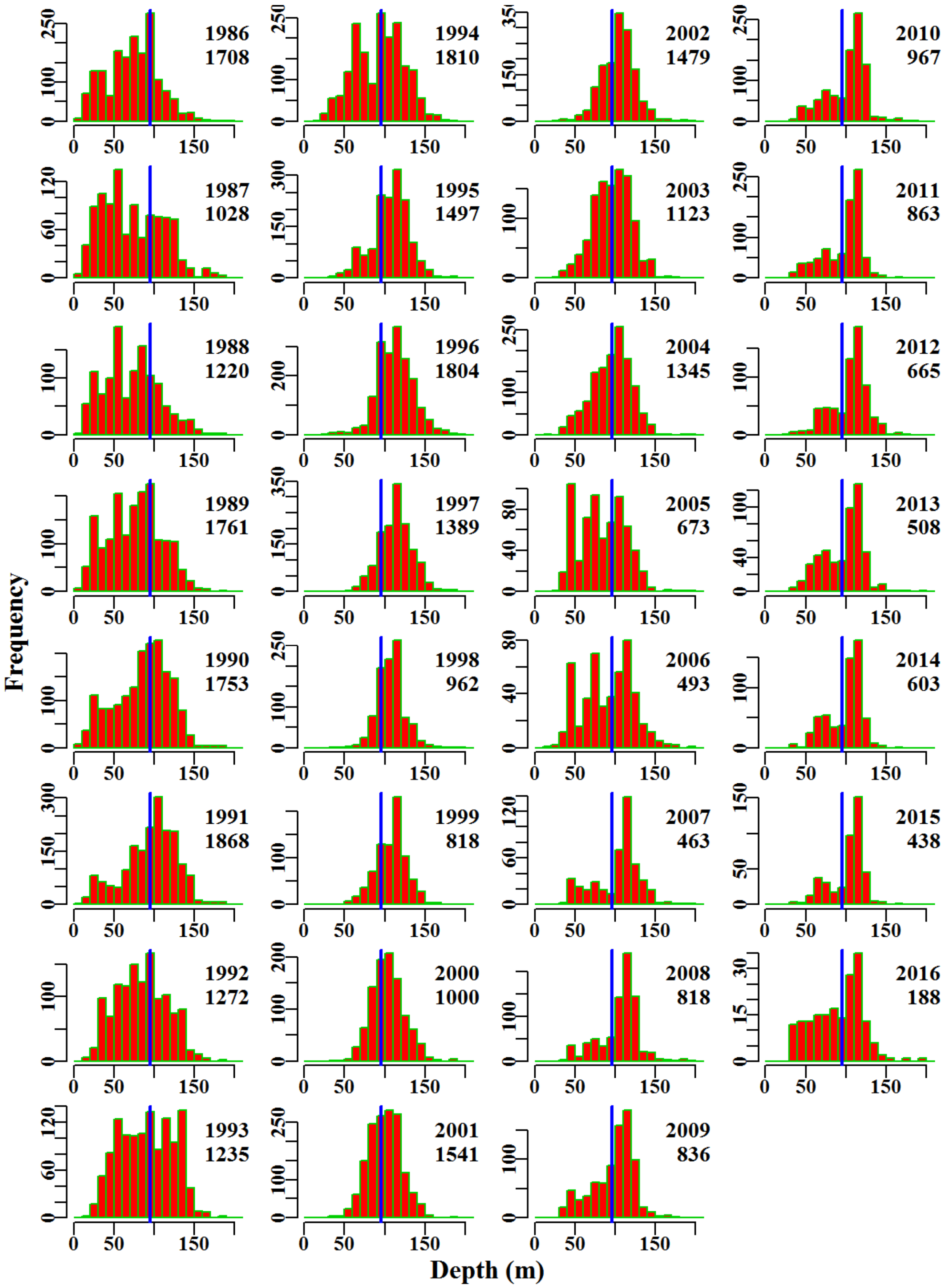


Figure 7.288. SilverTrevally1020nompa. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

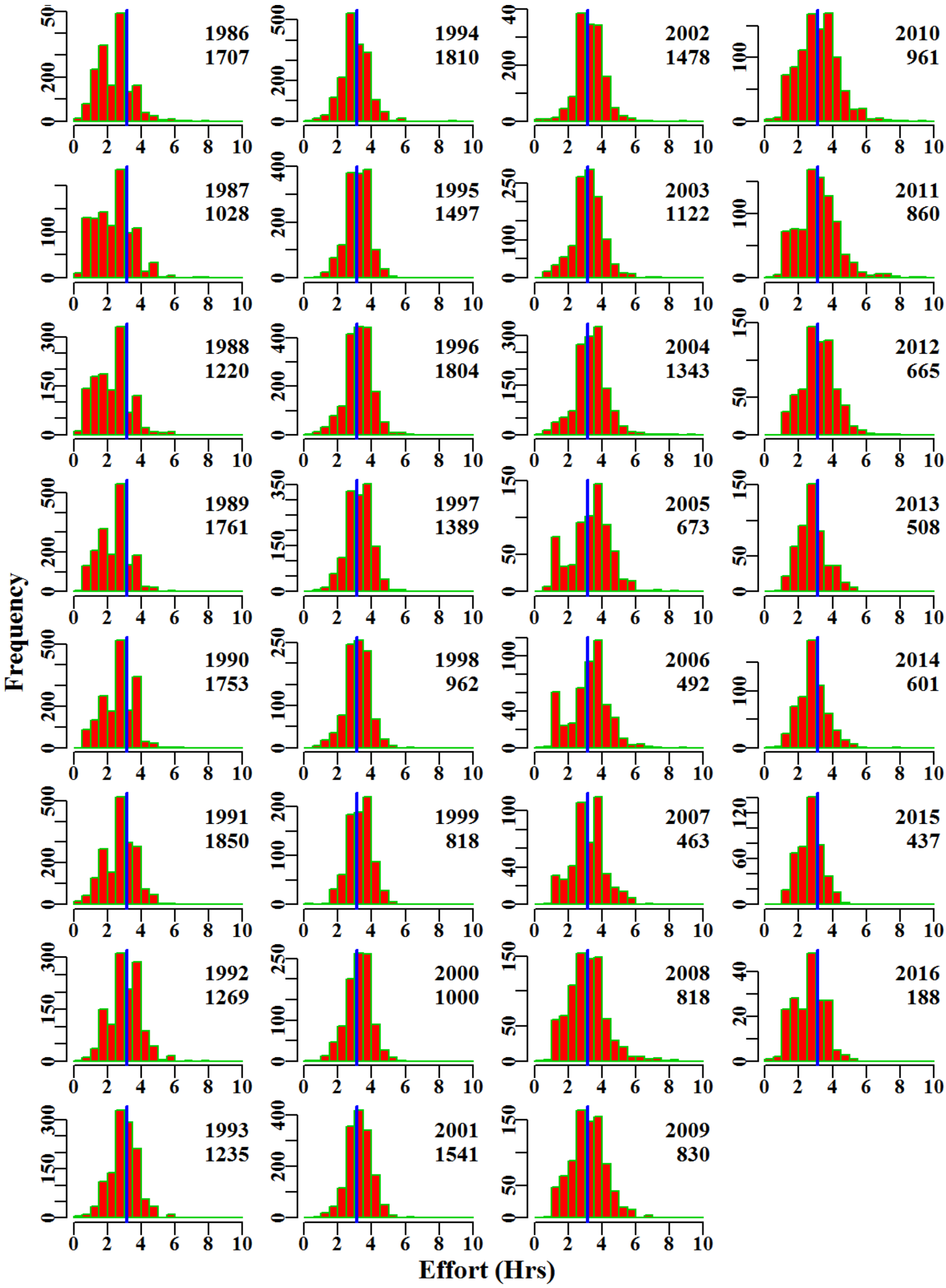


Figure 7.289. SilverTrevally1020nompa. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.40 Royal Red Prawn 10

Initial data selection for Royal Red Prawn (PRR - 28714005 - *Haliporoides sibogae*) in the SET was conducted according to the details given in Table 7.186.

A total of 8 statistical models were fitted sequentially to the available data.

7.40.1 *Inferences*

The terms Year, DepCat, Vessel, Month and one interaction term (Month:DepCat) had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot indicates that less than 5% of records, those in the lower tail of the distribution, deviate from the assumption of normality.

Annual standardized CPUE trend is noisy and relatively flat across the years analysed (Figure 7.290). From 2013 - 2016 the standardized trend deviates from the nominal geometric mean trend such that the trend stays on the long term average catch rate while the geometric mean appears to rise well above it. There are now very few vessels contributing to this fishery and it appears that they are fishing in more focussed depths. With so few vessels actively involved in the fishery the standardization can be expected to become more uncertain and dependent on their specific fishing activities.

7.40.2 *Action Items and Issues*

No issues identified.

Table 7.182. RoyalRedPrawn. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Month:DepCat.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	277.7	1592	231.8	47	71.7	0.7005	0.000	6.689	0.029
1987	351.3	1764	324.7	47	93.0	0.8842	0.038	4.759	0.015
1988	362.5	1395	344.5	41	124.6	0.9786	0.041	3.627	0.011
1989	329.3	1143	310.8	39	139.3	0.8371	0.043	3.462	0.011
1990	337.1	727	311.1	25	174.5	1.5811	0.049	0.615	0.002
1991	334.1	734	299.4	29	182.9	1.3874	0.050	1.447	0.005
1992	166.9	434	146.1	19	166.3	1.0286	0.058	0.753	0.005
1993	298.8	673	232.8	21	172.4	1.2245	0.050	1.377	0.006
1994	359.8	661	240.4	26	170.3	1.1569	0.050	1.308	0.005
1995	335.6	1070	252.9	25	105.0	0.9135	0.044	1.862	0.007
1996	360.8	1216	272.7	25	95.4	0.8085	0.042	1.653	0.006
1997	252.7	855	166.7	21	86.8	0.7581	0.047	1.309	0.008
1998	233.3	1234	190.7	23	67.9	0.7948	0.043	2.574	0.013
1999	367.0	1607	348.8	25	84.2	0.8095	0.041	2.599	0.007
2000	434.9	1540	398.7	27	127.1	1.0153	0.041	3.634	0.009
2001	276.8	1314	229.5	22	75.8	0.8556	0.043	3.874	0.017
2002	484.2	1740	417.4	23	131.4	1.0290	0.040	4.555	0.011
2003	230.8	801	163.2	26	115.3	1.0560	0.049	3.164	0.019
2004	193.9	579	170.7	22	206.4	1.0740	0.054	2.153	0.013
2005	173.9	601	159.8	21	153.1	0.9798	0.054	2.297	0.014
2006	192.3	455	178.6	17	297.3	1.1720	0.058	1.714	0.010
2007	121.5	324	116.4	9	251.2	0.8106	0.066	1.480	0.013
2008	75.8	252	70.6	8	220.9	0.6961	0.074	1.340	0.019
2009	68.8	250	67.6	9	158.9	0.8865	0.079	0.677	0.010
2010	96.8	343	82.8	9	138.1	0.8687	0.066	1.561	0.019
2011	110.9	291	109.0	8	206.3	1.2696	0.070	0.510	0.005
2012	126.5	363	122.8	9	169.1	0.9778	0.065	1.002	0.008
2013	212.2	428	208.2	9	286.6	1.2516	0.069	0.643	0.003
2014	121.7	351	118.5	11	176.3	1.0019	0.066	0.535	0.005
2015	126.5	345	119.8	8	219.9	1.0107	0.069	0.723	0.006
2016	145.3	327	140.2	9	276.8	1.1814	0.067	0.733	0.005

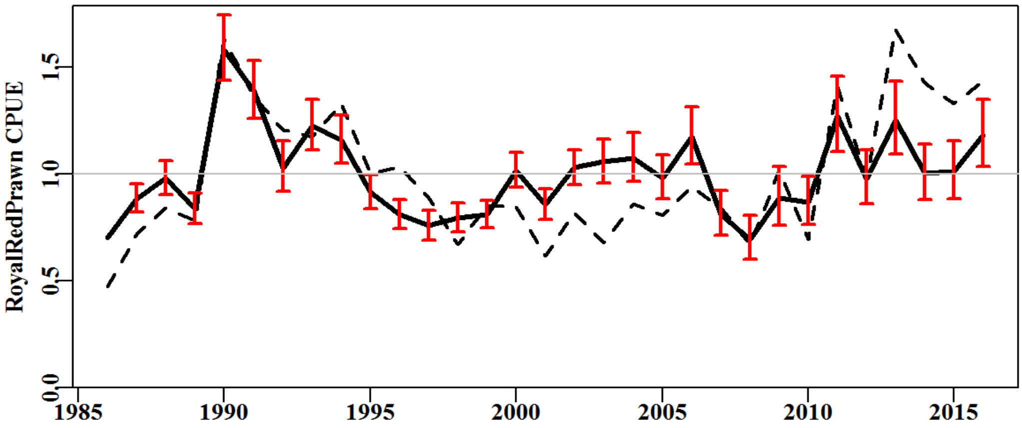


Figure 7.290. RoyalRedPrawn standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

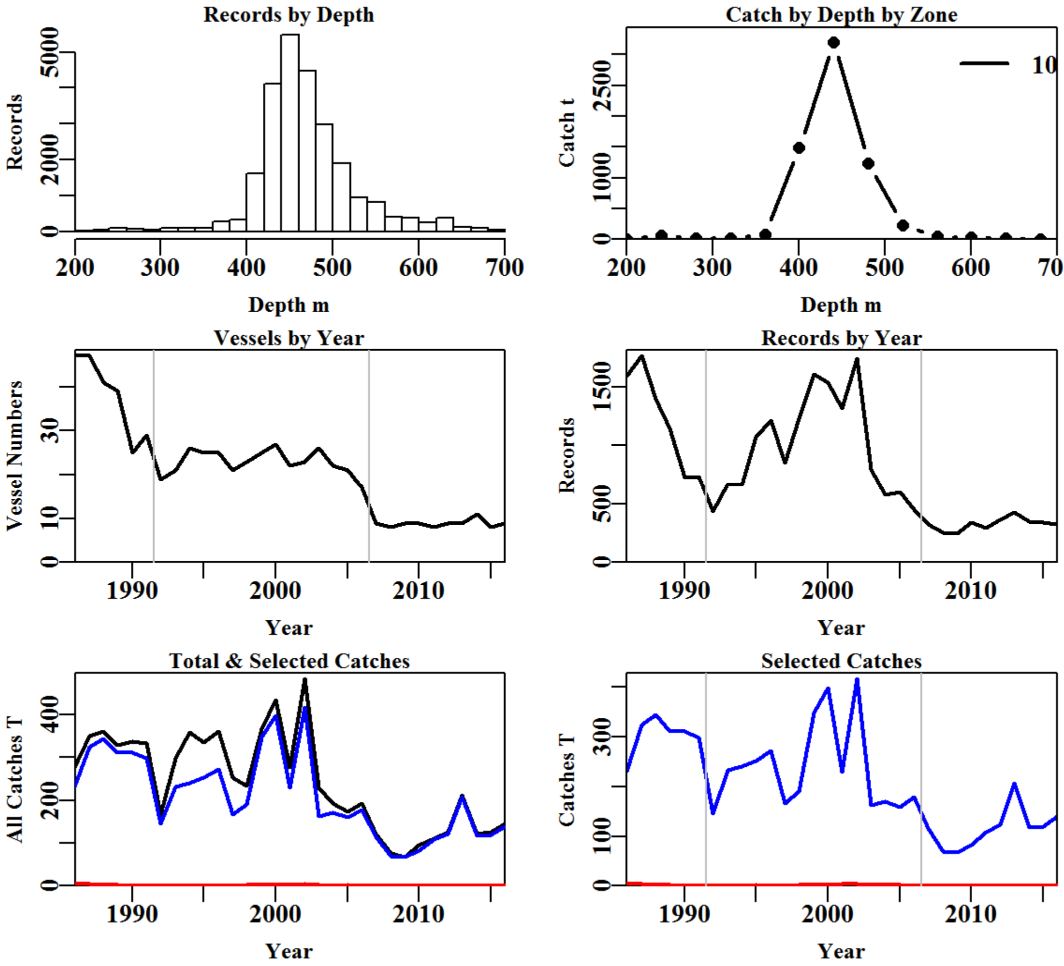


Figure 7.291. RoyalRedPrawn fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.183. RoyalRedPrawn data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	39642	32218	31924	31474	25535	25409	25409
Difference	0	7424	294	450	5939	126	0

Table 7.184. The models used to analyse data for RoyalRedPrawn.

	Model
Model1	Year
Model2	Year + DepCat
Model3	Year + DepCat + Vessel
Model4	Year + DepCat + Vessel + Month
Model5	Year + DepCat + Vessel + Month + DayNight
Model6	Year + DepCat + Vessel + Month + DayNight + DayNight:DepCat
Model7	Year + DepCat + Vessel + Month + DayNight + Month:DepCat
Model8	Year + DepCat + Vessel + Month + DayNight + DayNight:Month

Table 7.185. RoyalRedPrawn. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Month:DepCat

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	14323	44539	2202	25409	31	4.6	0.00
DepCat	9467	36614	10128	25253	43	21.1	16.48
Vessel	3588	28810	17931	25253	130	37.7	16.61
Month	1886	26909	19832	25253	141	41.8	4.09
DayNight	1691	26696	20045	25253	144	42.2	0.45
DayNight:DepCat	1584	26513	20228	25253	177	42.5	0.32
Month:DepCat	1179	25896	20846	25253	272	43.7	1.44
DayNight:Month	1688	26624	20117	25253	176	42.3	0.08

Table 7.186. RoyalRedPrawn. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	RoyalRedPrawn
csirocode	28714005
fishery	SET
depthrange	200 - 700
depthclass	40
zones	10
methods	TW, TDO, OTT, PTB, TMO
years	1986 - 2016

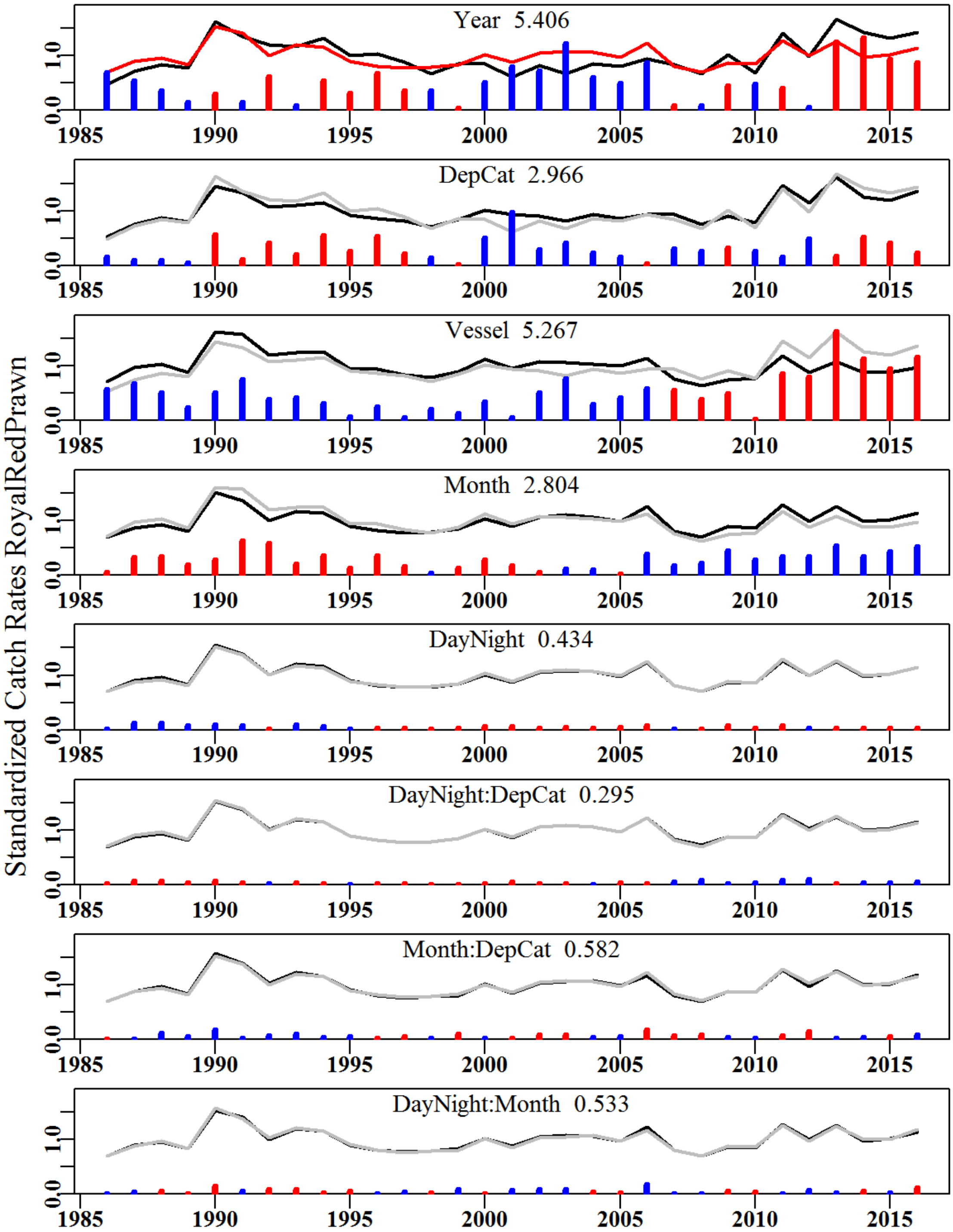


Figure 7.292. RoyalRedPrawn. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

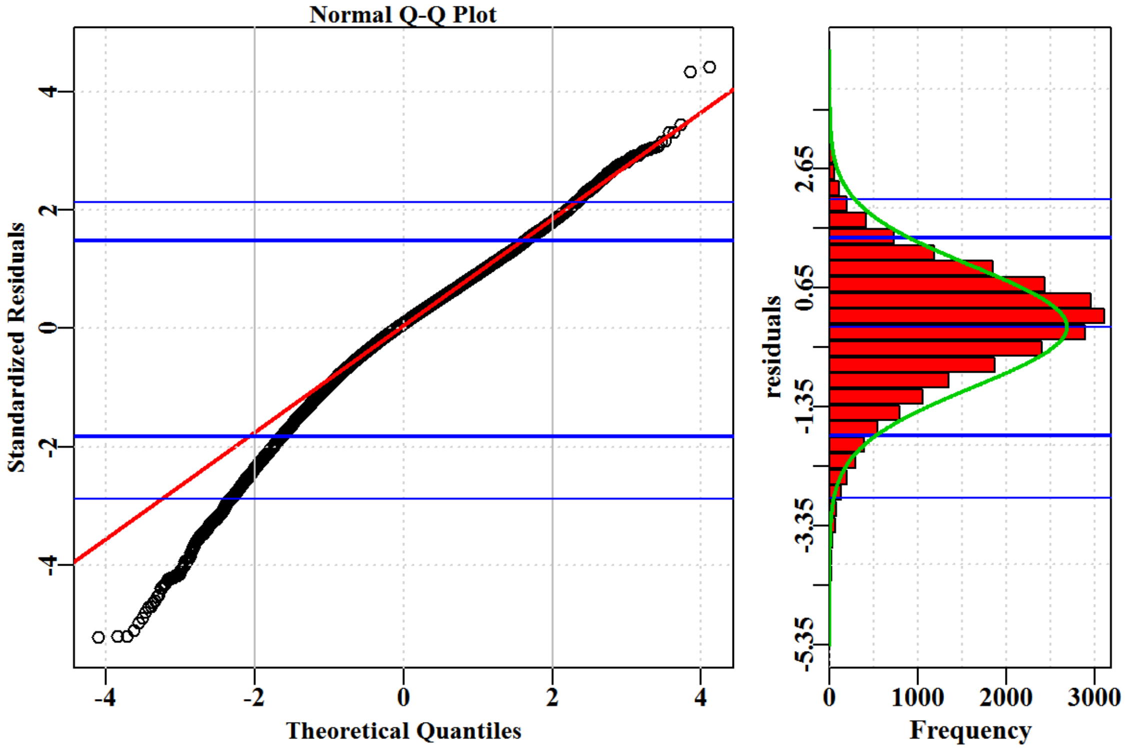


Figure 7.293. RoyalRedPrawn. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

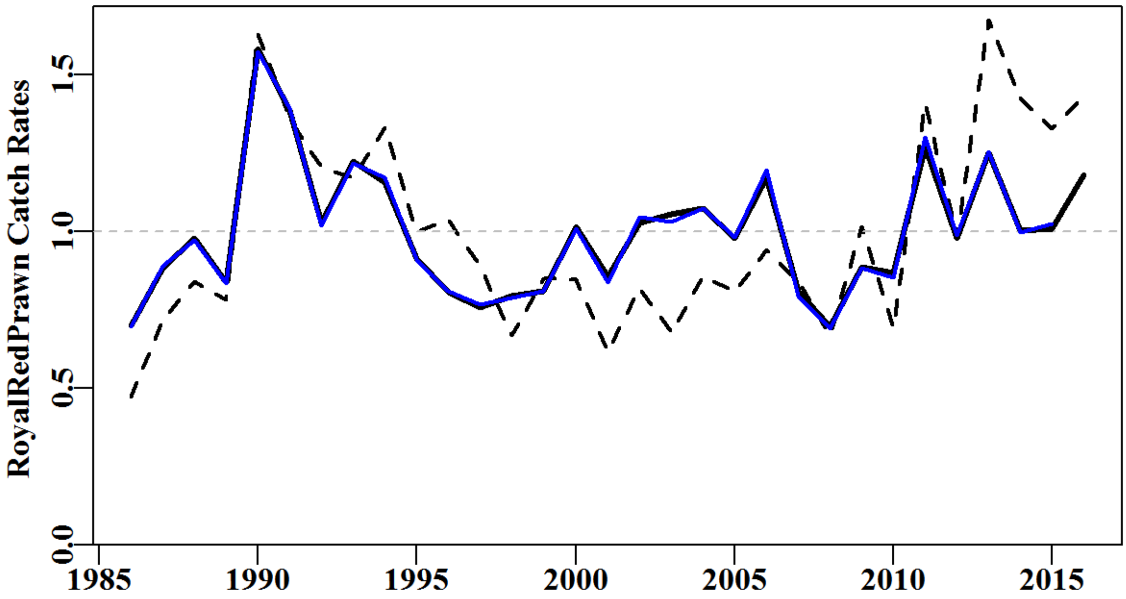


Figure 7.294. RoyalRedPrawn. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

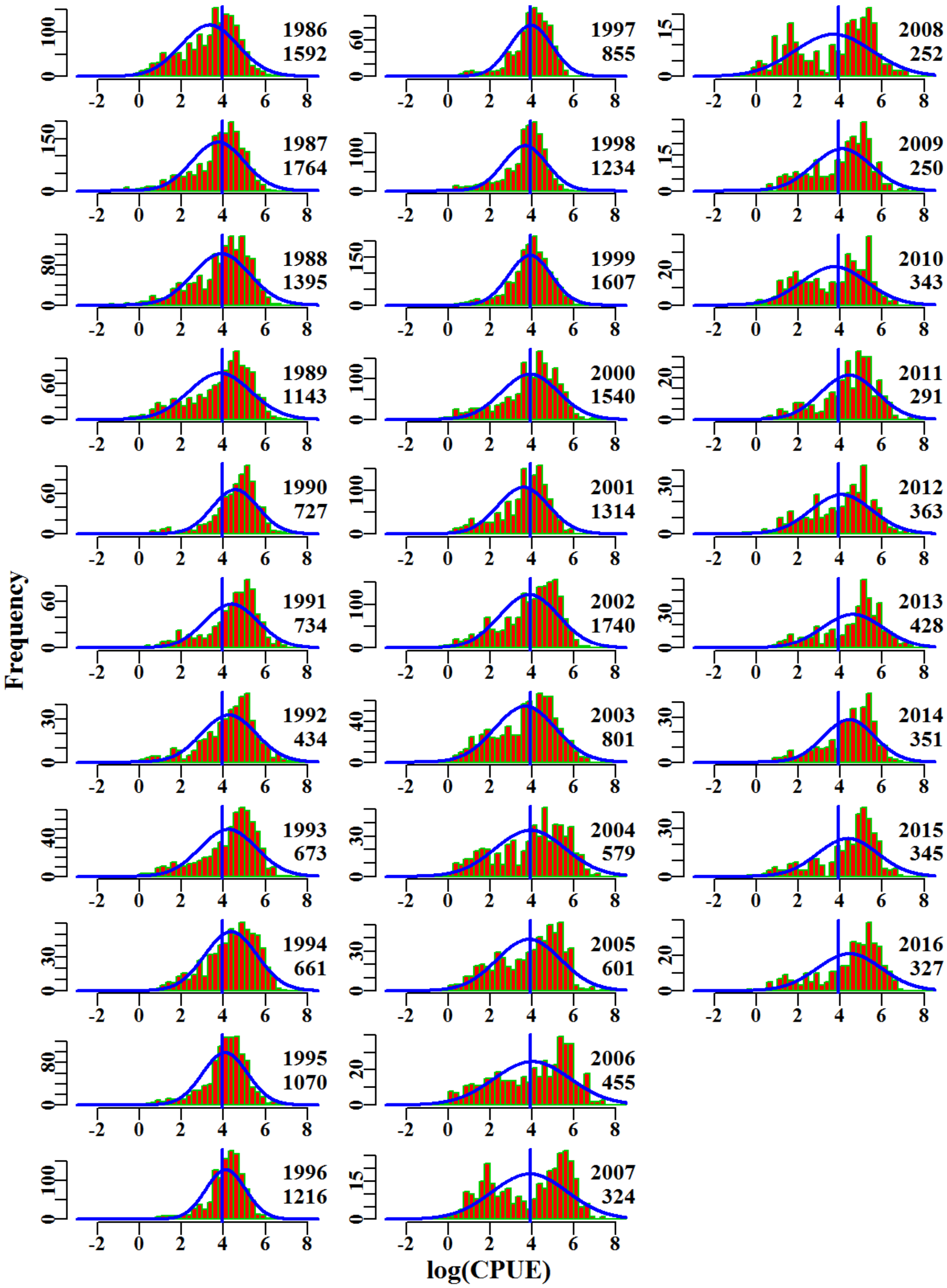


Figure 7.295. RoyalRedPrawn. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

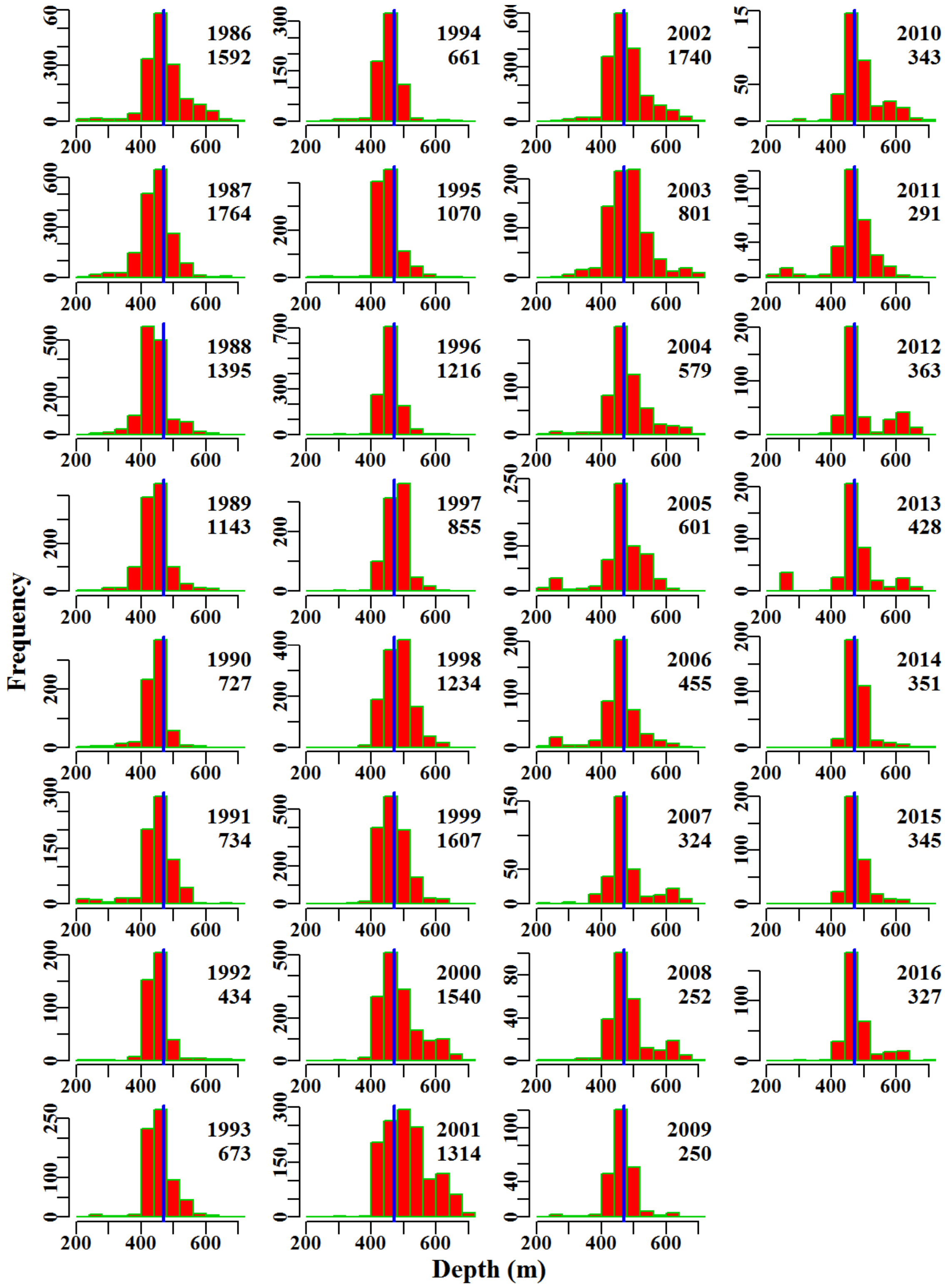


Figure 7.296. RoyalRedPrawn. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

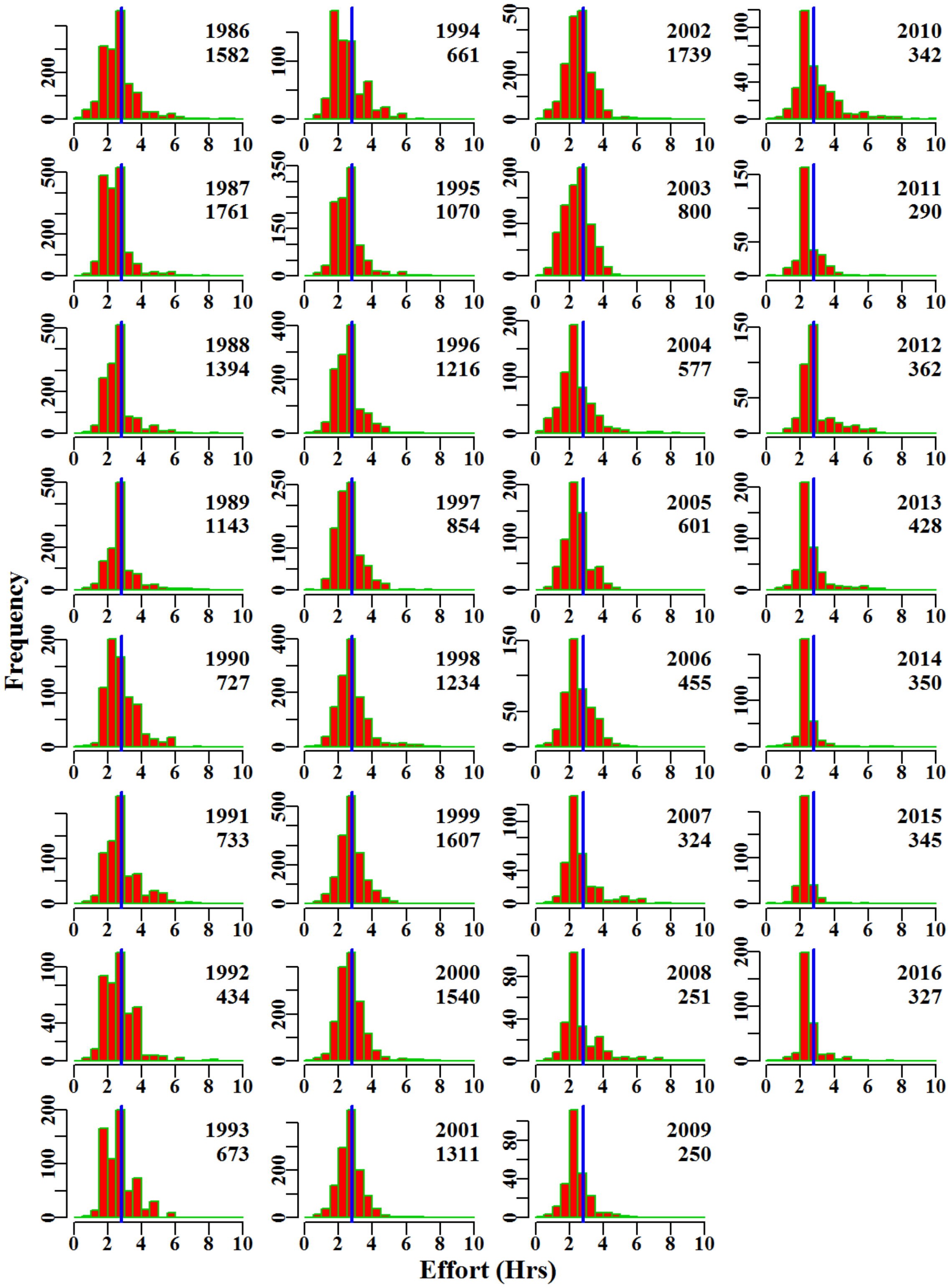


Figure 7.297. RoyalRedPrawn. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.41 Eastern Gemfish NonSpawning 10-40

For non-spawning Eastern Gemfish (GEM - 37439002 - *Rexea solandri*) in the SET, initial data selection was conducted according to the details given in.

A total of 8 statistical models were fitted sequentially to the available data.

7.41.1 *Inferences*

The majority of catch of this species occurred in zone 10, followed by 20 and 30.

The terms Year, Vessel and DepCat had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests that the assumed Normal distribution is valid with a slight departure as depicted at the lower tail of the distribution (Figure 7.301).

Following a large spike in catch rates in the late 1980s, which coincided with a large spike in catches, the annual standardized CPUE trend dropped rapidly despite large reductions in catches and, since 1995 has beenrelatively flat and below average although with what looks like a 14 - 15 year cycle of rise and fall (Figure 7.298). There have been efforts to actively avoid Eastern Gemfish for the last few years and this may have been reflected in the change apparent in the depth of fishing. It does mean that the most recent catchrates, from about 2013, will not be representative of even the depleted stock state.

7.41.2 *Action Items and Issues*

No issues identified.

Table 7.187. EasternGemfishNonSp. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:DepCat.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1986	647.9	2030	390.4	86	51.0	2.6154	0.000	13.705	0.035
1987	1027.6	1894	770.1	74	122.2	3.5873	0.043	9.761	0.013
1988	744.5	2203	509.6	77	65.5	2.9901	0.043	13.954	0.027
1989	306.7	1434	148.4	69	29.9	1.9721	0.048	13.941	0.094
1990	251.0	758	104.1	69	37.1	1.9803	0.057	5.806	0.056
1991	367.6	731	66.0	71	24.1	1.3256	0.059	7.147	0.108
1992	243.5	695	135.2	50	40.4	1.8237	0.059	4.953	0.037
1993	183.3	1536	94.3	58	20.1	1.4420	0.048	14.778	0.157
1994	148.2	1832	63.8	55	13.0	1.0011	0.046	18.284	0.287
1995	137.7	1685	50.0	54	11.5	0.8981	0.047	18.778	0.376
1996	223.7	1947	55.7	61	9.8	0.6967	0.046	18.770	0.337
1997	265.6	1786	66.0	58	9.6	0.7268	0.048	18.445	0.279
1998	238.8	1246	45.6	50	9.9	0.6831	0.051	12.943	0.284
1999	318.2	1344	30.3	53	7.2	0.5016	0.050	12.709	0.419
2000	248.6	1718	32.3	58	6.3	0.4527	0.048	15.070	0.466
2001	239.3	1642	32.2	50	4.7	0.3646	0.049	12.371	0.384
2002	146.9	1617	19.0	50	3.0	0.2817	0.049	10.885	0.572
2003	205.5	1583	20.0	48	3.7	0.3097	0.050	10.275	0.513
2004	454.9	1771	38.6	54	6.8	0.4360	0.049	12.494	0.324
2005	436.3	1745	41.0	48	7.3	0.4641	0.049	12.859	0.314
2006	425.6	1325	32.2	43	7.1	0.4910	0.052	10.216	0.318
2007	495.6	788	28.1	22	10.1	0.6574	0.059	5.909	0.210
2008	203.9	840	35.5	26	14.9	0.8788	0.058	6.825	0.192
2009	146.9	514	27.2	27	24.7	0.9028	0.068	3.854	0.142
2010	150.5	704	22.9	23	9.9	0.6508	0.061	5.538	0.242
2011	101.2	800	22.9	22	8.6	0.5881	0.060	5.801	0.253
2012	130.2	709	22.0	23	9.4	0.5621	0.062	4.985	0.227
2013	80.4	596	23.5	23	14.7	0.6436	0.066	4.207	0.179
2014	104.6	521	9.7	23	6.1	0.3742	0.068	3.462	0.356
2015	68.6	624	16.6	24	10.5	0.4199	0.065	3.450	0.208
2016	52.2	399	7.0	24	6.2	0.2786	0.076	2.495	0.357

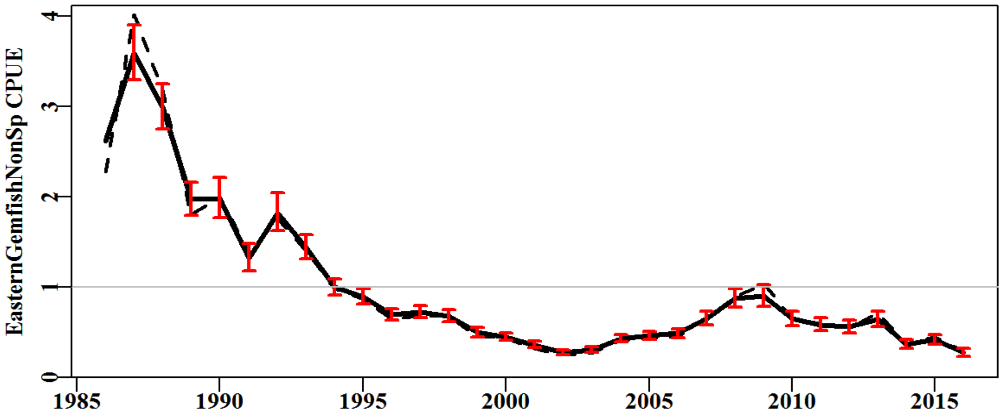


Figure 7.298. EasternGemfishNonSp standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

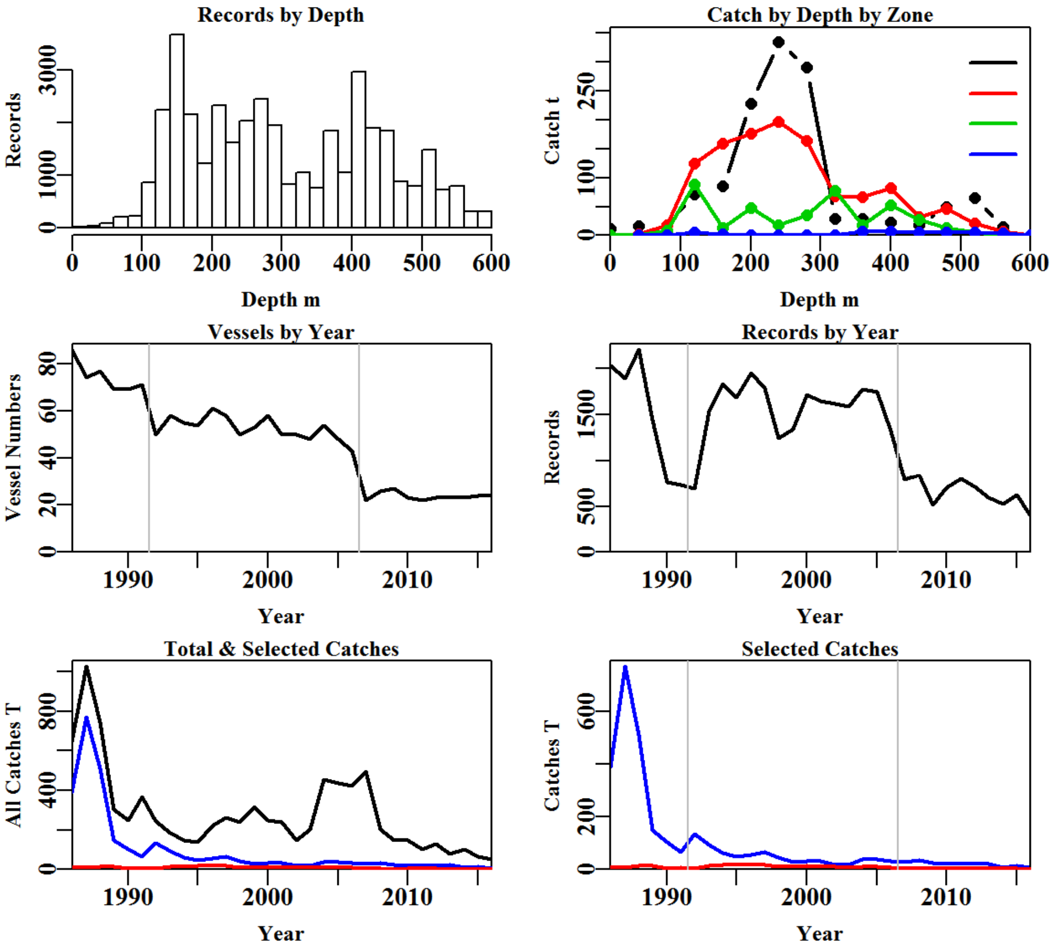


Figure 7.299. EasternGemfishNonSp fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.188. EasternGemfishNonSp data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	90113	80198	78951	76997	39761	39046	39017
Difference	0	9915	1247	1954	37236	715	29

Table 7.189. The models used to analyse data for EasternGemfishNonSp.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + Month
Model5	Year + Vessel + DepCat + Month + DayNight
Model6	Year + Vessel + DepCat + Month + DayNight + Zone
Model7	Year + Vessel + DepCat + Month + DayNight + Zone + Zone:DepCat
Model8	Year + Vessel + DepCat + Month + DayNight + Zone + Zone:Month

Table 7.190. EasternGemfishNonSp. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:DepCat.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	25023	73976	23726	39017	31	24.2	0.00
Vessel	19379	63396	34307	39017	220	34.7	10.52
DepCat	17461	60022	37680	38689	235	37.5	2.80
Month	16936	59180	38523	38689	246	38.4	0.86
DayNight	16626	58699	39003	38689	249	38.9	0.50
Zone	16344	58263	39439	38689	252	39.3	0.45
Zone:DepCat	15847	57389	40314	38689	296	40.2	0.84
Zone:Month	16046	57717	39985	38689	285	39.9	0.52

Table 7.191. EasternGemfishNonSp. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	EasternGemfishNonSp
csirocode	37439002
fishery	SET
depthrange	0 - 600
depthclass	40
zones	10, 20, 30, 40
methods	TW, TDO, OTT, PTB, TMO
years	1986 - 2016

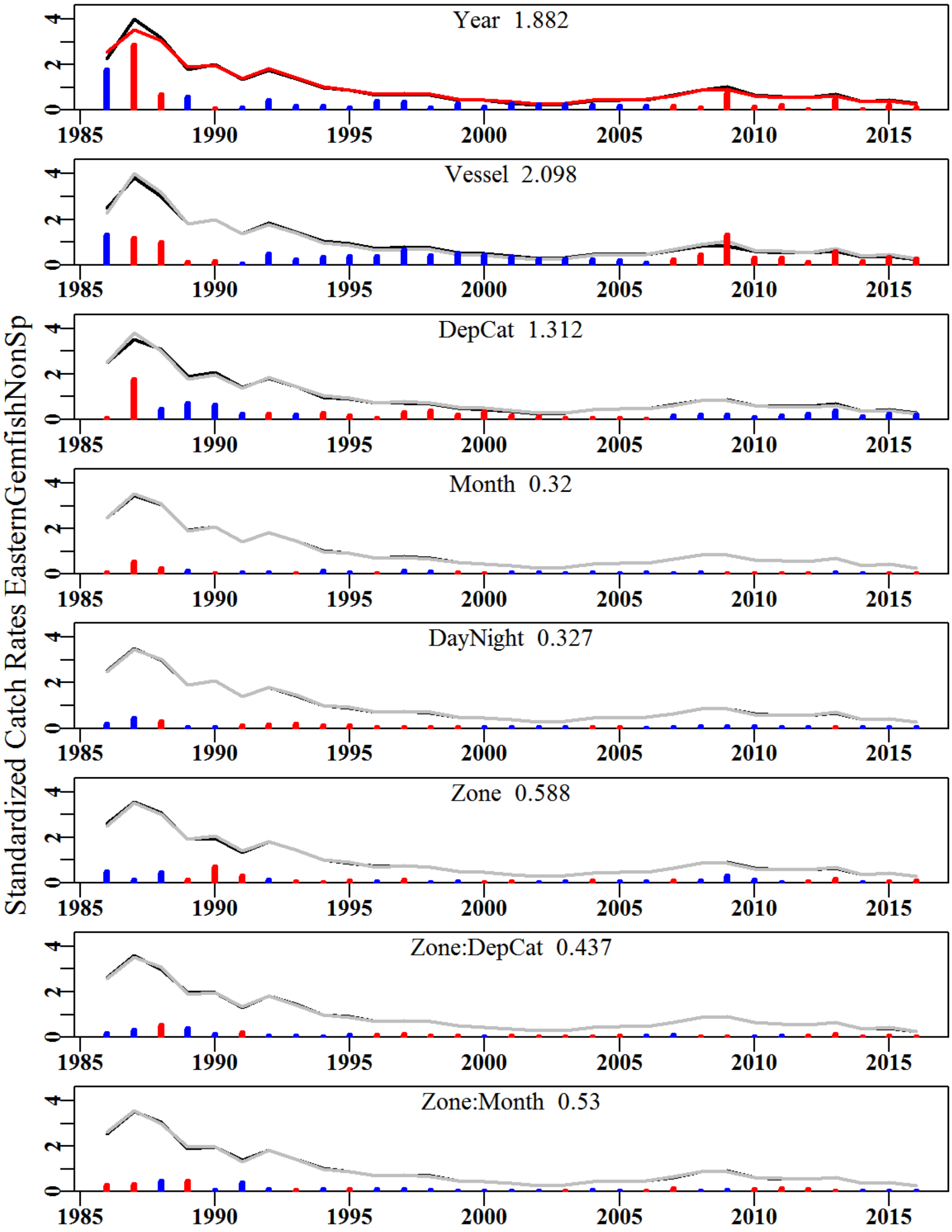


Figure 7.300. EasternGemfishNonSp. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

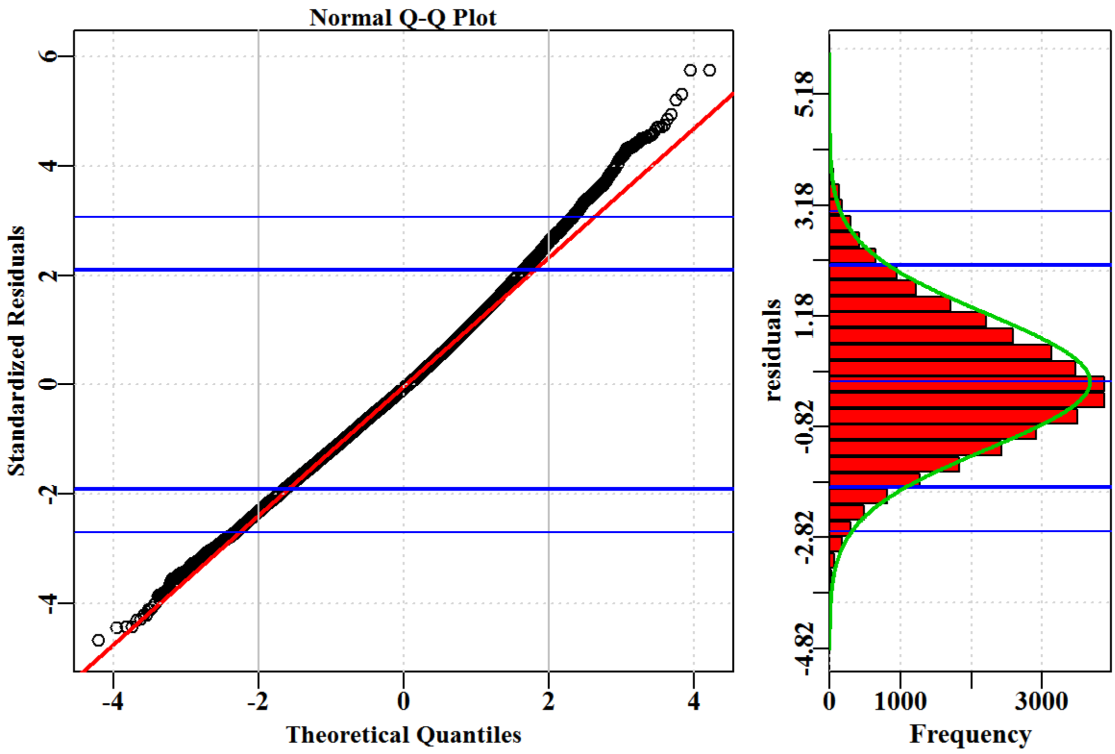


Figure 7.301. EasternGemfishNonSp. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

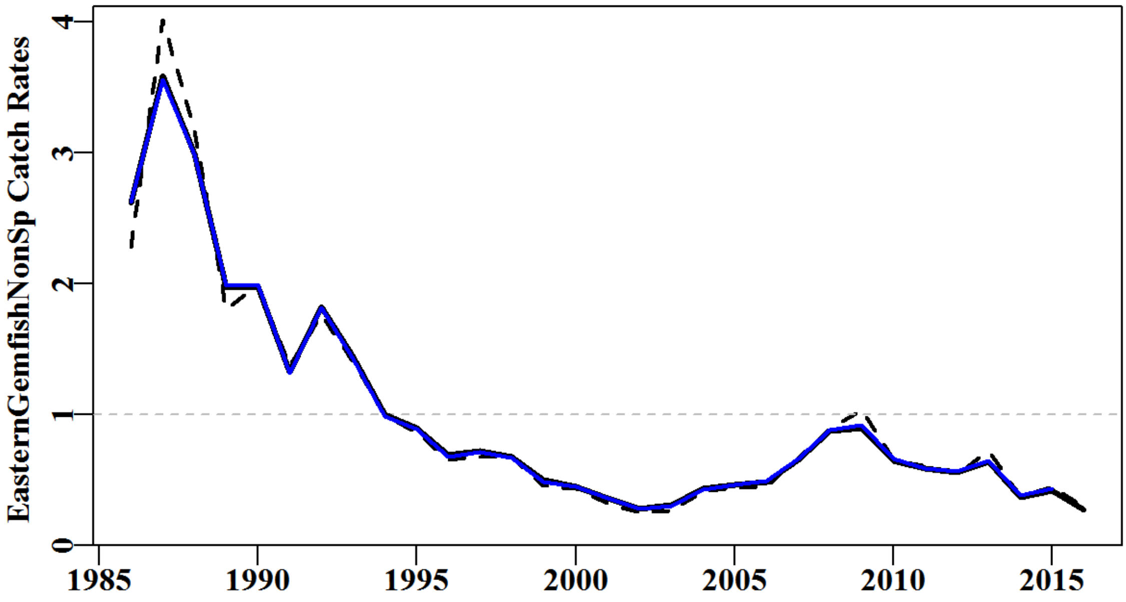


Figure 7.302. EasternGemfishNonSp. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

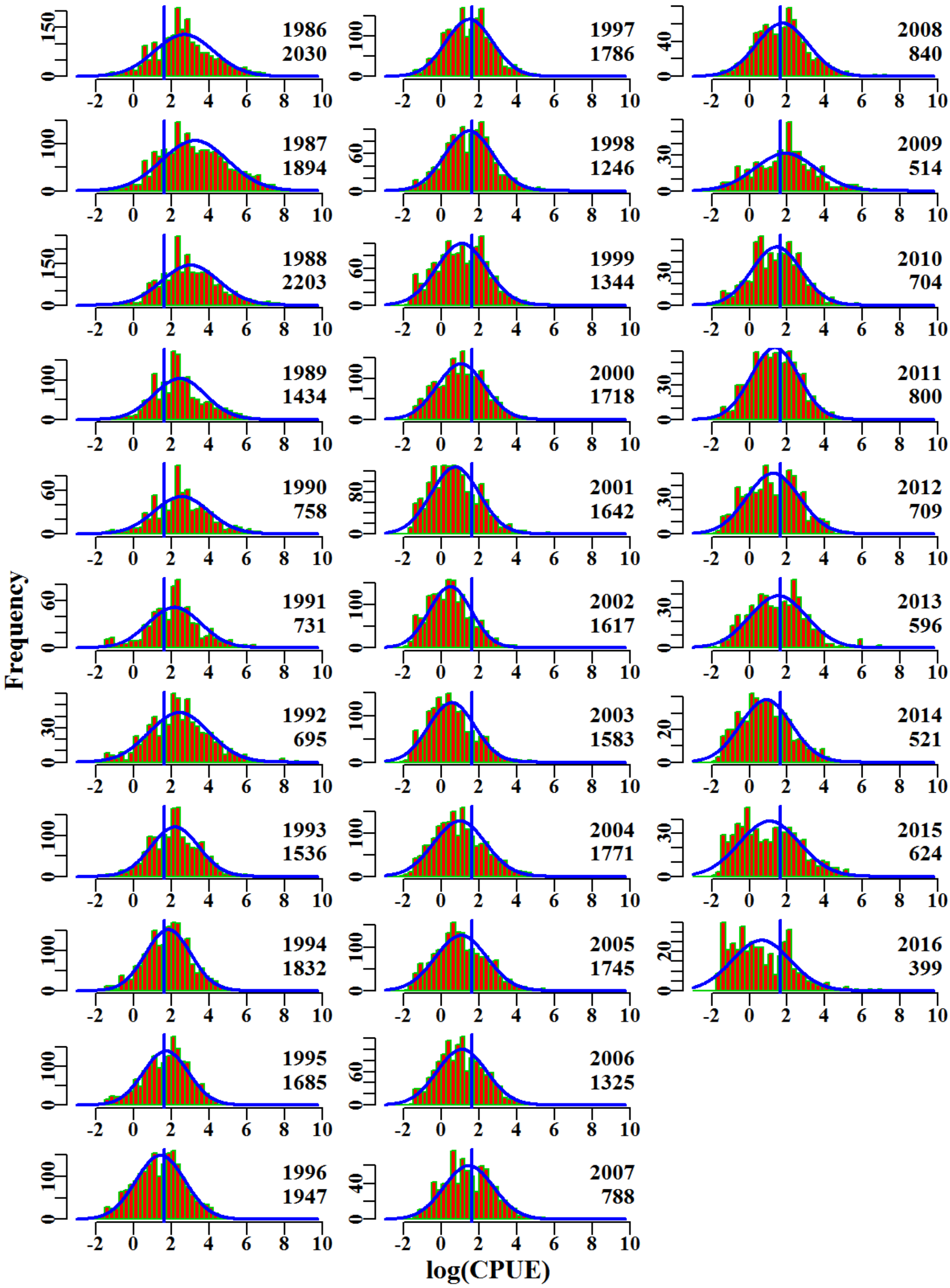


Figure 7.303. EasternGemfishNonSp. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

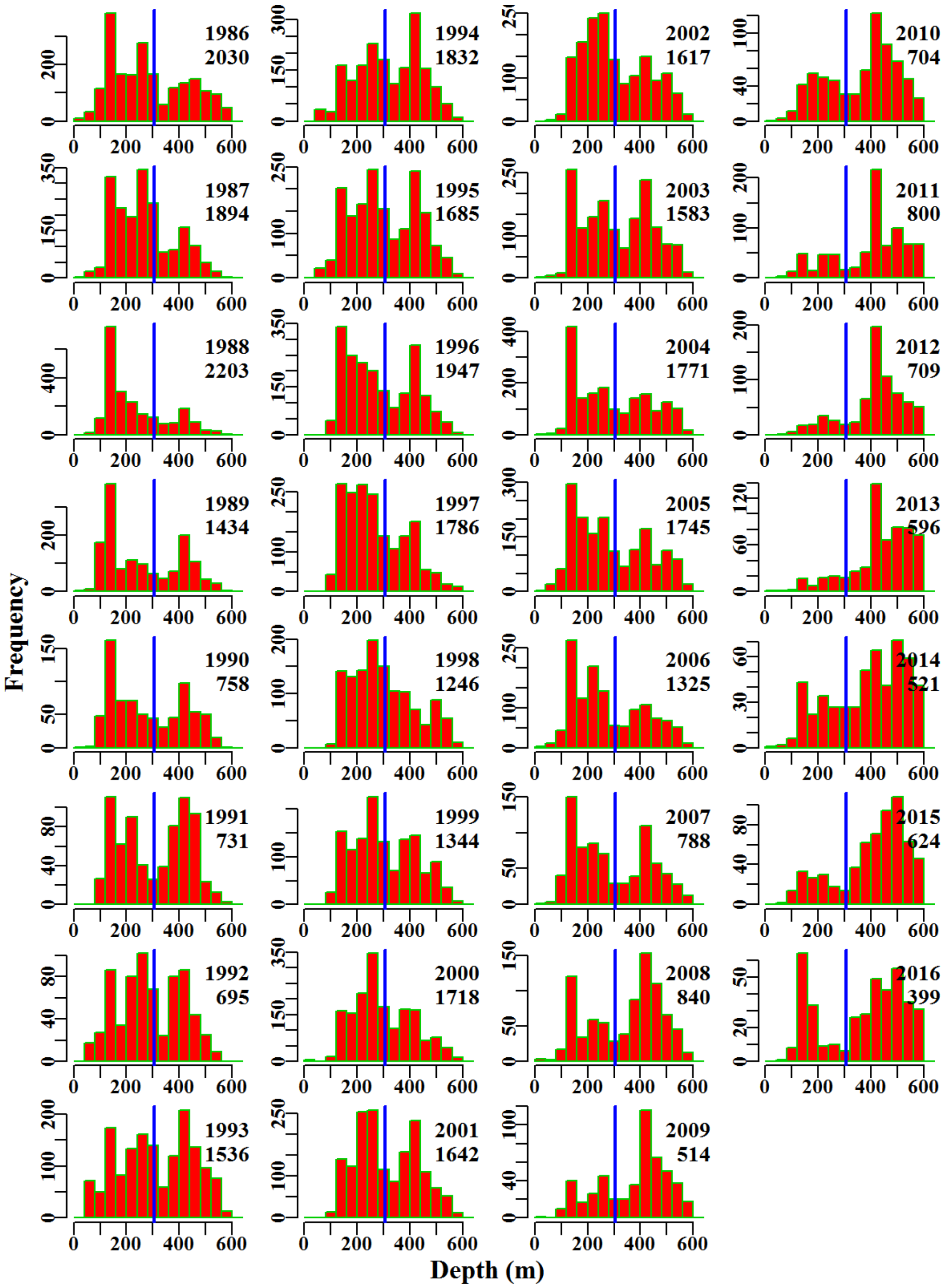


Figure 7.304. EasternGemfishNonSp. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

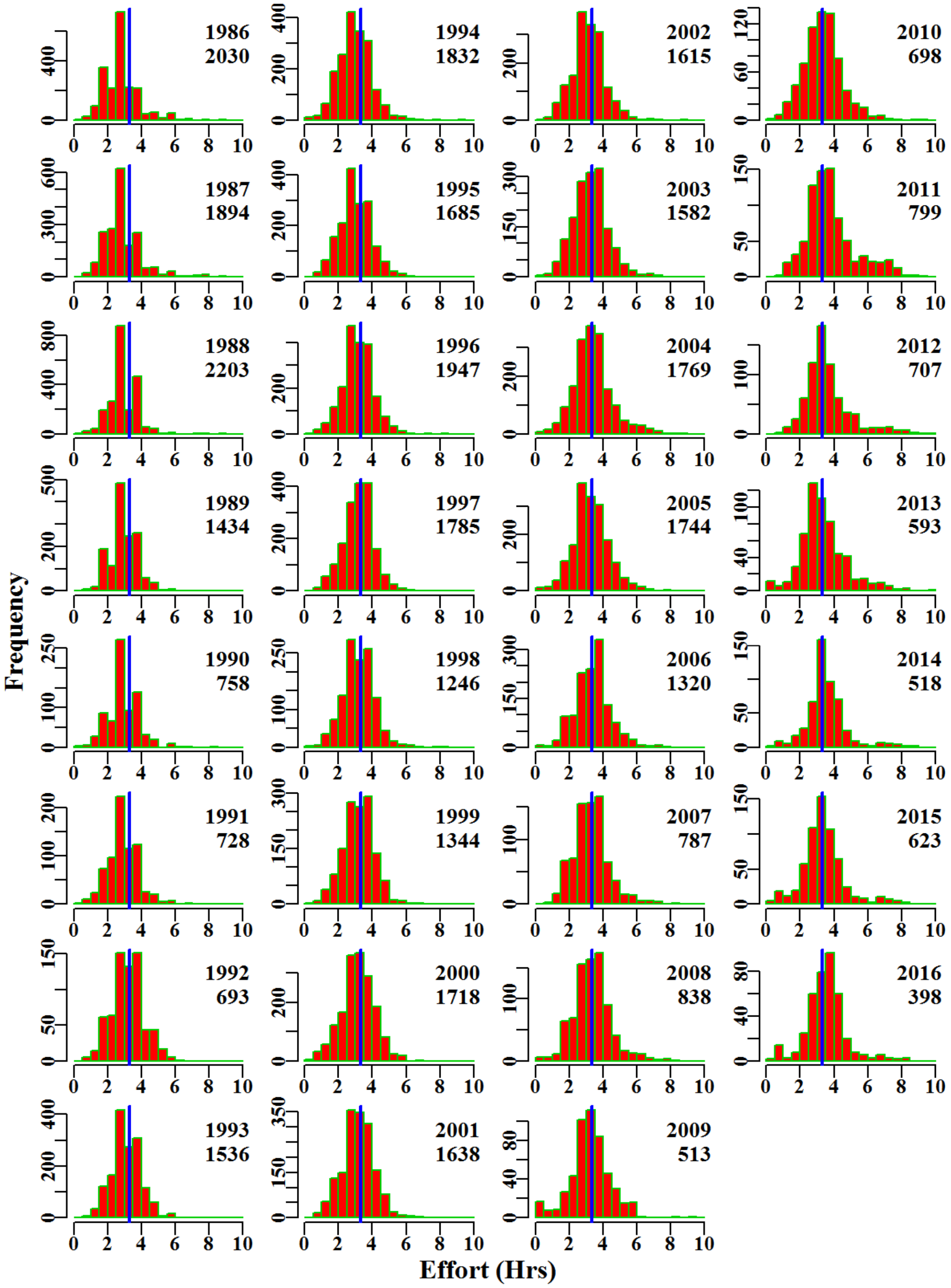


Figure 7.305. EasternGemfishNonSp. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.42 Eastern Gemfish Sp

Initial data selection for the Eastern Gemfish spawning run fishery (GEM - 37439002 - *Rexea solandri*) in the SET was conducted according to the details given in Table 7.196. In addition, specific Eastern Gemfish survey vessels and trips are removed from the data to be analysed as not being typical of standard fishing in recent years.

A total of 8 statistical models were fitted sequentially to the available data.

7.42.1 *Inferences*

The majority of catch of this species occurred in zone 10, followed by 20 and minimal catches in the remaining zones. Even though survey vessel data were removed there were still increased catches in 1996, 1997, and 1998, but after that catches have been less than 42 tonnes since 2000

The terms Year, Vessel, Month, DepCat and one interaction term (Zone:Month) had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot suggests that the assumed Normal distribution is valid with a slight departure as depicted at the upper tail of the distribution (Figure 7.309).

Annual standardized CPUE trend has declined since 2010 and remained below average since 2011 (Figure 7.306). This reflects what appears to be a longer term cycle of CPUE values, which suggests that CPUE values would soon be expected to rise. However, as the very low catches in the past two years indicate, the industry avoidance strategies are effective and this means the recent CPUE may not provide an unbiased representation of the stock status.

7.42.2 *Action Items and Issues*

No issues identified.

Table 7.192. EasternGemfishSp. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1993	205.9	824	133.2	50	40.2	2.2610	0.000	5.369	0.040
1994	97.2	819	49.0	47	22.2	1.4789	0.062	7.145	0.146
1995	57.2	657	21.9	48	12.1	0.9985	0.066	7.390	0.338
1996	197.6	769	135.1	49	35.3	1.2466	0.063	6.914	0.051
1997	342.5	1232	268.6	48	62.4	1.8595	0.059	7.418	0.028
1998	188.9	883	144.7	46	40.4	1.2372	0.063	7.632	0.053
1999	168.5	1065	87.9	45	21.7	1.0207	0.061	10.370	0.118
2000	103.4	1178	37.0	44	10.0	0.6929	0.061	11.992	0.324
2001	102.6	855	32.8	47	11.7	0.7063	0.065	8.239	0.251
2002	54.1	924	22.5	42	7.3	0.5092	0.064	8.894	0.396
2003	75.0	967	31.6	48	10.6	0.7163	0.063	8.564	0.271
2004	220.2	631	19.8	44	9.8	0.6795	0.070	5.380	0.272
2005	143.2	652	21.6	40	9.9	0.6014	0.069	6.129	0.283
2006	228.2	571	34.8	35	18.3	0.9370	0.072	4.275	0.123
2007	132.8	308	25.4	19	24.7	1.1559	0.087	1.752	0.069
2008	65.1	447	35.3	23	23.2	1.4043	0.079	3.389	0.096
2009	63.1	413	37.0	22	26.8	1.3013	0.080	3.226	0.087
2010	77.8	390	41.8	24	30.3	1.4003	0.081	2.602	0.062
2011	47.1	413	27.4	21	17.8	0.9833	0.079	3.392	0.124
2012	41.7	381	28.0	21	18.2	0.6387	0.082	3.299	0.118
2013	33.9	296	16.1	20	17.8	0.8164	0.088	2.968	0.184
2014	30.8	368	11.2	19	8.7	0.5790	0.082	3.000	0.267
2015	18.8	322	7.9	20	8.1	0.4429	0.087	2.591	0.328
2016	18.8	324	6.0	21	5.4	0.3328	0.088	2.658	0.441

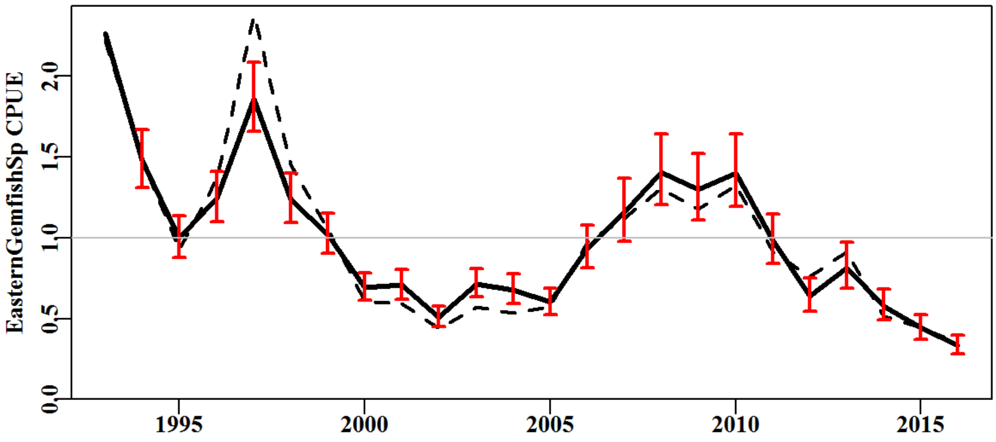


Figure 7.306. EasternGemfishSp standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

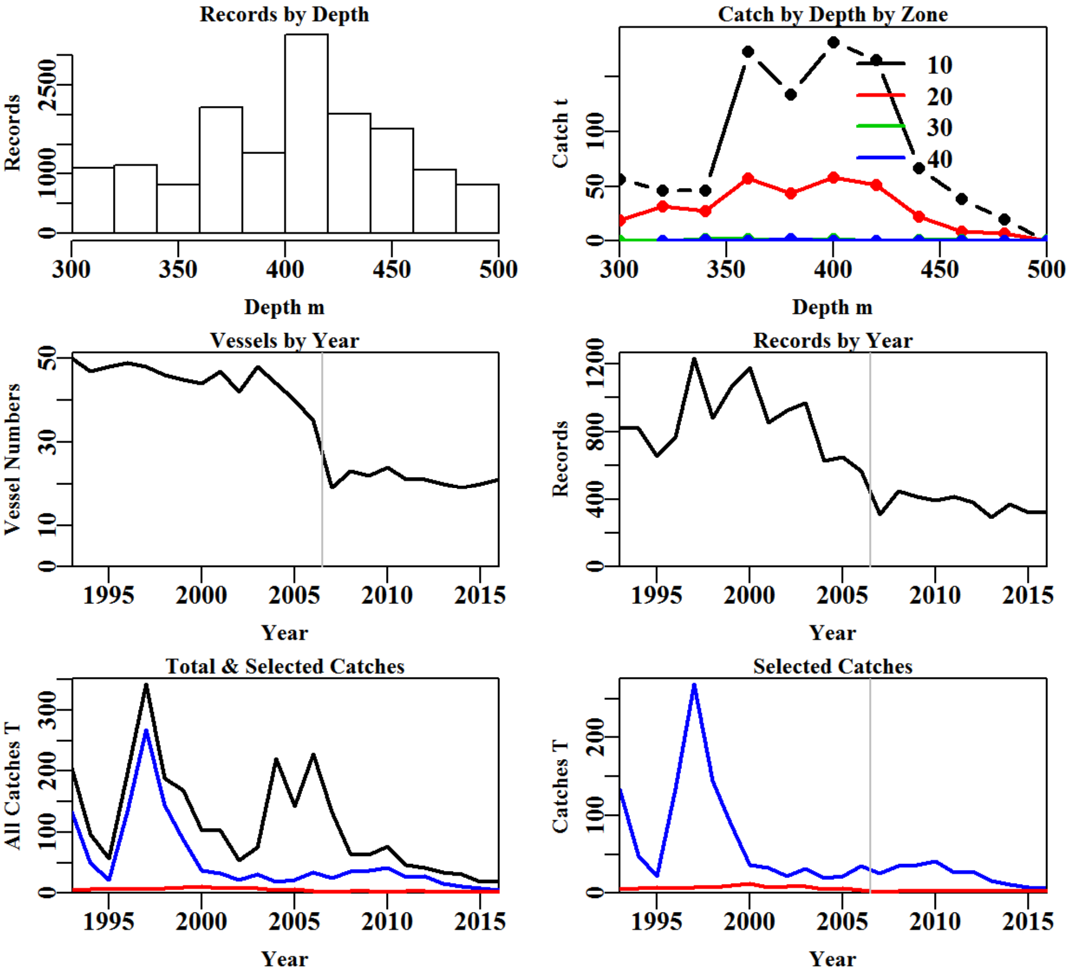


Figure 7.307. EasternGemfishSp fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.193. EasternGemfishSp data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	49704	44575	31463	20595	15819	15689	15689
Difference	0	5129	13112	10868	4776	130	0

Table 7.194. The models used to analyse data for EasternGemfishSp

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + Month
Model4	Year + Vessel + Month + DepCat
Model5	Year + Vessel + Month + DepCat + DayNight
Model6	Year + Vessel + Month + DepCat + DayNight + Zone
Model7	Year + Vessel + Month + DepCat + DayNight + Zone + Zone:Month
Model8	Year + Vessel + Month + DepCat + DayNight + Zone + Zone:DepCat

Table 7.195. EasternGemfishSp. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	9025	27804	4423	15689	24	13.6	0.00
Vessel	7261	24516	7711	15689	129	23.3	9.70
Month	6412	23216	9011	15689	132	27.4	4.05
DepCat	6032	22531	9696	15579	142	29.0	1.60
DayNight	5931	22376	9850	15579	145	29.4	0.47
Zone	5929	22365	9862	15579	148	29.4	0.02
Zone:Month	5665	21963	10264	15579	157	30.7	1.23
Zone:DepCat	5917	22271	9956	15579	175	29.6	0.17

Table 7.196. EasternGemfishSp. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	EasternGemfishSp
csirocode	37439002
fishery	SET
depthrange	300 - 500
depthclass	20
zones	10, 20, 30, 40
methods	TW, TDO, OTT, PTB, TMO
years	1993 - 2016

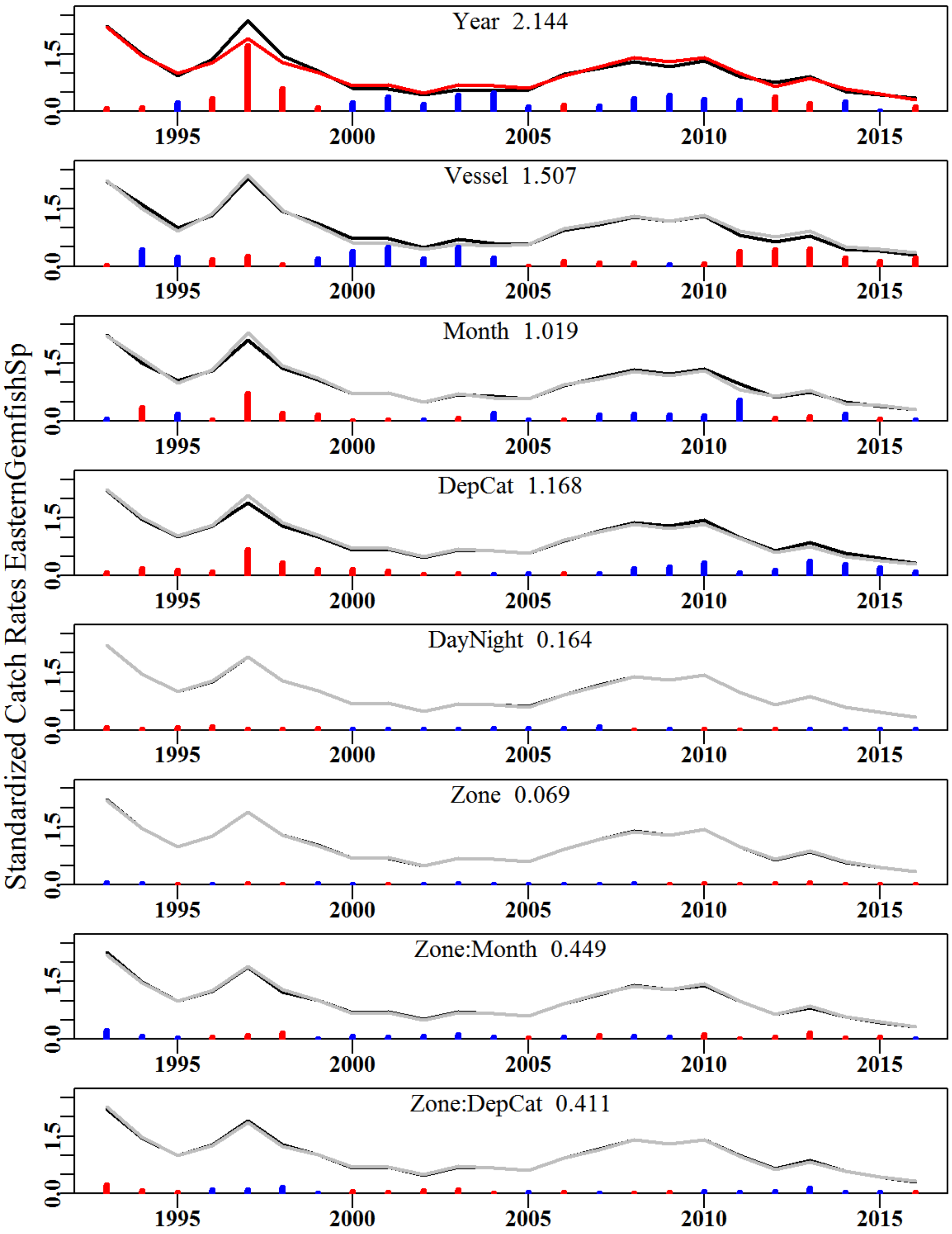


Figure 7.308. EasternGemfishSp. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

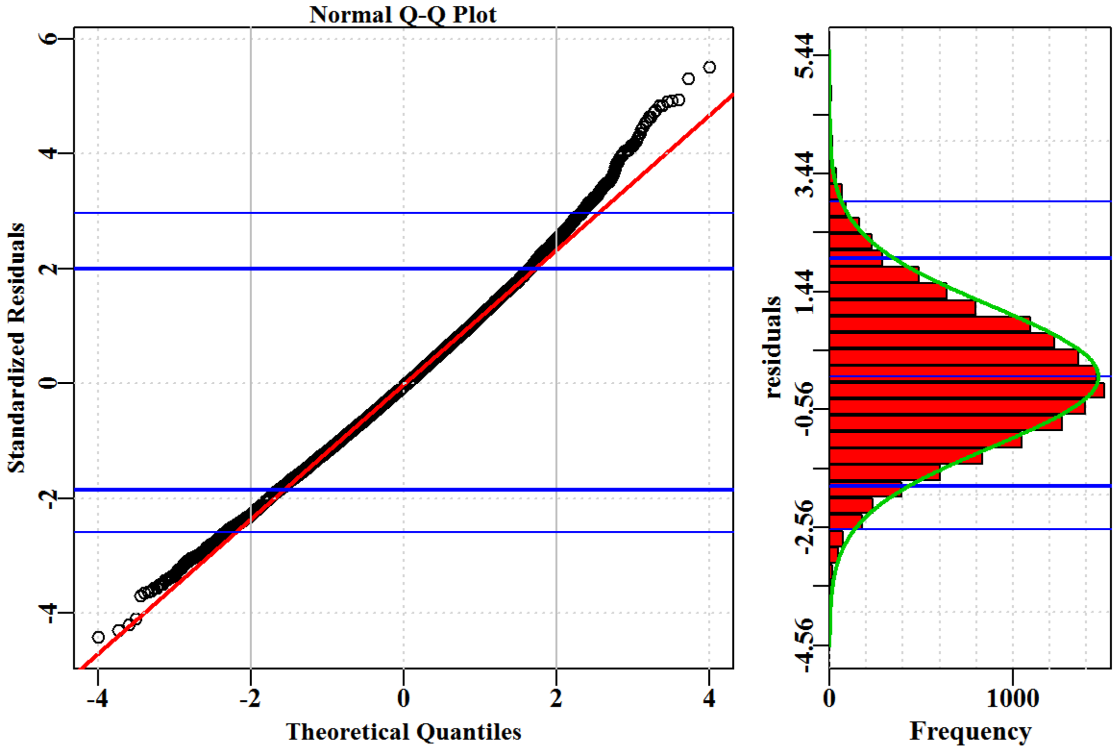


Figure 7.309. EasternGemfishSp. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

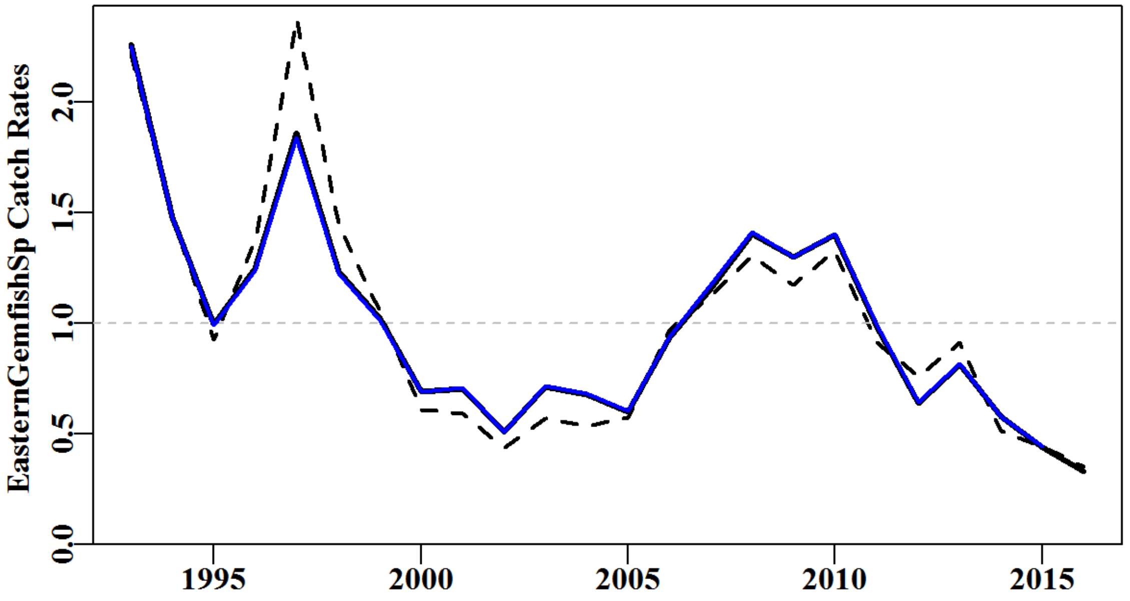


Figure 7.310. EasternGemfishSp. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

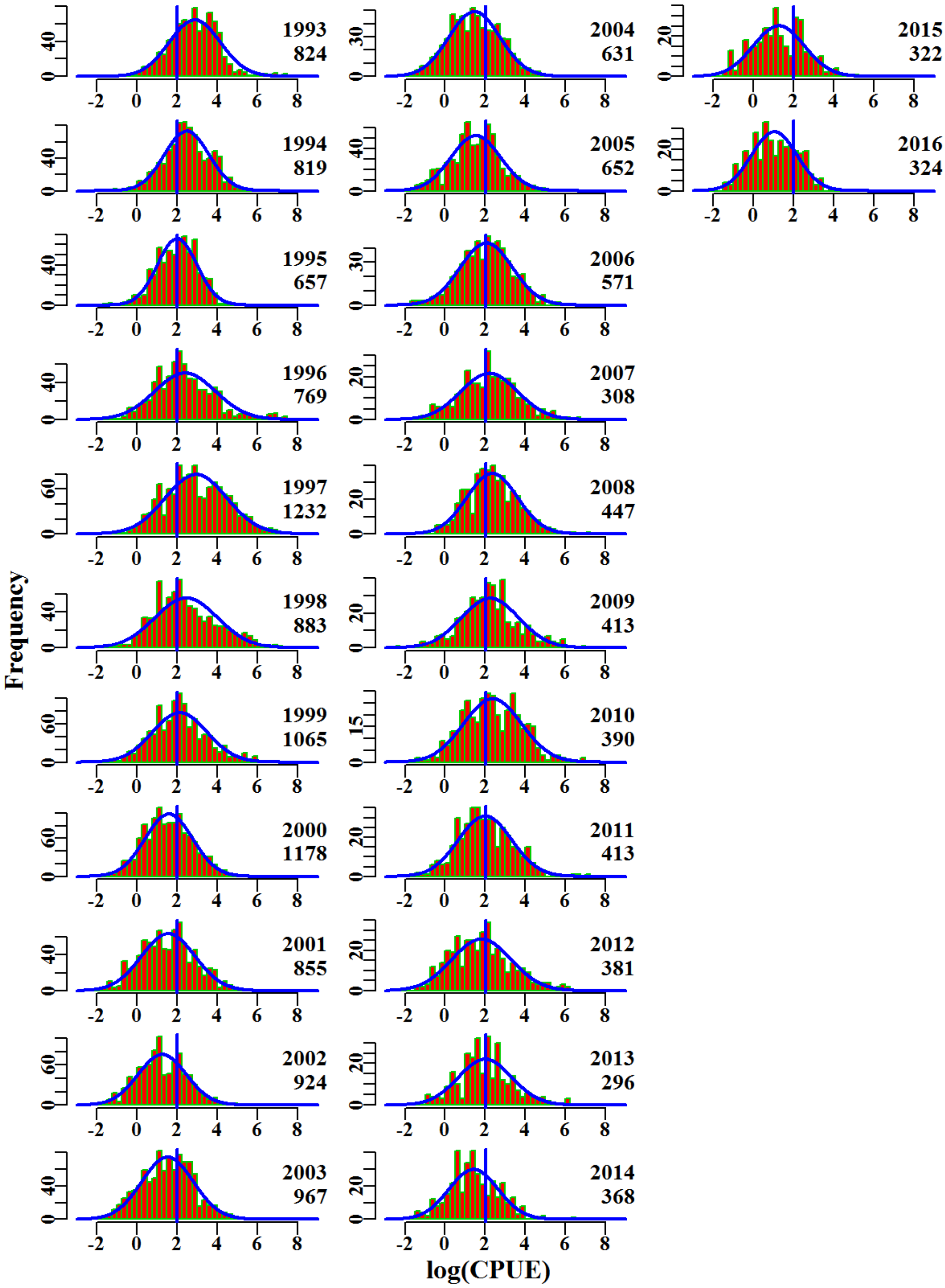


Figure 7.311. EasternGemfishSp. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

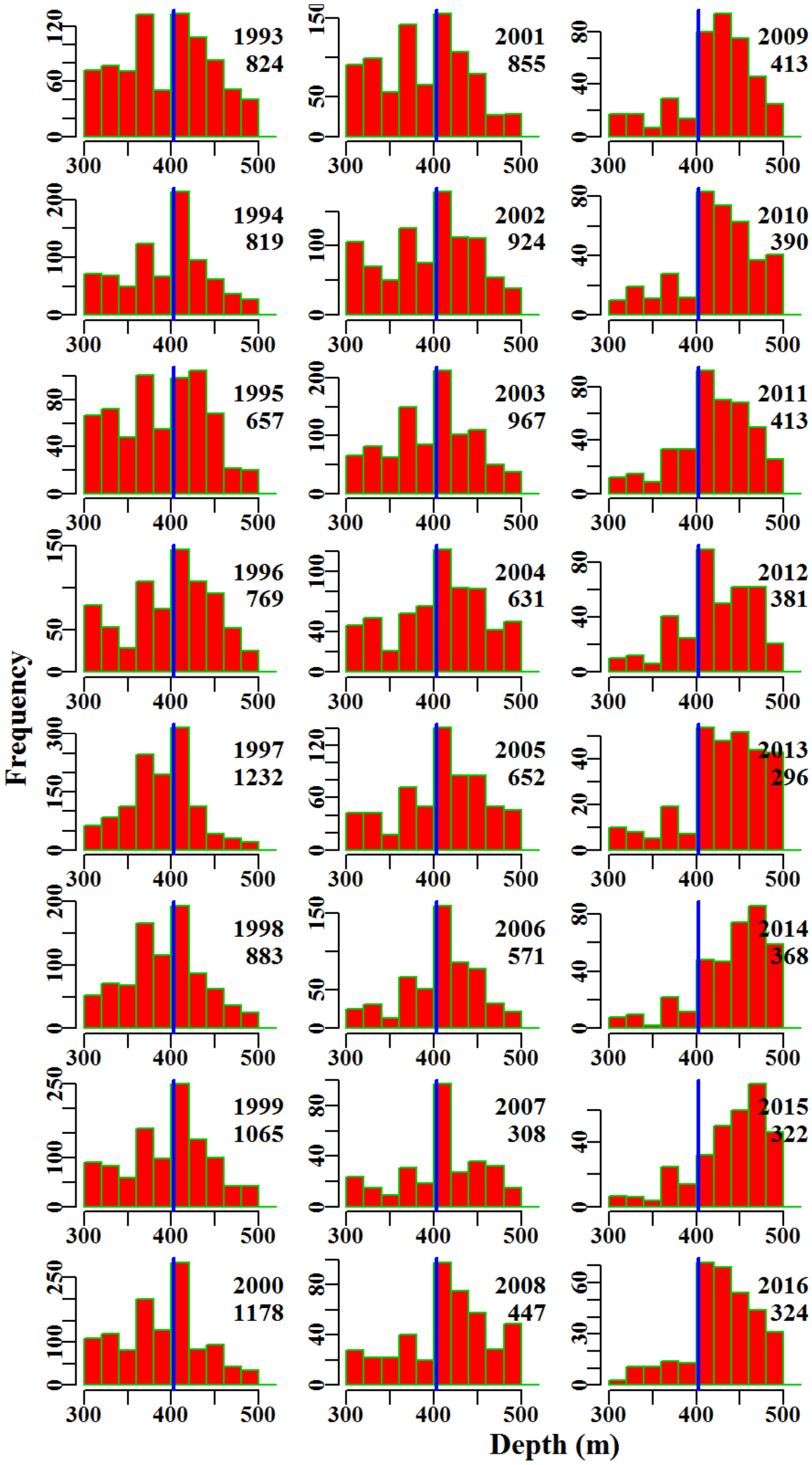


Figure 7.312. EasternGemfishSp. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

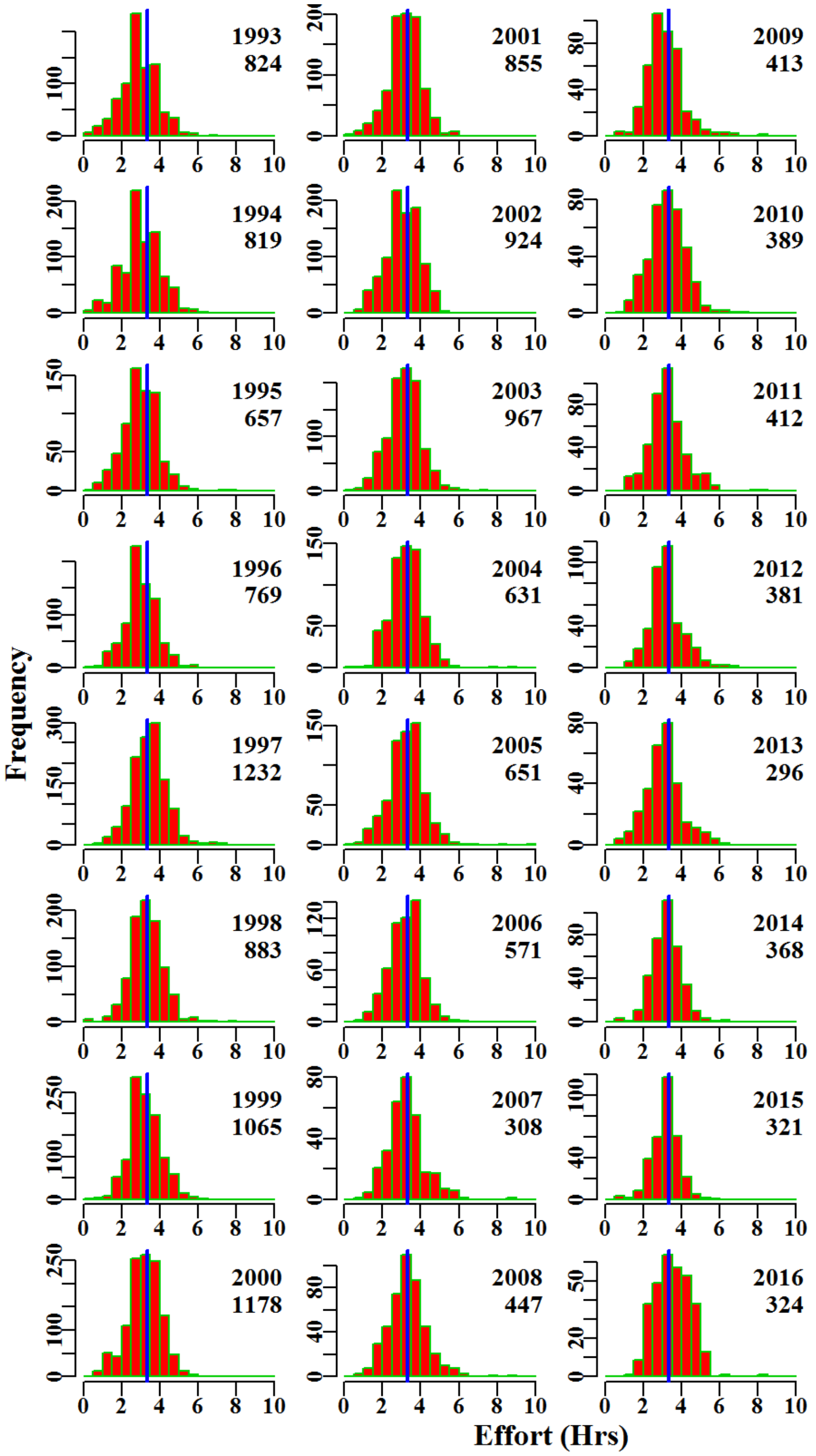


Figure 7.313. EasternGemfishSp. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.43 Alfonsino

Initial data selection for Alfonsino (ALF - 37258002 - *Beryx splendens*) in the SET was conducted according to the detials given in Table 7.201.

A total of 7 statistical models were fitted sequentially to the available data.

7.43.1 *Inferences*

The terms Year, DepCat, Vessel, Month and one interaction term (Month:DepCat) had the greatest contribution to model fit, with the remaining terms each explaining < 1% of the overall variation in CPUE, based on the AIC and R^2 statistics. The qqplot indicates that less than 5% of records, those in the lower tail of the distribution, deviate from teh assumption of normality.

Annual standardized CPUE trend is noisy and relatively flat across the years analysed (Figure 7.314). From 2013 - 2016 the standardized trend deviates from the nominal geometric mean trend such that the trend stays on the long term average catch rate while the geometric mean appears to rise well above it. There are now very few vessels contributing to this fishery and it appears that they are fishing in more focussed depths. With so few vessels actively invovled in the fishery the standardization can be expected to become more uncertain and dependent on their specific fishing activities.

7.43.2 *Action Items and Issues*

No issues identified.

Table 7.197. Alfonsino. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was Zone:DepCat.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1988	0.5	8	0.5	2	52.7	1.3687	0.000	0.138	0.257
1989	2.6	11	2.3	5	62.0	1.7749	0.645	0.120	0.052
1990	3.6	31	3.6	12	33.7	1.6647	0.588	0.352	0.097
1991	5.7	68	5.3	22	30.9	0.6549	0.559	0.962	0.182
1992	18.7	72	17.8	18	96.6	1.3015	0.525	0.565	0.032
1993	5.2	68	5.0	15	25.3	1.2054	0.544	0.826	0.164
1994	15.6	100	7.8	22	40.1	1.8749	0.543	1.137	0.146
1995	8.6	72	7.4	16	36.6	0.9803	0.553	0.834	0.113
1996	12.4	63	12.0	14	51.5	1.4873	0.558	0.727	0.061
1997	11.8	65	7.5	16	24.5	1.0055	0.561	0.805	0.107
1998	6.8	62	3.4	11	22.9	1.8177	0.567	0.501	0.146
1999	55.0	163	8.3	20	22.1	1.4465	0.544	1.971	0.238
2000	504.6	178	36.3	21	95.9	1.3094	0.548	2.463	0.068
2001	337.9	144	5.6	24	17.3	0.7881	0.549	1.948	0.350
2002	2643.0	222	24.9	31	153.3	1.0043	0.544	1.786	0.072
2003	1819.6	127	6.1	24	18.2	0.7735	0.549	1.589	0.259
2004	1411.3	172	16.1	27	19.7	0.9454	0.547	1.448	0.090
2005	445.2	162	7.9	24	23.4	0.8846	0.545	1.396	0.177
2006	458.4	223	11.0	22	29.8	1.0580	0.543	1.893	0.172
2007	530.2	207	8.5	13	15.2	1.1487	0.544	1.777	0.210
2008	260.2	361	50.2	13	40.2	1.1498	0.539	3.173	0.063
2009	98.8	341	15.5	14	23.9	0.8264	0.539	3.075	0.198
2010	57.9	264	8.8	16	9.9	0.4959	0.542	1.831	0.207
2011	807.2	233	4.3	15	4.5	0.4125	0.543	1.750	0.407
2012	616.1	139	1.9	14	4.0	0.3419	0.549	0.843	0.441
2013	225.6	96	3.7	14	8.3	0.3041	0.553	0.798	0.215
2014	85.0	100	5.9	12	85.4	0.3966	0.552	0.703	0.120
2015	76.2	180	13.7	13	124.6	0.3690	0.546	0.752	0.055
2016	23.3	96	3.2	10	18.9	0.2097	0.554	0.321	0.100

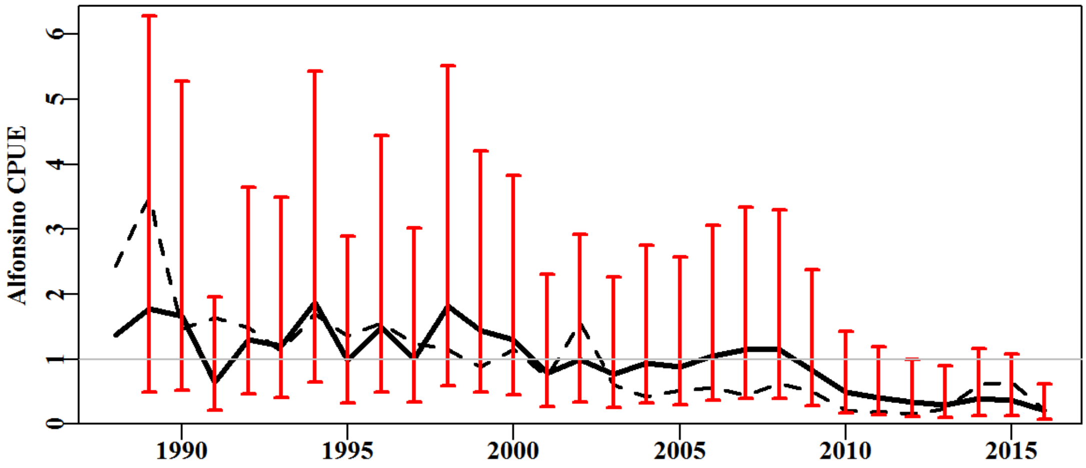


Figure 7.314. Alfonsino standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

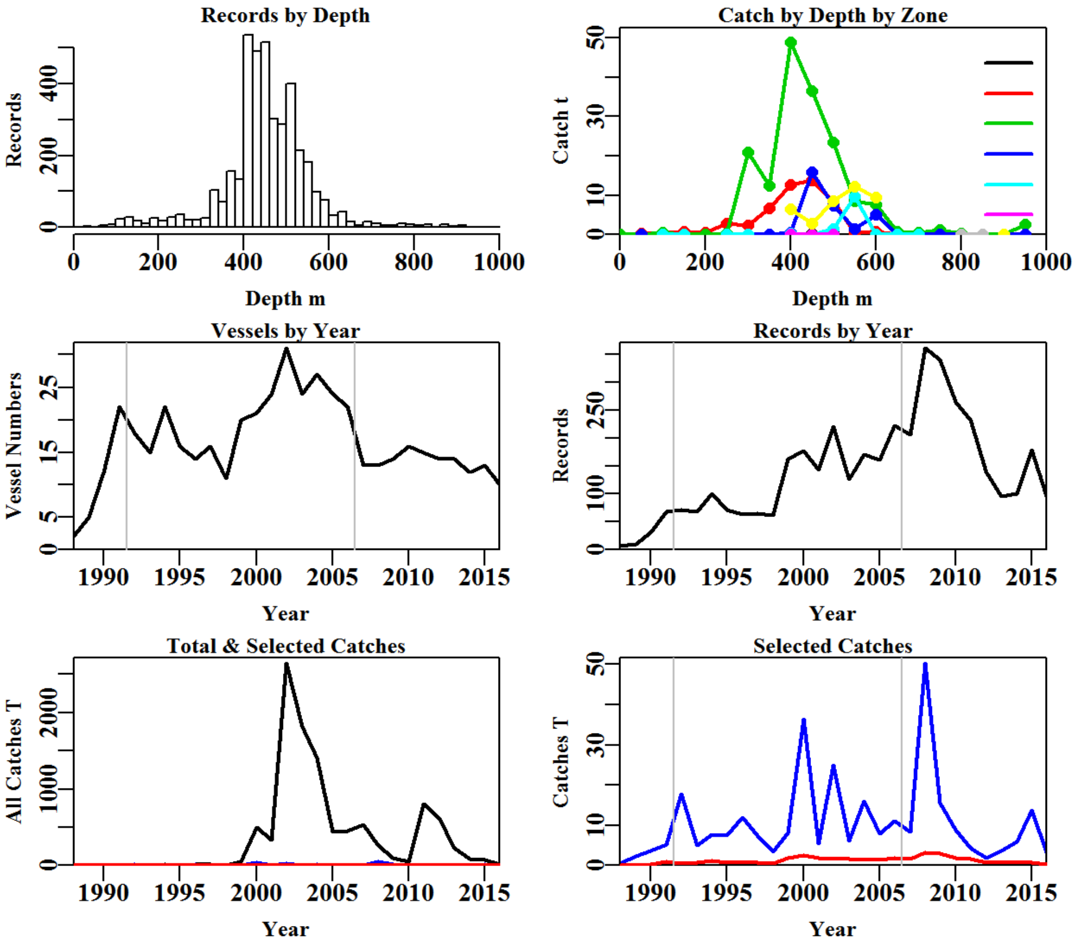


Figure 7.315. Alfonsino fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 7.198. Alfonsino data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	12971	9409	9362	9338	6029	5658	4028
Difference	0	3562	47	24	3309	371	1630

Table 7.199. The models used to analyse data for Alfonsino.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + Zone
Model5	Year + Vessel + DepCat + Zone + DayNight
Model6	Year + Vessel + DepCat + Zone + DayNight + Month
Model7	Year + Vessel + DepCat + Zone + DayNight + Month + Zone:DepCat

Table 7.200. Alfonsino. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was Zone:DepCat.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	4753	12920	1838	4028	29	11.8	0.00
Vessel	2590	7170	7588	4028	134	49.8	37.92
DepCat	2502	6925	7833	3998	153	50.6	0.87
Zone	2311	6579	8178	3998	160	53.0	2.38
DayNight	2288	6535	8223	3998	162	53.3	0.29
Month	2233	6410	8347	3998	173	54.1	0.76
Zone:DepCat	2199	6176	8582	3998	230	55.1	1.01

Table 7.201. Alfonsino. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	Alfonsino
csirocode	37258002
fishery	SET
depthrange	0 - 1000
depthclass	50
zones	10, 20, 30, 40, 50, 60, 70, 80, 81, 82, 83, 84, 85, 91, 92
methods	TW, TDO, OTT, PTB, TMO
years	1986 - 2016

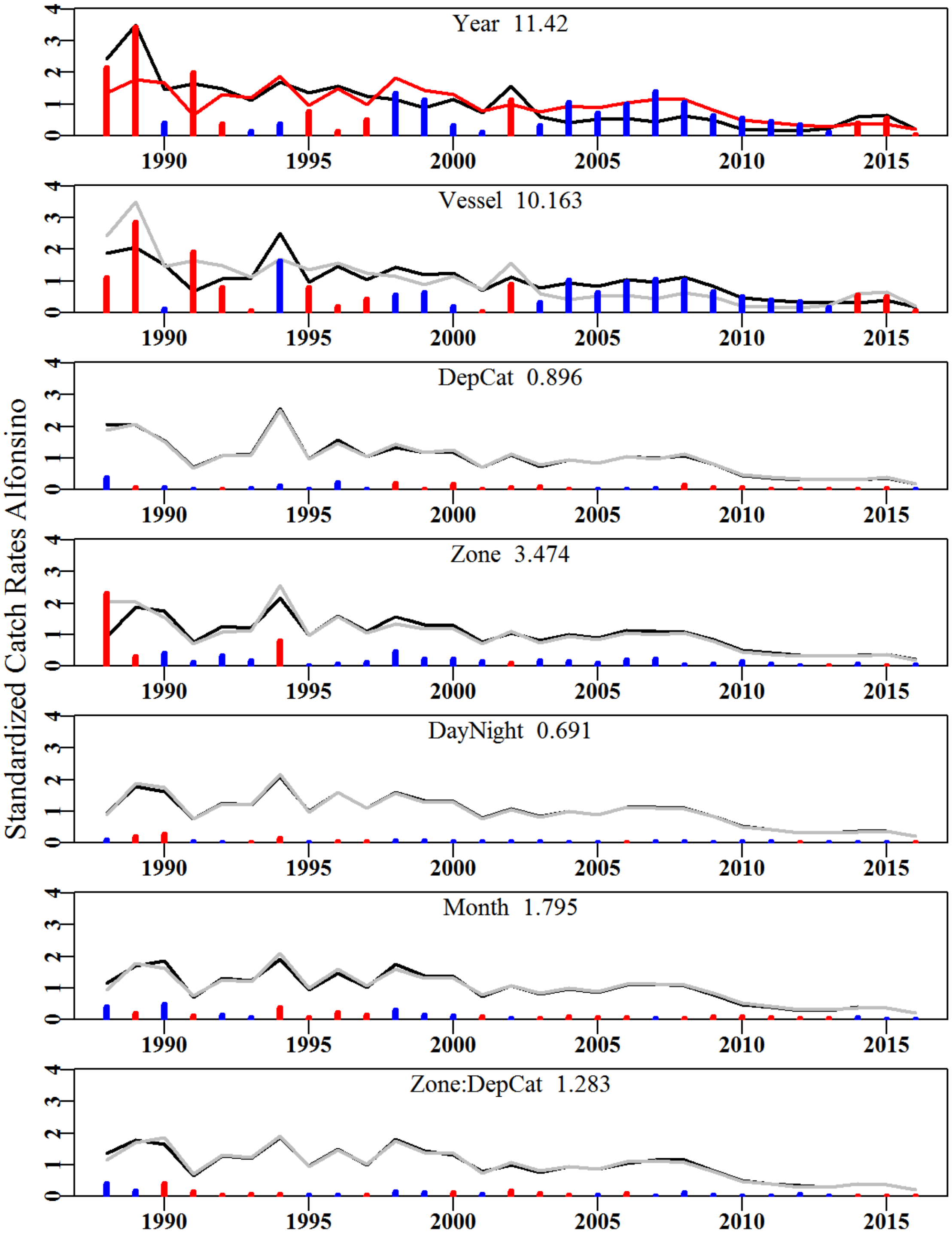


Figure 7.316. Alfonsino. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

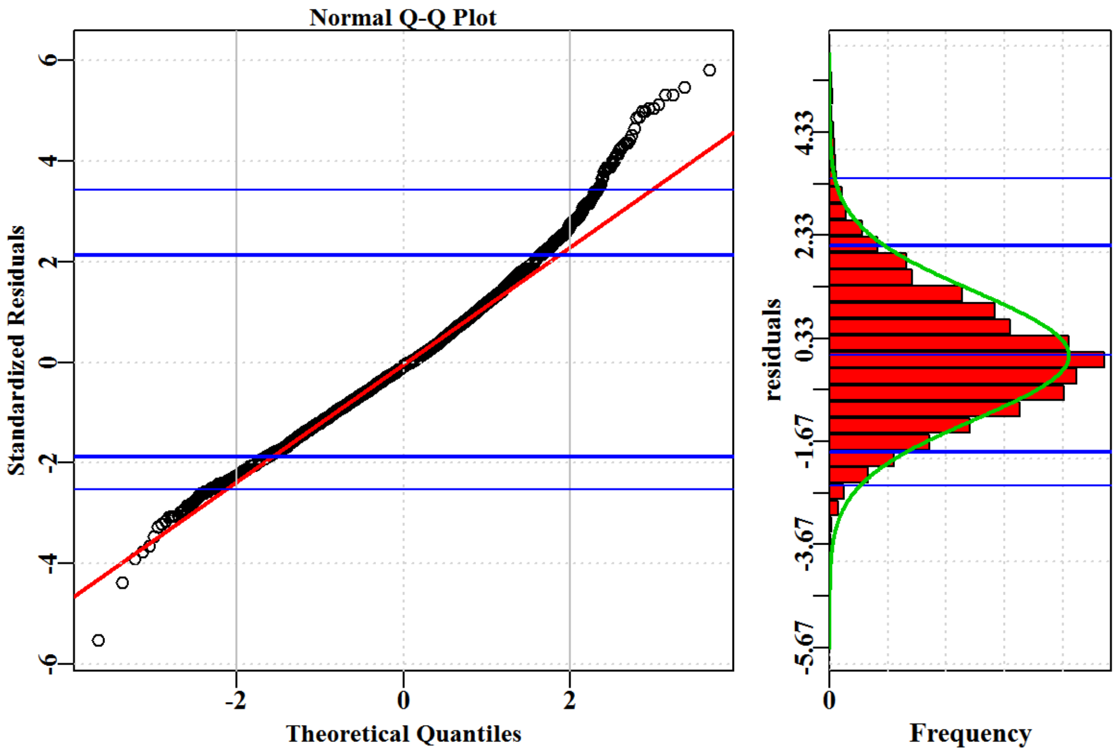


Figure 7.317. Alfonsino. diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

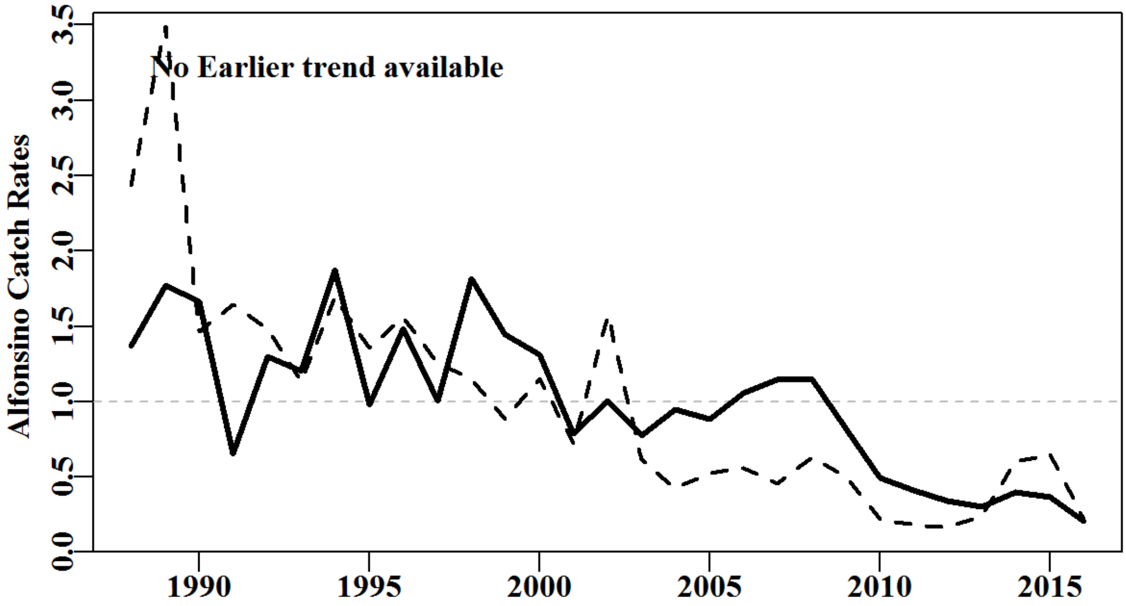


Figure 7.318. Alfonsino. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

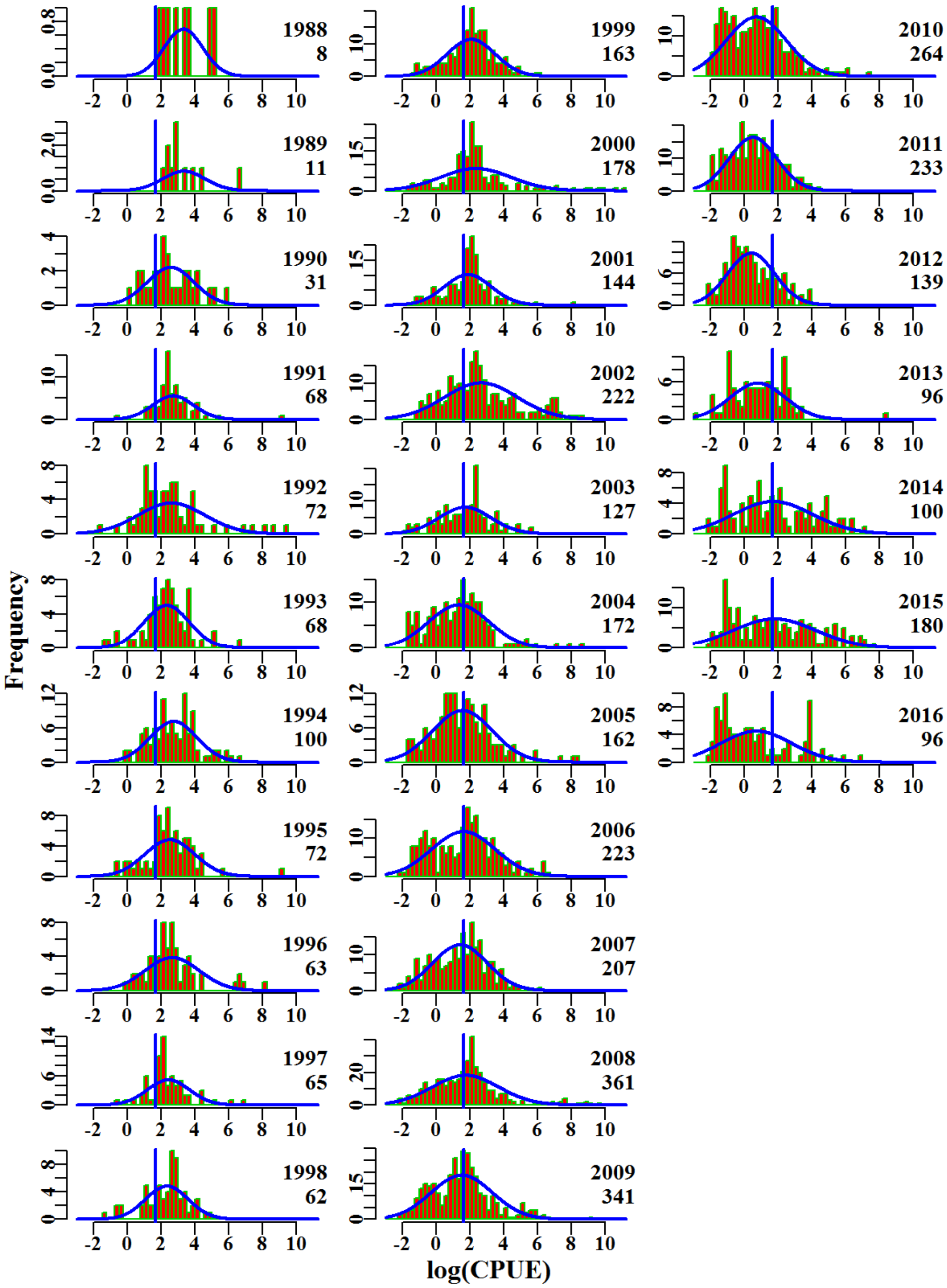


Figure 7.319. Alfonsino. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

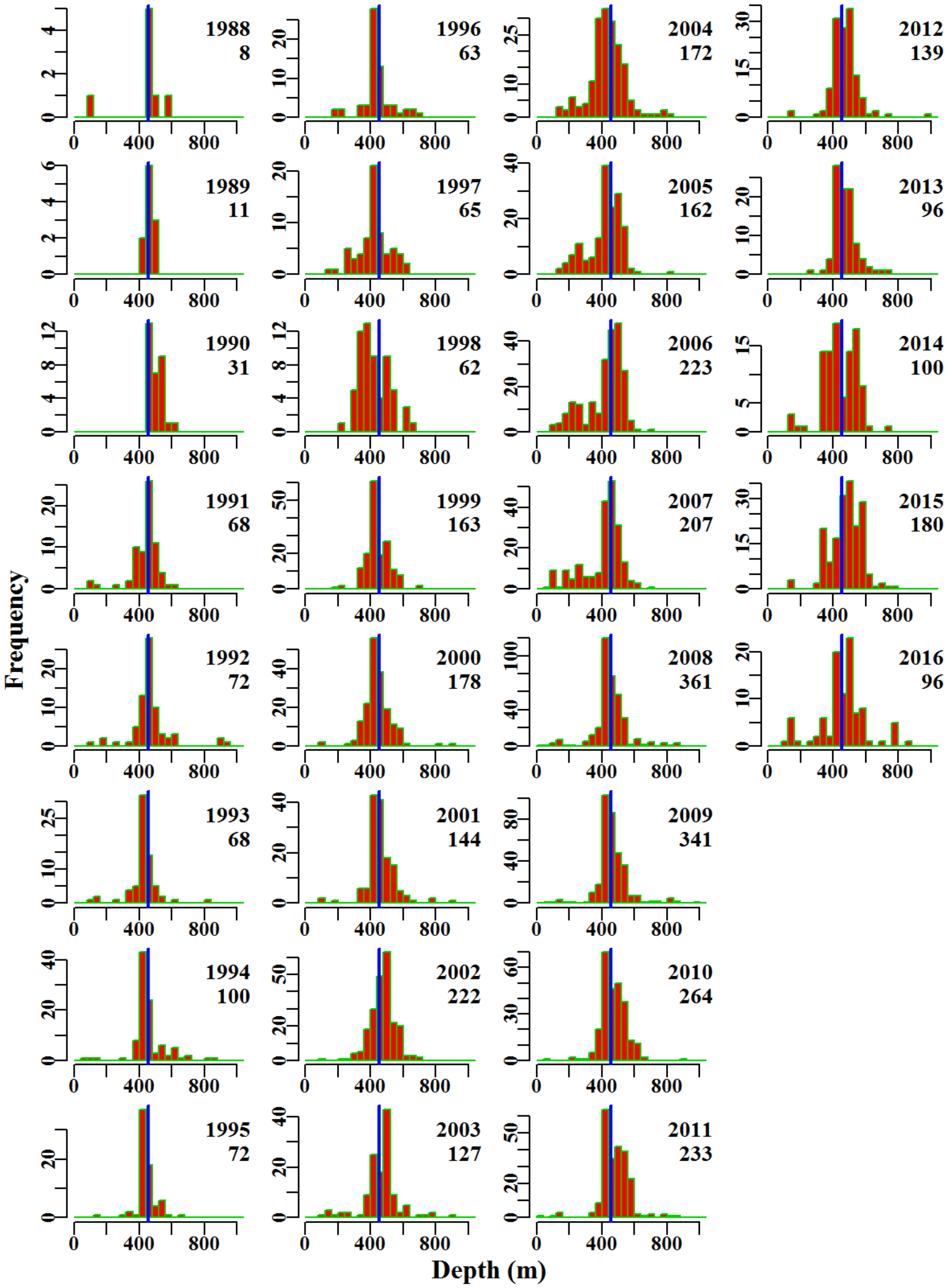


Figure 7.320. Alfonsino. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

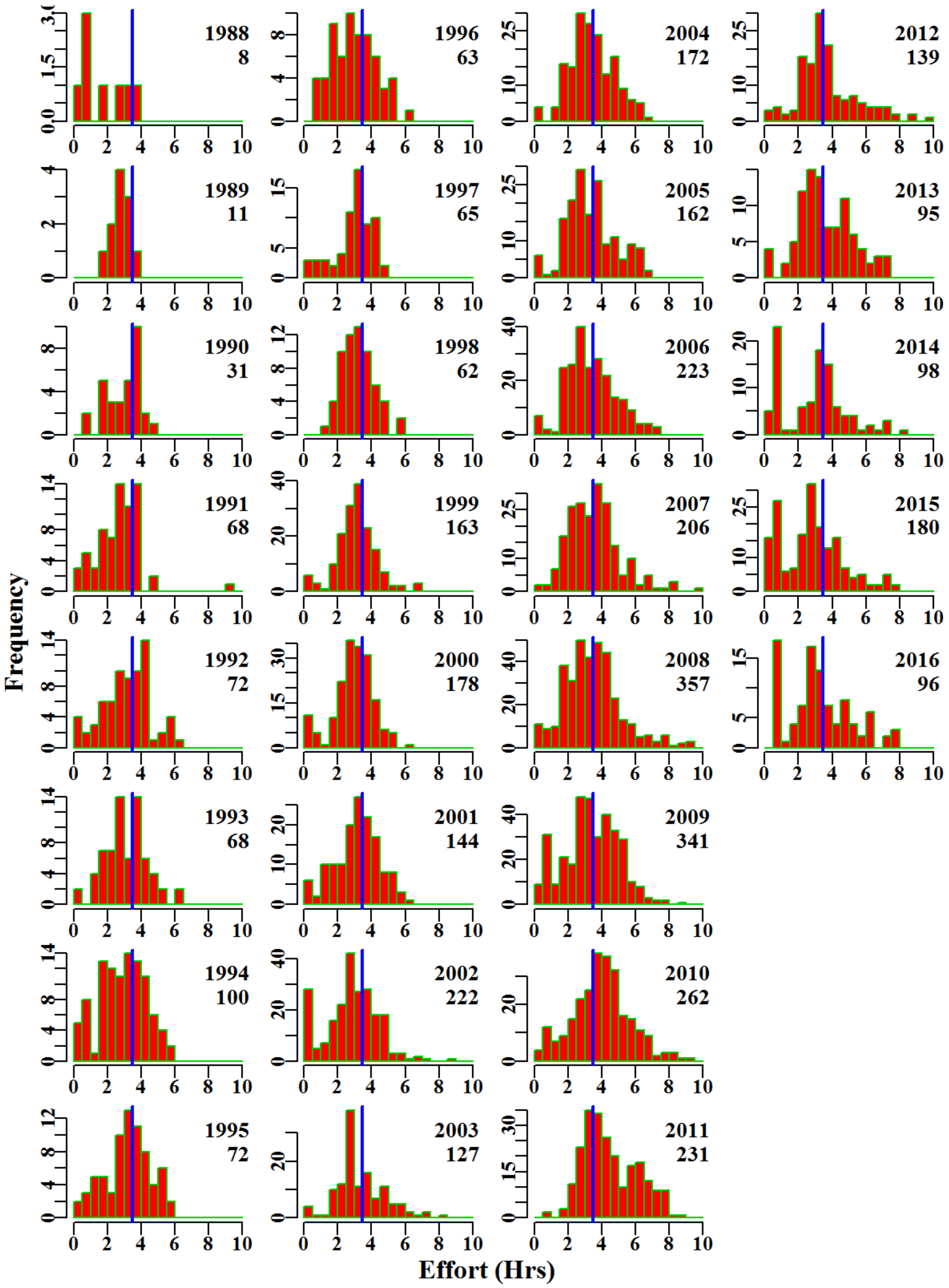


Figure 7.321. Alfonsino. The frequency distribution of effort each year for the available data. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

7.44 Acknowledgements

Thanks goes to the CSIRO database team for their preliminary processing of the catch and effort data as received from the Australian Fisheries management Authority. In addition, one author (MH) is indebted to FRDC for funding the project 2012/201 'Improving Catch Rate Standardizations', which provided the time to explore ways of making the mass production of CPUE standardizations more efficient and defensible.

7.45 References

Burnham, K.P. and D.R. Anderson (2002) *Model Selection and Inference. A Practical Information-Theoretic Approach.* Second Edition Springer-Verlag, New York. 488 p.

Neter, J., Kutner, M.H., Nachtsheim, C.J, and W. Wasserman (1996) *Applied Linear Statistical Models.* Richard D. Irwin, Chicago. 1408 p.

R Core Team (2017). *R: A language and environment for statistical computing.* R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

8. CPUE standardizations for selected shark SESSF Species (data to 2016)

Malcolm Haddon and Miriana Sporcic

CSIRO Oceans and Atmosphere, GPO Box 1538, Hobart, TAS 7001, Australia

8.1 Executive Summary

This report focuses on data from years 1995 - 2015 available in the Commonwealth logbook database. The logbook database contains records relating to all methods and areas and allow for a detailed analysis, which is required to provide a complete view of the current state of the fishery.

Reported catches of school shark are relatively low and those from trawling do not appear to be targeted, as evidenced by the large proportion of < 30 kg shots present in the logbook data. Nevertheless, the areas where they are caught have not changed greatly and yet the standardized catch-per-unit effort (CPUE) has continued to increase, with the exception of 2014. This is a positive sign, which when combined with the observation of increased proportions of smaller school sharks is evidence of school sharks showing some signs of recovery.

There has been an increase in reported gillnet catches of gummy shark and standardized CPUE in South Australia and Bass Strait since 2015. By contrast, standardized CPUE of gillnet caught gummy shark around Tasmania remained flat since 2014 and increasing to the long term average in 2016. Reported catches by bottom line remained at 229 t for both 2013 and 2014, dropped to 192 t in 2015, and dropped to 135 t in 2016. Also, there was a drop of ~8 t reported (i.e. 92 t to 84 t) in 2015 relative to 2014 and an increase of ~3 t reported (i.e. 84 t to 87 t) in 2016 relative to 2015 for trawl. Standardized CPUE for trawl have increased steadily since 2012, remaining above the long-term average. By contrast, standardized CPUE for bottom line have remained flat and noisy since 2012. These analyses used number of operations as the effort unit and ignore zero catches. It would be desirable, in future, to perform analyses that include (i) alternative effort unit(s), e.g. total net length and (ii) targeted gummy shark shots with no associated catches.

Like school shark, elephant fish are a non-targeted species, as indicated by the large proportion of small shots (i.e. <30 kg). Gillnet standardized CPUE is flat and noisy, while decreased in 2015, increased in 2016. However, this analysis ignores discarding and uses number of shots instead of net length as a unit of effort. In recent years discard rates for elephant fish have been very high, which may imply that their CPUE is in fact increasing. It would be desirable, in the future to perform analyses that account for discards.

Sawshark are considered to be a bycatch group which is supported by the high proportion of < 30 kg. Catches are reported by both gillnets, trawls and Danish seine. Standardized CPUE for gillnets exhibits a steady decline since about 2001, with small increases in recent years. However, a detailed analysis should be considered that uses net length as an effort unit instead of shot. Trawl caught sawshark standardized indices exhibit a noisy but flat trend, with an increase in 2014 reaching the long term average and an overall decrease below the long term average in 2016. By contrast, sawshark standardized CPUE by Danish seine (which has the highest proportion of shots < 30 kg among methods) has been flat since 2006 and increased above the long-term average in 2015, although not

significantly so. However, this species group is also discarded (16% to 50%; discarded for 2011-2016) may artificially inflate these estimates.

8.2 Introduction

Commercial catch and effort (CPUE) data are used in very many fishery stock assessments in Australia as an index of relative abundance. Using CPUE in this way assumes there is a direct relationship between catch rates and exploitable biomass. However, many other factors can influence catch rates, including vessel, gear, depth, season, area, and time of fishing (e.g. day or night). The use of CPUE as an index of relative abundance requires the removal of the effects of variation due to changes in these factors on the assumption that what remains will provide a better estimate of the underlying biomass dynamics. This process of adjusting the time series for the effects of other factors is known as standardization and the accepted way of doing this is to use some statistical modelling procedure that focuses attention onto the annual average catch rates adjusted for the variation in the averages brought about by all the other factors identified. The diversity of species and methods in the SESSF fishery means that each fishery/stock for which standardized catch rates are required entails its own set of conditions and selection of data. This report updates standardized indices (based on data to 2016 inclusive) for gummy shark (South Australia-gillnet; Bass Strait-gillnet; Tasmania gillnet; trawl; Bottom Line), school shark (Trawl), sawshark (gillnet; trawl; danish seine) and elephant fish (gillnet) within Australia's Southern and Eastern Scalefish and Shark Fishery (SESSF).

8.2.1 *The Limits of Standardization*

The use of commercial CPUE as an index of the relative abundance of exploitable biomass can be misleading when there are factors that significantly influence CPUE but cannot be accounted for in a generalized linear model (GLM) standardization analysis. Over the last two decades there have been a number of major management interventions in the South East Scalefish and Shark Fishery (SESSF) including the introduction of the quota management system in 1992 and that of the Harvest Strategy Policy (HSP) and associated structural adjustment in 2005 - 2007. The combination of limited quotas and the HSP is now controlling catches in such a way that many fishers have been altering their fishing behaviour to take into account the availability of quota and their own access to quota needed to land the species taken in the mixed species SESSF.

Some stocks, such as flathead, are currently near or around their target stock size and catch rates are at historically good levels. As a result of this success, some fishers report having to avoid catching species, such as flathead, so as to avoid having to discard and to stay within the bounds of their own quota holdings. Such influences on catch rates would tend to bias catch rates downwards, or at very least add noise to any CPUE signal, which could lead to misinformation passing to any assessment. Currently, there is no way to handle this issue, but care needs to be taken not to provide incorrectly conservative advice or inappropriately high catch targets. Included in the management changes is the on-going introduction of numerous area closures imposed for a range of different reasons.

8.3 Methods

8.3.1 *Catch Rate Standardization*

8.3.1.1 Preliminary Data Selection

The methods used when standardizing commercial catch and effort data in the SESSF continue to be discussed in the Commonwealth stock assessment RAGs because the catch rate time series (and associated standardized indices) are very influential in many of the assessments. Data were initially selected from the ORACLE database by CAAB code to obtain all data relating to a given species. Then selections were made using R (R Core Team, 2017) with respect to fishery (e.g. SET, GHT, GAB, etc), within a specified depth range and method (e.g. trawl, Auto Line, Danish seine etc) in specified statistical zones within the years specified for each analysis.

8.3.1.2 General Linear Modelling

In each case, catch rates, generally as kilograms per hour fished (though sometimes as catch per shot e.g. School Whiting caught by Danish Seine, or catch-per-hook for Blue-Eye Trevalla), were natural log-transformed. A General Linear Model was used rather than using a Generalized Linear Model with a log-link; this has advantages in terms of normalizing the data while stabilizing the variance, which the Generalized Linear Model approach does not always achieve appropriately (Venables & Dichmont, 2004). This relatively simple analytical approach means that the exact same methods can be applied to all species in a relatively robust manner. The statistical models were variants on the form: Ln(CPUE) = Year + Vessel + Month + Depth Category + Zone + DayNight. In addition, there were interaction terms which could sometimes be fitted, such as Month:Zone and/or Month:DepthCategory. Thus, the CPUE, conditioned on positive catches of the species of interest, was statistically modelled with a normal GLM on log-transformed CPUE data:

$$Ln(CPUE_i) = \alpha_0 + \alpha_1 x_{i,1} + \alpha_2 x_{i,2} + \sum_{j=3}^{N} \alpha_i x_{i,j} + \varepsilon_i$$

where Ln($CPUE_i$) is the natural logarithm of the catch rate (usually kg/hr, but sometimes kg/shot) for the i-th shot, x_{ij} are the values of the explanatory variables j for the i-th shot and the α_j are the coefficients for the N factors j to be estimated (where α_0 is the intercept, α_1 is the coefficient for the first factor, etc.).

8.3.1.3 The Mean Year Estimates

For the lognormal model the expected back-transformed year effect involves a bias-correction to account for the log-normality; this then focuses on the mean of the distribution rather than the median:

$$CPUE_t = e^{(\gamma_t + \sigma_t^2/2)}$$

where γ_t is the Year coefficient for year t and σ_t is the standard deviation of the log transformed data (obtained from the analysis). The year coefficients were all divided by the average of all the Year coefficients to simplify the visual comparison of catch rate changes.

$$CE_t = \frac{CPUE_t}{(\sum CPUE_t)/n}$$

where $CPUE_t$ is the yearly coefficients from the standardization, $(CPUE_t)/n$ is the arithmetic average of the yearly coefficients, n is the number of years of observations, and CE_t is the final time series of yearly index of relative abundance.

8.3.1.4 Model Development and Selection

In each case an array of statistical models are fitted sequentially to the available data, with the order of the non-interaction terms being determined by the relative contribution of each term to model fit.

This sequential development of the standardization models for each species simplifies the search for the optimum model and requires a consideration of different performance statistics such as the AIC (Akaike's Information Criterion, the smaller the better; Burnham and Anderson, 1992) or adjusted R^2 (the larger the better; Neter et al, 1996). In addition, the examination of the various diagnostic plots and tables allows for an improved interpretation of the observed trends.

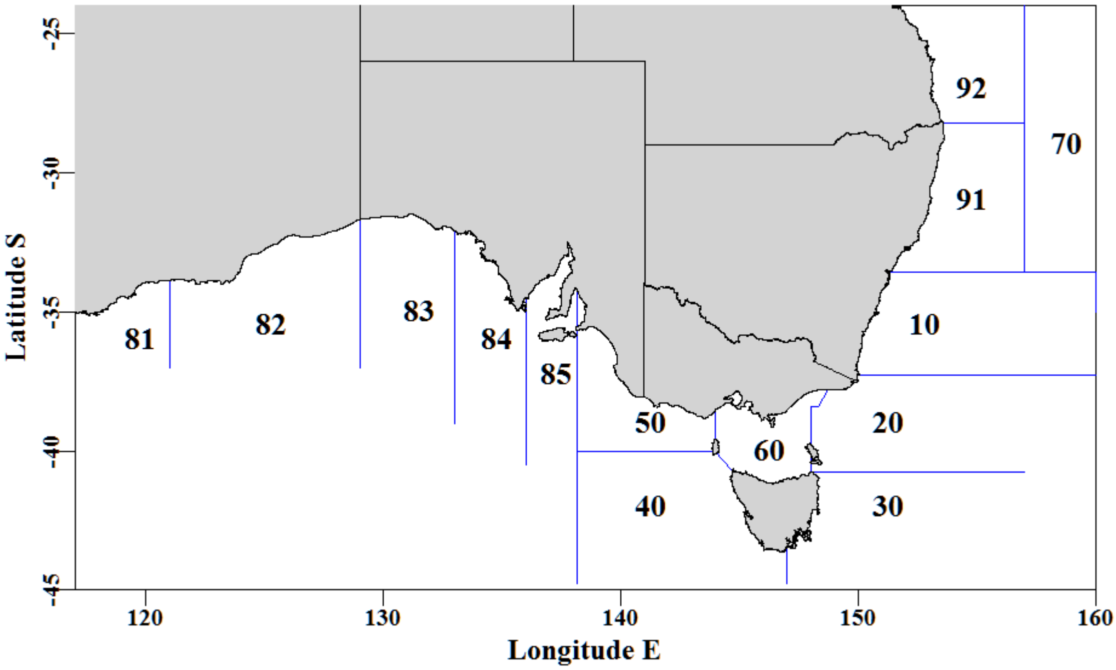


Figure 8.1. The statistical reporting zones in the SESSF.

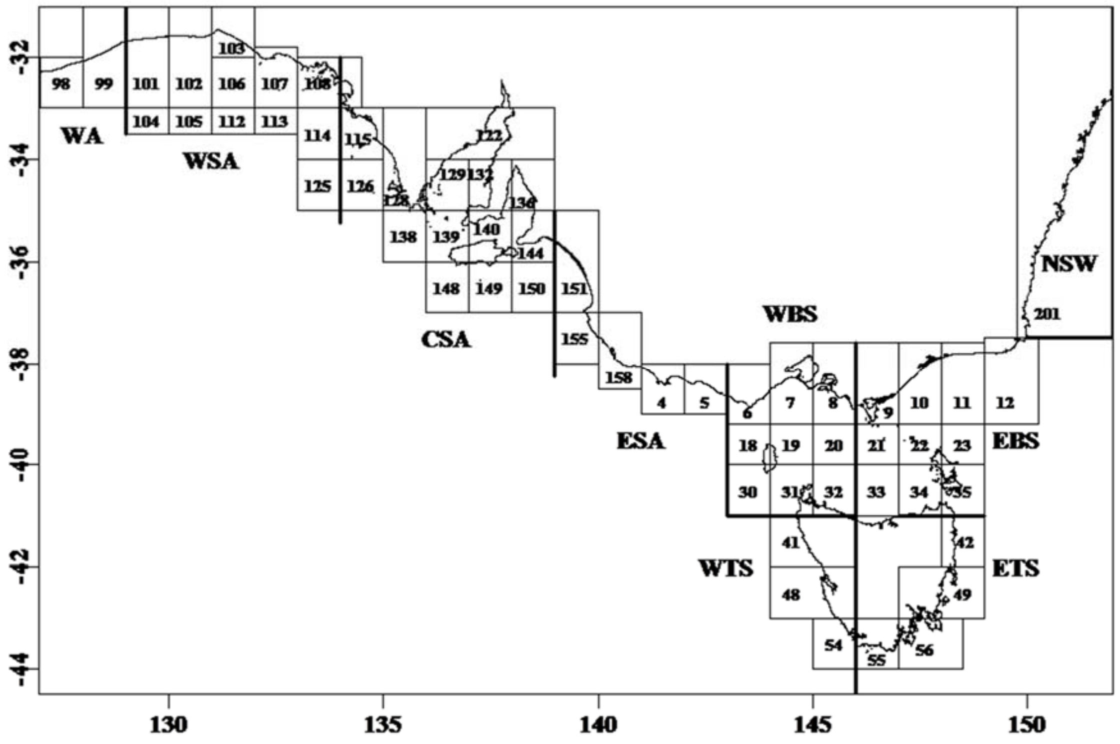


Figure 8.2. Shark statistical reporting areas and statistical regions. WA is Western Australia, WSA is Western South Australia, CSA is Central South Australia, ESA is Eastern South Australia (sometimes known as SAV - South Australia Victoria), WBS is Western Bass Strait, EBS is Eastern Bass Strait, NSW is New South Wales, ETS is Eastern Tasmania and WTS is Western Tasmania.

8.4 Gummy shark: South Australia Gillnet

Positive non-zero records of catch per shot were employed in the statistical standardization analyses for gummy shark caught by gillnets. Further investigation should be considered to determine whether total net length could be used as an alternative effort unit in standardization analyses.

8.4.1 *Inferences*

A total of 7 statistical models were fitted sequentially to the available data. The qqplot suggests a minor departure from the assumed Normal distribution. Standardized CPUE rose above the long term average in 2016.

8.4.2 *Action Items and Issues*

A further consideration of whether or not to consider the CPUE time-series as a valid index of relative abundance for gummy shark needs to be explored.

Table 8.1. GummySharkSA. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	GummySharkSA
csirocode	37017001
fishery	GHT_SEN_SSF_SSG_SSH
depthrange	0 - 160
depthclass	20
zones	1, 2, 3, 9
methods	GN
years	1997 - 2016

Table 8.2. GummySharkSA. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was SharkRegion:DepCat.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1997	952.1	4826	431.9	56	96.2	1.1148	0.000	27.199	0.063
1998	1401.1	7367	521.1	53	72.6	0.8948	0.022	50.807	0.097
1999	1923.8	6842	648.7	49	100.1	1.0754	0.023	38.963	0.060
2000	2436.9	6072	875.6	37	160.3	1.5436	0.024	24.242	0.028
2001	1703.3	5541	414.7	35	81.6	0.8373	0.025	30.145	0.073
2002	1527.1	5846	437.3	32	80.5	0.9012	0.025	35.877	0.082
2003	1653.0	5943	495.9	37	93.6	0.9736	0.025	33.592	0.068
2004	1669.9	5654	476.6	40	95.4	0.9991	0.026	30.295	0.064
2005	1573.2	5137	483.7	29	104.4	1.0746	0.027	27.698	0.057
2006	1577.1	5968	548.7	28	100.6	1.1022	0.026	31.127	0.057
2007	1575.0	4549	438.5	29	107.0	1.1615	0.027	22.012	0.050
2008	1727.7	4907	543.5	23	122.4	1.3571	0.027	21.515	0.040
2009	1500.9	5157	418.2	23	87.4	1.0348	0.027	30.674	0.073
2010	1404.8	5258	389.8	28	79.6	0.9062	0.027	32.880	0.084
2011	1364.7	3272	229.0	19	78.3	0.7940	0.031	21.004	0.092
2012	1304.2	1371	83.0	15	62.3	0.5945	0.039	10.043	0.121
2013	1307.6	800	60.5	18	77.6	0.6284	0.048	5.370	0.089
2014	1389.1	1462	126.0	19	96.5	0.8375	0.040	7.559	0.060
2015	1545.1	1544	151.6	15	105.7	0.9896	0.041	7.796	0.051
2016	1573.0	1062	134.5	11	132.4	1.1799	0.049	3.783	0.028

Table 8.3. GummySharkSA data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	370141.0	364263.0	338458.0	327256.0	117762.0	88578.0	88578.0
Difference	0.0	5878.0	25805.0	11202.0	209494.0	29184.0	0.0
Catch	31552.8	31552.8	30648.7	30266.6	9443.7	7908.9	7908.9
Difference	0.0	0.0	904.1	382.1	20822.9	1534.8	0.0

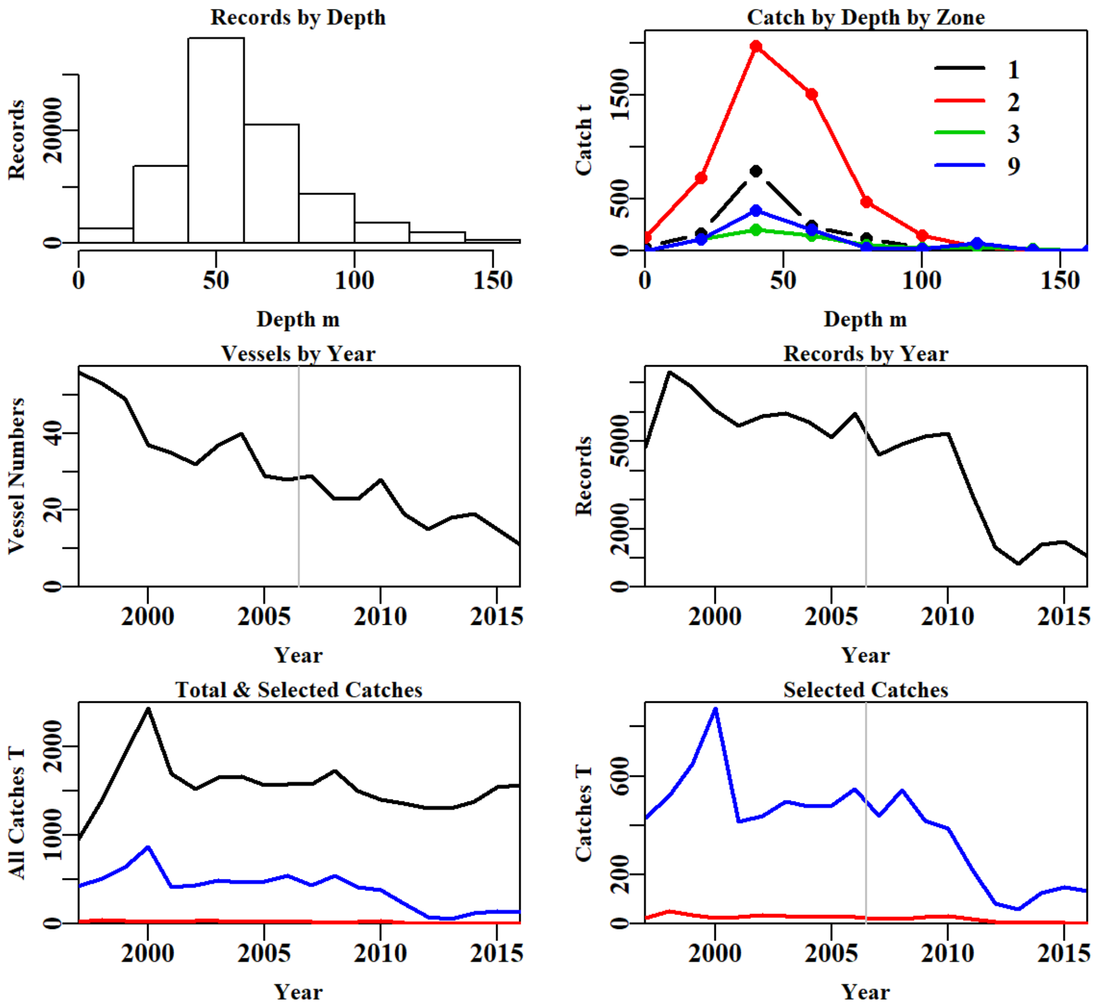


Figure 8.3. GummySharkSA fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 8.4. The models used to analyse data for GummySharkSA.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + SharkRegion
Model5	Year + Vessel + DepCat + SharkRegion + Month
Model6	Year + Vessel + DepCat + SharkRegion + Month + SharkRegion:DepCat
Model7	Year + Vessel + DepCat + SharkRegion + Month + SharkRegion:Month

Table 8.5. GummySharkSA. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was SharkRegion:DepCat.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	29105	122979	3358	88578	20	2.6	0.00
Vessel	24970	117004	9333	88578	158	7.2	4.59
DepCat	24067	115796	10540	88578	166	8.2	0.95
SharkRegion	23741	115364	10973	88578	169	8.5	0.34
Month	22515	113749	12587	88578	180	9.8	1.27
SharkRegion:DepCat	21610	112532	13805	88578	204	10.7	0.94
SharkRegion:Month	22131	113173	13163	88578	213	10.2	0.42

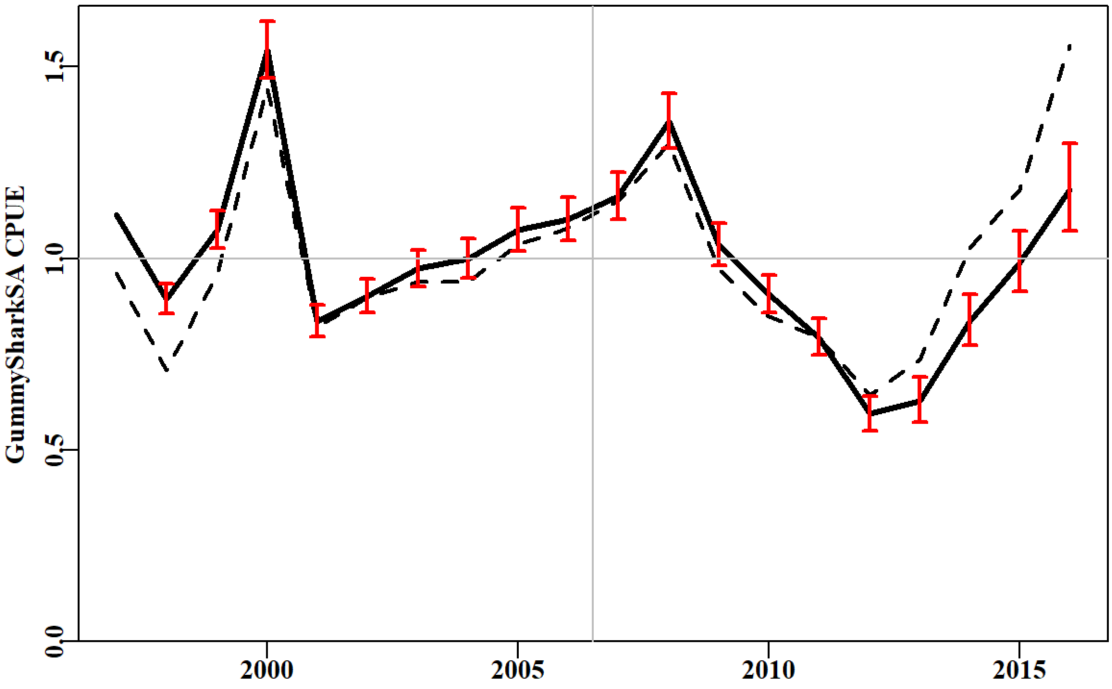


Figure 8.4. GummySharkSA standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

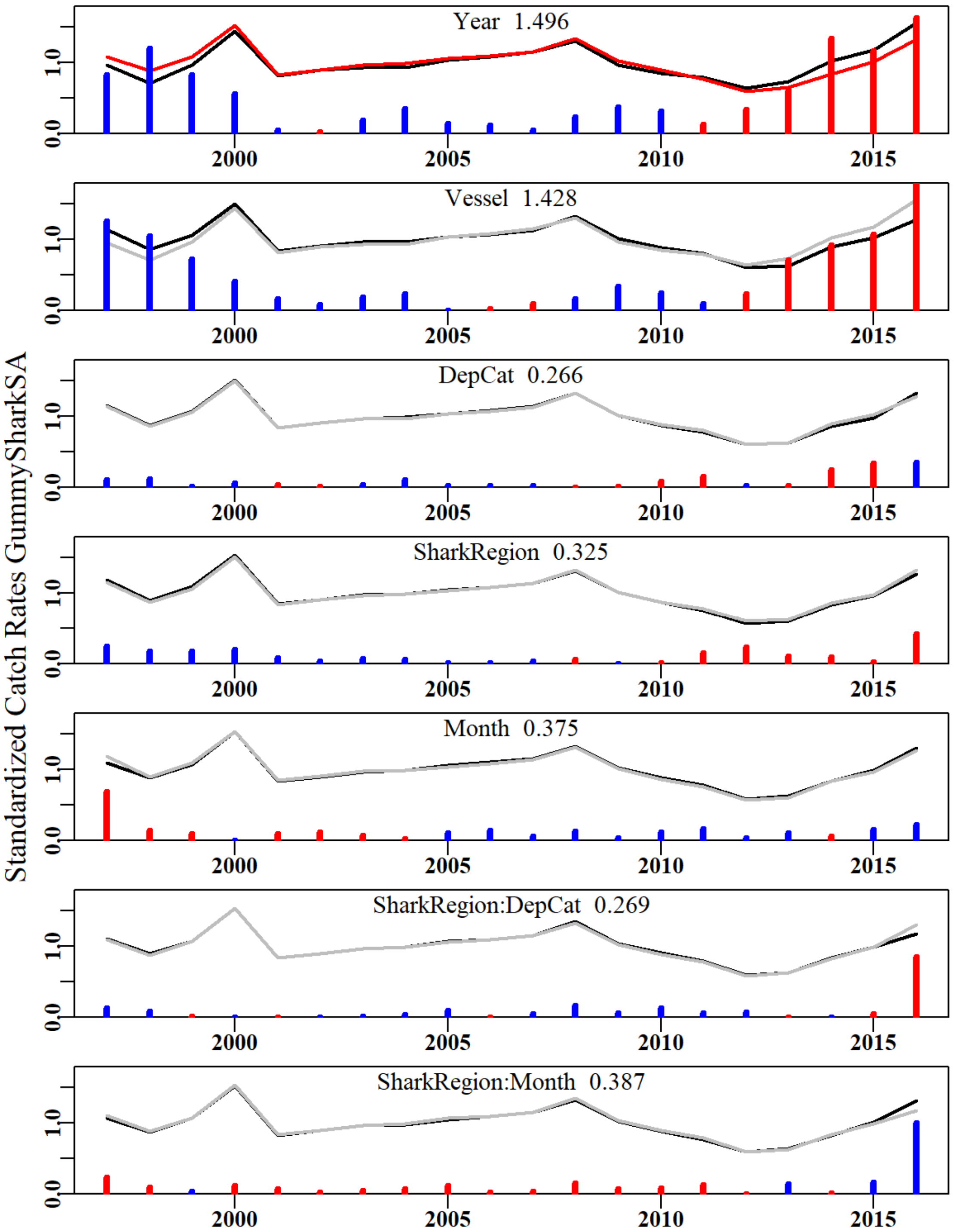


Figure 8.5. GummySharkSA. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

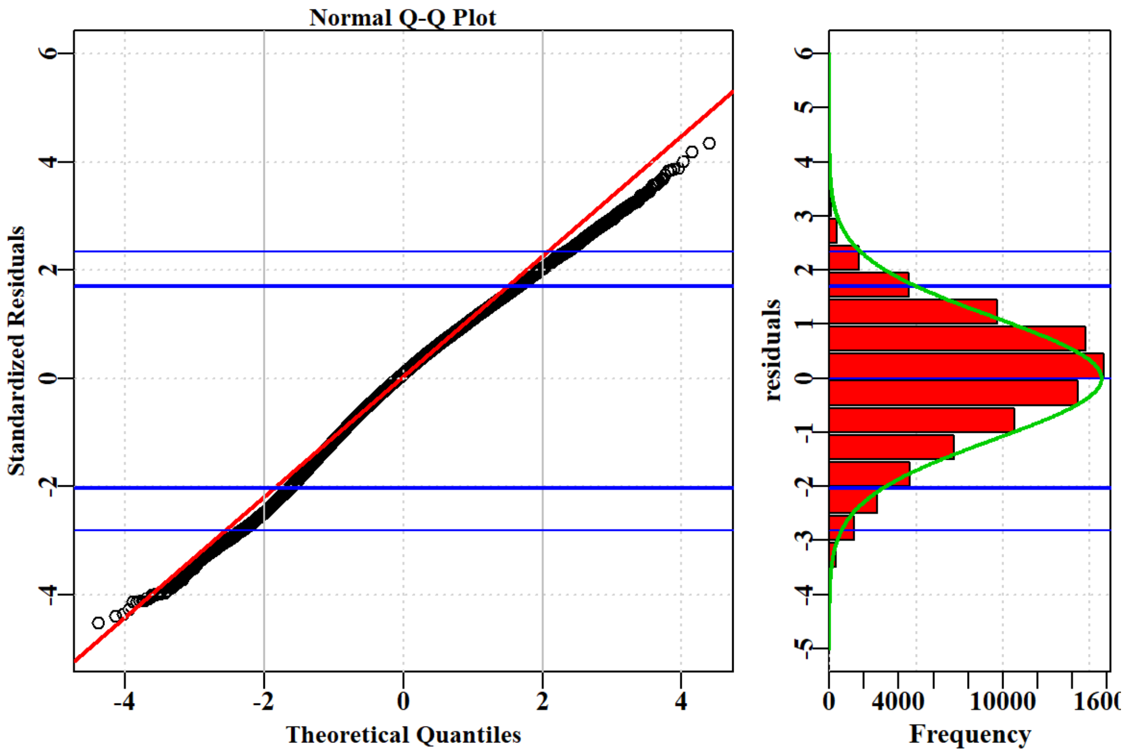


Figure 8.6. GummySharkSA. Diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

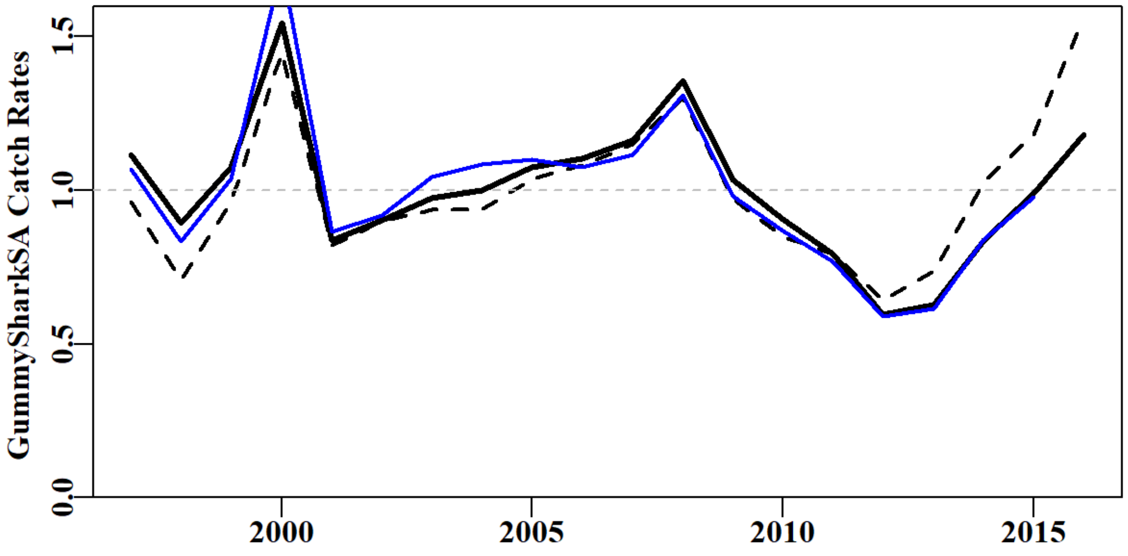


Figure 8.7. GummySharkSA. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

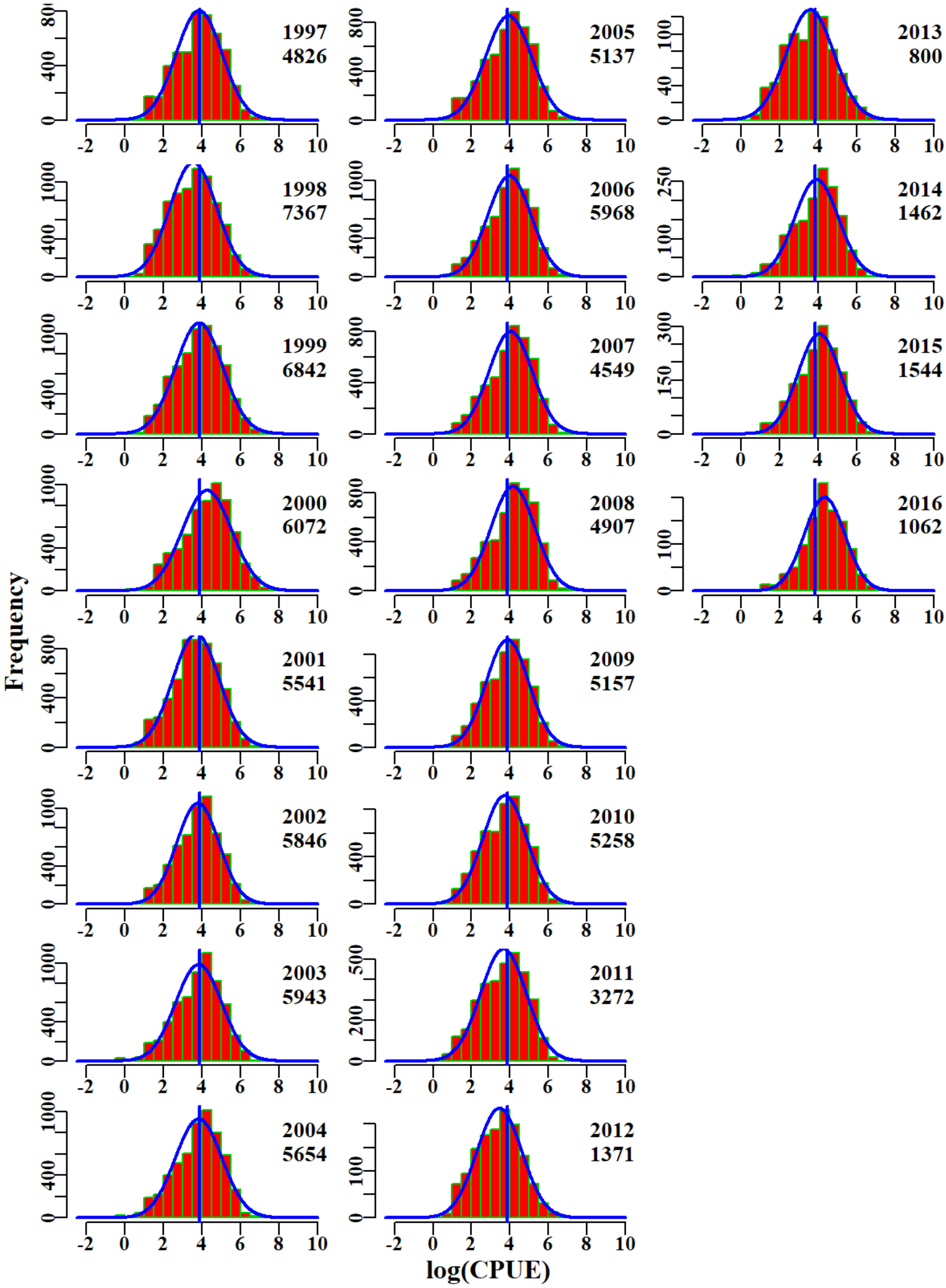


Figure 8.8. GummySharkSA. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

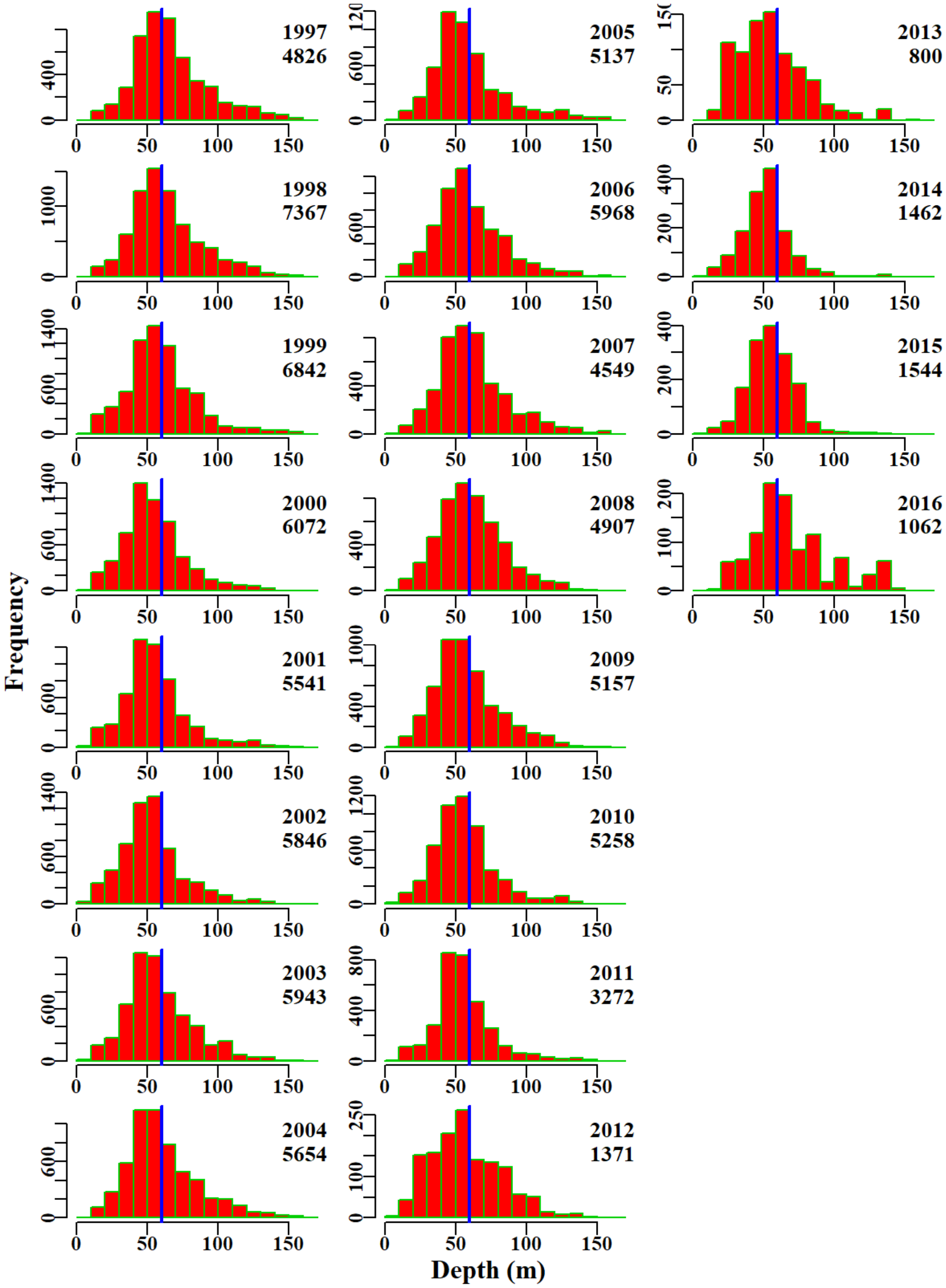


Figure 8.9. GummySharkSA. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

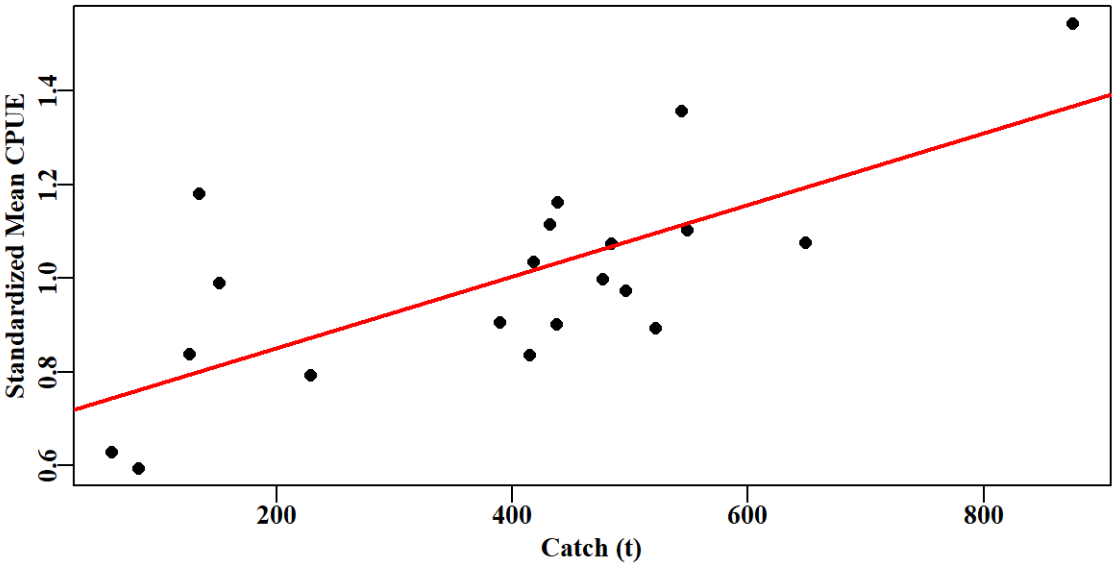


Figure 8.10. GummySharkSA. The linear relationship between Annual mean CPUE and Annual Catch.

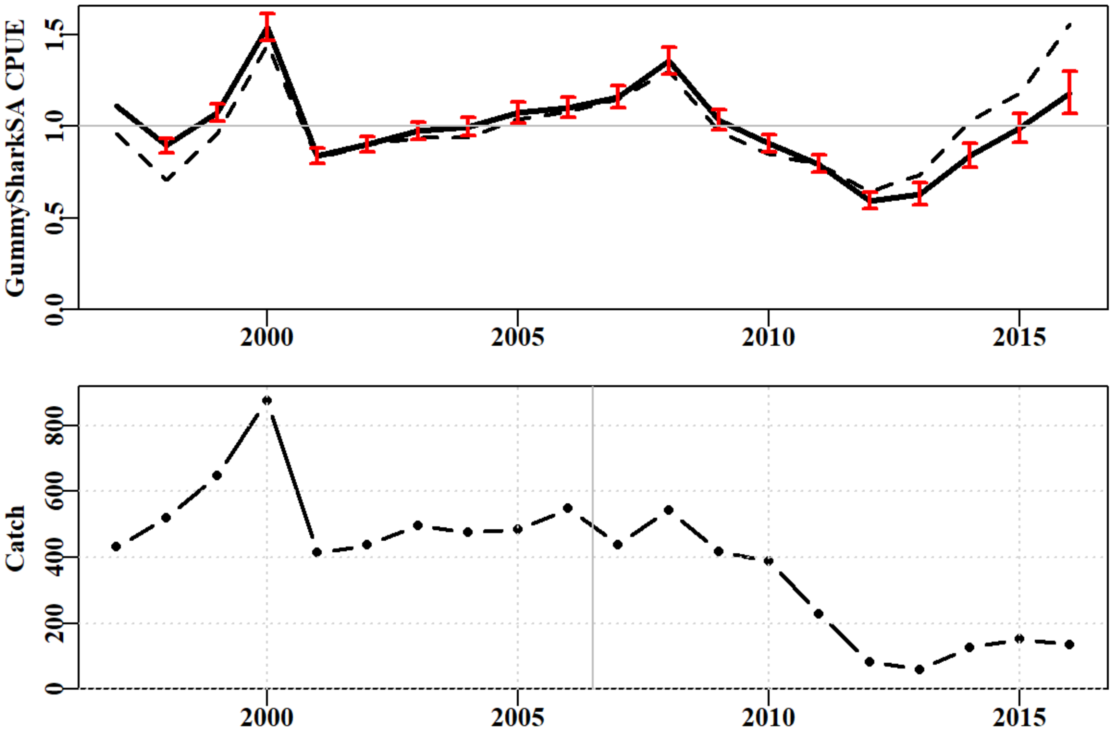


Figure 8.11. GummySharkSA. CPUE is correlated with catches through time. CPUE in the top plot and annual catch (t) in the lower plot.

8.5 Gummy shark: Bass Strait Gillnet

Positive non-zero records of catch per shot were employed in the statistical standardization analyses for gummy shark caught by gillnets. Further investigation should be considered to determine whether total net length could be used as an alternative effort unit in standardization analyses.

8.5.1 *Inferences*

A total of 7 statistical models were fitted sequentially to the available data. The optimum model was fitted with terms: Year, Vessel, DepCat, SharkRegion, Month and the interaction SharkRegion x Month. The first two terms had the greatest contribution to model fit. There appears to be a slight departure from the assumed Normal distribution as depicted by the qqplot. Standardized CPUE has been steadily increasing above the long term average since 2015.

8.5.2 *Action Items and Issues*

A further consideration of whether or not to consider the CPUE time-series as a valid index of relative abundance for gummy shark needs to be explored.

Table 8.6. GummySharkBS. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	GummySharkBS
csirocode	37017001
fishery	GHT_SEN_SSF_SSG_SSH
depthrange	0 - 160
depthclass	20
zones	4, 5
methods	GN
years	1997 - 2016

Table 8.7. GummySharkBS. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was SharkRegion:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1997	952.1	4397	417.0	50	103.8	0.6506	0.000	23.872	0.057
1998	1401.1	5947	704.8	51	132.4	0.7877	0.024	26.642	0.038
1999	1923.8	6666	1030.9	56	176.6	1.0313	0.024	25.060	0.024
2000	2436.9	6922	1257.5	49	211.5	1.1181	0.024	22.653	0.018
2001	1703.3	6318	1051.1	47	202.3	0.9929	0.024	20.486	0.019
2002	1527.1	6299	833.8	47	157.5	0.8115	0.025	24.050	0.029
2003	1653.0	6626	883.3	44	159.9	0.8048	0.025	25.951	0.029
2004	1669.9	6289	879.9	41	162.5	0.8707	0.025	21.121	0.024
2005	1573.2	5280	811.4	39	171.0	0.9684	0.026	15.256	0.019
2006	1577.1	4064	727.6	33	201.4	1.1000	0.027	10.785	0.015
2007	1575.0	3479	873.9	25	291.6	1.3431	0.028	7.472	0.009
2008	1727.7	3671	954.6	26	301.9	1.4396	0.028	7.287	0.008
2009	1500.9	4089	831.5	28	233.8	1.2554	0.028	9.391	0.011
2010	1404.8	4408	738.0	31	191.3	1.0072	0.027	13.268	0.018
2011	1364.7	5171	797.9	32	173.6	0.9044	0.027	18.833	0.024
2012	1304.2	5441	780.2	37	162.2	0.8713	0.026	19.117	0.025
2013	1307.6	5347	757.9	36	160.6	0.8358	0.026	21.012	0.028
2014	1389.1	5261	813.4	36	175.7	0.8938	0.026	18.070	0.022
2015	1545.1	4945	979.5	30	233.4	1.0917	0.027	13.152	0.013
2016	1573.0	5135	1109.2	31	250.6	1.2218	0.027	13.086	0.012

Table 8.8. GummySharkBS data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	370141.0	364263.0	338458.0	327256.0	167043.0	105755.0	105755.0
Difference	0.0	5878.0	25805.0	11202.0	160213.0	61288.0	0.0
Catch	31552.8	31552.8	30648.7	30266.6	18379.7	17233.3	17233.3
Difference	0.0	0.0	904.1	382.1	11886.9	1146.4	0.0

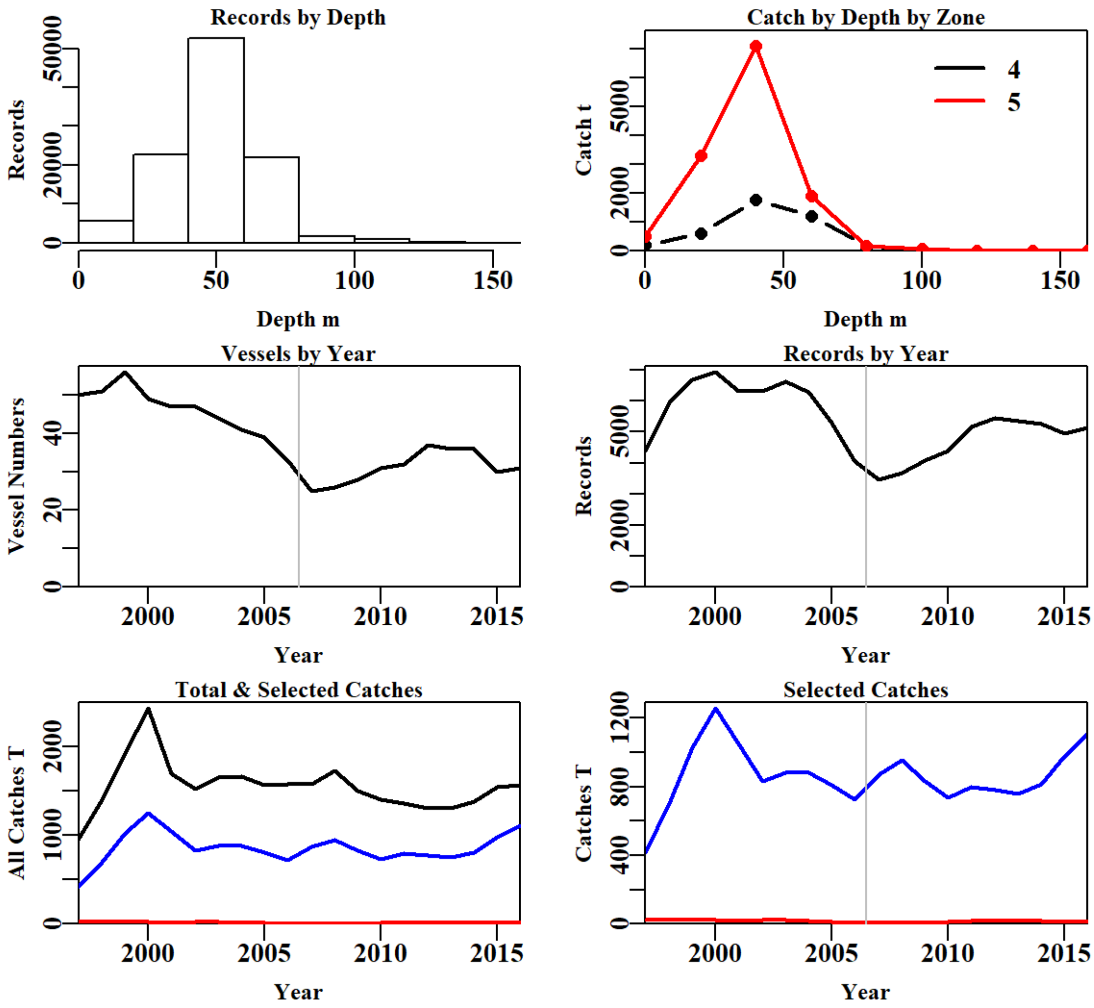


Figure 8.12. GummySharkBS fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 8.9. The models used to analyse data for GummySharkBS.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + SharkRegion
Model5	Year + Vessel + DepCat + SharkRegion + Month
Model6	Year + Vessel + DepCat + SharkRegion + Month + SharkRegion:DepCat
Model7	Year + Vessel + DepCat + SharkRegion + Month + SharkRegion:Month

Table 8.10. GummySharkBS. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was SharkRegion:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	42665	158250	5692	105755	20	3.5	0.00
Vessel	34510	146182	17760	105755	137	10.7	7.26
DepCat	33694	145037	18905	105755	145	11.4	0.69
SharkRegion	33694	145034	18908	105755	146	11.4	0.00
Month	33068	144148	19794	105755	157	11.9	0.53
SharkRegion:DepCat	32996	144031	19911	105755	164	12.0	0.07
SharkRegion:Month	32798	143751	20191	105755	168	12.2	0.23

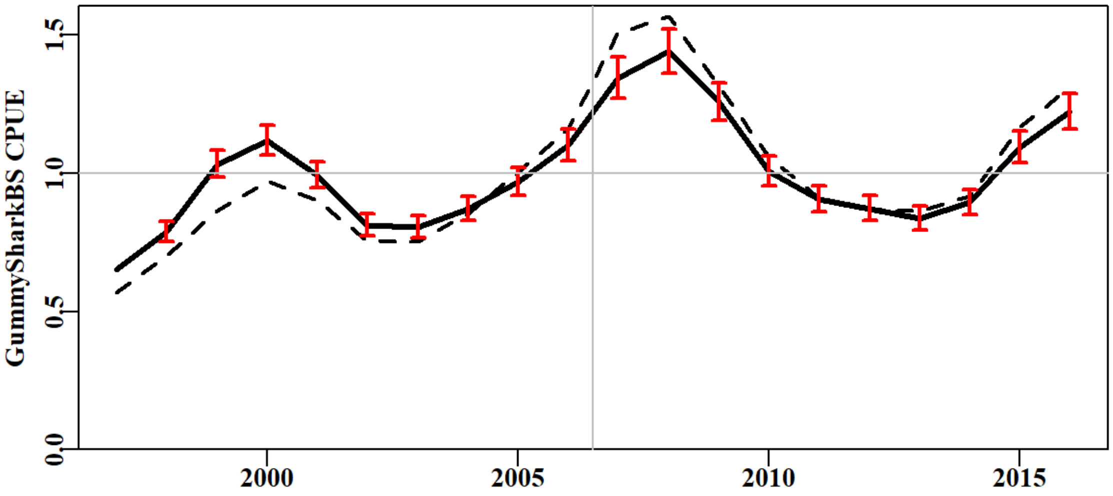


Figure 8.13. GummySharkBS standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

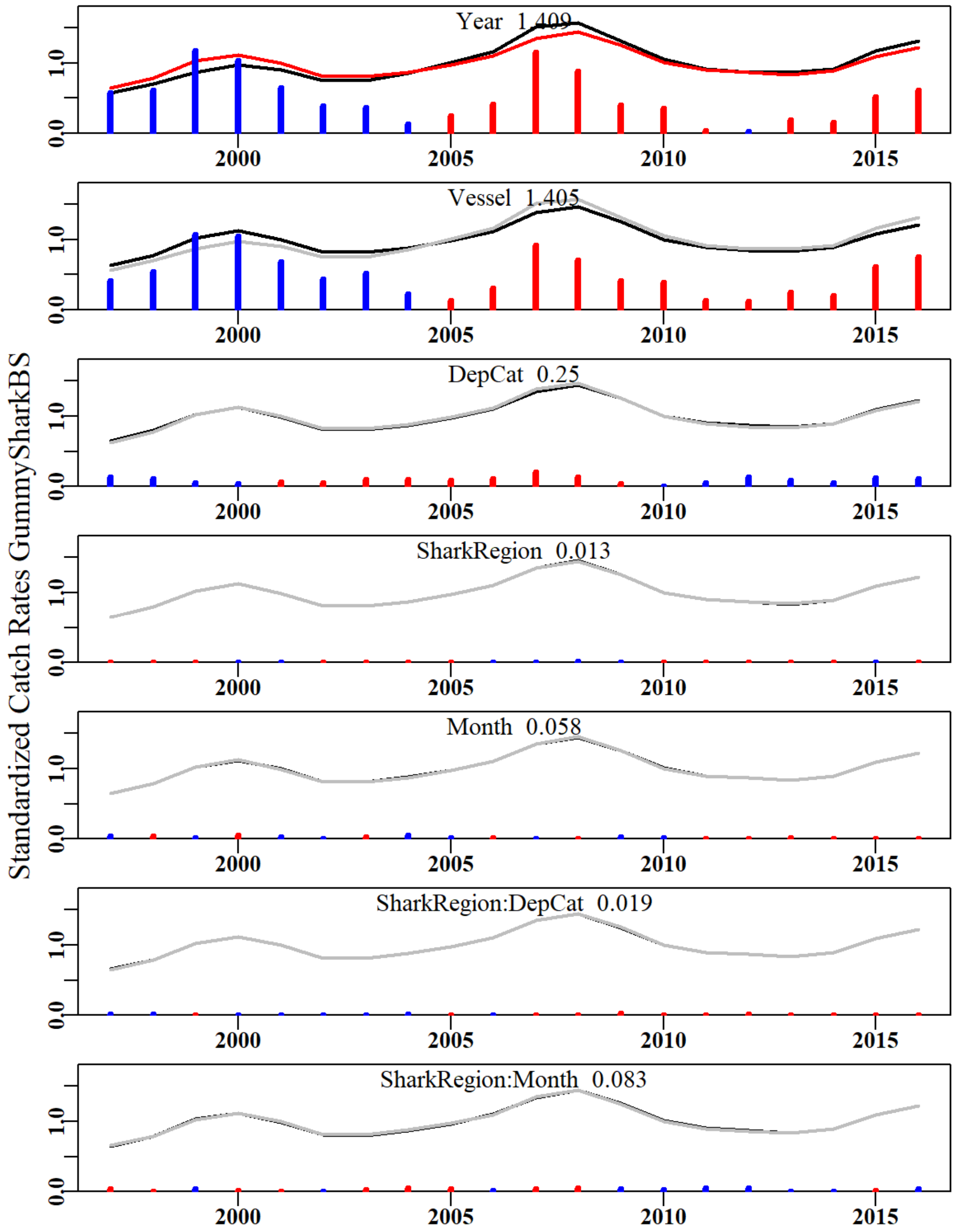


Figure 8.14. GummySharkBS. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

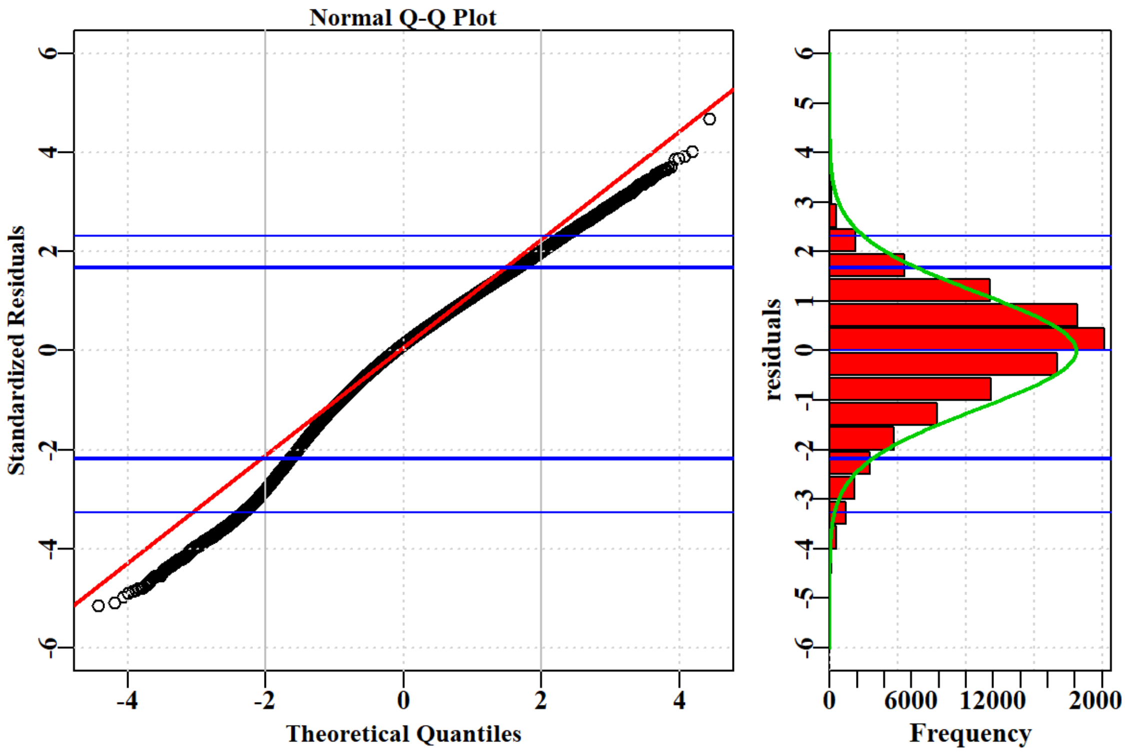


Figure 8.15. GummySharkBS. Diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

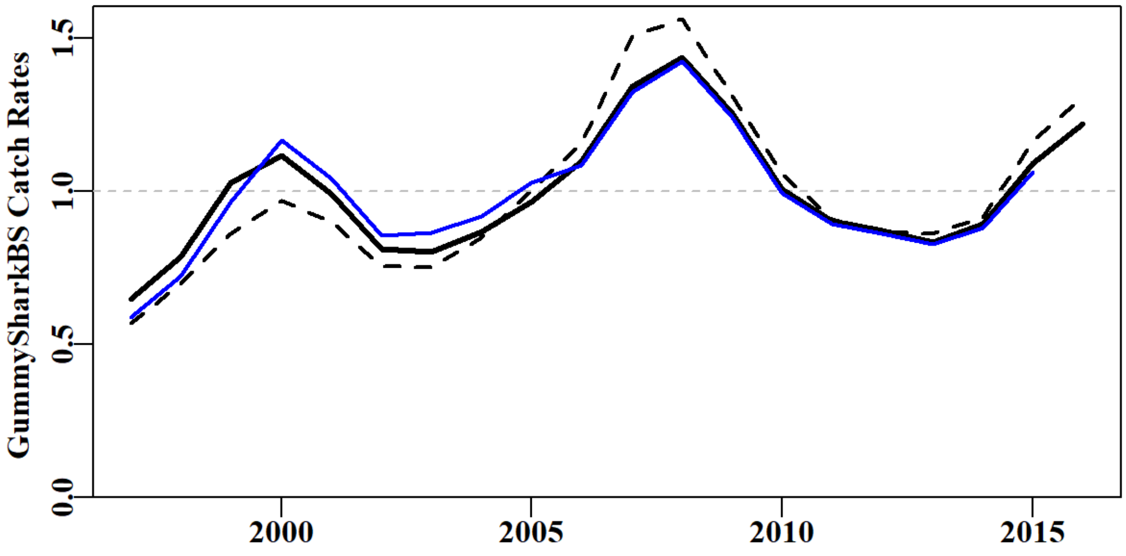


Figure 8.16. GummySharkBS. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

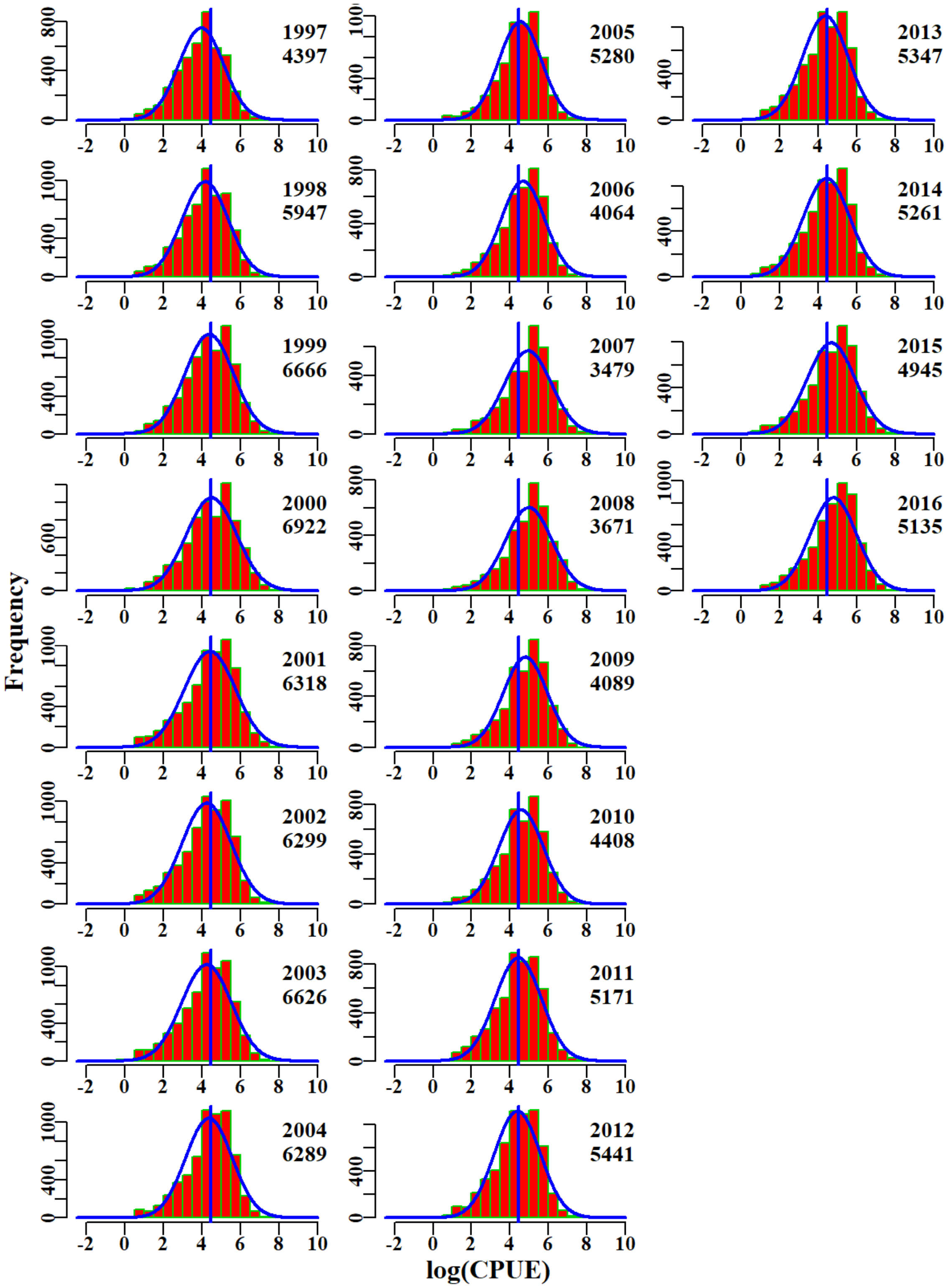


Figure 8.17. GummySharkBS. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

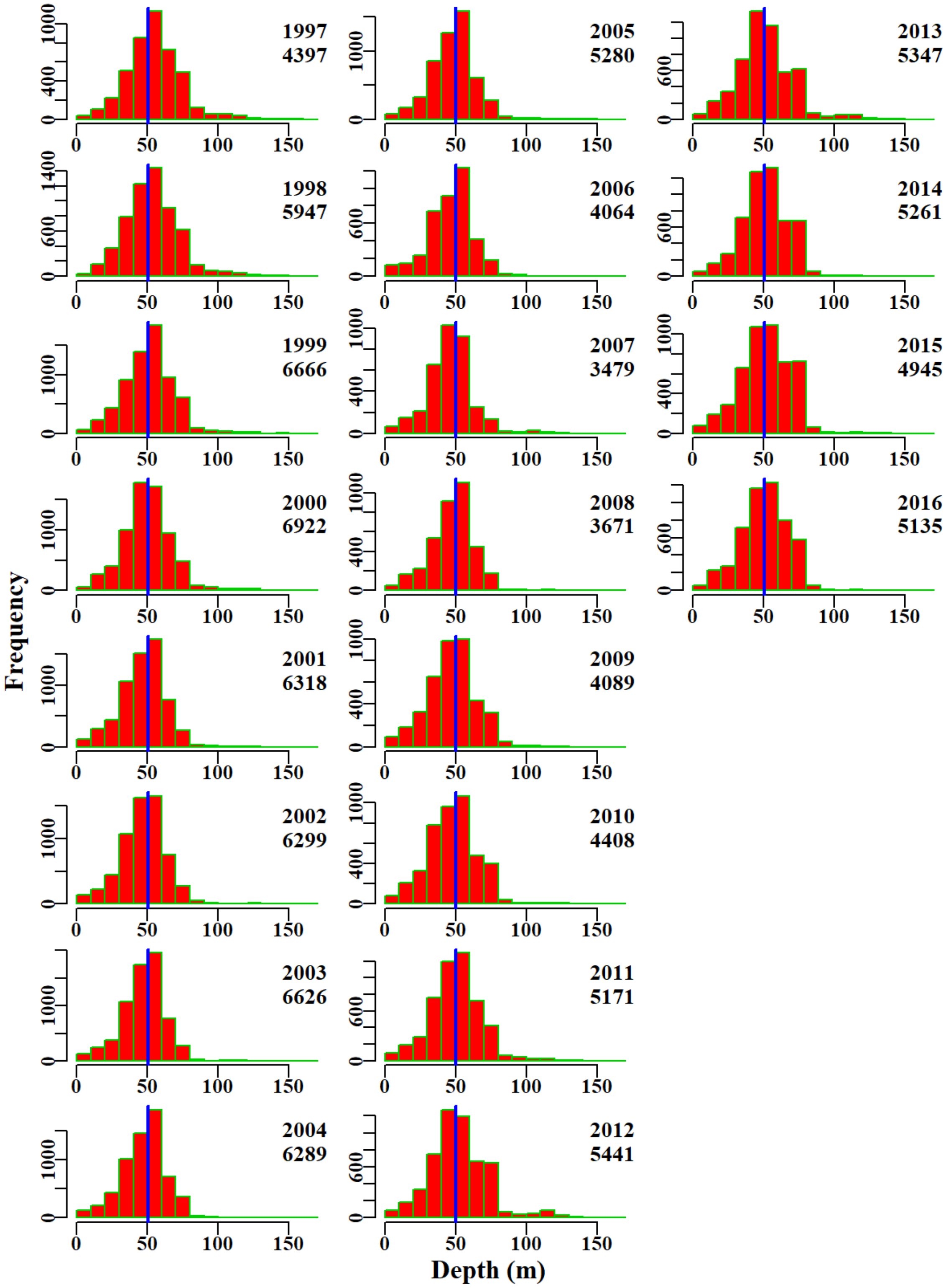


Figure 8.18. GummySharkBS. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

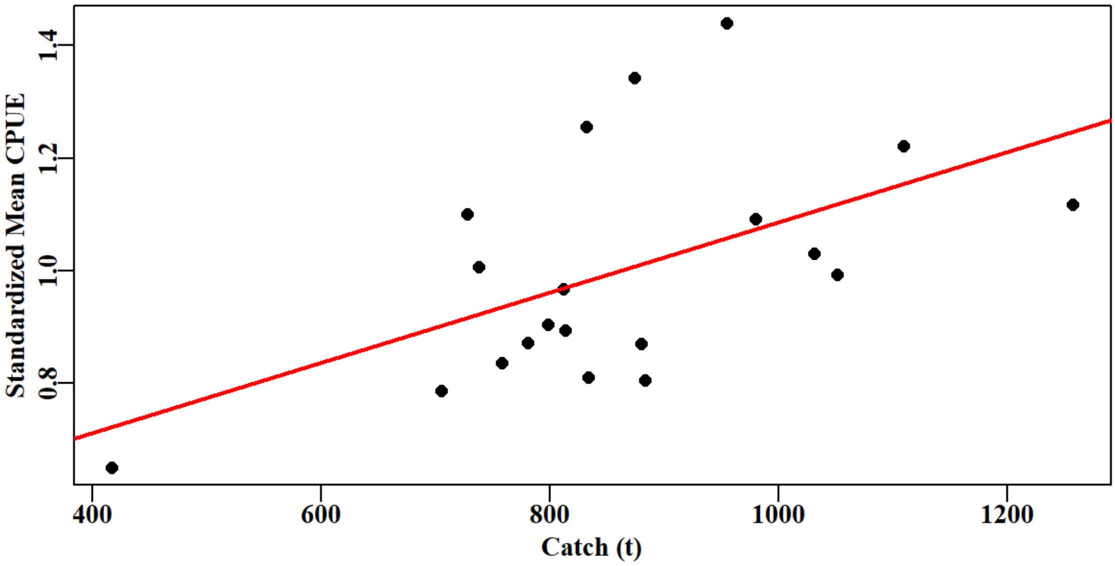


Figure 8.19. GummySharkBS. The linear relationship between Annual mean CPUE and Annual Catch.

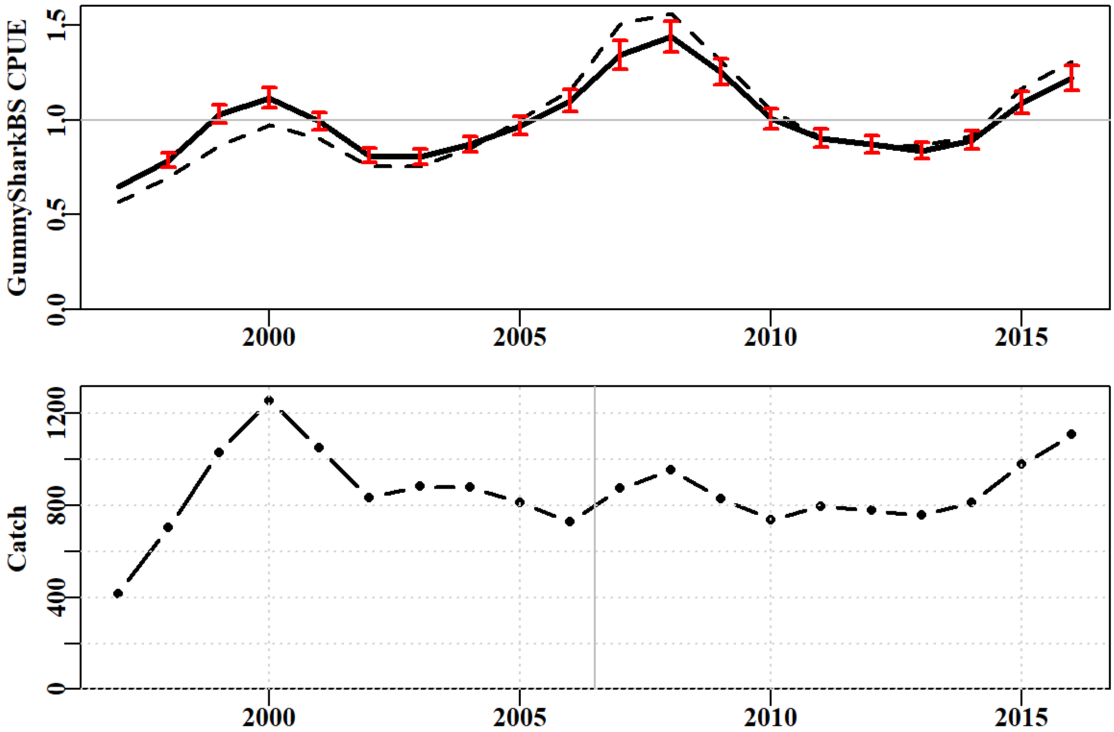


Figure 8.20. GummySharkBS. CPUE is correlated with catches through time. CPUE in the top plot and annual catch (t) in the lower plot.

8.6 Gummy shark: Tasmania Gillnet

Positive non-zero records of catch per shot were employed in the statistical standardization analyses for gummy shark caught by gillnets. Further investigation should be considered to determine whether total net length could be used as an alternative effort unit in standardization analyses.

8.6.1 Inferences

A total of 7 statistical models were fitted sequentially to the available data. The optimum model was fitted with terms: Year, Vessel, DepCat, SharkRegion, Month and the interaction SharkRegion x Month. The first two terms had the greatest contribution to model fit. The assumed Normal distribution appears to be valid as depicted by the qqplot. Standardized CPUE has been mostly flat since 1997 and increased above the long term average in 2016 (accounting for standard errors).

8.6.2 Action Items and Issues

A further consideration of whether or not to consider the CPUE time-series as a valid index of relative abundance for gummy shark needs to be explored.

Table 8.11. GummySharkTA. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	GummySharkTA
csirocode	37017001
fishery	GHT_SEN_SSF_SSG_SSH
depthrange	0 - 160
depthclass	20
zones	6, 7
methods	GN
years	1997 - 2016

Table 8.12. GummySharkTA. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was SharkRegion:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1997	952.1	203	17.3	14	96.0	0.7853	0.000	1.231	0.071
1998	1401.1	529	55.3	14	122.1	0.7074	0.109	3.061	0.055
1999	1923.8	854	102.0	18	134.8	0.9786	0.107	3.926	0.038
2000	2436.9	544	82.6	18	169.2	1.1864	0.113	1.909	0.023
2001	1703.3	600	65.1	21	125.2	1.2260	0.116	2.672	0.041
2002	1527.1	781	100.4	26	159.5	1.1460	0.116	3.399	0.034
2003	1653.0	873	90.5	23	118.0	1.2688	0.117	4.674	0.052
2004	1669.9	917	120.9	26	169.0	1.2090	0.116	3.893	0.032
2005	1573.2	657	85.8	15	157.2	1.0928	0.119	2.646	0.031
2006	1577.1	697	116.8	15	191.0	1.2287	0.119	2.334	0.020
2007	1575.0	835	95.3	14	135.6	1.0518	0.118	4.041	0.042
2008	1727.7	635	61.8	14	109.9	0.9124	0.120	3.464	0.056
2009	1500.9	527	67.2	14	160.0	1.0883	0.125	2.199	0.033
2010	1404.8	534	75.5	14	172.2	1.0838	0.125	2.089	0.028
2011	1364.7	687	102.7	13	178.8	0.8927	0.128	2.212	0.022
2012	1304.2	1119	130.0	18	126.8	0.9467	0.124	5.852	0.045
2013	1307.6	910	96.6	15	111.5	0.7859	0.127	4.804	0.050
2014	1389.1	482	65.1	13	144.0	0.7238	0.136	2.146	0.033
2015	1545.1	359	53.4	11	166.6	0.7019	0.137	1.439	0.027
2016	1573.0	344	68.1	7	235.9	0.9838	0.137	0.952	0.014

Table 8.13. GummySharkTA data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	370141.0	364263.0	338458.0	327256.0	20809.0	13087.0	13087.0
Difference	0.0	5878.0	25805.0	11202.0	306447.0	7722.0	0.0
Catch	31552.8	31552.8	30648.7	30266.6	1923.8	1652.4	1652.4
Difference	0.0	0.0	904.1	382.1	28342.8	271.5	0.0

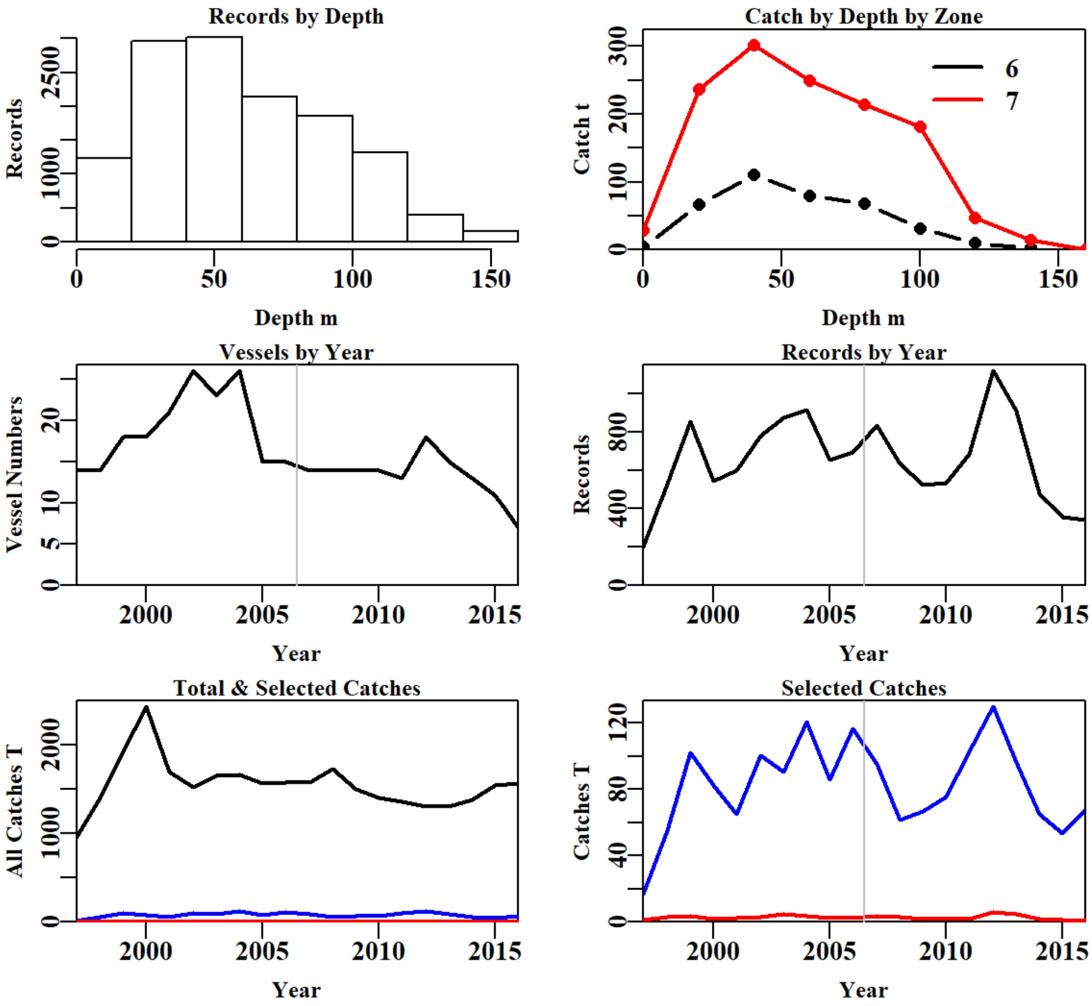


Figure 8.21. GummySharkTA fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 8.14. The models used to analyse data for GummySharkTA.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + SharkRegion
Model5	Year + Vessel + DepCat + SharkRegion + Month
Model6	Year + Vessel + DepCat + SharkRegion + Month + SharkRegion:DepCat
Model7	Year + Vessel + DepCat + SharkRegion + Month + SharkRegion:Month

Table 8.15. GummySharkTA. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was SharkRegion:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	6726	21813	587	13087	20	2.5	0.00
Vessel	1470	14425	7975	13087	98	35.1	32.65
DepCat	1447	14382	8018	13087	106	35.3	0.15
SharkRegion	1448	14381	8019	13087	107	35.3	0.00
Month	1139	14022	8378	13087	118	36.8	1.56
SharkRegion:DepCat	1105	13971	8429	13087	125	37.0	0.20
SharkRegion:Month	1060	13914	8486	13087	129	37.3	0.43

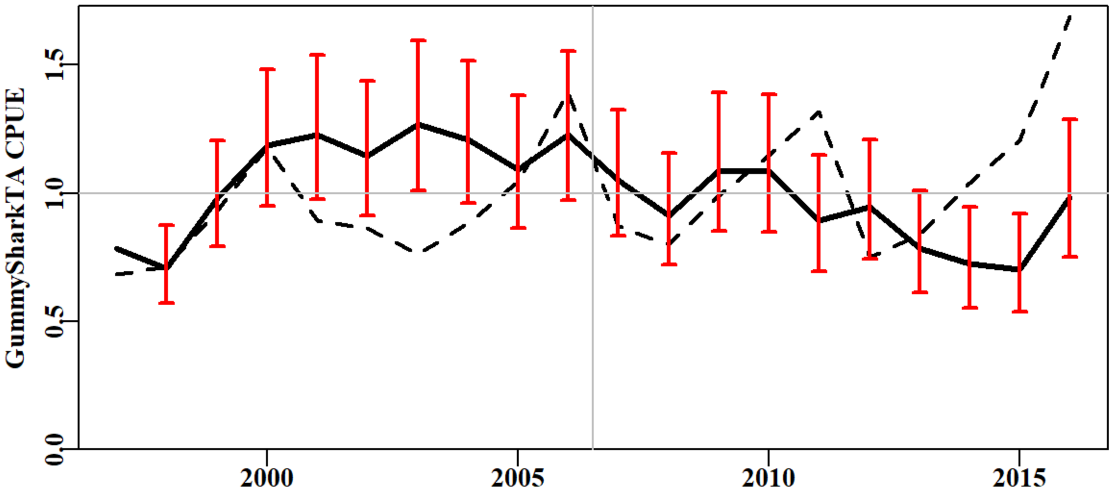


Figure 8.22. GummySharkTA standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

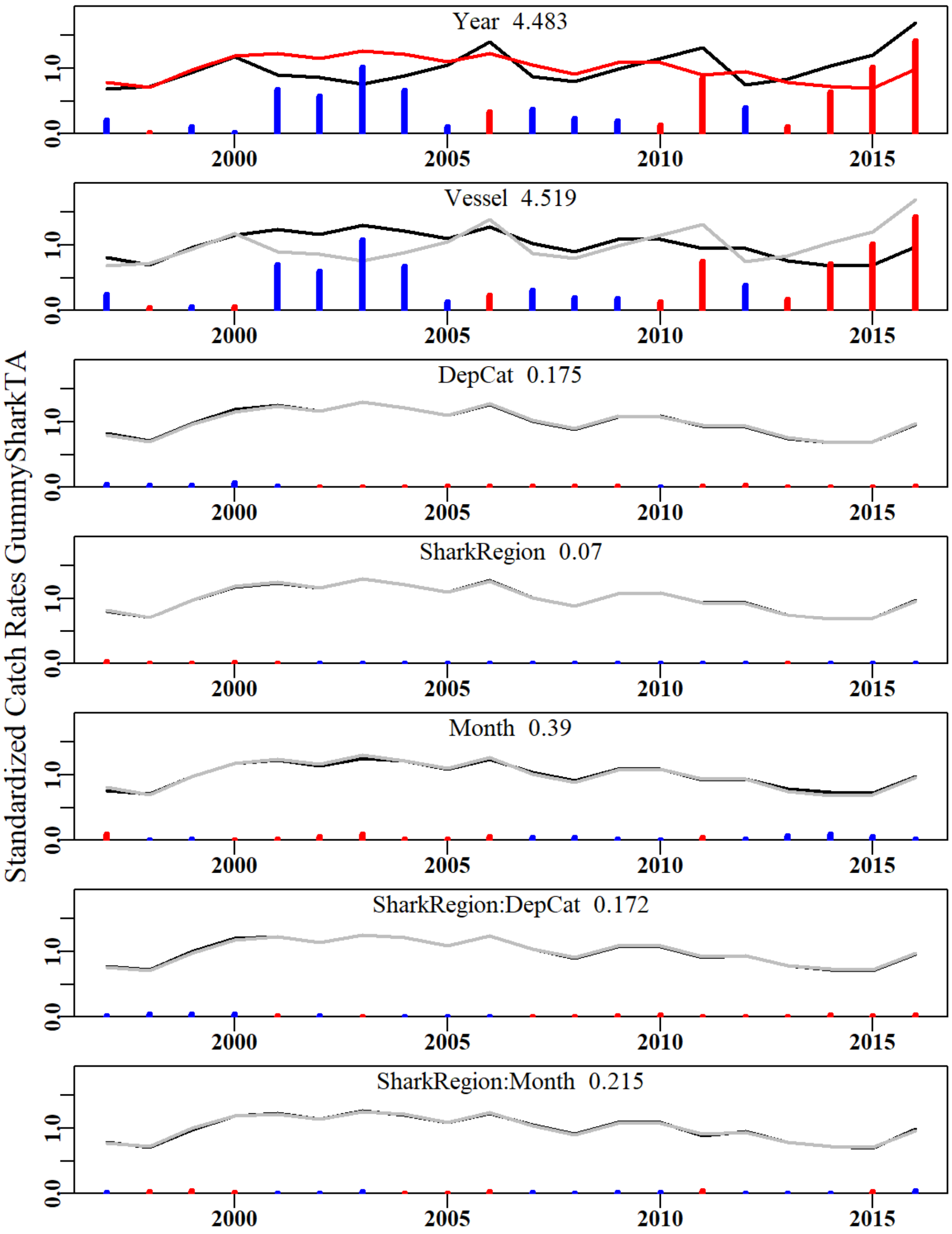


Figure 8.23. GummySharkTA. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

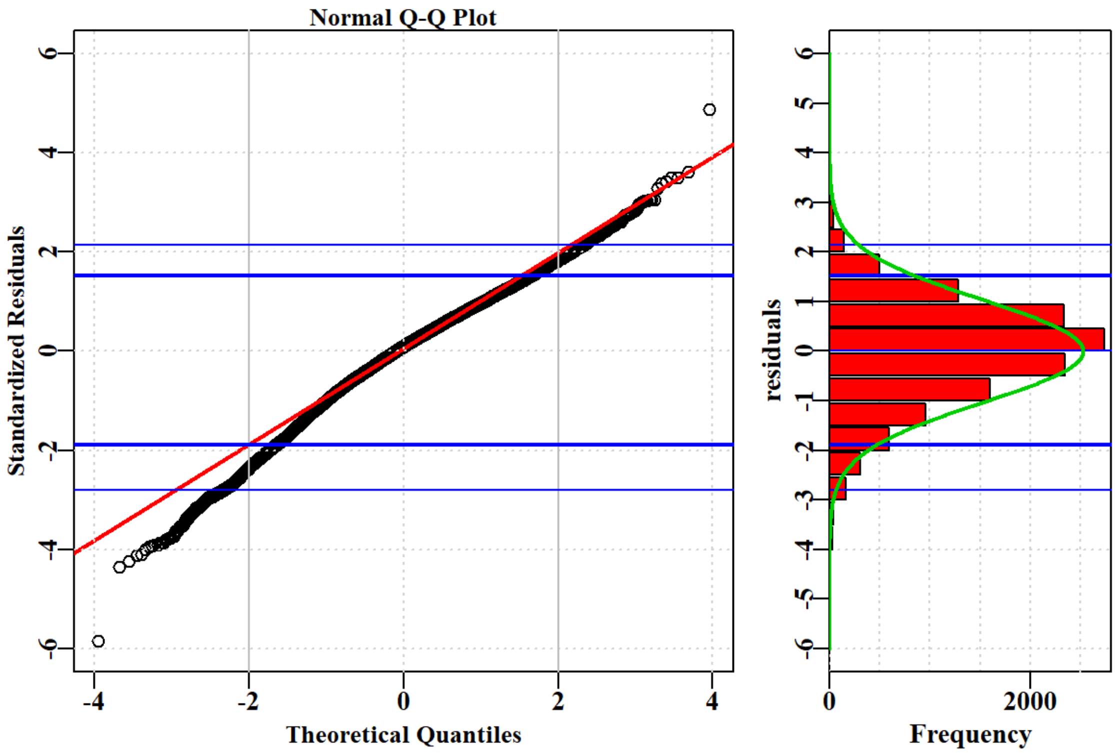


Figure 8.24. GummySharkTA. Diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

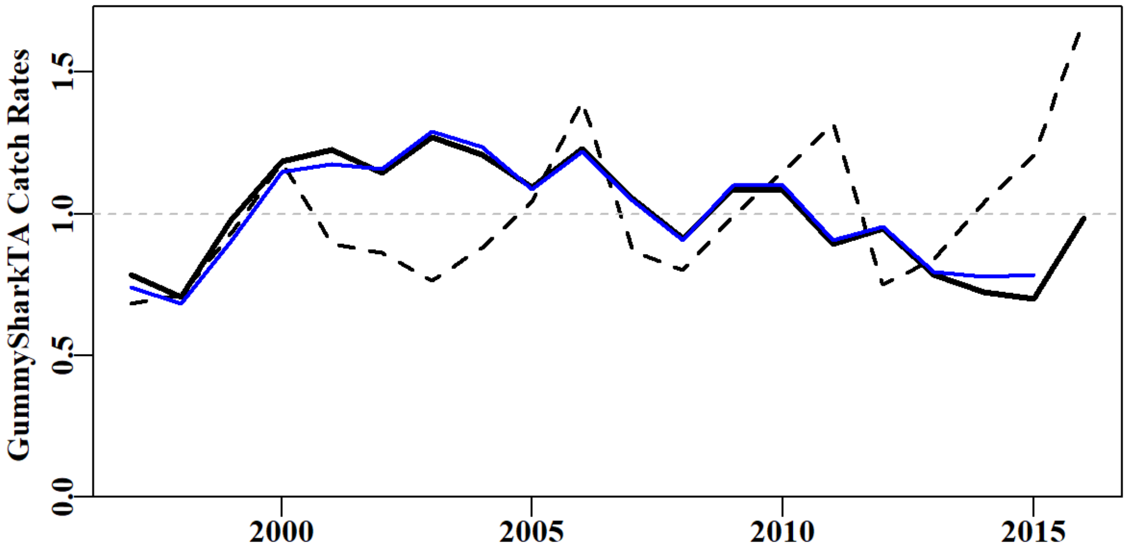


Figure 8.25. GummySharkTA. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

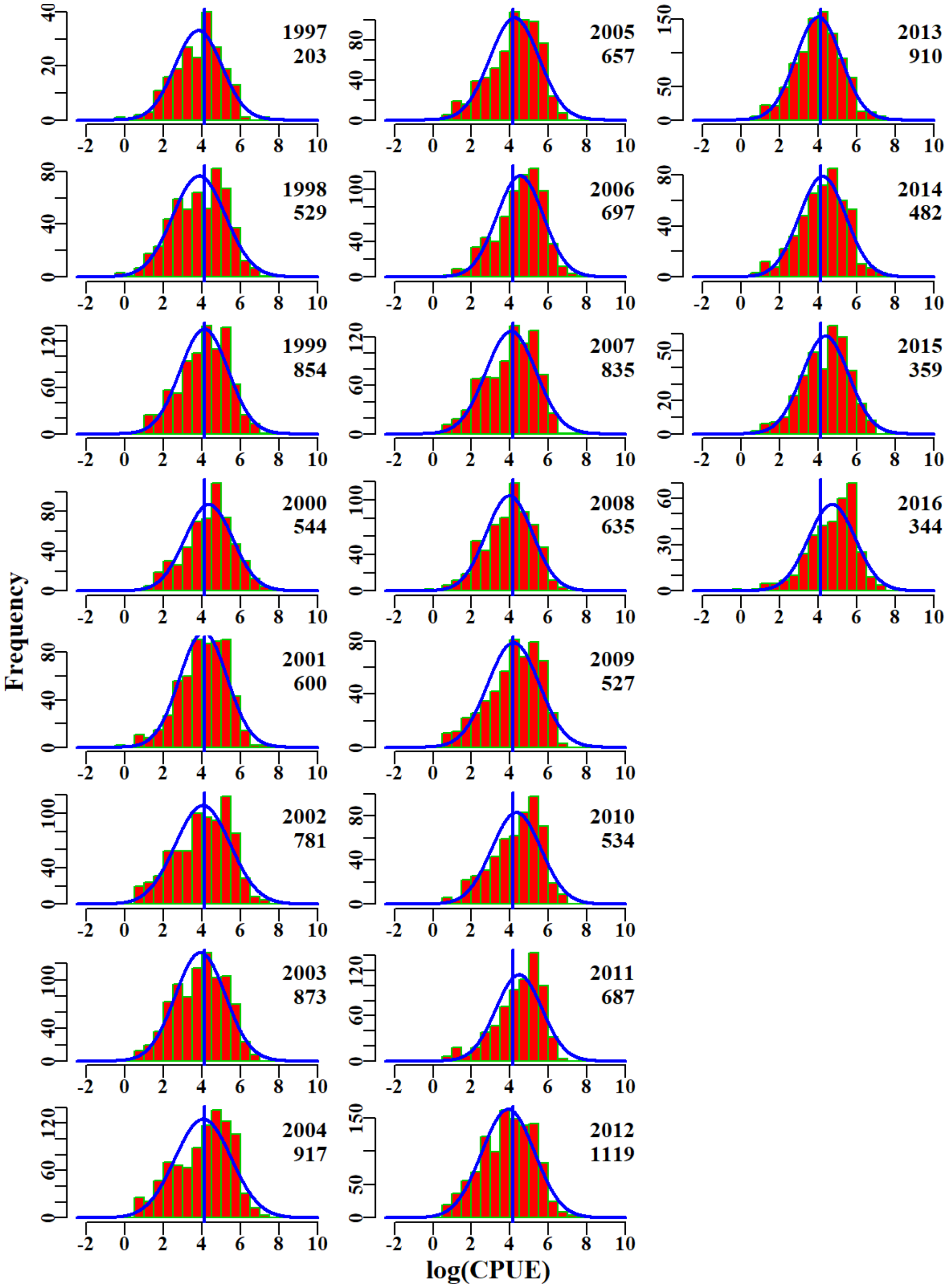


Figure 8.26. GummySharkTA. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

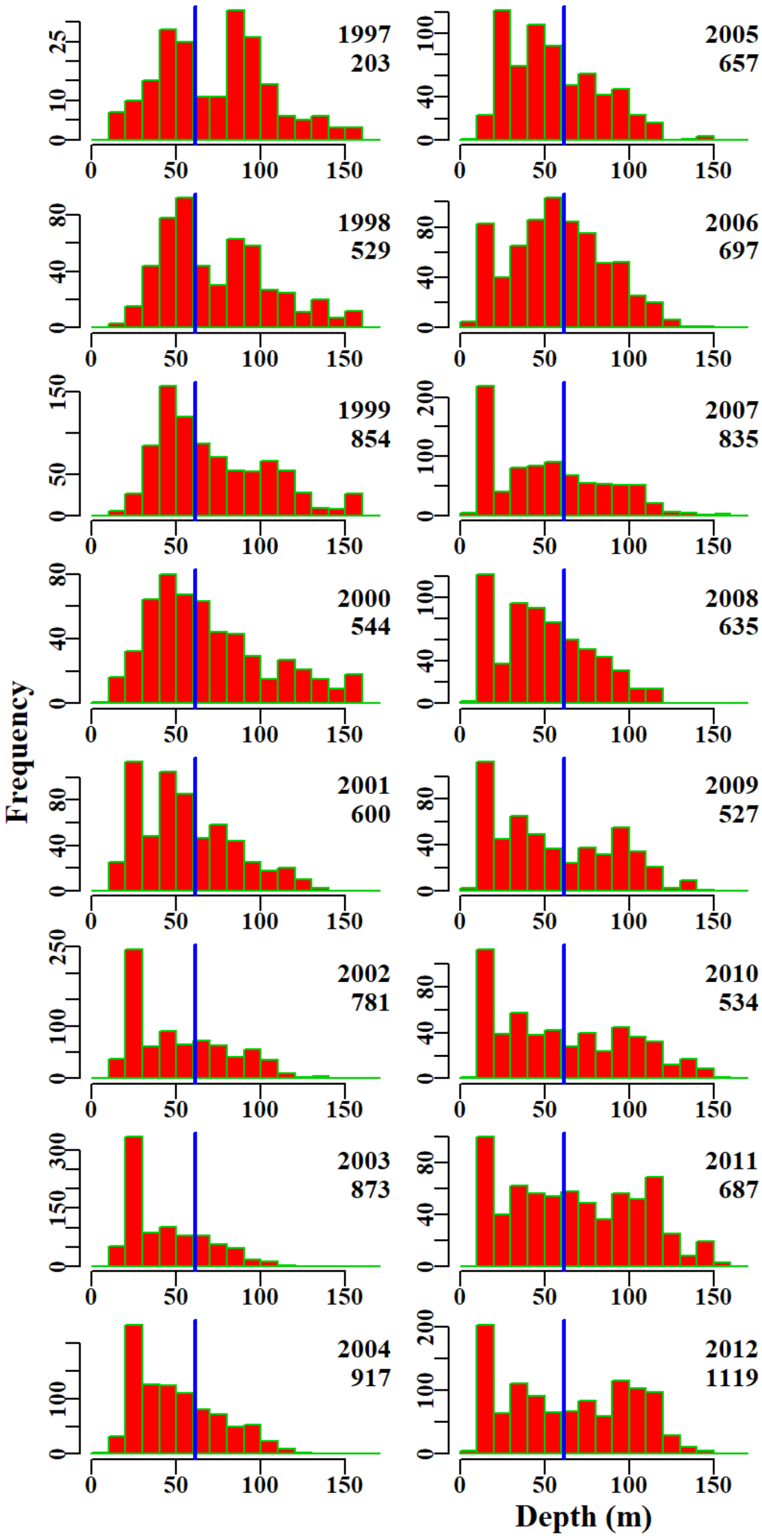


Figure 8.27. GummySharkTA. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

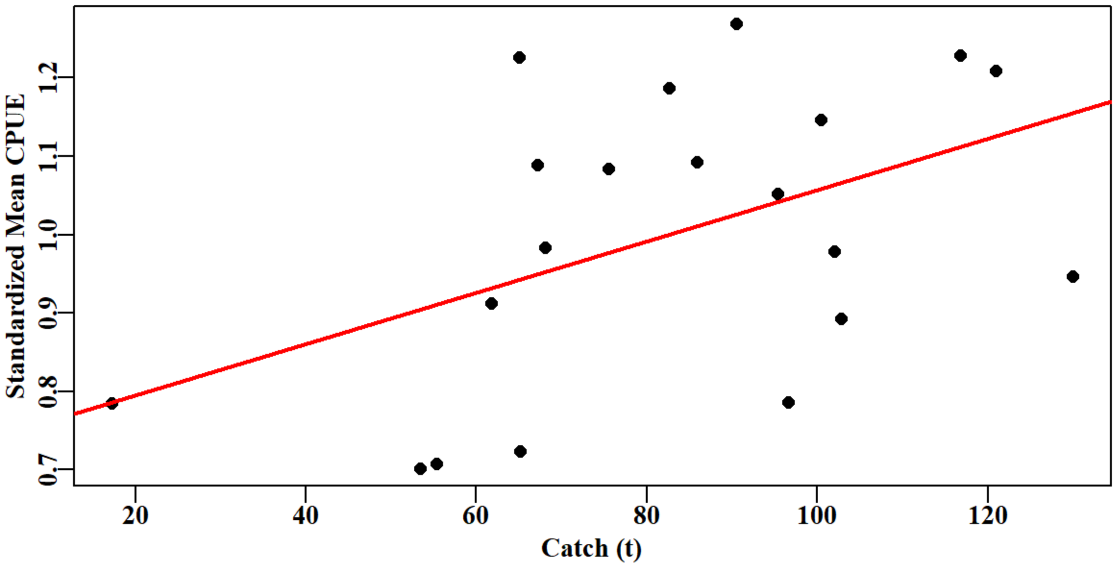


Figure 8.28. GummySharkTA. The linear relationship between Annual mean CPUE and Annual Catch.

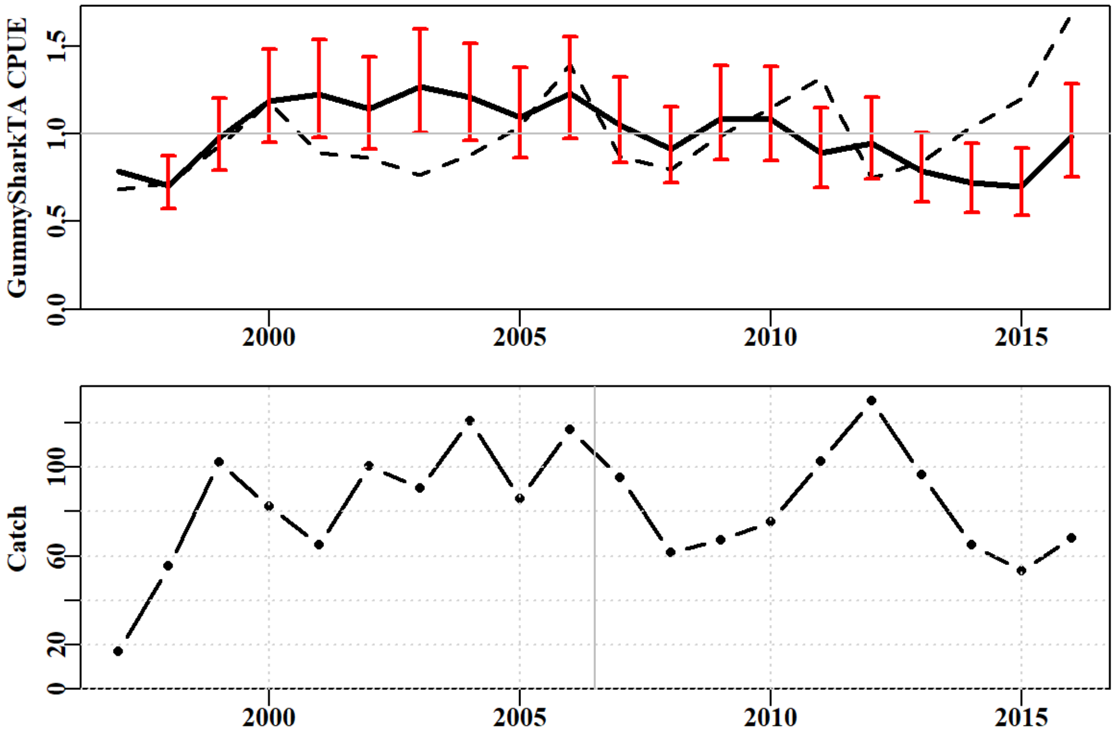


Figure 8.29. GummySharkTA. CPUE is correlated with catches through time. CPUE in the top plot and annual catch (t) in the lower plot.

8.7 Gummy shark: Trawl

CPUE (catch/hour) analysis used shots that reported catches of gummy shark (non zero shots), and included a factor for shark zones, more consistent with gillnet and line standardizations than the SESSF trawl zones previously considered (Haddon, 2014). The proportion of zero gummy shark catches reported by trawl (based on all records) is >60%. Since gummy shark are not targeted by trawl vessels, it is inappropriate to include zero catches in the analysis.

8.7.1 Inferences

A total of 8 statistical models were fitted sequentially to the available data. The optimum model was fitted with terms: Year, Vessel, DepCat, SharkRegion, Month and the interaction SharkRegion x DepCat. The first two terms had the greatest contribution to model fit. The assumed Normal distribution appears to be valid as depicted by the qqplot. Annual standardized CPUE has been mostly flat and below the long term average between 1997 and 2007. By contrast, standardized CPUE has steadily increased above the long term average since 2008.

8.7.2 Action Items and Issues

A further consideration of whether or not to consider the CPUE time-series as a valid index of relative abundance for gummy shark needs to be explored.

Table 8.16. GummySharkTW. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	GummySharkTW
csirocode	37017001
fishery	SET_GAB
depthrange	0 - 500
depthclass	20
zones	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
methods	TW, TDO, OTT
years	1996 - 2016

Table 8.17. GummySharkTW. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was SharkRegion:DepCat.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1996	49.4	2234	40.5	72	5.2	1.0267	0.000	24.951	0.616
1997	952.1	2778	43.6	77	4.5	0.9061	0.028	28.084	0.643
1998	1401.1	2462	39.2	62	4.5	0.8999	0.029	27.357	0.698
1999	1923.8	2395	38.2	69	4.7	0.9316	0.029	23.234	0.609
2000	2436.9	3141	50.4	76	4.8	0.8169	0.028	29.821	0.591
2001	1703.3	3355	56.5	63	4.6	0.8034	0.028	30.462	0.539
2002	1527.1	3994	61.2	67	4.1	0.7610	0.027	34.925	0.571
2003	1653.0	4572	80.4	73	4.4	0.8183	0.027	40.661	0.506
2004	1669.9	4788	89.4	73	4.6	0.8354	0.027	43.556	0.487
2005	1573.2	5056	95.9	70	4.6	0.8486	0.026	48.241	0.503
2006	1577.1	4897	102.1	62	5.0	0.8758	0.027	43.961	0.431
2007	1575.0	3599	85.0	37	5.6	0.8969	0.028	34.983	0.412
2008	1727.7	3771	86.7	36	5.4	1.0580	0.028	38.720	0.446
2009	1500.9	3492	87.6	31	5.8	1.1532	0.028	37.903	0.432
2010	1404.8	3640	90.2	33	5.9	1.1423	0.028	39.510	0.438
2011	1364.7	4289	100.7	32	5.5	1.0426	0.027	43.337	0.430
2012	1304.2	3816	101.8	31	6.2	1.1516	0.028	40.763	0.401
2013	1307.6	3513	96.9	33	6.6	1.2938	0.028	43.274	0.447
2014	1389.1	3159	91.3	34	6.9	1.2595	0.029	37.298	0.408
2015	1545.1	2939	82.9	36	6.9	1.2213	0.029	35.122	0.423
2016	1573.0	2844	86.7	34	7.7	1.2572	0.030	32.200	0.371

Table 8.18. GummySharkTW data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	370141.0	163626.0	161854.0	154204.0	153555.0	75002.0	74734.0
Difference	0.0	206515.0	1772.0	7650.0	649.0	78553.0	268.0
Catch	31552.8	7922.6	7859.8	7662.3	7638.8	1609.3	1607.2
Difference	0.0	23630.2	62.8	197.5	23.5	6029.5	2.1

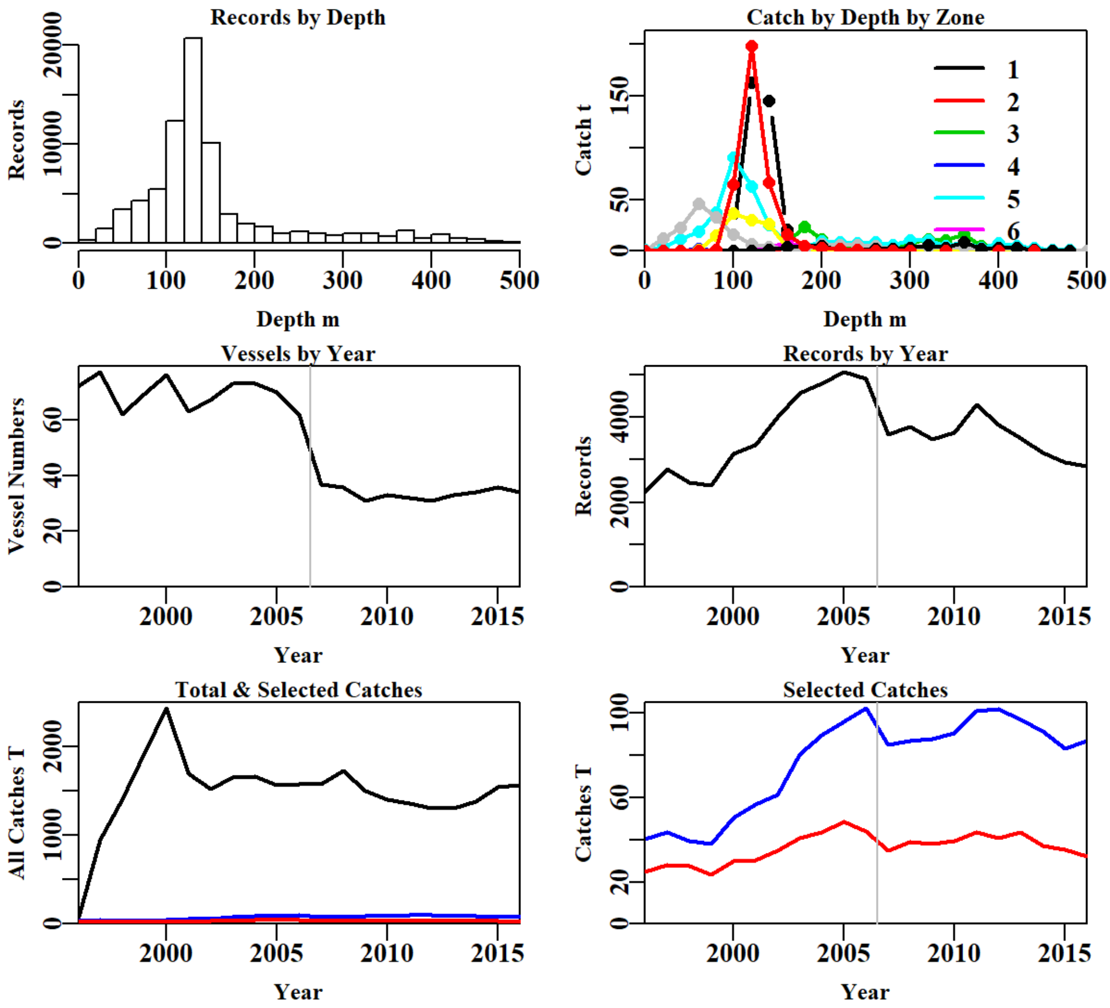


Figure 8.30. GummySharkTW fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 8.19. The models used to analyse data for GummySharkTW.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + SharkRegion
Model5	Year + Vessel + DepCat + SharkRegion + Month
Model6	Year + Vessel + DepCat + SharkRegion + Month + DayNight
Model7	Year + Vessel + DepCat + SharkRegion + Month + DayNight + ShkReg:DepCat
Model8	Year + Vessel + DepCat + SharkRegion + Month + DayNight + ShkReg:Month

Table 8.20. GummySharkTW. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was SharkRegion:DepCat.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	9367	84666	2223	74734	21	2.5	0.00
Vessel	-2491	71987	14902	74734	154	17.0	14.45
DepCat	-3873	70620	16268	74734	179	18.5	1.55
SharkRegion	-4619	69902	16987	74734	188	19.3	0.82
Month	-6474	68168	18720	74734	199	21.3	1.99
DayNight	-7600	67143	19745	74734	202	22.5	1.18
SharkRegion:DepCat	-9015	65561	21328	74734	386	24.2	1.64
SharkRegion:Month	-8209	66422	20466	74734	301	23.2	0.73

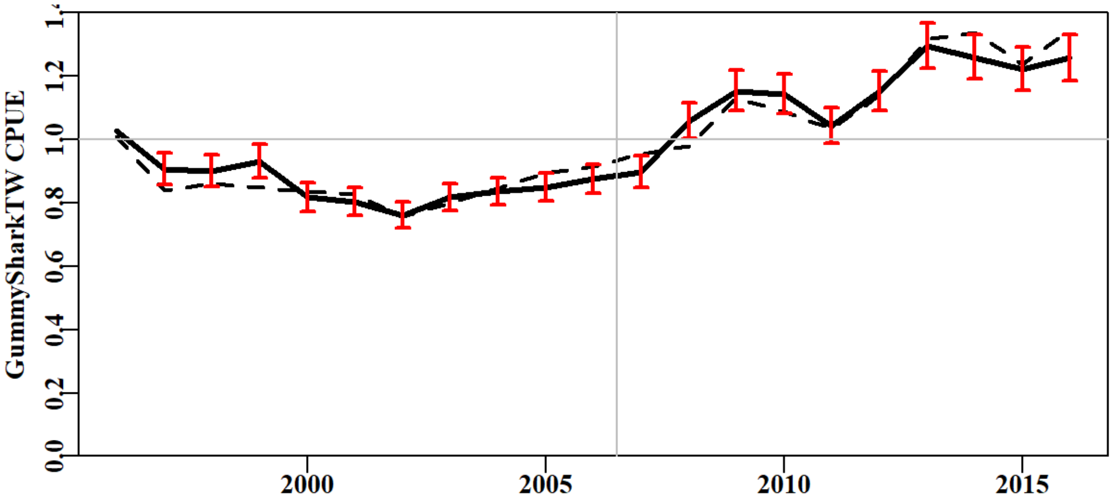


Figure 8.31. GummySharkTW standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

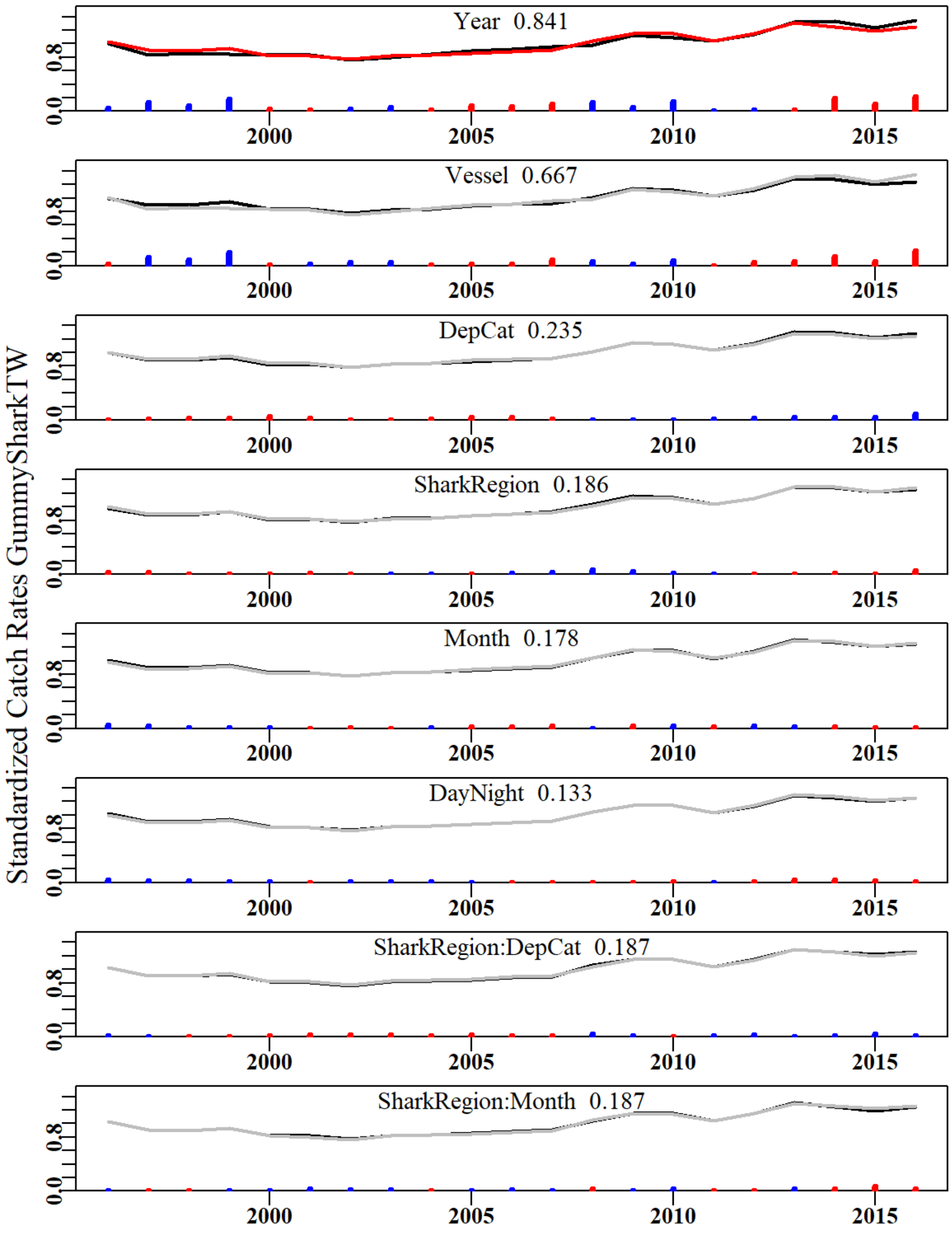


Figure 8.32. GummySharkTW. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

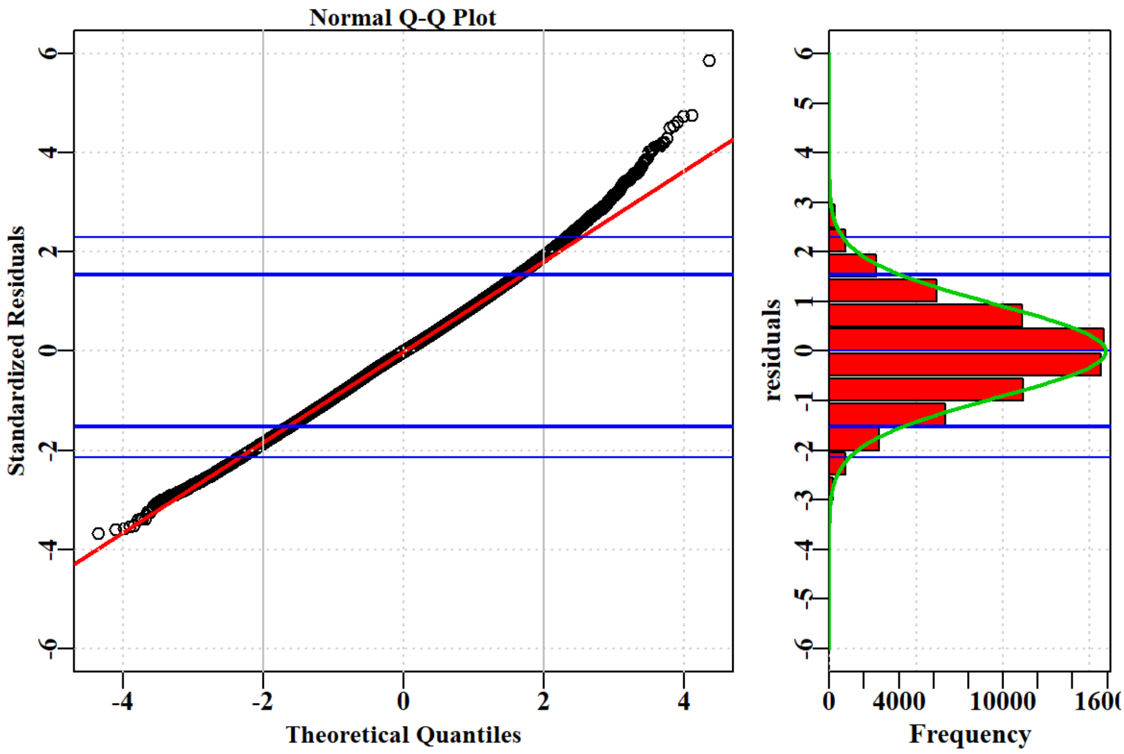


Figure 8.33. GummySharkTW. Diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

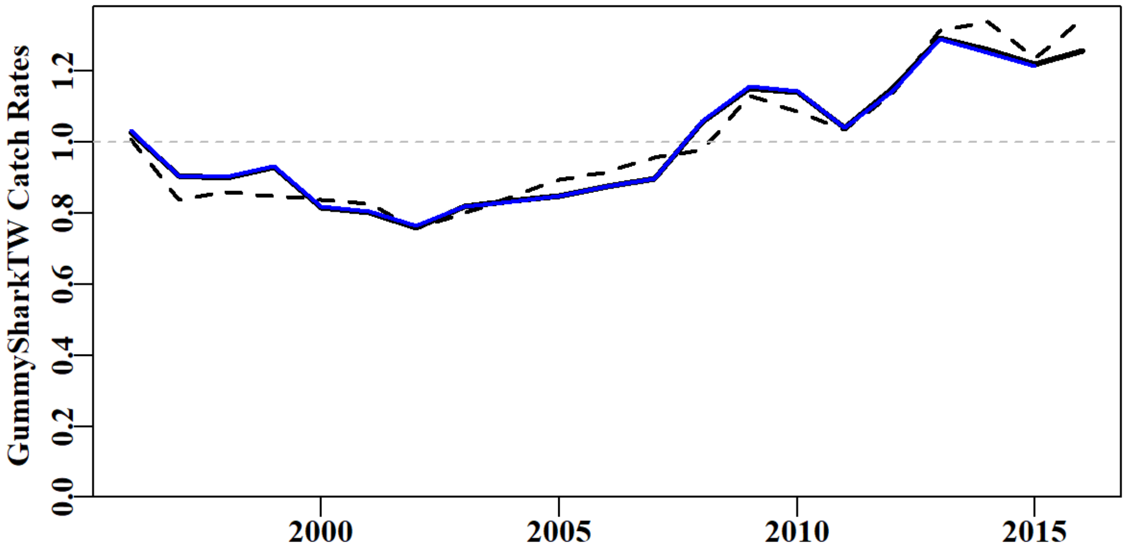


Figure 8.34. GummySharkTW. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

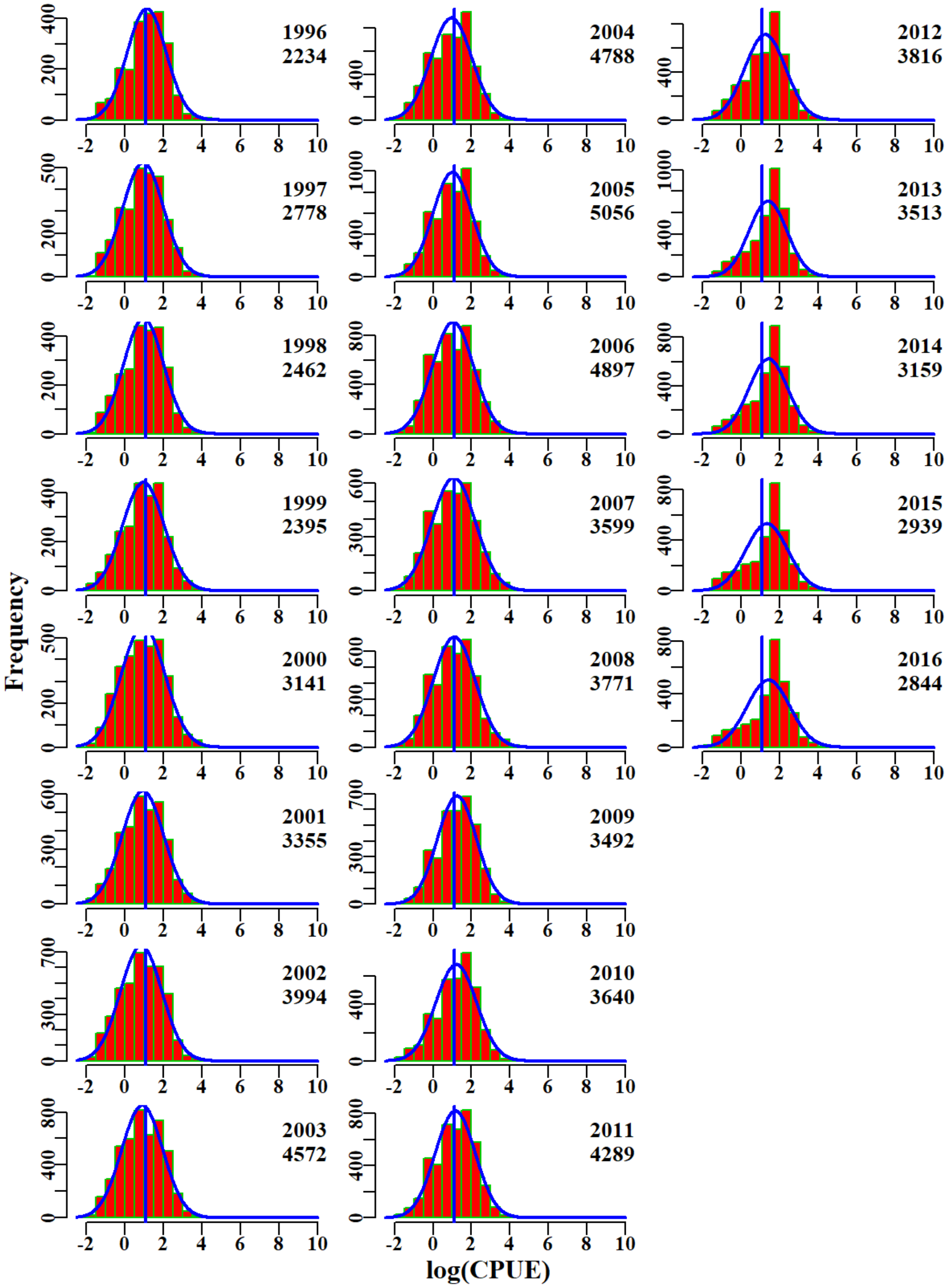


Figure 8.35. GummySharkTW. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

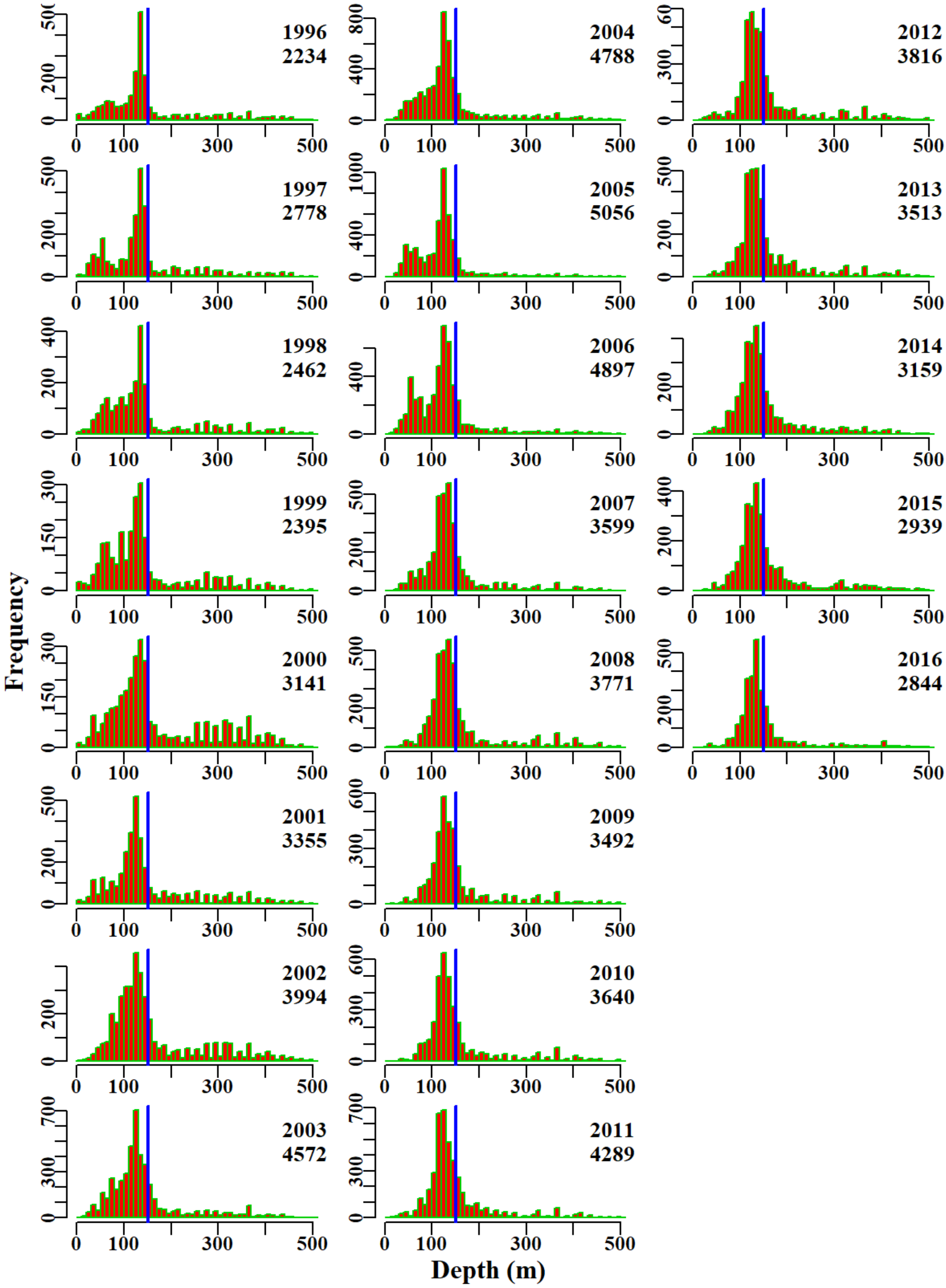


Figure 8.36. GummySharkTW. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

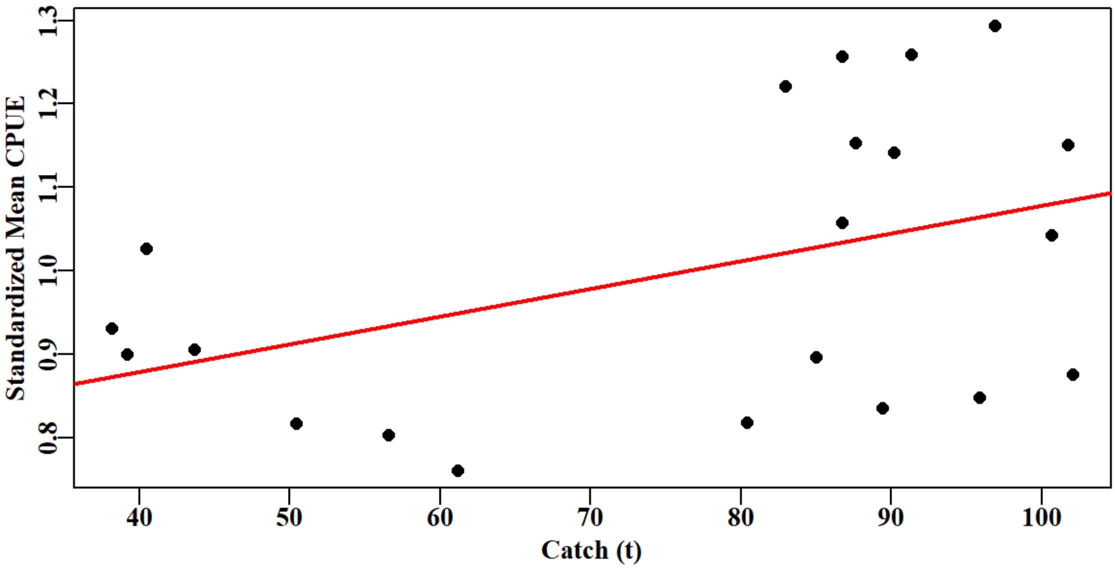


Figure 8.37. GummySharkTW. The linear relationship between Annual mean CPUE and Annual Catch.

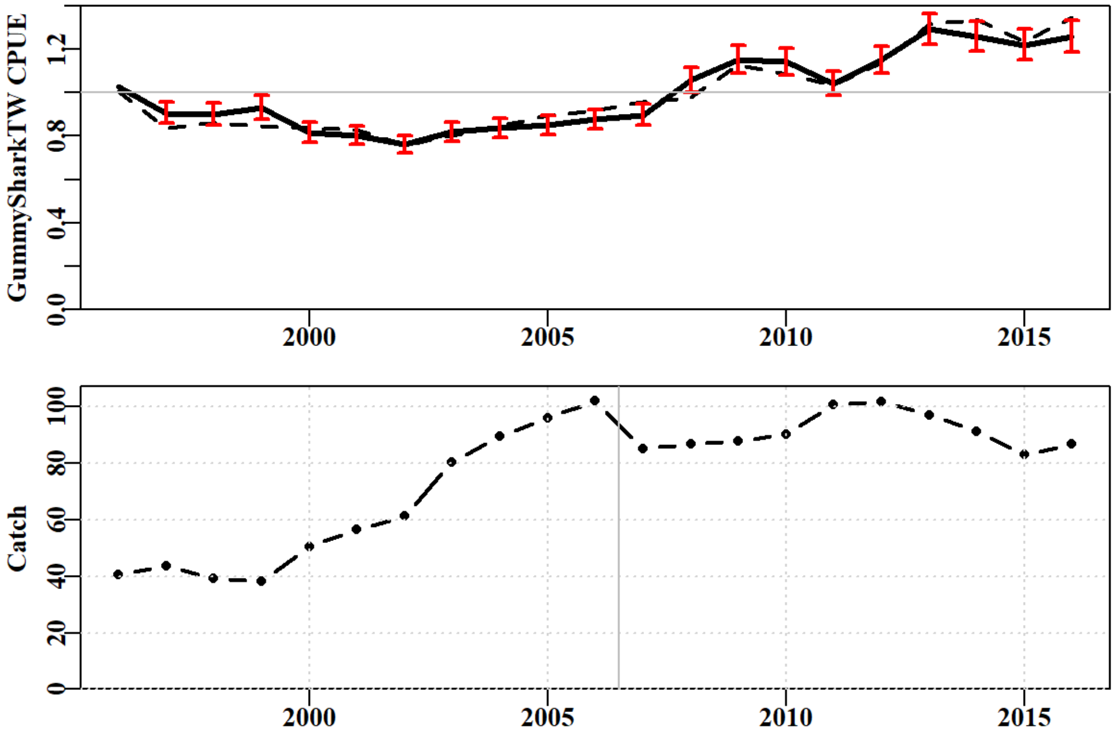


Figure 8.38. GummySharkTW. CPUE is correlated with catches through time. CPUE in the top plot and annual catch (t) in the lower plot.

8.8 Gummy shark Bottom Line

A total of 8 statistical models were fitted sequentially to the available data.

Records pertaining to shark zones 8 and 10 were omitted from analysis since they contributed very little to the overall catch (8: 0.02 %; 10: 0.007 %; less than one tonne in each shark zone). Furthermore, non-zero catches per shot were employed in the statistical standardization analyses for gummy shark caught by bottom line. Currently, effort units are recorded inconsistently in the logbook database for bottom line caught gummy shark. Any of three alternative pairs of units can be recorded for a shot:(i) THS (total hooks per set) and TLM (total length of mainline used); (ii) NLP (number of lines per shot) and THS (total number of hooks per set); and (iii) NLS (total number lines per shot) and THS (total number of hooks per shot) and/or HRS (hours). No clear method was apparent for including these inconsistent effort units in a single standardization. However, the alternative is to assume that every fishing operation has the same probability of catching sharks, regardless of the number of hooks used, length of line, or soak time. A detailed analysis of these effort units should be investigated to determine whether (i) through to (iii) or some combination could be used as an alternative effort unit in the standardization analyses.

8.8.1 *Inferences*

A total of 8 statistical models were fitted sequentially to the available data. The optimum model was fitted with terms: Year, Vessel, DepCat, SharkRegion, Month, DayNight and the interaction SharkRegion x Month. The first two terms had the greatest contribution to model fit. The assumed Normal distribution appears to be valid as depicted by the qqplot. Annual standardized CPUE has been noisy and mostly flat since the start of the time series.

8.8.2 *Action Items and Issues*

A further consideration of whether or not to consider the CPUE time-series as a valid index of relative abundance for gummy shark needs to be explored.

Table 8.21. GummySharkBL. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	GummySharkBL
csirocode	37017001
fishery	GHT_SSF_,SEN_SSH_SSG
depthrange	0 - 200
depthclass	20
zones	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
methods	BL
years	1998 - 2016

Table 8.22. GummySharkBL. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was SharkRegion:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1998	1401.1	72	8.5	3	123.8	1.0011	0.000	0.180	0.021
1999	1923.8	333	46.7	13	150.8	1.1572	0.156	0.656	0.014
2000	2436.9	481	111.4	14	276.2	1.3172	0.189	0.927	0.008
2001	1703.3	541	58.7	23	130.4	0.7864	0.191	2.494	0.043
2002	1527.1	495	59.0	21	136.5	0.8773	0.192	2.242	0.038
2003	1653.0	619	64.5	27	120.3	0.7613	0.191	2.949	0.046
2004	1669.9	640	66.9	24	119.8	0.7997	0.191	2.912	0.044
2005	1573.2	578	59.6	24	117.9	0.9425	0.193	2.713	0.046
2006	1577.1	495	48.7	19	105.5	1.0276	0.193	2.909	0.060
2007	1575.0	625	54.4	19	88.9	0.9279	0.193	4.651	0.085
2008	1727.7	599	50.1	16	91.8	0.6972	0.195	4.368	0.087
2009	1500.9	819	67.0	15	86.4	0.7970	0.194	5.516	0.082
2010	1404.8	684	72.0	19	119.4	0.9501	0.194	3.713	0.052
2011	1364.7	1045	87.2	28	96.2	1.0656	0.194	5.974	0.069
2012	1304.2	1407	124.2	24	97.8	1.1002	0.193	7.392	0.060
2013	1307.6	2515	229.1	27	100.5	1.2570	0.193	13.533	0.059
2014	1389.1	2758	225.7	29	89.6	1.0662	0.193	17.426	0.077
2015	1545.1	1948	187.3	28	106.9	1.3823	0.194	11.015	0.059
2016	1573.0	1337	135.0	25	113.2	1.0859	0.195	7.369	0.055

Table 8.23. GummySharkBL data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	370141.0	364263.0	344314.0	318203.0	317931.0	18370.0	17991.0
Difference	0.0	5878.0	19949.0	26111.0	272.0	299561.0	379.0
Catch	31552.8	31552.8	30818.7	29491.5	29460.9	1795.8	1756.0
Difference	0.0	0.0	734.1	1327.3	30.6	27665.1	39.7

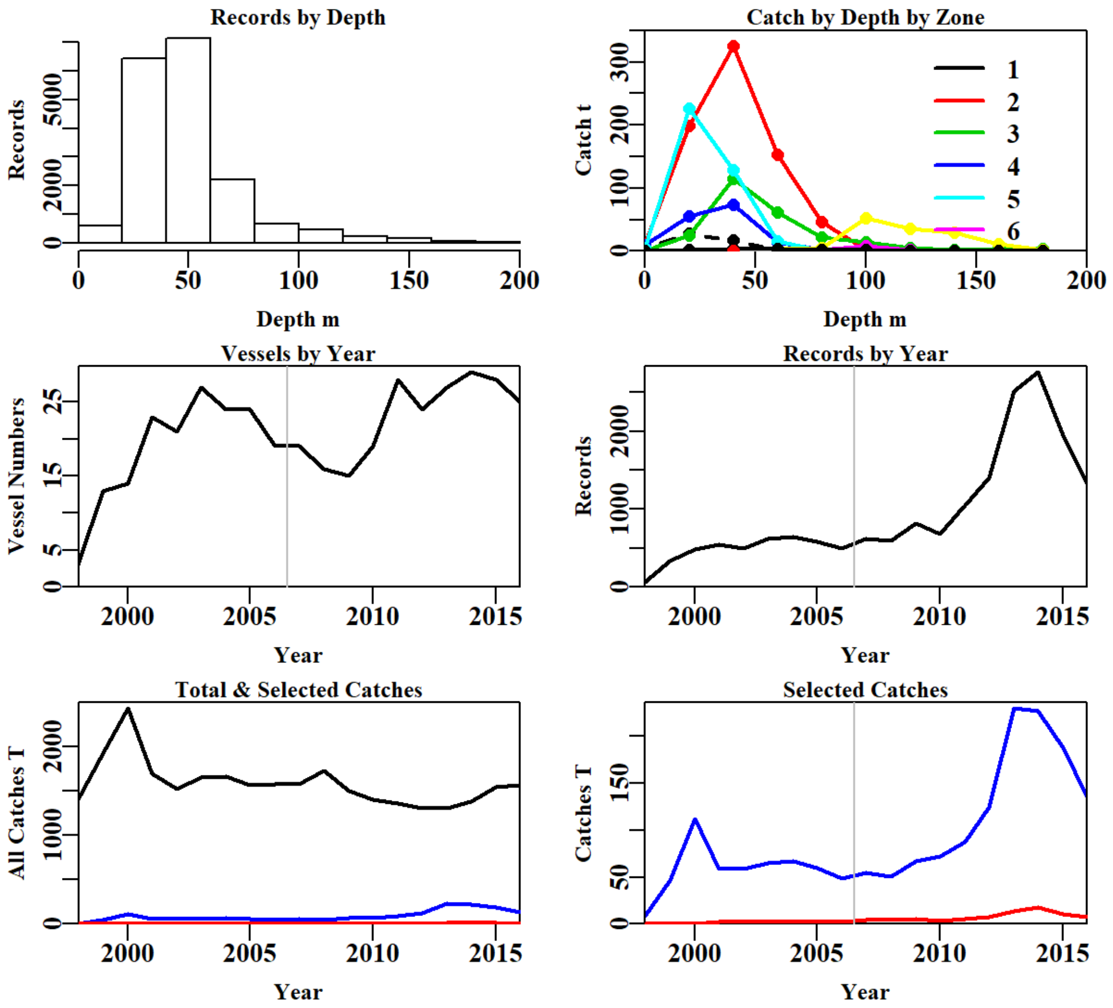


Figure 8.39. GummySharkBL fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 8.24. The models used to analyse data for GummySharkBL.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + SharkRegion
Model5	Year + Vessel + DepCat + SharkRegion + Month
Model6	Year + Vessel + DepCat + SharkRegion + Month + DayNight
Model7	Year + Vessel + DepCat + SharkRegion + Month + DayNight + ShkReg:DepCat
Model8	Year + Vessel + DepCat + SharkRegion + Month + DayNight + ShkReg:Month

Table 8.25. GummySharkBL. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was SharkRegion:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	7009	26505	1046	17991	19	3.7	0.00
Vessel	16	17723	9829	17991	143	35.2	31.46
DepCat	-120	17572	9979	17991	152	35.7	0.52
SharkRegion	-159	17516	10035	17991	161	35.9	0.17
Month	-198	17457	10094	17991	172	36.0	0.17
DayNight	-198	17452	10100	17991	175	36.0	0.01
SharkRegion:DepCat	-210	17335	10216	17991	229	36.3	0.23
SharkRegion:Month	-360	17148	10404	17991	252	36.9	0.84

Figure 8.40. GummySharkBL standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

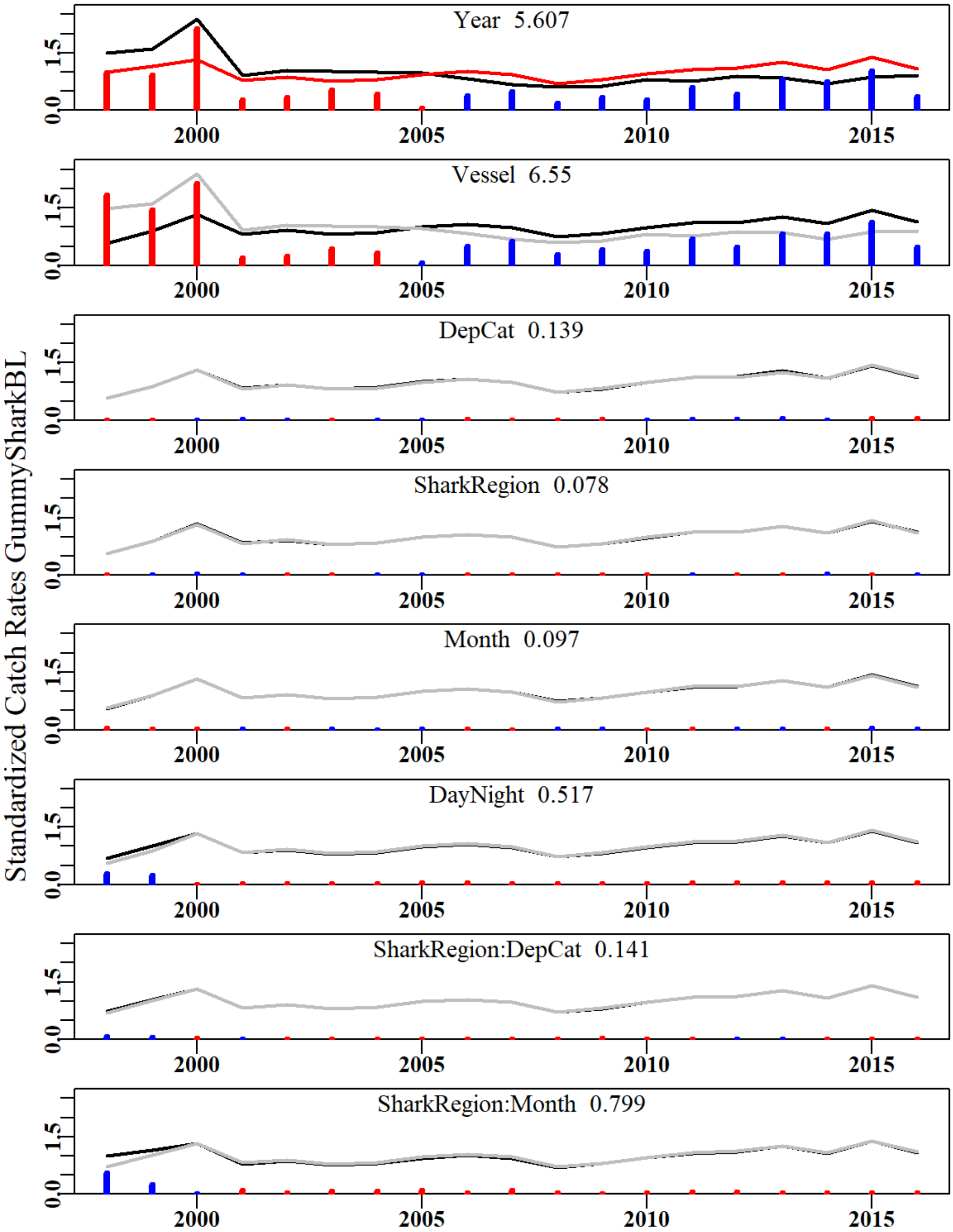


Figure 8.41. GummySharkBL. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

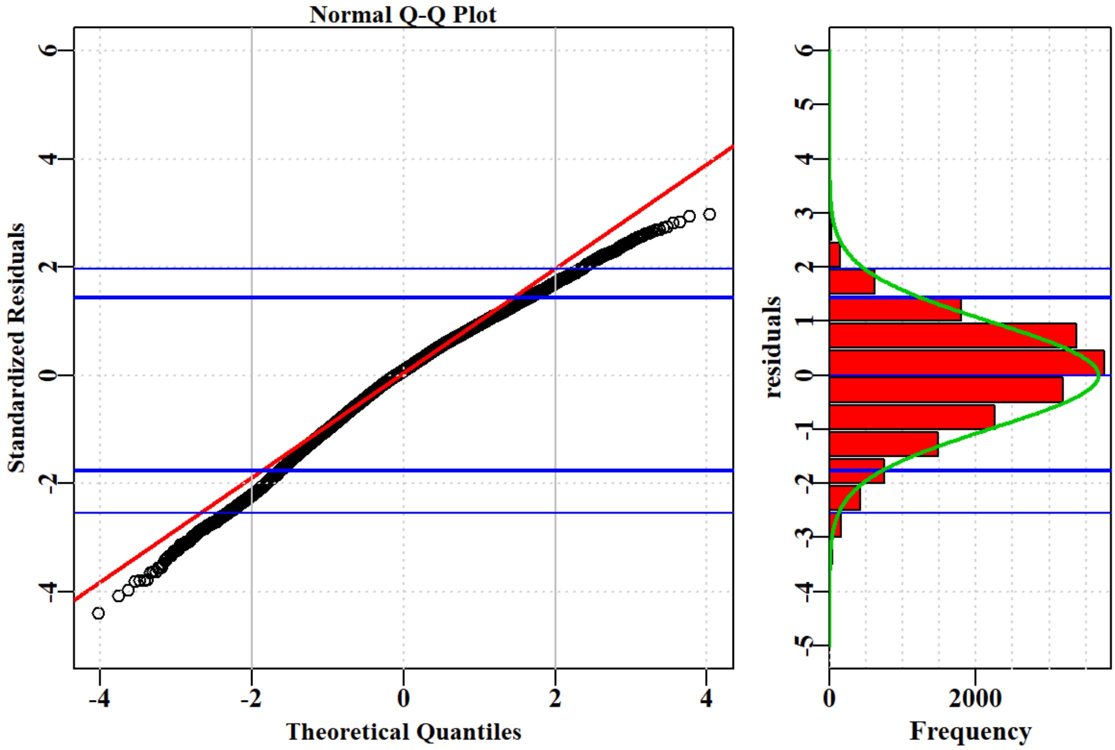


Figure 8.42. GummySharkBL. Diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

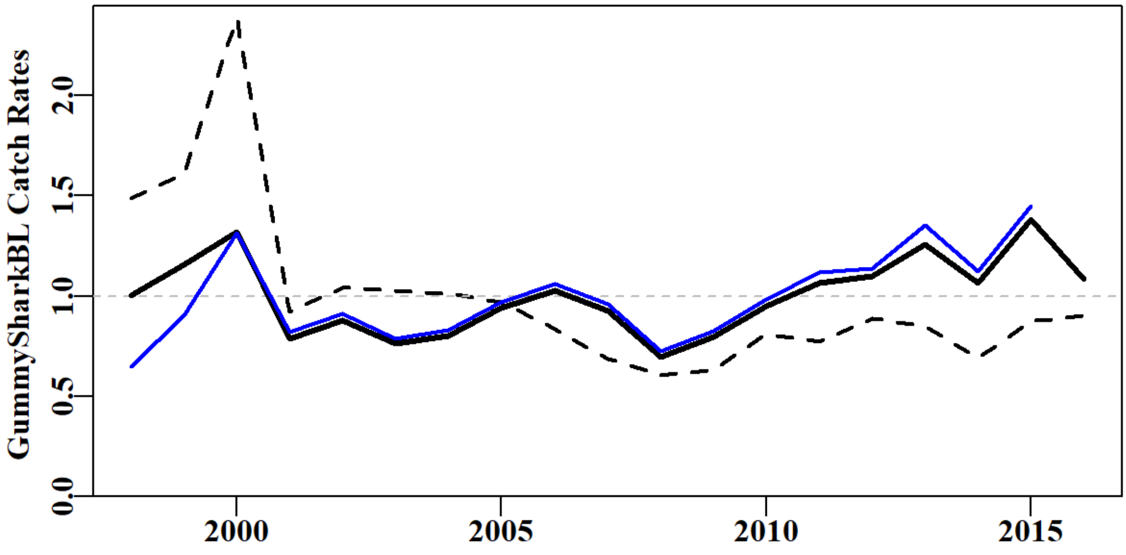


Figure 8.43. GummySharkBL. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

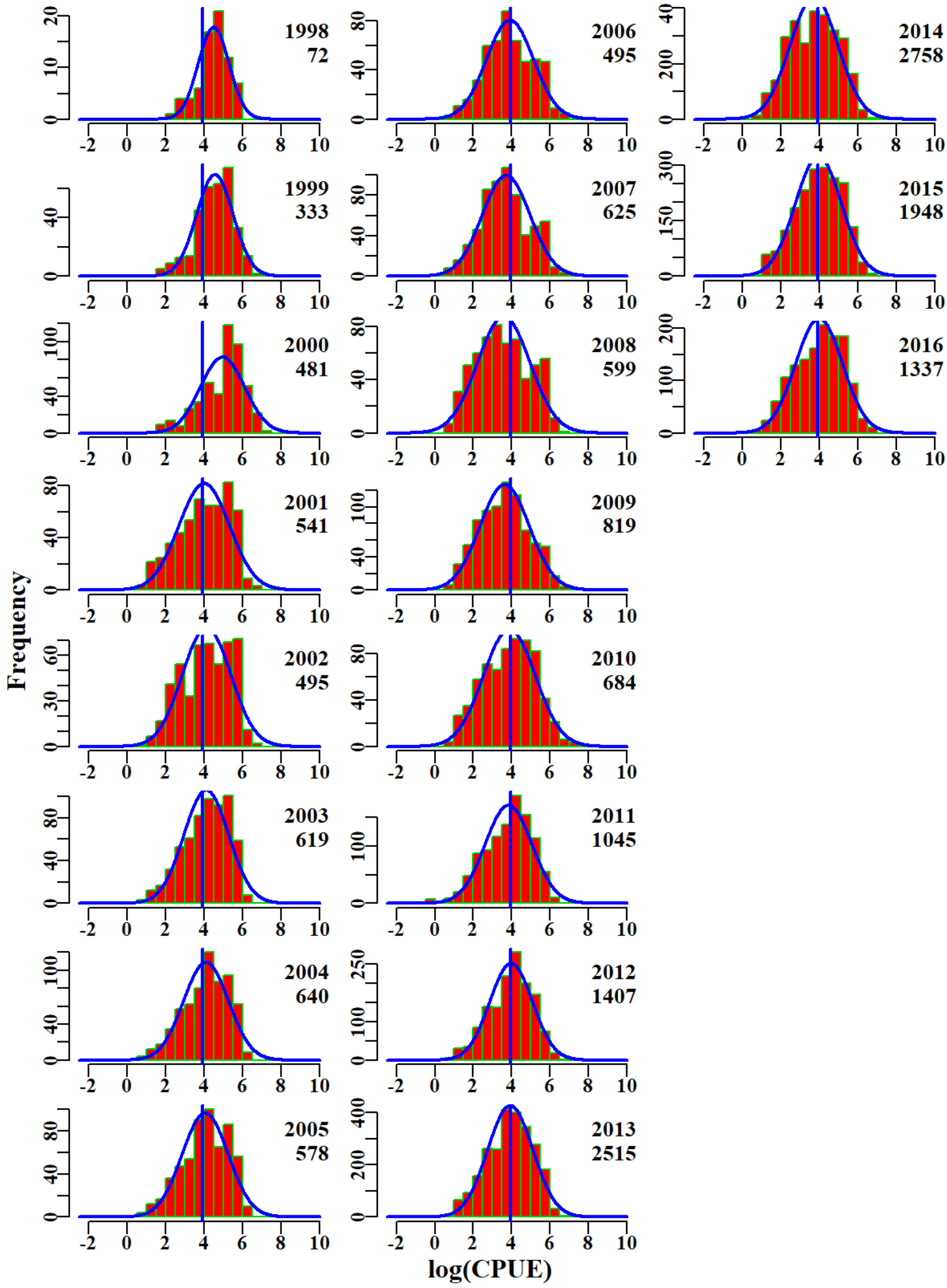


Figure 8.44. GummySharkBL. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

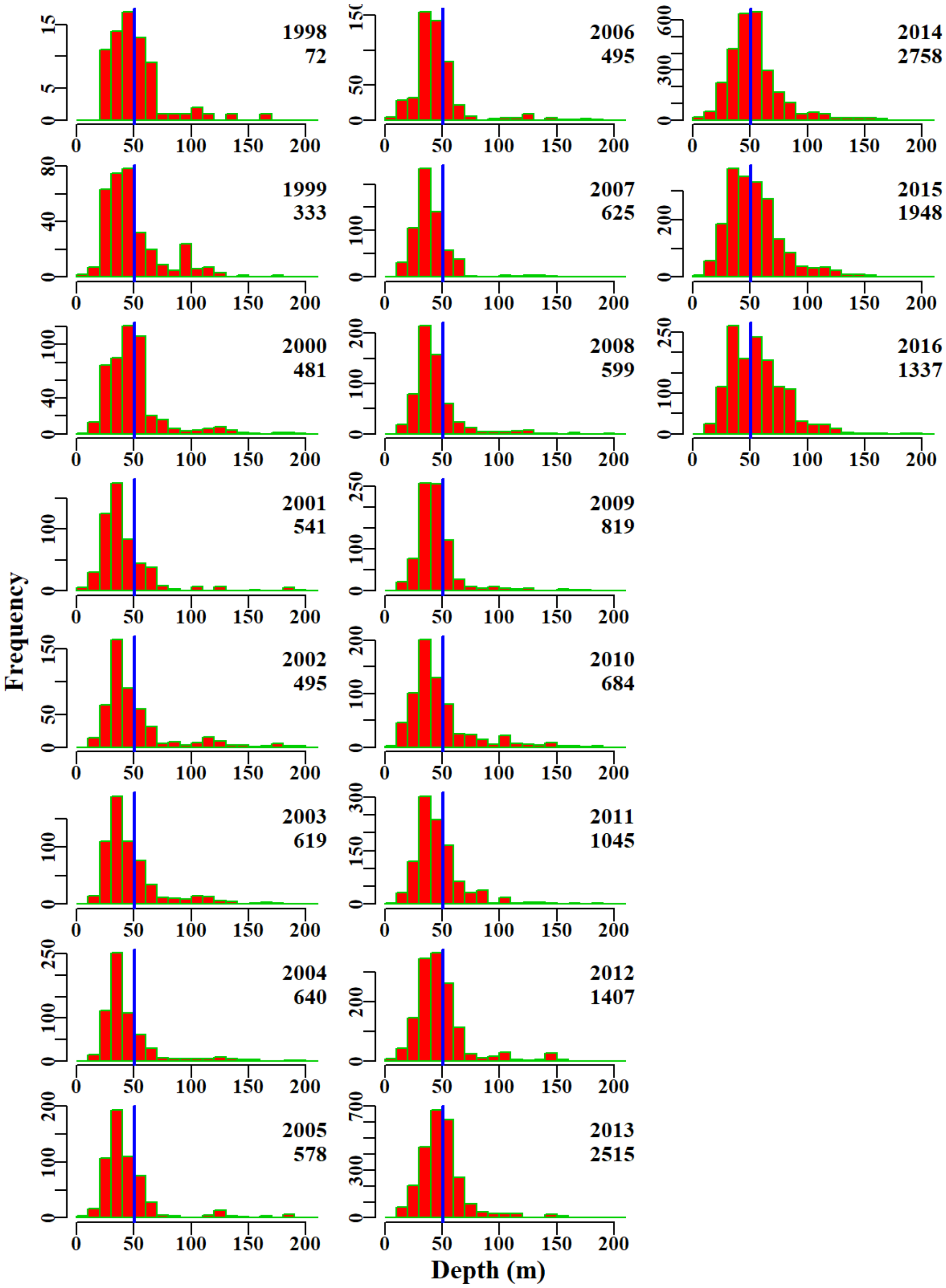


Figure 8.45. GummySharkBL. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

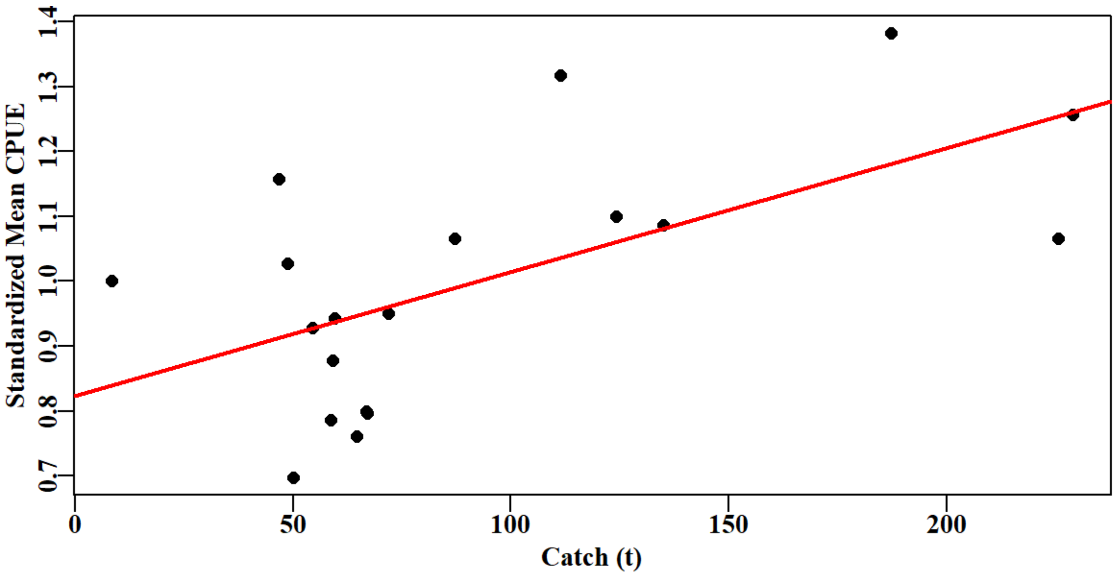


Figure 8.46. GummySharkBL. The linear relationship between Annual mean CPUE and Annual Catch.

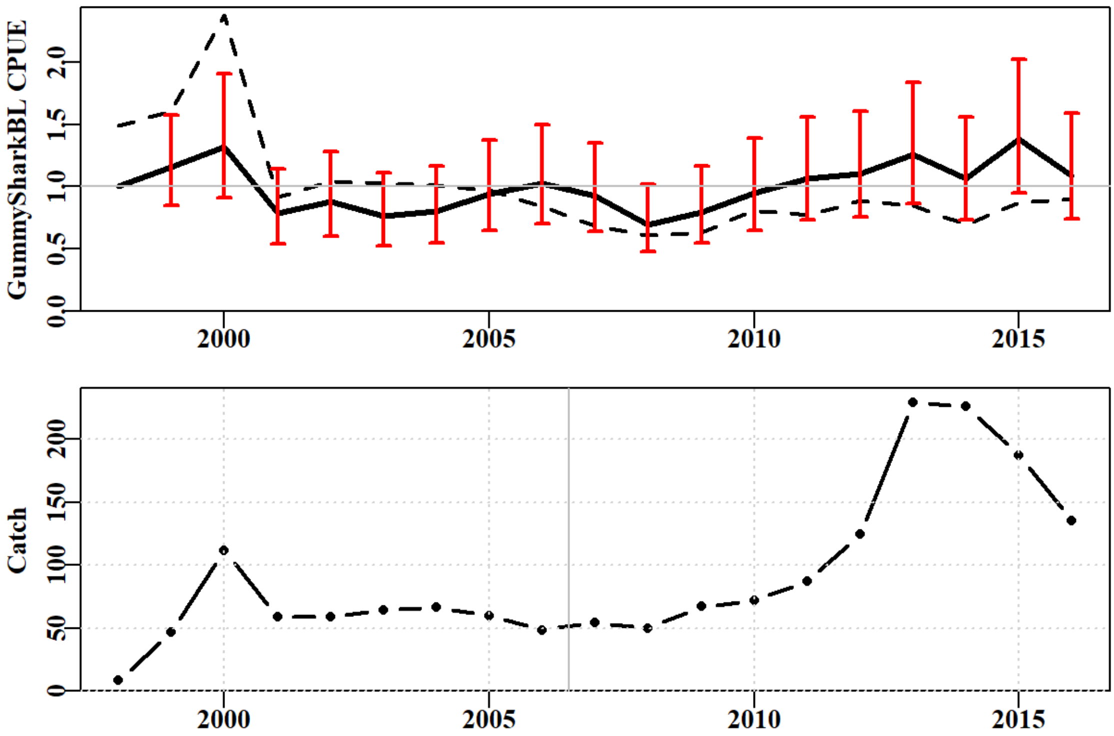


Figure 8.47. GummySharkBL. CPUE is correlated with catches through time. CPUE in the top plot and annual catch (t) in the lower plot.

8.9 School shark Trawl

Given the change from targeting, to increasingly active avoidance of school shark by gillnet fishers during the available time series, an analysis of gillnet CPUE would be invalid and misleading. However, the trawl fishery is unlikely to have targeted school shark at any time, providing a consistent time series of catch and effort data. These were standardized using classical statistical methods. There were various data selections made with respect to gear types, depths and years prior to data analysis.

8.9.1 Inferences

A total of 8 statistical models were fitted sequentially to the available data. The optimum model was fitted with terms: Year, Vessel, DepCat, SharkRegion, Month, DayNight and the interaction SharkRegion x DepCat. The first two terms had the greatest contribution to model fit. The assumed Normal distribution appears to be valid as depicted by the qqplot. Annual standardized CPUE has slowly increased since 2003 and has been above the long term average since 2012.

8.9.2 Action Items and Issues

Table 8.26. SchoolSharkTW. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	SchoolSharkTW
csirocode	37017008
fishery	SET_GAB
depthrange	0 - 600
depthclass	25
zones	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
methods	TW, TDO, OTT
years	1996 - 2016

Table 8.27. SchoolSharkTW. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was SharkRegion:DepCat.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1996	29.1	922	24.4	67	7.6	1.2685	0.000	11.882	0.486
1997	457.0	1187	23.7	60	6.4	1.0775	0.042	13.246	0.560
1998	562.0	957	19.8	51	6.0	1.0413	0.045	10.817	0.546
1999	490.6	759	14.1	51	5.4	0.9550	0.049	9.078	0.644
2000	464.9	919	16.6	70	5.0	0.8236	0.047	8.720	0.524
2001	190.6	859	15.7	47	5.2	0.7901	0.048	8.919	0.568
2002	219.5	943	16.9	57	5.2	0.8157	0.048	9.283	0.550
2003	218.2	767	13.2	59	4.8	0.7398	0.051	7.482	0.568
2004	200.3	697	13.3	54	4.5	0.7674	0.052	6.954	0.521
2005	210.3	517	8.3	45	4.2	0.8233	0.056	4.784	0.577
2006	212.0	570	10.9	47	4.9	0.8349	0.055	5.154	0.474
2007	197.8	348	7.3	32	5.9	0.8534	0.064	3.469	0.474
2008	234.4	405	9.0	30	5.7	1.0109	0.060	3.820	0.425
2009	253.1	438	13.6	28	6.7	1.0734	0.058	4.441	0.326
2010	180.1	428	12.6	26	7.2	1.0095	0.060	4.007	0.318
2011	182.4	449	13.8	28	6.8	1.0467	0.059	4.004	0.290
2012	136.0	342	10.9	26	8.2	1.1117	0.064	2.979	0.274
2013	150.0	372	18.3	32	12.2	1.2358	0.064	3.218	0.176
2014	200.0	394	11.2	26	7.1	1.1619	0.061	3.829	0.341
2015	146.9	333	12.3	26	8.1	1.2047	0.065	3.557	0.290
2016	131.7	363	14.1	26	8.7	1.3545	0.063	4.188	0.297

Table 8.28. SchoolSharkTW data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	103459.0	38570.0	37983.0	33593.0	33389.0	12970.0	12969.0
Difference	0.0	64889.0	587.0	4390.0	204.0	20419.0	1.0
Catch	5279.3	1879.9	1851.8	1683.5	1680.3	300.0	299.9
Difference	0.0	3399.4	28.1	168.3	3.2	1380.3	0.0

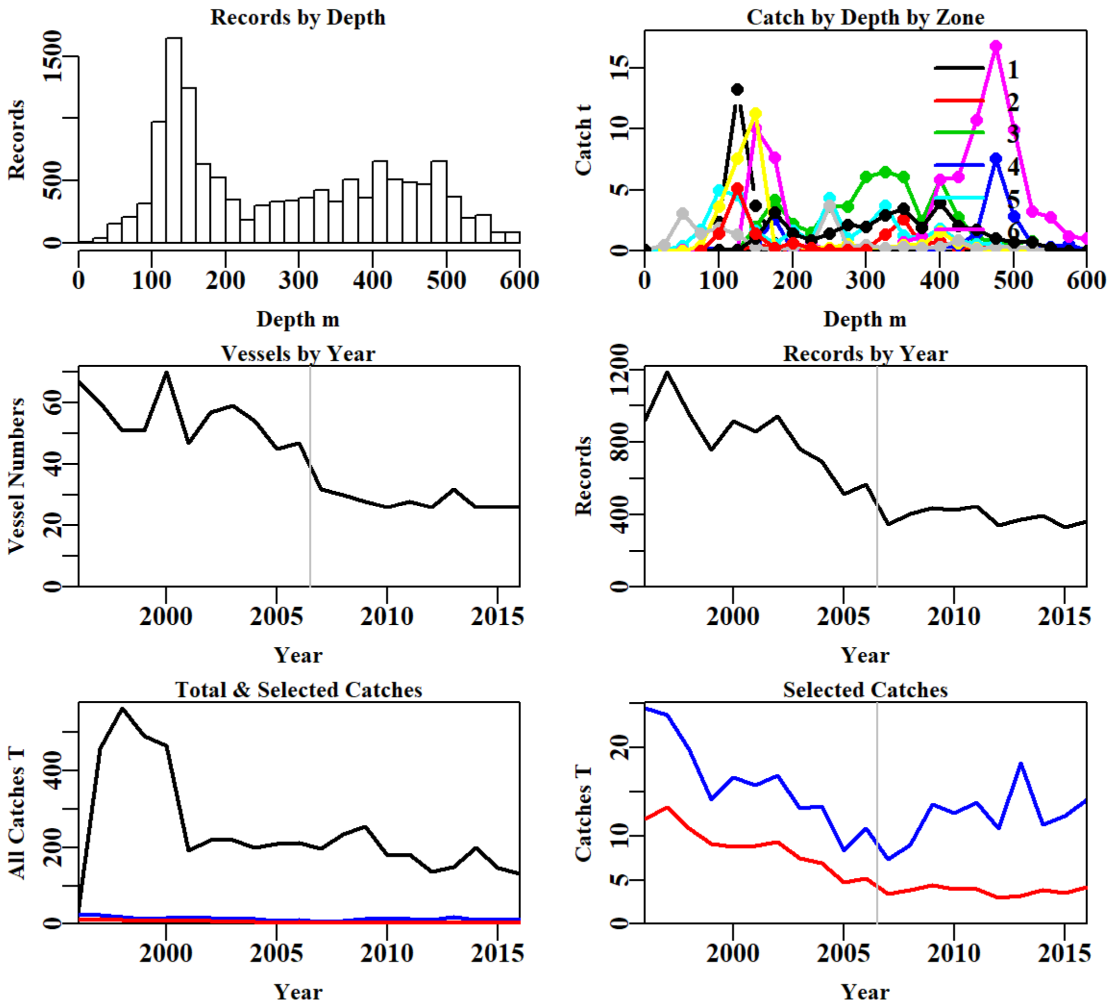


Figure 8.48. SchoolSharkTW fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 8.29. The models used to analyse data for SchoolSharkTW.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + SharkRegion
Model5	Year + Vessel + DepCat + SharkRegion + Month
Model6	Year + Vessel + DepCat + SharkRegion + Month + DayNight
Model7	Year + Vessel + DepCat + SharkRegion + Month + DayNight + ShkReg:DepCat
Model8	Year + Vessel + DepCat + SharkRegion + Month + DayNight + ShkReg:Month

Table 8.30. SchoolSharkTW. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was SharkRegion:DepCat.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	2740	15968	418	12969	21	2.4	0.00
Vessel	-644	12048	4338	12969	156	25.6	23.18
DepCat	-1295	11415	4970	12969	180	29.4	3.77
SharkRegion	-1960	10829	5556	12969	189	32.9	3.58
Month	-2042	10743	5642	12969	200	33.4	0.48
DayNight	-2093	10696	5690	12969	203	33.7	0.28
SharkRegion:DepCat	-2276	10283	6103	12969	367	35.4	1.73
SharkRegion:Month	-2303	10366	6020	12969	301	35.2	1.55

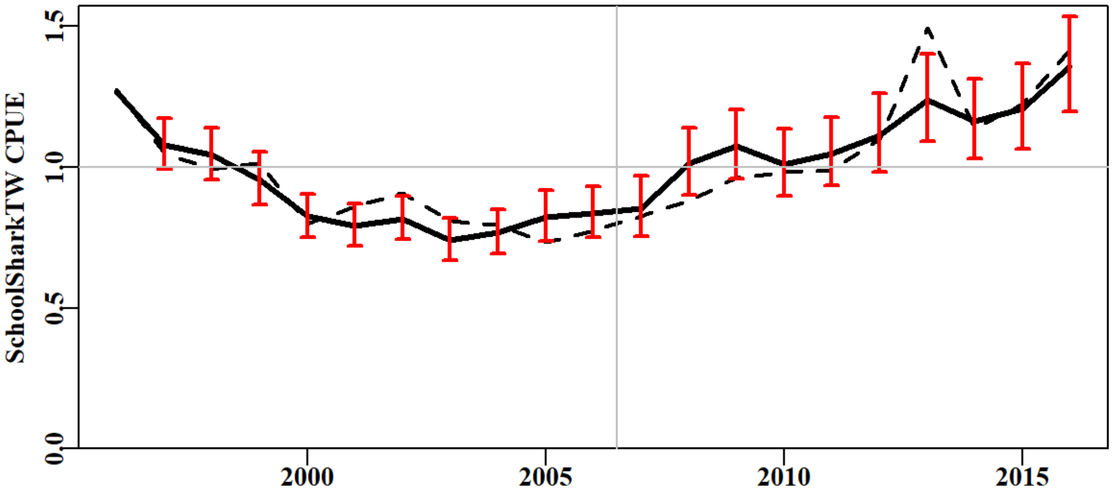


Figure 8.49. SchoolSharkTW standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

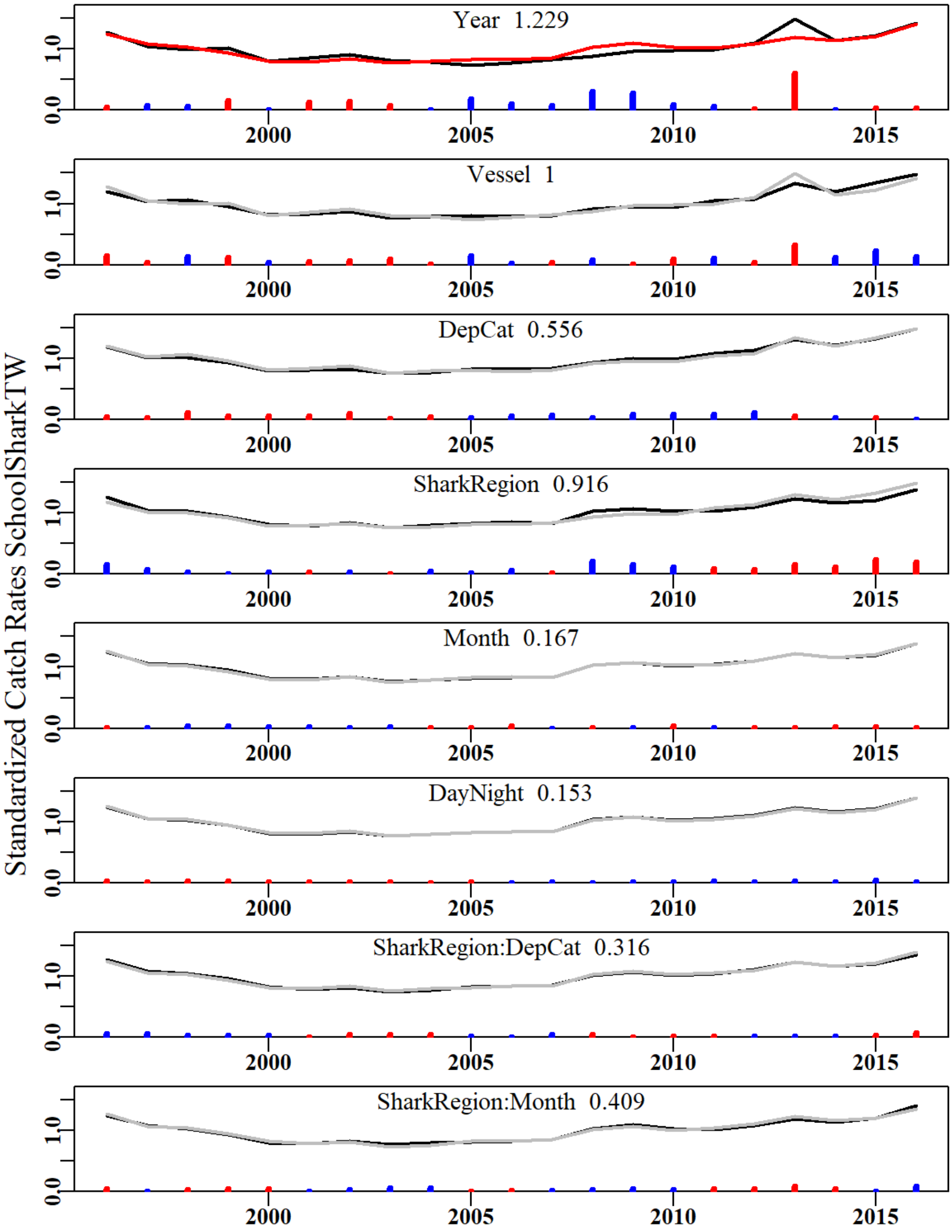


Figure 8.50. SchoolSharkTW. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

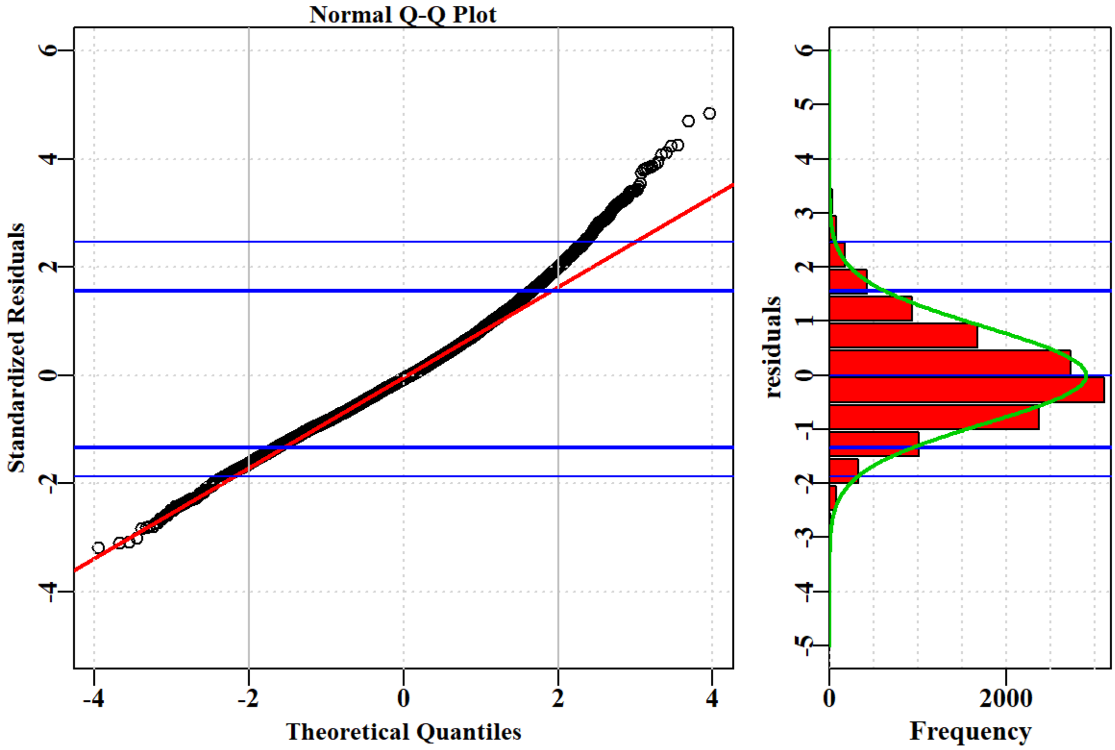


Figure 8.51. SchoolSharkTW. Diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

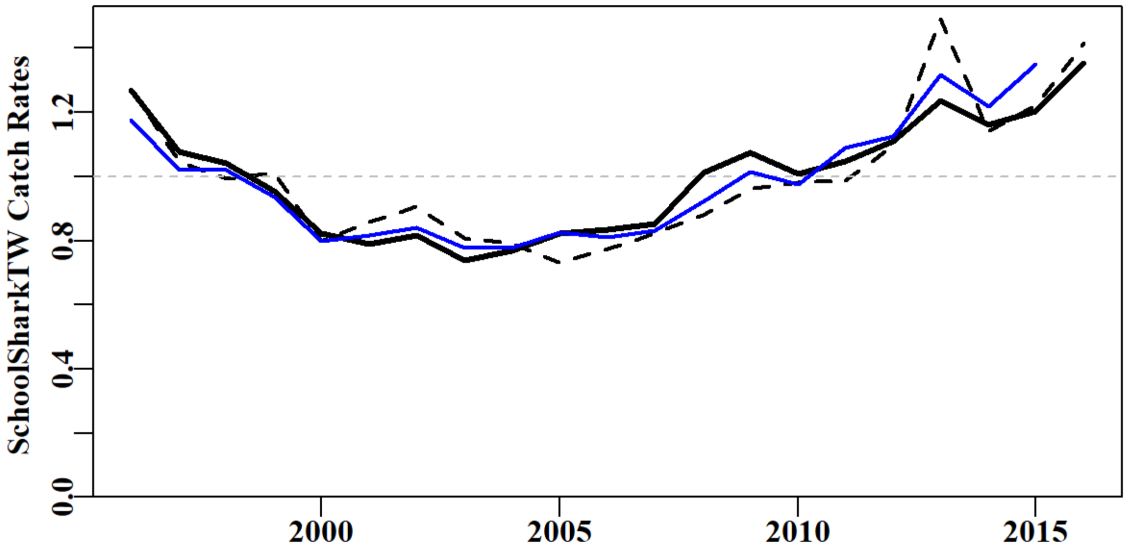


Figure 8.52. SchoolSharkTW. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

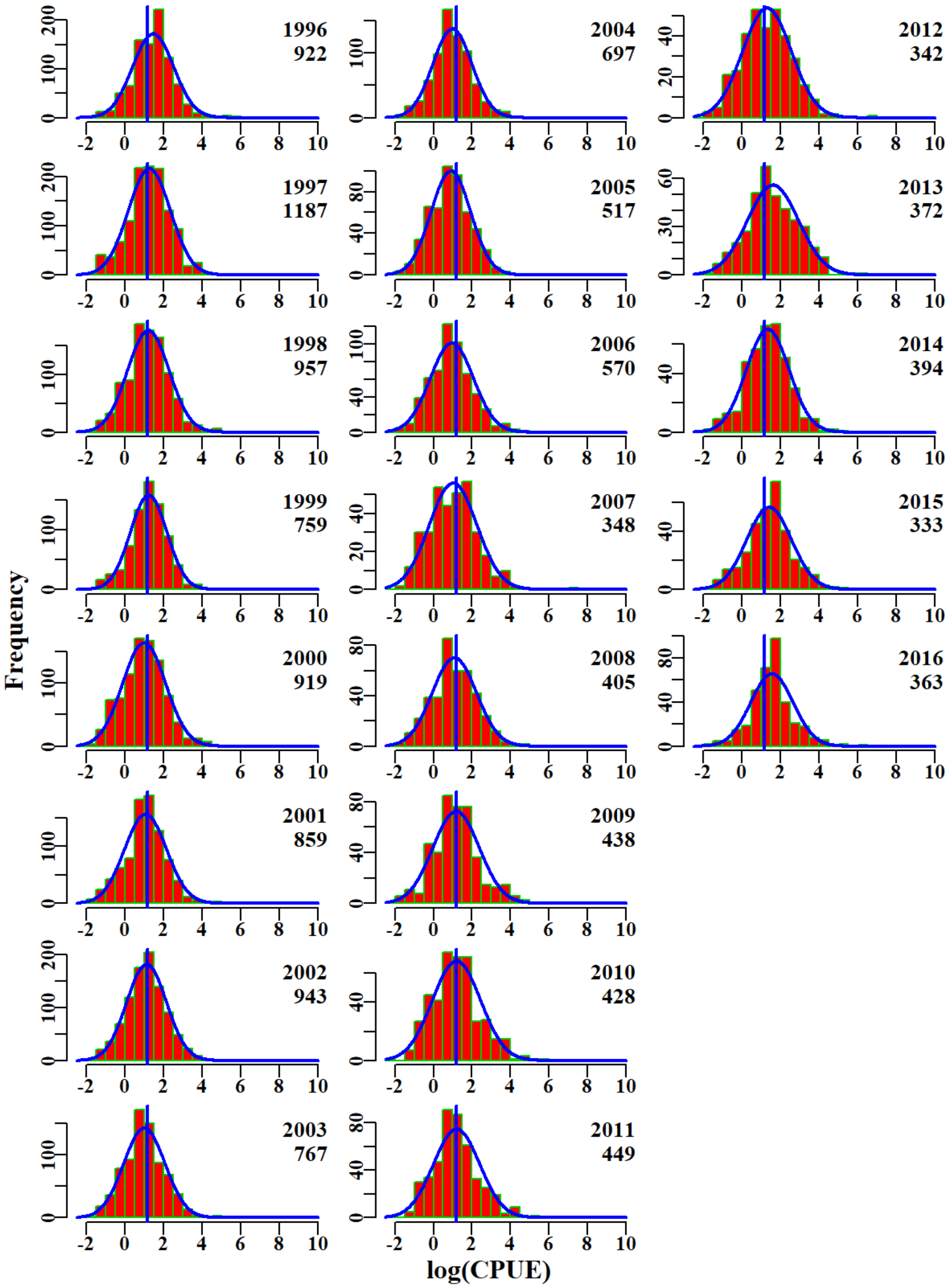


Figure 8.53. SchoolSharkTW. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

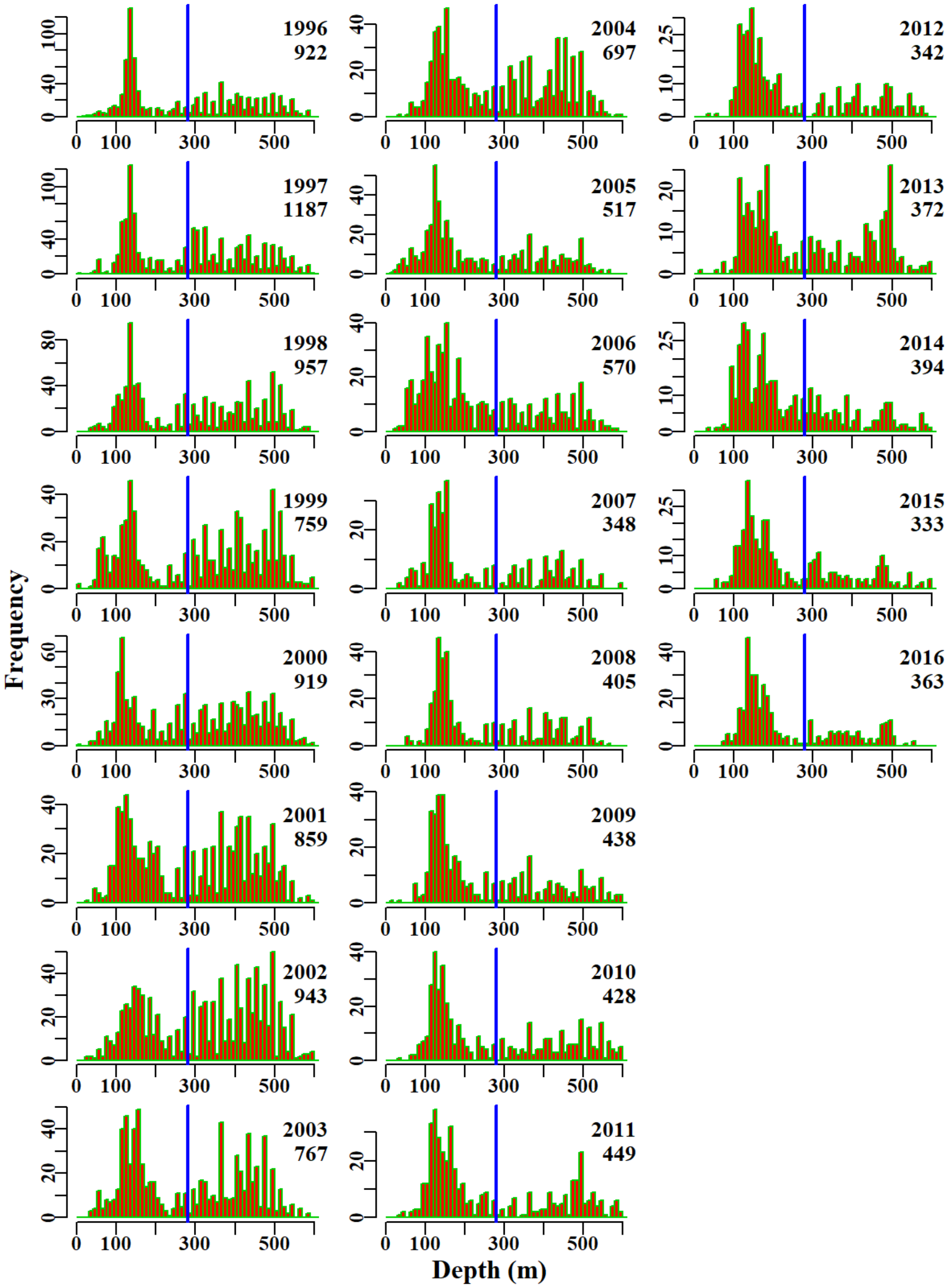


Figure 8.54. SchoolSharkTW. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

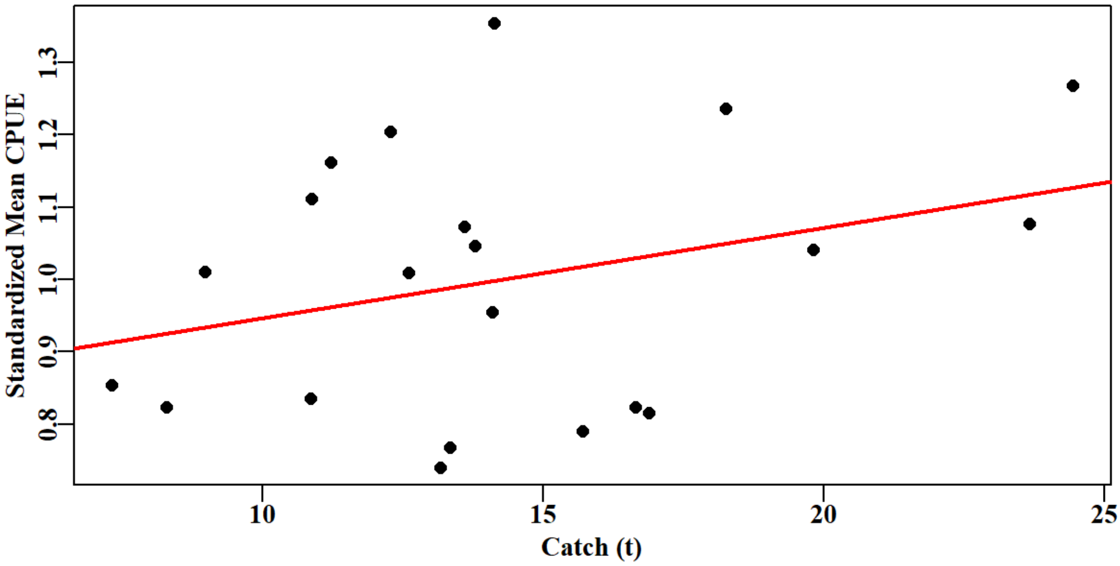


Figure 8.55. SchoolSharkTW. The linear relationship between Annual mean CPUE and Annual Catch.

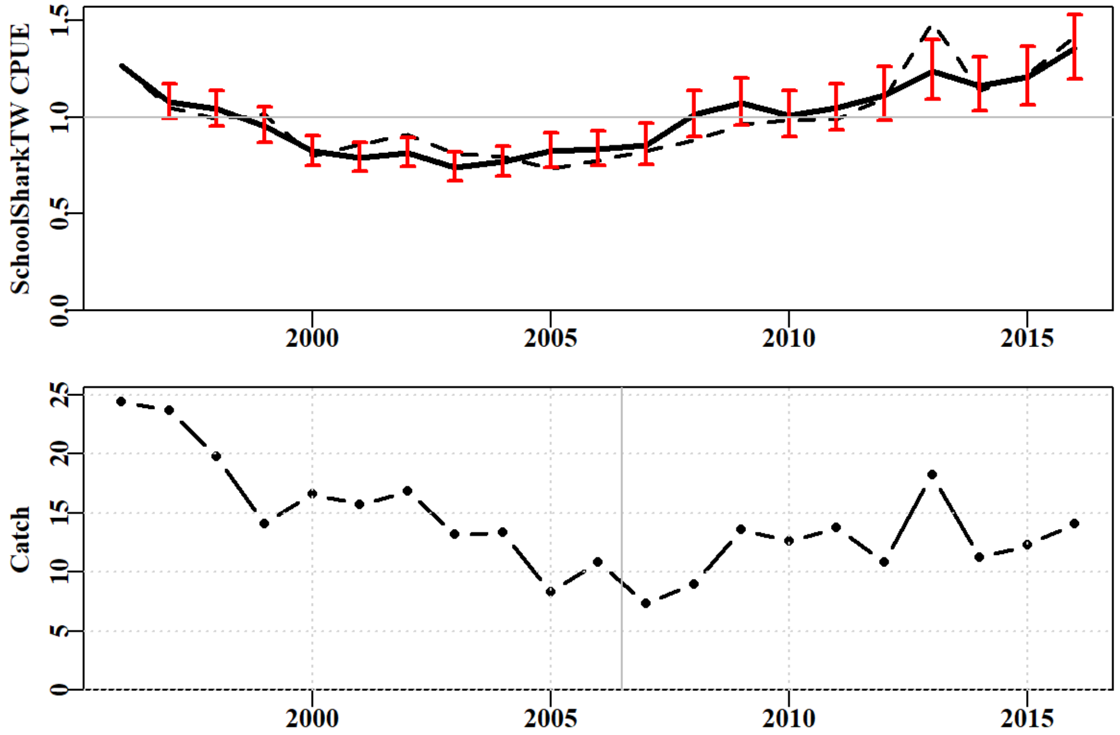


Figure 8.56. SchoolSharkTW. CPUE is correlated with catches through time. CPUE in the top plot and annual catch (t) in the lower plot.

8.10 Sawshark Gillnet

Sawshark are considered to be primarily a bycatch species and are taken mostly by gillnets, trawl and Danish seine. The amounts landed by each of these methods are sufficient to allow a standardization for each method with comparison of outcomes. In each case, the same set of years was used but usually a different set of gears, depths, and shark zones were selected on the basis of the number of fishing operations available.

8.10.1 *Inferences*

There is a strong correlation between total annual catch and annual standardized CPUE estimates. In addition, the large proportion of the total catch taken in shots of < 30kg indicates the by-product nature of this fishery (confirmed by the large proportion of discards from this fishery). A total of 7 statistical models were fitted sequentially to the available data. The optimum model was fitted with terms: Year, Vessel, DepCat, SharkRegion, Month and the interaction SharkRegion x Month. The terms Year, Vessel and SharkRegion had the greatest contribution to model fit. The assumed Normal distribution appears to be valid as depicted by the qqplot. Annual standardized CPUE has been below the long term average since 2009, with minor increases since 2013.

8.10.2 *Action Items and Issues*

A further consideration of whether or not to consider the CPUE time-series as a valid index of relative abundance for sawshark needs to be explored.

Table 8.31. SawSharkGN. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	SawSharkGN
csirocode	37023002, 37023001, 37023000, 37023900
fishery	GHT_SEN_SSF_SSG_SSH
depthrange	0 - 150
depthclass	10
zones	1, 2, 3, 4, 5, 6, 7, 8, 9
methods	GN
years	1997 - 2016

Table 8.32. SawSharkGN. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was SharkRegion:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1997	214.2	4722	146.9	81	32.8	1.2117	0.000	40.042	0.273
1998	284.2	6875	225.0	81	33.7	1.2075	0.023	49.272	0.219
1999	295.6	7638	229.4	85	31.3	1.2927	0.022	58.951	0.257
2000	361.7	7192	275.4	76	39.4	1.6579	0.023	56.498	0.205
2001	340.7	6483	260.1	80	41.7	1.7268	0.023	48.260	0.186
2002	256.6	6251	157.3	77	26.7	1.0534	0.024	47.071	0.299
2003	319.7	6955	190.3	81	29.3	1.0743	0.023	48.450	0.255
2004	314.9	6560	190.8	73	30.7	1.1190	0.024	47.709	0.250
2005	296.7	5783	169.8	62	29.9	1.0124	0.024	42.053	0.248
2006	317.7	5270	155.6	58	30.6	1.0205	0.025	34.869	0.224
2007	214.5	4710	105.9	44	22.3	0.8864	0.026	29.244	0.276
2008	211.7	4651	114.4	44	26.2	1.0179	0.026	30.916	0.270
2009	191.5	4872	88.5	44	18.6	0.8629	0.026	34.081	0.385
2010	192.5	5080	91.4	47	18.7	0.8313	0.026	36.924	0.404
2011	197.0	5331	102.4	46	18.9	0.7935	0.025	38.456	0.376
2012	158.6	4606	73.8	42	16.0	0.6379	0.026	32.666	0.443
2013	165.7	4355	70.7	39	16.4	0.5976	0.027	34.782	0.492
2014	167.2	4179	80.7	38	19.3	0.6489	0.027	32.266	0.400
2015	164.2	4077	75.8	35	19.0	0.6406	0.027	31.405	0.414
2016	165.2	4388	96.1	33	22.4	0.7066	0.027	34.467	0.359

Table 8.33. SawSharkGN data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	234547.0	231281.0	205839.0	191367.0	186565.0	109978.0	109978.0
Difference	0.0	3266.0	25442.0	14472.0	4802.0	76587.0	0.0
Catch	5303.9	5303.9	4312.4	3983.5	3841.5	2900.4	2900.4
Difference	0.0	0.0	991.5	328.9	142.0	941.1	0.0

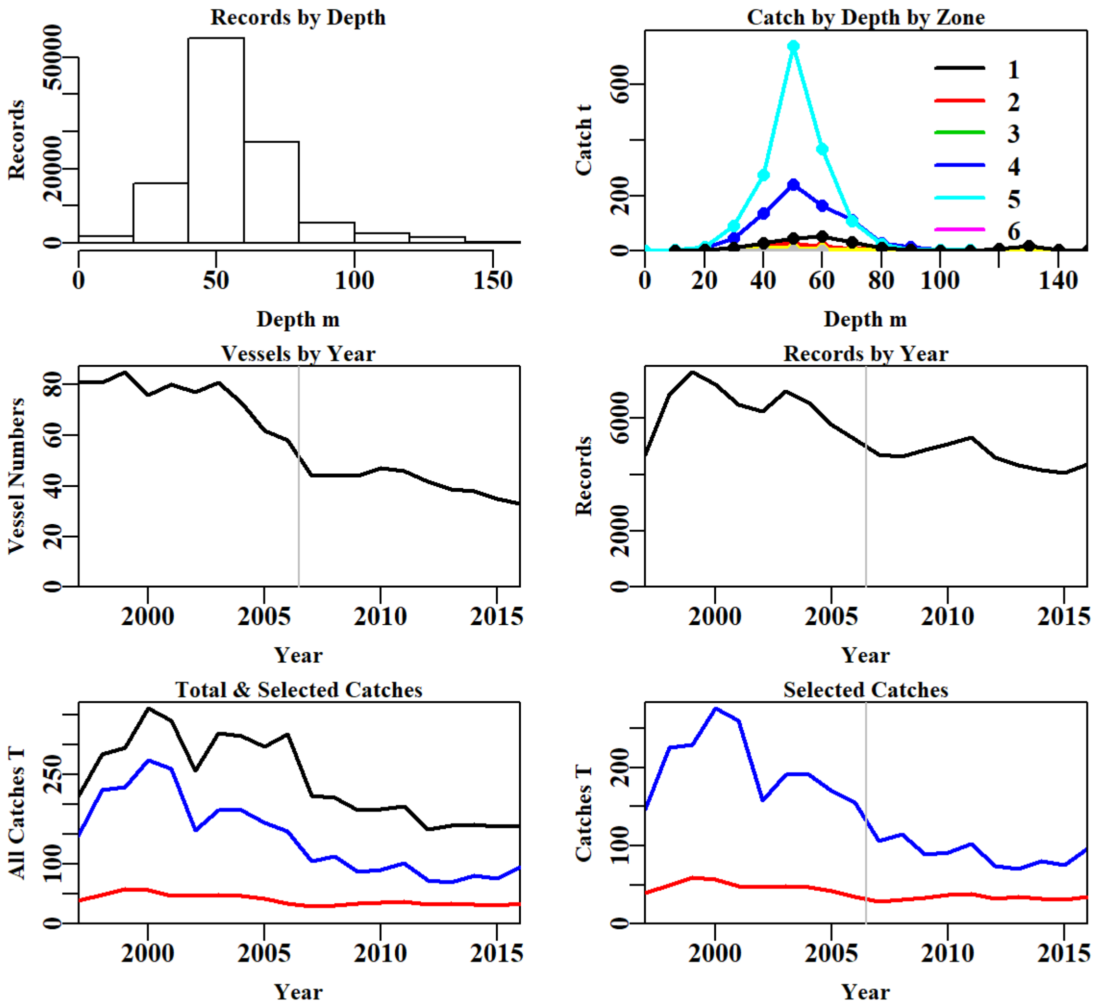


Figure 8.57. SawSharkGN fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 8.34. The models used to analyse data for SawSharkGN.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + SharkRegion
Model5	Year + Vessel + DepCat + SharkRegion + Month
Model6	Year + Vessel + DepCat + SharkRegion + Month + SharkRegion:DepCat
Model7	Year + Vessel + DepCat + SharkRegion + Month + SharkRegion:Month

Table 8.35. SawSharkGN. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was SharkRegion:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	68718	205358	7740	109978	20	3.6	0.00
Vessel	44497	164208	48890	109978	206	22.8	19.18
DepCat	37240	153680	59417	109978	221	27.7	4.94
SharkRegion	32405	147048	66049	109978	229	30.9	3.11
Month	30381	144339	68759	109978	240	32.1	1.27
SharkRegion:DepCat	26883	139548	73549	109978	347	34.3	2.19
SharkRegion:Month	26233	138776	74321	109978	327	34.7	2.56

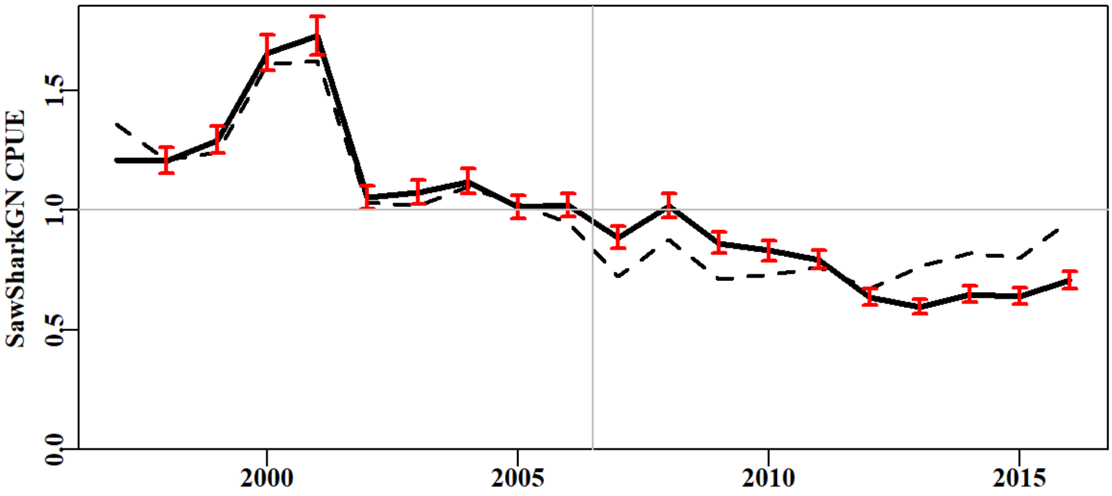


Figure 8.58. SawSharkGN standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

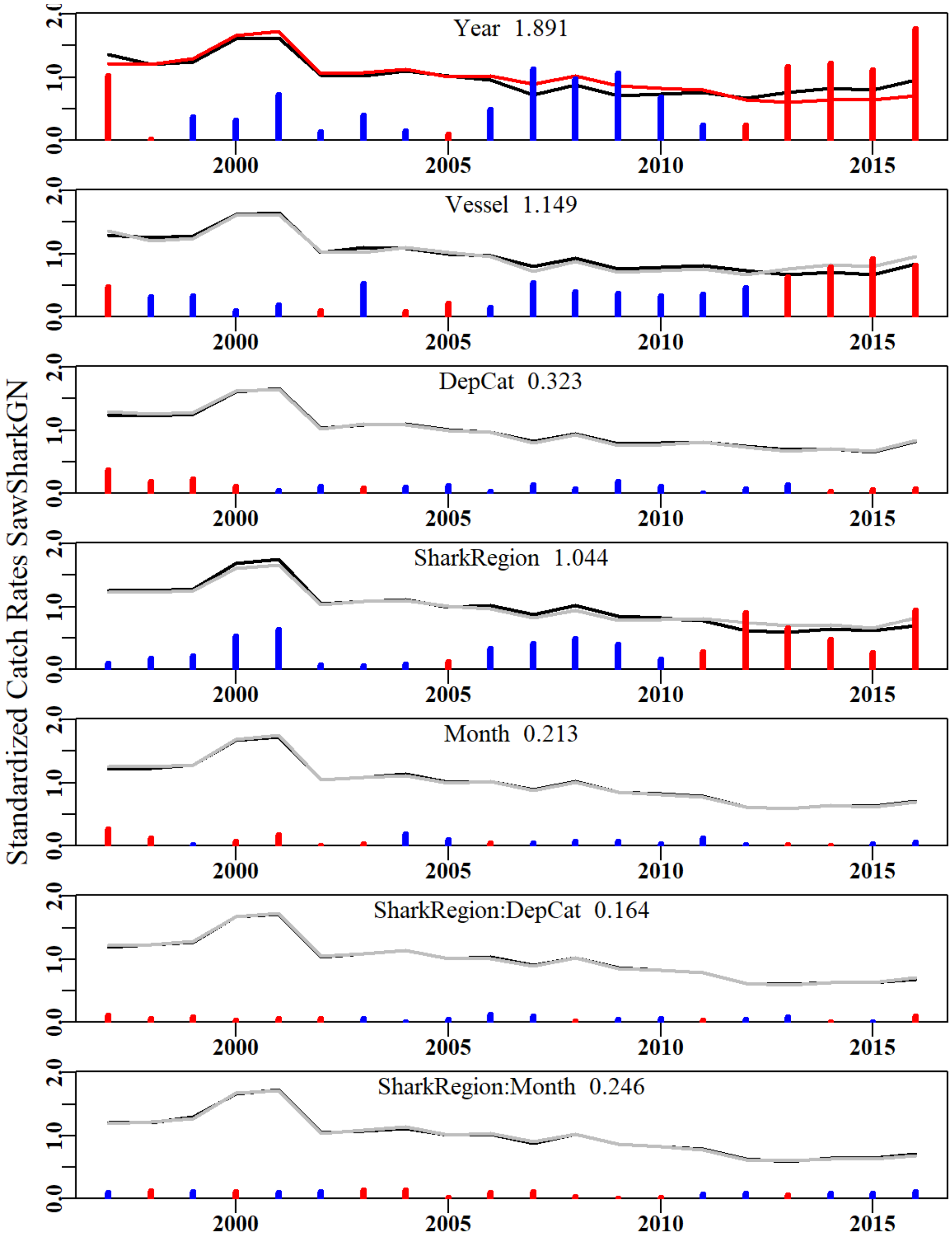


Figure 8.59. SawSharkGN. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

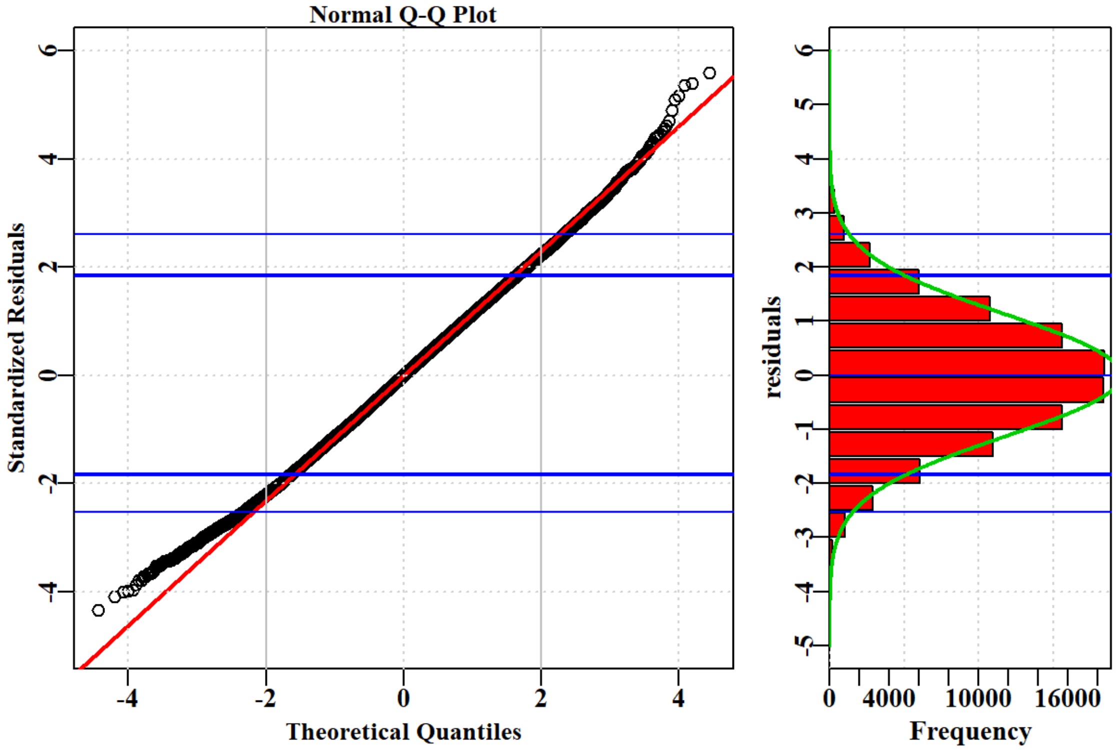


Figure 8.60. SawSharkGN. Diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

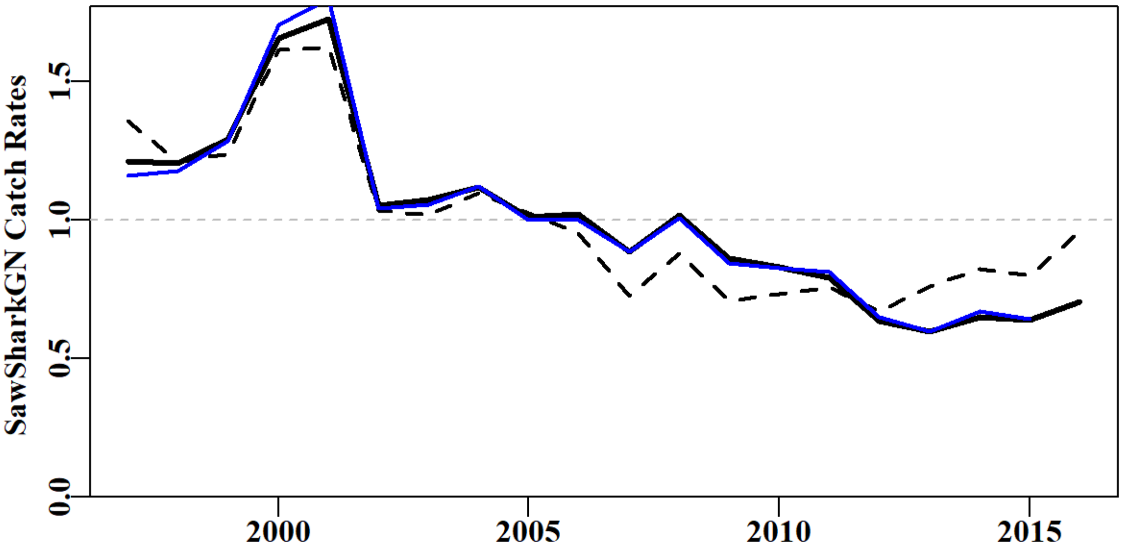


Figure 8.61. SawSharkGN. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

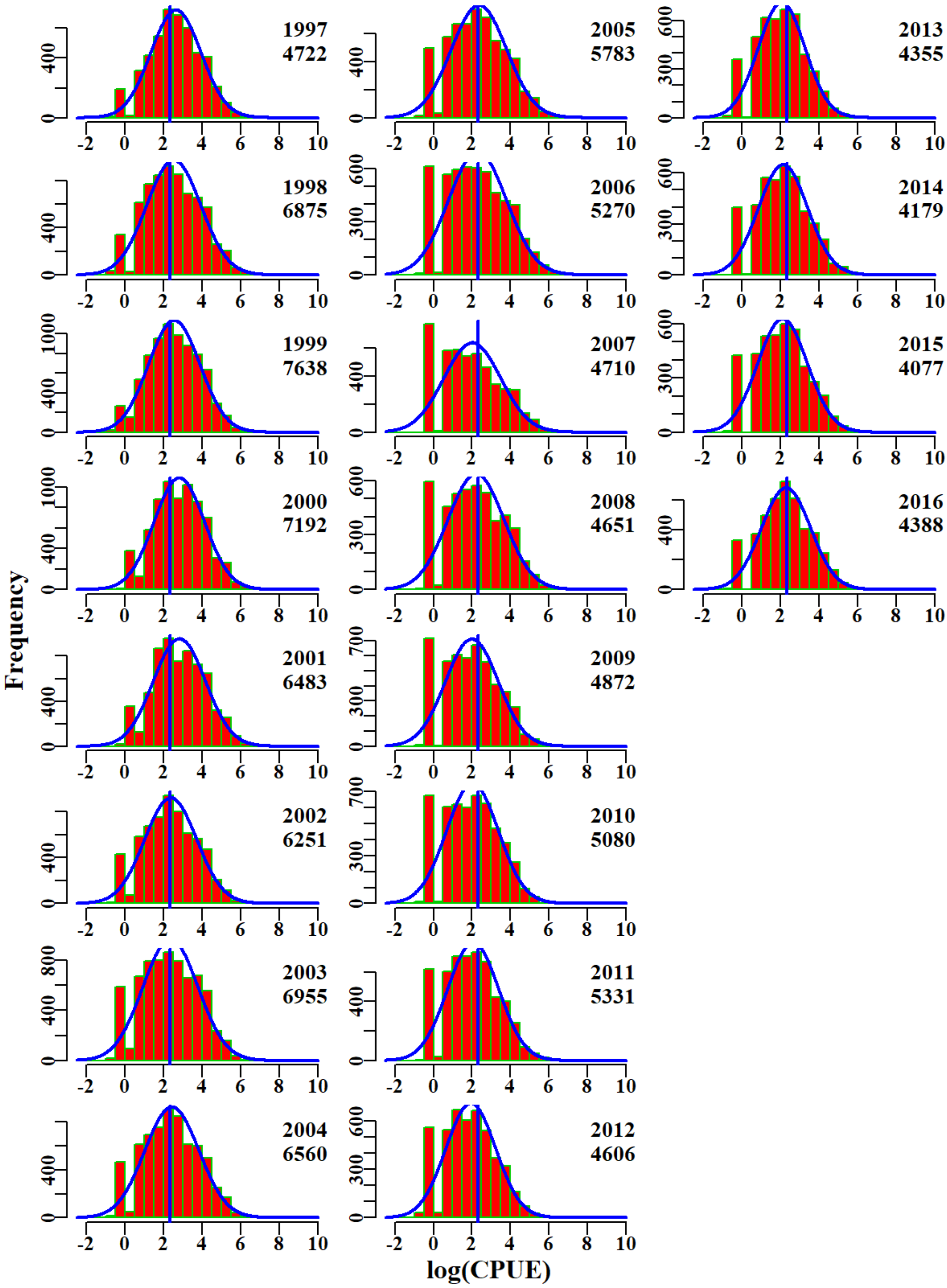


Figure 8.62. SawSharkGN. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

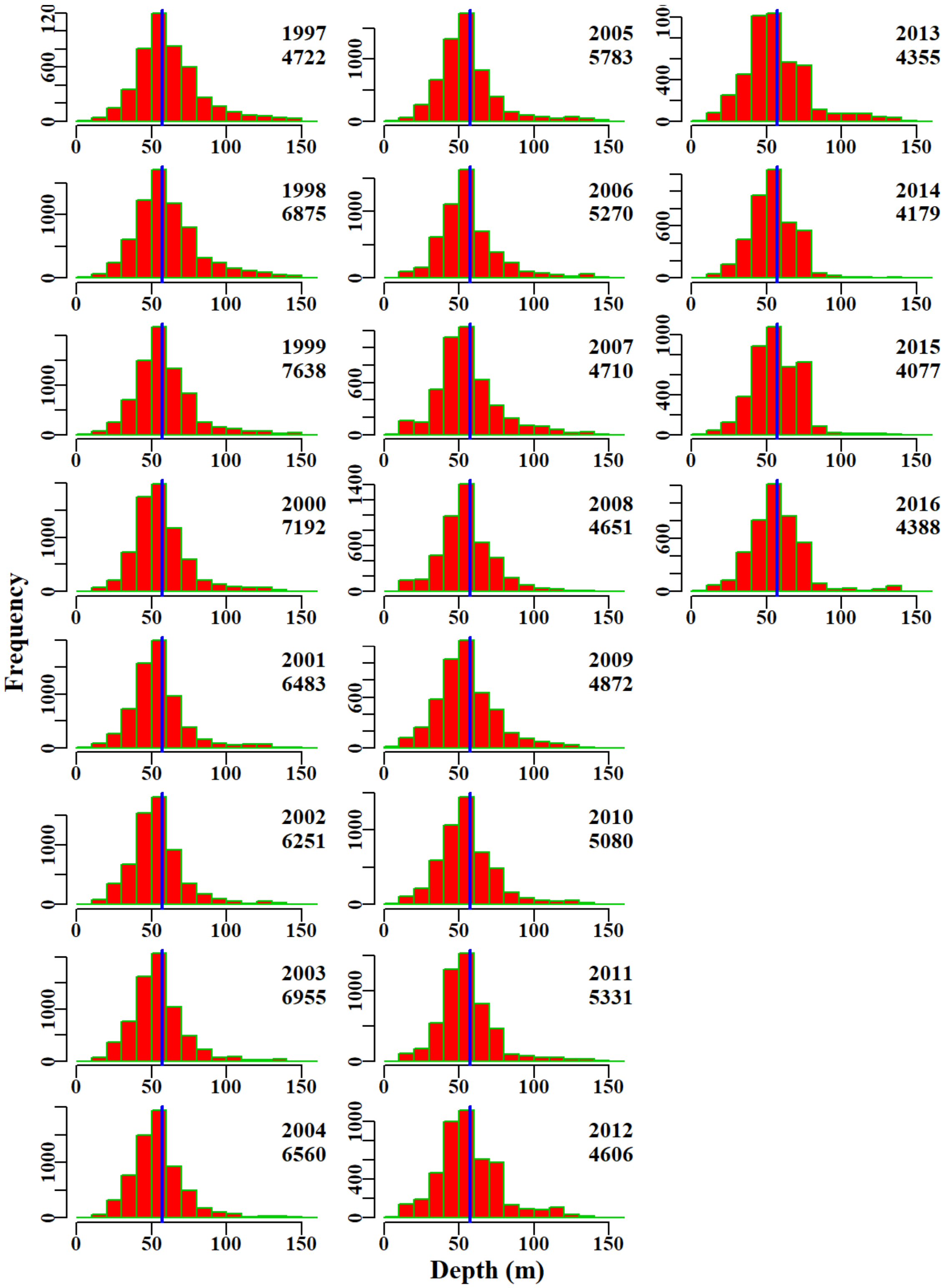


Figure 8.63. SawSharkGN. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

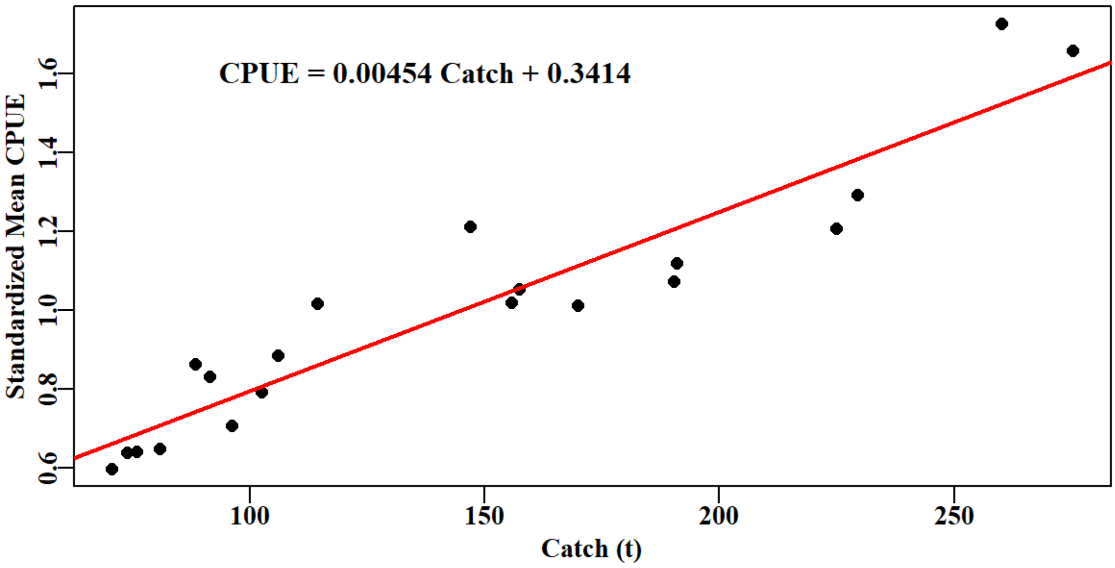


Figure 8.64. SawSharkGN. The linear relationship between Annual mean CPUE and Annual Catch.

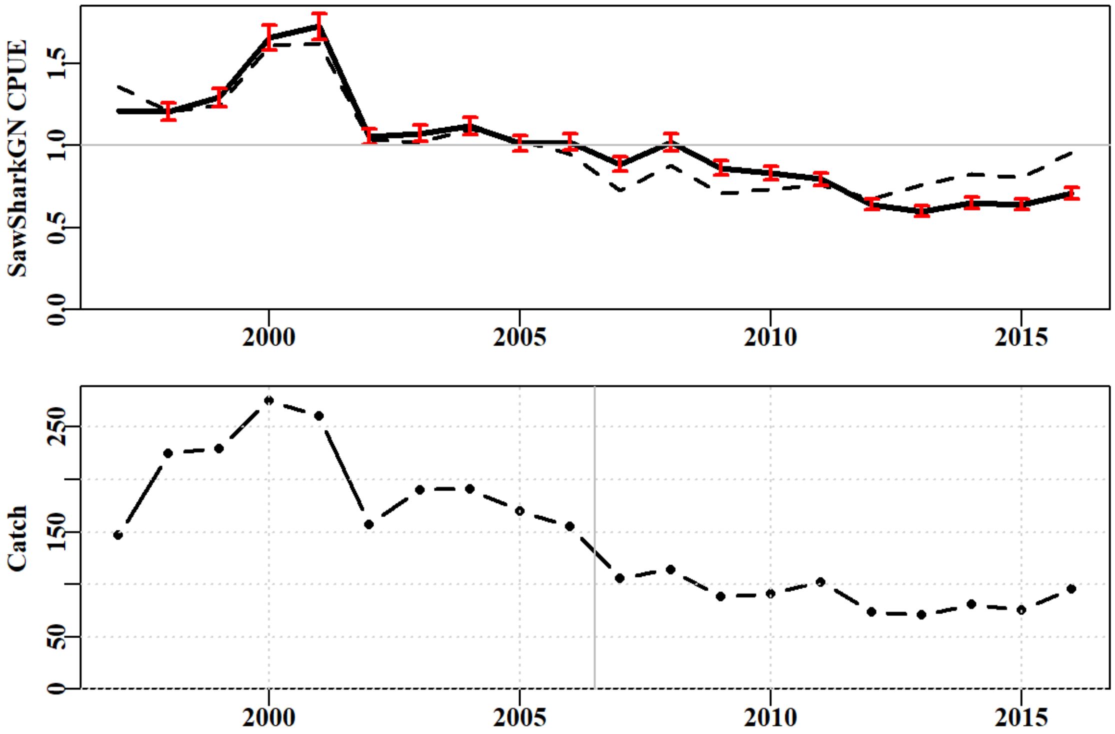


Figure 8.65. SawSharkGN. CPUE is correlated with catches through time. CPUE in the top plot and annual catch (t) in the lower plot.

8.11 Sawshark Trawl

Non-zero records of catch per hour were employed in the statistical standardization analyses for sawshark caught by trawl.

8.11.1 *Inferences*

A total of 8 statistical models were fitted sequentially to the available data. The optimum model was fitted with terms: Year, Vessel, DepCat, SharkRegion, Month, DayNight and the interaction SharkRegion x Month. The terms Year, Vessel and SharkRegion had the greatest contribution to model fit. The assumed Normal distribution appears to be valid as depicted by the qqplot. Annual standardized CPUE has decreased in 2016 compared to 2015 and is below the long term average.

8.11.2 *Action Items and Issues*

A further consideration of whether or not to consider the CPUE time-series as a valid index of relative abundance for sawshark needs to be explored.

Table 8.36. SawSharkTrawl. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	SawSharkTrawl
csirocode	37023002, 37023001, 37023000, 37023900
fishery	SET_GAB
depthrange	0 - 500
depthclass	20
zones	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
methods	TW, TDO, OTT, PTB
years	1995 - 2016

Table 8.37. SawSharkTrawl. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was SharkRegion:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1995	57.1	1764	51.7	54	7.9	1.3135	0.000	17.727	0.343
1996	67.5	1992	59.9	60	8.1	1.3338	0.035	19.324	0.323
1997	214.2	2443	59.4	60	6.5	1.1837	0.035	24.417	0.411
1998	284.2	1694	47.9	54	6.8	1.0906	0.038	16.888	0.353
1999	295.6	1813	51.2	50	7.6	1.2529	0.037	17.384	0.339
2000	361.7	2361	69.0	65	10.2	1.1011	0.036	23.081	0.335
2001	340.7	2555	68.1	54	6.9	1.0665	0.036	23.629	0.347
2002	256.6	3298	70.8	68	5.9	0.9359	0.034	28.762	0.406
2003	319.7	4400	100.8	75	5.7	0.8538	0.033	34.943	0.347
2004	314.9	4270	95.4	76	6.3	0.8401	0.033	33.848	0.355
2005	296.7	4931	104.6	71	5.7	0.8446	0.033	40.154	0.384
2006	317.7	4625	137.2	64	7.4	0.9368	0.033	33.402	0.243
2007	214.5	2561	82.0	39	7.4	0.8139	0.036	20.114	0.245
2008	211.7	2893	71.7	40	5.6	0.8536	0.035	24.800	0.346
2009	191.5	2806	78.4	34	6.7	1.0858	0.035	25.884	0.330
2010	192.5	3138	80.4	37	5.9	0.9790	0.035	29.956	0.373
2011	197.0	2914	66.8	36	5.5	0.8724	0.035	25.062	0.375
2012	158.6	2426	60.5	36	6.2	0.8649	0.036	21.854	0.361
2013	165.7	2526	70.0	36	6.7	1.0087	0.036	26.220	0.375
2014	167.2	2261	70.1	36	7.5	1.0071	0.037	24.565	0.351
2015	164.2	2213	59.4	36	7.0	0.9205	0.037	22.834	0.385
2016	165.2	1977	47.2	37	6.7	0.8408	0.038	19.457	0.412

Table 8.38. SawSharkTrawl data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	234547.0	126928.0	125494.0	113587.0	113348.0	61950.0	61861.0
Difference	0.0	107619.0	1434.0	11907.0	239.0	51398.0	89.0
Catch	5303.9	2882.8	2852.6	2529.2	2525.9	1603.8	1602.5
Difference	0.0	2421.2	30.1	323.4	3.3	922.1	1.4

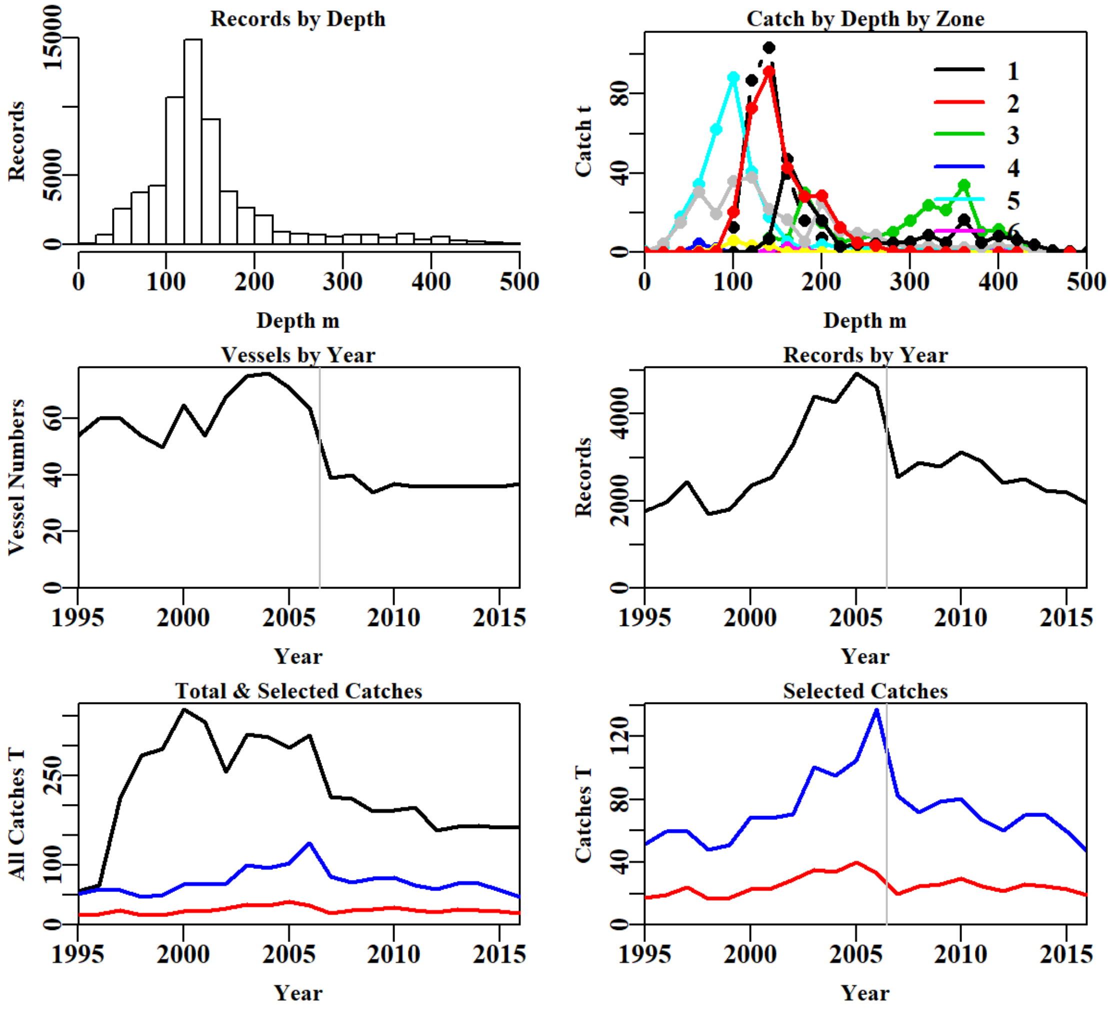


Figure 8.66. SawSharkTrawl fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 8.39. The models used to analyse data for SawSharkTrawl.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + SharkRegion
Model5	Year + Vessel + DepCat + SharkRegion + Month
Model6	Year + Vessel + DepCat + SharkRegion + Month + DayNight
Model7	Year + Vessel + DepCat + SharkRegion + Month + DayNight + SharkRegion:DepCat
Model8	Year + Vessel + DepCat + SharkRegion + Month + DayNight + SharkRegion:Month

Table 8.40. SawSharkTrawl. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was SharkRegion:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	28023	97239	1093	61861	22	1.1	0.00
Vessel	10530	72969	25364	61861	157	25.6	24.53
DepCat	8567	70632	27700	61861	182	28.0	2.35
SharkRegion	6831	68658	29674	61861	191	30.0	2.00
Month	5316	66973	31360	61861	202	31.7	1.71
DayNight	5227	66870	31462	61861	205	31.8	0.10
SharkRegion:DepCat	4089	65252	33080	61861	394	33.2	1.45
SharkRegion:Month	3258	64569	33764	61861	304	34.0	2.24

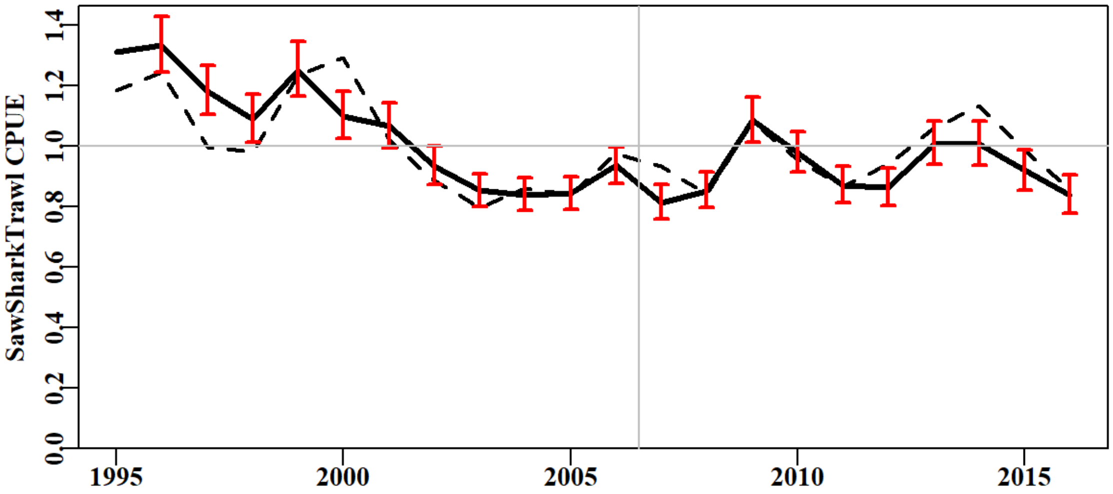


Figure 8.67. SawSharkTrawl standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

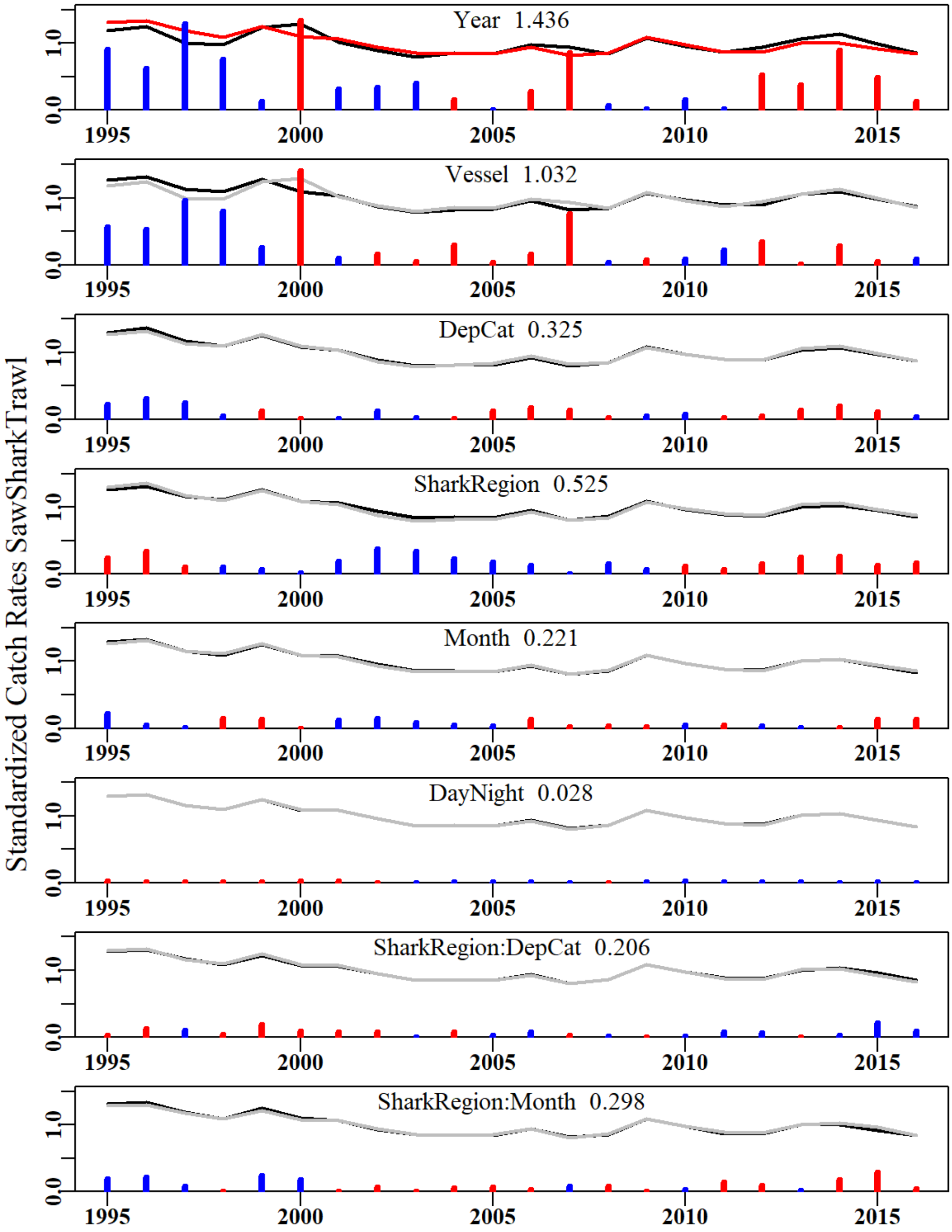


Figure 8.68. SawSharkTrawl. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

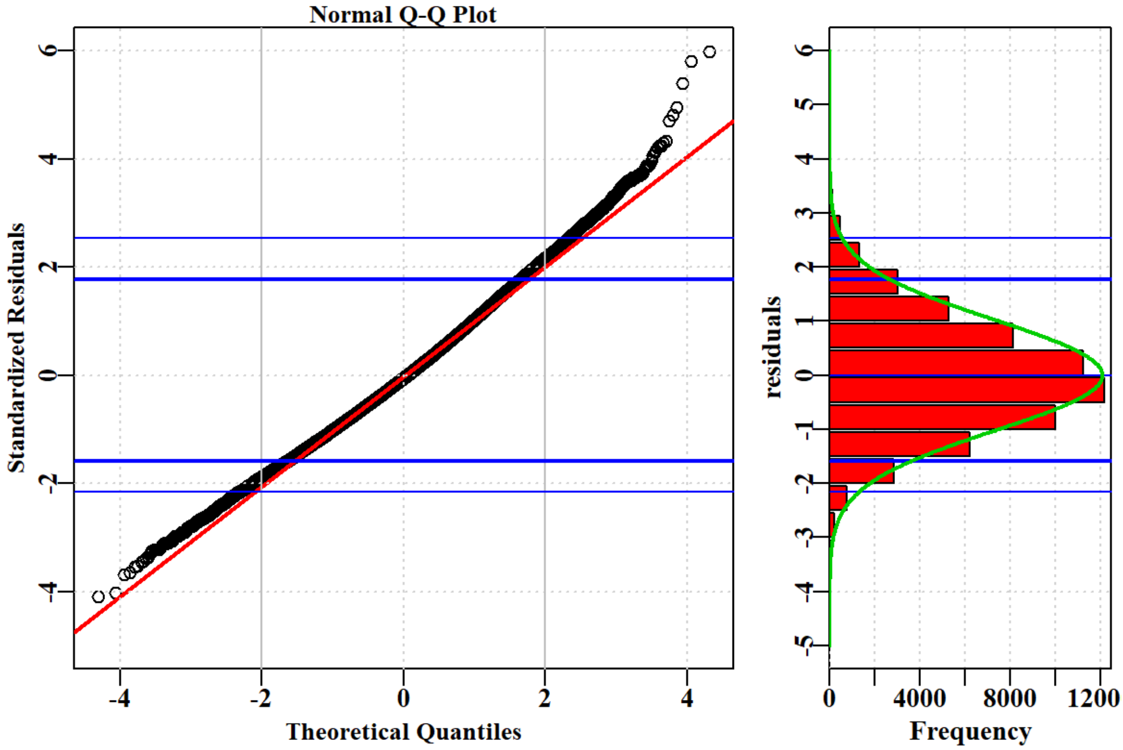


Figure 8.69. SawSharkTrawl. Diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

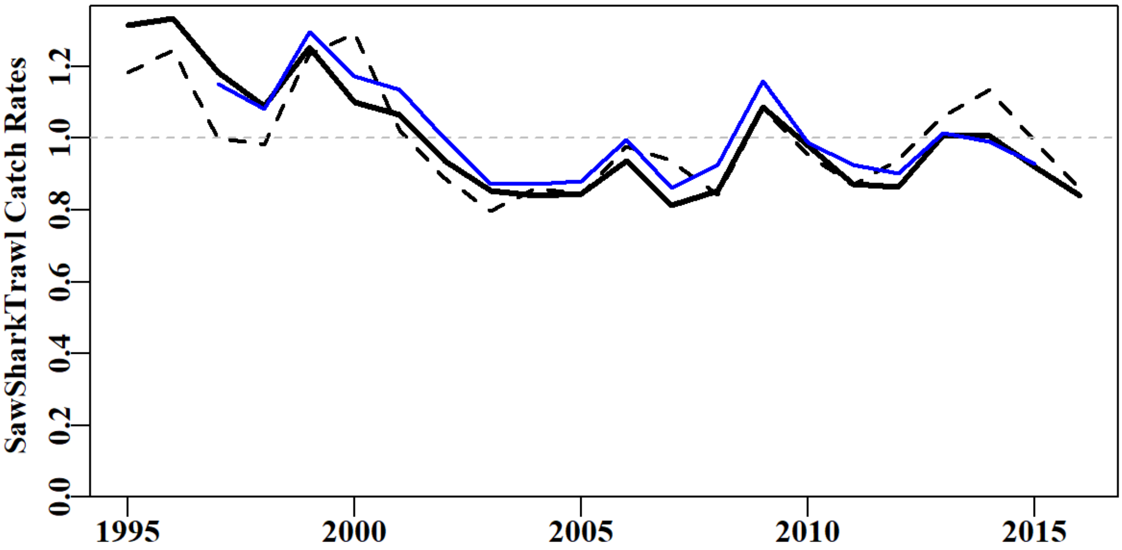


Figure 8.70. SawSharkTrawl. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

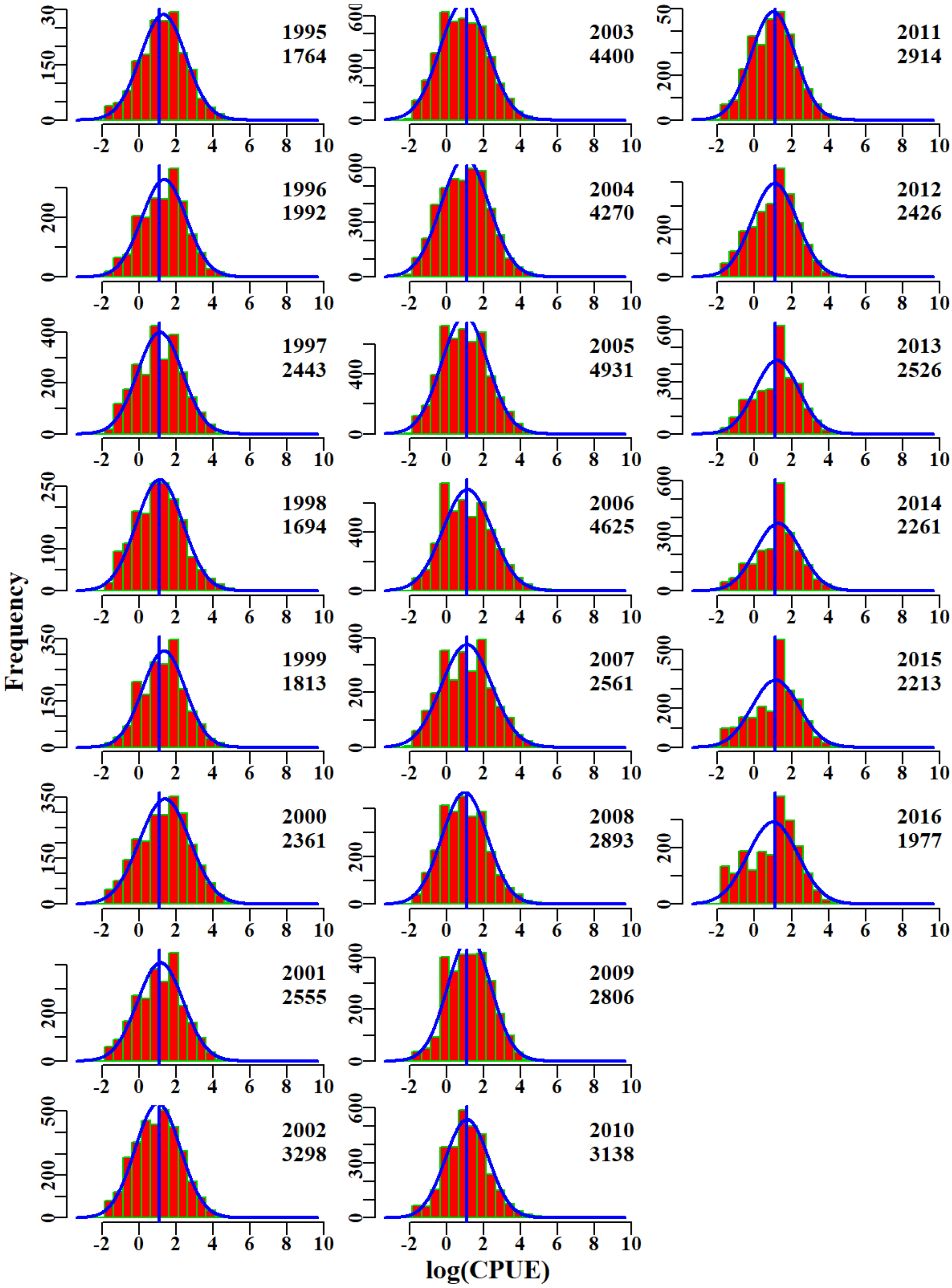


Figure 8.71. SawSharkTrawl. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

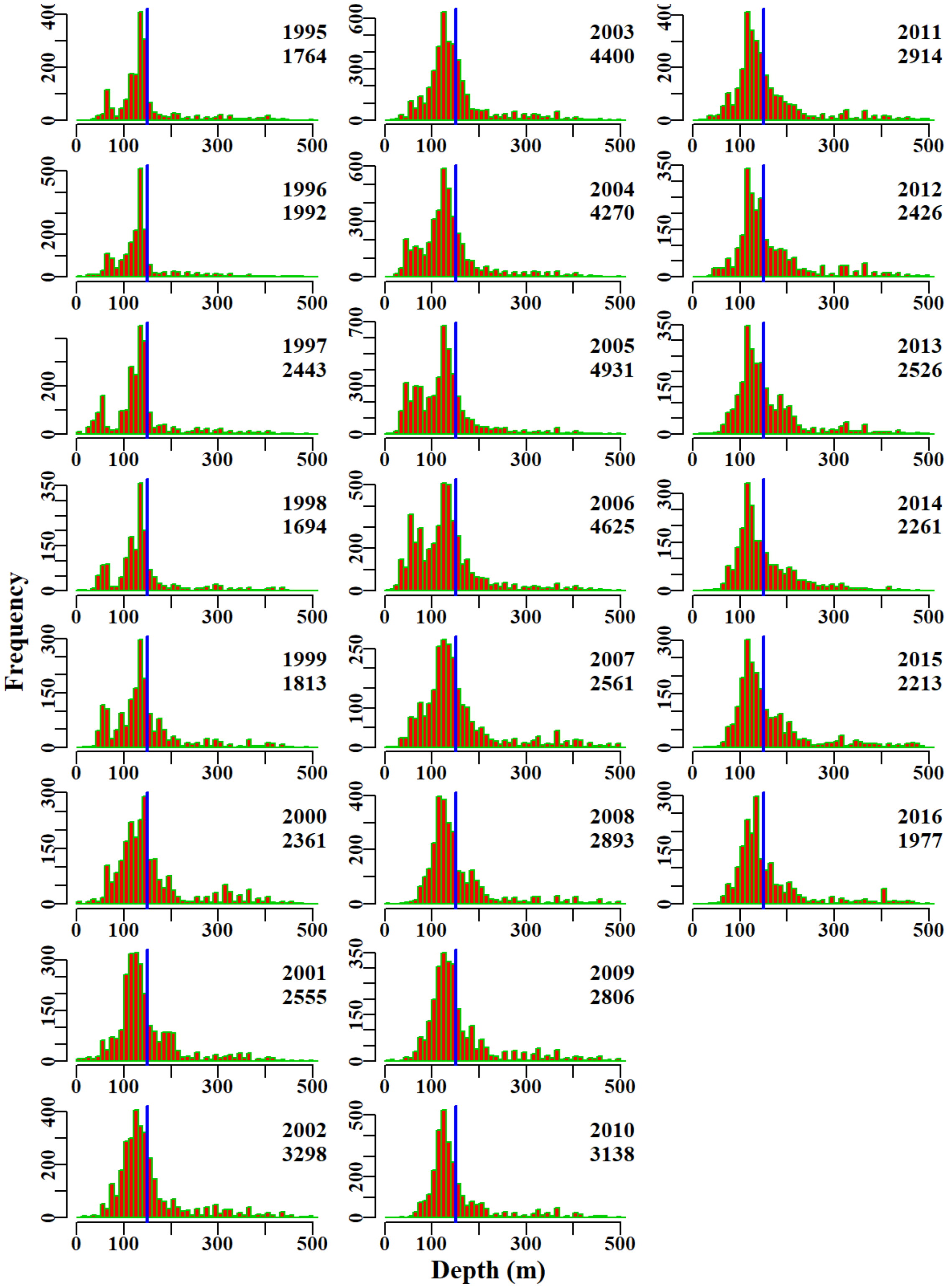


Figure 8.72. SawSharkTrawl. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

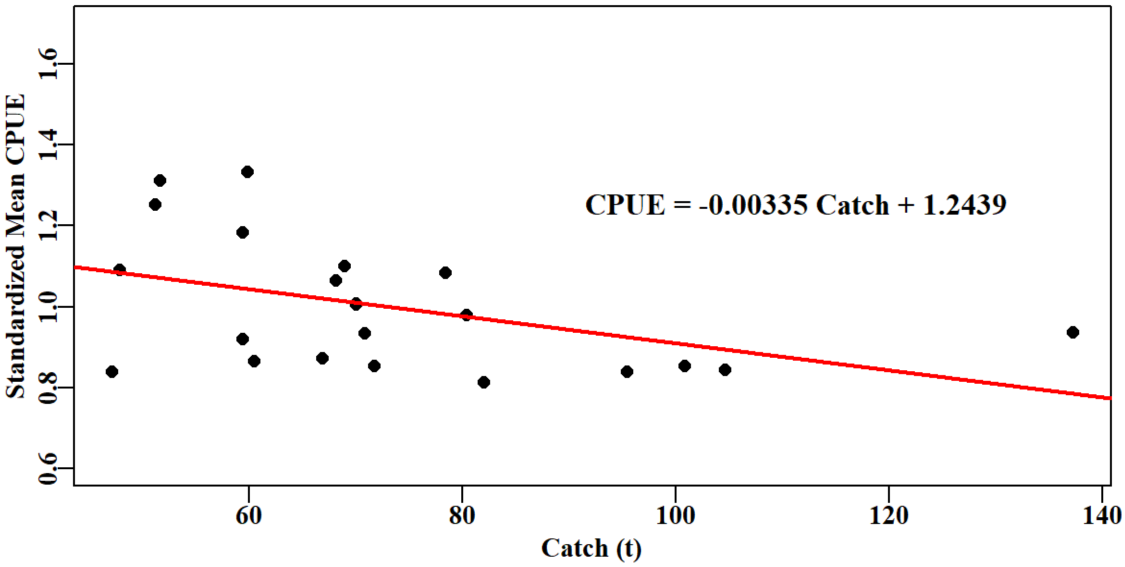


Figure 8.73. SawSharkTrawl. The linear relationship between Annual mean CPUE and Annual Catch.

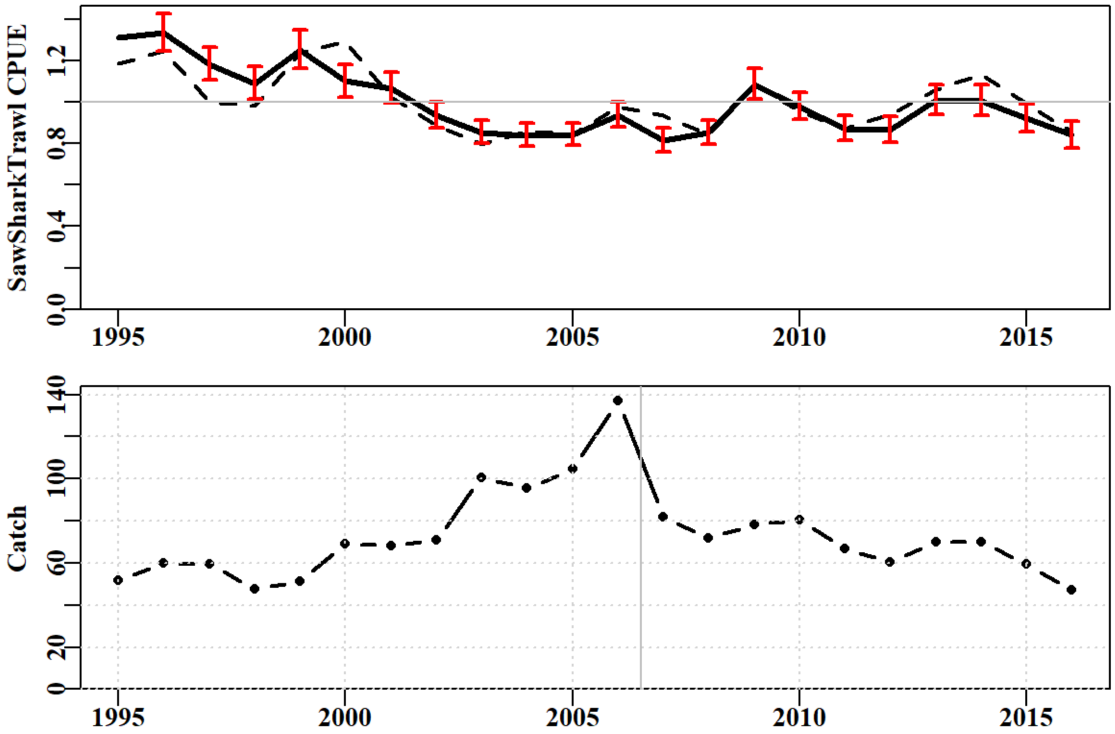


Figure 8.74. SawSharkTrawl. CPUE is correlated with catches through time. CPUE in the top plot and annual catch (t) in the lower plot.

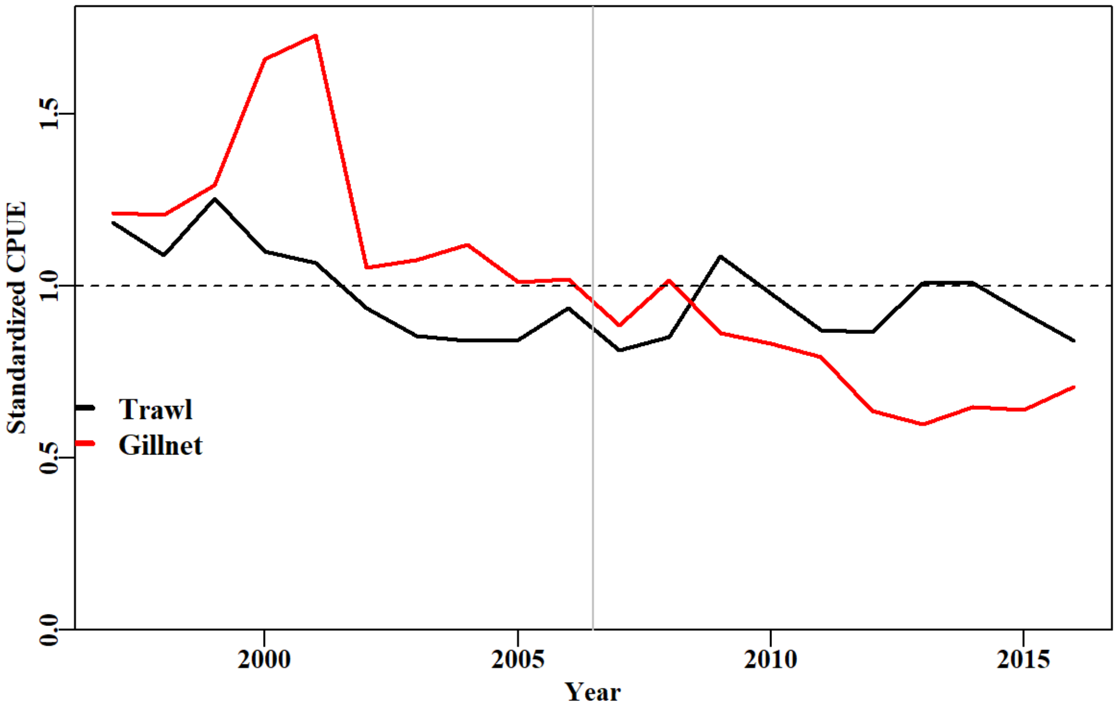


Figure 8.75. Sawshark CPUE from Trawl compared with that from Gillnet.

8.12 Sawshark Danish Seine

A large proportion of records contain missing effort entries, so CPUE used in the analyses was kg/shot. Data pertaining to Shark Zones 4 and 5 (Western and Eastern Bass Strait respectively) were used in the analysis.

8.12.1 *Inferences*

A total of 8 statistical models were fitted sequentially to the available data. The optimum model was fitted with terms: Year, Vessel, DepCat, SharkRegion, Month, DayNight and the interaction SharkRegion x Month. The terms Year, Vessel, Depcat and SharkRegion had the greatest contribution to model fit. The assumed Normal distribution appears to be valid as depicted by the qqplot. Annual standardized CPUE has remained at the long term average since 2015.

8.12.2 *Action Items and Issues*

A further consideration of whether or not to consider the CPUE time-series as a valid index of relative abundance for Saw sharks could be explored. SharkRAG recommended that sawshark-danish seine standardized CPUE would not be used as a relative index of abundance (SharkRAG Meeting 1, October 2015).

Table 8.41. SawShark_DS. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	SawShark_DS
csirocode	37023002, 37023001, 37023000, 37023900
fishery	SET_GAB
depthrange	0 - 240
depthclass	20
zones	4, 5
methods	DS
years	1997 - 2016

Table 8.42. SawShark_DS. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was SharkRegion:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1997	214.2	428	4.0	13	9.2	1.3950	0.000	3.588	0.904
1998	284.2	481	6.7	12	13.9	1.6298	0.068	4.918	0.732
1999	295.6	611	6.4	13	10.0	1.2807	0.064	4.834	0.752
2000	361.7	396	7.1	11	16.9	1.8912	0.072	3.528	0.495
2001	340.7	504	7.0	12	13.2	1.0714	0.071	4.367	0.626
2002	256.6	2646	23.5	22	8.4	0.8921	0.057	16.749	0.712
2003	319.7	2965	21.5	22	6.8	0.7897	0.057	17.386	0.810
2004	314.9	3123	23.5	22	6.7	0.7314	0.057	16.076	0.685
2005	296.7	2555	16.8	22	5.7	0.6498	0.057	12.193	0.724
2006	317.7	2189	17.3	19	7.1	0.7610	0.058	12.107	0.698
2007	214.5	2194	20.9	15	8.5	0.8520	0.058	12.614	0.603
2008	211.7	2407	21.9	15	8.4	0.8982	0.058	14.812	0.675
2009	191.5	2792	20.8	15	6.6	0.8612	0.058	14.685	0.707
2010	192.5	2333	16.7	15	6.7	0.8850	0.058	13.210	0.791
2011	197.0	2796	24.6	14	8.3	0.8626	0.058	17.448	0.709
2012	158.6	2164	20.0	14	8.6	0.8425	0.058	13.778	0.688
2013	165.7	2487	20.5	14	7.7	0.8610	0.058	15.328	0.747
2014	167.2	1706	13.1	14	6.9	0.7628	0.060	9.631	0.736
2015	164.2	2103	23.7	15	10.3	1.0709	0.059	13.550	0.573
2016	165.2	1853	18.8	15	9.1	1.0117	0.060	11.598	0.617

Table 8.43. SawShark_DS data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	234547.0	231281.0	220971.0	204568	133311.0	39108.0	38733.0
Difference	0.0	3266.0	10310.0	16403	71257.0	94203.0	375.0
Catch	5303.9	5303.9	4883.0	4474	2985.2	336.9	334.9
Difference	0.0	0.0	420.9	409	1488.8	2648.3	2.0

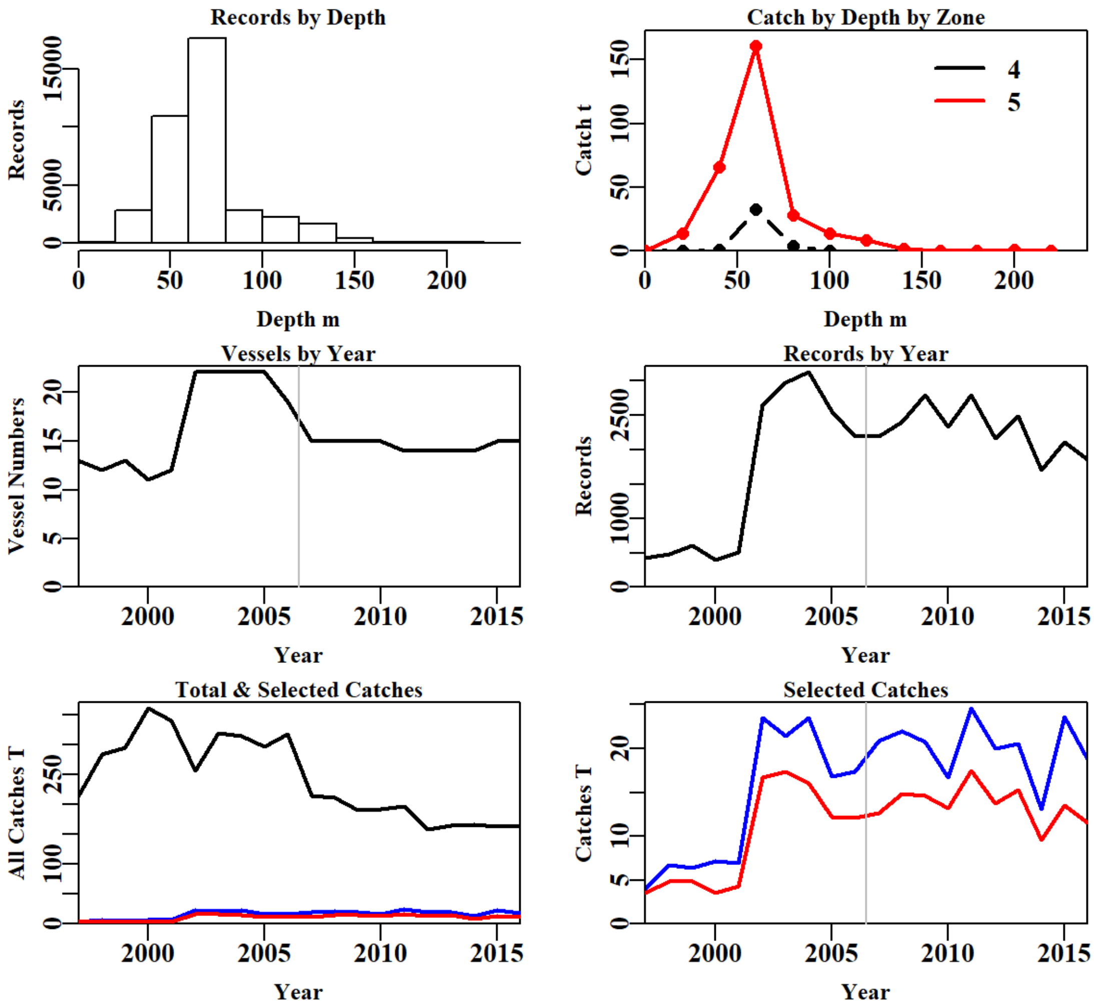


Figure 8.76. SawShark_DS fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 8.44. The models used to analyse data for SawShark_DS.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + DepCat
Model4	Year + Vessel + DepCat + SharkRegion
Model5	Year + Vessel + DepCat + SharkRegion + Month
Model6	Year + Vessel + DepCat + SharkRegion + Month + DayNight
Model7	Year + Vessel + DepCat + SharkRegion + Month + DayNight + SharkRegion:DepCat
Model8	Year + Vessel + DepCat + SharkRegion + Month + DayNight + SharkRegion:Month

Table 8.45. SawShark_DS. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was SharkRegion:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	5170	44219	1483	38733	20	3.2	0.00
Vessel	3297	42061	3641	38733	52	7.8	4.65
DepCat	1403	40031	5671	38733	63	12.3	4.42
SharkRegion	1174	39793	5909	38733	64	12.8	0.52
Month	728	39315	6387	38733	75	13.8	1.02
DayNight	637	39217	6485	38733	78	14.0	0.21
SharkRegion:DepCat	501	39067	6635	38733	84	14.3	0.32
SharkRegion:Month	433	38989	6713	38733	89	14.5	0.47

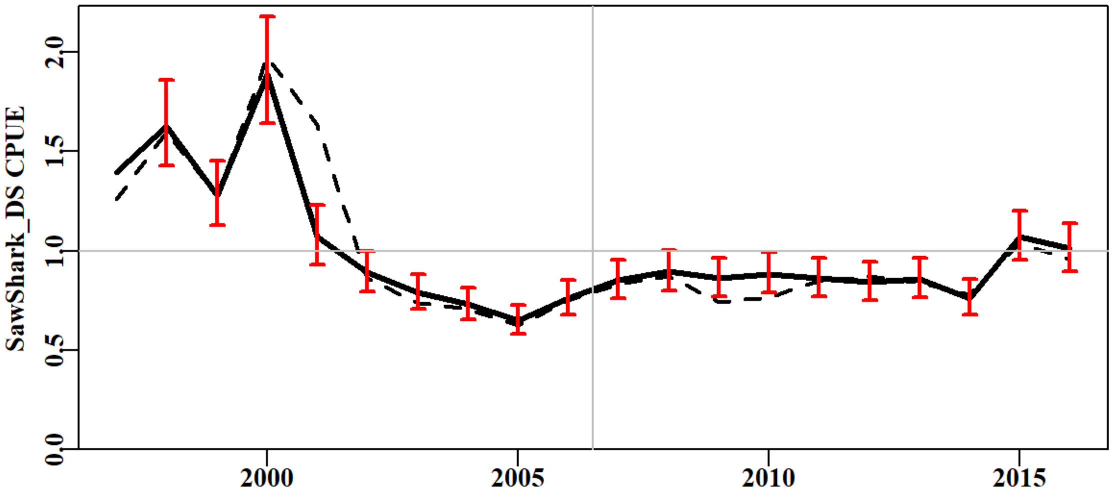


Figure 8.77. SawShark_DS standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

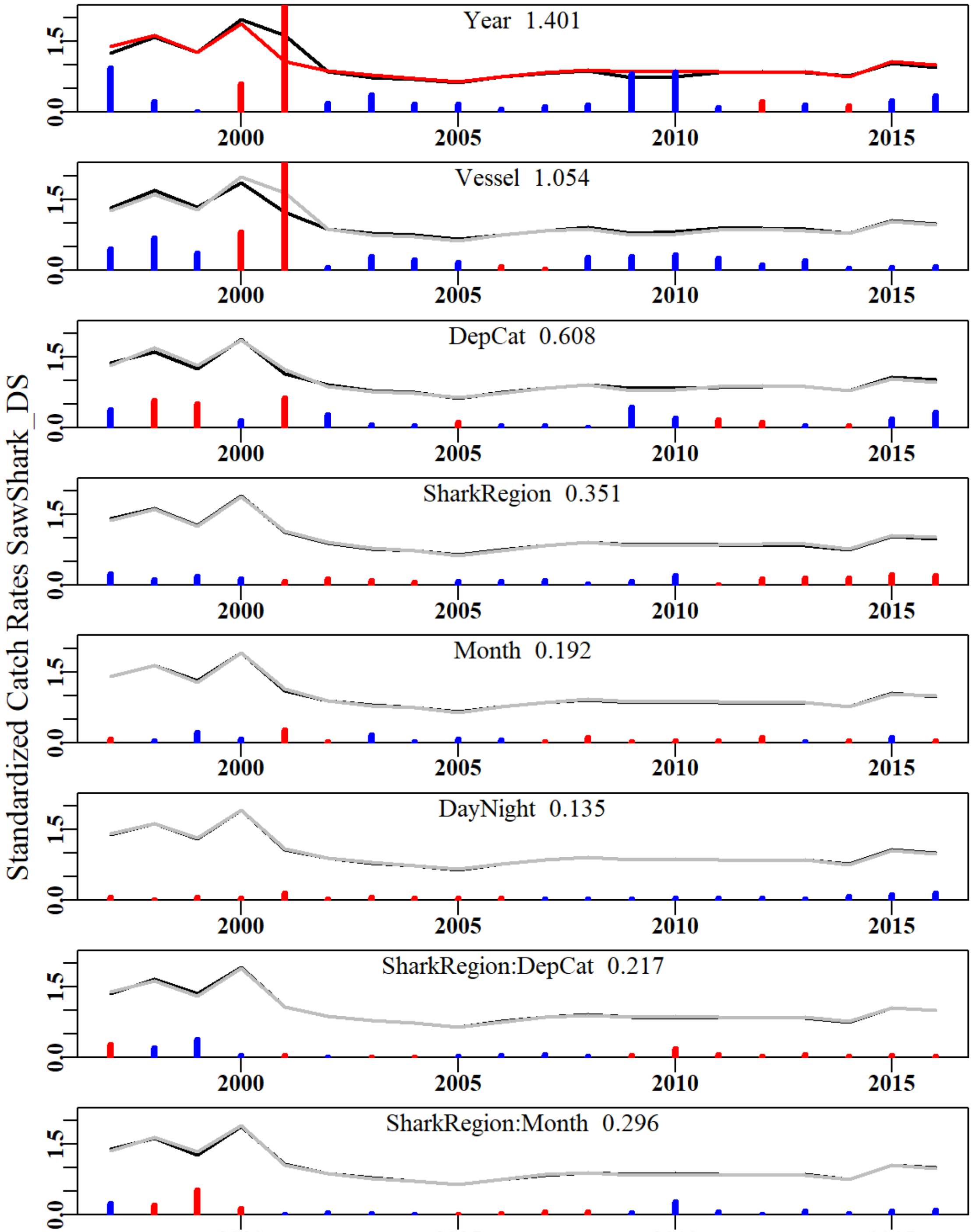


Figure 8.78. SawShark_DS. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

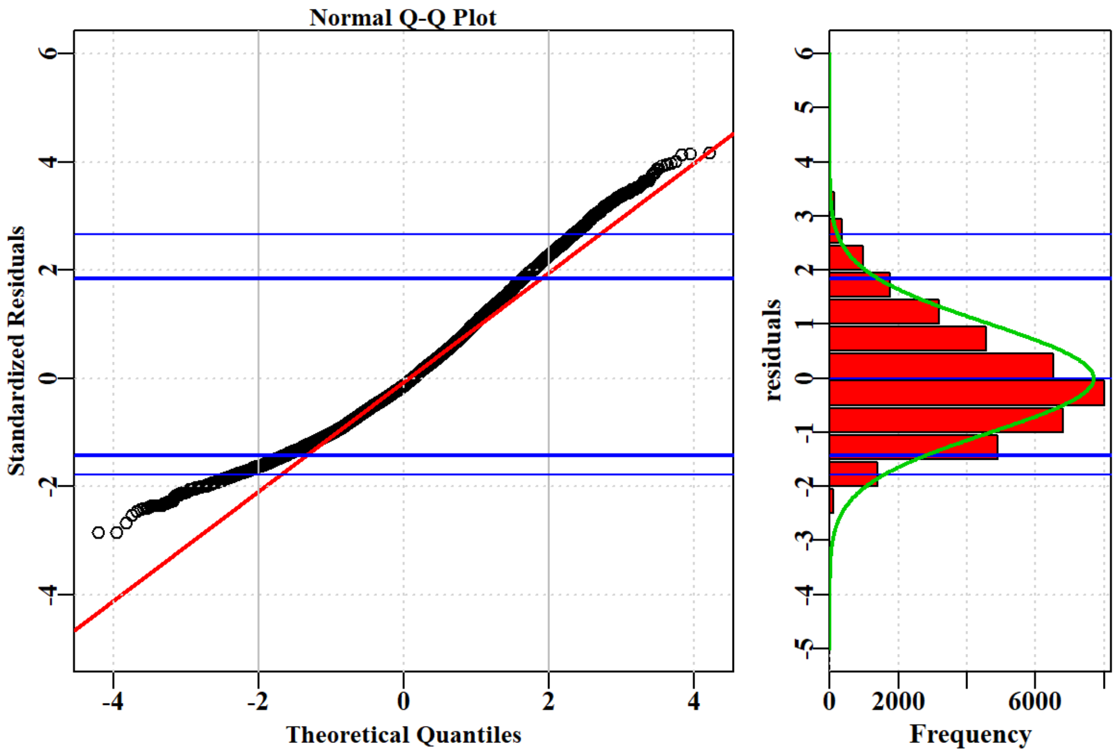


Figure 8.79. SawShark_DS. Diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

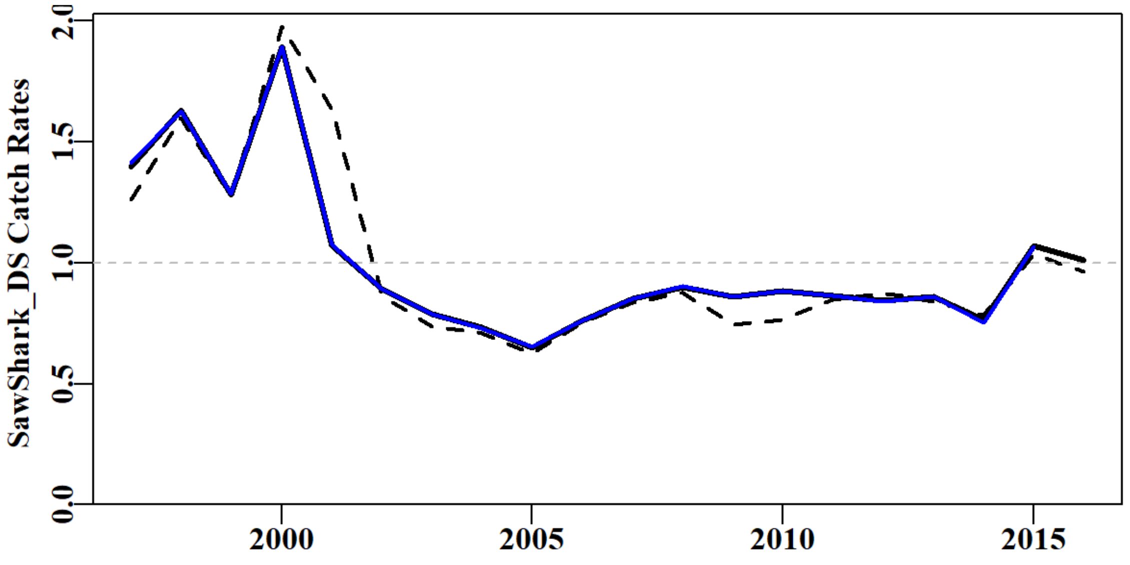


Figure 8.80. SawShark_DS. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

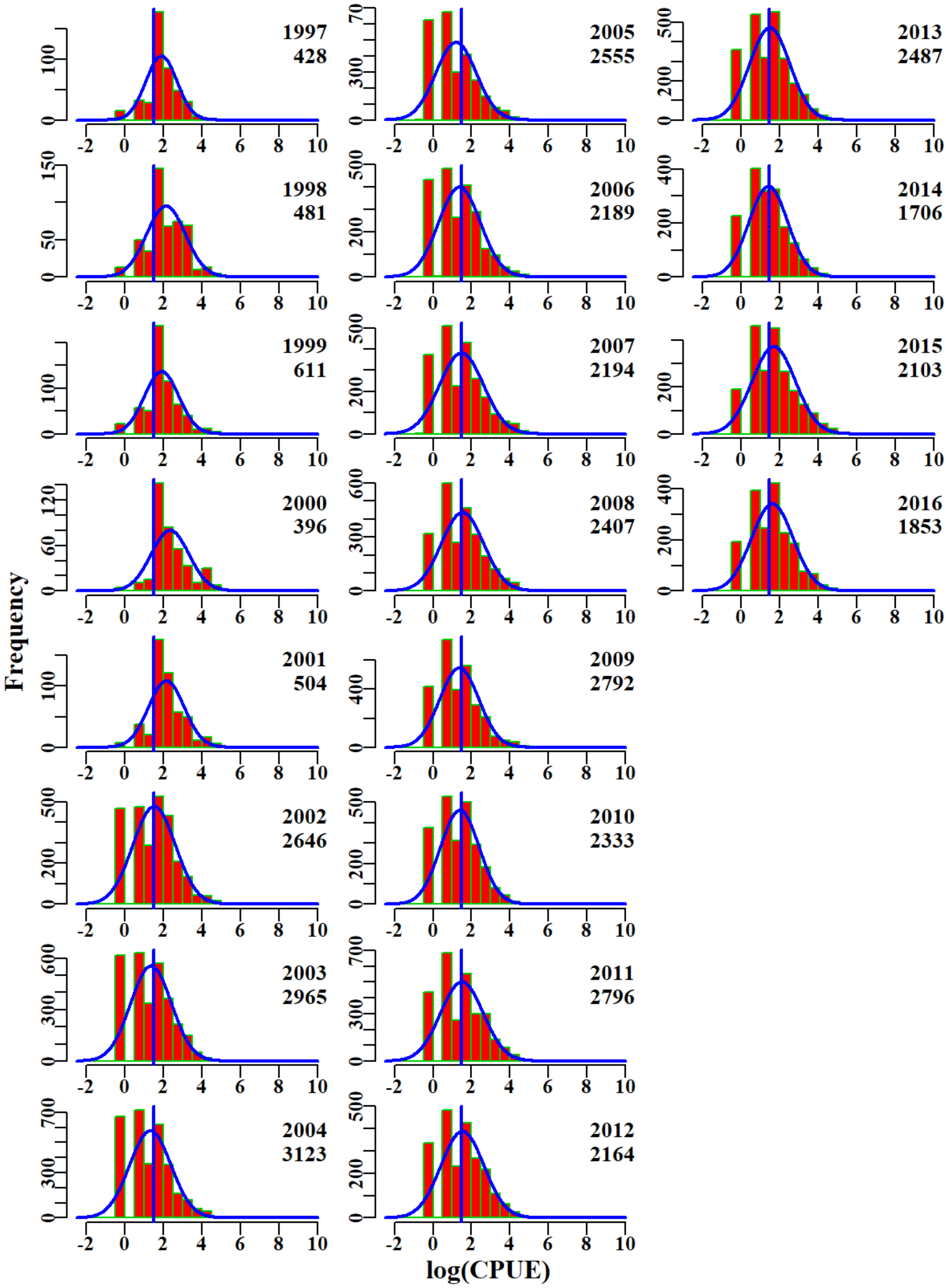


Figure 8.81. SawShark_DS. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

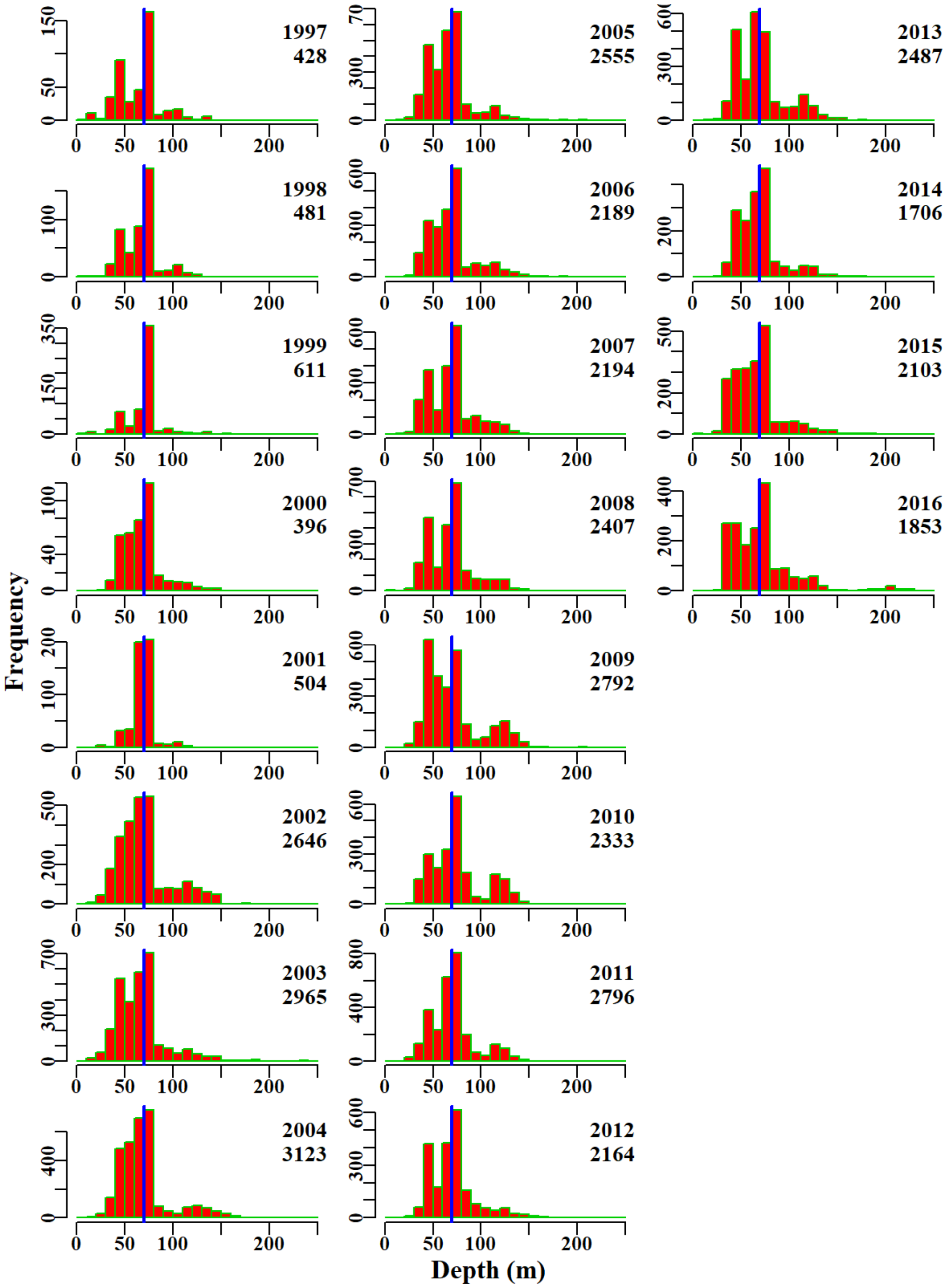


Figure 8.82. SawShark_DS. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

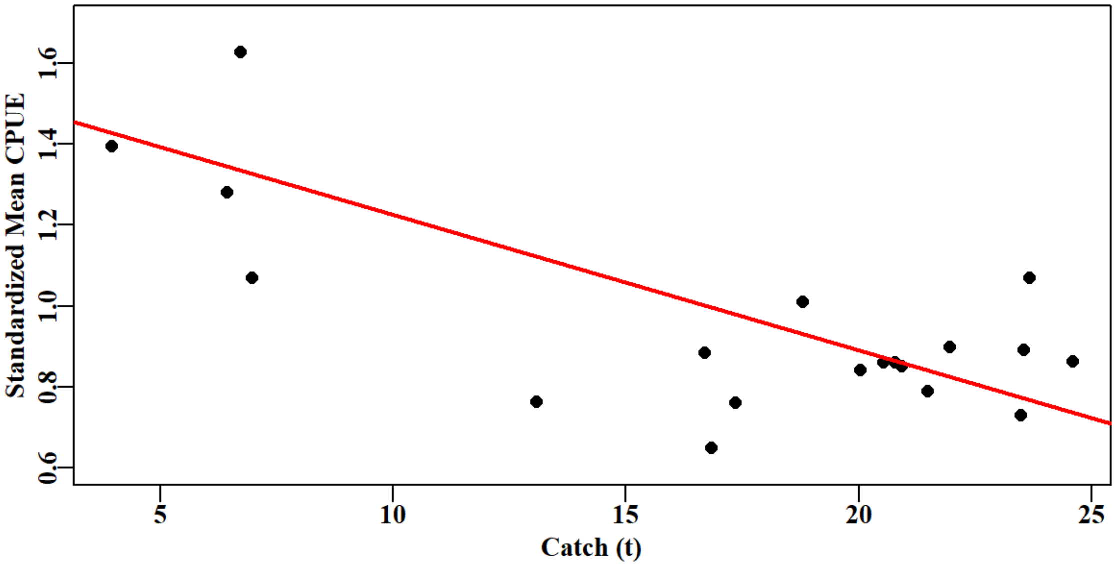


Figure 8.83. SawShark_DS. The linear relationship between Annual mean CPUE and Annual Catch.

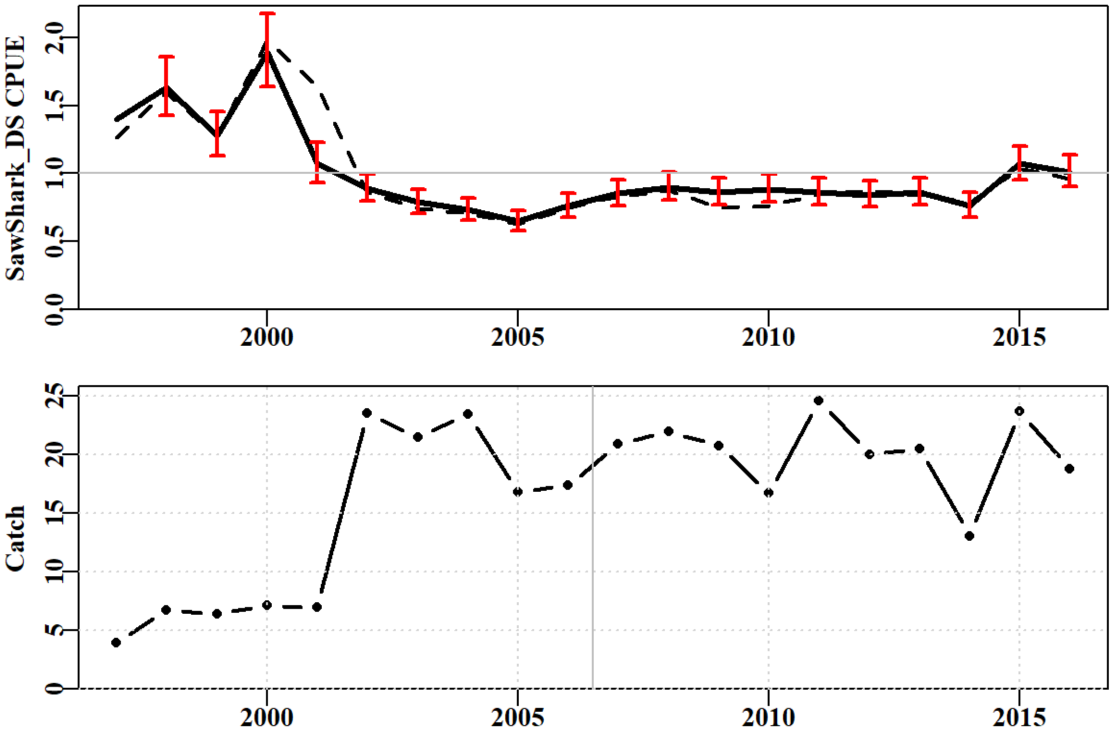


Figure 8.84. SawShark_DS. CPUE is correlated with catches through time. CPUE in the top plot and annual catch (t) in the lower plot.

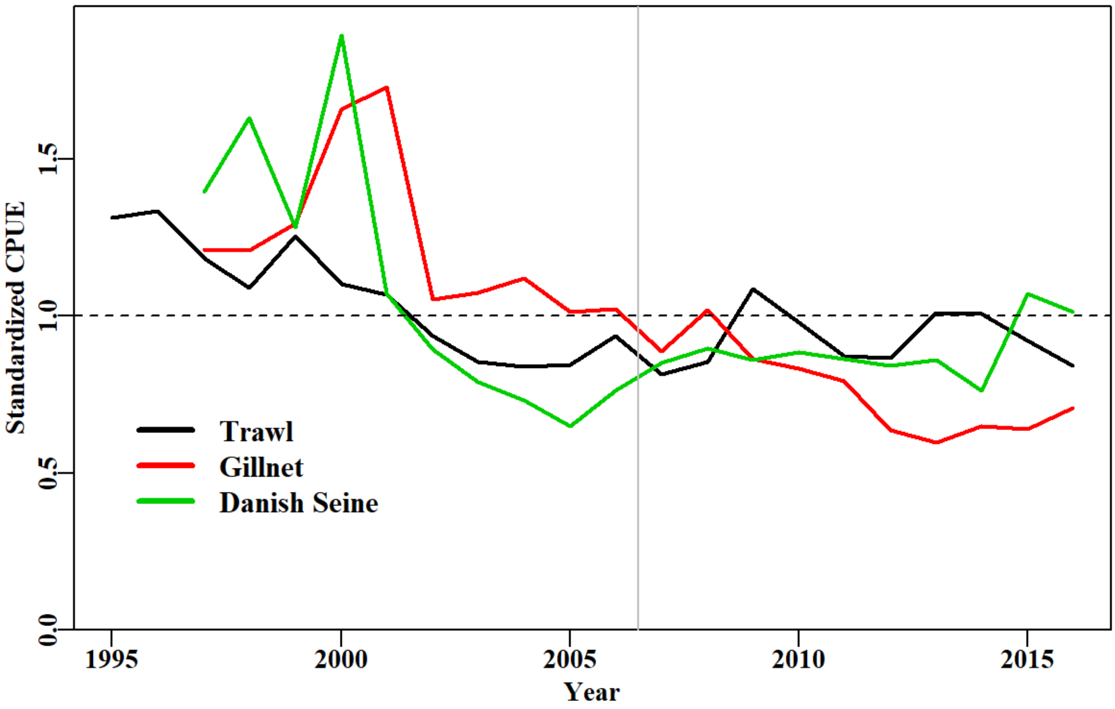


Figure 8.85. Sawshark CPUE from Trawl compared with that from Gillnet and Danish Seine.

8.13 Elephant Fish: Gillnet

A total of 7 statistical models were fitted sequentially to the available data.

The proportion of catches recording < 30 kg is relatively high in elephant fish reports, indicating that elephant fish are not a primary target species and tend to be caught in small numbers and weights in each shot (Figure 23). The preliminary estimate of the proportion discarded for 2015 is 0.75, corresponding to 182.66 t (Thomson and Upston 2016). Given the high proportion of discards, it is questionable as to whether an analysis including zero catches would be valid. Therefore, only non-zero shots were analysed. The use of effort in units of net length should be investigated for future analyses. Exploratory analyses shows inconsistency in the recording of gillnet effort units in the logbook database, particularly in 1997 and 1998 compared to later years. A detailed effort analysis is required towards utilizing this in subsequent standardizations.

8.13.1 *Inferences*

As with sawshark taken by gillnet there is a strong correlation between total annual catch and annual standardized CPUE estimates. In addition, the large proportion of the total catch taken in shots of < 30kg indicates the by-product nature of this fishery (confirmed by the large proportion of discards from this fishery).

A total of 7 statistical models were fitted sequentially to the available data. The optimum model was fitted with terms: Year, Vessel, DepCat, SharkRegion, Month, and the interaction SharkRegion x Month. The terms Year and Vessel contributed most to the model fit. There appears to be slight departure from the assumed Normal distribution as depicted by the qqplot. Annual standardized CPUE has remained below the long term average since 2014, with a slight increase in the most recent estimate.

8.13.2 *Action Items and Issues*

Exploration of other CPUE trends from other methods may illustrate whether this measure of CPUE constitutes a valid index of relative abundance for Elephantfish.

Table 8.46. ElephantFishGN. The data selection criteria used to specify and identify the fishery data to be included in the analysis.

Property	Value
label	ElephantFishGN
csirocode	37043000, 37043001
fishery	GHT_SEN_SSF_SSG_SSH
depthrange	0 - 160
depthclass	20
zones	2, 3, 4, 5, 6, 7
methods	GN
years	1997 - 2016

Table 8.47. ElephantFishGN. Total catch (Total; t) is the total reported in the database, number of records used in the analysis (N), reported catch (Catch; t) in the area and depth used in the analysis and number of vessels used in the analysis (Vess). GeoM is the geometric mean of catch rates (kg/hr), standard deviation (StDev) relates to the optimum model. C<30Kg denotes the amount of catch in shots of <30kg, and P<30Kg is the proportion of total. The optimum model was SharkRegion:Month.

	Total	N	Catch	Vess	GeoM	Opt	StDev	C<30Kg	P<30Kg
1997	32.0	1441	25.4	56	15.9	0.9284	0.000	9.165	0.361
1998	51.9	2123	41.5	57	16.1	0.8628	0.047	12.809	0.308
1999	69.0	2804	55.3	65	17.6	1.0155	0.046	17.984	0.325
2000	78.7	2716	62.0	57	18.5	1.2675	0.046	19.992	0.322
2001	88.8	2750	71.2	62	22.6	1.3027	0.047	19.192	0.269
2002	59.4	2108	37.0	61	15.9	0.9410	0.049	13.508	0.365
2003	71.2	2172	42.1	60	15.8	0.9224	0.049	13.049	0.310
2004	64.8	1760	30.5	51	14.7	0.8905	0.051	10.666	0.350
2005	66.4	1875	32.7	40	16.1	0.9153	0.050	11.577	0.354
2006	53.3	1681	31.1	43	15.8	0.9975	0.052	10.146	0.326
2007	51.7	1783	33.8	38	17.4	1.0968	0.052	11.920	0.353
2008	61.4	2056	39.9	34	18.4	1.1565	0.050	14.017	0.351
2009	65.3	2128	43.9	35	21.1	1.3072	0.050	15.614	0.356
2010	56.7	2270	34.7	35	14.6	1.0241	0.050	14.777	0.425
2011	50.5	2688	33.8	35	11.4	0.8857	0.050	17.644	0.522
2012	65.9	2701	44.3	38	15.5	1.0237	0.049	17.894	0.404
2013	61.9	2485	38.2	34	14.8	0.9594	0.050	18.042	0.472
2014	47.4	2239	30.4	31	12.9	0.8617	0.050	15.809	0.519
2015	49.3	1845	28.4	27	14.0	0.8050	0.052	11.424	0.402
2016	49.1	2103	35.8	27	14.9	0.8363	0.050	12.839	0.358

Table 8.48. ElephantFishGN data selection effects. Total is the total number of records in the database, NoCE removes those records with either missing catch or effort, and then only those records are kept that meet the criteria for depth, years, zone, method, and fishery.

	Total	NoCE	Depth	Years	Zones	Method	Fishery
Records	80863.0	76694.0	69401.0	67602.0	65236.0	43728.0	43728.0
Difference	0.0	4169.0	7293.0	1799.0	2366.0	21508.0	0.0
Catch	1252.5	1252.5	1165.3	1124.9	1078.8	792.2	792.2
Difference	0.0	0.0	87.2	40.4	46.1	286.6	0.0

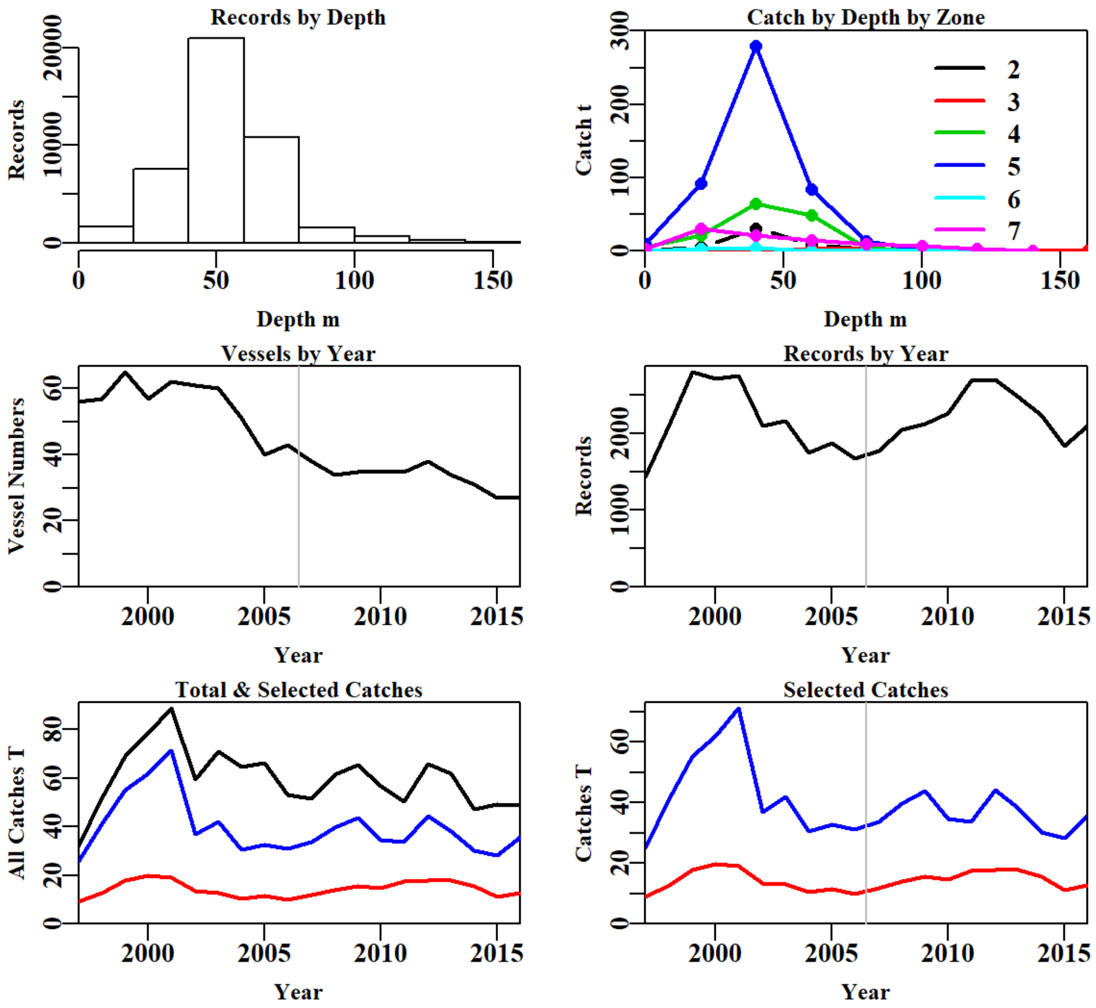


Figure 8.86. ElephantFishGN fishery details. The bottom left plot depicts all known catches (top black line), and all selected catches used in the analysis (middle blue line); the lower red line: selected catches < 30 kg).

Table 8.49. The models used to analyse data for ElephantFishGN.

	Model
Model1	Year
Model2	Year + Vessel
Model3	Year + Vessel + Month
Model4	Year + Vessel + Month + DepCat
Model5	Year + Vessel + Month + DepCat + SharkRegion
Model6	Year + Vessel + Month + DepCat + SharkRegion + ShkReg:DepCat
Model7	Year + Vessel + Month + DepCat + SharkRegion + ShkReg:Month

Table 8.50. ElephantFishGN. The row names are the Akaike Information Criterion (AIC), residual sum of squares (RSS), model sum of squares (MSS), number of usable observations (Nobs), number of parameters (Npars), adjusted R^2 (adj_r2) and the change in adjusted R^2 (%Change). The optimum model was SharkRegion:Month.

	AIC	RSS	MSS	Nobs	Npars	adj_r2	%Change
Year	25539	78345	859	43728	20	1.0	0.00
Vessel	22450	72488	6716	43728	174	8.1	7.07
Month	22226	72082	7122	43728	185	8.6	0.49
DepCat	22209	72028	7176	43728	193	8.7	0.05
SharkRegion	22032	71720	7485	43728	198	9.0	0.38
SharkRegion:DepCat	21824	71269	7935	43728	232	9.5	0.50
SharkRegion:Month	21638	70899	8306	43728	253	10.0	0.93

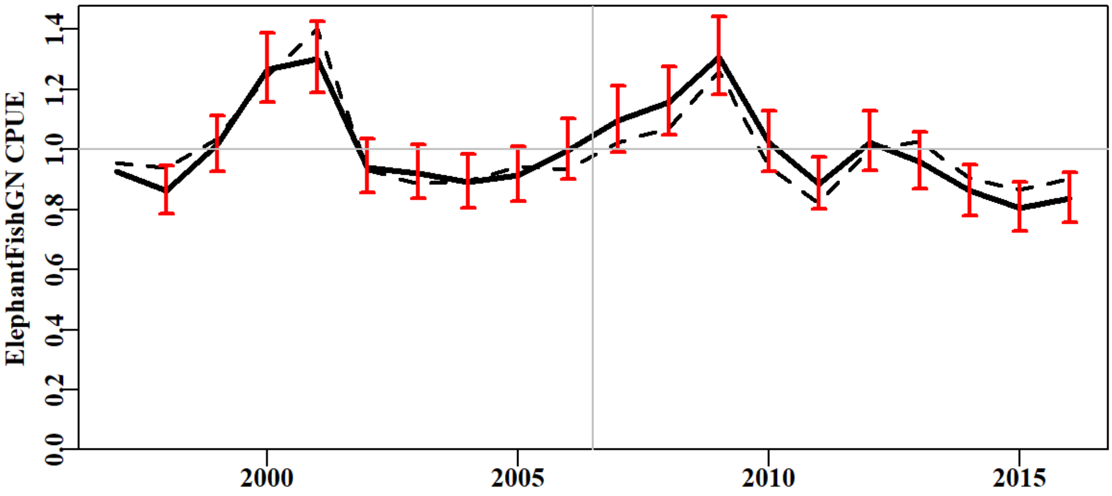


Figure 8.87. ElephantFishGN standardization. The dashed black line represents the geometric mean catch rate, solid black line the standardized catch rates. The red bars are the 95% confidence intervals about the mean estimates. The graph scales both time-series of standardized catch rates relative to the mean of each time-series.

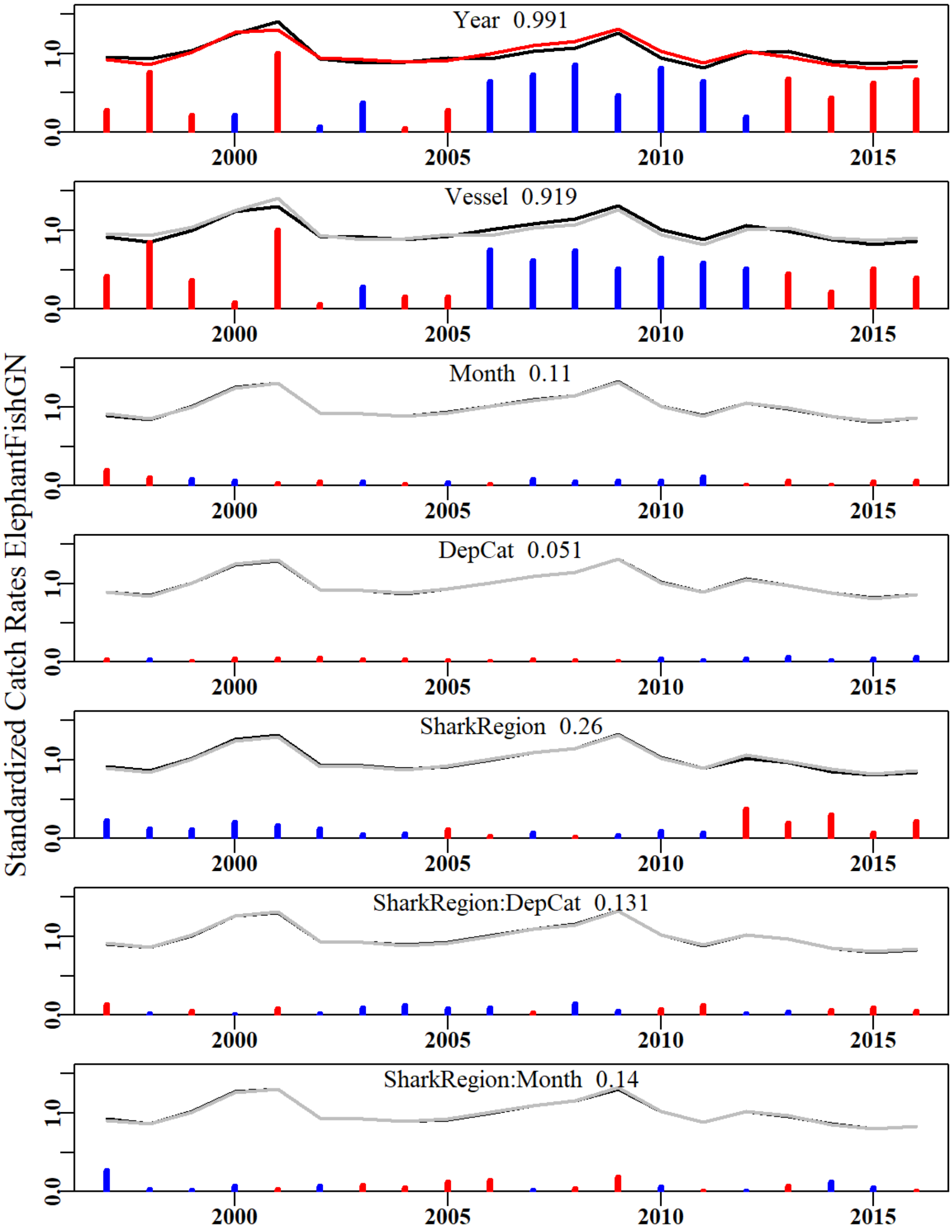


Figure 8.88. ElephantFishGN. The influence of each factor on the optimal standardization. The top graph depicts the geometric mean (black line) and the optimum model (red line). The difference between them is illustrated by vertical bars with blue bars indicating the optimum model is higher than the geometric mean and red bars indicating it is lower. The top graph bars are the sum of all the bars in the graphs below. The graphs for individual factors are cumulative. Thus the second graph has the geometric mean (grey line) and the effect of adding Year + factor2 (Model 2). In the third graph, the grey line represents Model 2 and the black line the effect of adding factor3 to the model. The remaining graphs continue in the same cumulative manner except for the interaction terms which are added singularly to the final single factor model.

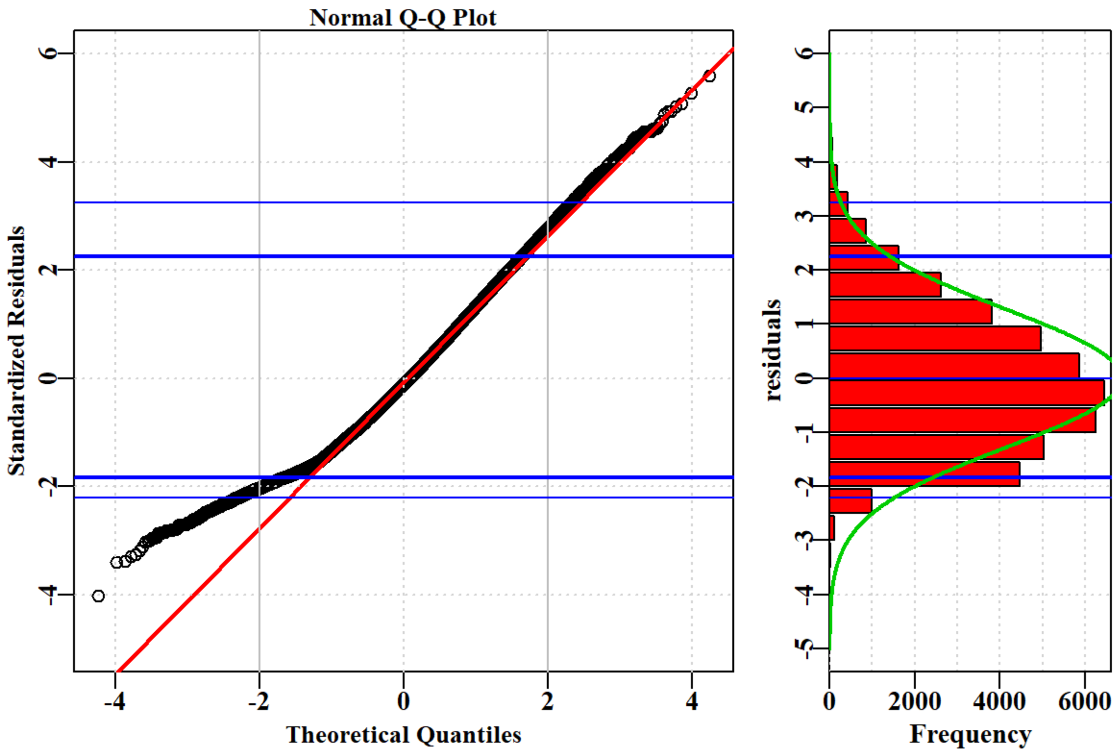


Figure 8.89. ElephantFishGN. Diagnostic plots. The distribution of residuals from the optimum fit. The qqplot indicates the fit to the expected normality, while the histogram of residuals also illustrates the 1%, 5%, 95% and 99% quantiles to indicate the intensity of any lack of fit at the margins of the distribution (reflected also in the qqplot.

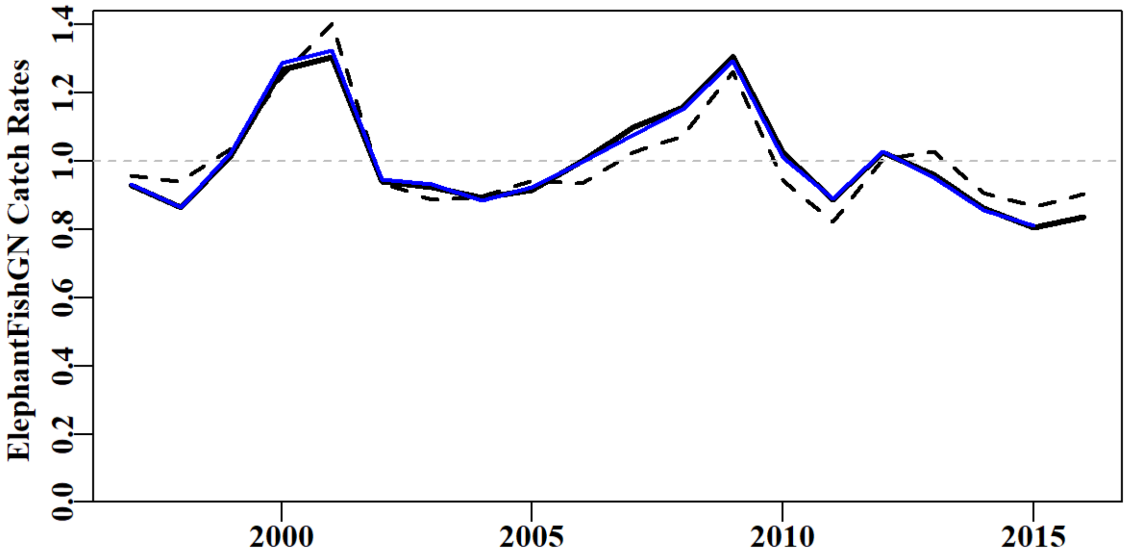


Figure 8.90. ElephantFishGN. A comparison of the previous year's standardization (blue line) with this year's. They should lie on top of each other, although small deviations may relate to data adjustments, particularly in very recent years.

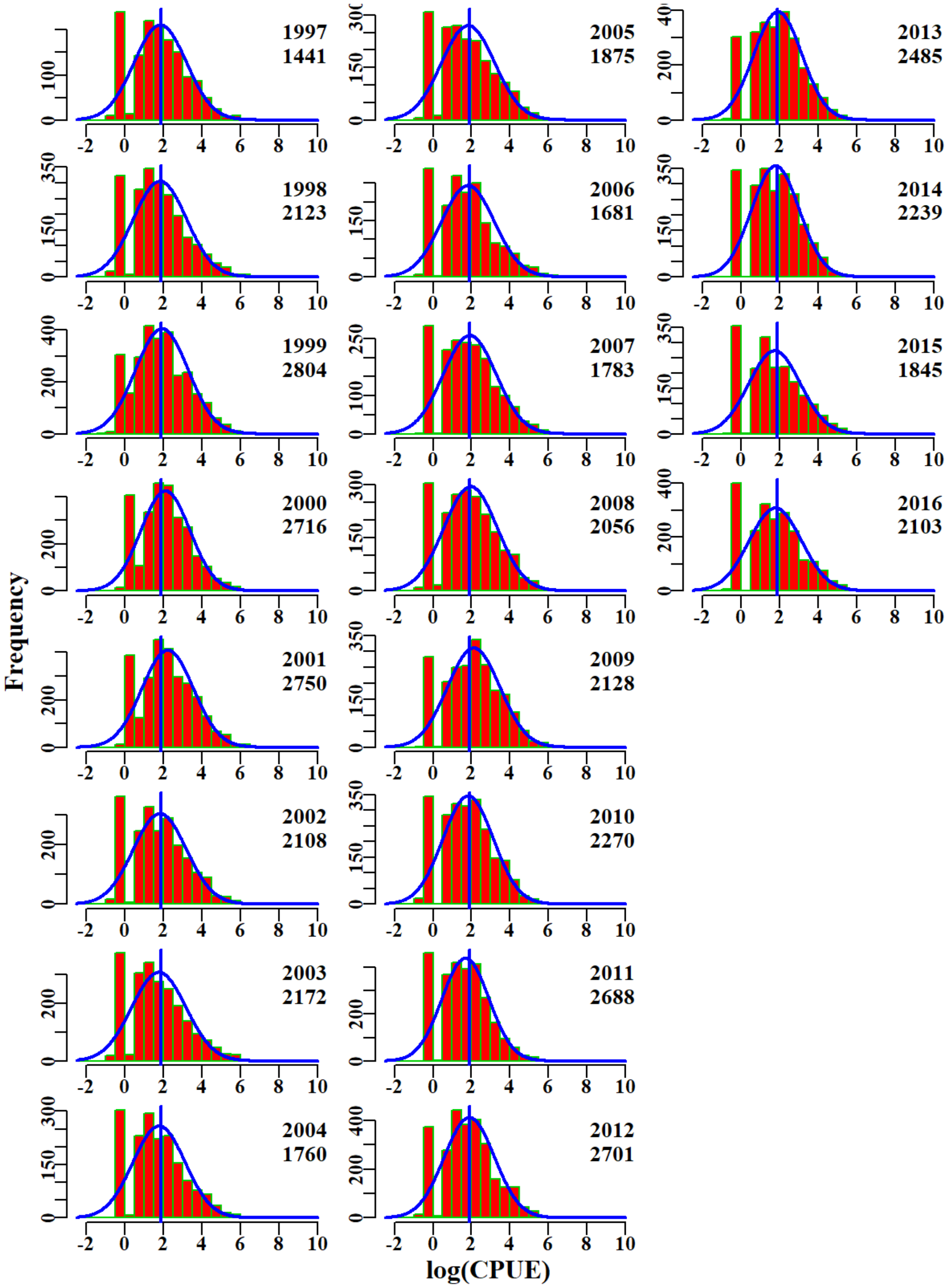


Figure 8.91. ElephantFishGN. The log(CPUE) for each year of data available the blue lines are normal distributions fitted to the histogram frequencies. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

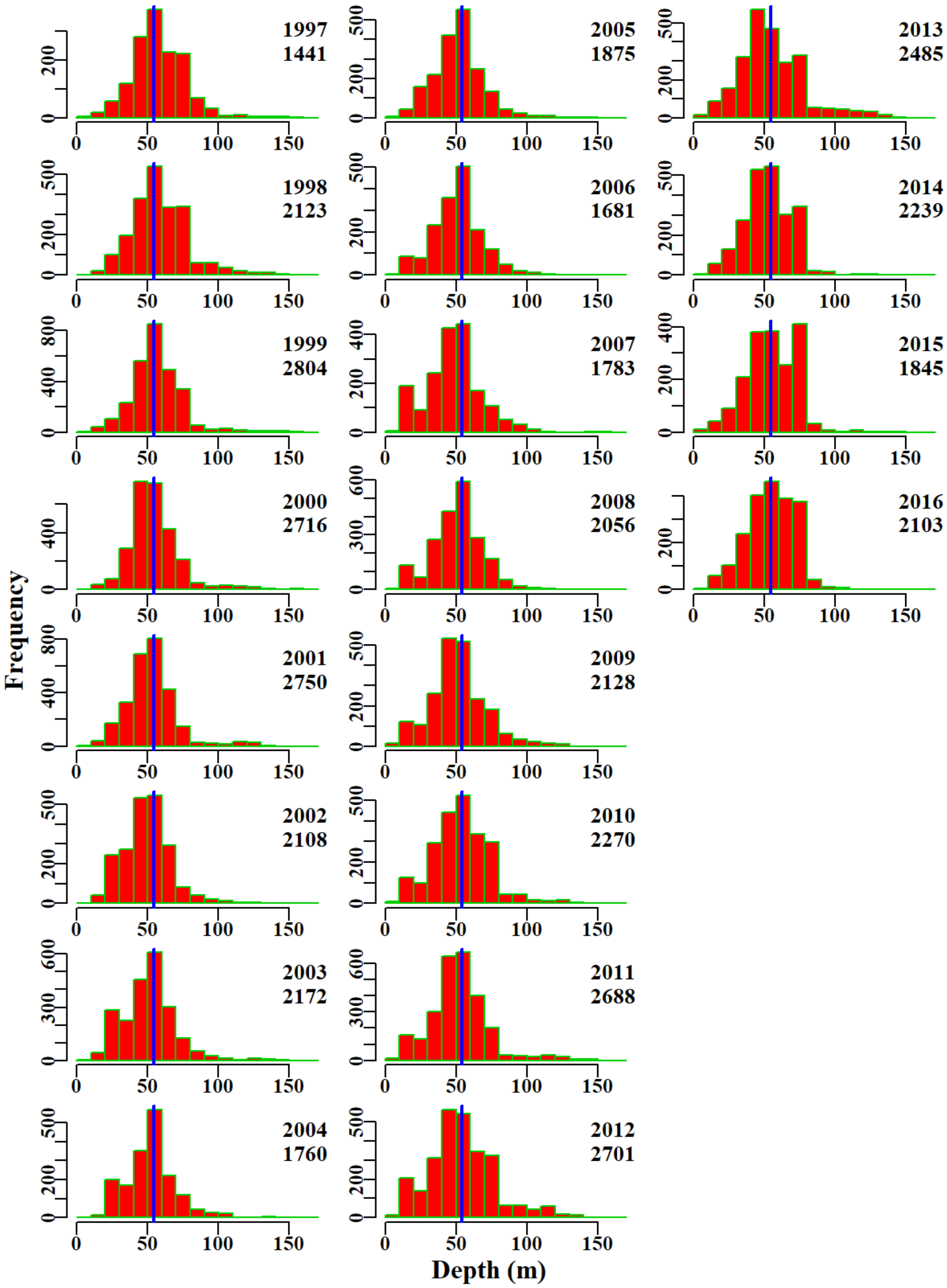


Figure 8.92. ElephantFishGN. The average Depth of fishing for each year of data available to illustrate the development of the fishery through time. The numbers in each plot are the year and number of records. The vertical blue line is the average across all years.

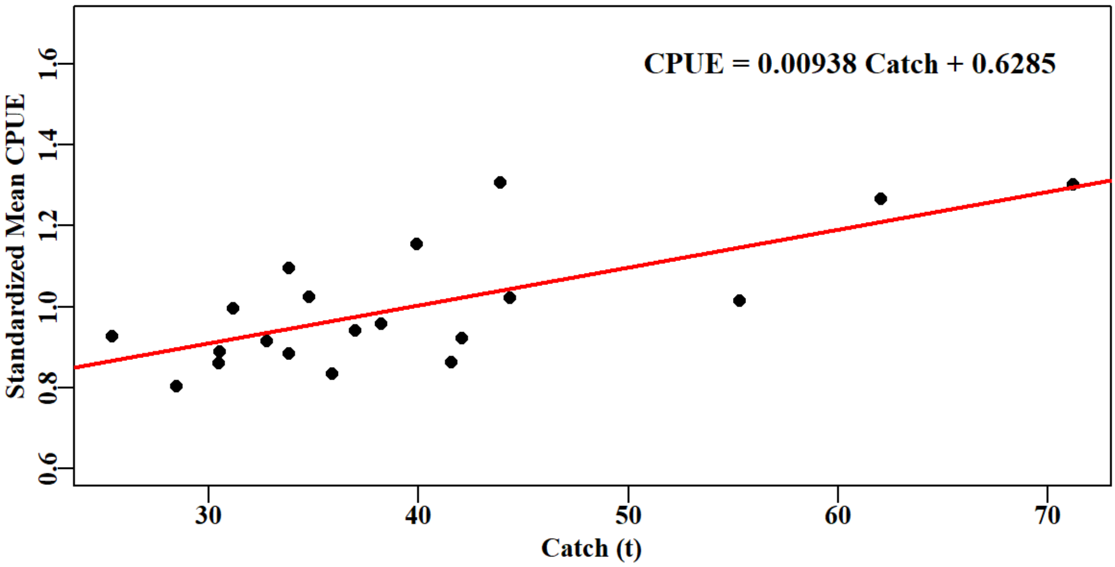


Figure 8.93. ElephantFishGN. The linear relationship between Annual mean CPUE and Annual Catch.

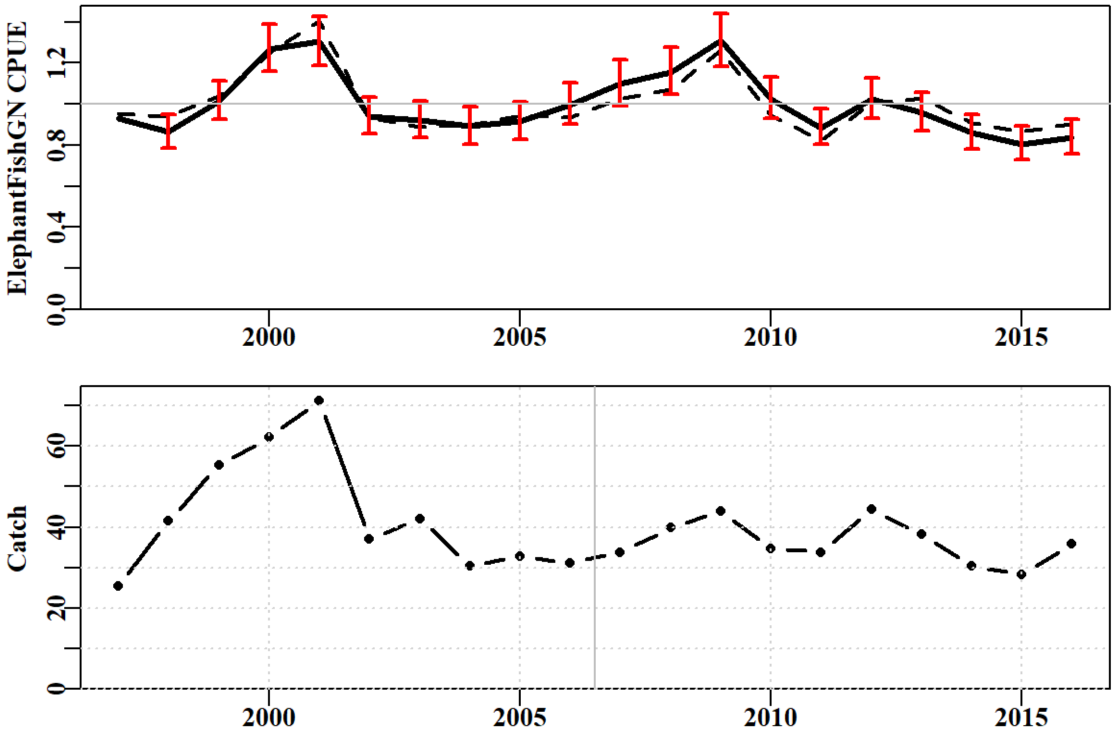


Figure 8.94. ElephantFishGN. CPUE is correlated with catches through time. CPUE in the top plot and annual catch (t) in the lower plot.

8.14 Acknowledgements

Thanks goes to the CSIRO database team for their preliminary processing of the catch and effort data as received from the Australian Fisheries management Authority. In addition, one author (MH) is indebted to FRDC for funding the project 2012/201 'Improving Catch Rate Standardizations', which provided the time to explore ways of making the mass production of CPUE standardizations more efficient and defensible.

8.15 References

Burnham, K.P. and D.R. Anderson (2002) *Model Selection and Inference. A Practical Information-Theoretic Approach.* Second Edition Springer-Verlag, New York. 488 p.

Neter, J., Kutner, M.H., Nachtsheim, C.J, and W. Wasserman (1996) *Applied Linear Statistical Models.* Richard D. Irwin, Chicago. 1408 p.

R Core Team (2017). *R: A language and environment for statistical computing.* R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Venables, W.N., and Dichmont, C.M. (2004). GLMs, GAMs and GLMMs: an overview of theory for applications in fisheries research. *Fisheries Research.* 70. 315-333.

9. Yield, total mortality values and Tier 3 estimates for selected shelf and slope species in the SESSF 2017

Claudio Castillo-Jordán

CSIRO Oceans and Atmosphere, GPO Box 1538, Hobart, TAS 7001, Australia

9.1 Summary

This document updates yield analyses presented in Thomson (2014) for John dory caught in the Southern and Eastern Scalefish and Shark Fishery (SESSF) on the shelf and slope. Much of the data processing and analysis has been automated, following procedures documented particularly in Thomson (2002a) and Klaer *et al*. (2008).

Yield and total mortality estimates are provided. Yield estimates were made using a yield-per-recruit model with the following input: selectivity-at-age, length-at-age, weight-at-age, age-at-maturity, and natural mortality. Total mortality values corresponding to various reference equilibrium biomass depletions were calculated for the species.

Recent average total mortality was estimated from catch curves constructed from length frequency information. Length frequency data were from ISMP port and/or onboard measurements. The method used to estimate total mortality also estimates average fishery selectivity.

New ageing data are available for John dory in 2017, the previous sampling is from 2011. ShelfRAG has indicated that the sampling for John dory in 2011 was not representative, having under sampled the winter period. Including the new ageing data (2010 to 2016), the 2018 RBC for John dory is 485t, compared to the 2013 RBC of 203t (Thomson 2014).

9.2 Methods

9.2.1 Zoning

The fishery region and zones referred to here are as shown in Figure 9.1.

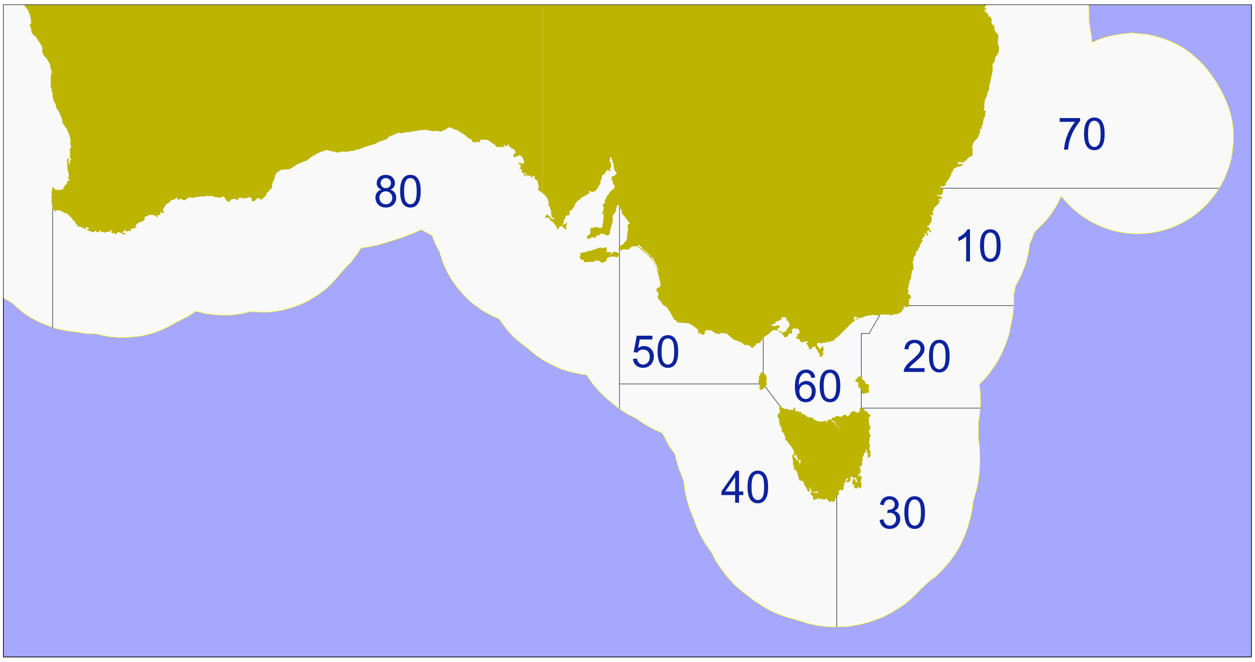


Figure 9.1. Map of the SESSF showing 8 statistical zones used in analyses here.

9.2.2 Yield analysis

The information required for this calculation was: selectivity-at-age, length-at-age, weight-at-age; age-at-maturity; and natural mortality. The parameters used are shown in Table 9.1.

Table 9.1. Population parameters used for yield analysis: natural mortality (M), steepness (h), growth parameters (L_∞, k, t_0), length-weight relationship (a, b), gear selectivity (l_{25}, l_{50}), length at first maturity (l_{mat}), maximum age for plus group (a_{max}), maximum age for inclusion in catch curve ($\mathrm{CC}_{\mathrm{amax}}$).

Species	M	h	L_∞	k	t_0	a	b	l_{25}	l_{50}	l_{mat}	a_{max}	$\mathrm{cc}_{\mathrm{amax}}$	S_{25}
John dory	0.36	0.45	53.2	0.15	-1	0.0458	2.9	15.54	30	31.5	20	19	1.303

The primary source of information on population parameters was Smith and Wayte (2002) or, failing that, the Fishbase website (http://www.fishbase.com). A meta-analysis performed by Koopman *et al.* (2001) was used to provide values for steepness.

9.2.2.1 Length- and weight-at-age

Length-at-age was calculated using the von Bertalanffy growth equation (parameters are l_∞, k and t_0) and the weight-at-age using the allometric length-weight relationship (parameters are a and b). The von Bertalanffy parameters were calculated using length and age data supplied by the Fish Ageing Services (FAS, Kyne Krusic-Golub pers com). The type of length measurement (e.g. standard length or total length) used was specified in the data. It is assumed the parameters of the length-weight relationship (Smith and Wayte, 2002) use the same measures. The units for these parameters are not specified and do not all appear to use the same units. These were manipulated until the results appeared to be in kg per cm. Parameters that were not available from Smith and Wayte (2002) were obtained from the Fishbase website (http://www.fishbase.org), using values that had been calculated from Australian fish or, if necessary, New Zealand fish.

9.2.2.2 Female length-at-maturity

Length-at-maturity for females (l_{mat}) (which is converted into a knife-edged function of age using the calculated lengths-at-age) was obtained, where possible, from Wayte and Smith (2002). If separate values were not available for males and females, the value for both sexes combined was used.

The natural mortality value (M) for John dory was updated by the Shelf Research Assessment Group in 2005 based on an additional meta-analysis performed by Matt Koopman.

9.2.2.3 Selectivity

A logistic selectivity curve is assumed. Selectivity parameters (l_{25}, l_{50}) are typically drawn from Bax and Knuckey's calculated selectivity factors. All parameters used in the present investigation apply to a 90mm trawl mesh and non-trawl gear types are not considered. However, values were not available for John dory from Bax and Knuckey. Values for Mirror dory were applied to John dory because, of all the quota species, Mirror dory are most like John dory in shape.

The selectivity parameters used in this study have been estimated from an empirical relationship between fish size and mesh size derived from covered cod end (or trouser haul) experiments on a subset of the species. These pertain purely to gear selectivity, which is not the function often referred to in stock assessments as "selectivity". Fishers are able to target fish of a particular size by fishing in particular areas and in particular different depths - all SEF quota shelf-associated species show a pattern of larger fish being caught at greater depths. No account is taken in this study of how trawl selectivity changes as a function of gear design or gear deployment (e.g. changing door separation with depth) that have been shown to exert large influences on overall selectivity in other studies.

It has been suggested that practices such as double bagging might reduce the selectivity of commercial trawls below that expected for a 90 mm mesh cod end, however there was no evidence for this.

The "selectivity" estimated in stock assessment models is a function of both gear selectivity, targeting by the fishery and availability of fish to being caught.

9.2.2.4 Maximum age

Maximum observed age (a_{max}) values were selected after examining available aged otolith samples. As the maximum age is treated as a plus group, a maximum age for catch curve analysis (cca_{max}) is also required that is normally at least one age less than the maximum. This was chosen after examination of age samples from the last 5 years.

9.2.2.5 Stock-recruit relationship

A Beverton-Holt stock-recruit relationship is assumed using the single-parameter formulation suggested by Francis (1992a). The value of this parameter (steepness - h) was investigated by

Koopman *et al*. (2001) using meta-population analysis. The histograms presented by Koopman *et al*. were examined and likely figures for steepness chosen.

9.2.2.6 Management reference points

Using virgin biomass estimates provided by stock reduction analysis in combination with yield-per-recruit analysis, a number of common F-based management reference point values were calculated. While $F_{0.1}$ (Gulland and Boerema 1973) and F_{spr30} (or $F_{30\%\mathrm{SPR}}$, Gabriel *et al.* 1989) are reasonably widely known, the method used to calculate F_{msy} is given below (from Klaer 2006).

Fisheries management decisions are often based on abundance relative to target and limit reference points. The most common reference point is the population size where maximum sustainable yield (MSY) is achieved. The fully-selected fishing mortality corresponding to MSY, F_{msy}, is defined as the instantaneous rate of fishing mortality at which yield is maximized, i.e:

$$\left.\frac{dY(F)}{dF}\right|_{F_{MSY}} = 0$$

where $Y(F)$ is yield as a function of fully-selected fishing mortality, i.e:

$$Y(F) = \tilde{Y}(F)\,R(F)$$

$\tilde{Y}(F)$ is yield-per-recruit as a function of F, and

$R(F)$ is recruitment as a function of F.

Yield-per-recruit is defined according to the formula:

$$\tilde{Y}(F) = \sum_{s}\sum_{a=0}^{x} w_a^s \frac{S_a^s F}{Z_a^s(F)} N_a^s(F)\,(1 - e^{-Z_a^s(F)})$$

where w_a^s is the weight of an animal of sex s and age a,

S_a^s is the selectivity for animals of sex s and age a,

$Z_a^s(F)$ is the total mortality on fish of sex s and age a,

$$Z_a^s(F) = M + S_a^s F$$

$N_a^s(F)$ is the number of fish of sex *s* and age *a* relative to the number of animals of age 0 (both sexes combined):

$$N_a^s(F) = \begin{cases} 0.5 & \text{if } a = 0 \\ N_{a-1}^s(F)\, e^{-Z_{a-1}^s(F)} & \text{if } 0 < a < x \\ N_{x-1}^s(F)\, e^{-Z_{x-1}^s(F)} / (1 - e^{-Z_x^s(F)}) & \text{if } a = x \end{cases}$$

x is the maximum age-class.

The recruitment as a function of *F* depends on the assumed form of the stock-recruitment relationship, e.g:

$$R(F) = \frac{S(F)}{\alpha + \beta\, S(F)}$$

where $S(F)$ is spawner biomass as a function of *F*:

$$S(F) = \tilde{S}(F)\, R(F)$$

$\tilde{S}(F)$ is spawner biomass-per-recruit as a function of *F*:

$$\tilde{S}(F) = \sum_{a=1}^{x} f_a\, N_a^{\text{fem}}(F)$$

f_a is fecundity as a function of age.

9.2.3 *Catch curves*

9.2.3.1 Data

This investigation used length frequency data from ISMP port measurements (eg Knuckey *et al* 2001). For a given year, fleet and population (see below for further detail) length frequencies are catch-weighted and summed to give annual length frequencies.

Age and length data were obtained from the Central Ageing Facility. Age-length keys (ALKs) were constructed from these data.

Two methods were used to convert length frequencies data into age frequencies: ALKs and chopping. The ALK method was used, where possible, to generate age frequency data by multiplying the length frequency for a given year by the ALK for that same year. No allowances were made for inadequate sampling of an ALK so that, if no age samples were taken from a particular length class then all samples from this length class in the length frequency were ignored. This occurs because the ALK has a zero for all ages for that length class so that the length frequency is always multiplied by zero. 'Chopping' involves using the von Bertalanffy to chop the length frequency into age classes. Catch curve analysis was applied to all resulting age frequencies.

Age samples from the 2010 to 2016 calendar years became available for John dory during September 2017 (Table 9.2) and were used to provide age-based Tier 3 results. In both cases, all samples were used to provide an average age-length key that was applied to length data from the most recent 5 years.

The age data that were available for this analysis are shown in Figure 9.2 and Table 9.2 (John dory). The corresponding length distribution *of the aged sample* is also shown.

Table 9.2. Age and length samples for aged John dory per year from 2010 to 2016 calculations applied to data to 2016.

Year	**N**
2010	294
2011	436
2012	424
2013	206
2014	222
2015	263
2016	215

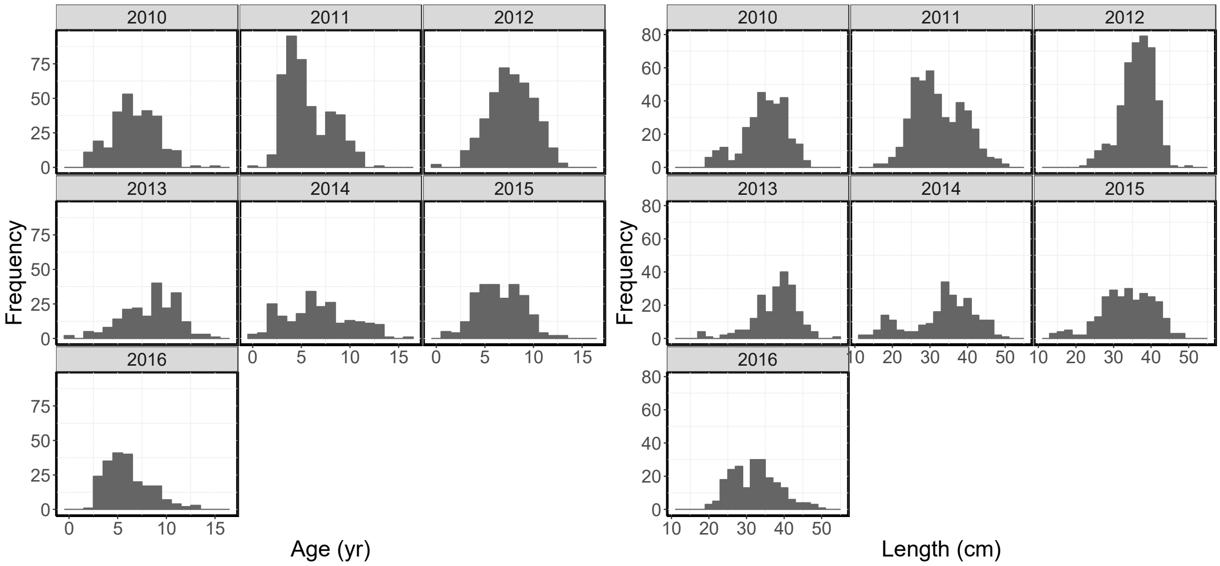


Figure 9.2. (A) Age and (B) length frequencies for aged John dory from 2010 to 2016 for which data are available.

9.2.3.2 *Fleets and populations*

The difference between a fleet and a population is that although the length frequency data are separated for both, the ALK data are separated into populations but are combined across fleets.

9.2.3.3 Automated catch curve analysis

The method of F_{CUR} estimation used is an improved method of catch-curve estimation which involves fitting an equilibrium age-structured production model to the most recent five years of age-composition data to estimate F_{CUR} and two selectivity parameters. This method accounts for selectivity-at-age and integrates over all years used in the estimation. Estimated numbers at age in each year are fitted to the observed using simple sum of squares difference as a goodness of fit measure. The advantages of this method over traditional catch-curve methods are that averaging of annual mortality estimates is not required to obtain an estimate of F_{CUR} and all selected ages are used, rather than just the assumed fully-selected ages, as selectivity is taken into account in the estimation.

Specifically, the population model is of the form:

$$N_a = \begin{cases} 1 & \text{if } a = 0 \\ N_{a-1} e^{-(s_{a-1}F_{CUR}+M)} & \text{if } 0 < a <= a_{\max} \\ & \end{cases}$$

where the N_a are the numbers-at-age a, s_a is the (estimated) selectivity-at-age (assumed to be asymptotic and to follow a logistic curve with two parameters, age at 50% and 95% selectivity), $a_{\max}$ is the maximum age used for catch curve analysis (a value less than maximum age), F_{CUR} is the estimated rate of current fishing mortality, and M is the assumed rate of natural mortality. The selectivity equation is:

$$s_a = 1/\left(1+\exp\left(-Ln(19)*(a-a_{50})/(a_{95}-a_{50})\right)\right)$$

9.2.4 ***Average length method***

Catch curve analysis relies on measurement of the decline in numbers at age of a population in equilibrium under constant levels of fishing pressure. If equilibrium conditions apply, the slope of the right hand limb of an age frequency distribution can be used to estimate fishing mortality. For some SESSF fish populations, otoliths have not been collected or aged, sometimes because of the physical difficulty in doing so. Some species, for example, have very tiny otoliths that are both difficult to collect and age. Normally, however, all quota species are measured by onboard observers, or in the port data collection program, so we have reasonably large length frequency samples for most quota species in most years.

The current Tier 3 method for dealing with species with length samples but no age samples is to slice the length-frequency distribution into assumed ages based on the age transitions calculated from the von Bertalanffy parameters, and then apply the standard catch curve analysis to the derived age distribution. This method is not optimal compared to an analysis based on age samples at least because it does not account for the distribution of lengths at age – that the lengths of fish at any age follow a distribution that overlaps with lengths at age for adjacent aged fish.

A procedure has been developed as part of the Reducing Uncertainty in Stock Status (RUSS) project that uses length frequency samples alone to estimate fishing mortality and is described in detail in Klaer *et al*. (2012). Management Strategy Evaluation (MSE) testing of the procedure indicated that it works in theory and provides comparable results to the age-based catch curve method. The greatest disadvantage of the procedure determined by testing was that it produced more variable RBC values than standard catch curve analysis.

The key assumption of the average length method is that the relative number of large fish in the population will reduce as fishing pressure increases. This is intuitively true, and the determination of stock status indicators from average length measurements has a long history (e.g. see Pauly 1984).

The procedure implemented here first requires the selection of a reference length (L_{ref}) where the stock can be assumed to be fully selected. By default, L_{ref} is assumed to be 2cm greater than the length at 50% selection (S_{50}), as most species are assumed to have relatively knife-edged selection for Tier 3 analyses. The intention was to select a reference length greater than where selectivity effects occur, but as low as possible to allow the largest sample sizes from existing fishery length-frequencies.

Using yield-per-recruit calculations, it is possible to calculate what the average length of the catch above L_{ref} would be for any level of F (Figure 9.3). To determine current F (F_{cur}) that corresponds to F_{cur} using catch curves, calculate the average length of the catch above L_{ref}, then use the relationship in Figure 9.3 to determine F_{cur}. The average length of the catch at the limit F_{20} and target F_{48} are shown as dotted lines in Figure 9.3.

As all current Tier 3 stocks have size at age data, results using the average length method have not been included in this document.

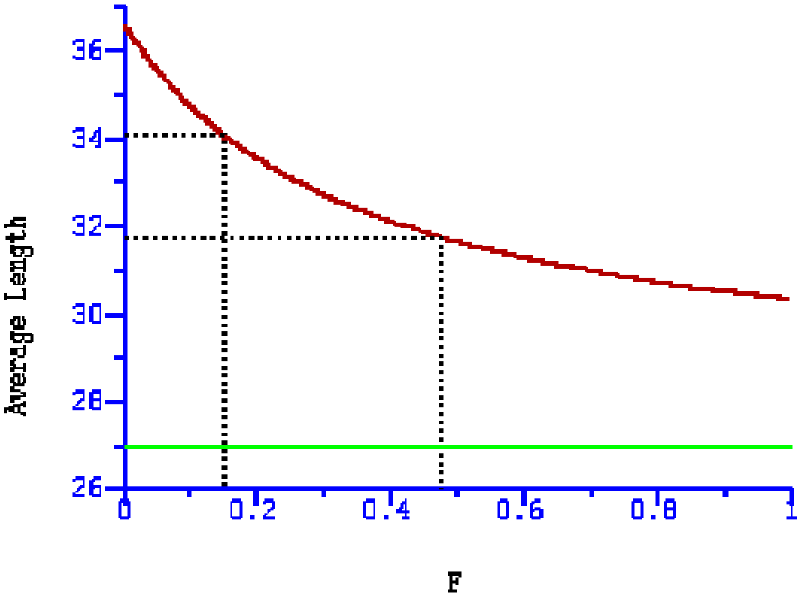


Figure 9.3. Average length reference point calculations.

9.2.5 *Harvest control rule*

The method used to calculate the Tier 3 RBC has been improved and is described in Klaer *et al*. 2008 and Wayte and Klaer (2010), Figure 9.4. The new Tier 3 control rule that has limit and target fishing levels was implemented and applied for the first time for the 2008 stock assessments.

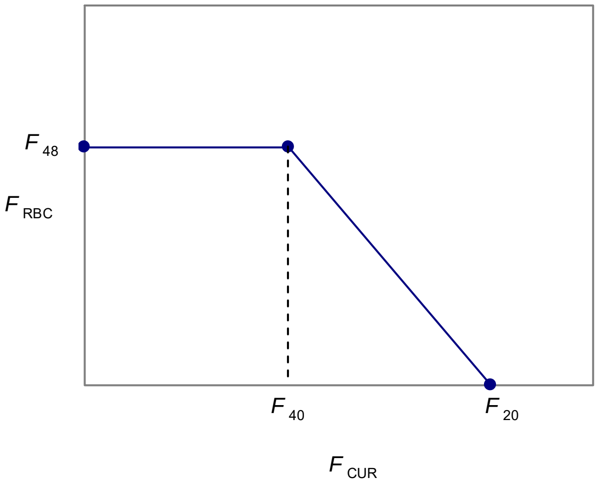


Figure 9.4. Method for selecting F_{RBC} based on estimated F_{cur}.

Yield per recruit calculations were used to calculate F values that will reduce the spawning biomass to 20% (F_{20}), 40% (F_{40}) and 48% (F_{48}) of the unexploited level. The relationship given in Fig. 1 is then used to assign the value of F_{RBC} using F_{cur}. This relationship has properties similar to the Tier 1 harvest control rule, with F_{20} as the limit and F_{48} as the target fishing mortality rate.

The following formula that adjusts current catch according to the ratio of the intended and current exploitation rates is then used to calculate C_{RBC}:

$$C_{RBC} = \frac{(1-e^{-F_{RBC}})}{(1-e^{-F_{cur}})} C_{cur}$$

where F_{cur} is the estimated current fishing mortality, C_{cur} is current catch, F_{RBC} is the selected F for the recommended biological catch from the control rule, and C_{RBC} is the recommended biological catch from the control rule.

It can be seen from the above formula that as the F_{cur} estimate approaches zero, that the multiplier on C_{cur} exponentially increases to infinity. Clearly, it is possible for the control rule to generate very large RBC values that are not realistic and would not result in good behaviour of the HCR. One method for avoiding such behaviour would be to apply direct limits on possible values for the C_{cur} multiplier. The upper limit of the multiplier on recent average catch was 1.2 in the previous and first implementation of Tier 3 in the SESSF (Klaer and Thomson 2007). To date there has been no agreement via the RAG process on what direct limits may be applied to the new implementation.

The current SESSF application of harvest control rules includes a TAC change limitation rule that was designed to dampen RBC changes from year to year. This applies to all TACs generated from RBCs. In testing the Tier 3 HCR (Wayte and Klaer 2010), the current SESSF catch change limitation rule was also included, which effectively limits the extreme values that may be generated by the Tier 3 HCR. Testing of the Tier 3 rule showed that it was effective in meeting expected management performance measures in the case where the TAC change limitation rule was applied. If such a change limitation rules was not applied, then it is likely that the Tier 3 behaviour would be considerably degraded.

Good performance of the Tier 3 HCR depends on the application of the catch change limitation rule to avoid extreme behaviour. In practice, when the Tier 3 HCR produces unrealistically high or low RBC values due to (1) noise in population age structure data (2) incorrect fixed value for M (3) incorrect biological assumptions in yield-per-recruit calculations (4) incorrect assumptions about fishery selectivity, the behaviour is limited by the TAC change control rule.

In the past, the actual RBC value generated by the Tier 3 HCR has been criticised if it was well above any of the known historical catch levels. The reason why such values are possible using the current HCR have been described here, and how they are correctly dealt with in the overall TAC setting framework. Unexpectedly large RBC values can be generated using the current HCR simply due to the imprecision in the method used to estimate F_{cur}, and it is difficult to determine whether this is the main cause.

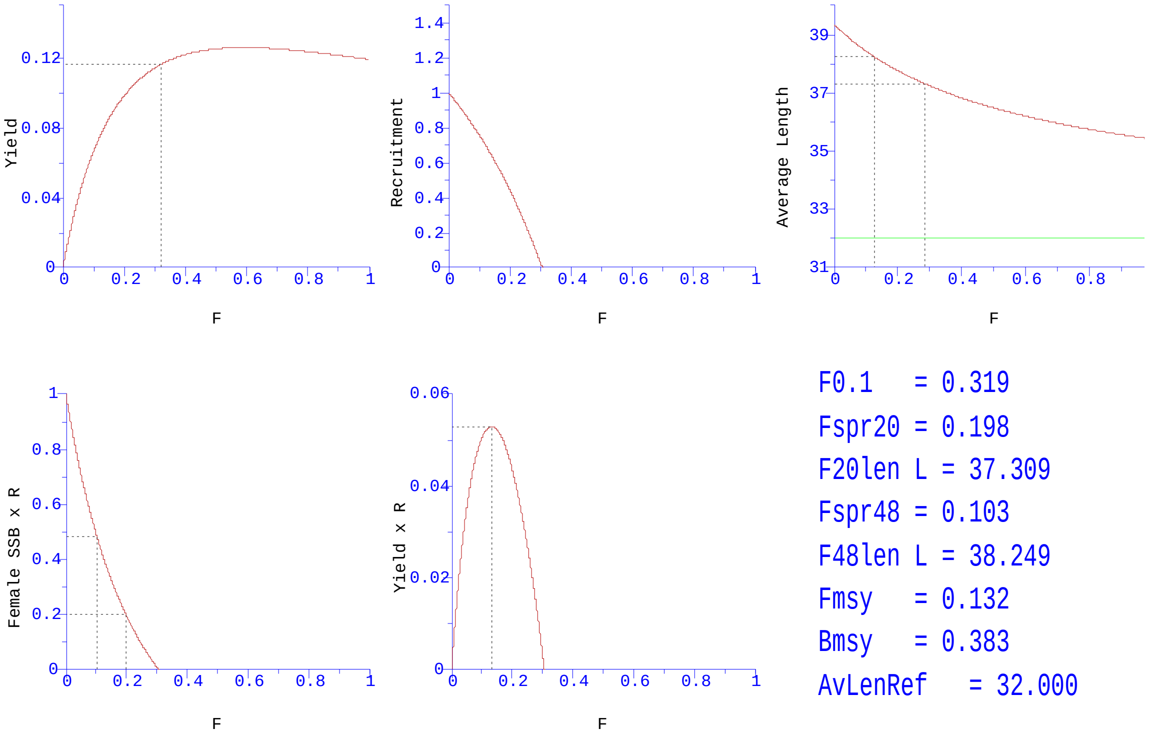
A Tier 3 analysis that consistently produces inflated RBC values suggests either that the fishery is having a low impact on the stock, or that some assumptions of the method (e.g. M value) need to be re-examined.

According to Klaer (2012) at the SESSFRAG meeting it was agreed to allow an M-based threshold to limit the size of the RBC multiplier produced by Tier 3 analyses. For this limitation, the current analysis F_{cur} has been limited by the following equation:

$$Zcur - M < \frac{M}{10}\begin{cases} if\ yes\,; & Fcur = M/10 \\ if\ no\,; & Fcur = Zcur - M \end{cases}$$

9.3 Results

The yield per recruit calculations are changed partially from those presented in Thomson (2014) because the model has been refined to fully comply with the method for calculating F_{msy} in Klaer (2006) (see Figure 9.5 and Tables 3 and 4). The previous calculation multiplied female SSB times R, without accounting for the equilibrium nature of that calculation.



```
F0.1    = 0.319
Fspr20 = 0.198
F20len L = 37.309
Fspr48 = 0.103
F48len L = 38.249
Fmsy    = 0.132
Bmsy    = 0.383
AvLenRef    = 32.000
```

Figure 9.5. John dory yield per recruit reference point calculations.

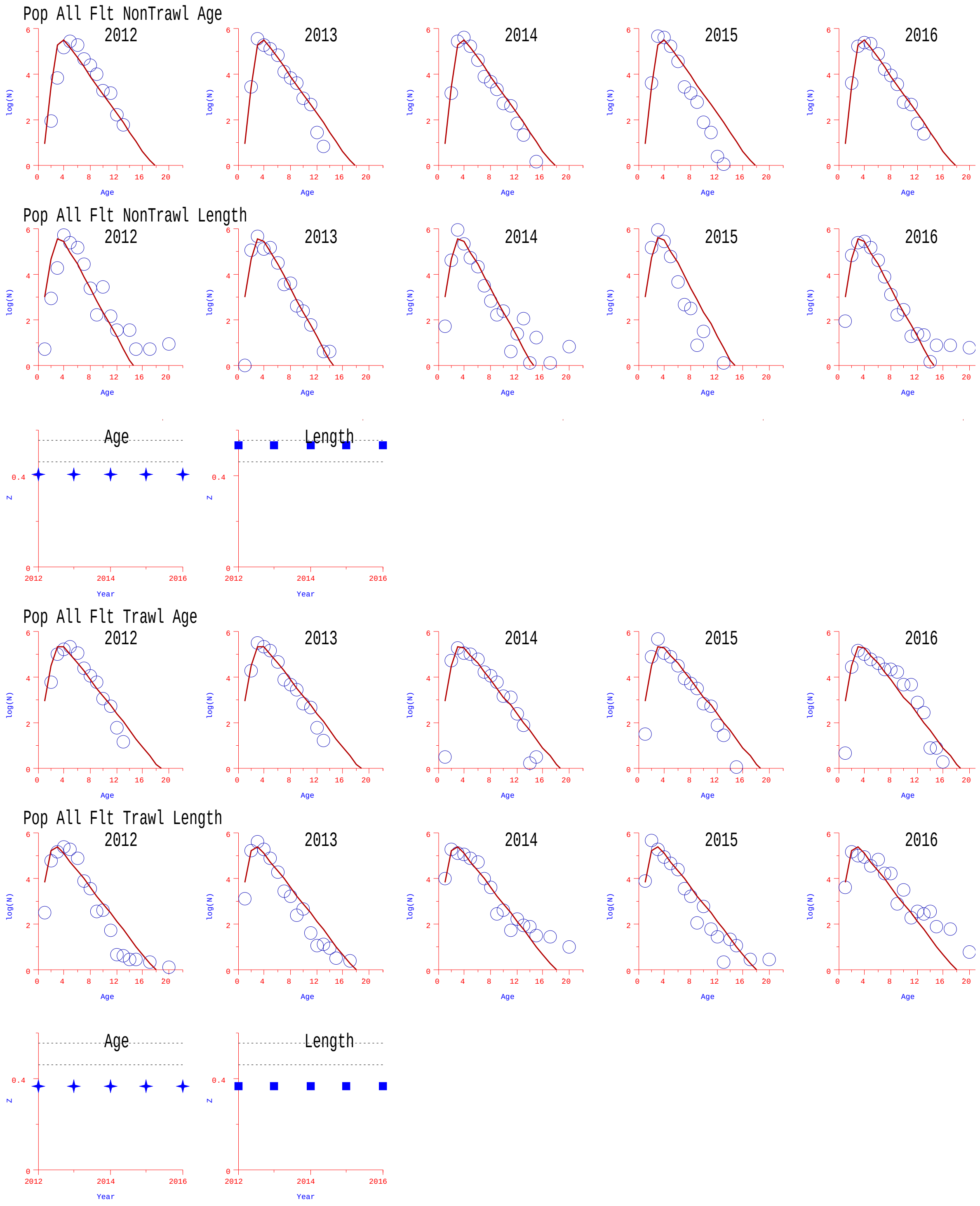


Figure 9.6. John dory catch curve results.

9.3.1 *Catch curves*

The resulting estimates of Z is shown in Figure 9.6. Average catch curve fits to annual age compositions are shown, as well as plots of the estimated Z value versus year per population and fleet. The results of catch curve analysis are shown together with the total mortality figures (Z) that resulted in spawning biomasses of 20% and 48% of pristine (dotted horizontal lines).

9.3.2 *RBC calculations*

A summary of Z and current F estimates from catch curve analysis performed in 2013 is given in Table 9.3 and from the most recent data in Table 9.4. The F values resulting in 20% and 48% depletion from the previous yield analysis are also shown. Recent Z estimates are taken from the values in Figures 8.8 and 8.9 from age-based estimates from fleets that take the majority of catches. The actual values chosen for averaging are highlighted in Appendix 2.

At Shelf and Slope RAG October 2012 it was agreed to follow the advice from SESSFRAG in 2011 that non-target species MEY target values may be set to F_{spr40} rather than F_{spr48}. In Table 9.3 the F_{spr} target used for RBC calculations is highlighted in bold, and the target for John dory is now F_{spr40}.

Table 9.3. F reference points, Z_{cur}, C_{cur} and RBC estimates from 2014 calculations applied to data to 2013.

Species	F_{spr20}	F_{spr40}	F_{spr48}	Z_{cur}	F_{cur}	p	y_{min}	y_{max}	C_{cur}	F_{rbc}	RBC
John dory	0.287	0.159	0.126	0.480	0.120	1.30	1995	2012	157	0.159	203

Table 9.4. F reference points, Z_{cur}, C_{cur} and RBC estimates from 2017 calculations applied to data to 2016.

Species	F_{spr20}	F_{spr40}	F_{spr48}	Z_{cur}	F_{cur}	p	y_{min}	y_{max}	C_{cur}	F_{rbc}	RBC
John dory	0.198	0.126	0.103	0.370	0.036	2.77	1998	2015	145	0.126	485

Figure 9.7 shows a retrospective analysis using the previous and the current LW methods, showing that both models follow the same trend for F48 (orange, red), but with lower RBC values for the refined method (orange). The RBC values shown are raw and unadjusted by limitation rules. The estimated RBC values from the refined method and with a target of Fspr40 (green) shows the same trend and, co-incidentally, similar estimated RBC values to the old method (red).

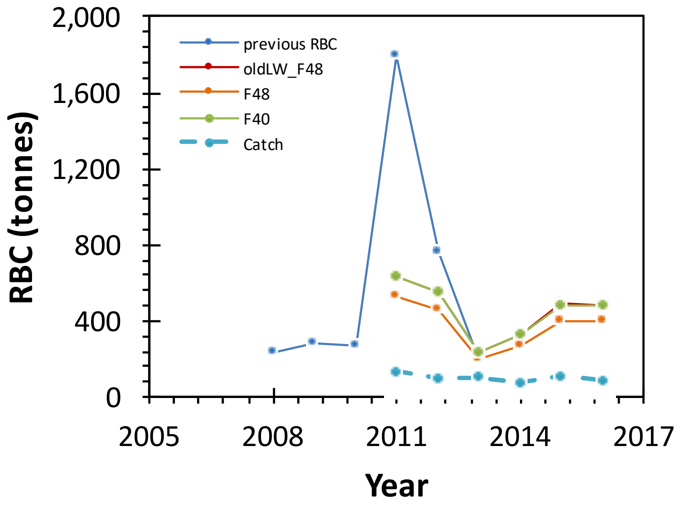


Figure 9.7. Retrospective analysis for John dory RBC.

9.4 Acknowledgements

Age data was provided by Kyne Krusic-Golub (Fish Ageing Services), parts of the ISMP and AFMA logbook data were processed and provided by John Garvey (AFMA). Mike Fuller, Francis Althaus, Roy Deng (CSIRO) loaded and pre-processed AFMA logbook and CDR data. Neil Klaer, Jemery Day, Robin Thomson, Malcolm Haddon, and Geoff Tuck are thanked for helpful discussions on this work.

9.5 References

Andrew, N.L., Graham, K.J., Hodgson, K.E. and Gordon, G.N.G. 1997. Changes after twenty years in relative abundance and size composition of commercial fishes caught during fishery independent surveys on SEF trawl grounds. NSW Fisheries Final Report Series No. 1. FRDC Project No. 96/139. 210pp.

Bax, N.J., and Knuckey, I.A. 2002. Evaluation of selectivity in the South-East fishery to determine its sustainable yield. Final Report to the Fisheries Research and Development Corporation. FRDC Project 96/140.

Fay, G., Koopman, M. and Smith, T. 2005. Catch curve analysis for Ribaldo (*Mora moro*). Paper to Slope RAG 2005.

Francis, R. I. C. C. 1992a. Use of risk analysis to assess fishery management strategies: a case study using orange roughy (*Hoplostethus atlanticus*) on the Chatham Rise, New Zealand. Canadian Journal of Fisheries and Aquatic Sciences. 49: 922-30.

Francis, R. I. C. C. 1992b. Recommendations regarding the calculation of maximum constant yield (MCY) and current annual yield (CAY). New Zealand Fisheries Assessment Research Document.92/8: 29pp.

Gabriel, W.L., Sissenwine, M.P. and Overholtz, W.J. 1989. Analysis of spawning stock biomass per recruit: an example for Georges Bank haddock. North American Journal of Fisheries Management 9, 383–391.

Gulland, J.A. and Boerema, L.K. 1973. Scientific advice on catch levels. Fisheries Bulletin (U.S.). 71,325– 335.

Haddon, M. 2005. TIER 4 Analyses. Presented to the Shelf and Slope Assessment Groups, 2005.

Klaer, N., Wayte, S., Punt, A., Day, J., Little, R., Smith, A., Thomson, R., Tuck, G. 2008. Simulation testing of alternative Tier 3 assessment methods and control rules for the SESSF. Pager to ShelfRAG and SlopeRAG, August 2008.

Klaer, N. 2003. Yield and total mortality estimates for principal shelf species in the South East Fishery. Presented to the Shelf Assessment Group, June 2003.

Klaer, N. and Thomson, R. 2004. Yield and total mortality estimates for principal shelf species in the South East Fishery. Presented to the Shelf and Slope Assessment Groups, 2004.

Klaer, N.L. 2006. Changes in the structure of demersal fish communities of the south east Australian continental shelf from 1915 to 1961. PhD Thesis, University of Canberra.

Klaer, N. and Thomson, R. 2007. Yield, total mortality and Tier 3 estimates for selected shelf and slope species in the South East Fishery. Presented to the Shelf and Slope Assessment Groups, 2007.

Klaer, N. 2009. Yield, total mortality and Tier 3 estimates for selected shelf and slope species in the SESSF. Presented to the Shelf and Slope Assessment Groups, 2009.

Klaer, N. 2010. Yield, total mortality and Tier 3 estimates for selected shelf and slope species in the SESSF 2010. Presented to the Shelf and Slope Assessment Groups, 2010.

Klaer, N. 2011a. Yield, total mortality and Tier 3 estimates for selected shelf and slope species in the SESSF 2011. Presented to the Shelf and Slope Assessment Groups, 2011.

Klaer, N., 2011b. Tiger flathead (*Neoplaycephalus richardsoni*) stock assessment based on data up to 2009. In: Tuck, G.N. (Ed.), Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2010, vol. 1. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart, pp. 238–247.

Klaer, N. and Wayte, S. 2011. Demersal MSE for trawl fish in the Southern and Eastern Scalefish and Shark Fishery and other like species. Report prepared for the Department of Agriculture, Fisheries and Forestry as part of the Reducing Uncertainty in Stock Status Project.

Klaer, N. 2012. Yield, total mortality and Tier 3 estimates for selected shelf and slope species in the SESSF 2012. Presented to the Shelf and Slope Assessment Groups, 2012.

Klaer, N.L., Wayte, S.E., Fay, G. 2012. An evaluation of the performance of a harvest strategy that uses an average-length-based assessment method, *Fisheries Research (*2012), doi:10.1016/j.fishres.2012.08.010

Knuckey, I.A., Berrie, S.E. and Gason, S.H. 2001. South East Fishery Integrated Scientific Monitoring Program. 2000 Report to the South East Fishery Assessment Group. 108pp.

Koopman, M.T., Punt, A.E. and Smith, D.C. 2001. Production parameters from the fisheries literature for SEF-like species. Final Report to the Australian Fisheries Management Authority Research Fund. ARF Project R99/0308.

Pauly, D. 1984. Fish population dynamics in tropical waters: a manual for use with programmable calculators. ICLARM Studies and Reviews 8. International Center for Living Aquatic Resources Management, Manila, Philippines. 325 p.

Polacheck, T., Haskard, K., Klaer, N., Betlehem, A. and Preece, A. 1998. An index for weighting results in catch-at-age models based on diagnostic tests for lack of fit. In: Funk, F., Quinn II, T.J., Heifetz, J., Ianelli, J.N., Powers, J.E., Schweigert, J.F., Sullivan, P.J. and Zhang, C.I. (eds). Fishery stock assessment models. University of Alaska Sea Grant, AK-SG-98-01, Fairbanks.

Smith, A.D.M. and Wayte, S.E. (eds) 2002. The South East Fishery 2002. Compiled by the South East Fishery Assessment Group. 271pp.

Smith, A.D.M. 2005. A harvest strategy framework for the SESSF. Presented to the Shelf and Slope and Deepwater Assessment Groups, 2005.

Thomson, R.B. 2014. Yield, total mortality and Tier 3 estimates for selected shelf and slope species in the SESSF 2014. Presented to the Shelf and Slope Assessment Groups, 2014.

Thomson, R.B. 2002a. South East Fishery data for stock assessment purposes. Draft version. May 2002. 26pp.

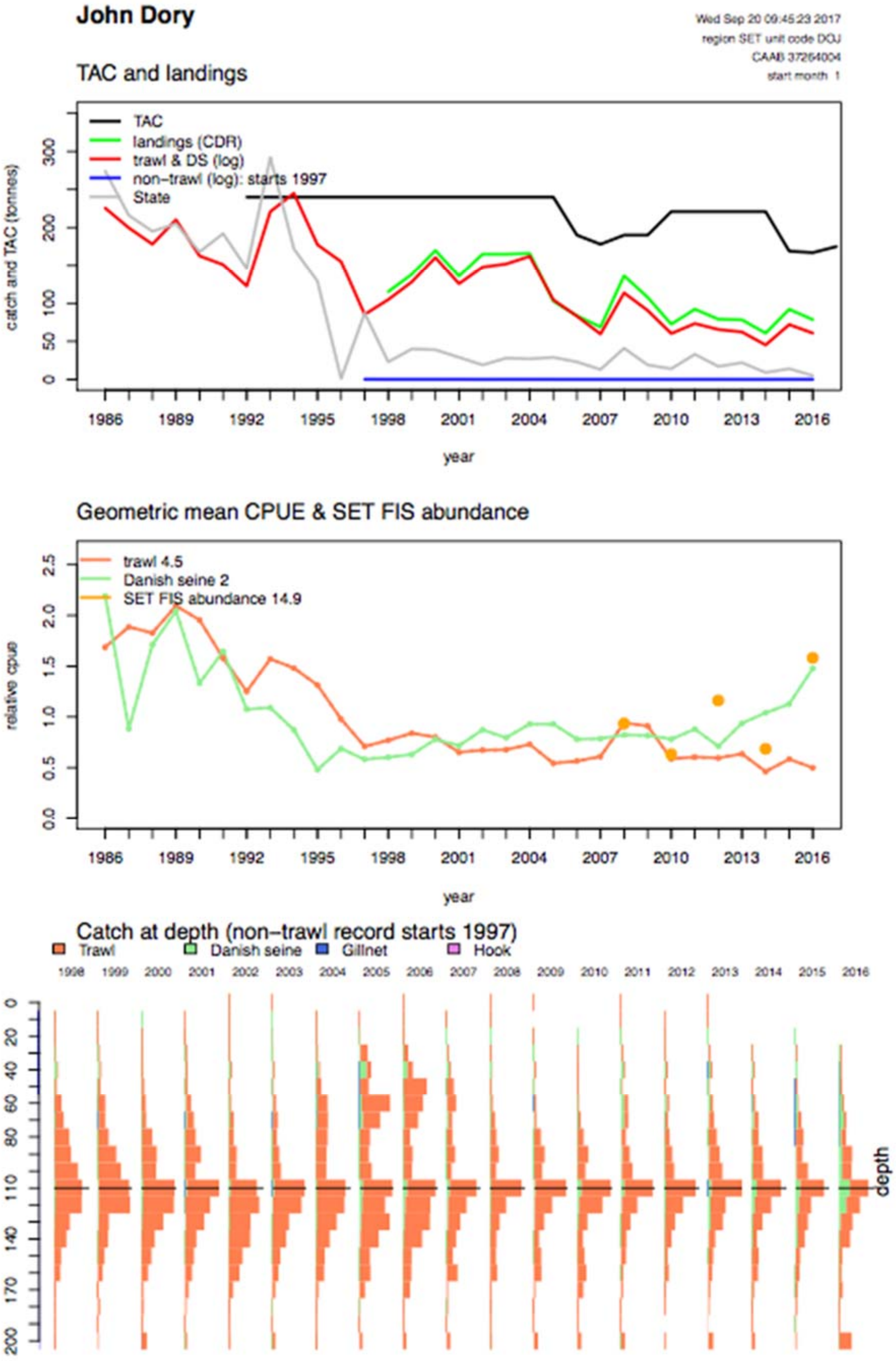
Thomson, R.B. 2002b. Automated catch curve analysis of South East Fisheries quota species. Presented to the South East Fishery Assessment Group, July 2002.

Thomson, R.B. 2002c. South East Fishery data for stock assessment purposes. Draft CSIRO Report.

Thomson, R. and Smith, A. 2002. Yield-per-recruit calculations for SEF quota species. CSIRO Report.

Wayte, S.E. and Klaer, N.L. 2010. An effective harvest strategy using improved catch-curves. Fisheries Research 106:310–320.

9.6 Appendix 1 – Data summary for John Dory



9.7 Appendix 2 – details of values that were used as estimates of total Z (shown highlighted)

DOJCCRes	All	NonTrawl	2012	6.096	1	-99	-99	0.410313	0.53542	1999	242
DOJCCRes	All	NonTrawl	2013	7.5975	1	-99	-99	0.410313	0.53542	1999	411
DOJCCRes	All	NonTrawl	2014	7.1955	1	-99	-99	0.410313	0.53542	1999	648
DOJCCRes	All	NonTrawl	2015	14.5363	1	-99	-99	0.410313	0.53542	1999	1407
DOJCCRes	All	NonTrawl	2016	17.9495	1	-99	-99	0.410313	0.53542	1999	1183

DOJCCRes	All	Trawl	2012	59.4406	1	-99	-99	0.370182	0.370093	1999	2533
DOJCCRes	All	Trawl	2013	54.6821	1	-99	-99	0.370182	0.370093	1999	1954
DOJCCRes	All	Trawl	2014	37.9966	1	-99	-99	0.370182	0.370093	1999	1884
DOJCCRes	All	Trawl	2015	57.4826	1	-99	-99	0.370182	0.370093	1999	2352
DOJCCRes	All	Trawl	2016	42.8365	1	-99	-99	0.370182	0.370093	1999	1198

10. Tier 4 Assessments for Blue Eye

Malcolm Haddon and Miriana Sporcic

CSIRO Oceans and Atmosphere, GPO Box 1538, Hobart, TAS 7001, Australia

10.1 Introduction

10.1.1 *Tier 4 Harvest Control Rule*

The TIER 4 harvest control rules are the default procedure applied to species which only have catches and CPUE data available; specifically there is no other reliable information on either current biomass levels or current exploitation rates.

Ideally, in line with the notion of being more precautionary in the absence of information, the outcome from these analyses should be more conservative than those available from higher TIER analyses; this is now explicitly implemented by imposing a 15% discount factor on the RBC as a precautionary measure unless there are good reasons for not imposing such a discount on particular species. The application of the discount factor will occur unless RAGs generate explicit advice that alternative equivalent precautionary measures are in place (such as spatial or temporal closures) or that there is evidence of historical stability of the stock at current catch levels (AFMA, 2009).

In essence TIER 4 analyses require, as a minimum, a time series of total catches and of standardized catch rates.

The current TIER 4 analysis and control rule underwent Management Strategy Evaluation (Wayte, 2009, Little et al, 2011a), which demonstrated its advantages over an earlier implementation used in 2007 and 2008. Further work has since demonstrated that as long as there is a limit on increases and decreases to the RBC of no more than 50% then the notion of including a maximum RBC (at 1.25 times the target) is redundant (Little et al, 2011b).

10.1.2 *The Tier 4 Assumptions*

10.1.2.1 Informative CPUE

There is a linear relationship between catch rates and exploitable biomass; *if there is hyper-stability (catch rates remain stable while stock size changes) or hyper-depletion (catch rates decline much faster than stock size changes) then the standard Tier 4 analysis would provide biased results.*

10.1.2.2 Consistent CPUE Through Time

The character of the estimated catch rates has not changed in significant ways through the period from the start of the reference period to the end of the most recent year; *If there has been significant effort creep altering the catchability, or there have been changes to the fleet that have altered the relative efficiency of the vessels fishing, or the catchability of the species by the fleet has been altered by other changes then the comparability of recent catch rates with the target period may be compromised. Such changes would obviously reduce the responsiveness of the Tier 4 method to change and may generate* *completely inappropriate management advice. Included in this clause are the effects of targeting or not targeting of deep water or aggregated species. When catch rates are extremely variable through time, such that mean estimates become unreliable measures of stock status, then the Tier 4 approach cannot be validly applied.*

10.1.2.3 Plausible Target Reference Period

The reference period provides a good estimate of the stock when at a depletion level of 48% unfished spawning biomass; *the Tier 4 method is based on catch rates and thus relates to exploitable biomass and not spawning biomass. As a minimum the reference period will refer to a period when the stock was in an acceptable, productive and sustainable state. But there can be no guarantees that the target aimed for is really* $B_{48\%}$.

10.1.2.4 Accurate Total Catch History

Accurate estimates are required for all catches from the stock under consideration during the accepted target period, irrespective of what method was used or whether it was retained or discarded. *This assumption is especially vulnerable to being breached when large proportions of catches are discarded. While there is a procedure for adjusting the standardized CPUE for these missed catches the uncertainty over the actual amount of fish killed remains.*

10.1.3 *Some Implications of the Assumptions*

The outcomes of the Tier 4 analysis should not be regarded with the same confidence as those from Tier 1 assessments. Even though they are termed stock assessments, in actuality they are empirical considerations of catches and CPUE. Any uncertainty in the catch or CPUE time-series is propagated directly through to the outputs of the analysis. For quota species the catches and reported CPUE is usually relatively well founded because of the quota catch disposal records and other compliance requirements. However, where there is a relatively high degree or variable discarding of catches this can lead to much greater levels of uncertainty.

At some point soon the assessments for those species that are conducted using a Tier 4 analysis should be reviewed for their inter-annual consistency and how the fishery has been responding to the management advice derived from the Tier 4 assessments.

10.2 Blue Eye Non-Trawl

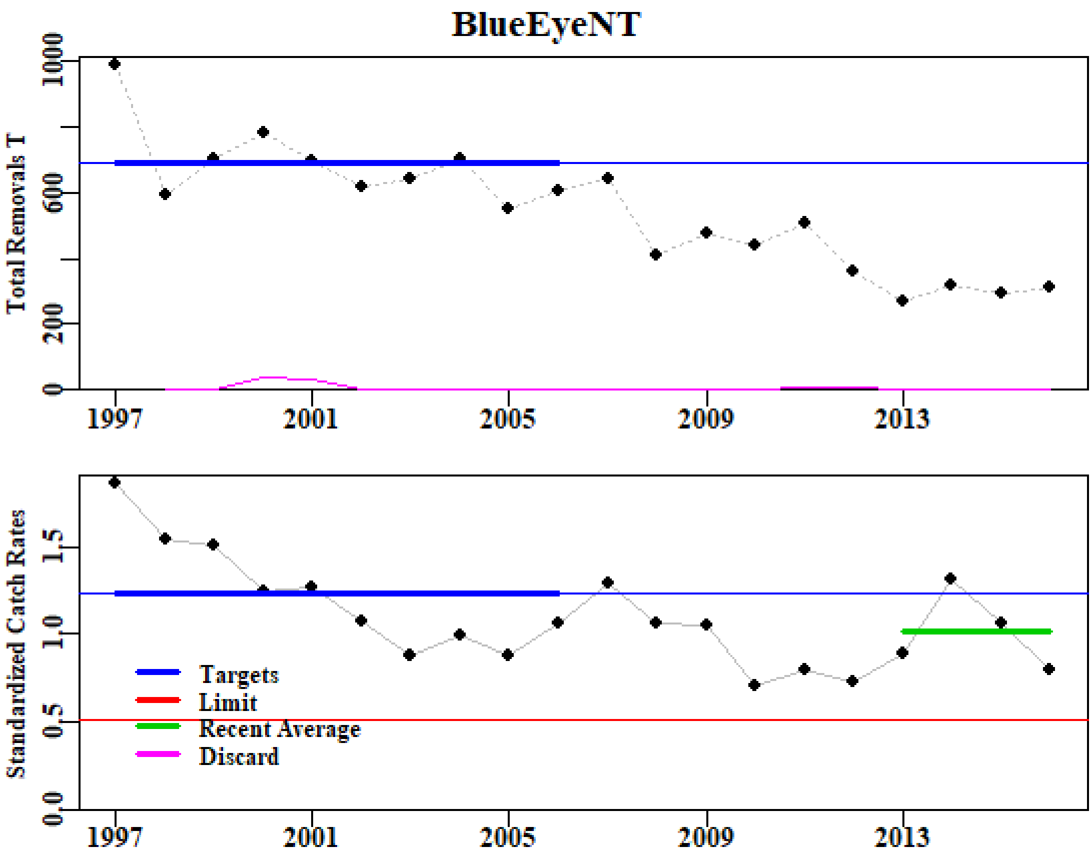


Figure 10.1. Blue-Eye. Top plot is the total removals with the fine line illustrating the target catch. Bottom plot represents the standardized catch rates with the upper fine line representing the target catch rate and the lower line the limit catch rate. Thickened lines represents the reference period for catches, catch rates, and the recent average catch rate.

Table 10.1. Blue-Eye RBC calculations. Ctarg and CPUEtarg are the targets identified in the figure above, CPUELim is 20% of the B0 proxy (which relate to the CPUEtarg), and the most recent CPUE is the average catch rate over the last four years. The RBC calculation does not account for predicted discards of predicted State catches. Wt_Discard is the weighted average discards from the last four years.

Parameter	Value		Parameter	Value
Reference_Years	1997 - 2006	|	Scaling	0.6999
CE_Target	1.2295	|	Last Year's TAC	
CE_Limit	0.5123	|	Ctarg	688.073
CE_Recent	1.0143	|	RBC	481.599
Wt_Discard	0.247	|	-	-

Table 10.2. Blue-Eye data for the TIER 4 calculations. Total is the sum of Discards, State, Non Trawl and SEF2 catches. All values in Tonnes. CE is the standardized catch rate (Haddon and Sporcic, 2017). GeoMean is the geometric mean catch rates. Discards are estimates from 1998 to present. The ratio of discards to catch over the 1998 - 2006 period was used to estimate the discards between 1986 and 1997, the proportion of which is the PDiscard.

Year	Catch	Discards	Total	State	CE	GeoMean	TAC
1997	989		989.000		1.8588		-
1998	595	0.006	595.305		1.5397		-
1999	705	0.007	705.304		1.5036		-
2000	746	37.135	783.445		1.2457		-
2001	664	32.976	697.161		1.2633		-
2002	614	0.123	614.595		1.0710		-
2003	640	0.128	639.815		0.8816		-
2004	698	1.399	699.650		0.9974		-
2005	548	0.005	548.448		0.8747		-
2006	608	0.061	608.005		1.0588		-
2007	638	2.821	641.234		1.2958		-
2008	408	0.982	409.008		1.0615		-
2009	478	0.005	478.457		1.0451		-
2010	443	0.142	443.325		0.7093		-
2011	501	7.467	508.380		0.8034		-
2012	356	4.989	361.048		0.7243		-
2013	266	1.014	267.362		0.8877		-
2014	315	0.480	315.630		1.3099		-
2015	296	0.296	296.231		1.0655		-
2016	314	0.068	314.437		0.7939		-

11. Tier 4 Analysis For Elephant Fish and Sawshark

Miriana Sporcic

CSIRO Oceans and Atmoshpere, GPO Box 1538, Hobart, TAS 7001, Australia

11.1 Executive Summary

TIER 4 analyses were conducted to calculate Recommended Biological Catches (RBCs) for elephant fish and sawshark within the SESSF. Standardized CPUE for both species were estimated using the Commonwealth logbook database only (instead of including earlier data into the same time series). This reflects the fact that the reference periods selected by SharkRAG derive from periods that are covered using the Commonwealth logbook data. TIER 4 analyses assume the target CPUE is a proxy for 40% of unfished biomass for both species (groups), which was recommended by SharkRAG (SharkRAG Meeting No. 1 Minutes, October 2015).

Elephant fish data used to standardize CPUE were also extracted from the Commonwealth logbook database. In 2014, standardized gillnet-CPUE fell below the long-term mean, with increases in recent years. However, these annual standardized-CPUE indices do not include discards, which since 2007, and particularly since 2011 have been found to be large. Including discards in the calculation of CPUE, total catch and updated recreational catch in a TIER 4 analysis increased CPUE and increased the estimated RBC (469.09 t). This RBC estimate corresponds to a 163.5 t increase compared to the 2015 RBC estimate (305.614 t). When discards are relatively high, as is the case with elephant fish then including discards more closely reflects the fishery dynamics. The TIER 4 method used to adjust CPUE to account for discarding assumes that a portion of each shot of elephant fish catch is discarded. If a significant portion of shots of elephant fish catch are entirely discarded then this assumption is violated and the adjustment will be biased high because catches that were entirely discarded, contributed to, and inflated, the estimated discard rate, but did not contribute to the standardized CPUE. In addition, once discard rates become greater than 0.5 then more fish are discarded than landed. As the discard rate increases the multiplier effect this has increases in a non-linear fashion (see Appendix). Above a rate of something like 0.6 or 0.65 the risk of the total catches being biased high by the inclusion of discards will increase. Given the discard rates of elephant fish the question arises of whether to accept the discard modified TIER 4 assessment or whether to use the non-discard adjusted assessment without removing discards from the RBC when generating a TAC. Given the high discard rates for elephant fish, it was recommended by SharkRAG that a TIER 4 analysis excluding discards be conducted (SharkRAG, Meeting No. 1 Minutes, 7 Dec 2017). The RBC estimate for elephant fish (excluding discards) was 293.252 t. This corresponds to a 12.36 t decrease compared to the 2015 RBC estimate (305.614 t).

The estimated RBC for sawshark was 518.56 t, an approximate 16.4 t reduction compared to the RBC estimated in 2015.

11.2 Introduction

11.2.1 *TIER 4 Harvest Control Rule*

The TIER 4 harvest control rules are the default procedure applied to species which only have catches and CPUE data available; specifically, there is no other reliable information on either current biomass levels or current exploitation rates.

Ideally, in line with the notion of being more precautionary in the absence of information, the outcome from these analyses should be more conservative than those available from higher TIER analyses; this is now explicitly implemented by imposing a 15% discount factor on the RBC as a precautionary measure unless there are good reasons for not imposing such a discount on particular species. The application of the discount factor will occur unless RAGs generate explicit advice that alternative equivalent precautionary measures are in place (such as spatial or temporal closures) or that there is evidence of historical stability of the stock at current catch levels (AFMA, 2009).

In essence TIER 4 analyses require, as a minimum, a time series of total catches and of standardized catch rates.

The current TIER 4 analysis and control rule underwent Management Strategy Evaluation (Wayte, 2009, Little et al., 2011a), which demonstrated its advantages over an earlier implementation used in 2007 and 2008. Further work has since demonstrated that as long as there is a limit on increases and decreases to the RBC of no more than 50% then the notion of including a maximum RBC (at 1.25 times the target) is redundant (Little et al., 2011b).

11.2.2 *The TIER 4 Assumptions*

11.2.2.1 Informative CPUE

There is a linear relationship between catch rates and exploitable biomass; *if there is hyper-stability (catch rates remain stable while stock size changes) or hyper-depletion (catch rates decline much faster than stock size changes) then the standard TIER 4 analysis would provide biased results*.

11.2.2.2 Consistent CPUE Through Time

The character of the estimated catch rates has not changed in significant ways through the period from the start of the reference period to the end of the most recent year; *If there has been significant effort creep altering the catchability, or there have been changes to the fleet that have altered the relative efficiency of the vessels fishing, or the catchability of the species by the fleet has been altered by other changes then the comparability of recent catch rates with the target period may be compromised. Such changes would obviously reduce the responsiveness of the TIER 4 method to change and may generate completely inappropriate management advice. Included in this clause are the effects of targeting or not targeting of deep water or aggregated species. When catch rates are extremely variable through time, such that mean estimates become unreliable measures of stock status, then the TIER 4 approach cannot be validly applied.*

11.2.2.3 Plausible Target Reference Period

48% unfished spawning biomass; *the TIER 4 method is based on catch rates and thus relates to exploitable biomass and not spawning biomass. As a minimum the reference period will refer to a* *period when the stock was in an acceptable, productive and sustainable state. But there can be no guarantees that the target aimed for is really* $B_{48\%}$*.*

11.2.2.4 Accurate Total Catch History

Accurate estimates are required for all catches from the stock under consideration during the accepted target period, irrespective of what method was used or whether it was retained or discarded. *This assumption is especially vulnerable to being breached when large proportions of catches are discarded. While there is a procedure for adjusting the standardized CPUE for these missed catches the uncertainty over the actual amount of fish killed remains.*

11.2.3 *Some Implications of the Assumptions*

The outcomes of the TIER 4 analysis should not be regarded with the same confidence as those from TIER 1 assessments. Even though they are termed stock assessments, in actuality they are empirical considerations of catches and CPUE. Any uncertainty in the catch or CPUE time series is propagated directly through to the outputs of the analysis. For quota species the catches and reported CPUE is usually relatively well founded because of the quota catch disposal records and other compliance requirements. However, where there is a relatively high degree or variable discarding of catches this can lead to much greater levels of uncertainty.

At some point soon the assessments for those species that are conducted using a TIER 4 analysis should be reviewed for their inter-annual consistency and how the fishery has been responding to the management advice derived from the TIER 4 assessments.

11.3 Elephant Fish (Callorhinchus milii) discards

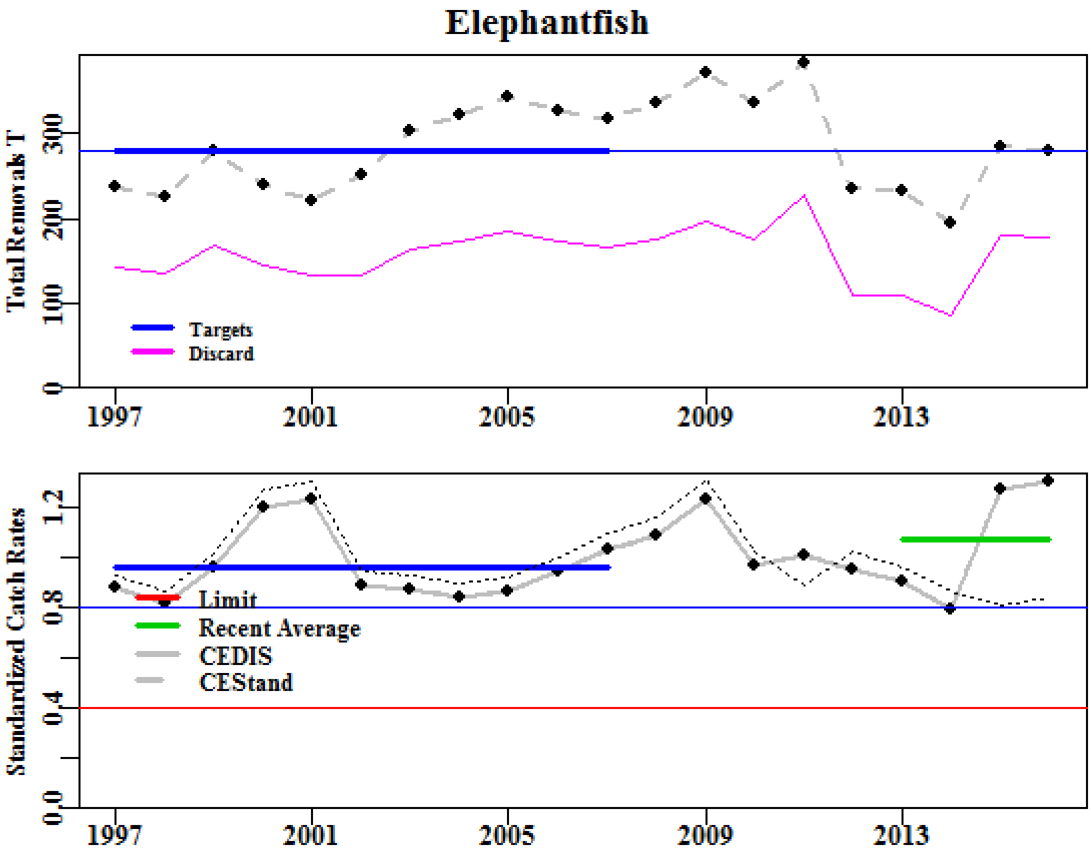


Figure 11.1. Elephant Fish Discard. Top plot is the total removals with the fine line illustrating the target catch. Bottom plot represents the standardized catch rates with the upper fine line representing the target catch rate and the lower line the limit catch rate. Thickened lines represent the reference period for catches, catch rates, and the recent average catch rate. The thin black dotted line is the unmodified standardized CPUE before the inclusion of discards.

Table 11.1. Elephant Fish Discard RBC calculations. Ctarg and CPUEtarg are the targets identified in the figure above, CPUELim is 20% of the B0 proxy (which relate to the CPUEtarg), and the most recent CPUE is the average catch rate over the last four years. The RBC calculation does not account for predicted discards of predicted State catches. Wt_Discard is the weighted average discards from the last four years.

Parameter	Value		Parameter	Value
Reference_Years	1997 - 2007	|	Scaling	1.6816
CE_Target	0.795	|	Last Year's TAC	92
CE_Limit	0.3975	|	Ctarg	278.953
CE_Recent	0.8656	|	RBC	469.089
Wt_Discard	161.245	|	-	-

Table 11.2. Elephant Fish Discard data for the TIER 4 calculations. Catch (t) is the reported landings, Discards (t) are the estimated discards, Total (t) is the sum of Discards, State (t), Non_T (t): Non-Trawl, recreational catch and landings (where these are available). CE: standardized catch rate (Sporcic and Haddon, 2017). DiscCE: standardized catch rate including discards. Discards are estimates from 1997 to present. The ratio of discards to catch over the 1998 - 2006 period was used to estimate the discards between 1986 and 1997, the proportion of which is the PDiscard. Recreational catch estimates were made in 2002 (29 t) and in 2008 (45 t) and these are included in the total catch. The values for 2003 - 2007 were linearly interpolated between the two samples, and the 2008 estimate used from 2009 - 2016. TAC: Total Allowable Catch (t).

Year	Catch	Discards	Total	(D/C)+1	CE	DiscCE	TAC	PDiscard
1997	95	142.377	236.927	2.506	0.9284	0.8746	-	0.6009
1998	90	135.228	225.030	2.506	0.8628	0.8128	-	0.6009
1999	112	168.088	279.712	2.506	1.0155	0.9566	-	0.6009
2000	96	144.261	240.062	2.506	1.2675	1.1940	-	0.6009
2001	88	132.333	220.213	2.506	1.3027	1.2272	-	0.6009
2002	89	133.635	251.379	2.506	0.9410	0.8865	-	0.6009
2003	108	163.005	302.921	2.506	0.9224	0.8689	-	0.6009
2004	115	172.993	322.207	2.506	0.8905	0.8389	130	0.6009
2005	122	184.407	343.868	2.506	0.9153	0.8622	130	0.6009
2006	115	173.419	328.250	2.506	0.9975	0.9397	130	0.6009
2007	110	165.605	317.913	2.506	1.0968	1.0332	123	0.6009
2008	116	175.117	336.408	2.506	1.1565	1.0895	94	0.6009
2009	131	196.596	372.151	2.506	1.3072	1.2314	94	0.6009
2010	116	174.756	335.808	2.506	1.0241	0.9647	65	0.6009
2011	112	227.064	383.932	3.030	0.8857	1.0088	89	0.6699
2012	75	110.026	234.905	2.461	1.0237	0.9469	89	0.5794
2013	73	108.703	232.376	2.494	0.9594	0.8996	109	0.5801
2014	59	85.896	194.571	2.449	0.8617	0.7934	109	0.5743
2015	56	180.112	284.830	4.206	0.8050	1.2729	163	0.7510
2016	57	177.217	280.975	4.128	0.8363	1.2980	92	0.7510

11.3.1 *Results and Discussion*

Elephant fish caught by recreational fishers is not insignificant and estimates of catch are uncertain. Analyses in this report incorporate such catches, by interpolating 29 t (2002) to 45 t (2008) and remaining constant (45 t) thereafter (recommended by SharkRAG (Meeting No. 1 Minutes, October 2015)). The latter estimate of 45 t (corresponding to 13,931 fish) inside Western Port is based on Braccini et al. 2008. The latter suggests that recreational catches are much higher than employed in TIER 4 analyses prior to 2015.

Following on from the 2015 analyses, i.e. assuming a recreational catch of 29 t from 2002 through to 45 t in 2016, led to an approximate increase of 163.5 t compared to the 2015 RBC estimate (i.e., 305.614 t (2015) versus 469.089 t (2017); Table 11.1) when discards were included.

Despite the implied level of discarding back into the earlier years of the fishery the recent discards had a positive effect upon the final RBC.

11.4 Elephant Fish (Callorhinchus milii) - no discards

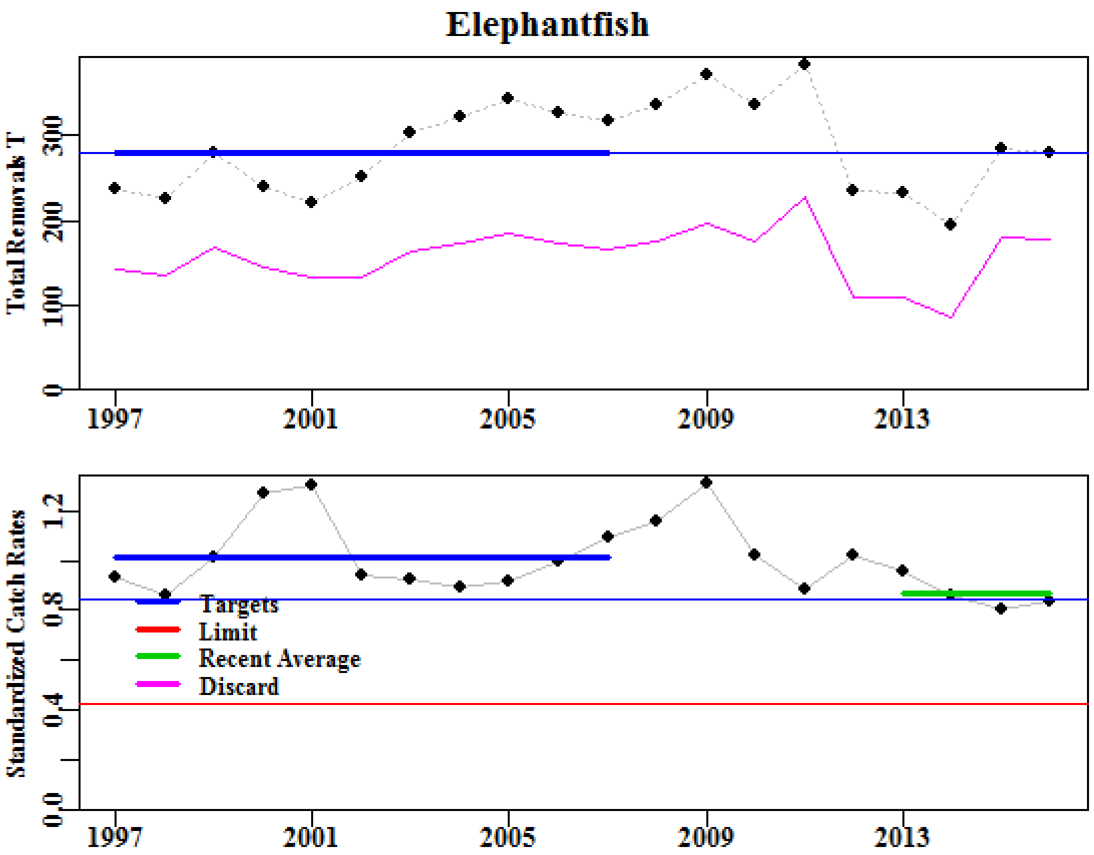


Figure 11.2. Elephant Fish no Discards. Top plot is the total removals with the fine line illustrating the target catch. Bottom plot represents the standardized catch rates with the upper fine line representing the target catch rate and the lower line the limit catch rate. Thickened lines represents the reference period for catches, catch rates, and the recent average catch rate.

Table 11.3. Elephant Fish no Discards RBC calculations. Ctarg and CPUEtarg are the targets identified in the figure above, CPUELim is 20% of the B0 proxy (which relate to the CPUEtarg), and the most recent CPUE is the average catch rate over the last four years. The RBC calculation does not account for predicted discards of predicted State catches. Wt_Discard is the weighted average discards from the last four years.

Parameter	Value		Parameter	Value
Reference_Years	1997 - 2007	|	Scaling	1.0513
CE_Target	0.844	|	Last Year's TAC	92
CE_Limit	0.422	|	Ctarg	278.953
CE_Recent	0.8656	|	RBC	293.252
Wt_Discard	161.245	|	-	-

Table 11.4. Elephant Fish no Discards data for the TIER 4 calculations. Catch (t) is the reported landings, Discards (t) are the estimated discards, Total (t) is the sum of Discards, State (t), Non_T (t): Non-Trawl, recreational catch and landings (where these are available). CE: standardized catch rate (Sporcic and Haddon, 2017). GeoMean: geometric mean catch rates. Discards are estimates from 1997 to present. The ratio of discards to catch over the 1998 - 2006 period was used to estimate the discards between 1986 and 1997, the proportion of which is the PDiscard. Recreational catch estimates were made in 2002 (29 t) and in 2008 (45 t) and these are included in the total catch. The values for 2003 - 2007 were linearly interpolated between the two samples, and the 2008 estimate used from 2009 - 2016. TAC: Total Allowable Catch (t).

Year	Catch	Discards	Total	State	Non_T	CE	GeoMean	TAC	PDiscard
1997	95	142.377	236.927			0.9284	0.9815	-	0.6009
1998	90	135.228	225.030			0.8628	0.9938	-	0.6009
1999	112	168.088	279.712	0.384		1.0155	1.0864	-	0.6009
2000	96	144.261	240.062	0.699		1.2675	1.1420	-	0.6009
2001	88	132.333	220.213	0.420		1.3027	1.3951	-	0.6009
2002	89	133.635	251.379	0.472	33.3767	0.9410	0.9815	-	0.6009
2003	108	163.005	302.921	0.439	44.1692	0.9224	0.9753	-	0.6009
2004	115	172.993	322.207	0.731	31.9474	0.8905	0.9074	130	0.6009
2005	122	184.407	343.868	0.663	34.8664	0.9153	0.9938	130	0.6009
2006	115	173.419	328.250	3.933	36.2931	0.9975	0.9753	130	0.6009
2007	110	165.605	317.913	11.952	35.7970	1.0968	1.0741	123	0.6009
2008	116	175.117	336.408	2.087	44.1460	1.1565	1.1358	94	0.6009
2009	131	196.596	372.151	3.846	51.3428	1.3072	1.3025	94	0.6009
2010	116	174.756	335.808	3.560	37.4905	1.0241	0.9012	65	0.6009
2011	112	227.064	383.932	8.793	35.1851	0.8857	0.7037	89	0.6699
2012	75	110.026	234.905	4.484	46.5338	1.0237	0.9568	89	0.5794
2013	73	108.703	232.376	5.904	42.5147	0.9594	0.9136	109	0.5801
2014	59	85.896	194.571	4.224	35.0368	0.8617	0.7963	109	0.5743
2015	56	180.112	284.830	3.497	32.0666	0.8050	0.8642	163	0.7510
2016	57	177.217	280.975	2.111	38.1537	0.8363	0.9198	92	0.7510

11.4.1 *Results and Discussion*

Elephant fish caught by recreational fishers is not insignificant and estimates of catch are uncertain. Analyses in this report incorporate such catches, by interpolating 29 t (2002) to 45 t (2008) and remaining constant (45 t) thereafter (recommended by SharkRAG (Meeting No. 1 Minutes, October 2015)). The latter estimate of 45 t (corresponding to 13,931 fish) inside Western Port is based on Braccini et al. 2008. The latter suggests that recreational catches are much higher than employed in TIER 4 analyses prior to 2015.

Following on from the 2015 analyses, i.e. assuming a recreational catch of 29 t from 2002 through to 45 t in 2016, but excluding discards, led to an approximate RBC of 293.25 t.

11.5 Sawshark

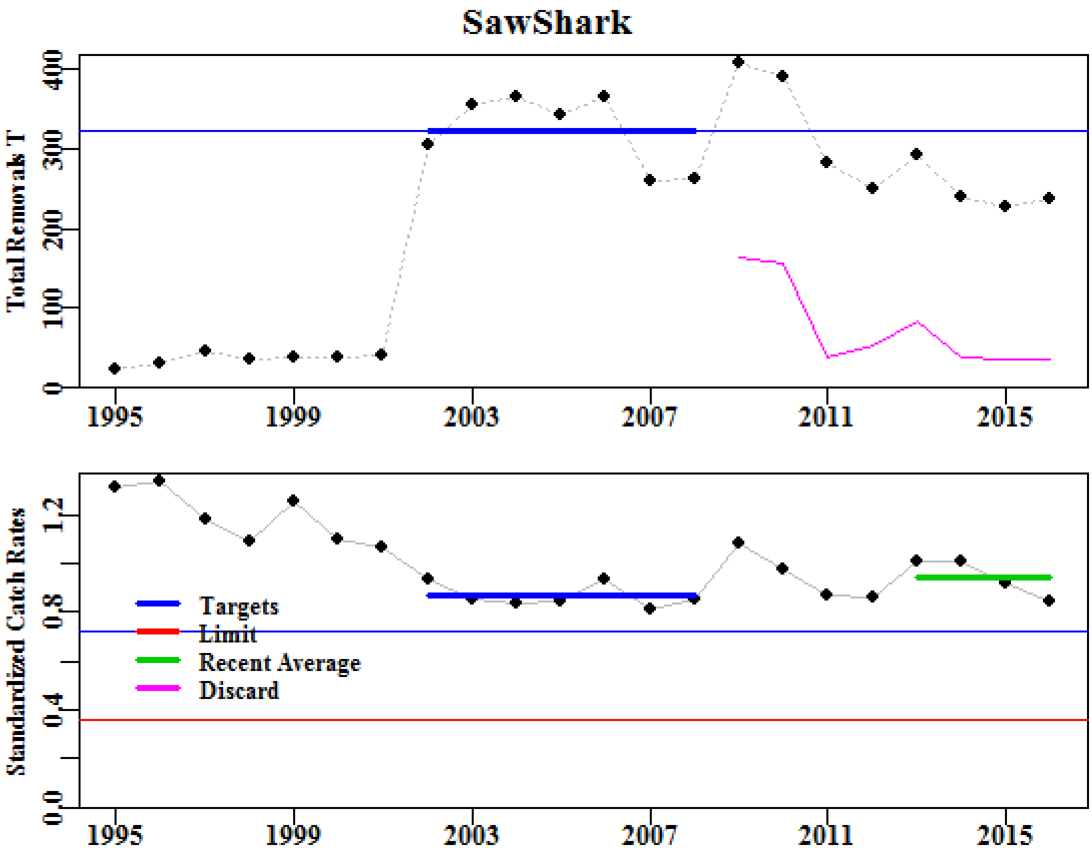


Figure 11.3. SawShark Trawl. Top plot is the total removals with the fine line illustrating the target catch. Bottom plot represents the standardized catch rates with the upper fine line representing the target catch rate and the lower line the limit catch rate. Thickened lines represent the reference period for catches, catch rates, and the recent average catch rate.

Table 11.5. SawShark Trawl RBC calculations. Ctarg and CPUEtarg are the targets identified in the figure above, CPUELim is 20% of the B0 proxy (which relate to the CPUEtarg), and the most recent CPUE is the average catch rate over the last four years. The RBC calculation does not account for predicted discards of predicted State catches. Wt_Discard is the weighted average discards from the last four years.

Parameter	Value	Parameter	Value
Reference_Years	2002 - 2008 |	Scaling	1.6097
CE_Target	0.7237 |	Last Year's TAC	433
CE_Limit	0.3618 |	Ctarg	322.13
CE_Recent	0.9443 |	RBC	518.545
Wt_Discard	39.714 |	-	-

Table 11.6. SawShark Trawl data for the TIER 4 calculations. Catch (t) is the reported landings, Discards (t) are the estimated discards, Total (t) is the sum of Discards, State (t), Non_T (t): Non-Trawl, recreational catch and landings (where these are available). CE: standardized catch rate (Sporcic and Haddon, 2017). GeoMean: geometric mean catch rates. Discards are estimates from 1997 to present. TAC: Total Allowable Catch (t).

	Year	Catch	Discards	Total	State	CE	GeoMean	TAC
317	1995	24		24.375	0.000	1.3135	0.1924	-
318	1996	30		29.537	0.000	1.3338	0.1954	-
319	1997	45		45.139	17.528	1.1837	0.1734	-
320	1998	36		36.170	10.444	1.0906	0.1597	-
321	1999	37		37.453	14.330	1.2529	0.1835	-
322	2000	39		38.885	15.240	1.1011	0.1613	-
323	2001	42		42.071	8.387	1.0665	0.1562	-
324	2002	305		304.860	17.006	0.9359	0.1371	-
325	2003	355		355.425	23.210	0.8538	0.1251	-
326	2004	364		364.397	25.753	0.8401	0.1231	434
327	2005	342		341.605	27.749	0.8446	0.1237	434
328	2006	366		365.769	29.252	0.9368	0.1372	434
329	2007	259		259.381	24.601	0.8139	0.1192	410
330	2008	263		263.470	15.618	0.8536	0.1250	312
331	2009	244	164.594	408.259	17.278	1.0858	0.1590	312
332	2010	233	157.669	391.082	20.308	0.9790	0.1434	255
333	2011	245	38.033	282.612	15.695	0.8724	0.1278	226
334	2012	162	53.056	250.394	18.215	0.8649	0.1267	339
335	2013	165	83.138	293.250	15.850	1.0087	0.1477	339
336	2014	163	37.318	240.153	11.024	1.0071	0.1475	339
337	2015	168	35.477	228.308	9.249	0.9205	0.1348	459
338	2016	178	37.004	238.136	11.527	0.8408	0.1232	433

11.5.1 *Results and Discussion*

Sawshark catches have been split primarily between gillnets and trawls (with a lesser quantity taken by Danish seine). The standardized gillnet-CPUE has been declining since 2004, with slight increases in recent years, although it does not account for the level of discarding that occurs. By contrast, the standardized trawl-CPUE has been relatively flat. Catches by trawl are now almost as high as those taken by gillnets, illustrating the uncertainty in this analysis and providing some evidence that there may be an element of avoidance by gillnet fishers. This avoidance could, in turn, lead to a reduction in gillnet-CPUE. The potential avoidance of this species by gillnets suggests that the corresponding standardized CPUE may not adequately reflect stock abundance. Therefore, SharkRAG recommended using standardized trawl-CPUE (see SharkRAG Meeting No. 1 Minutes, October 2015).

The estimated RBC without discards was 518.56 t (Table 11.3) a reduction of 16.4 t compared to the 2015 RBC estimate.

11.6 Appendix: Methods

11.6.1 TIER 4 Harvest Control Rule

The data required are time series of catches and catch rates. The analyses have been conducted on total catches across the entire SESSF (including State catches, SEF2 landing records, and any discards). For some species, where there is only a single stock and a single primary fishing method, analyses are presented using standardized CPUE data (Haddon, 2014). For other species, there may be multiple stocks or areas or multiple methods and selecting which time series of catch rates to use in the analyses is not always straightforward. In those cases, the standardized time series for the method now accounting for the majority of current catch was used.

All 2010 data relating to catches and discards, from both State waters and SEF2 data sets, were provided by AFMA, with initial processing by N. Klaer and J. Upston of CSIRO. All catch rate data were derived from the standard commercial catch and effort database processed from the AFMA data by M. Fuller of CSIRO Hobart.

Standard analyses were set up in the statistical software, R Core Team (2016), which provided the tables and graphs required for the TIER4 analyses. The data and results for each analysis are presented for transparency. The TIER 4 harvest control rule formulation essentially uses a ratio of current catch rates with respect to the selected limit and target reference points to calculate a scaling factor for the current year. This scaling factor is applied to the target catch to generate an RBC. To generate a TAC, known discards and State catches are first removed and then, if applicable, the 15% discount is applied. The TAC calculations are conducted by AFMA. This report focusses on providing the estimates of the Recommended Biological Catches (RBCs).

$$\text{Scaling Factor } = SF_t = \max\left(0, \frac{\overline{CPUE} - CPUE_{\text{lim}}}{CPUE_{\text{targ}} - CPUE_{\text{lim}}}\right)$$

If new data becomes available, for example, more State data has become available this year, or other large changes occur in the catch rates then the RBC could undergo large changes. Such changes are constrained by the following limits:

$$\begin{array}{ll} RBC_y = 1.5RBC_{y-1} & RBC_y > 1.5RBC_{y-1} \\ RBC_y = 0.5RBC_{y-1} & RBC_y < 0.5RBC_{y-1} \end{array}$$

where

1. RBC_y is the RBC in year *y,*
2. $CPUE_{\text{targ}}$ is the target CPUE for the species,
3. $CPUE_{\text{lim}}$ is the limit CPUE for the species = 0.4 * $CPUE_{\text{targ}}$,
4. $\overline{CPUE}$ is the average CPUE over the past *m* years; *m* tends to be the most recent four years,
5. C_{targ} is a catch target derived from a period of historical catch that has been identified as a desirable target in terms of CPUE, catches and status of the fishery,

   e.g. 1986 - 1995. This is an average of the total removals for the selected reference period, including any discards.

$$C_{\text{targ}} = \frac{\sum^{y=yr1} \ yr2L_y}{(yr2 - yr1 + 1)}$$

where L_y represents the landings in year y.

$$CPUE_{\text{targ}} = \frac{\sum_{y=yr1}^{yr2} CPUE_y}{(yr2 - yr1 + 1)}$$

where $CPUE_y$ is the catch rate in year y, *yr2* and *yr1* represent the last and the first years in the reference period respectively.

Percent discards are estimated from ISMP observations from 1998 to the current year. Discards for earlier years, prior to ISMP sampling, are generally estimated by taking the overall average percent discard from 1998 to the 2006 and applying that discard rate to the reported landings for the earlier years. The year 2006 was selected as the final year as discarding practices altered at about that time following the structural adjustment and the introduction of the Harvest Strategy Policy. For Eastern Gemfish the average discard rate was determined for 1998-2002 to allow for the non-target nature of the fishery following 2002. The calculation of the earlier discards is done so that the total catches can be estimated even though only the landed catches are available. To calculate the discards for a given year we used:

$$D_y = \frac{C_y \overline{D}_{98-06}}{\left(1 - \overline{D}_{98-06}\right)}$$

Discard proportions for the projected year for which the RBC is being calculated are taken as a weighted mean of the previous four years:

$D_{\text{CUR}} = (1.0\ D_{y-1} + 0.5\ D_{y-2} + 0.25\ D_{y-3} + 0.125\ D_{y-4})/1.875$

where D_{CUR} is the estimated discard rate for the coming year y, D_{y-1} is the discards rate in year *y-1*. The discard rate in year y is the ratio of discards to the sum of landed catches plus those discards (this can vary between 0 - 100%):

$$D_y = \frac{Discard_y}{\left(Catches_y + Discard_y\right)}$$

For each species, reference years were selected by the RAGs to generate estimates of target catches and target catch rates. In addition, a decision was required as to whether the fishery could be considered as fully developed or otherwise. Where a fishery was not considered to be fully developed the target catch rate, $CPUE_{\text{targ}}$, was divided by two as a proxy for expected changes to catch rates as the fishery develops and the resource stock size declines towards the target of 48% unfished biomass.

Plots are given of the total removals illustrating the target catch level. In addition, the standardized catch rates are illustrated with the target catch rate and the limit catch rate. Finally, where the data are available, plots are given of the Total removals contrasted with State removals, and of discards and non-trawl catches.

11.6.2 *The Inclusion of Discards*

Some species, especially elephant fish (*Callorhinchus milii*) have experienced high levels of discarding but the reported catch rates relate only to the estimated landed weights. In those species where discarding makes up a significant proportion of the catch it is reasonable to ask how the discards would have affected catch rates. This is an important question because standardized commercial catch rates are used in Australian stock assessments as an index of relative abundance (Sporcic and Haddon, 2017); if ignoring discards leads to a consistent bias this could affect the outcome of the assessments and thus, assessments should become aware of the effects of discards.

Catch rates are used in assessments as an index of relative abundance through time and it is the trends exhibited by the catch rates that are important rather than their absolute values. If the discard levels are relatively constant through time and evenly distributed amongst the fleet, then their inclusion would not be expected to influence the trends in catch rates except to add noise. In all cases the discard rates are estimates based on sub-sampling the fleet of vessels.

For those species, such as elephant fish, where discard rates are much higher (~0.58-0.75) it was decided to include those estimated catches to determine their effect on the outcome of the TIER 4 analyses.

11.6.2.1 Analyses Including Discards

Discard rates cannot simply be added to known catches on the way to calculating catch rates. The standardized catch rates are estimated from individual catch and effort records but the estimates of discards are summary estimates for each fishery. While a method for incrementing the standardized catch rates has been developed it should be noted that this ignores all complications relating to unknown aspects of discarding behaviour (is the discard rate constant across all catch sizes, across all vessels, across all areas? etc.). This means that including discard catches into the annual catch rate estimates introduces an unknown amount of uncertainty into the analysis. It should also be noted that the discard estimates are highly variable from year to year and derive from relatively small samples of all trips contributing to catches.

The method developed was to find the multiplier needed to adjust ratio mean catch rates and apply that to the standardized catch rates (Haddon, 2010). The ratio mean catch rates require the annual sum of catches for the fishery along with the sum of effort and ratio means calculated for each year. The discard estimates from the fishery can be added to the catch totals and new ratio means calculated and compared. The multiplier needed to make the same changes to the ratio mean catch rates can then be developed and applied to the standardized catch rates.

The ratio mean is simply the sum of all catches divided by the sum of effort

$$\hat{I}_{R,t} = \frac{\sum C_t}{\sum E_t}$$

where $\hat{I}_{R,t}$ is the ratio mean catch rate for year *t*, $\sum C_t$ is the sum of landed catches in year *t*, and $\sum E_t$ is the sum of effort (as hours trawled) in year *t*. If $\sum D_t$ is the sum of discards in year *t* then the discard incremented ratio mean catch rate would be:

$$\hat{I}_{D,t} = \frac{\sum C_t + \sum D_t}{\sum E_t}$$

The same values of $\hat{I}_{D,t}$ can also be obtained using the following multiplier:

$$\hat{I}_{D,t} = [(\sum D_t / \sum C_t) + 1] \times I_t$$

here I_t is the catch rate estimate to be modified by the inclusion of discards. If this is the ratio mean then the augmented catch rates would be identical to the first equation dealing with $\sum D_t$. In practice, the catch rates used with the multiplier are the standardized catch rates (e.g. Haddon, 2014).

11.6.2.2 The Limitations of Including Discards

The discard rates are estimated as the proportion of the total catch (= landed catch plus discards), which means that discard proportions greater than 0.5 imply that more fish are discarded than landed. To calculate the discarded catches from a discard rate and the landed catches we use:

$$D_t = \left(\frac{C_t}{1 - P_t}\right) - C_t$$

where D_t is the discarded catches in year t, C_t is the total landed catches in year t, and P_t is the proportion of discards in year t. Because the divisor is $1 - P_t$ as P_t tends to 1.0 the divisor becomes very small and hence acts as a multiplier on total landed catch C_t. The effect of this is that when P_t is estimated to be above 0.5 the multiplying effect in the calculation of discards becomes grossly exaggerated.

It is recommended that once discard proportions are estimated to be above 0.5 or 0.6 then attention needs to be paid to whether or not the inclusion of discards into the CPUE and the calculation of the RBC can be considered valid.

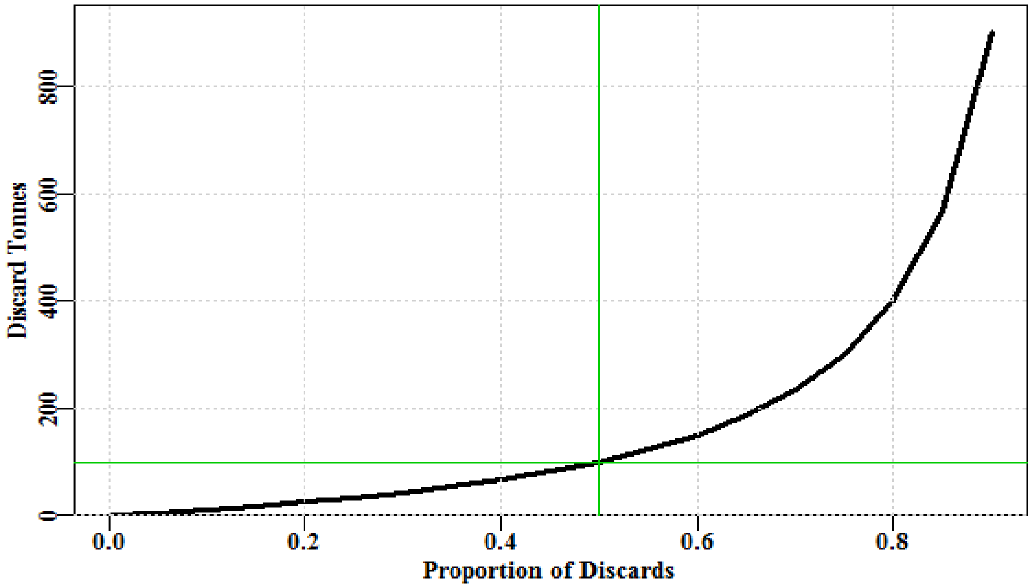


Figure 11.4. The influence of the proportion discarded on estimates of discarded catches.

11.6.3 *Selection of Reference Periods*

The TIER 4 requires a reference period to be selected in order to establish target and limit levels of catch rates and associated target levels of catch that are deemed by the RAG to act as a proxy for the desired state for the fishery. These act as a proxy for the Harvest Strategy Policy reference points of 48% and 20% unfished spawning biomass. The original TIER 4 rule that used a linear regression of the last four years catch rates to determine whether catches increase or decrease was not able to rebuild a resource towards a desired target level and the current approach was developed so as to be able to manage a fishery towards a target and away from a limit.

The essence of the TIER 4 control rule is that it sets a RAG agreed target catch rate, which has an associated target catch. An estimate of current catch rates (usually the average of the last four years) is compared with the target and a multiplier is estimated which is to be applied to the target catch to generate the recommended biological catch.

To select a reference period requires a time series of comparable catch rates. For this reason the use of standardized catch rates should be an improvement over using, for example, the observed arithmetic or geometric mean catch rates. Catch rate data is available in the SESSF for all targeted species from 1986 - 2011, although it needs to be noted that the character of the fishery has changed markedly during that period. Little et al. (2009) provide a discussion on how reference periods might be selected. They proposed a default ten year period of 1986 to 1995, stating: We have assumed that the average CPUE from 1986 to 1995 corresponds to that which would be attained if the stock were at the level that provides the maximum economic yield, B_{MEY}. The limit CPUE is 40% of this CPUE (Little et al., 2009, p 234).

For each species, reference years were selected by the RAGs to generate estimates of target catches and target catch rates. In addition, a decision was required as to whether the fishery could be considered as fully developed or otherwise during the reference period or not. Where a fishery was not considered to be fully developed the target catch rate, $CPUE_{\mathrm{targ}}$, was divided by two as a proxy for expected changes to catch rates as the fishery develops and the resource stock size declines towards the assumed proxy target for 48% unfished biomass.

Little et al. (2009) proposed three rules used to estimate the CPUE target:

1. The CPUE target for stocks fully exploited at or prior to 1986 is based on the average CPUE from 1986-1995.
2. Where fishing exploitation up to 1986 is thought to be minimal, the CPUE determined in step 1 is halved (to provide a catch rate proxy for B_{MEY}).
3. Where fishing exploitation after 1986 is low, the first year in which catches are above 100t signifies the start of the 10 year period for which CPUE targeted is calculated.

These rules are not always applicable for bycatch shark species (e.g. total catch of elephant fish rarely reaches 100 t annually). Instead, periods were chosen during which the fishery was considered to be well developed but in a good and relatively stable condition. For elephant fish the reference period chosen was 1997 - 2007 and for sawshark the reference period chosen was 2002 - 2008.

11.6.4 *Target as 40% or 48% B0*

Each harvest control rule in the Commonwealth harvest strategy policy requires both a limit and target reference point. The TIER 4 harvest control rule (HCR) is no exception. As the TIER 4 harvest strategy relies on an empirical HCR (and an empirical 'assessment'), then both reference points are taken to be proxies for the default Commonwealth reference points.

Primary economic species all have an implied target of 48%B_0, which, in its turn, is assumed to be a proxy for B_{MEY} (i.e. a proxy for a proxy). However, where a species is a byproduct rather than a primary target species, currently a lower target of 40%B_0 is used. With the TIER 4 HCR this would have no effect upon the catch target but would lower both the CPUE target and limit reference points (implying that the stock could be depleted to a lower level; this assumes the CPUE really is an index of relative abundance). Hence in the diagram illustrating the catch time series and target a different target reference point should have no effect. However, in the plot of the time series of CPUE, the original target CPUE will remain as a thickened line and the new CPUE target will appear as a thinner line below the original target, and the limit will be calculated relative to the new actual CPUE target. If the thick and thin blue target lines are coincident this implies the target to be 48%B_0, if they are separate on the plot this implies the target is less than 48%B_0.

11.7 References

AFMA (2009) SESSF Stock Assessment Methods and TAC Setting Process Version 1.5. 8pp.

AFMA (2017) *Southern and Eastern Scalefish and Shark Fishery Management Arrangements Booklet 2017* Australian Fisheries Management Authority, Canberra, Australia. 92pp.

Braccini, J. M., Walker, T. I., Conron, S. D. (2008) Evaluation of effects of targeting breeding elephant fish by recreational fishers in Western Port. Draft Final report to Fisheries Revenue Allocation Committee. (December 2008) 59 + ii pp. (Fisheries Research Brand: Queenscliff, Victoria, Australia).

Haddon, M. (2010) Tier 4 Analyses (data from 1986 - 2008. Pp 319 - 369 in Tuck, G.N. (*ed*) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2009 Part 2.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 428 pp.

Haddon, M. (2014) Catch Rate Standardizations for Selected Species from the SESSF (data 1986-2012) pp 57 275 in Tuck, G.N. (*ed*) (2014) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2013. Part 2.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 487 pp.

Little, R., Tuck, G.N., Haddon, M., Day, J., Klaer, N., Smith, A.D.M., Thomson, R., Wayte, S. (2009) Developing CPUE targets for the Tier 4 harvest strategy of the SESSF. Pp 233-254 in Tuck, G.N. (*ed*) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2008 Part 2.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 331 pp.

Little, L.R., Wayte, S.E., Tuck, G.N., Smith, A.D.M., Klaer, N., Haddon, M., Punt, A.E., Thomson, R., Day, J, Fuller, M. (2011a) Development and evaluation of a cpue-based harvest control rule for the southern and eastern scalefish and shark fishery of Australia. *ICES Journal of Marine Science* **68(8)**: 1699-1705.

Little, L.R., Wayte, S.E. and Tuck, G.N. (2011b) The effects of Cmax on the Tier 4 Harvest Control Rule. Pp 3-9 in Tuck, G.N. (*ed*) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2010 Part 2.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 419 pp.

R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Sporcic, M., Haddon, M. (2016) Statistical CPUE standardizations for selected SESSF species (data to 2015). DRAFT - Prepared for the Australian Fisheries Management Authority SERAG meeting 11-12 October 2016. CSIRO Oceans and Atmosphere, Hobart. 206 pp.

Sporcic, M., Haddon, M. (2017) Catch Rate Standardizations for Shark Species in the SESSF (data to 2016). Report to the Shark RAG November 2017. 99 pp.

Wayte, S.E., Fuller , M. (2008) Tier 4 Harvest Control Rule applied to deepwater species 2008. Report to Deep RAG, December 2008. 23 pp.

Wayte, S.E. (ed.) 2009. *Evaluation of new harvest strategies for SESSF species.* CSIRO Marine and Atmospheric Research, Hobart and Australian Fisheries Management Authority, Canberra. 137 pp.

12. School Whiting (*Sillago flindersi*): additional data and 2017 assessment options

Jemery Day

CSIRO Oceans and Atmosphere, GPO Box 1538, Hobart, TAS 7001, Australia

12.1 School whiting

12.1.1 *Previous assessment and summary of data used*

School whiting (*Sillago flindersi*) in the Southern and Eastern Scalefish and Shark Fishery (SESSF) was last examined in 2011 (Day, 2011), which considered a range of fixed catch levels projections with the aim of finding a long term RBC. This work was based on the last accepted assessment in 2009 (Day, 2009). The 2009 assessment stated that:

> School whiting is a short lived species. Spawning biomass is particularly sensitive to variation in recruitment events and good and bad recruitment years can have a very rapid impact on the fish stock. As a result there will always be some uncertainty about the status of the stock. Further exploration of some biological parameters, such as age and length at maturity may help reduce this uncertainty, but the high mortality rate and short expected life time for this species mean that rapid changes are always possible and projections will always be subject to uncertainty relating to the most recent recruitment events, which may be poorly informed until the cohorts involved fully enter the fishery.

The 2009 assessment assumed school whiting to be a single stock off the east coast of Australia and in Bass Strait, which is largely encompassed by the SESSF but does continue further north above Barrenjoey Point to Ballina.

Data used in the 2009 assessment included catch data from 1947-2008, separated into three fleets:

(i) Victorian Danish seine (1947-2008, Commonwealth data since 1985),

(ii) Otter trawl (1947-2008, incorporating both Commonwealth and state fleets), and

(iii) NSW Danish seine (1957-1994, data from NSW state waters).

A catch rate index was used only for the Victorian Danish seine fleet from 1986-2008, based on Commonwealth logbook data. This catch rate index now extends from 1986-2015.

Port measurements of length composition data was available from: the Victorian Danish seine fleet (1991 (Vic Fisheries), 1994-2008 (Commonwealth)); the NSW trawl fleet (1983, 1988, (NSW Fisheries), 1997-2008 (Commonwealth)); and for NSW Danish seine from the Sydney fish markets (1983-1989).

Age-at-length data was available for the Victorian Danish seine fleet from 1994-2006 (whole otoliths) and 2007-2008 (sectioned otoliths) and for the otter trawl fleet from 2001-2006 (whole otoliths). The maximum age was thought to be around six years, with a plus group of six years used.

NSW catch figures were provided on a state wide basis and separated into trawl and NSW Danish seine catches, with adjustments made (by NSW Fisheries) to remove stout whiting from the catch totals used from NSW.

12.1.2 *Additional data and issues to be considered*

12.1.2.1 Sectioning otoliths

Sectioning school whiting otoliths now suggests a maximum age of 10 years, compared to the six years used in the 2009 assessment. Some of the previously aged whole otoliths are being sectioned and re-aged, which may result in considerable changes to the school whiting age data, which is expected to lead to changes in the assessment outcomes (these changes could also be considerable). The previous assessment only had 2 years of sectioned otoliths. Given there were issues relating to the short life span and relatively late maturity of school whiting, this change to methodology is likely to have a large effect on the assessment outcomes and provides sufficient grounds to warrant a new assessment, regardless of any other issues.

12.1.2.2 Genetic structure and stock status

Early studies (Dixon et al. 1986, Dixon et al. 1987) produced some genetic evidence for a break between Forster and Coffs Harbor, although this evidence is not particularly strong. If the stock was to be split, it would be preferable to have a new genetic study using modern markers and representative sampling, so an informed decision can be made about school whiting stock structure and where such a split in the stock structure should be made.

If SERAG decides that some NSW data is to be excluded (without a further genetic study), this should only be NSW data north of either Forster or the Barrenjoey line. However, the NSW data used in the 2009 assessment cannot be easily separated within NSW zones, as this data was provided in an aggregated form. If exclusion of some NSW data is to be done, either some assumptions will need to be made (after discussion and agreement within SERAG), or advice will be required from NSW Fisheries. Such a split would need to be performed for both NSW catch data and NSW length frequency data.

Another issue with the 2009 school whiting assessment is the uneven quality of data available, with the best data (including the only catch rate data) coming from the Commonwealth logbook data, which is largely based on the Danish seine fleet operating out of Lakes Entrance. The Commonwealth data also includes lesser quantities of Commonwealth trawl data, but presently without a catch rate index for this fleet. The data from NSW fisheries has not included catch rate data, has limited (and possibly unrepresentative) length frequency data and no age data. The catches of school whiting in NSW are substantial (greater than 50% of the total catch in the period 1996-2008).

12.1.2.3 Additional NSW data

Additional NSW data on school whiting may be available for a potential 2017 school whiting assessment. This data includes some new age data (possibly only one year of age data), updated catch data (which may include some changes to catch by fleet, possibly requiring inclusion of an additional prawn trawl fleet, and includes more information on the spatial distribution of catch in NSW) and some catch rate data.

Additional age data could be very influential in the assessment, especially from a different geographic region, and improvements to catch data would also assist in improving the model reflecting reality more closely. While some work has been done examining catch rate data, it is not clear whether a standardised catch rate series would be sufficiently informative to use as an additional abundance series in a stock assessment (if the series is extremely variable then it fails to inform or constrain the model fit). Prior to 2010, the data is reported monthly so may not be useful for producing an informative standardised catch rate as an abundance index. Since July 2009, data has been collected at a finer temporal resolution. However, unlike the Commonwealth logbook data used in the Victorian Danish seine fleet catch rate standardisation, the NSW catch rate data do not contain a depth covariate and is sometimes aggregated into trips or days, rather than being reported per shot or hour of operation. In some cases it seems that some fields may be missing, which further reduces the number of observations available for analysis. Further data exploration is required before the utility of a standardisation can be assessed. It is not clear whether catch rates can be reliably separated for school whiting and stout whiting in all cases, especially in northern NSW.

In the 2009 assessment (Day 2009), the trawl fleet is a combination of data from NSW and Commonwealth trawl jurisdictions. If a standardised abundance index is to be obtained from only one part of this fleet (e.g. NSW), it may be sensible to separate the trawl fleet into two separate fleets, a Commonwealth trawl fleet and a NSW trawl fleet. A standardised catch rate series can be calculated for the Commonwealth trawl data, although this index was rejected by ShelfRAG for use as an abundance index in the 2009 school whiting assessment. This decision could be revisited.

The NSW Danish Seine fleet stopped operating in the mid-1990s, but Danish seine vessels have been operating in NSW waters again since 2010. This fleet consists largely of one vessel with two additional vessels (which both catch very small quantities of school whiting) operating sporadically since 2010. Further data exploration is required to ascertain whether a standardized index would be informative for this fleet.

Separation of prawn trawl and fish trawl gear, may provide a further complication, and distinguishing trips targeting school whiting and prawns may also present challenges in estimating a reliable abundance index in the northern NSW.

12.1.2.4 Possible 2017 assessment structure

For an updated 2017 school whiting assessment, the following data sources should be considered:

1. Commonwealth data largely from Lakes Entrance, including catch data, standardised catch rate data, length and age data
2. Historical NSW catch data (as included previously), including catch data, some length data
3. New NSW data – possibly including revisions to state catches, ageing data, length frequency data and possible standardised catch rate data.

The 2009 school whiting assessment, only included 1 and 2 above. The data described in 3 was not available at that stage.

A 2017 school whiting assessment should consider a range of options (with input from SERAG as appropriate) including:

A. Use data from 1 and 2 above.
B. Use data from 1 and 2, and include all usable data from 3.
C. Use data from 1 only (but this options should probably only be a sensitivity as there is no genetic or stock status evidence to support this particular separation).

12.2 Acknowledgements

Malcolm Haddon, Miriana Sporcic, Geoff Tuck, Robin Thomson, Rich Little, and Judy Upston are thanked for helpful discussions on this work.

12.3 References

Day J 2009. School whiting (*Sillago flindersi*) stock assessment based on data up to 2008. Report to ShelfRAG. 58 pp.

Day J 2011. School whiting (*Sillago flindersi*): Further exploration of fixed projected catches, potential indicators and alternative harvest strategy analyses. Report to ShelfRAG. 43 pp.

Dixon P I, Crozier R H and Black M 1986. School whiting – how many species. *Australian Fisheries* **45**: 33-38.

Dixon P I, Crozier R H, Black M and Church A 1987. Stock identification and discrimination of commercially important whitings in Australian waters using genetic criteria (FIRTA 83/16). Centre for Marine Science, University of New South Wales. 69 p. Appendices 1-10.

13. Discussion paper: options for use of NSW data in a School Whiting assessment in 2017

Jemery Day, Malcolm Haddon, Miriana Sporcic, Geoff Tuck

CSIRO Oceans and Atmosphere, GPO Box 1538, Hobart, TAS 7001, Australia

13.1 Current Assessment

The most recent School Whiting stock assessment (Day 2009) incorporates all Commonwealth and State catch data, including all NSW State and Commonwealth catch data. It includes length frequencies from three fleets: Commonwealth Danish seine; Commonwealth trawl and NSW Danish seine (historical). It includes age data from two fleets: Commonwealth Danish seine and Commonwealth trawl. It uses a single standardized CPUE series from the Commonwealth Danish seine fleet.

13.2 Issue

There is a suggestion to exclude NSW School Whiting data from the assessment, but this is not as simple as it sounds.

1. The School Whiting assessment is needed as the ageing data has been greatly changed and they are now thought to live longer than before (from maximum age 6 to 10). This may change the natural mortality estimate (M) which is currently estimated within the assessment.
2. Currently all Commonwealth catches and all State catches are included but only the Danish seine CPUE is used as an index of abundance.
3. Examination of Commonwealth logbook data found significant Commonwealth trawl catches along the NSW coast. So the assessment should not ignore catches along the NSW coast at least up to the Barrenjoey line.
4. NSW State fisheries hold State catch data (large catches) and also age and length composition data. However, much of this data appears to come from well north of the Barrenjoey line. We do not (yet) have all of this data for use in an assessment. There are calls for the following alternative actions:
    a. Exclude all State data north of Barrenjoey.
    b. Include all available State data: catch, age, and length composition, as well as a standardized cpue series.
    c. Exclude all data north of the Vic/NSW border.

13.2.1 *Option 4(a)*

Option 4(a) (exclude data north of the Barrenjoey line) would require:

1. Generating and including a new Commonwealth trawl standardized CPUE series.
2. Including the southern NSW catch data (up to Barrenjoey).

3. Considering including sparse state length data (small sample sizes) from southern NSW.

Option 4(a) would provide a solution for generating a TAC for the Commonwealth fishery. This is achievable in 2017, contingent on agreement from NSW and their provision of the required annual catch totals south of Barrenjoey.

13.2.2 *Option 4(b)*

Option 4(b) (the status quo with addition of extra NSW data) would require:

1. Generating and including a new Commonwealth trawl standardized CPUE series and investigating a potential State trawl CPUE series starting in 2010 (NSW central zone).
2. Including new age and length composition data (depending on its quality and its metadata – e.g. what area does it purport to represent, is there enough data to provide more signal than noise).

Detailed use of NSW data would be dependent upon the time taken to obtain, process and determine its utility in an assessment model.

Option 4(b) would provide a solution for generating a TAC for the Commonwealth fishery and would also provide an RBC that would assist NSW Fisheries with their management. However, it would involve making assumptions concerning representativeness of data (e.g. prawn trawl vs fish trawl, stout vs school whiting, and the assumption of an extensive single large stock). This would also require considerable work (currently unfunded) to incorporate NSW data in the assessment. The additions to the status quo listed above in 4(b) are unlikely to be achievable in 2017.

13.2.3 *Option 4(c)*

This option does not provide a solution for generating a TAC for the Commonwealth fishery in Zone 10 without including a separate assessment for Zone 10. Simply including catches from Zone 10 to an assessment that otherwise excludes this zone is inappropriate as Zone 10 catches are taken by trawl, rather than Danish seine. Also, there is insufficient data to generate a trawl series south of Zone 10.

Creating a new separate assessment for Zone 10 alone would be difficult, due to limited data. This option is not recommended.

13.3 Acknowledgements

Robin Thomson is thanked for helpful discussion on this work.

13.4 References

Day Jemery 2009. School whiting (*Sillago Flindersi*) stock assessment based on data up to 2008.pp 190-240. In Tuck, G.N. (ed.) 2010. Stock assessment for the Southern and Eastern Scalefish and Shark Fishery 2009, Part 1. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 334p.

14. School whiting (*Sillago flindersi*) stock assessment based on data up to 2016 – development of a preliminary base case

Jemery Day

CSIRO Oceans and Atmosphere, GPO Box 1538, Hobart, TAS 7001, Australia

14.1 Executive Summary

This document presents a suggested base case for an updated quantitative Tier 1 school whiting (*Sillago flindersi*) assessment for presentation at the first SERAG meeting in 2017. The last full assessment was presented in Day (2009). The preliminary base case has been updated by the inclusion of data up to the end of 2016, which entails an additional eight years of catch, discard, CPUE, length and age data and ageing error updates since the 2009 assessment and incorporation of an additional trawl CPUE index from 1995-2016. This document describes the process used to develop a preliminary base case for school whiting through the sequential updating of recent data to the stock assessment, using the stock assessment package Stock Synthesis (SS-V3.30).

Changes to the last stock assessment include: separating length frequencies into onboard and port collected components; weighting length frequencies by shots and trips rather than fish measured; and using a new balancing method.

Results show remarkably good fits to the catch rate data, length data and conditional age-at-length data. This assessment estimates that the projected 2018 spawning stock biomass will be 42% of virgin stock biomass (projected assuming 2016 catches in 2017), compared to 50% at the start of 2010 from the last assessment (Day 2009).

14.2 Introduction

14.2.1 *Bridging from 2010 to 2017 assessments*

The previous full quantitative assessment for school whiting was performed in 2009 (Day, 2009) using Stock Synthesis (version SS-V3.03a, Methot, 2009). The 2017 assessment uses the current version of Stock Synthesis (version SS-V3.30.07.01, Methot et. al, 2016), which has many changes from SS_ V3.03a.

As a first step in the process of bridging to a new model, the model was converted from version SS-V3.03a (Methot, 2009) to version SS-V3.24Q (Methot 2015) and then translated to version SS-V3.30.07.01, (Methot et al, 2016), using the data and model structure used in the 2009 assessment. One of the major changes to assessment procedures since 2009 is advances in model balancing, so after transferring to the most recent software, the current model balancing techniques were applied to the old model structure. This was followed by removing the rebalancing, and initially updating historical data (up to 2008). This was followed by including the data from 2009-2016 into the model. This additional data included new catch, discard, CPUE, length frequency, age-at-length data, an updated ageing error matrix and an additional CPUE index (trawl). The last year of recruitment estimation was extended to 2013 (2005 in the 2009 assessment). The use of updated software and the inclusion of additional data resulted in some differences in the fits to CPUE, age and length data. The usual process of bridging to a new model by adding new data piecewise and analysing which components of the data could be attributed to changes in the assessment outcome was conducted with the details outlined below.

14.2.2 *Update to Stock Synthesis SSV-3.30.07.01 and updated catch history*

The 2009 school whiting assessment was initially converted to a more recent version of the software, Stock Synthesis version SS-V3.24Q (base2009_3.24). The translation from version 3.24 to 3.30 is complex and involves many changes to the structure of input data files, so this interim step was used to make it easier to understand any changes to the assessment. The translation to version 3.30 (translated_3.30_3) was successful and this model was then balanced (translated_3.30_4).

The next step (from translated_3.30_3) included updated catch history used in the 2009 assessment, which involved significant revisions to both the state and Commonwealth catch histories to 2008 and replacing the estimated 2009 catch with the actual 2009 catch. These changes in catch history were included after the transition to SS-V3.30. There were negligible changes to the spawning biomass and recruitment time series for any of these additional steps. When these time series are plotted together, there are minimal relative changes in the translation to SS-V3.30 but more considerable changes when the model was balanced using current model balancing techniques (Figure 14.1 and Figure 14.2). However, the fit to the Danish seine CPUE is considerably improved simply by using the current model balancing techniques (Figure 14.3). There are changes to the absolute value of recruitment (Figure 14.4), although the relative changes are less significant (especially excluding the re-balancing step).

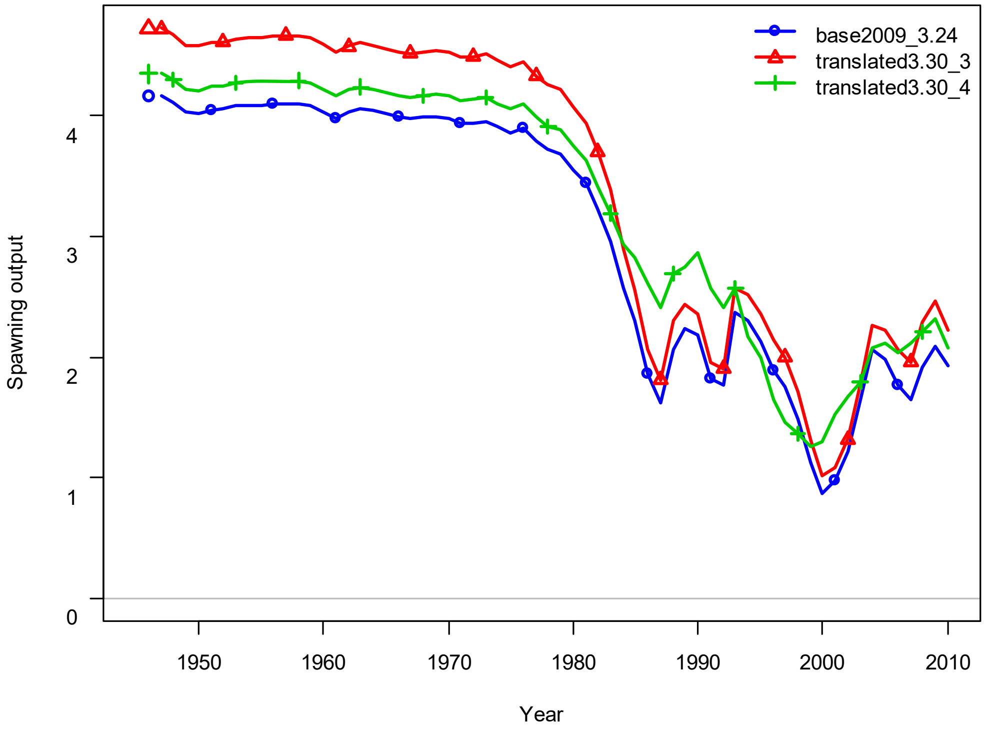


Figure 14.1. Comparison of the absolute spawning biomass time series for the 2010 assessment (base2009_3.24 – in blue), and a model converted to SS-V3.30 (translated3.30_3 in blue) and this same model balanced using the latest balancing procedures (translateed3.30_4 – in green).

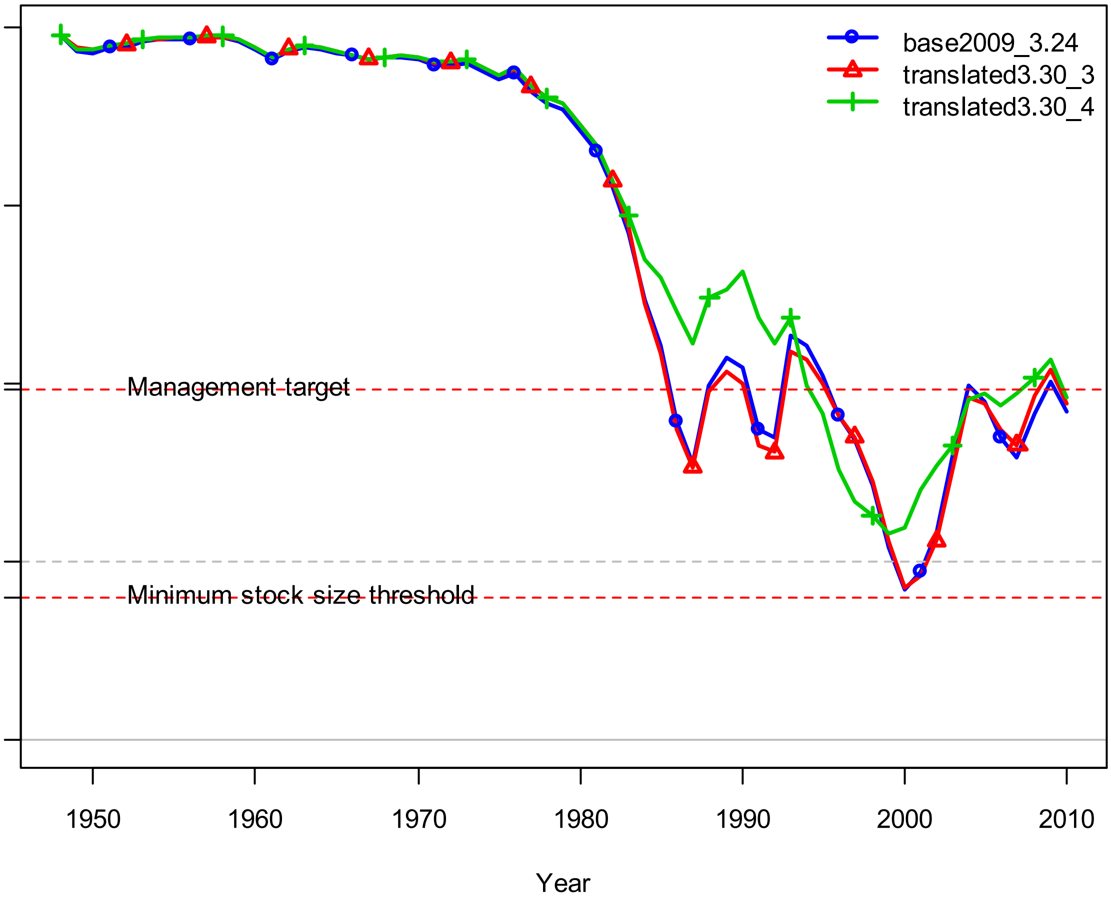


Figure 14.2. Comparison of the relative spawning biomass time series for the 2010 assessment (base2009_3.24 – in blue), and a model converted to SS-V3.30 (translated3.30_3 in blue) and this same model balanced using the latest balancing procedures (translateed3.30_4 – in green).

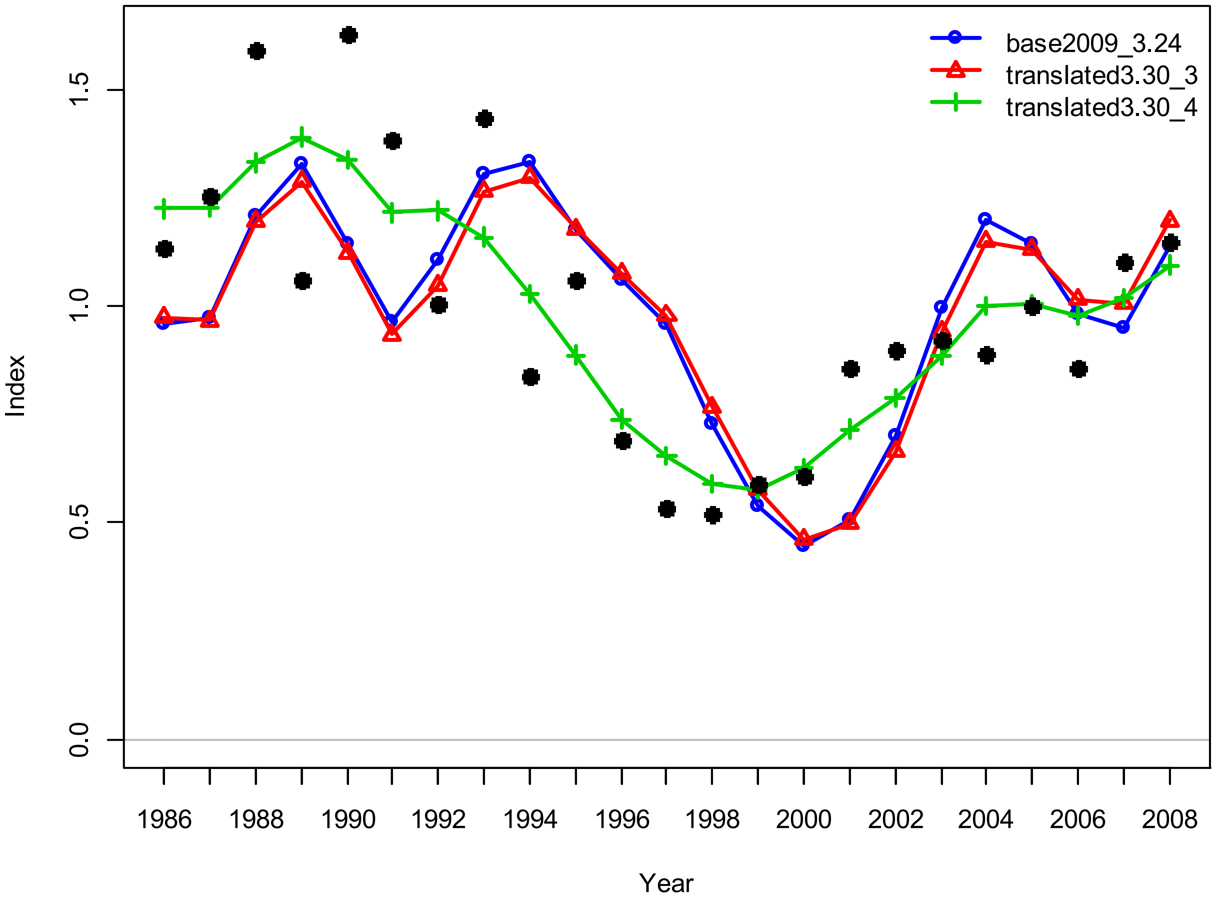


Figure 14.3. Comparison of the fit to the Danish seine CPUE index for the 2010 assessment (base2009_3.24 – in blue), and a model converted to SS-V3.30 (translated3.30_3 in blue) and this same model balanced using the latest balancing procedures (translateed3.30_4 – in green).

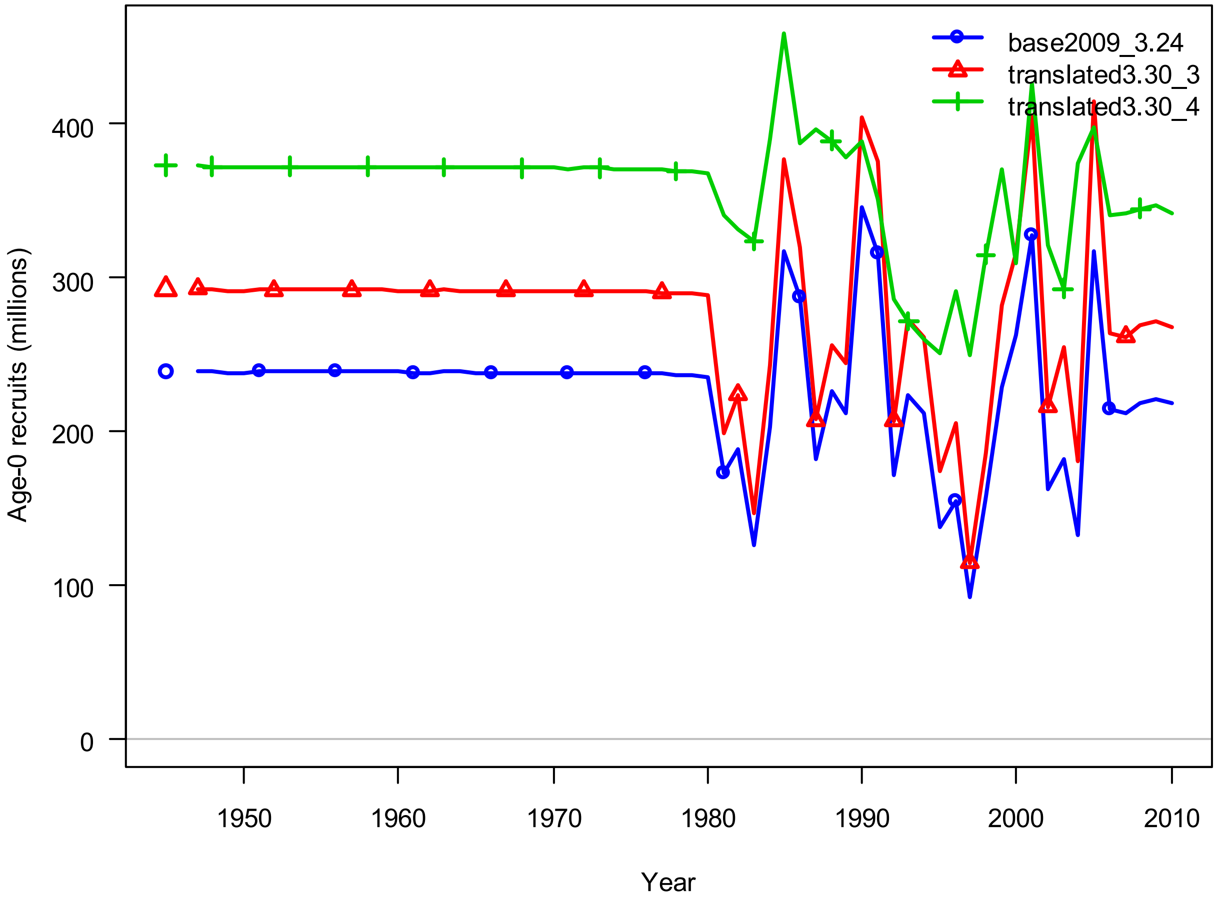


Figure 14.4. Comparison of the recruitment time series for the 2010 assessment (base2009_3.24 – in blue) and a model converted to SS-V3.30 (translateed3.30_3 in blue) and this same model balanced using the latest balancing procedures (translated3.30_4 – in green).

14.2.3 *Inclusion of new data: 2009-2016*

Starting from the converted 2009 base case model with updated data to 2008, additional data from 2009-2016 were added sequentially to develop a preliminary base case for the 2016 assessment:

1. Change final assessment year to 2016, add catch to 2016 (addCatch2016).
2. Add CPUE to 2016 (from Haddon and Sporcic (2016)), including trawl CPUE from 1995 to 2016.
3. Add updated discard fraction estimates to 2016 (addDiscards2016).
4. Add updated length frequency data to 2016 (addLength2016).
5. Add length frequencies for onboard fleets and weighting all length frequencies by number of shots or trips, rather than number of fish (addOnbdLength2016).
6. Add updated age error matrix and age-at-length data to 2016 and change maxiumum age from six to nine years.
7. Change the final year for which recruitments are estimated from 2005 to 2013 (extendRec2013).

8. Rebalance using latest model balancing protocols, including Francis weighting on lengths and ages (baseBalance2017_2).

Inclusion of the new data resulted in a series of changes to the estimates of recruitment and the relative spawning biomass time series (Figure 14.5, Figure 14.6 and Figure 14.7), with perhaps the largest change resulting from the re-balancing of the model.

Since the 2009 assessment, standard changes to the procedures used in the Stock Synthesis assessments in the SESSF include:

1. including both port and onboard length frequency data,
2. weighting length frequency data by shot or trip numbers rather than fish measured,
3. modification to the balancing procedures including use of Francis weighting for length and age data, balancing the CPUE series within Stock Synthesis, and improvements to the recruitment bias ramp adjustment.

These are substantial changes to the balancing procedures used in the 2009 assessment, so it is not surprising that balancing resulted in considerable changes.

Inclusion of eight years of new data resulted in relatively large changes to estimates of recruitment and the spawning biomass time series. With recruitment estimated up until 2015, this resulted in seven out of eight years of new estimated recruitment residuals below average. This has resulted in an estimate of the depletion at the start of 2018 of 42% of unexploited stock biomass, SSB_0.

There are some unresolved issues relating to anomalies in catch databases in the Victorian SEF2/VIT catches. These may result in minor changes to the catch history used in the assessment.

Recent NSW state data (age and length composition data and possibly some catch rate data) has not been made available for quality checking and potential use in this assessment. It would be useful to incorporate such data in this assessment in future.

NSW state catch has been separated north and south of the Barrenjoey line. It will be possible to exclude all NSW state waters catch north of Barrenjoey as a sensitivity to the base case (to be presented by the next RAG meeting), but not as an alternative base case.

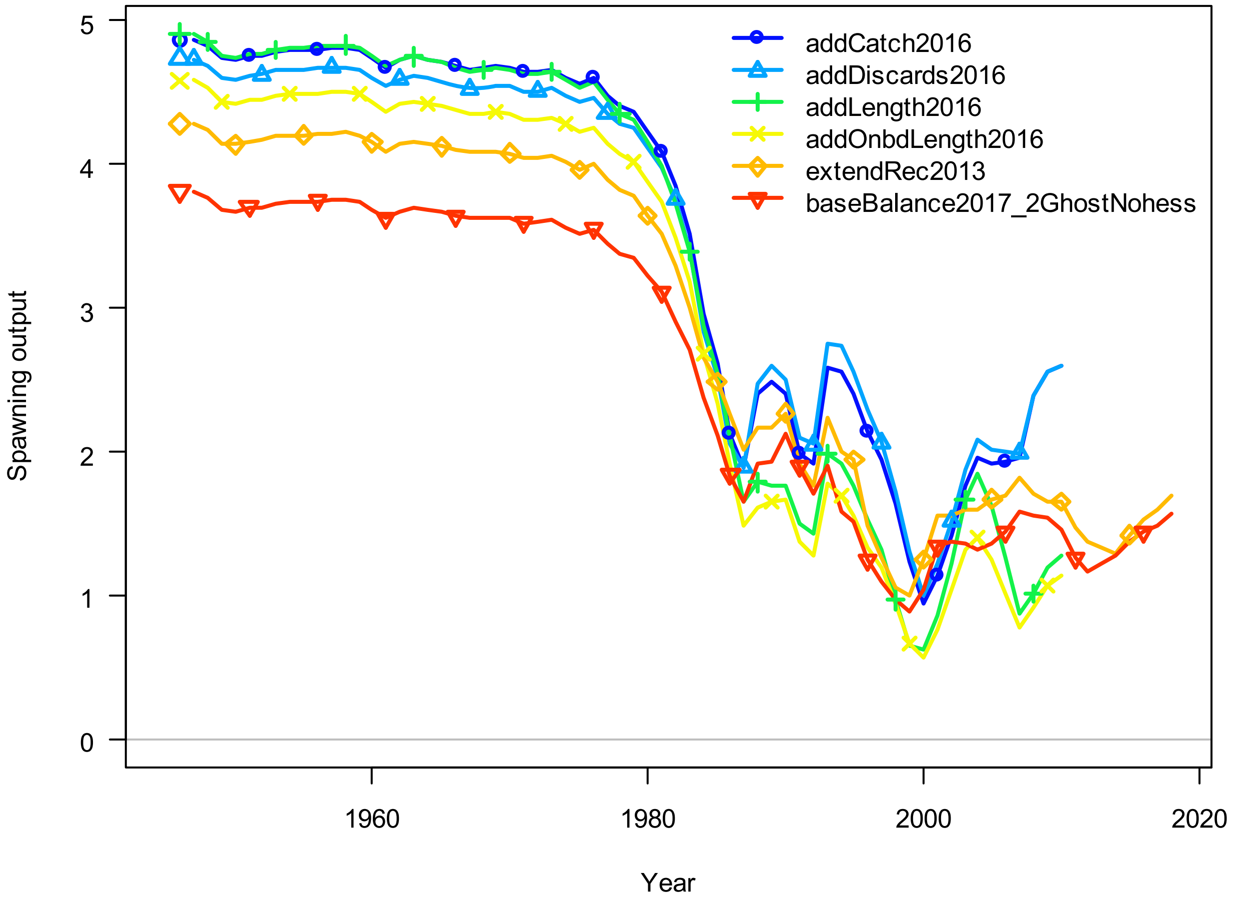


Figure 14.5. Comparison of the absolute spawning biomass time series for the 2010 assessment model converted to SS-V3.30 with various bridging models leading to a proposed 2017 balanced base case model (baseBalance2017_2).

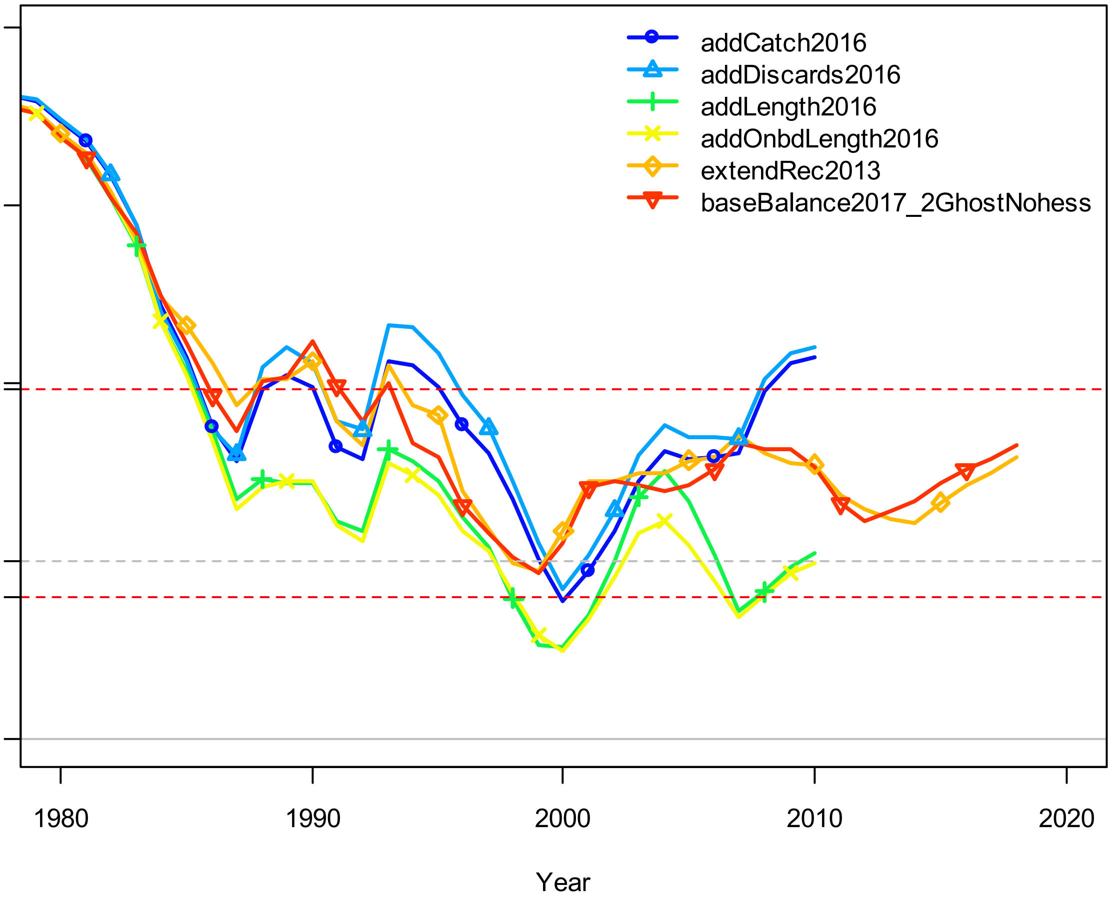


Figure 14.6. Comparison of the relative spawning biomass time series for the 2010 assessment model converted to SS-V3.30 with various bridging models leading to a proposed 2017 balanced base case model (baseBalance2017_2).

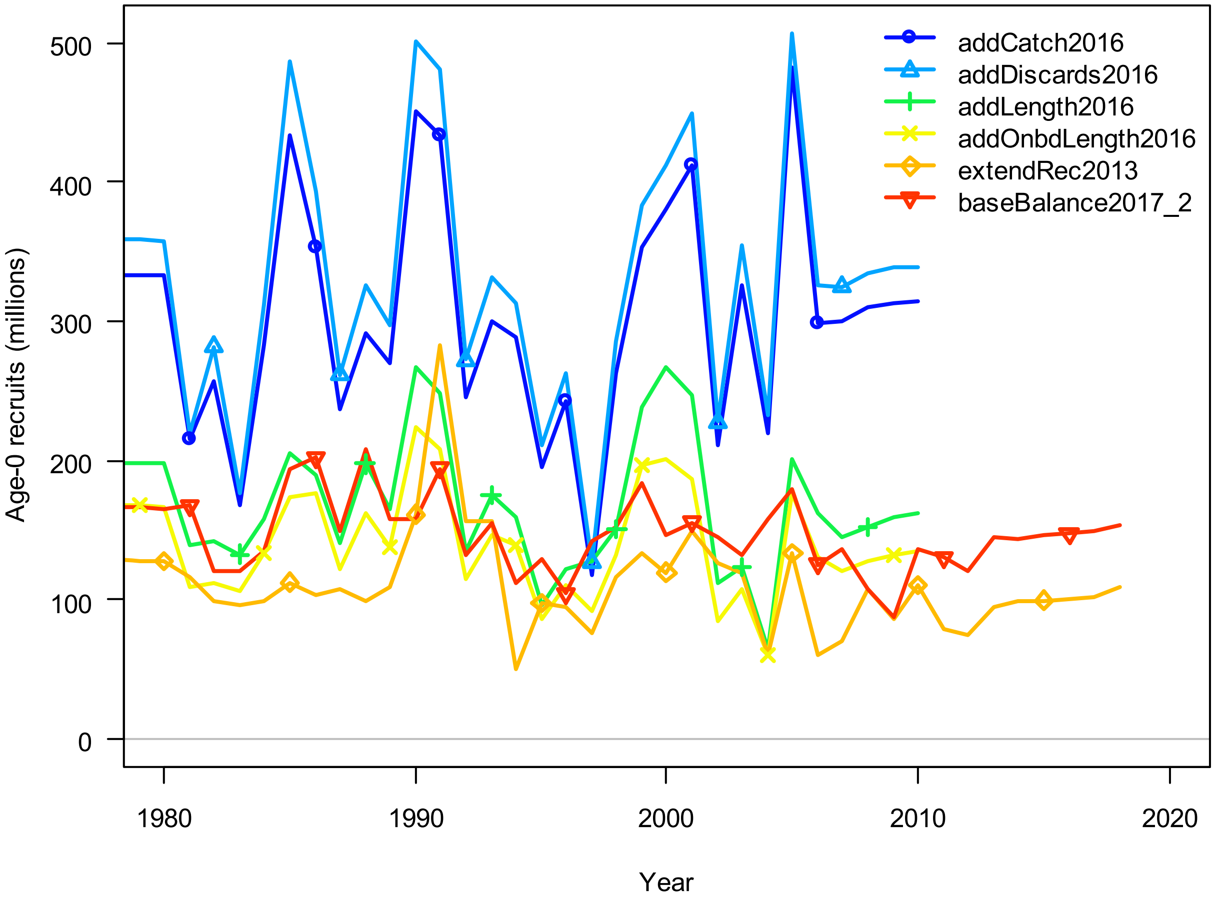


Figure 14.7. Comparison of the recruitment time series for the 2010 assessment model converted to SS-V3.30 with various bridging models leading to a proposed 2017 balanced base case model (baseBalance2017_2).

14.3 Acknowledgements

Age data was provided by Kyne Krusic-Golub (Fish Ageing Services), ISMP and AFMA logbook and CDR data were provided by John Garvey (AFMA). Mike Fuller, Roy Deng and Franzis Althaus (CSIRO) pre-processed the data. Karina Hall (NSW DPI) provided NSW catch data and advice on school whiting fisheries in NSW state waters. Malcolm Haddon provided useful code for auto-balancing, Athol Whitten provided useful R code for organising plots. Geoff Tuck, Malcolm Haddon, Andre Punt, Ian Taylor, Robin Thomson, Miriana Sporcic and Claudio Castillo-Jordán are thanked for helpful discussions on this work.

14.4 References

Day J (2009) School whiting (*Sillago flindsersi*) stock assessment based on data up to 2008. Unpublished report to Shelf RAG. 58 pp.

Haddon M and Sporcic M and (2017). Catch rate standardizations for selected SESSF Species (data to 2016). Unpublished report to SESSF RAG Data Meeting, August 2017, Hobart. 339 pp.

Methot RD (2009) User manual for Stock Synthesis. Model Version 3.03a. NOAA Fisheries Service, Seattle. 143 pp.

Methot RD (2015) User manual for Stock Synthesis. Model Version 3.24s. NOAA Fisheries Service, Seattle. 152 pp.

Methot RD, A'mar T, Wetzel, C and Taylor, I (2016) Stock Synthesis User Manual. Version 3.30 beta. NOAA Fisheries Service, Seattle. 170 pp.

14.5 Appendix A

14.5.1 *Preliminary base case diagnostics*

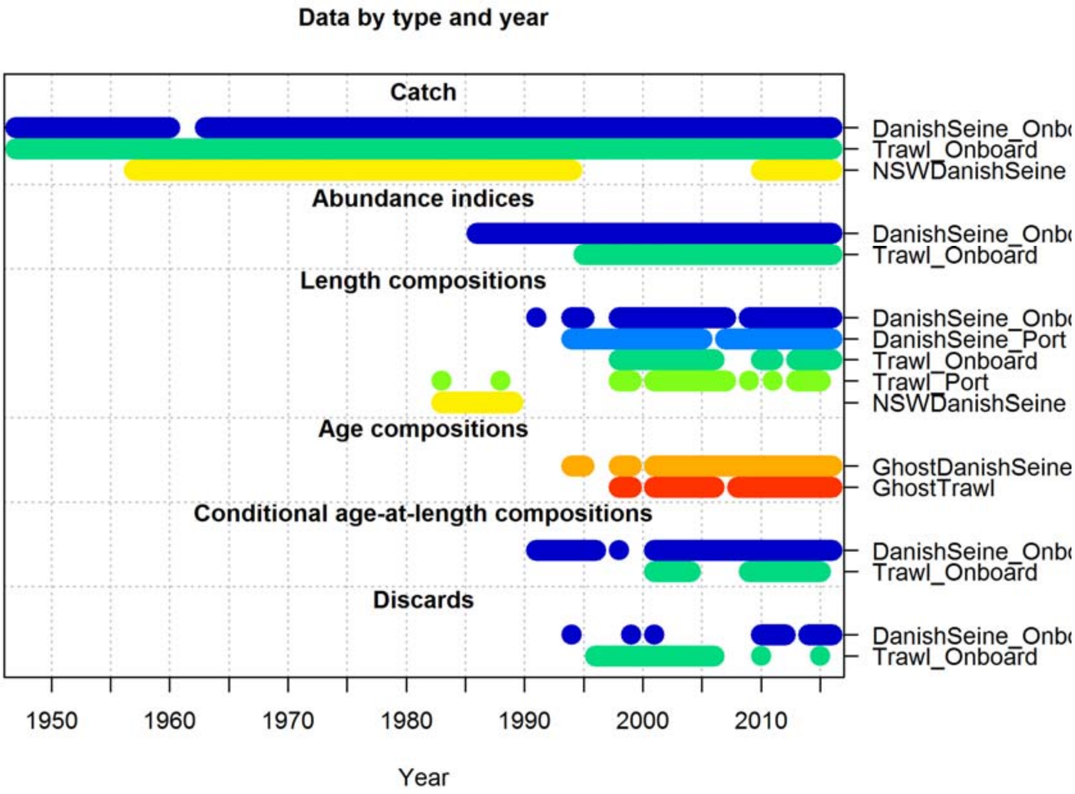


Figure A 14.1. Summary of data sources for school whiting stock assessment.

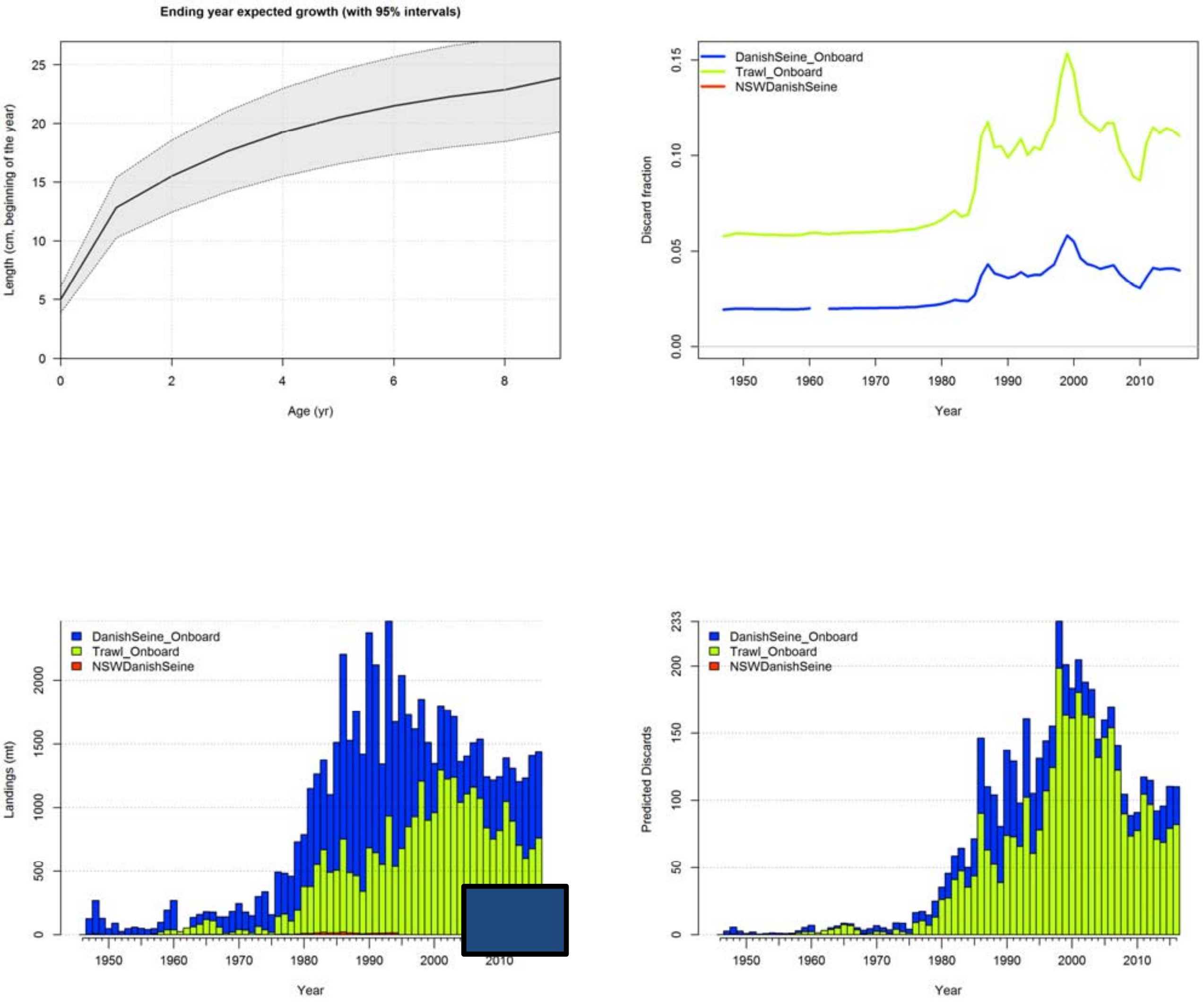

[redacted]

Figure A 14.2. Growth, discard fraction estimates, landings by fleet and predicted discards by fleet for school whiting.

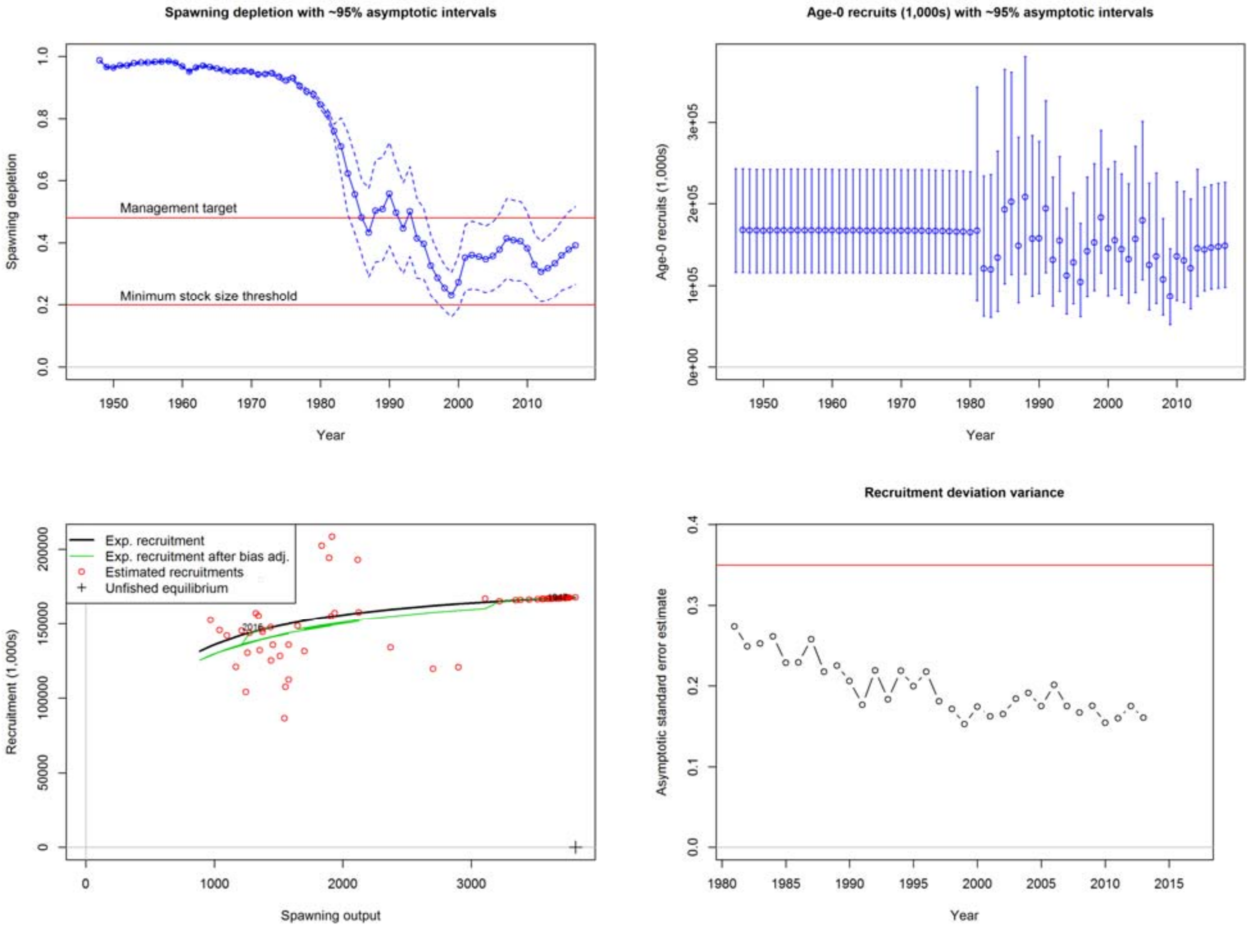
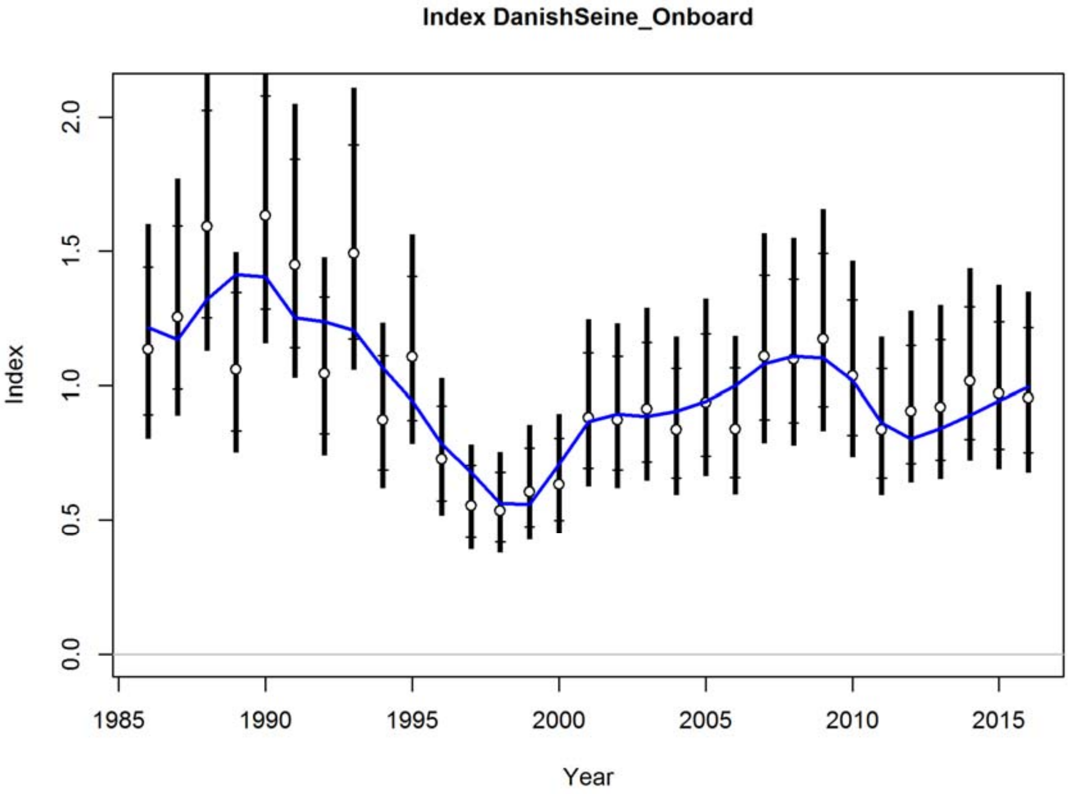


Figure A 14.3. Time series showing depletion of spawning biomass with confidence intervals, recruitment estimates with confidence intervals, stock recruitment curve and recruitment deviation variance check for school whiting.



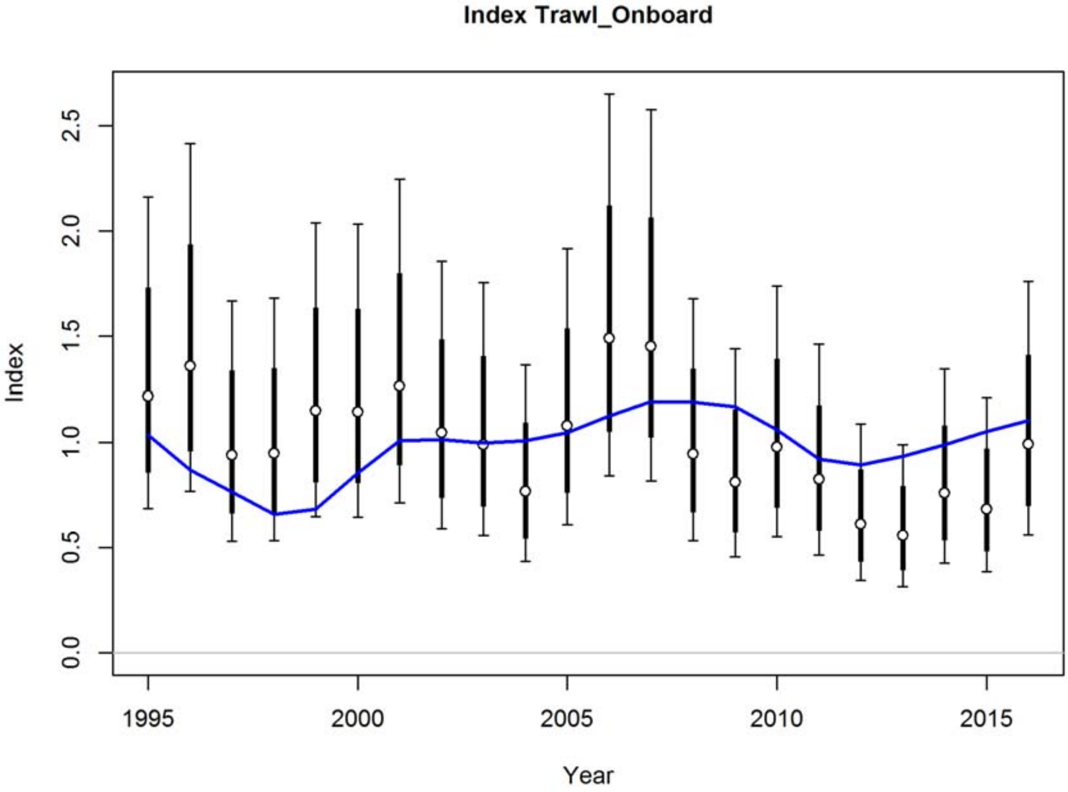


Figure A 14.4. Fits to CPUE by fleet for school whiting: Danish seine and trawl.

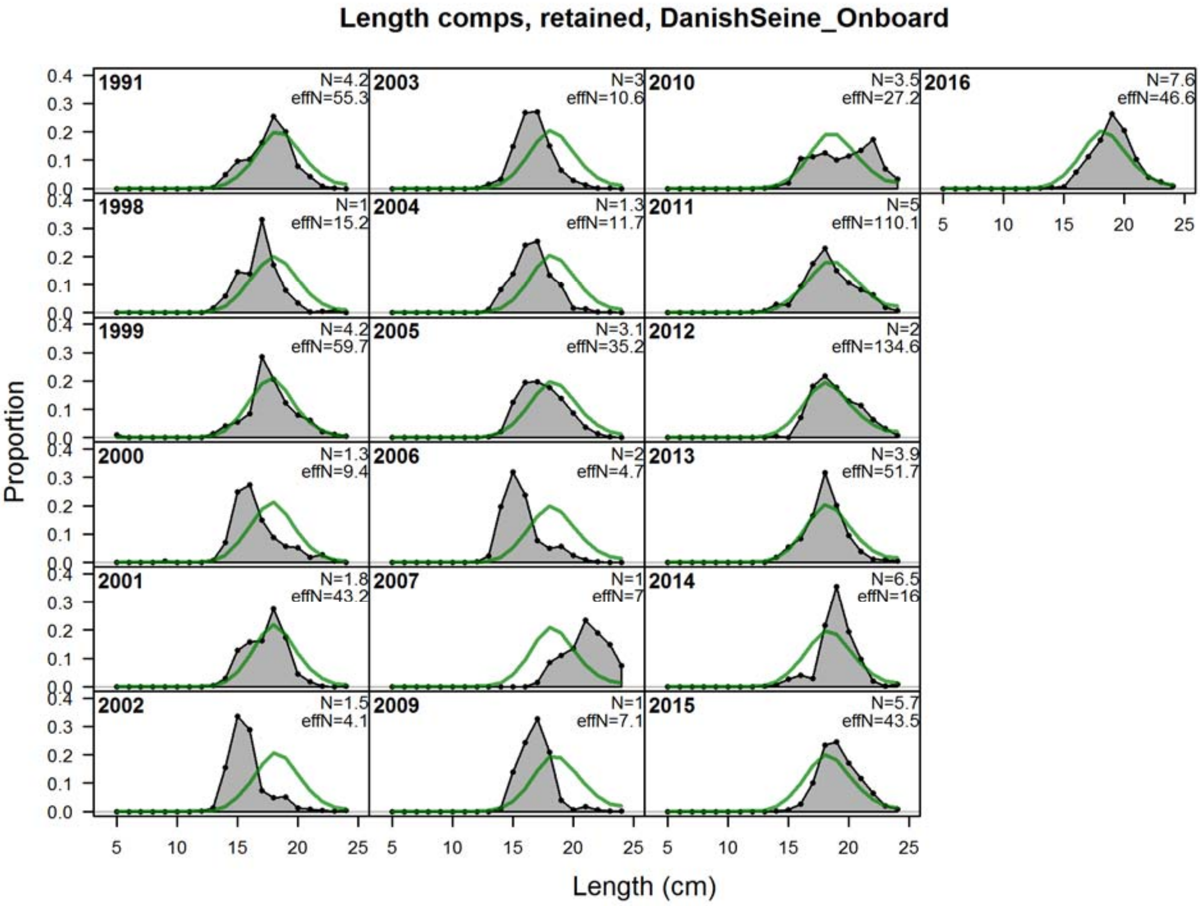


Figure A 14.5. School whiting length composition fits: Danish seine onboard retained.

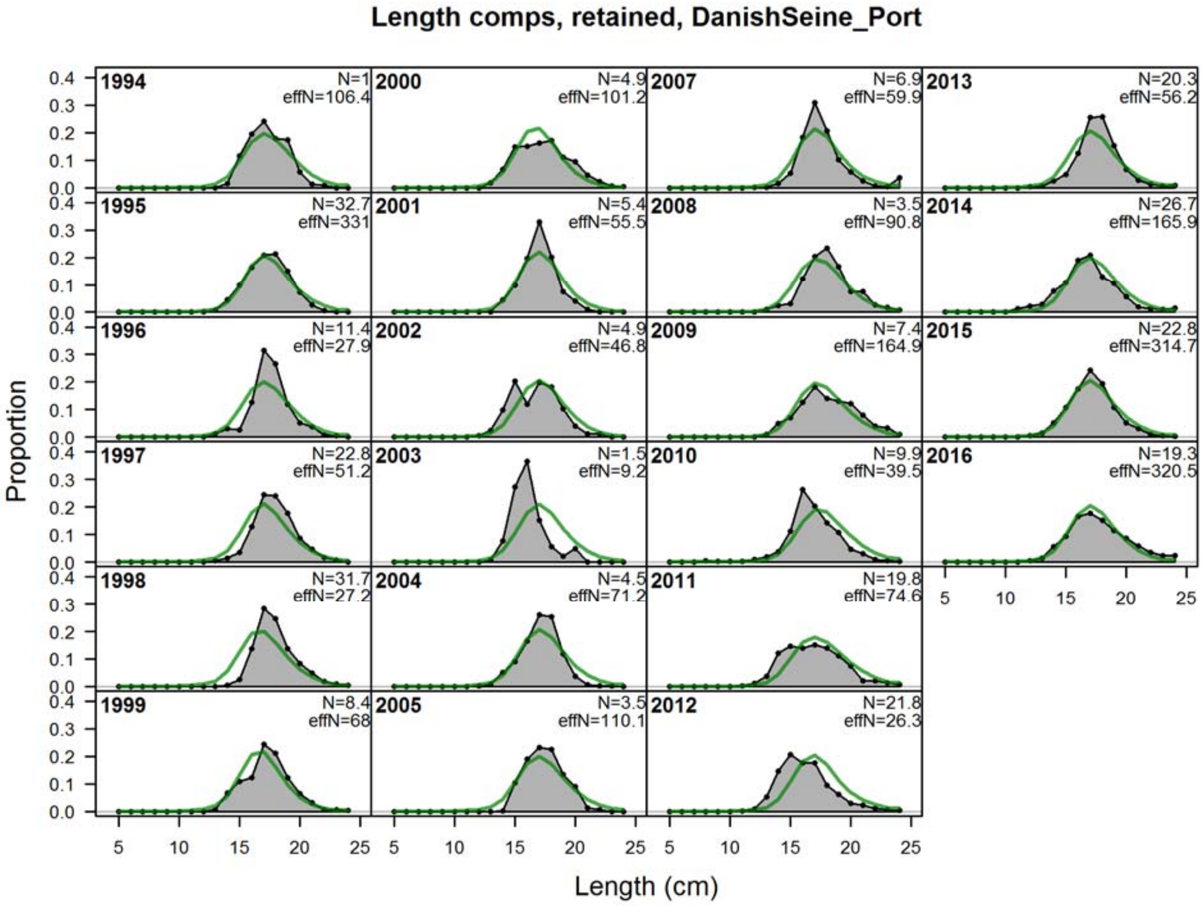


Figure A 14.6. School whiting length composition fits: Danish seine port retained.

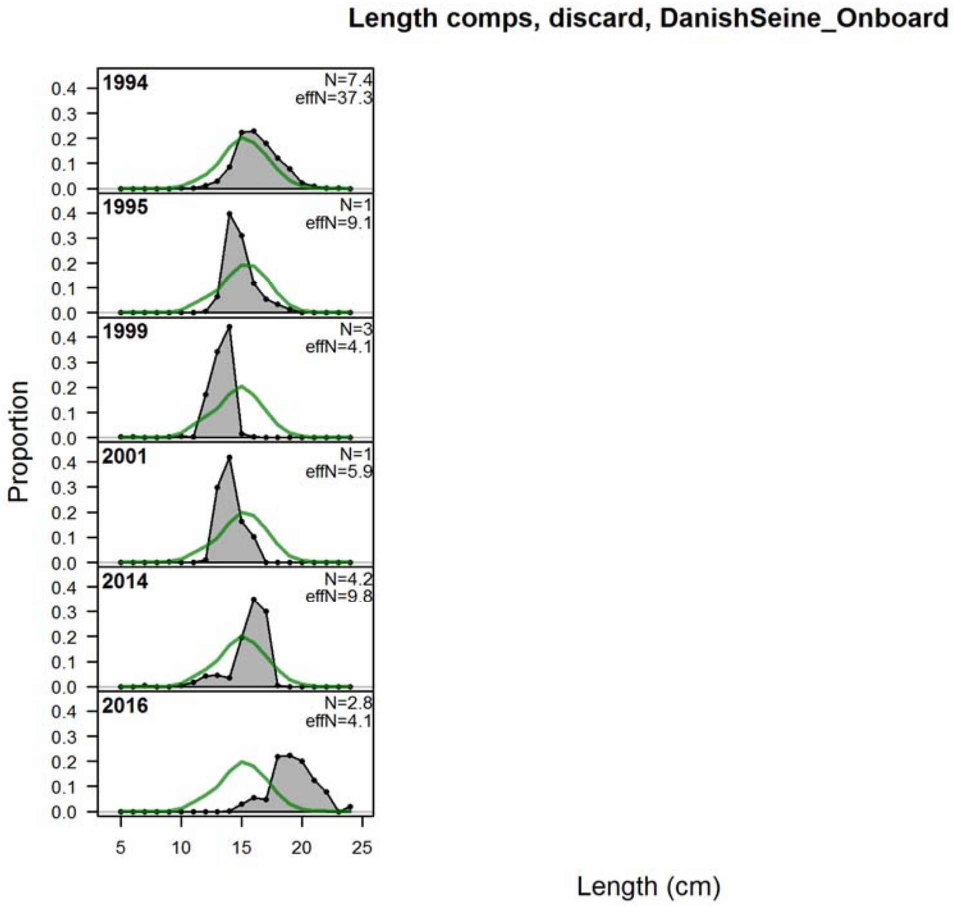


Figure A 14.7. School whiting length composition fits: Danish seine discarded.

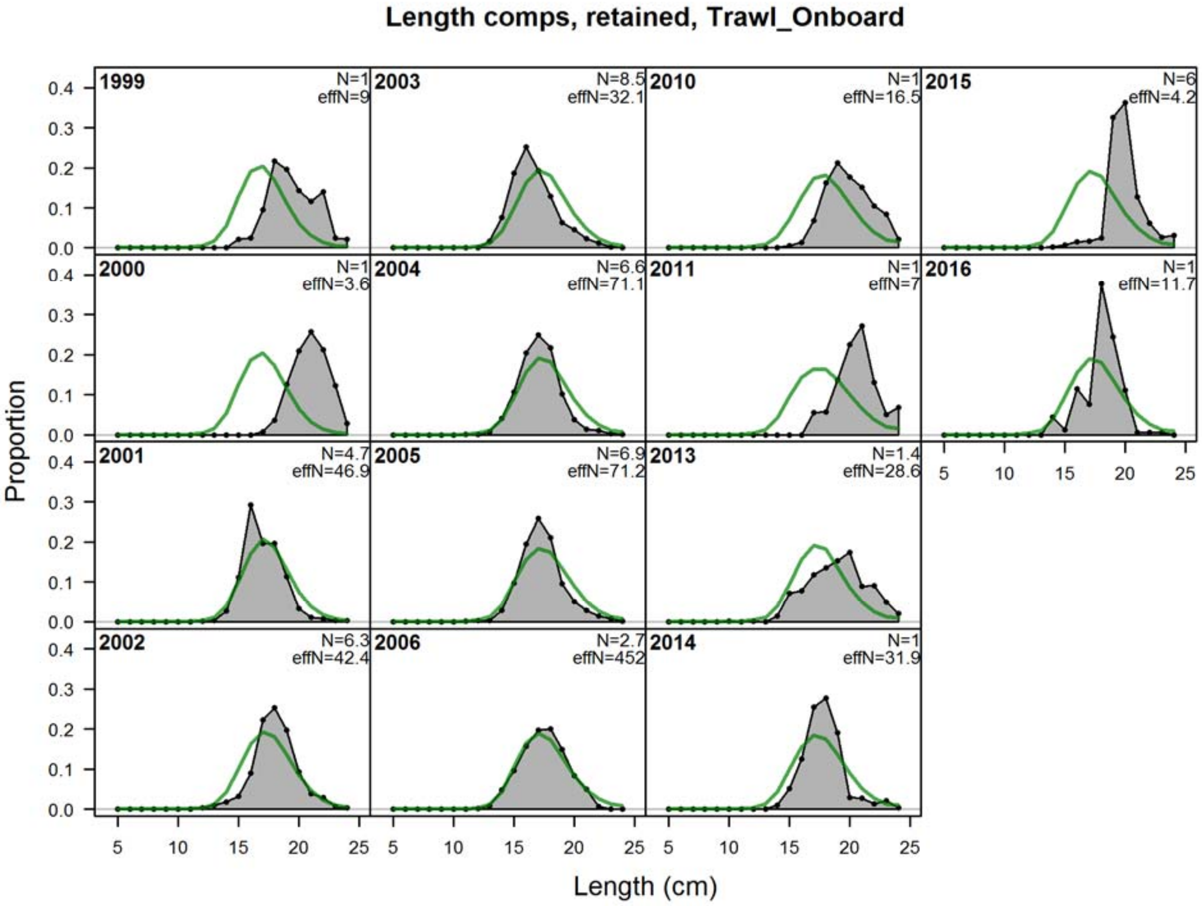


Figure A 14.8. School whiting length composition fits: trawl onboard retained.

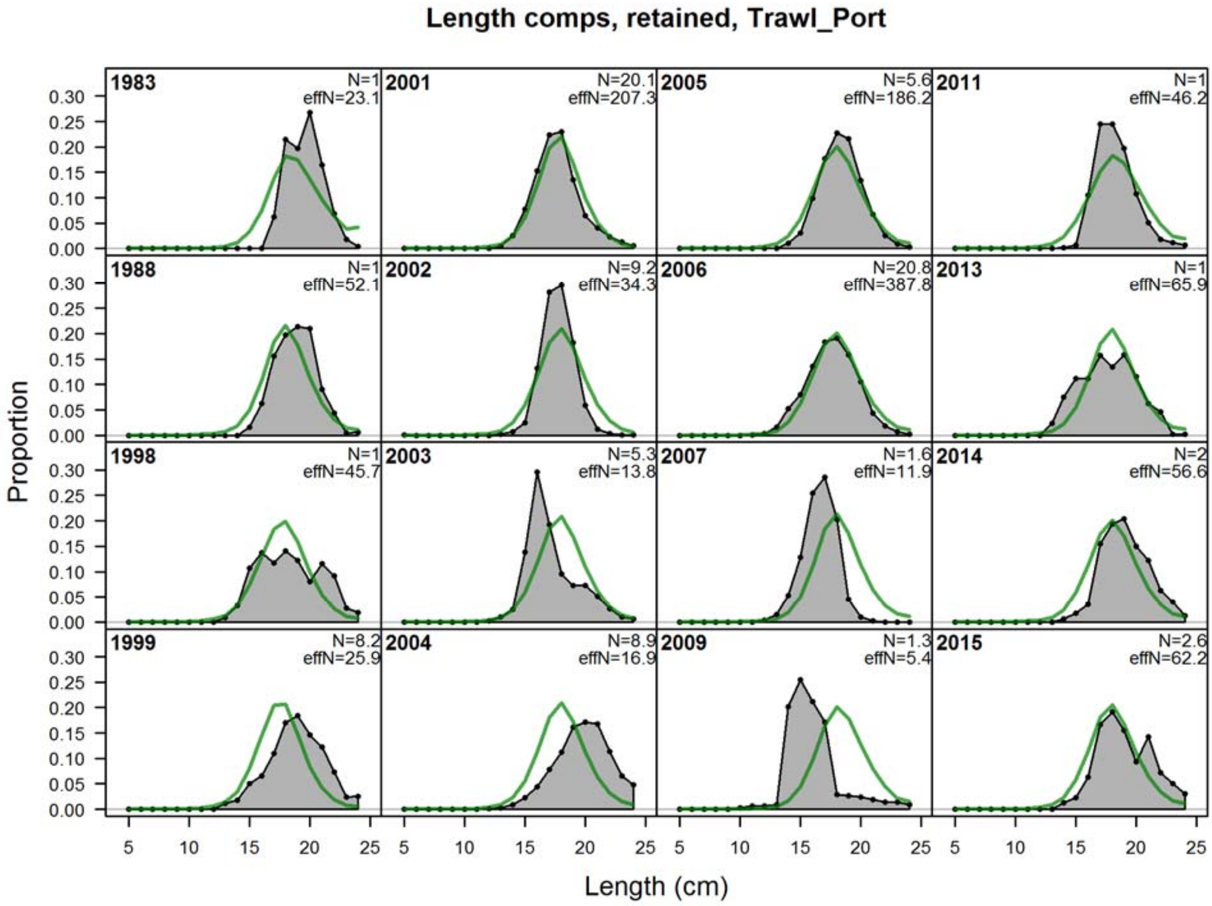


Figure A 14.9. School whiting length composition fits: trawl port retained.

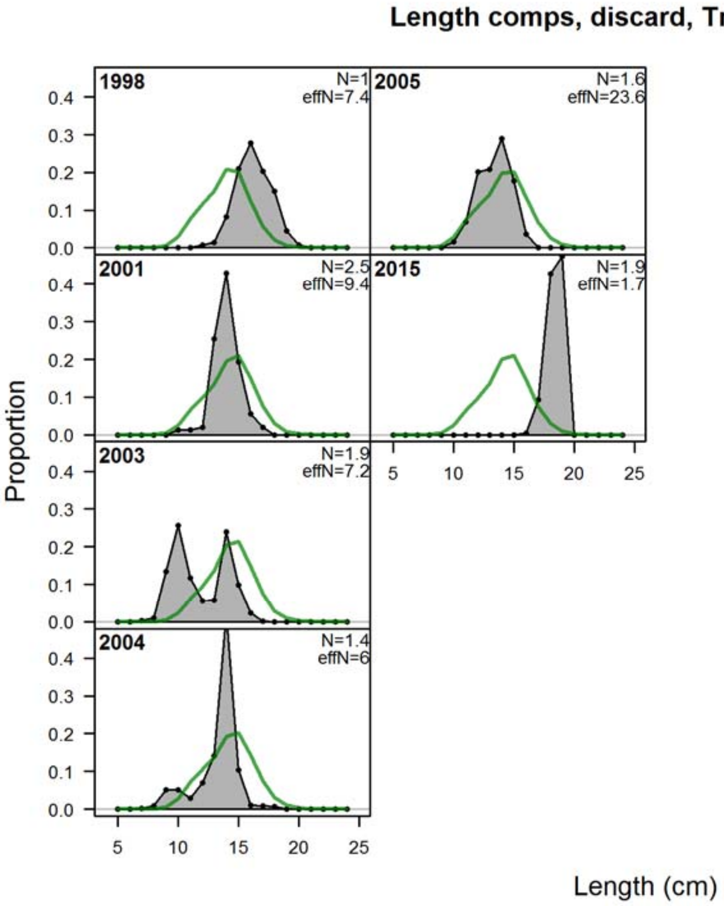


Figure A 14.10. School whiting length composition fits: trawl discarded.

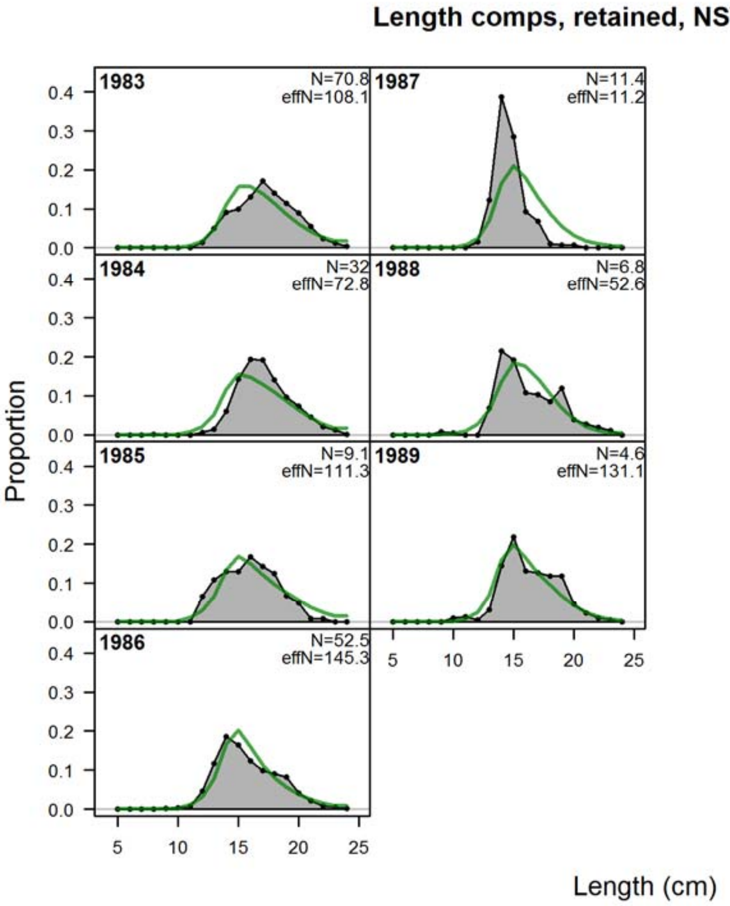


Figure A 14.11. School whiting length composition fits: NSW Danish seine retained.

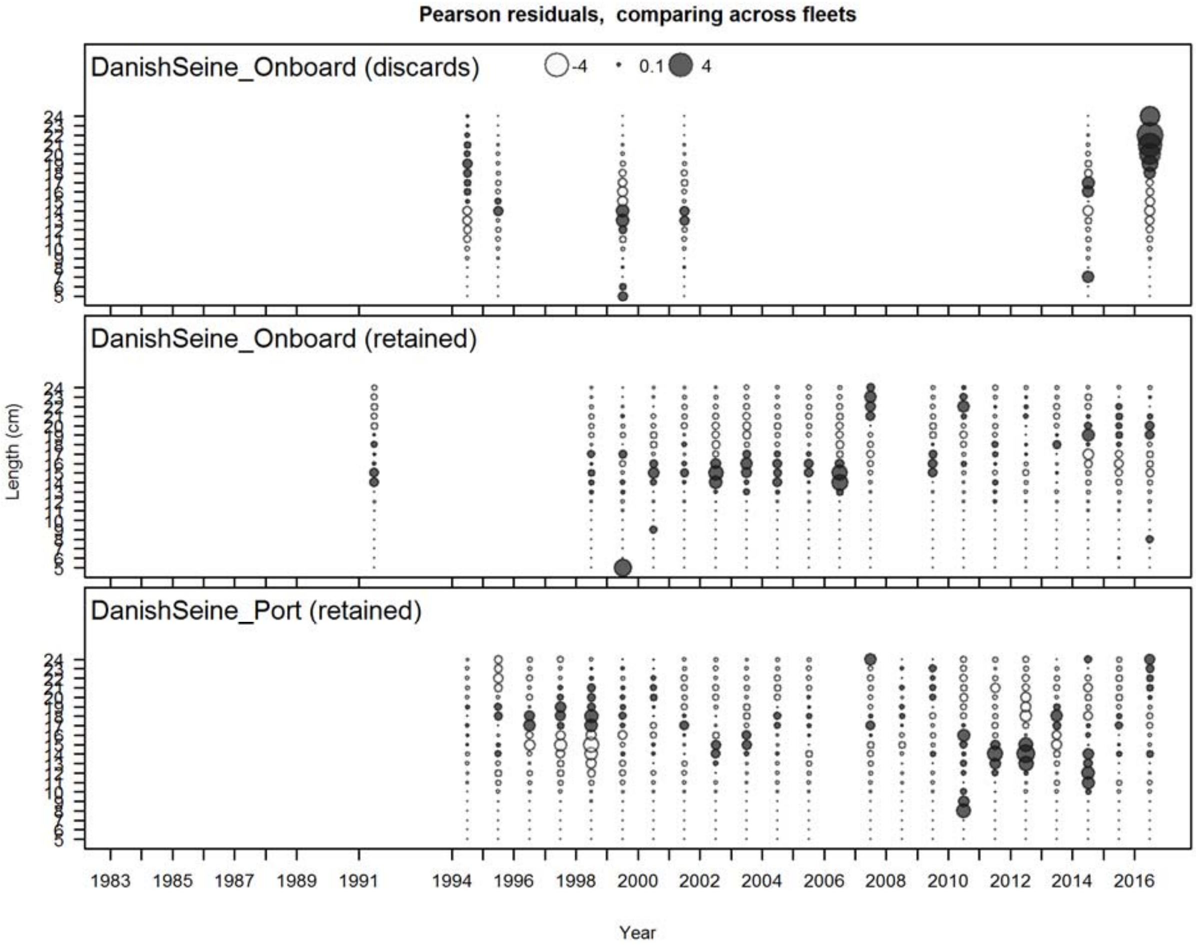


Figure A 14.12. Residuals from the annual length compositions (retained) for school whiting displayed by year for Danish seine fleets.

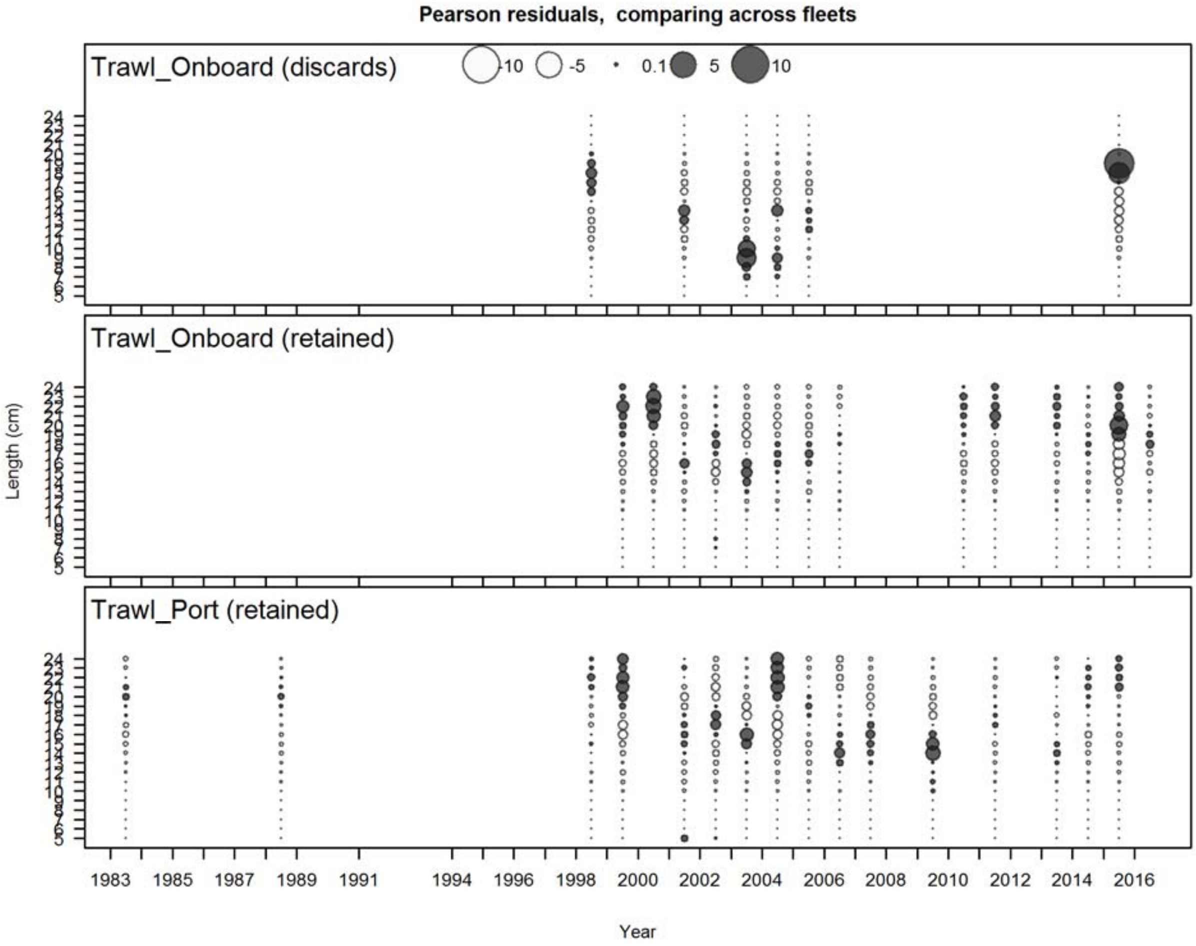


Figure A 14.13. Residuals from the annual length compositions (retained) for school whiting displayed by year for the trawl fleets.

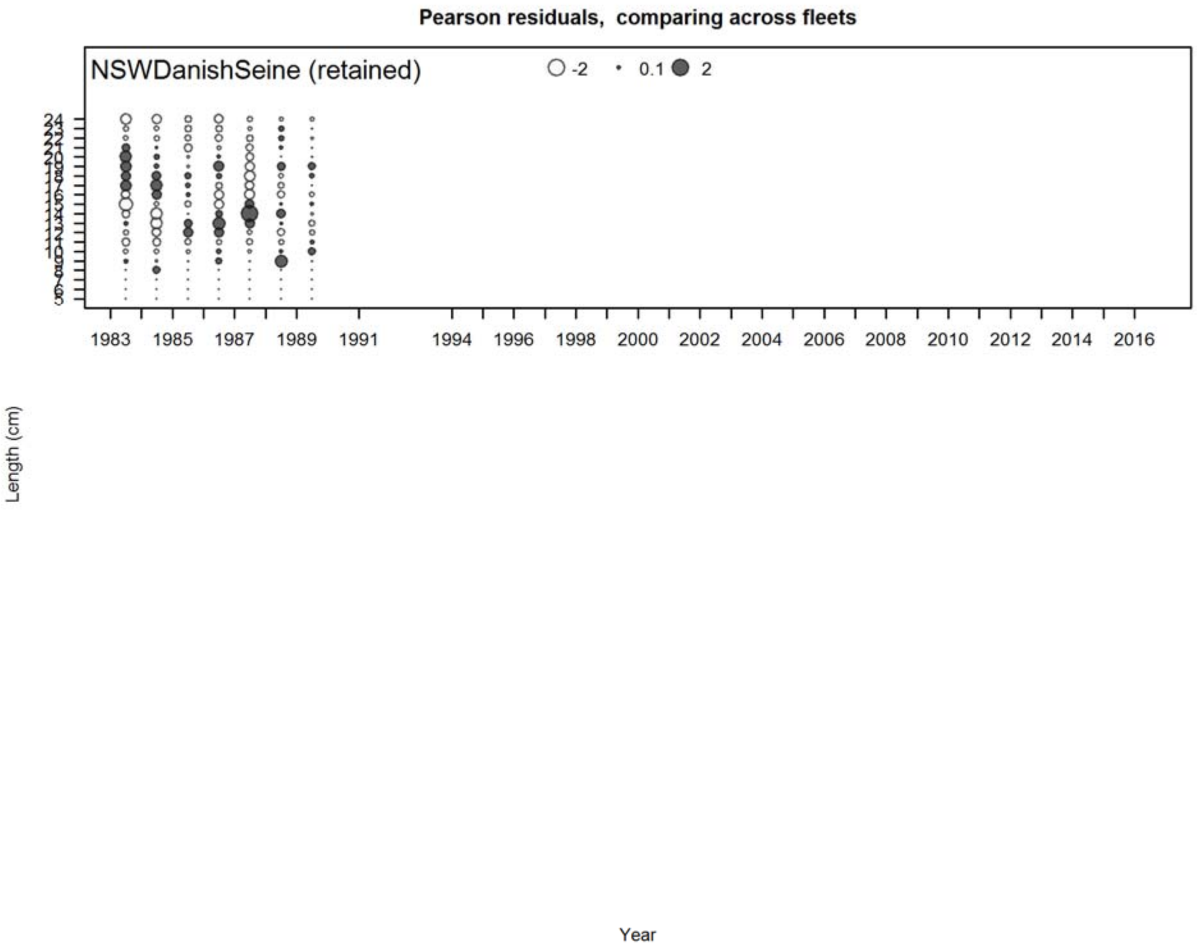


Figure A 14.14. Residuals from the annual length compositions (retained) for school whiting displayed by year for the NSW Danish seine fleet.

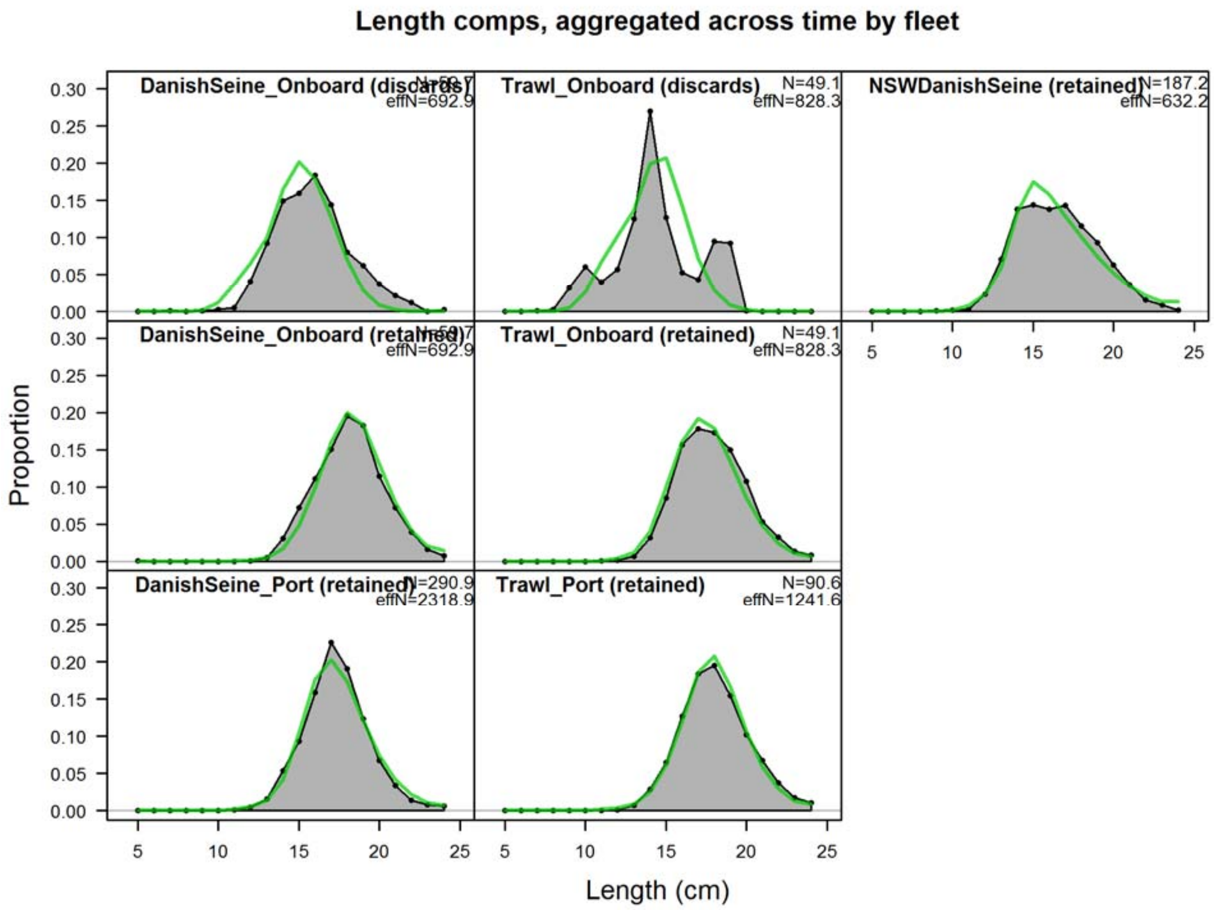


Figure A 14.15. Aggregated fits (over all years) to the length compositions for school whiting displayed by fleet.

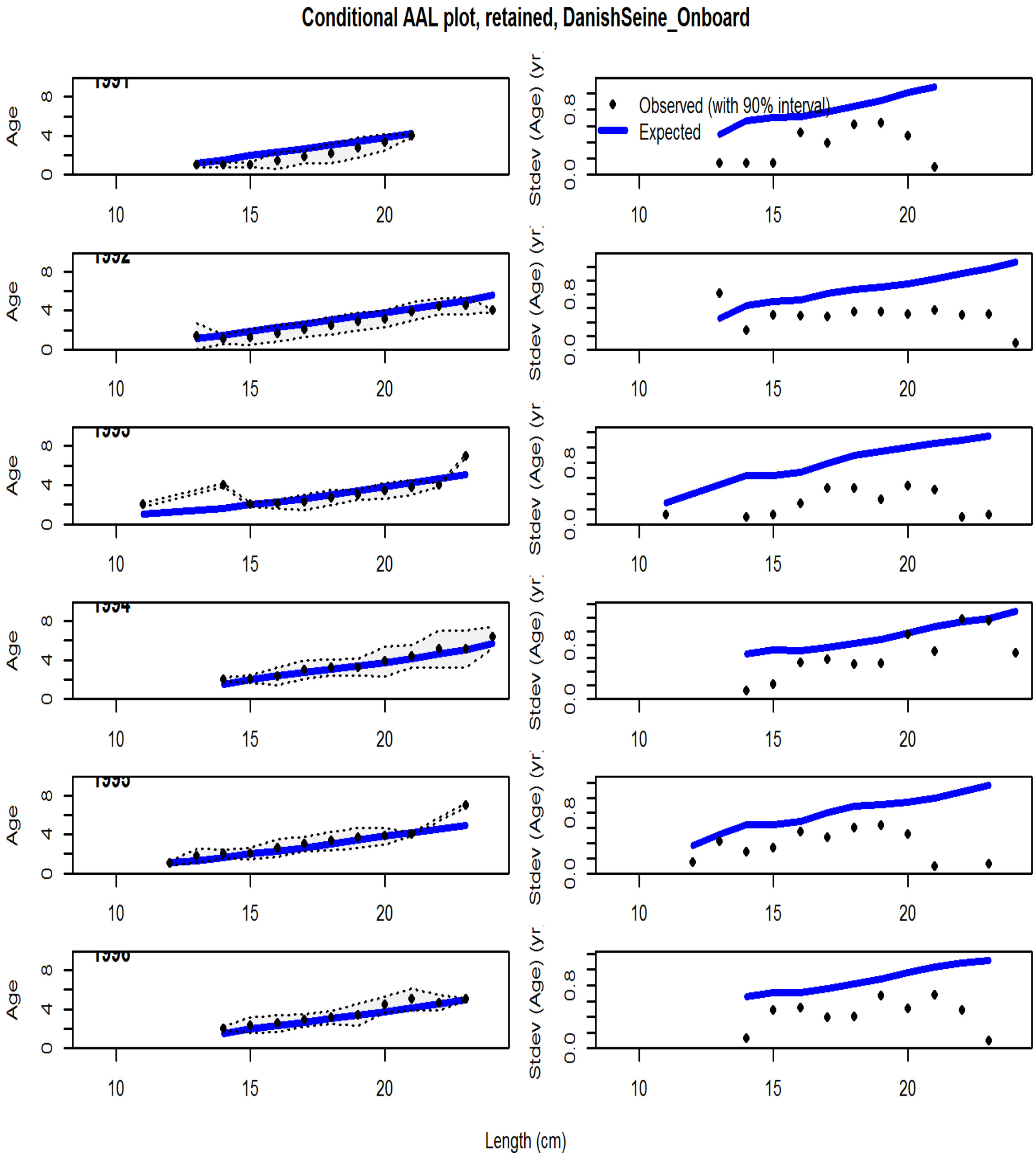


Figure A 14.16. School whiting conditional age-at-length fits: Danish seine part 1.

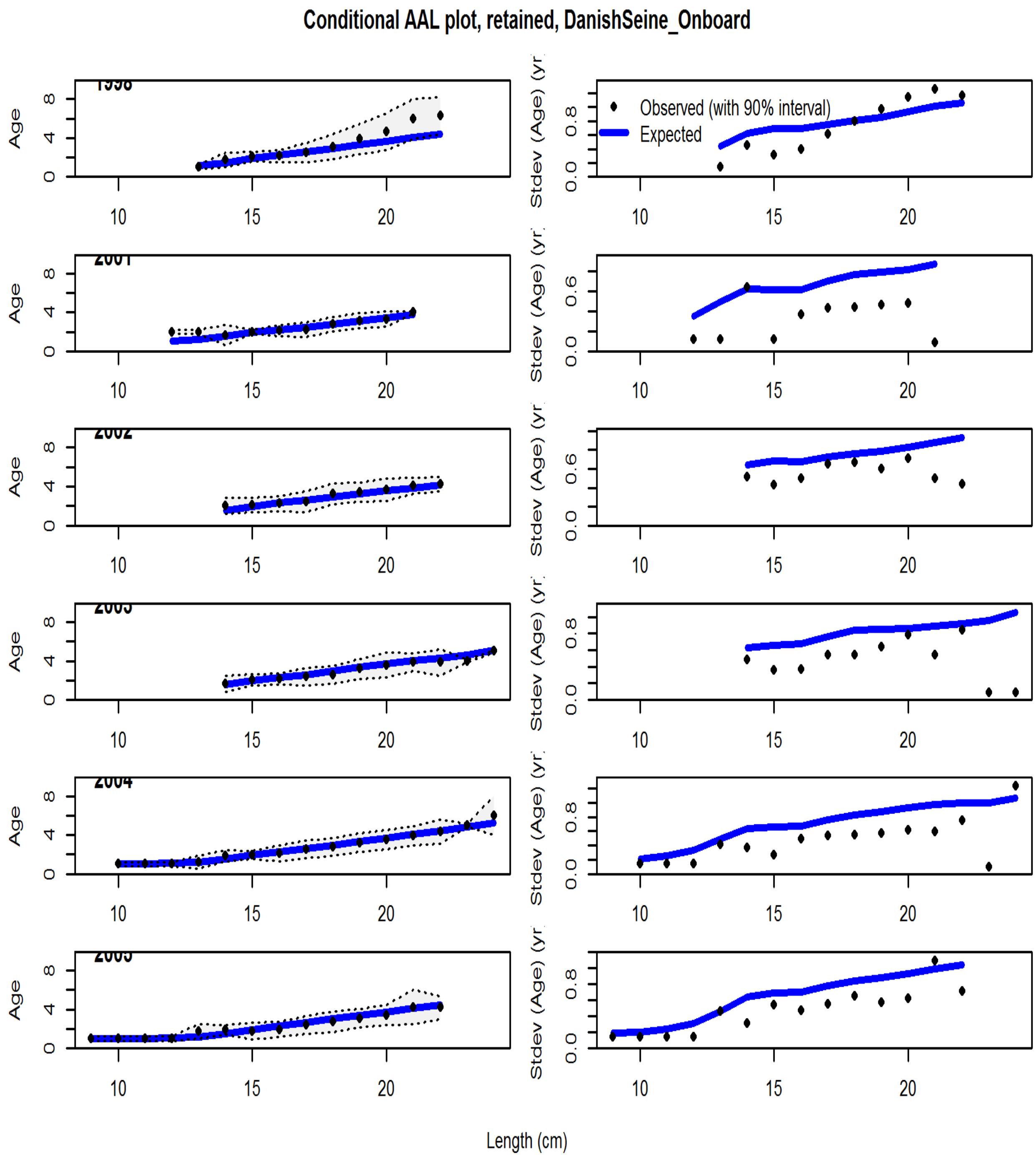


Figure A 14.17. School whiting conditional age-at-length fits: Danish seine part 2.

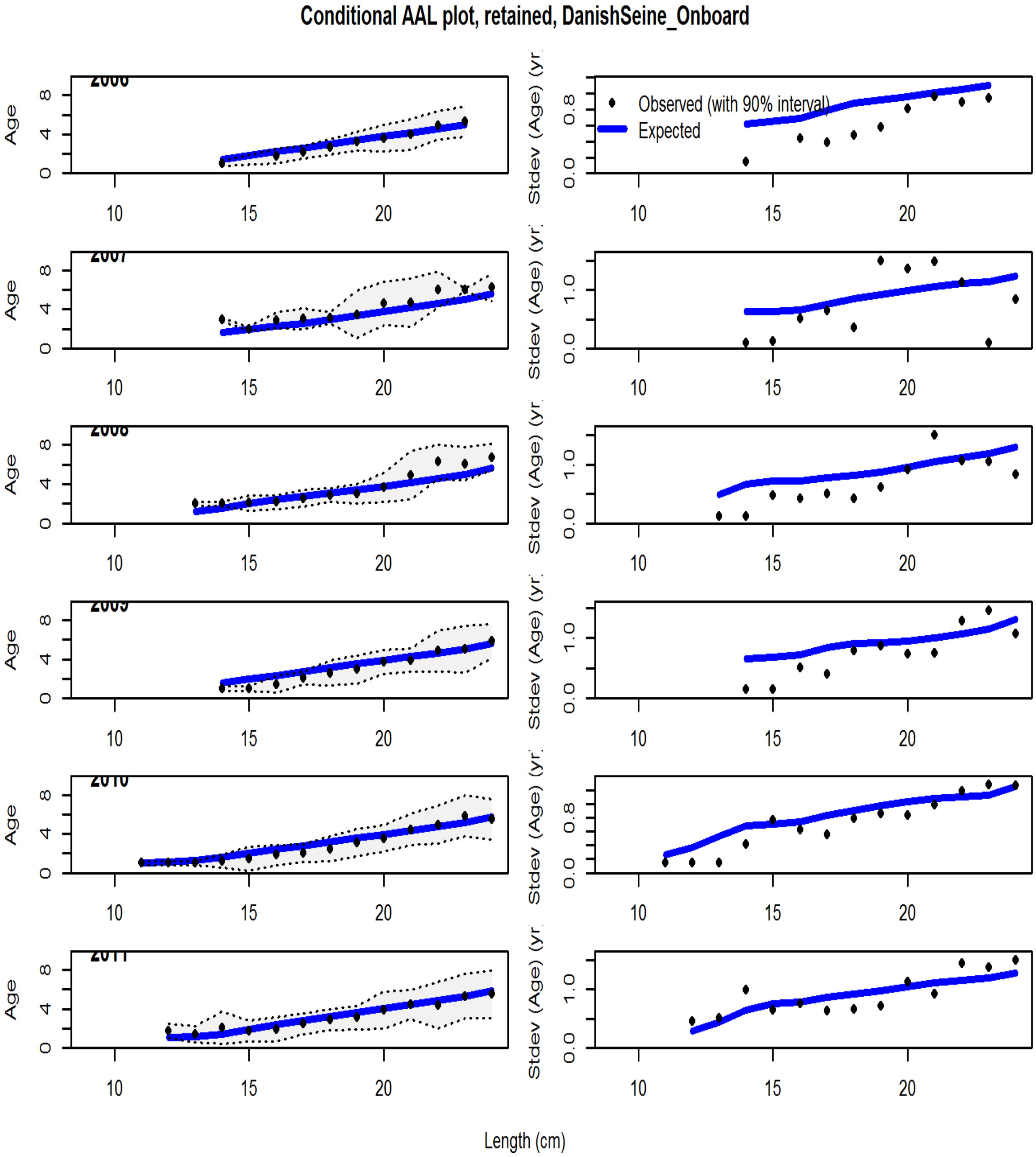


Figure A 14.18. School whiting conditional age-at-length fits: Danish seine part 3.

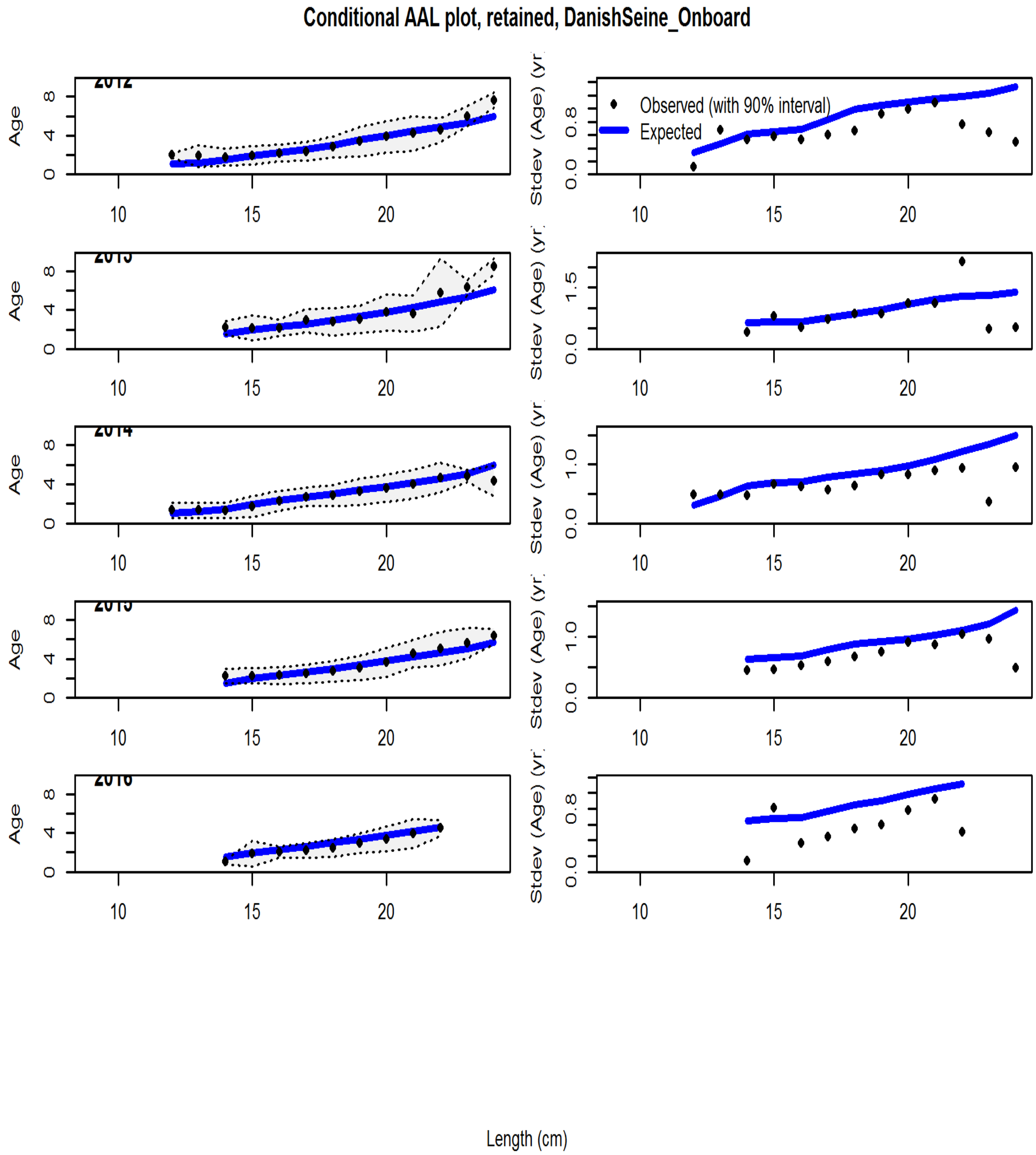


Figure A 14.19. School whiting conditional age-at-length fits: Danish seine part 4.

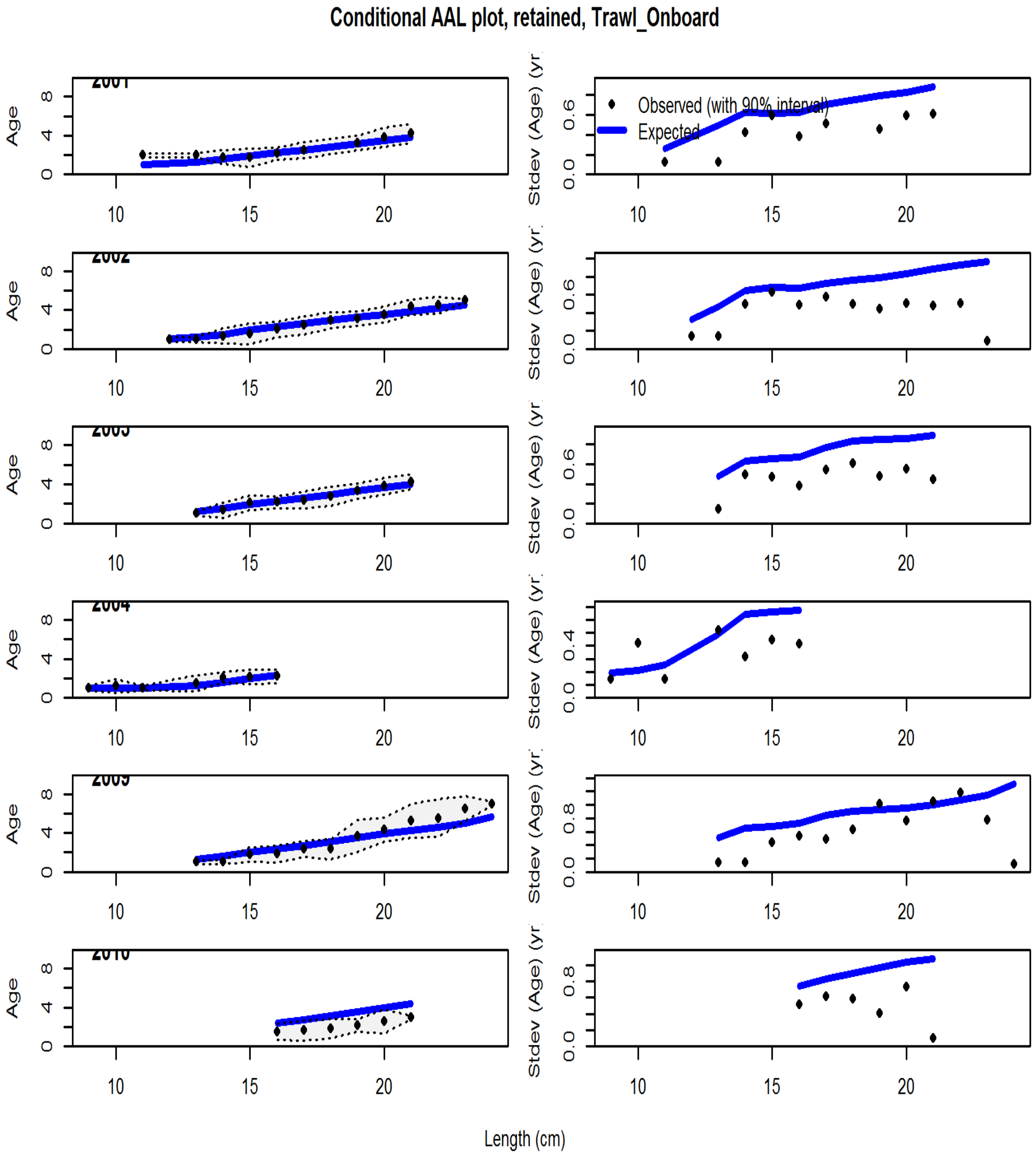


Figure A 14.20. School whiting conditional age-at-length fits: trawl part 1.

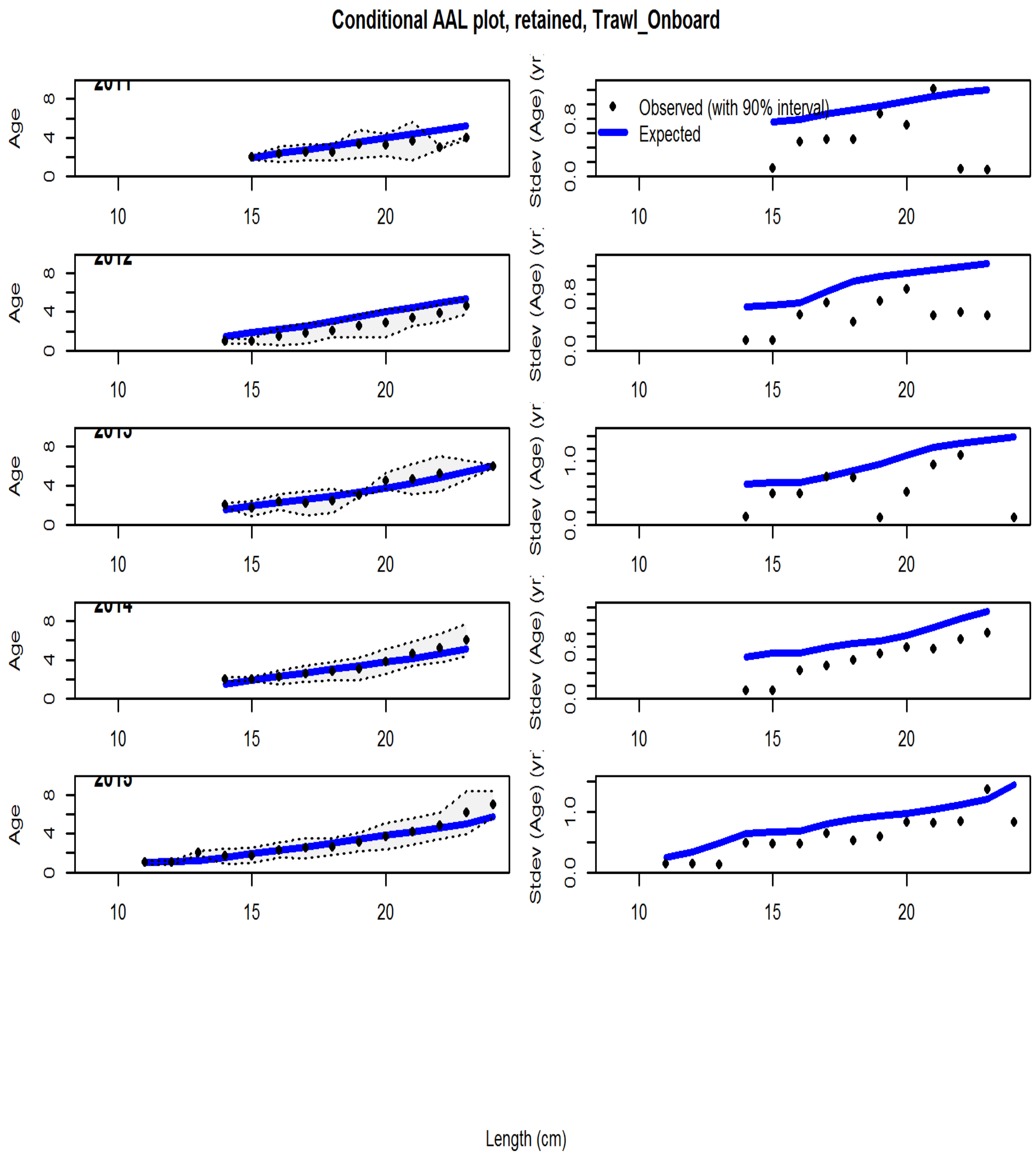


Figure A 14.21. School whiting conditional age-at-length fits: trawl part 2.

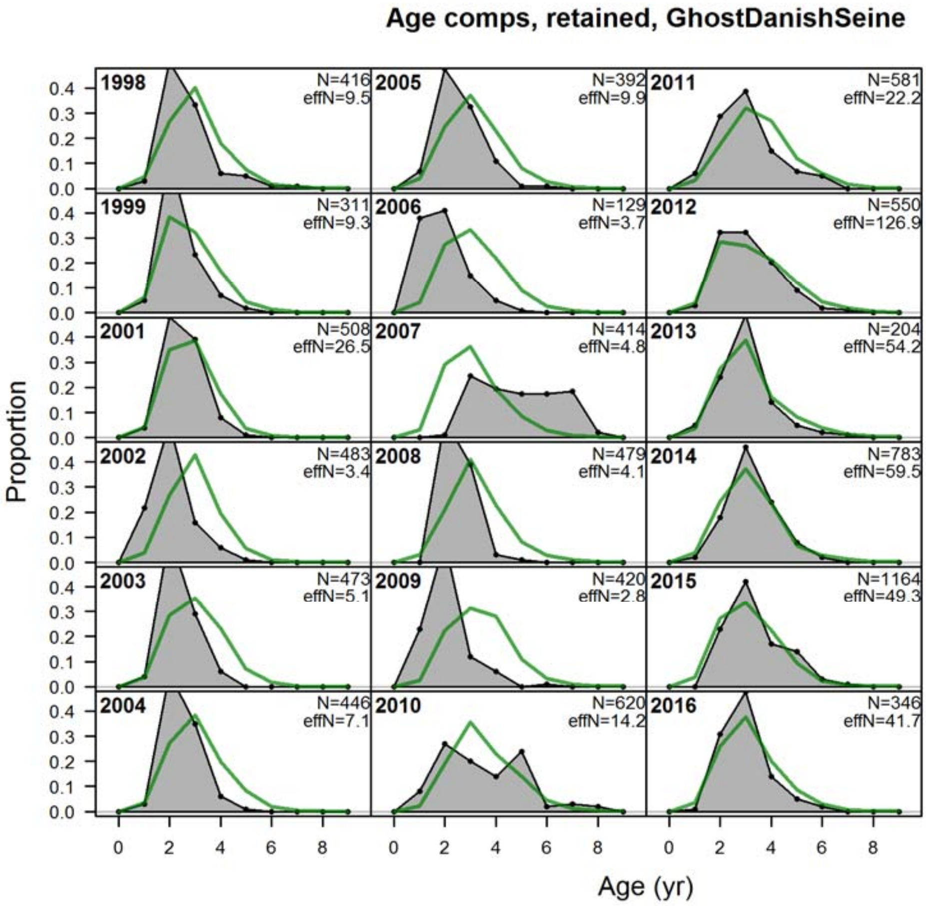


Figure A 14.22. School whiting implied fits to age: Danish seine retained.

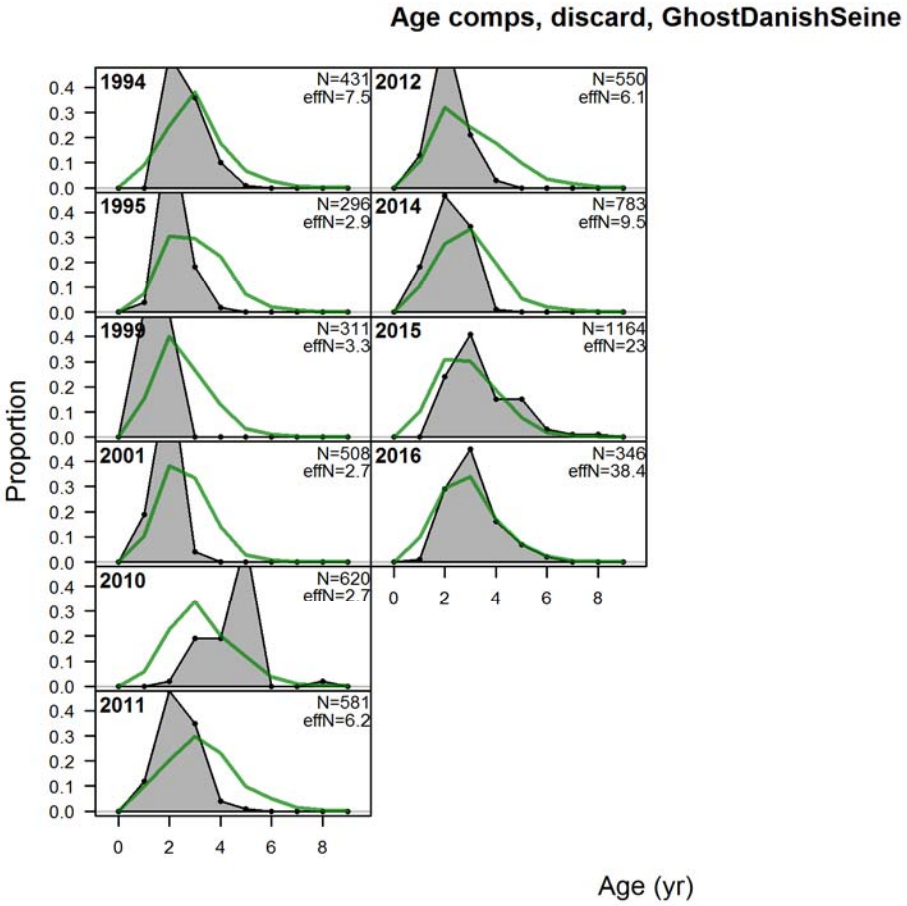


Figure A 14.23. School whiting implied fits to age: Danish seine discarded.

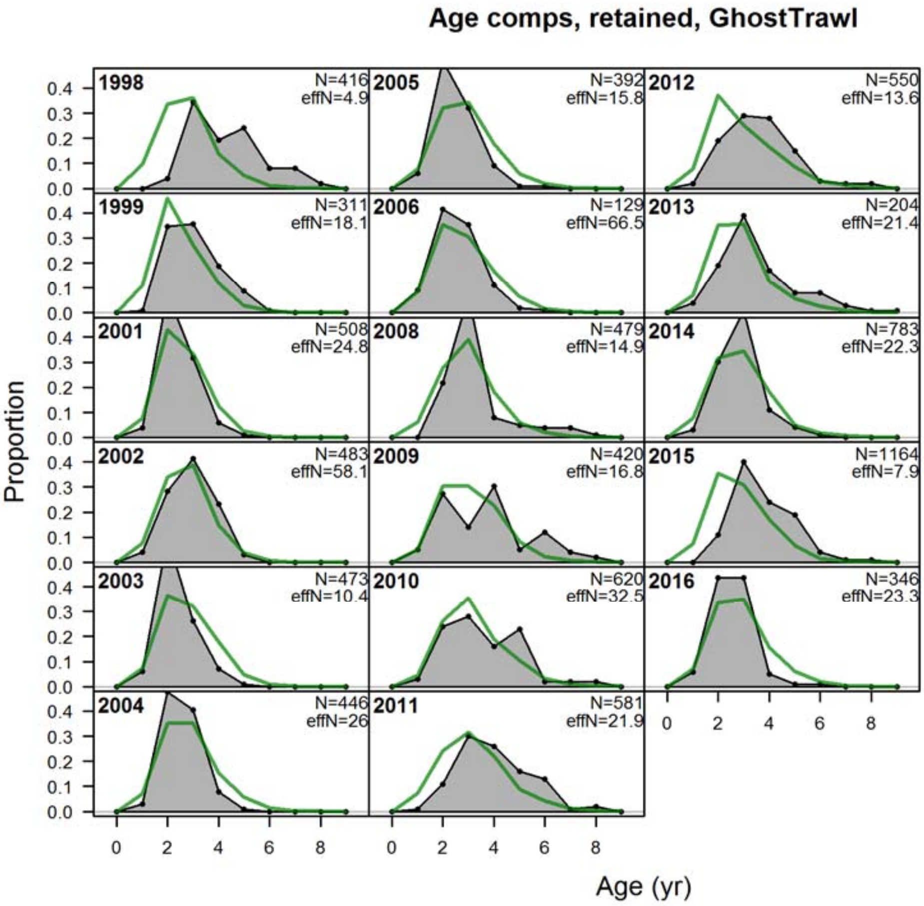


Figure A 14.24. School whiting implied fits to age: trawl retained.

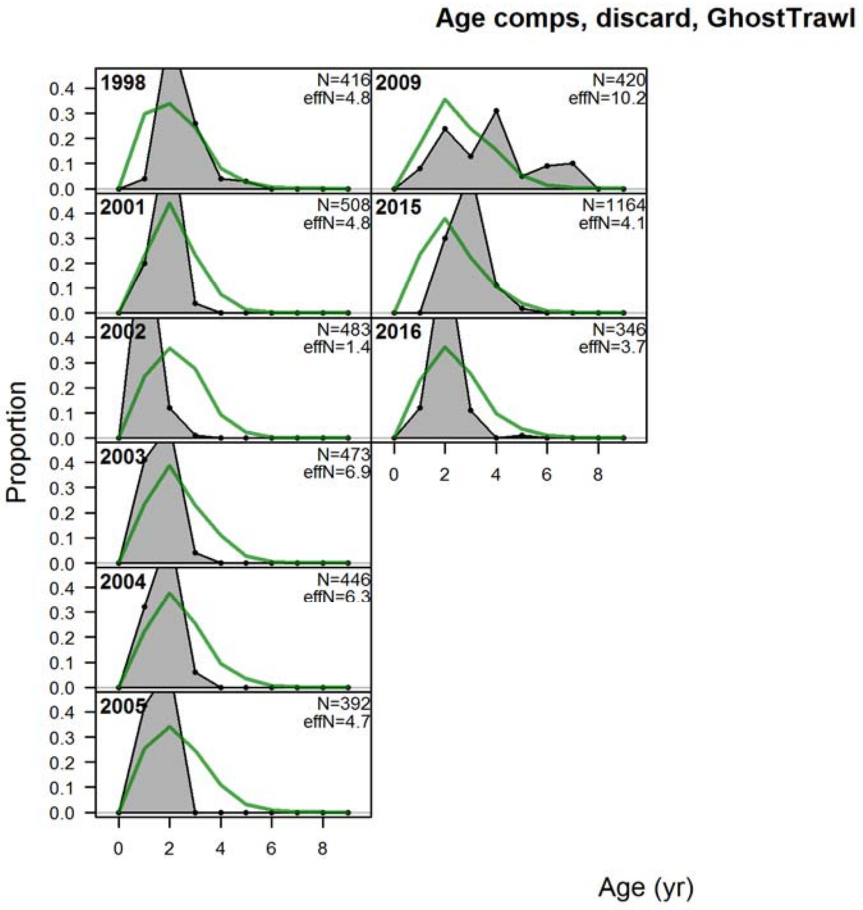


Figure A 14.25. School whiting implied fits to age: trawl discarded.

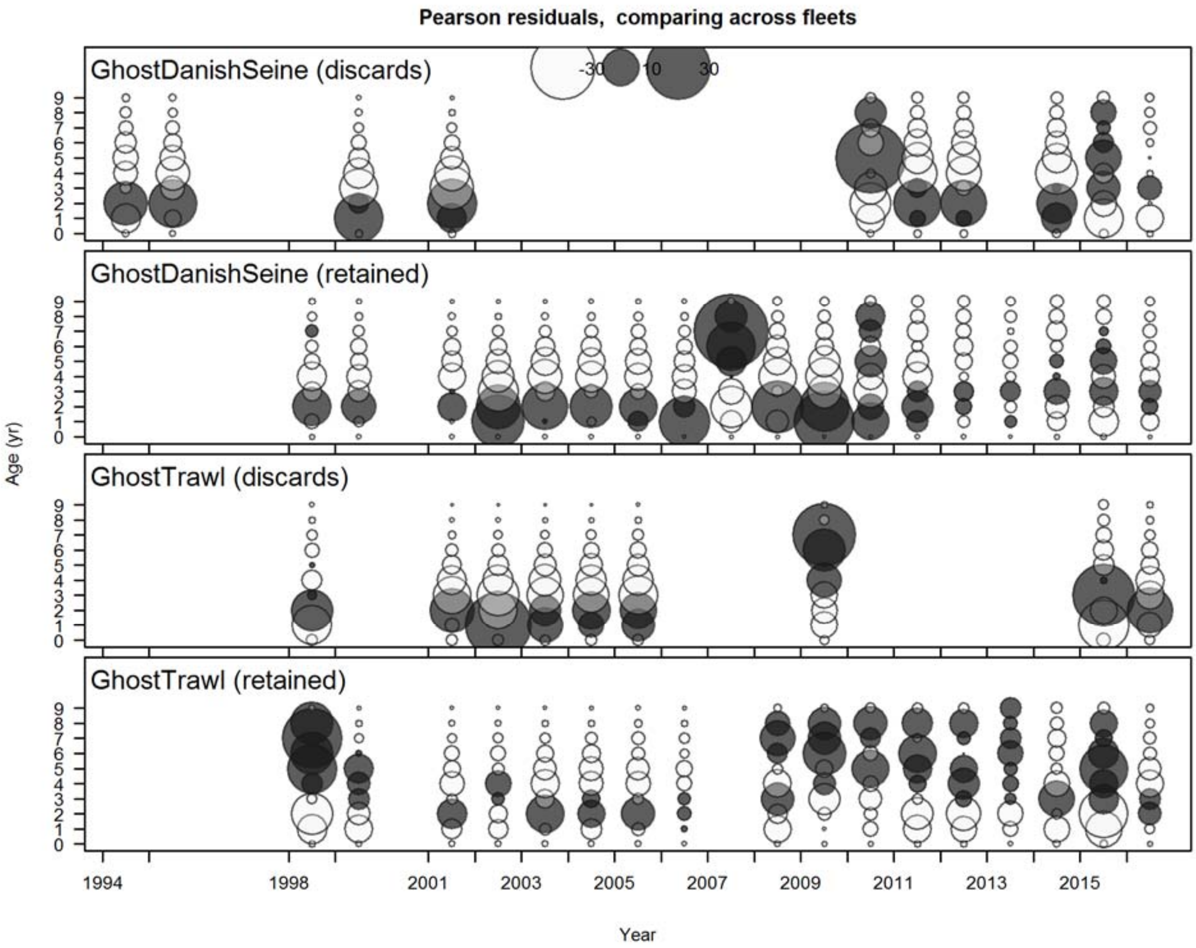


Figure A 14.26. Residuals from the annual implied fits to age compositions for school whiting displayed by year and fleet.

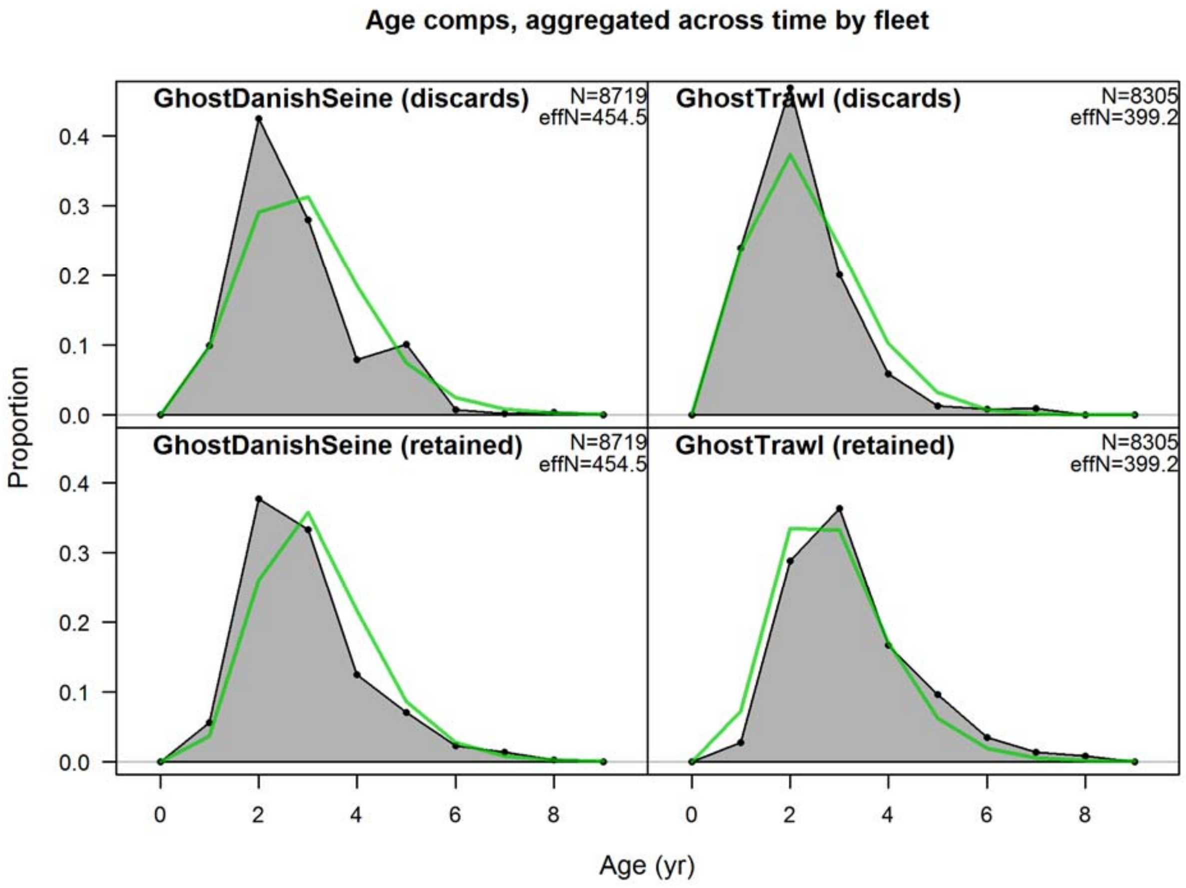


Figure A 14.27. Aggregated fits (over all years) to the implied age compositions for school whiting displayed by fleet.

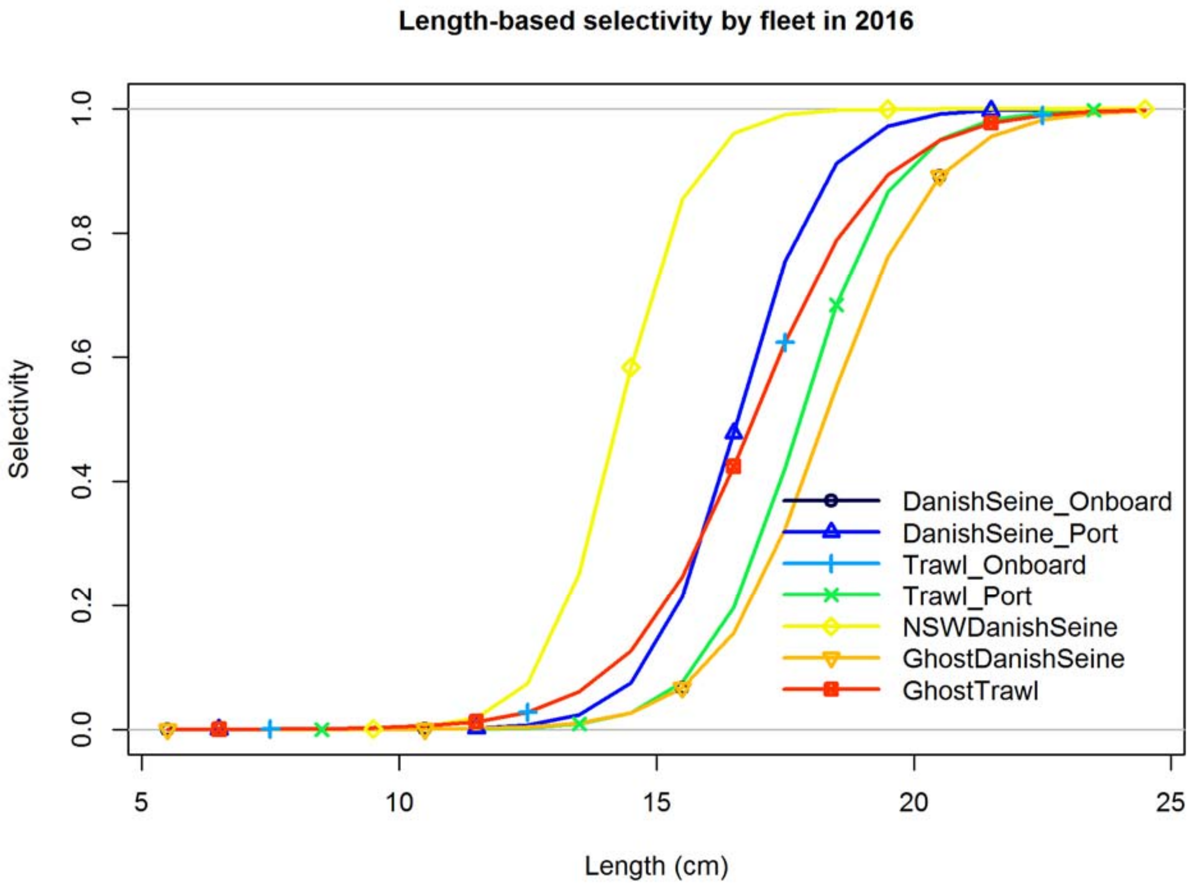


Figure A 14.28. Fits to selectivity for school whiting fleets.

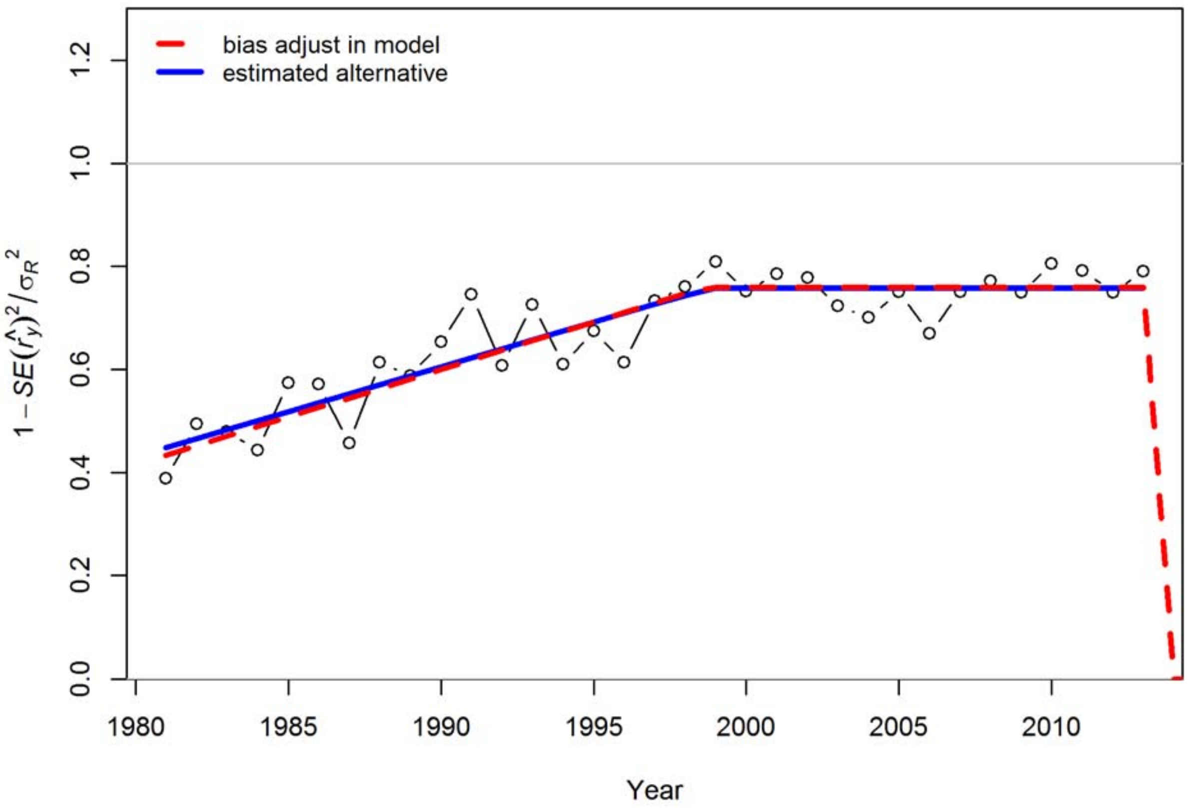


Figure A 14.29. Bias ramp adjustment for school whiting.

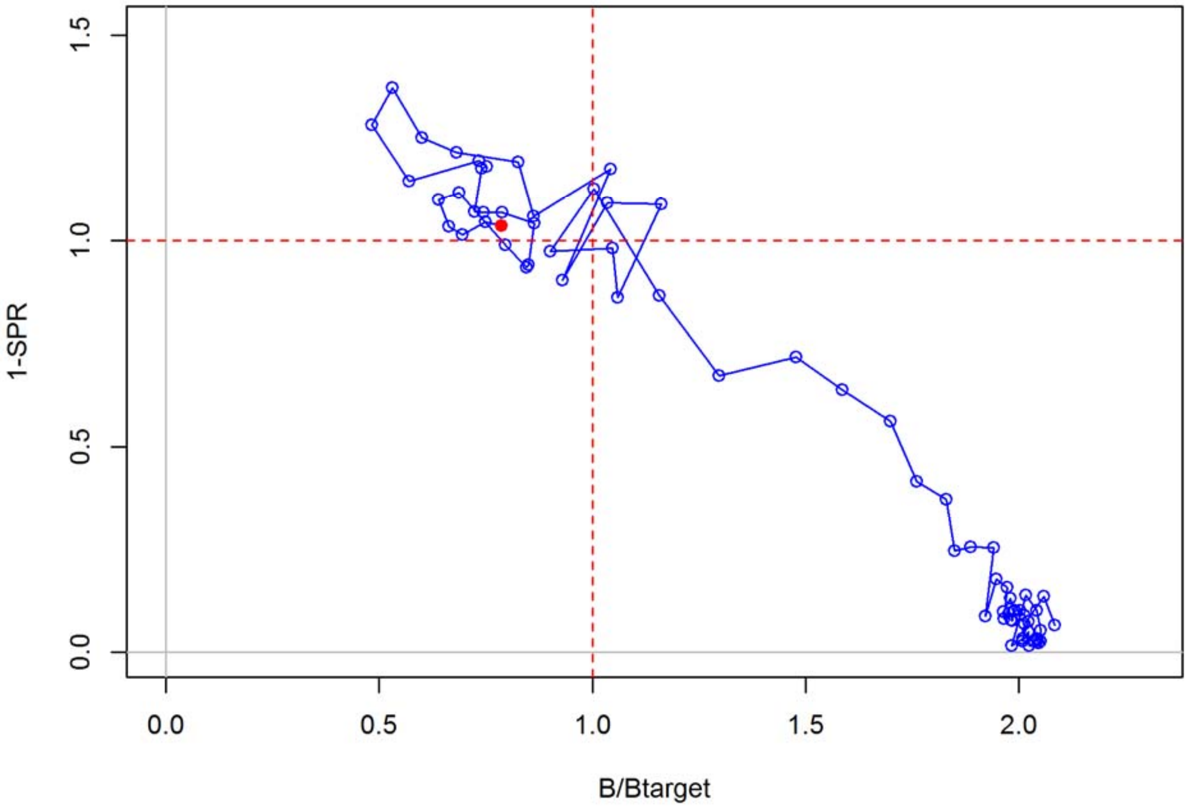


Figure A 14.30. Phase plot of biomass vs SPR ratio.

15. School whiting (*Sillago flindersi*) stock assessment based on data up to 2016

Jemery Day

CSIRO Oceans and Atmosphere, GPO Box 1538, Hobart, TAS 7001, Australia

15.1 Executive Summary

This document updates the 2009 assessment of school whiting (*Sillago flindersi*) to provide estimates of stock status in the SESSF at the start of 2018 and describes the base case assessment and some of the issues encountered during development. This assessment was performed using the stock assessment package Stock Synthesis (version V3.30.08.03). The 2009 stock assessment has been updated with the inclusion of data up to the end of 2016, comprising an additional eight years of catch, discard, CPUE, length and age data and ageing error updates. A range of sensitivities were explored.

A preliminary base case was presented at the September SERAG meeting and a provisional base case at the November SERAG meeting, with improvements to the balancing of the conditional age-at-length in the provisional base case and incorporating fixes to a bug discovered in Stock Synthesis in the interim. Following the November SERAG meeting, the November provisional base case was updated by changing the spawning month from July to January, at the request of SERAG, and a further variation was produced with improvements to the estimated growth curve, again with January spawning. This gave a choice of 3 fully balanced alternative base cases to be considered by SERAG in December 2017. SERAG chose the base case with January spawning and improved growth fits (listed as Sensitivity 17 in this report).

The base-case assessment estimates that current spawning stock biomass is 47% of unexploited stock biomass (*SSB_0*). Under the agreed 20:35:48 harvest control rule, the 2018 recommended biological catch (RBC) is 1,606 t, with the long term yield (assuming average recruitment in the future) of 1,641 t. The average RBC over the three year period 2018-2020 is 1,615 t and over the five year period 2018-2022, the average RBC is 1,621 t.

Exploration of model sensitivity showed variation in spawning biomass across all sensitivities ranging from 39% to 57% of *SSB_0* with greatest sensitivity to age at 50% maturity. A preliminary sensitivity removing all catch data north of Barrenjoey Point resulted in a depletion of 17%, but the resulting estimate of mortality was unrealistically low. This sensitivity was repeated with mortality fixed at 0.6, corresponding to the fixed value for mortality used in the 2008 assessment which resulted in a 2018 depletion of 39%. A balanced sensitivity with winter rather than summer spawning produced very similar results to the agreed base case with summer spawning.

Changes to the 2009 stock assessment include: separating length frequencies into onboard and port collected components, with a joint selectivity pattern estimated; weighting length frequencies by shots and trips rather than fish measured; and using the latest agreed best practice tuning method. The updated assessment is remarkably consistent with the results from the 2009 assessment, despite an additional 8 years of data, improvements to data processing and modifications to Stock Synthesis.

15.2 Introduction

15.2.1 *The fishery*

School whiting (*Sillago flindersi*) occur in the eastern regions of the SESSF and Bass Strait (zones 10, 20, 30, 60 and 91) and are commonly found on sandy substrates to depths of about 60m, and sometimes as deep as 150m. School whiting are benthic feeders and they mainly spawn during summer in the southern parts of their range, but with some evidence of spawning in the spring, winter and possibly all year round in the northern parts of their range. They grow rapidly, reach a maximum age of about nine years and become sexually mature at about two years of age.

In the SESSF, full recruitment to the fishery occurs at around three years of age. Selectivity of 50% is only achieved for three year old fish for the Danish seine fishery and the otter trawl fishery. Except for the NSW Danish seine fleet, selectivity for two year olds is less than 20% and for one year olds is less than 2%. The majority of the catch from 1947-1995 has been taken using Danish seine (mainly in zone 60 of the SESSF - Bass Strait) although the fraction of the catch taken by otter trawl has increased recently, and averaged more than 65% of the total catch from 1998-2010 and around 50% of the total catch since 2011. In contrast to the Danish seine catches, catches by otter trawl occur predominantly in SESSF zone 10, with most of this catch taken by state registered trawlers. Much of the school whiting caught by the Lakes Entrance Danish seine fleet since 1993 has been sent to an export market, although issues with quality of whiting caught in the summer months have reduced catches for the export market during this time.

Annual catches (landings and discards) of school whiting used in the 2009 preliminary assessment are shown in Table 15.1 and also in Figure 15.1 (separated by fleet) and Figure 15.2 (separated by jurisdiction). Large catches of school whiting were first taken in the 1980s (Smith, 1994) and catches increased to over 2,000 t in 1986, with a further four years with catch totals over 2,000 t up until 1995. Catches have remained over 1,200 t since 1986, with the peaks in catches generally reducing since the 1990s. Catches since 2008 have generally been between 1,200 and 1,500 t. Discard percentages are variable and appear market driven. From 1986-1996, more than 50% of the catch was taken by Commonwealth registered vessels, dropping to around 35% in the period 1997-2013 and then increasing back to around 50% since 2014. Catches of school whiting taken by state registered vessels comprised more than 50% of the total catch for the period 1997-2013 and have varied between 40% and 50% since 2014 (Figure 15.2).

The Commonwealth TAC for calendar years 2005 and 2006 was 1,500 t and in 2007 this was reduced to 750 t, maintained at 750 t in 2008 and increased to 1125 t in 2009. Since 2009 the Commonwealth TAC has varied between 600 and 1,000 t. The total landed catch (state and Commonwealth) has averaged 1,350 t since 2004, ranging between 1,200 t and just over 1,500 t. In the period 1994-2003, the total landed catch averaged over 1,700 t. The total state catch has averaged around 750 t since 2008, with an average of around 1,000 t in the decade 1998-2007.

15.2.2 *Stock Structure*

School whiting is assumed to be a single stock off the east coast of Australia and in Bass Strait, which is largely encompassed by the SESSF but does continue further north above Barrenjoey Point to Ballina. Stout whiting (*Sillago robusta*) is caught off northern New South Wales and the range of these two species overlaps between Ballina and Clarence River, with the northern limit for school whiting at Ballina. NSW catches of stout whiting and school whiting were split equally between the two whiting species in this region where they both occur.

Dixon *et al.* (1986, 1987) report a discontinuity in the relatedness between samples observed between Forster and Coffs Harbour, which may indicate some degree of separation between the fish from northern and southern NSW. However, the genetic techniques used in this work had little genetic variation and hence low power and this was combined with low sample sizes and possible non-representative sampling (A, Moore, pers. comm.). While this may indicate a possible location to split stocks genetically, it remains unconfirmed using modern techniques. This species would benefit greatly from a new study that uses modern molecular markers and representative sampling. Both the resolution of modern markers and the analysis techniques have increased dramatically the late 1980s. Modern markers and a new study would help to clarify the population structure in this species (A, Moore, pers. comm.).

15.2.3 *Previous assessments*

A full stock assessment for school whiting was last performed in 2009 using data up to 2008 (Day 2009). This assessment was an update of the 2008 assessment (Day 2008b), which in turn extended the 2007 assessment (Day 2007). There were some earlier stock assessments for school whiting, using limited data (Cui *et al*. 2004, Punt 1999).
Given a lack of reliable age- and length-composition data, the 2004 assessment (Cui *et al*. 2004) just used data from the Commonwealth logbook, and ignored catches taken under state jurisdictions and all catches before 1991. As a result, this assessment was only able to give information about biomass levels relative to 1991. Cui *et al*. (2004) looked at the probabilities of falling below the 1991 spawning biomass and half the 1991 spawning biomass for 5 different levels of future catch and predicted large recruitments in 2002 and 2003, albeit with high uncertainty. As a result the 2003 estimate of spawning biomass was higher than the 1991 spawning biomass, but was also highly uncertain.

The 2007 stock assessment (Day 2007) used much more data than the earlier assessments, including catch data from 1947-2006, conditional age-at-length data, length data, discards, ageing error and estimated the growth parameters within the assessment. This assessment estimated a 2008 spawning stock biomass of 35% of unfished stock biomass, but warned that there was some uncertainty about the status of the stock and that with a short lived species this estimate is sensitive to estimates of recruitment. This assessment showed that three out of the last seven recruitment events were above average. This resulted in a 2008 RBC of 904 t under the 20:40:48 control rule, with a corresponding long term RBC of 1,685 t.

The 2008 stock assessment (Day 2008b) incorporated additional data for 2007 and also incorporated a number of revisions to both sample sizes and the distributions of length frequencies for the Danish seine and the otter trawl fleets in the period 1994-2006, due to improvements in the data extraction process. This assessment estimated a 2009 spawning stock biomass of 82% of unfished stock biomass, and again warned that there was some uncertainty about the status of the stock and that with a short lived species this estimate is sensitive to estimates of recruitment. The 2008 assessment showed that six of the last seven estimated recruitment events were above average and warned that “if these recent strong recruitment events are not supported by future data, the evidence for a recent strong recovery in the stock may need to be moderated”. This resulted in a 2009 RBC of 3,785 t under the 20:35:48 control rule, with a corresponding long term RBC of 2,070 t.

The 2009 stock assessment (Day 2009) incorporated a number of changes, including: (a) revised historical catch, length and age data for the period 1994-2007, (b) the addition of updated length frequencies, catches and catch-rates for data collected in 2008, (c) the estimation of recruitment up to 3 years before the most recent data and (d) the estimation of the natural mortality parameter, M. This assessment estimated a 2010 spawning stock biomass of 50% of unfished stock biomass. The 2009 assessment showed that four of the last seven estimated recruitment events were above average, in contrast to the 2008 assessment. This resulted in a 2010 RBC of 1,723 t under the 20:35:48 control rule, with a corresponding long term RBC of 1,660 t.

Due to the variation in depletion results produced by assessment reports between 2007 and 2009, fixed catch scenarios were examined after the 2009 stock assessment (Day 2010, Day 2011) exploring projections with fixed long term catches ranging between 1,400 t and 2,000 t and estimating the probability of falling below the limit Biomass (B_{20}) for these fixed catch scenarios, and for a range of sensitivities for some of the key fixed parameters. This gave support to an RBC of around 1,660 t, the long term RBC from the 2009 assessment. Recruitment retrospectives were examined (Day 2010) to explore the reliability of the most recently estimated recruitment events and to test the age at which useful recruitment data can be estimated. This also suggested changes in recent recruitment estimates were linked to changes in other parameters fitted by Stock Synthesis, revisions to historical data sets and possible non-representative sampling in some years. Other issues were explored (Day 2011) including unsuccessfully searching for correlations of spawning biomass with biological parameters, a brief assessment update using data to 2010 and running this assessment update using Commonwealth data only.

15.2.4 *Modifications to the previous assessments*

The 2017 assessment uses Stock Synthesis version SS-V3.30.08.03, (Methot et al 2017), updated from version SS-V3.03a (Methot 2009) that was used in the 2009 assessment. New catch, discard, length and conditional age at-length data is available from the eight year period from 2009-2016. Conditional age-at-length data used in the 2009 assessment was based on ageing of whole otoliths in the period 1994-2006 and sectioned otoliths from 2007 and 2008. The ageing data from whole otoliths from 1994-2006 was not used in the 2017 assessment due to differences in the age range obtained from readings of sectioned and whole otoliths. These data were replaced by age-at-length data obtained by sectioning and re-ageing a selection of the available historical otoliths. This resulted in the 2017 assessment only using age data from sectioned otoliths, using newly read conditional age-at-length data for the period 1991-2006, the previous data from sectioned otoliths from 2007-2008 and new conditional age-at-length data for the period 2009-2016. As a consequence, the maximum age (or the age for the plus group) changed from six to nine years. In addition to these new and updated data, there is an updated standardised CPUE series for the Commonwealth Danish seine fleet with eight additional data points, a new standardised CPUE series for the Commonwealth trawl fleet from 1995 and updated estimates for the ageing error matrix (using sectioned otoliths only).

15.2.4.1 Data-related issues

1. Length-frequency data are included separately for onboard data by fleet, in addition to the port based length frequency data which were the only length-frequency data used in the 2009 assessment. Port and onboard fleets share a single selectivity pattern.
2. Length frequency data are weighted by shot or trip numbers rather than numbers of fish measured. A cap of 100 trips and 200 shots was used to set an upper limit on the sample size, although the limit on trip numbers was never exceeded.
3. The longest catch-rate time series is from the Victorian Danish seine fleet (Haddon and Sporcic, 2017) from 1986-2016.
4. A new catch rate time series is included for the trawl fleet (Haddon and Sporcic, 2017) using Commonwealth logbook data from 1995-2016.

5. State catches have been added to catches from the appropriate fleets with some revision of the historical NSW state catch.
6. The ageing error matrix has been updated (using sectioned otoliths only).
7. Catch, discard, length-composition, age-at-length, and catch rate data have been added for the period 2009-2016.

15.2.4.2 Model-related issues

1. Growth is assumed to follow a von Bertalanffy type length-at-age relationship, with all four growth parameters estimated separately, based primarily on the age-at-length data from fish that were measured and aged from extracted otoliths. In the 2009 assessment, it was only possible to estimate three of the four growth parameters, with K fixed to get a reasonable growth curve and to avoid very high correlations between K and L_{max}.
2. Natural mortality, M, is estimated within the model.
3. Recruitment residuals are estimated from 1981-2013, with the last recruitment event estimated three years before the most recent available data.
4. An updated tuning procedure has been used to balance the weighting of each of the data sources that contribute to the overall likelihood function, using Francis weighting for length and age data (Francis, 2011), balancing the CPUE series within Stock Synthesis, and improvements to the recruitment bias ramp adjustment.

The usual process of bridging to a new model by adding new data piecewise and analysing which components of the data could be contributing to changes in the assessment outcome was conducted (Day, 2017).

15.3 Methods

15.3.1 *The data and model inputs*

15.3.1.1 Biological parameters

A single-sex model (i.e. both sexes combined) was used, as the length composition data for school whiting are not available by sex.

Age-at-length data was used as an input, and all four parameters of the von Bertalanffy growth equation were estimated within the model fitting procedure. This is more appropriate than pre-specifying these values because it accounts for the impact of gear selectivity on the age-at-length data collected from the fishery and the impact of ageing error.

As in the 2009 assessment, M was able to be estimated within the model. The base-case value for the steepness of the stock-recruitment relationship, h, is 0.75.

School whiting become sexually mature at a length of about 16 cm, when the fish are around two years of age. Fecundity is assumed to be proportional to spawning biomass. The parameters of the length-weight relationship are obtained from Klaer and Thomson (2006) (a=1.32 × 10^{-5}, b=2.93).

15.3.1.2 Fleets

As was the case in the 2009 assessment, this assessment for school whiting is based on three fleets: two Danish seine fleets (with NSW and Victorian fleets treated separately) and a single otter trawl fleet. Time-invariant logistic selectivity is assumed for all three fleets.

1. Victorian Danish seine – Danish seine based around Lakes Entrance in eastern Victoria and Bass Strait and Eastern Tasmania (1947 – 2016). Length frequency data are available for this fleet from Victorian Fisheries in 1991 and from the Integrated Scientific Monitoring Program (ISMP) records in the years 1994-2008. This fleet largely comprises catches from Commonwealth registered Danish seine vessels, but also includes small catches from Victorian and Tasmanian Danish seine vessels.
2. Otter trawl – otter trawlers from NSW, eastern Victoria and Bass Strait, including both Commonwealth and state registered vessels (1947 – 2016). Length frequency data are available for this fleet for two years from the Sydney Fish Market, 1983 and 1988, and from ISMP records from 1997-2008. In addition, there are length frequency data from 1971 and 1974 for otter trawl from the northern limit of the school whiting range.
3. NSW Danish seine – Danish seine fleet operating in state waters in NSW (1957 – 1994, 2010-2016). Length frequency data are available for this fleet from the Sydney Fish Market from 1983 -1989. This fleet was not operating when the 2009 assessment was conducted but has become active again since 2010.

In addition to these fleets, an ocean prawn trawl fleet operates in NSW state waters, largely north of Barrenjoey Point. Given the absence of available length data for this fleet, making it impossible to estimate selectivity, and the difficulty separating historical catches for this fleet prior to 1998, catches from this fleet are attributed to the otter trawl fleet. If length frequency data from this fleet can be obtained in the future, it may be worth reviewing this decision. Similarly length frequency data from the more recent NSW Danish seine catches, since 2010, would be useful to compare to the only length frequency data available from this fleet from 1983-1989.

Catches from the Victorian Danish seine fleet and the otter trawl fleet include catches from both Commonwealth and state registered vessels. Allocating the catch data, which is provided separately by jurisdiction, into catch by fleet requires careful processing of the raw data, with rules to allocate this catch by fleet varying over both time and data source.

15.3.1.3 Landed catches

The model uses a calendar year for all catch data. Landings data come from a number of sources. Early Victorian school whiting catches are available from 1947-1978 (Wankowski, 1983) and later Victorian state catches, from 1979-2006, were provided by Matt Koopman. Information enabling these Victorian state catches to be separated by fleet is not available so it is assumed that 3% of these catches are from the otter trawl fleet and 97% are from Danish seine for the whole period. Matt Koopman supplied a catch history separated into state and Commonwealth catches for the period 1957-2006. None of these catches are separated by fleet.

The original data for the NSW component of this catch for the period from 1957-1992 is from Pease and Grinberg (1995). Corrections were made to these catches to remove the stout whiting component from the catch (Kevin Rowling, pers. comm.), with these corrections based on how far north the catch was landed along the NSW coast. Due to limited availability of catch data in the period 1957-1984, 66% of the NSW catches reported by Pease and Grinberg were assigned to school whiting in this period. These adjusted catches of school whiting were incorporated into the NSW state catch history initially provided by Matt Koopman.

The NSW state catch history from 1985 onwards was further revised in 2017 (Karina Hall, pers. comm.) to improve the estimates of school whiting catches, by excluding the best estimates of stout whiting catches in specific northern fishing zones in NSW state waters during this period. The proportion of whiting catch comprising stout whiting increases the further north the catch is taken.

After all of these adjustments to the NSW catch total are completed, the total NSW state catch was then allocated in the ratio of 97% to the otter trawl fleet and 3% to the NSW Danish seine fleet from 1957-1994. From 1995 to 2009 all of the NSW state catch was assumed to be otter trawl. From 2010 to 2016, the Danish seine component of the NSW state catch is known and the remaining catch is assumed to be otter trawl. The NSW Danish seine catch from 2010 onwards is not publicly available.

Tasmanian state catches are available from 1995-2016 and all of this catch was assigned to the Victorian Danish seine fleet.

Commonwealth catches from 1985-2016 are separated into otter trawl and Danish seine (assumed to be the “Victorian Danish seine” fleet). These data come from the Commonwealth logbook records.

Annual landed catches for the three fleets used in this assessment (Victorian Danish seine, otter trawl and NSW Danish seine) are shown in Figure 15.1 and Table 15.1, with recent NSW Danish seine catches redacted, and with only the total catches listed in Table 15.1 for the period 2010-2016 (catches by fleet are not listed for these years), to maintain confidentiality of NSW Danish seine catches. The same catch history separated into state and Commonwealth components is shown in Figure 15.2.

This catch history is slightly modified from the catch history presented at the September 2017 SERAG meeting (Day 2017). Issues were discovered in both the NSW state catch data and the Commonwealth catch data with catches misreported on both sides of the line at Barrenjoey Point, and corrections were made to these data sources where possible. In addition to these changes, the Commonwealth catch history between 2003 and 2007 was updated in the preliminary base case (Day 2017) using data provided by AFMA. Updates to the Victorian Inshore Trawl component of this catch were inconsistent in the AFMA database with the data used in 2009, which was compiled by Neil Klaer (SEF2 VIC catches). Discrepancies between the two data sources could not be resolved. As the data compiled by Neil Klaer was processed closer to the collection of the data, a decision was made to use this data source. The maximum difference in any one year between these two sources of data was 50 t in 2004, with a combined difference of 34 t over a five year period, so the effect of this change was minor.

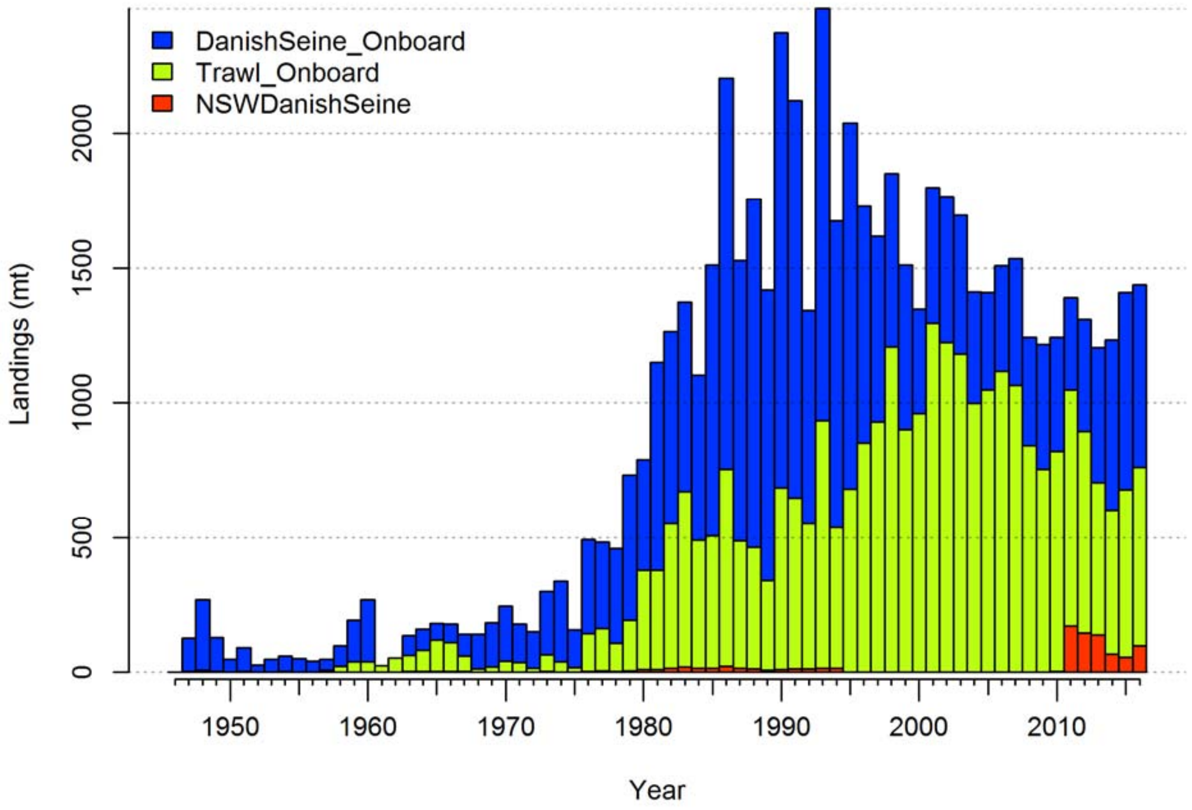


Figure 15.1. Total landed catch (tonnes) of school whiting by fleet (stacked) from 1947-2016. Recent NSW Danish seine catches are not publicly available.

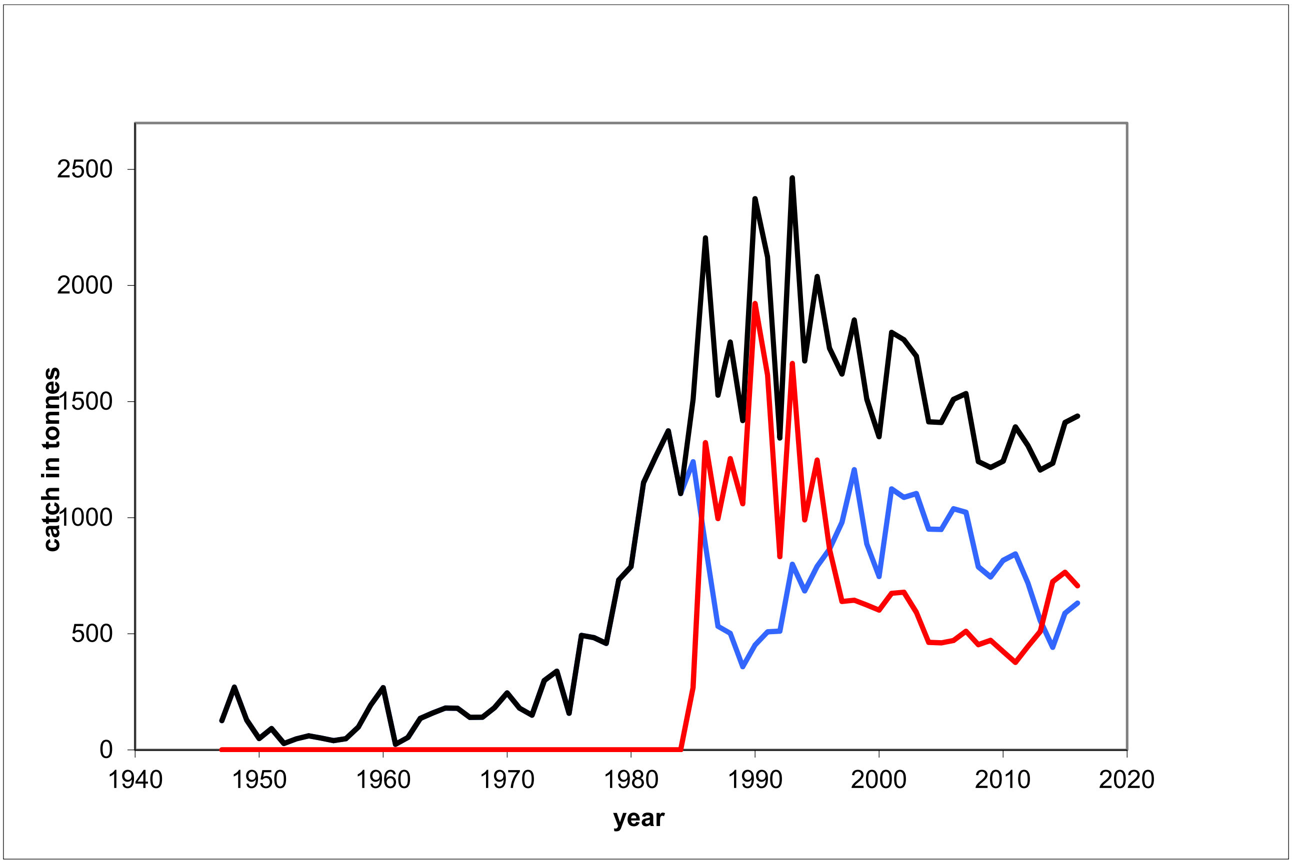


Figure 15.2. Total landed catch of school whiting in the SESSF from 1947-2016 (black line with circles) and this same catch separated into jurisdiction with state catches (blue) and Commonwealth catches (red). The Commonwealth catch was larger than the state catch in the periods 1987-1996 and 2014-2015. The state catches (blue) comprise the whole catch until 1985. The Commonwealth catch starts in 1985.

Table 15.1. Total retained catches (tonnes) of school whiting per fleet for calendar years from 1947-2009. Only the combined total for all fleets is shown for 2010-2016.

Year	Vic DS	Otter trawl	NSW DS	Total	Year	Vic DS	Otter trawl	NSW DS	Total
1947	122	4	0	126	1982	714	535	16	1264
1948	262	8	0	270	1983	705	650	19	1374
1949	125	4	0	129	1984	614	476	14	1104
1950	47	1	0	49	1985	1005	492	14	1511
1951	89	3	0	92	1986	1451	732	21	2205
1952	26	1	0	27	1987	1041	473	14	1528
1953	46	1	0	47	1988	1293	451	13	1756
1954	59	2	0	61	1989	1079	331	8	1418
1955	49	2	0	51	1990	1691	673	10	2375
1956	39	1	0	40	1991	1477	634	12	2123
1957	41	7	0	48	1992	791	540	12	1343
1958	76	22	1	98	1993	1529	919	16	2464
1959	154	38	1	193	1994	1138	521	16	1675
1960	230	37	1	268	1995	1359	680	0	2039
1961	0	23	1	24	1996	880	850	0	1731
1962	0	52	2	54	1997	688	931	0	1619
1963	73	61	2	136	1998	645	1207	0	1852
1964	78	79	2	159	1999	610	901	0	1511
1965	59	117	4	180	2000	388	961	0	1349
1966	69	107	3	179	2001	502	1296	0	1799
1967	81	57	2	140	2002	544	1223	0	1767
1968	128	12	0	140	2003	515	1180	0	1696
1969	164	18	0	183	2004	415	998	0	1413
1970	204	40	1	245	2005	362	1047	0	1410
1971	143	36	1	180	2006	393	1117	0	1510
1972	135	14	0	149	2007	469	1065	0	1534
1973	233	64	2	299	2008	400	842	0	1242
1974	301	37	1	338	2009	463	754	0	1216
1975	139	17	0	157	2010				1243
1976	351	138	4	493	2011				1391
1977	322	157	5	483	2012				1310
1978	352	104	3	459	2013				1205
1979	538	188	5	732	2014				1234
1980	412	367	11	789	2015				1410
1981	772	368	11	1151	2016				1438

The state catch is a significant proportion of the total catch for school whiting (Figure 15.2) From 1986-1996 the state catch averaged around 30% of the total catch, but from 1997-2013, the state catch increased and the Commonwealth catch decreased and as a result the state catch averaged around 60% of the total catch in this period. Since 2014, the Commonwealth catch has increased and the state catch has decreased, with the Commonwealth catch averaging just over 50% in this period. The difference between catches in state and Commonwealth jurisdictions does not affect this assessment directly, but it does affect how catches are allocated to the different fleets, and it will have an impact on the allocation of the RBC.

The NSW trawl fleet averages around 85% of the total state catches in the period 1986-2016. The Commonwealth catch starts in 1985 and the Victorian Danish seine fleet comprises around 85% of the Commonwealth catch since 1986. The Commonwealth catch was less than the state catch in the period 1997-2013.

In order to calculate the Recommended Biological Catch (RBC) for 2018, it is necessary to either estimate the calendar year catch for 2017, or to make an assumption about this catch. Without any other information, the 2017 catch for each fleet was assumed to be the same as the 2016 catch. The recent TAC history, which only applies to the Commonwealth component of the catch, is listed in Table 15.2.

Table 15.2. Total allowable catch (tonnes) from 1993 to 2017.

Year	TAC Agreed
1993	2000
1994	2000
1995	2000
1996	2000
1997	2000
1998	2000
1999	1500
2000	1500
2001	1500
2002	1500
2003	1500
2004	1500
2005	1500
2006	1500
2007	734
2008	750
2009	1125
2010	844
2011	641
2012	641
2013	809
2014	809
2015	747
2016	868
2017	986

15.3.1.4 Discard rates

Information on the discard proportions of school whiting by fleet is available from the ISMP for 1994-2016. This program was run by PIRVic from 1992-2006 and by AFMA from 2007. These data are summarised in Table 15.3. Discard proportions vary amongst years and have been as high as 40% (in 1998). Members of the fishing industry have indicated that discarding of small school whiting can vary rapidly in response to demands from the export market.

Table 15.3. Discard proportions for Vic Danish seine and otter trawl fleets from 1994 to 2016 with sample sizes for each data point. Entries in grey indicate data that are not used either due to small sample size (less than 10 samples) or because the value is too close to zero (less than 0.02).

Year	Vic DS discard proportion	n	Trawl discard proportion	n
1994	0.0564	150	1	3
1995	0.0024	102	1	1
1996			0.2705	17
1997			0.0540	10
1998			0.3986	15
1999	0.1199	17	0.1740	37
2000			0.1049	45
2001	0.0753	28	0.1260	120
2002			0.1009	98
2003	0.0088	36	0.0888	127
2004	0.0000	19	0.0637	98
2005			0.1928	93
2006			0.0456	71
2007			0.0412	4
2008				
2009			0.0027	15
2010	0.0033	22	0.0609	21
2011	0.0575	35	0.0387	9
2012	0.0278	17		
2013	0.0084	24	0.4664	6
2014	0.0811	35	0.1187	4
2015	0.0311	51	0.2592	39
2016	0.0462	58	0.0580	7

Discard practices can be variable between years for reasons that are difficult to model, with some years having very low discard rates and others having considerable discard rates. Without a mechanism to explain these years of very low discarding, discarding practices are assumed to be constant through time. Given the coefficient of variation associated with discard measurements, using years with very low discard proportions forces the model to fit very low discard rates to all years, even those when discarding is known to be higher, and underestimates discarding over all years. As a result, years with very low discard proportions (less than 2%) are excluded as inputs to stock synthesis (the greyed figures in the proportion columns in Table 15.3 – all from the Victorian Danish seine fleet) giving more believable estimates of discarding in general. Note that any discard estimate coming from a sample size of less than 10 is also excluded as it is likely to be unrepresentative (greyed figures in the sample size columns in Table 15.3 – all from the otter trawl fleet). Note that this excludes some years which appear to have very high discarding (e.g. 47% in trawl in 2013 from 6 samples, or 100%

discarding with 3 samples or fewer in 1994 and 1995), so both very large and very small outliers are excluded in this process.

Observations were then used to estimate discard rates, for each fleet (Figure 15.3) and hence discarded catches for each fleet (Figure 15.4, Figure 15.5), with estimated discard rates of around 5% for the Danish seine fleet and around 10% for the trawl fleet.

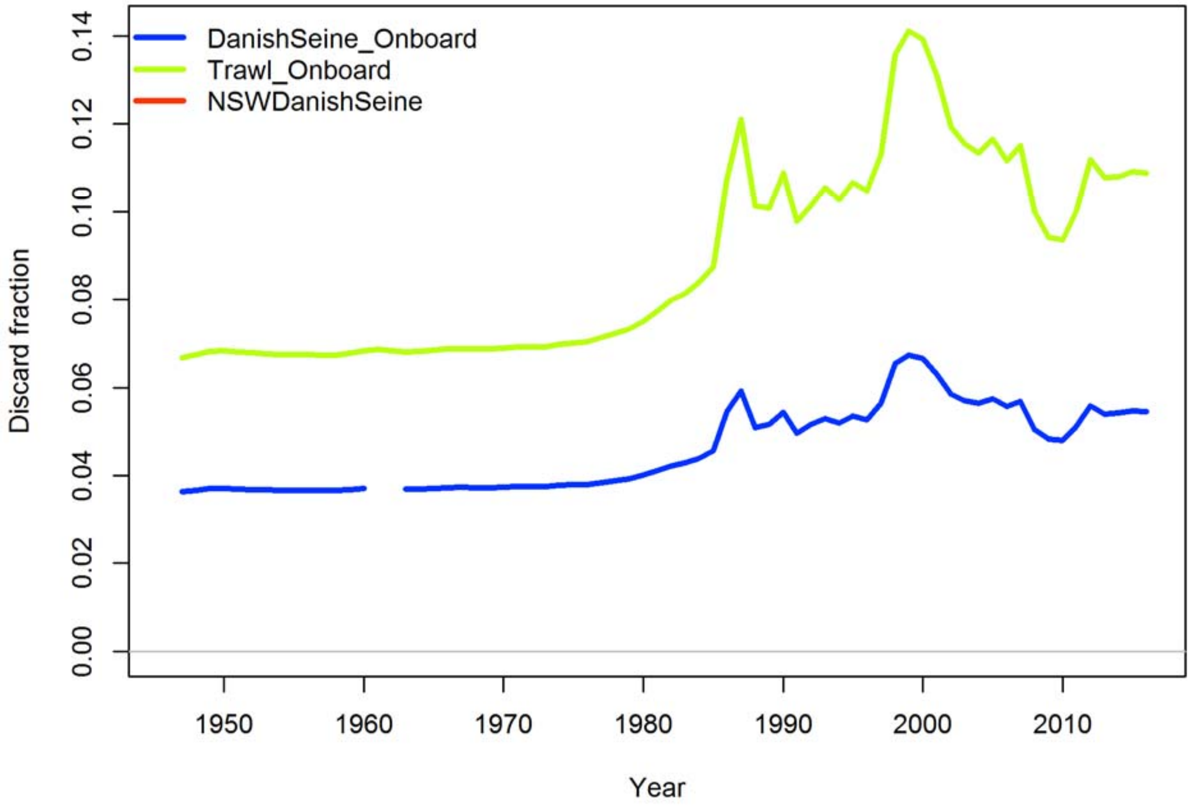


Figure 15.3. Model estimates of discard fractions by fleet, Danish seine (blue) and otter trawl (green).

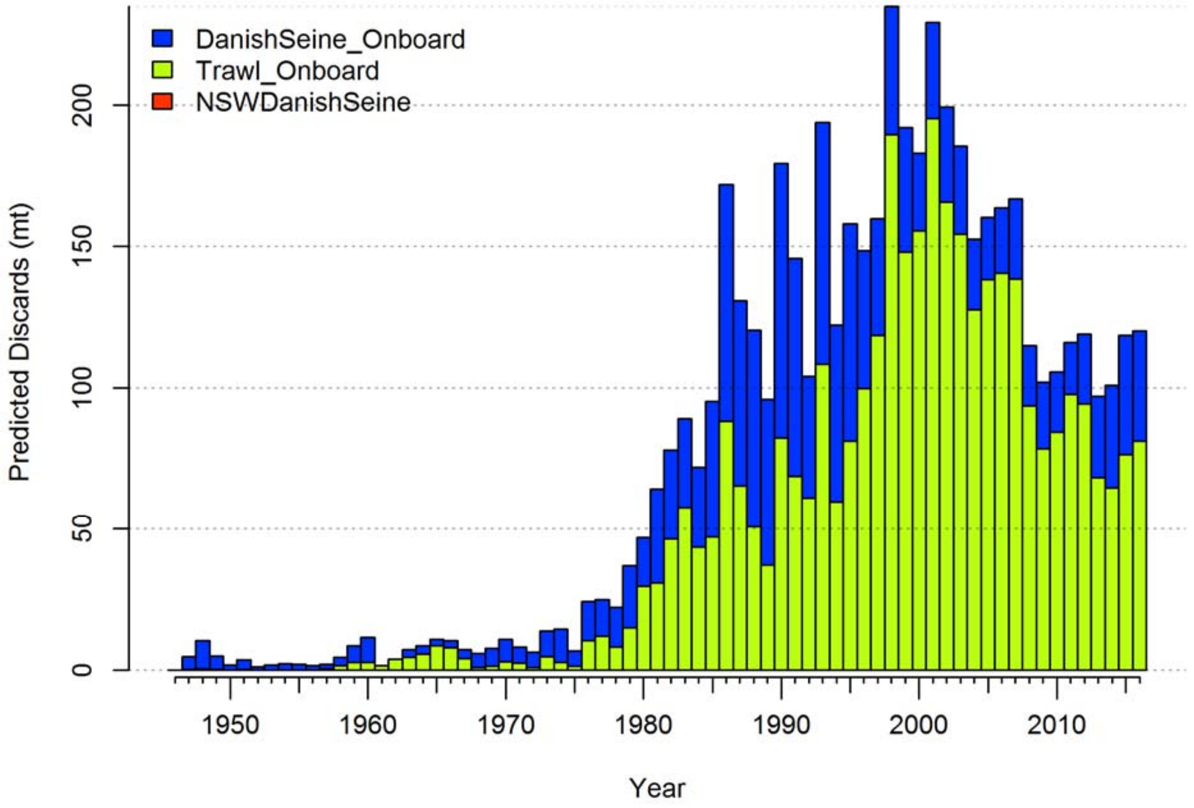


Figure 15.4. Estimated discards (tonnes, stacked) of school whiting in the SESSF from 1947-2016, Danish seine (blue) and otter trawl (green).

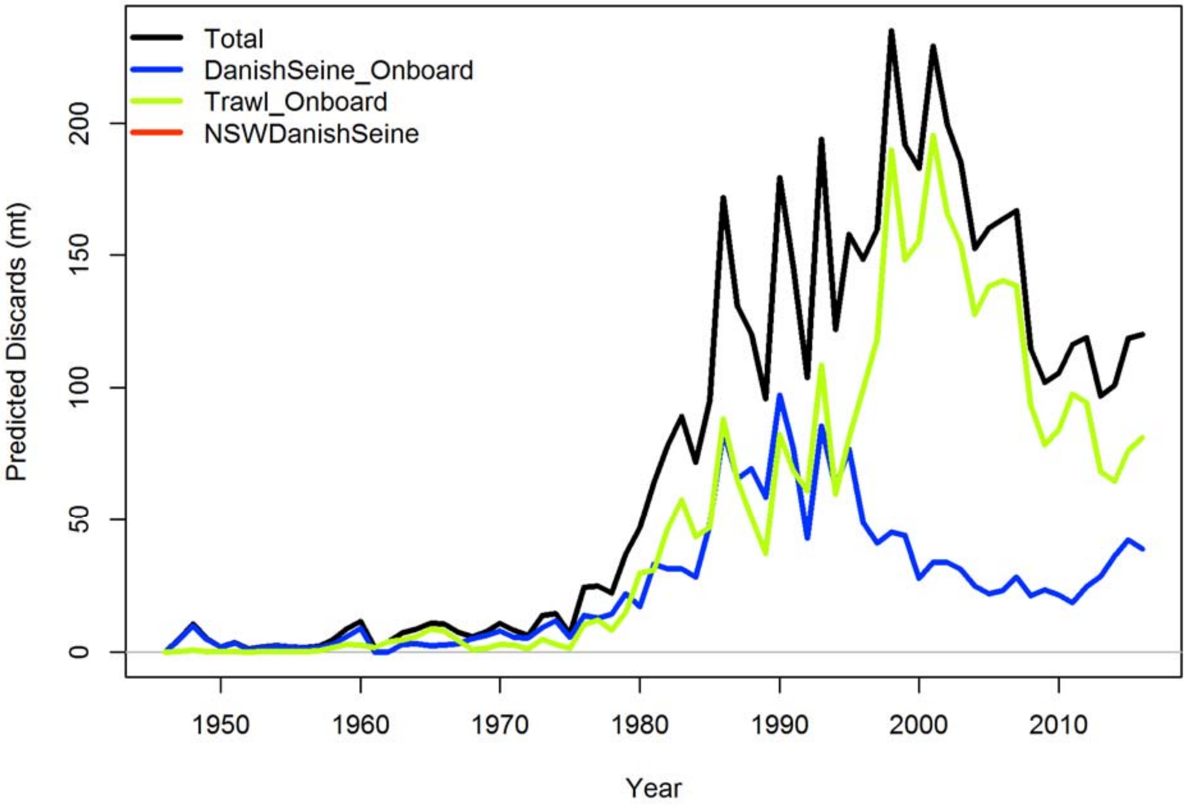


Figure 15.5. Estimated discards (tonnes) of school whiting in the SESSF from 1947-2016, Danish seine (blue), otter trawl (green), combined total (black).

15.3.1.5 Catch rate indices

Catch and effort data from the SEF1 logbook database were standardised using GLMs to obtain indices of relative abundance (Haddon and Sporcic, 2017; Table 15.4) from the period 1986-2016 for the Victorian Danish seine fleet and from 1995-2016 for the trawl fleet.

Table 15.4. Standardised catch rate indices and coefficient of variation (Haddon and Sporcic, 2017) for the Victorian Danish seine fleet and the trawl fleet for school whiting. The coefficient of variation is initially set at a value equal to the root mean squared deviation from a loess fit (Haddon and Sporcic, 2017).

Year	Catch rate Vic DS	cv (DS)	Catch rate trawl	cv c.v. (TW)
1986	1.1337	0.176		
1987	1.2540	0.176		
1988	1.5934	0.176		
1989	1.0596	0.176		
1990	1.6333	0.176		
1991	1.4501	0.176		
1992	1.0455	0.176		
1993	1.4916	0.176		
1994	0.8731	0.176		
1995	1.1067	0.176	1.2167	0.180
1996	0.7274	0.176	1.3600	0.180
1997	0.5536	0.176	0.9395	0.180
1998	0.5340	0.176	0.9470	0.180
1999	0.6047	0.176	1.1483	0.180
2000	0.6335	0.176	1.1447	0.180
2001	0.8824	0.176	1.2643	0.180
2002	0.8722	0.176	1.0444	0.180
2003	0.9129	0.176	0.9874	0.180
2004	0.8366	0.176	0.7679	0.180
2005	0.9377	0.176	1.0794	0.180
2006	0.8391	0.176	1.4908	0.180
2007	1.1093	0.176	1.4509	0.180
2008	1.0978	0.176	0.9456	0.180
2009	1.1732	0.176	0.8113	0.180
2010	1.0369	0.176	0.9782	0.180
2011	0.8365	0.176	0.8242	0.180
2012	0.9046	0.176	0.6116	0.180
2013	0.9210	0.176	0.5563	0.180
2014	1.0175	0.176	0.7577	0.180
2015	0.9727	0.176	0.6817	0.180
2016	0.9555	0.176	0.9918	0.180

The restrictions used in selecting data for analysis for Danish seine fleet were: (a) vessels had to have been in the fishery for three or more years, (b) the catch rate had to be larger than zero, (c) catches in zone 60 only (d) catches in less than 100m depth and (e) effort is considered as catch per shot rather than as catch per hour, to allow for missing records of total time for each shot for data early in the fishery.

The restrictions used in selecting data for analysis for the trawl fleet seine were: (a) vessels had to have been in the fishery for three or more years, (b) the catch rate had to be larger than zero, (c) catches in zones 10, 20 and 91 only (d) catches in less than 150m depth and (e) effort is considered as catch per hour. Catches recorded in zone 91 are apparently caught in state waters, but it appears there were issues with location recorded for some shots and these either represent shots which were actually in zone 10 or at least record school whiting caught by Commonwealth registered vessels in zone 91. In either case the catch rate data should be informative so records from zone 91 were included.

15.3.1.6 Length composition data

In 2010 the RAGs decided to include both port and onboard retained length frequency data (for both historic and current years) in future assessments, whereas in previous assessments only port data have been used (Day, 2009). For the 2017 assessment, port and onboard length composition data are both used separately, with the gear selectivity estimated jointly from both port and onboard data from each fleet (Victorian Danish seine and otter trawl). The 2009 assessment weighted length samples by the number of fish measured. For onboard data, the number of shots, is considered to be more representative of the information content in the length frequencies than the number of fish measured. For port data, the number of shots is not available, but the number of trips can be used instead. In the 2017 assessment, the initial sample size associated with each length frequency in the assessment is the number of shots or trips.

Length data were excluded for years with less than 100 individual fish measured, as this was considered to be unrepresentative (with excluded data listed in grey in Table 15.5 and Table 15.6). Sample sizes for retained length frequencies, including both the number of individuals measured and number of trips (inferred numbers of trips listed in blue in Table 15.6) are listed in Table 15.6 for each fleet and year for the period 1983-2016 and for discarded length frequencies in Table 15.5 for the period 1994-2016. For years and gear types where the number of trips is not available (port measurements for NSW Danish seine and NSW trawl fleet between 1983-1989 and one year of data from the Victorian Danish seine fleet in 1991), the number of trips is inferred from the number of fish measured per trip for years where this data is available for each gear type.

Length composition information for the retained component of the catch by the Victorian Danish seine fleet is available from port sampling for the period 1994-2016 and from onboard sampling from 1998-2016. Onboard data collected by the ISMP were used to calculate the length frequency of the discarded component of the catch from this fleet for five years only in this same period. An additional year (1991) of Victorian Fisheries length frequency data for the retained catch from the Victorian Danish seine fleet was also used (Anonymous, 1992).

Length composition information for the retained component of the catch by the Commonwealth trawl fleet is available from port and onboard sampling for 1998-2016 and in 1983 and 1988 from NSW state otter trawl sampled in port (Kevin Rowling, pers. comm. 2006). Onboard data collected by the ISMP were used to calculate the length frequency of the discarded component of the catch for six years only from 1998-2016.

Length composition information for the retained component of the catch by the NSW Danish seine fleet is available from Sydney Fish Market measurements for the period 1983-1989.

Table 15.5. Number of port and onboard discarded lengths and number of shots for length frequencies included in the base case assessment by fleet 1994-2016. Entries in grey indicate data that are not used due to small sample size (less than 100 fish measured).

year	**fleet**	**(discard)**		
	Vic DS	**trawl**	**Vic DS**	**trawl**
	onboard	**onboard**	**onboard**	**onboard**
	# fish	**# fish**	**# shots**	**# shots**
1994	4720		40	
1995	199		2	
1998		133		1
1999	292		16	
2001	160	251	4	9
2002		81		2
2003		532		7
2004		155		5
2005		205		6
2009		14		2
2010	1		1	
2011	5		2	
2012	95		8	
2014	202		23	
2015	46	178	3	7
2016	277	18	15	1

Table 15.6. Number of port and onboard retained lengths and number of shots or trips for length frequencies included in the base case assessment by fleet 1983-2016. The number of trips from early NSW data (in blue) is inferred from numbers of fish measured. Entries in grey indicate data that are not used due to small sample size (less than 100 fish measured).

year	**fleet**	**(retained)**								
	Vic DS onboard	**Vic DS port**	**trawl onboard**	**trawl port**	**NSW DS port**	**Vic DS onboard**	**Vic DS port**	**trawl onboard**	**trawl port**	**NSW DS port**
	# fish	**# fish**	**# fish**	**# fish**	**# fish**	**# shots**	**# trips**	**# shots**	**# trips**	**# trips**
1983				436	2790				3	31
1984					1275					14
1985					370					4
1986					2046					23
1987					449					5
1988				500	260				3	3
1989					220					2
1991		2026					23			
1994		527					2			
1995		3511					66			
1996		2390					23			
1997		4190					46			
1998	233	5708	52	250		3	64	1	2	
1999	861	1588	153	2547		23	17	3	25	
2000	462	776	253	45		7	10	3	1	
2001	453	858	1018	6340		10	11	17	61	
2002	743	727	2553	1726		8	10	23	28	
2003	1836	315	3074	1615		16	3	31	16	
2004	767	1147	2757	11019		7	9	24	27	
2005	2425	1003	2392	7609		17	7	25	17	
2006	1333		1127	16866		11		10	63	
2007	242	2558		1056		1	14		5	
2008	67	894	52			4	7	2		
2009	335	880	20	288		5	15	1	4	
2010	558	1179	481			19	20	3		
2011	1607	1222	133	435		27	40	2	1	
2012	379	1263	40	46		11	44	1	1	
2013	1488	1488	278	181		21	41	5	3	
2014	861	1704	280	708		35	54	2	6	
2015	1841	2776	1265	1086		31	46	22	8	
2016	2157	2456	122	94		41	39	2	1	

15.3.1.7 Age composition data

Age-at-length measurements, based on sectioned otoliths provided by Kyne Krusic-Golub of Fish Ageing Services Pty Ltd, are available from 1991-2016 for the Victorian Danish seine fleet and from 2001-2015 for the otter trawl fleet. These data replaced the age-at-length data up to 2006 based on reading whole otoliths used in the 2009 assessment. An estimate of the standard deviation of age-reading error was calculated by André Punt (pers. comm., 2017) using data supplied by Kyne Krusic-Golub and a variant of the method of Richards *et al*. (1992) (Table 15.7).

Age-at-length measurements, based on sectioned otoliths, provided by Fish Ageing Services, were available for the years 1991-1996, 1998, 2000-2016 for the Danish seine fleet; 2001-2004, 2009-2015 for the otter trawl fleet. The Victorian Danish seine age-at-length data from the year 2000 listed all fish in the oldest age group and was excluded as a result. Further investigation revealed a transcription error in processing this data with length measurements recorded in place of age readings, so this year of age data can be corrected and incorporated in a future assessment.

Table 15.7. Standard deviation of age reading error (A Punt pers. comm. 2017).

Age	sd
0.5	0.190385
1.5	0.190385
2.5	0.264961
3.5	0.292396
4.5	0.302489
5.5	0.306201
6.5	0.307567
7.5	0.308070
8.5	0.308255
9.5	0.308323

Table 15.8. Number of age-length otolith samples included in the base case assessment by fleet 1991-2016.

Year	Fleet Vic DS	Trawl	Total
1991	100		100
1992	419		419
1993	309		309
1994	430		430
1995	296		296
1996	278		278
1998	416		416
2000	156		156
2001	309	100	409
2002	233	250	483
2003	284	189	473
2004	370	76	446
2005	390		390
2006	128		128
2007	98		98
2008	478		478
2009	291	128	419
2010	564	50	614
2011	520	56	576
2012	437	113	550
2013	128	38	166
2014	646	134	780
2015	816	347	1163
2016	346		346

Implied age distributions for retained and discarded fish are obtained by transforming length frequency data to age data by using the information contained in the conditional age-at-length data from each year and the age-length relationship. Implied age distributions can be calculated separately for both onboard and port fleets and for the retained and discarded length frequencies and can be calculated from 1998-2016 for the Victorian Danish seine fleet and from 1994-2016 for the otter trawl fleet.

15.3.1.8 Input data summary

The data used in this assessment is summarised in Figure 15.6, indicating which years the various data types were available.

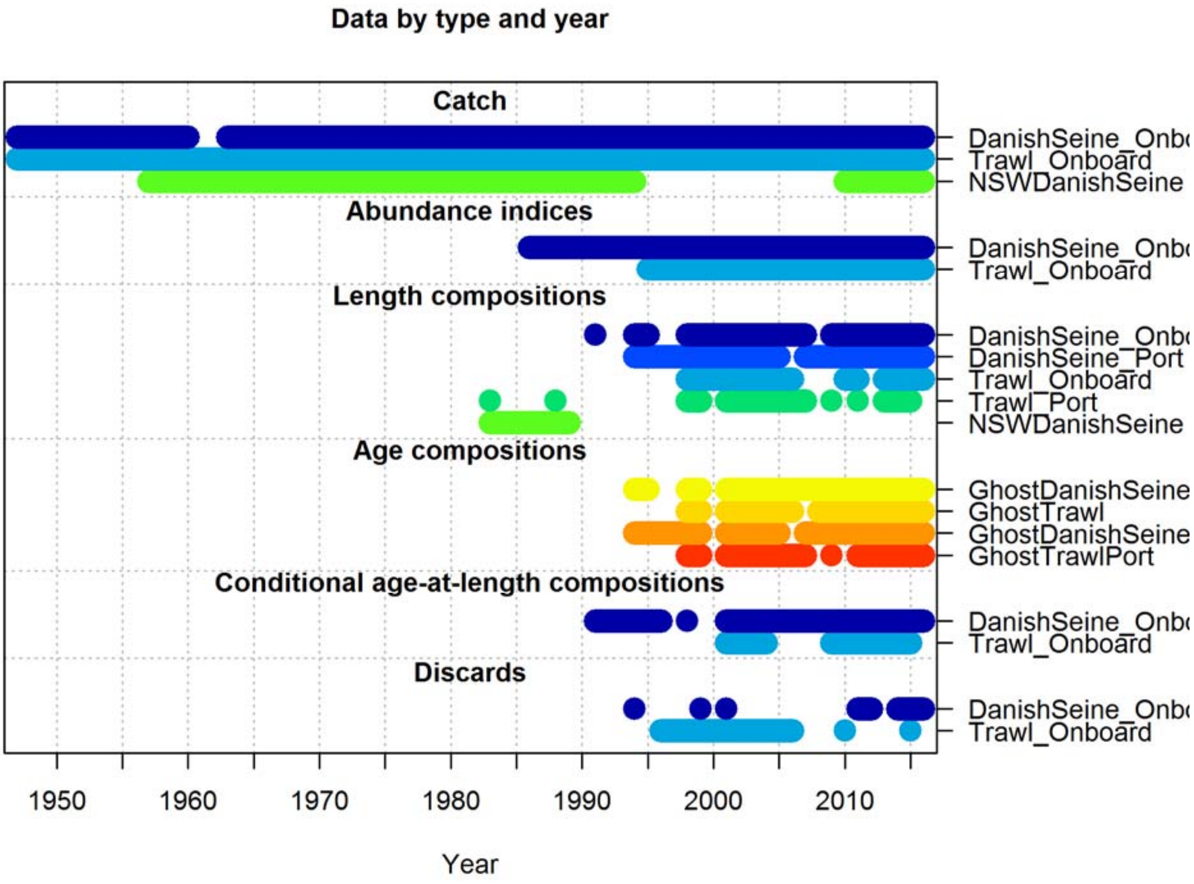


Figure 15.6. Summary of input data used for the school whiting assessment.

15.3.2 *Stock assessment method*

15.3.2.1 Population dynamics model and parameter estimation

A single-sex stock assessment for school whiting was conducted using the software package Stock Synthesis (version SS-V3.30.08.03, Methot *et al*. 2017). Stock Synthesis is a statistical age- and length-structured model which can allow for multiple fishing fleets, and can be fitted simultaneously to the types of information available for school whiting. The population dynamics model, and the statistical approach used in the fitting of the model to the various types of data, are described in the SS technical documentation (Methot, 2005) and are not reproduced here. Some key features of the base-case model are:

a) School whiting constitute a single stock within the area of the fishery (Smith and Wayte, 2005).

b) The population was at its unfished biomass with the corresponding equilibrium (unfished) age-structure at the start of 1947. This corresponds to a break in fishing during World War II and, given the facts that the species is short lived and was only lightly exploited prior to World War II, this seems a reasonable assumption.

c) The CVs of the CPUE indices for the Victorian Danish seine and otter trawl fleets were initially set to the root mean squared deviation from a loess fit to the fleet specific indices (Haddon and Sporcic, 2017) and then tuned to match the model-estimated standard errors by estimating an additional variance parameter within Stock Synthesis.

d) Three fishing fleets are modelled.

e) Selectivity was assumed to vary among fleets, but the selectivity pattern for each separate fleet was modelled as length-specific, logistic and time-invariant. The two parameters of the selectivity function for each fleet were estimated within the assessment.

f) Retention was also defined as a logistic function of length, and the inflection and slope of this function were estimated for the two fleets where discard information was available (Victorian Danish seine and otter trawl). Retention for the NSW Danish seine fleet was implicitly assumed to be independent of length as no length frequency composition data is available on discards for this fleet.

g) The rate of natural mortality, M, is assumed to be constant with age and also time-invariant. The value for M was estimated within the model in this assessment.

h) Recruitment to the stock is assumed to follow a Beverton-Holt type stock-recruitment relationship, parameterised by the average recruitment at unexploited spawning biomass, R_0, and the steepness parameter, h. Steepness for the base-case analysis is set to 0.75. Deviations from the average recruitment at a given spawning biomass (recruitment residuals) are estimated for 1981 to 2013. Deviations are not estimated prior to 1981 or after 2013 because there are insufficient data to permit reliable estimation of recruitment residuals outside of this time period.

i) The value of the parameter determining the magnitude of the process error in annual recruitment, σ_r, is set equal to 0.35 in the base case. Attempts were made to balance this parameter value to match the standard deviations of estimated recruitment about the stock-recruitment relationship. This resulted in unrealistically low values for σ_r with the model expecting a lower value, so σ_r was fixed at a lower bound (0.35) set for this parameter.

j) A plus-group is modelled at age nine years.

k) Growth of school whiting is assumed to be time-invariant, meaning there is no change over time in mean size-at-age, with the distribution of size-at-age being estimated along with the remaining growth parameters within the assessment. No differences in growth related to gender are modelled, because the stock is modelled as a single-sex.

l) The sample sizes for length and age frequencies were tuned for each fleet so that the input sample size was approximately equal to the effective sample size calculated by the model. Before this retuning of length frequency data was performed by fleet, any sample sizes with a sample size greater than 100 trips or 200 shots were individually down-weighted to a maximum sample size of 100 and 200 respectively. This is because the appropriate sample size for length frequency data is probably more closely related to the number of shots sampled, rather than the number of fish measured.

15.3.2.2 Relative data weighting

Iterative reweighting of input and output CVs or input and effective sample sizes is an imperfect but objective method for ensuring that the expected variation is comparable to the input. This makes the model internally consistent, although some argue against this approach, particularly if it is believed that the input variance is well measured and potentially accurate. It is not necessarily good to down weight a data series just because the model does not fit it, if in fact, that series is reliably measured. On the other hand, most of the indices we deal with in fisheries underestimate the true variance by only reporting measurement and not process error.

Data series with a large number of individual measurements such as length or weight frequencies tend to overwhelm the combined likelihood value with poor fits to noisy data when fitting is highly partitioned by area, time or fishing method. These misfits to small samples mean that apparently simple series such as a single CPUE might be almost completely ignored in the fitting process. This model behaviour is not optimal, because we know, for example, that the CPUE values are in fact derived from a very large number of observations.

Length compositions were initially weighted using trip and shot numbers, where available, instead of numbers of fish measured and by adopting the Francis weighting method for age and length composition data.

Shot or trip number is not available for all data, especially for some of the early length frequency data. In these cases, the number of trips was inferred from the number of fish measured using the average number of fish per trip for the relevant gear type for years where both data sources were available. The number of trips were also capped at 100 and the number of shots capped at 200. Samples with less than 100 fish measured per year were excluded.

These initial sample sizes, based on shots and trips, are then iteratively reweighted so that the input sample size is equal to the effective sample size calculated by the model using the Francis weighting method.

15.3.2.3 Tuning procedure

In iterative reweighting, the effective annual sample sizes are tuned/adjusted so that the input sample size is equal to the effective sample size calculated by the model. In SSv3.30 there is an automatic adjustment made to survey CVs (CPUE).

1. Set the standard error for the relative abundance indices (CPUE, acoustic abundance survey, or FIS) to their estimated standard errors for each survey or for CPUE (and FIS values) to the root mean squared deviation of a loess curve fitted to the original data (which will provide a more realistic estimate to that obtained from the original statistical analysis). SSv3.30 then re-balances the relative abundance variances appropriately.

An automated tuning procedure was used for the remaining adjustments. For the recruitment bias adjustment ramps:

2. Adjust the recruitment variance (σ_R) by replacing it with the RMSE (as long as this falls within specified minimum and maxima (0.35 to 0.7)) and iterate to convergence (keep altering the recruitment bias adjustment ramps as predicted by SSv3.30 at the same time).

Finally for the conditional age-at-length and length composition data:

3. Multiply the initial sample sizes by the sample size multipliers for the age composition data using Francis weights (Francis, 2011).

4. Similarly multiply the initial samples sizes by the sample size multipliers for the length composition data.
5. Repeat steps 2 to 4, until all are converged and stable (proposed changes are < 1%).

This procedure may change in the future after further investigations but constitutes current best practice.

15.3.2.4 Calculating the RBC

The SESSF Harvest Strategy Framework (HSF) was developed during 2005 (Smith *et al*. 2008) and has been used as a basis for providing advice on TACs in the SESSF quota management system for fishing years 2006-2016. The HSF uses harvest control rules to determine a recommended biological catch (RBC) for each stock in the SESSF quota management system. Each stock is assigned to one of four Tier levels depending on the basis used for assessing stock status or exploitation level for that stock. School whiting is classified as a Tier 1 stock as it has an agreed quantitative stock assessment.

The Tier 1 harvest control rule specifies a target and a limit biomass reference point, as well as a target fishing mortality rate. Since 2005 various values have been used for the target and the breakpoint in the rule. In 2009, AFMA directed that the 20:40:40 (B_{lim}: B_{MSY}: F_{targ}) form of the rule is used up to where fishing mortality reaches F_{48}. Once this point is reached, the fishing mortality is set at F_{48}. Day (2008) determined that for most SESSF stocks where the proxy values of B_{40} and B_{48} are used for B_{MSY} and B_{MEY} respectively, this form of the rule is equivalent to a 20:35:48 (B_{lim}: Inflection point: F_{targ}) strategy.

15.3.2.5 An evolving base case model

While SERAG accepted the model structure of the preliminary base case assessment for school whiting presented in September 2017, investigations since the September 2017 SERAG discovered that the model had not been properly tuned to ages. The minimum sample size for ages was not sufficiently small to allow appropriate re-weighting of the age-at-length data. As a consequence, the age-at-length variance adjustment parameters were not fully balanced, as instead of some sample sizes being down-weighted below one, they were reset to the minimum sample size (one) at each step and hence were not completely balanced. This particular aspect was not identified until 2 November 2017. This problem has now been corrected (which is only possible with SSv3.30) and fully balanced base case assessment results are presented. There were also issues under SSv3.30 with projections using the Australian Harvest Control rules when the spawning month was set to July. This required a software update (Rick Methot, pers. comm.) and a new version of Stock Synthesis addressing this bug in the code which was not available until 7 November 2017. These problems meant that a full assessment report was unable to be prepared in time for the November 2017 SERAG meeting. However, a provisional base case was able to be presented at this meeting, with the balancing issues addressed, the projections behaving appropriately and with the spawning month set to July and settlement 6 months later.

This arrangement led to a growth curve which was flat between ages 0 and 1, due to the difficulty of resolving the age of fish that were six months old to an integral number of years on the Stock Synthesis census day of January 1. These six month old fish had to be assigned either to age zero or age 1. Assigning them to age zero made little sense and, assigning them to age 1 essentially meant that growth began for fish at age 1 rather than age zero, resulting in an unconventional looking growth curve (Figure 15.7).

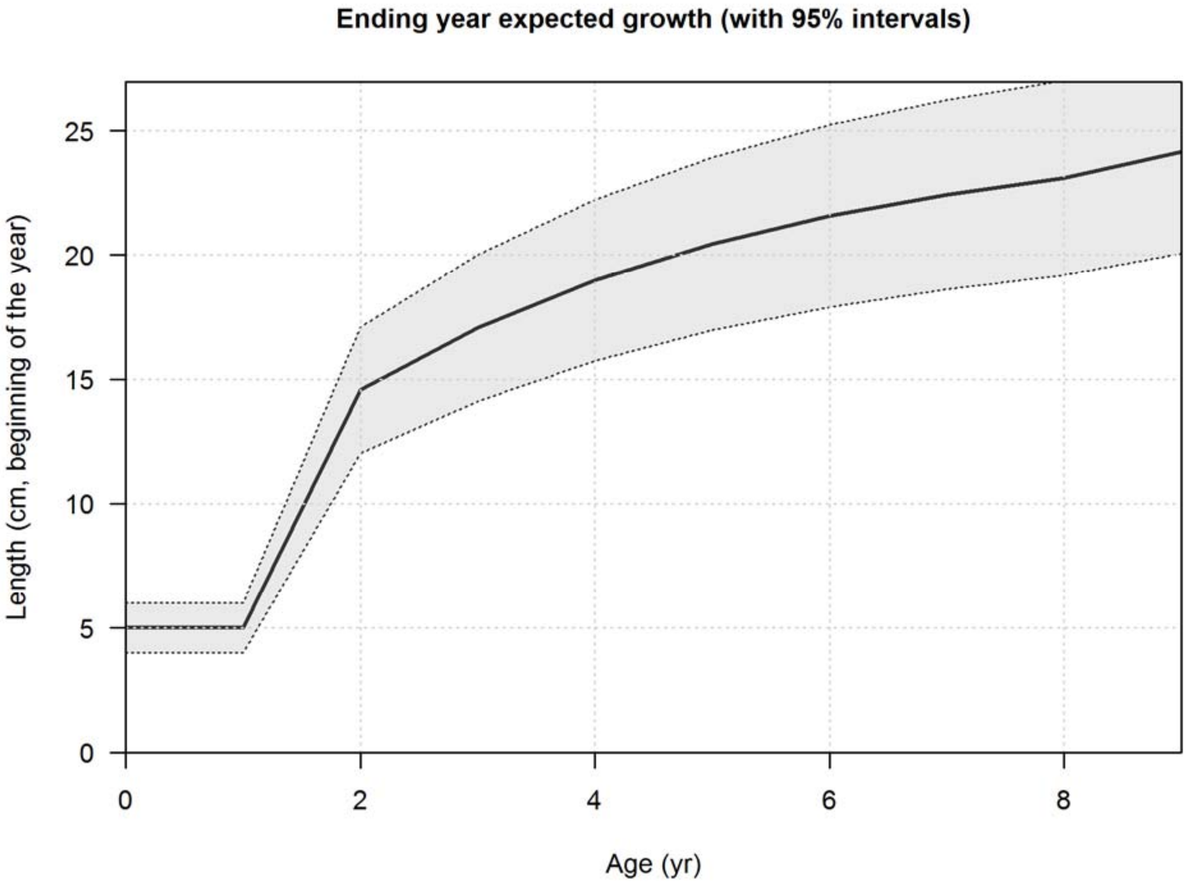


Figure 15.7. Estimated growth curve for the November provisional base case with spawning in July.

At the November SERAG meeting, a decision was made to modify the provisional base case and set the spawning month to January as the base case and consider winter spawning (in July - the November provisional base case) as a sensitivity. This enables the spawning month and the Stock Synthesis census date to line up and produces more conventional and biologically plausible growth curves with growth starting at age zero (Figure 15.8).

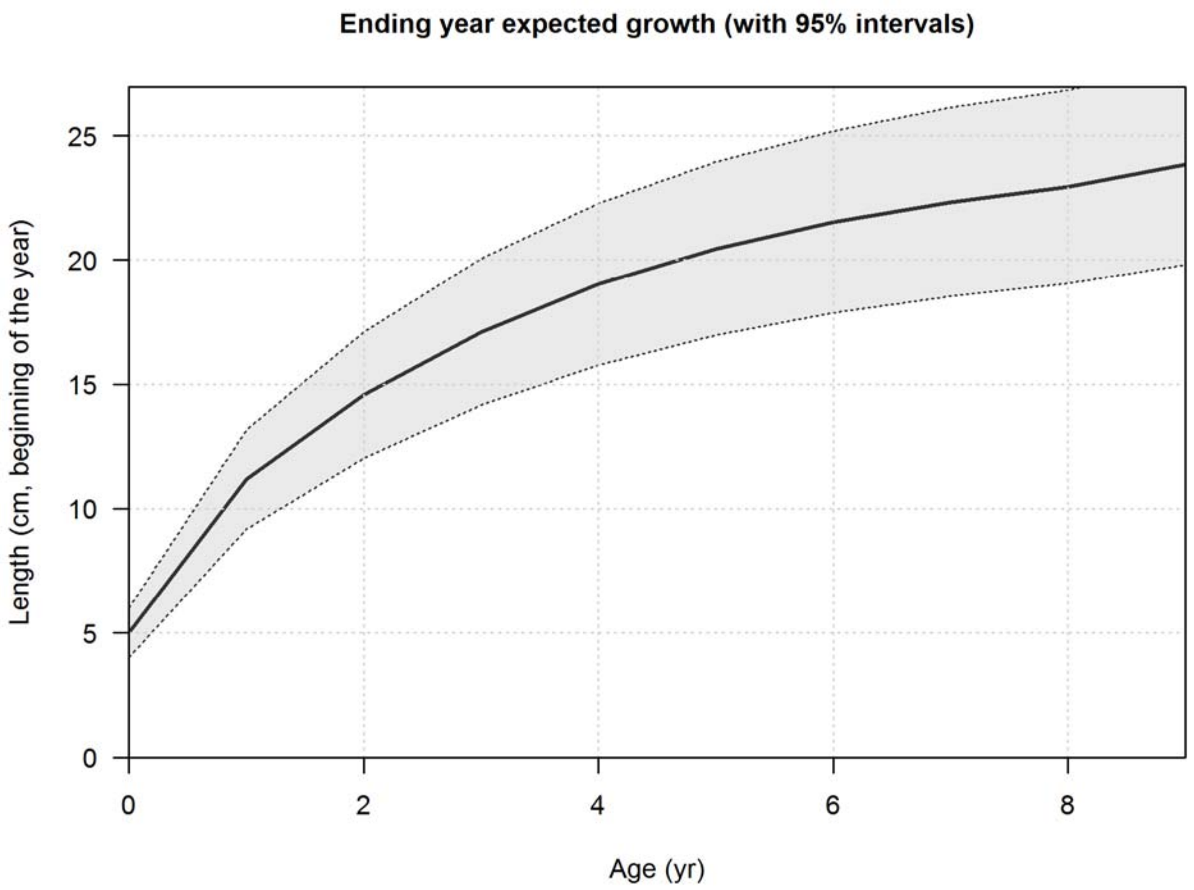


Figure 15.8. Estimated growth curve for the SERAG suggested base case with spawning in January.

While SERAG did not request further changes to the estimated growth curve, investigations of these spawning month issues led to improvements in estimating the growth curve, by estimating growth over a broader range than the length data was available and at a finer resolution. This results in an even smoother growth curve which appears to be a further improvement from a biological perspective (Figure 15.9). This improved fit to growth is included as a sensitivity to the base case agreed at the November SERAG meeting.

Diagnostic figures for the fully balanced base-case model, balanced according to the now agreed tuning methods, and results of sensitivities are provided below. Plots of the time-series of the spawning biomass and recruitment residuals for the agreed base case are similar to those shown at the November SERAG meeting.

Three models are fully balanced in this assessment report to allow SERAG to choose the base case to be used for management advice:

1. July spawning (provisional base case presented at November SERAG.
2. January spawning (November SERAG suggested base case).
3. January spawning with improved growth estimates.

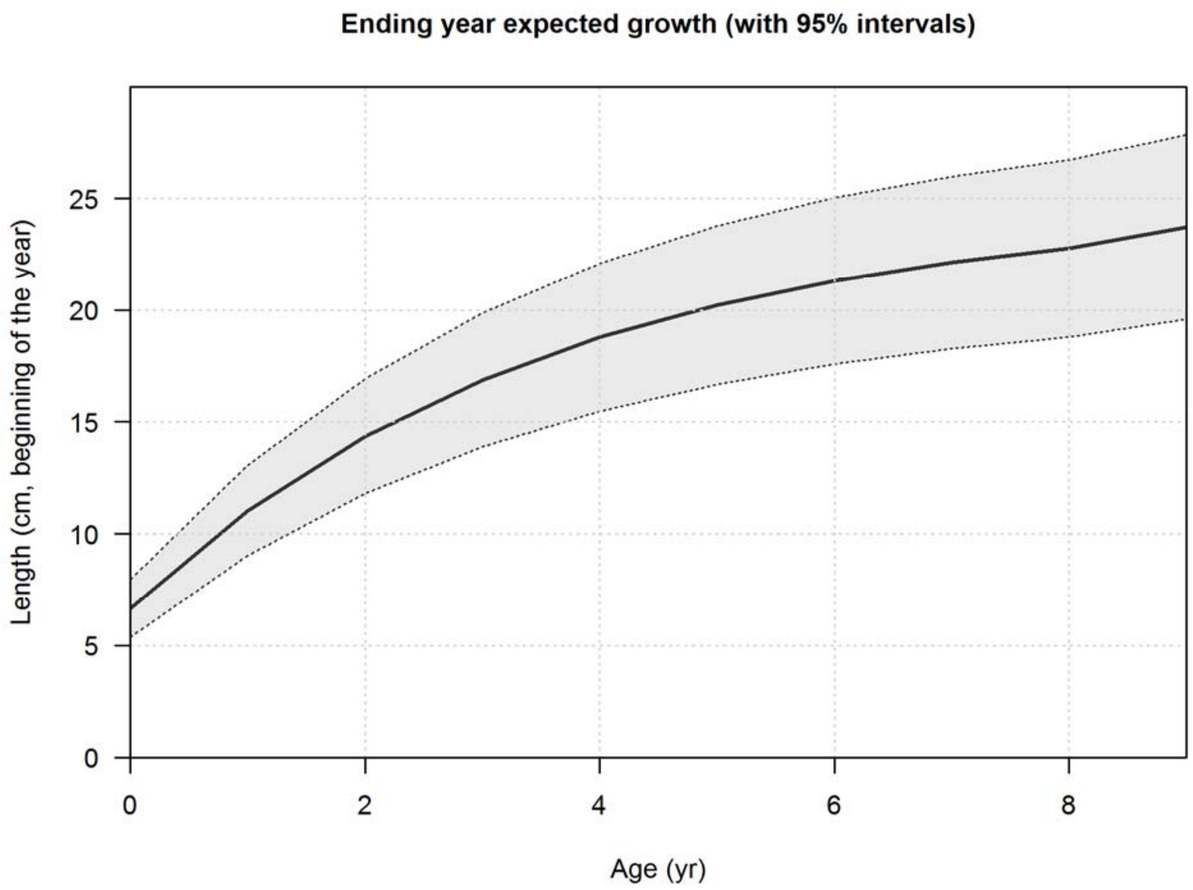


Figure 15.9. Estimated growth curve with improved growth estimates and spawning in January.

15.3.2.6 Sensitivity tests and alternative models

A number of tests were used to examine the sensitivity of the results of the model to some of the assumptions and data inputs:

1. $h = 0.65$ yr^{-1}.
2. $h = 0.85$ yr^{-1}.
3. 50% maturity at 14 cm.
4. 50% maturity at 18 cm.
5. σ_R set to 0.325.
6. σ_R set to 0.4.
7. Double the weighting on the length composition data.
8. Halve the weighting on the length composition data.
9. Double the weighting on the age-at-length data.
10. Reduce the weighting on the age-at-length data.
11. Increase the weighting on the survey (CPUE) data.

12. Halve the weighting on the survey (CPUE) data.
13. Double the discard values input to the model.
14. Halve the discard values input to the model.
15. Exclude catches north of Barrrenjoey Point.
16. Spawning in July.
17. Improve growth estimates.

The results of the sensitivity tests are summarized by the following quantities (Table 15.12):

1. SSB_0: the average unexploited female spawning biomass.
2. SSB_{2018}: the female spawning biomass at the start of 2018.
3. SSB_{2018}/SSB_0: the female spawning biomass depletion level at the start of 2018.
4. Mortality: the model estimated value for mortality.
5. RBC_{2018}: the recommended biological catch (RBC) for 2018.
6. $\text{RBC}_{2018\text{-}20}$: the mean RBC over the three years from 2018-2020.
7. $\text{RBC}_{2018\text{-}22}$: the mean RBC over the five years from 2018-2022.
8. $\text{RBC}_{\text{longterm}}$: the longterm RBC.

The RBC values were calculated for the final agreed base case only (listed as Sensitivity 17 in this report).

15.4 Results and Discussion

15.4.1 *The base-case analysis*

15.4.1.1 Transition from 2009 base case to 2017 base case

Development of a preliminary base case and a bridging analysis from the 2009 assessment (Day, 2009), was presented at the September 2017 SERAG meeting (Day 2017), including updating the version of Stock Synthesis and sequentially updating data. This bridging analysis is not repeated in this report.

15.4.1.2 Parameter estimates

Figure 15.8 shows the estimated growth curve for school whiting. All growth parameters are estimated by the model (parameter values are listed in Table 15.9).

Table 15.9. Summary of parameters of the base case model.

Feature	Details	
Natural mortality M	estimated	0.62
Steepness h	fixed	0.75
σ_R in	fixed	0.35
Recruitment devs	estimated	1981-2013, bias adjustment ramps 1955-1999 and 2013
CV growth	estimated	0.0821
Growth K	estimated	0.287
Growth l_{min}	estimated	9.08
Growth l_{max}	estimated	24.8

Selectivity is assumed to be logistic for all fleets. The parameters that define the selectivity function are the length at 50% selection and the spread (the difference between length at 50% and length at 95% selection). The estimates of these parameters for the Victorian Danish seine fleet are 16.7cm and 2.54cm, for otter trawl are 17.6cm and 2.99cm (somewhat smaller than the selectivity estimated in the 2009 assessment) and for NSW Danish seine are 14.6cm and 2.28cm. The selectivity for the otter trawl fleet is a little smaller (around 2cm) than that estimated in the 2009 assessment, but the selectivity for the other two fleets are similar to that estimated in 2009. Figure 15.10 shows the selectivity and retention functions for each of the commercial fleets. Note that these fitted selectivities show that otter the trawl fleet catches slightly larger fish than either of the Victorian Danish seine fleets and that the NSW Danish seine fleet catches smaller fish than the other two fleets. Retention for the NSW Danish seine fleet was implicitly assumed to be independent of length as no length frequency composition data is available on discards for this fleet. The estimate of the parameter that defines the initial numbers (and biomass), $ln(R_0)$, is 12.6 for the base case.

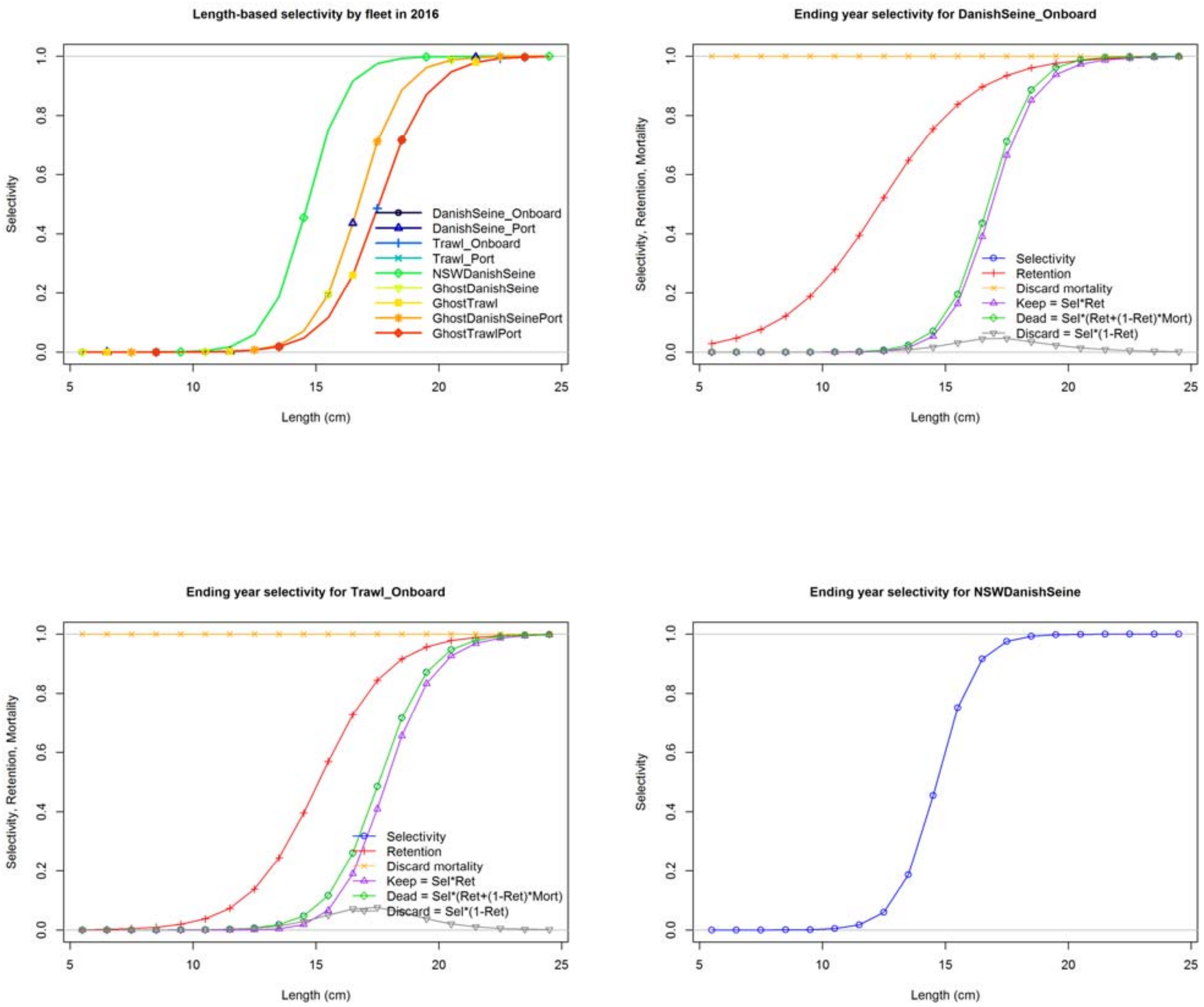


Figure 15.10. Selectivity for all three fleets (top left: Victorian Danish seine (orange); trawl (red); NSW Danish seine (green)) and selectivity (blue/green) and retention (red) functions for the three commercial fleets (Victorian Danish seine (top right); trawl (bottom left); NSW Danish Seine (bottom right)).

15.4.1.3 Fits to the data

The fits to the catch rate indices are remarkably good for the Victorian Danish seine (Figure 15.11) and greatly improved on the fits from the 2009 assessment, especially in relation to matching the timing of the lowest catch rate point in the late 1990s. This index is balanced by estimating an additional variance parameter within Stock Synthesis, which in this case is negative, suggesting the model fits well with less variance than the initial values from the loess fit. The fits to the catch rates for the otter trawl fleet (Figure 15.12) are not quite as good, but there is clearly some conflict between the two catch rate series. The additional variance parameter estimated within Stock Synthesis is positive for the otter trawl fleet, suggesting the model requires more variance than the initial values from the loess fit to achieve a good fit. The catch rate indices for the Victorian Danish seine fleet shows a considerable decline from the late 1980s to the late 1990s, with some recovery after that decline, with both series showing a relatively stable trend since the early 2000s.

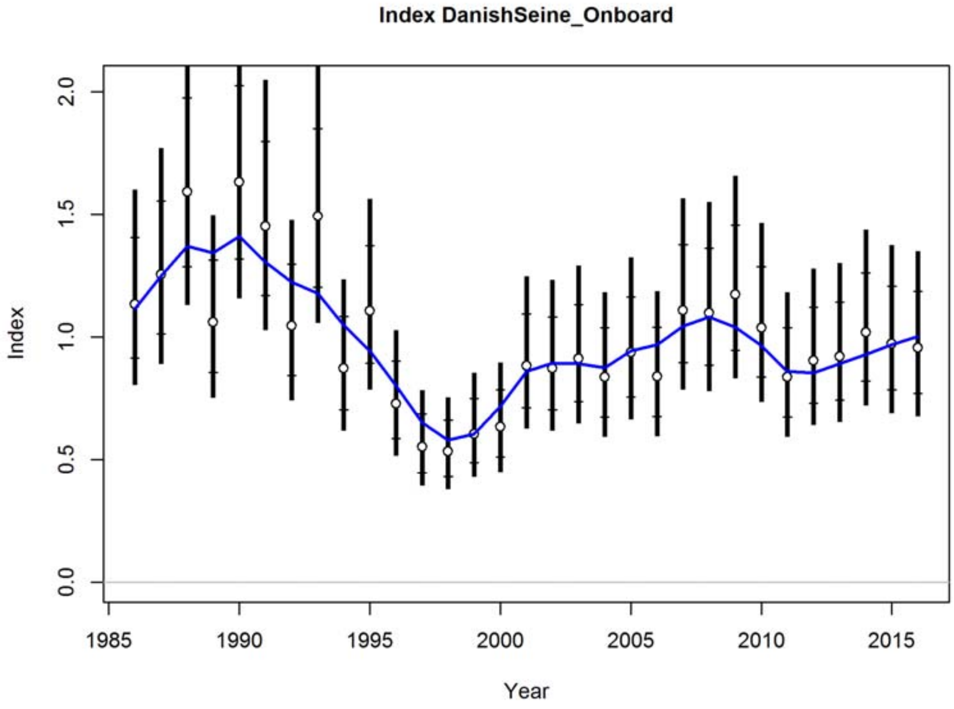


Figure 15.11. Observed (circles) and model-estimated (blue line) catch rates vs year, with approx 95% asymptotic intervals for Victorian Danish seine fleet. The thin lines with capped ends should match the thick lines for a balanced model. This index is balanced by estimating an additional variance parameter within Stock Synthesis, which in this case is negative, suggesting the model fits well with less variance than the initial values from the loess fit.

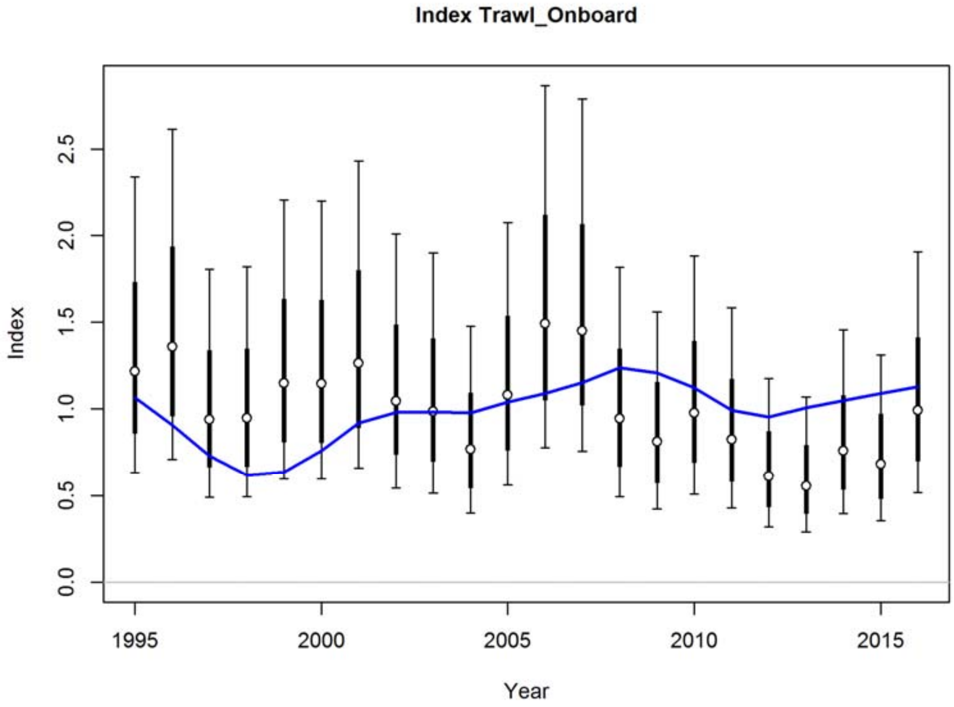


Figure 15.12. Observed (circles) and model-estimated (blue line) catch rates vs year, with approx 95% asymptotic intervals for otter trawl fleet. The thin lines with capped ends should match the thick lines for a balanced model. This index is balanced by estimating an additional variance parameter within Stock Synthesis, which in this case is positive, suggesting the model requires more variance than the initial values from the loess fit to achieve a good fit.

The fits to the discard rate data (Figure 15.13) are reasonable for the Victorian Danish seine and acceptable for the otter trawl fleets for the base case. To achieve reasonable levels of predicted discards, six years of very low (<1%) discard rate data were excluded (1995, 2003, 2004, 2010, 2013 for Victorian Danish seine and 2009 for otter trawl, Table 15.3). If these very low discard rates are included in the model, the fitted discard rates match these very low rates well but give very poor fits to all other years with discard rates >1%. Including these low discard rates results in much lower overall predicted discard rates compared to the mean of the discard rates over all years with discard data for each fleet. To achieve predicted discard rates which have a better match to the overall discard rates, these six data points were excluded. In addition to these years with very low discard rates, seven years of discard data for the otter trawl fleet were excluded in 1994, 1995, 2007, 2011, 2013, 2014 and 2016 (with discard rates varying between 4% and 100%) as these data come from sample sizes of less than ten (Table 15.3), resulting in very uncertain estimates of the discard rate for this fleet in these years. Fits to the age and length composition data for discarded catches are shown in Appendix A.

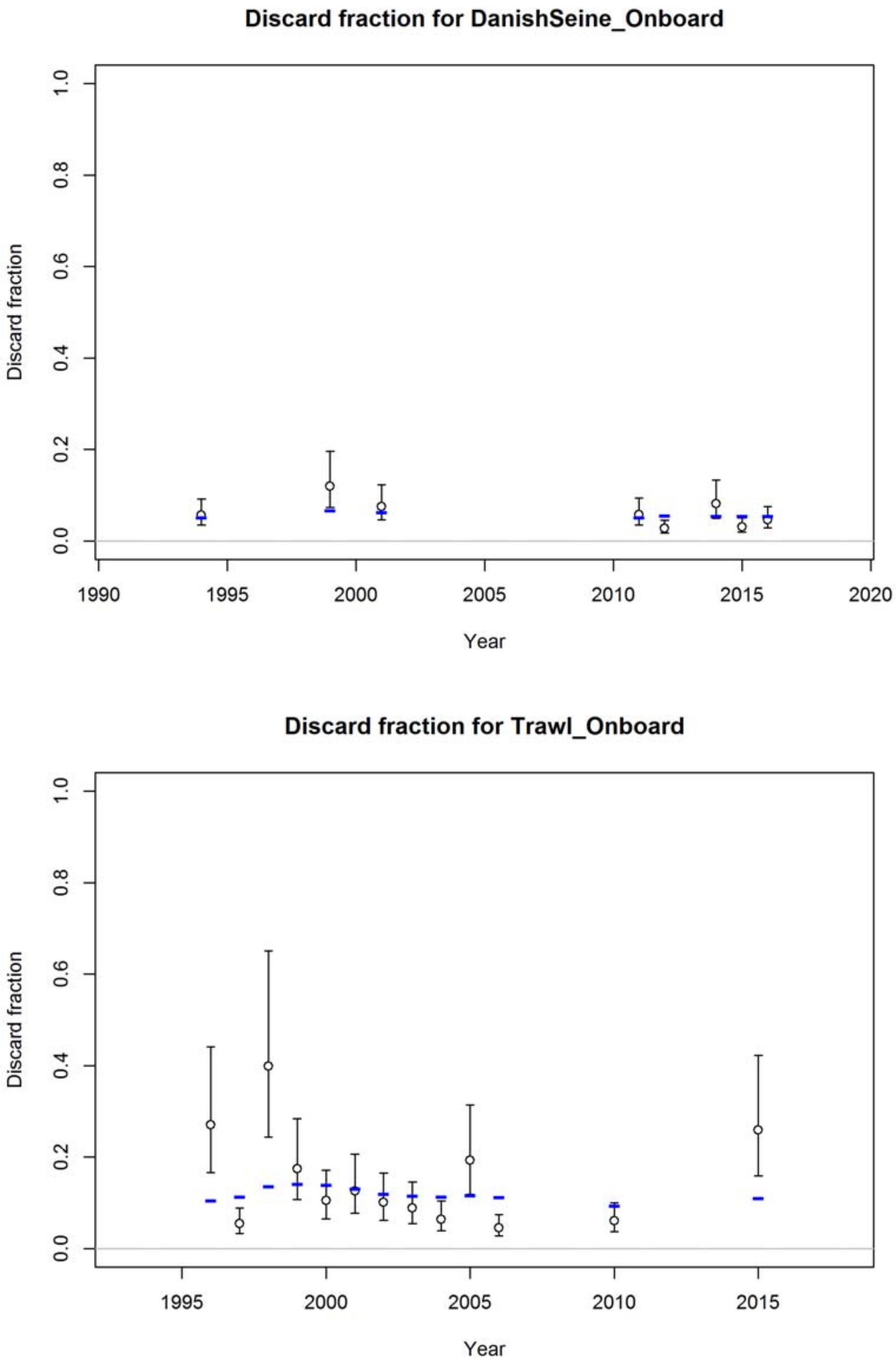


Figure 15.13. Observed (circles) and model-estimated (blue lines) discard estimates versus year for the Victorian Danish seine fleet (top) and the otter trawl fleet (bottom), with approximate 95% asymptotic intervals.

The base-case model is able to fit the retained and discarded length-frequency distributions adequately (Figure 15.14 and Appendix A), with the exception of the discards from the otter trawl fleet. This is not surprising, as the observed discard length frequencies are quite variable from year to year, and actual sample sizes are small in comparison to the retained length frequencies. The aggregated fits to the port measurements are excellent.

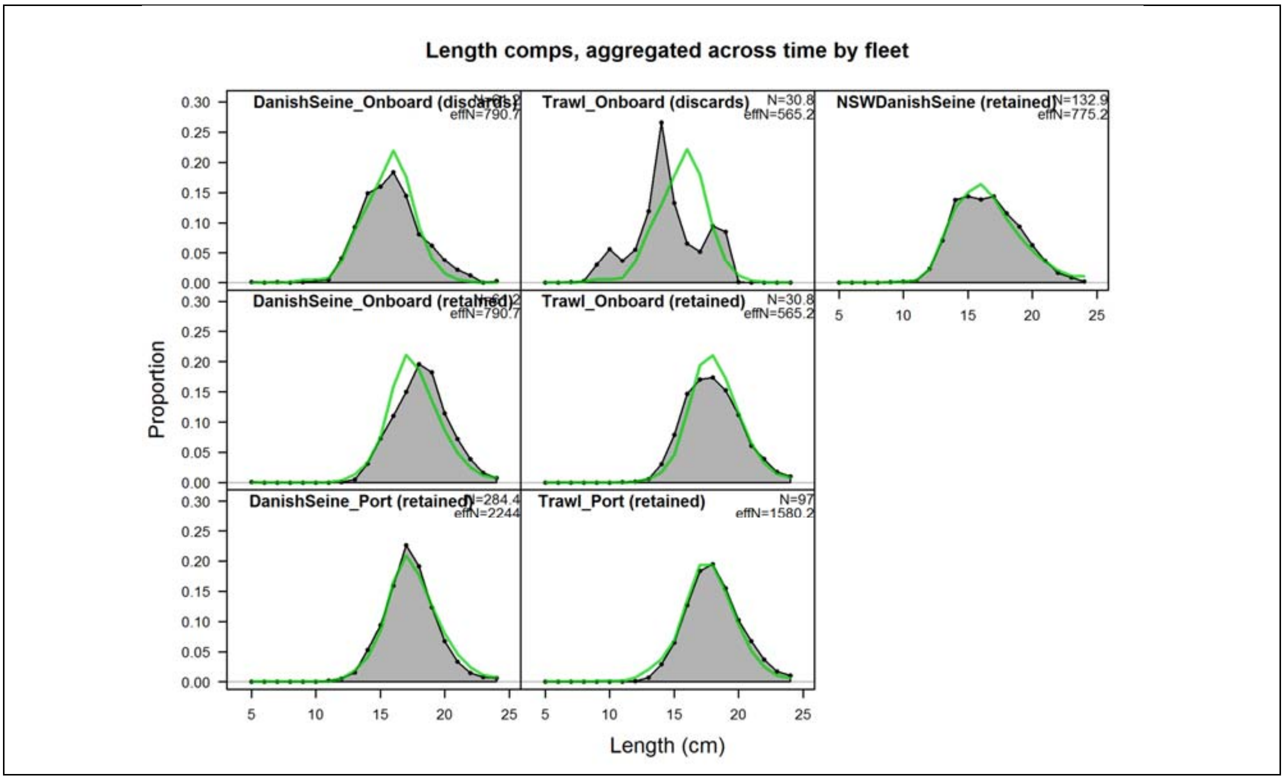


Figure 15.14. Fits to retained and discarded length compositions by fleet, separated by port and onboard samples, aggregated across all years. Observed data are grey and the fitted value is the green line.

The implied fits to the age composition data are shown in Appendix A. The age compositions were not fitted to directly, as age-at-length data were used. However, the model is capable of producing implied fits to these data for years where length frequency data are also available, even though they are not fitted directly in the assessment. The model fits the observed age data reasonably well for the two fleets with age data.

The conditional age-at-length data is quite noisy between years, with occasionally quite large changes in mean age between adjacent years, in some instances larger changes than would be expected through biology and fishing mortality. The mean age varies between 2 and 4 years for Danish seine and between 2 and 3½ years for trawl. This variability in the age-at-length data is likely to be due to spatial or temporal variation in collection of age samples. The fits to conditional age-at-length are as good as can be expected, considering the noise in the data. Residuals for these fits and mean age for each year, aggregated across length bins, are shown in Appendix A.

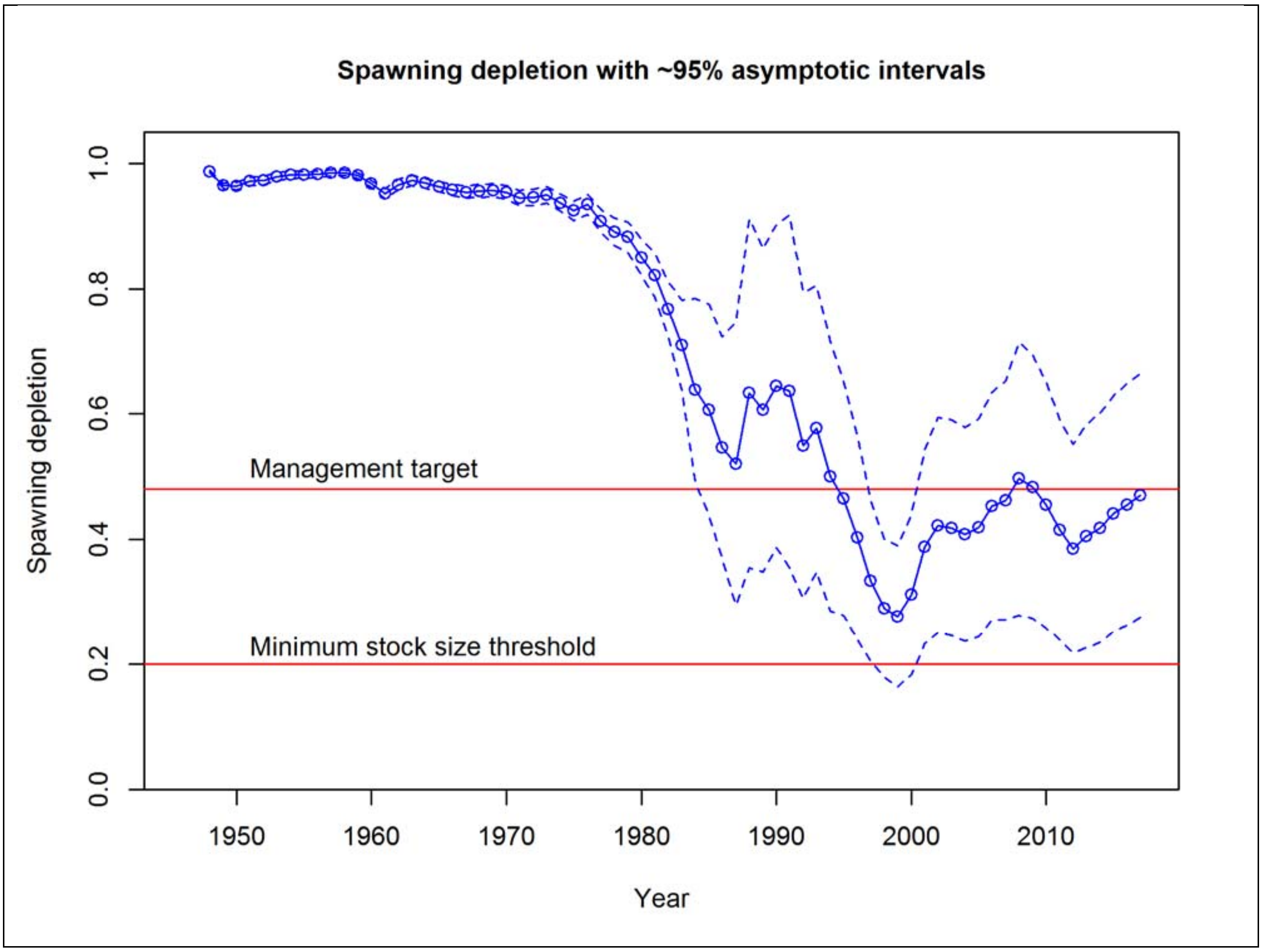


Figure 15.15. Time-trajectory of spawning biomass depletion (with approximate 95% asymptotic intervals) corresponding to the MPD estimates for the base-case analysis for school whiting (January spawning).

15.4.1.4 Assessment outcomes

The current spawning stock biomass (Figure 15.15) is estimated to be 49% of unfished stock biomass (i.e. 2018 spawning biomass relative to unfished spawning biomass), albeit with considerable uncertainty (with 95% asymptotic intervals from around 30% to 70%). The stock declines slowly from the beginning of the fishery in 1947, before a sharp decline in the 1980s corresponding to an increase in catch. The stock declines to 28% SSB_0 in 1999, before increasing to over 40% SSB_0 since 2002 and varying between around 40% and 50% SSB_0 since then. This increase came part way through a period of general decline in total catches over about 20 years, which started in the early 1990s, with this rebound also boosted by good recruitment in 1999, 2003 and 2005 (Figure 15.16). The stock has seen a gradual increase in *SSB* since 2011.

The recoveries in the late 1980s and in the early 2000s are driven by higher recruitment events, especially in the mid 1980s. After these good recruitment events, the stock declined following poor recruitments and continued harvesting (e.g. the period of six consecutive years of average or below average recruitment from 1992-1997) and as a result the stock shows considerable short term sensitivity to recruitment. Generally above average recruitment from 1998-2005 allowed a recovery in the stock from a depletion of 28% in 1999 to a depletion of over 48% in 2007. While the most recent years of recruitment are generally informed by less data and hence could potentially change with the inclusion of additional data in a future assessment, the last four years of estimated recruitment are close to average, so any such changes are unlikely to result in substantial revisions to the spawning biomass.

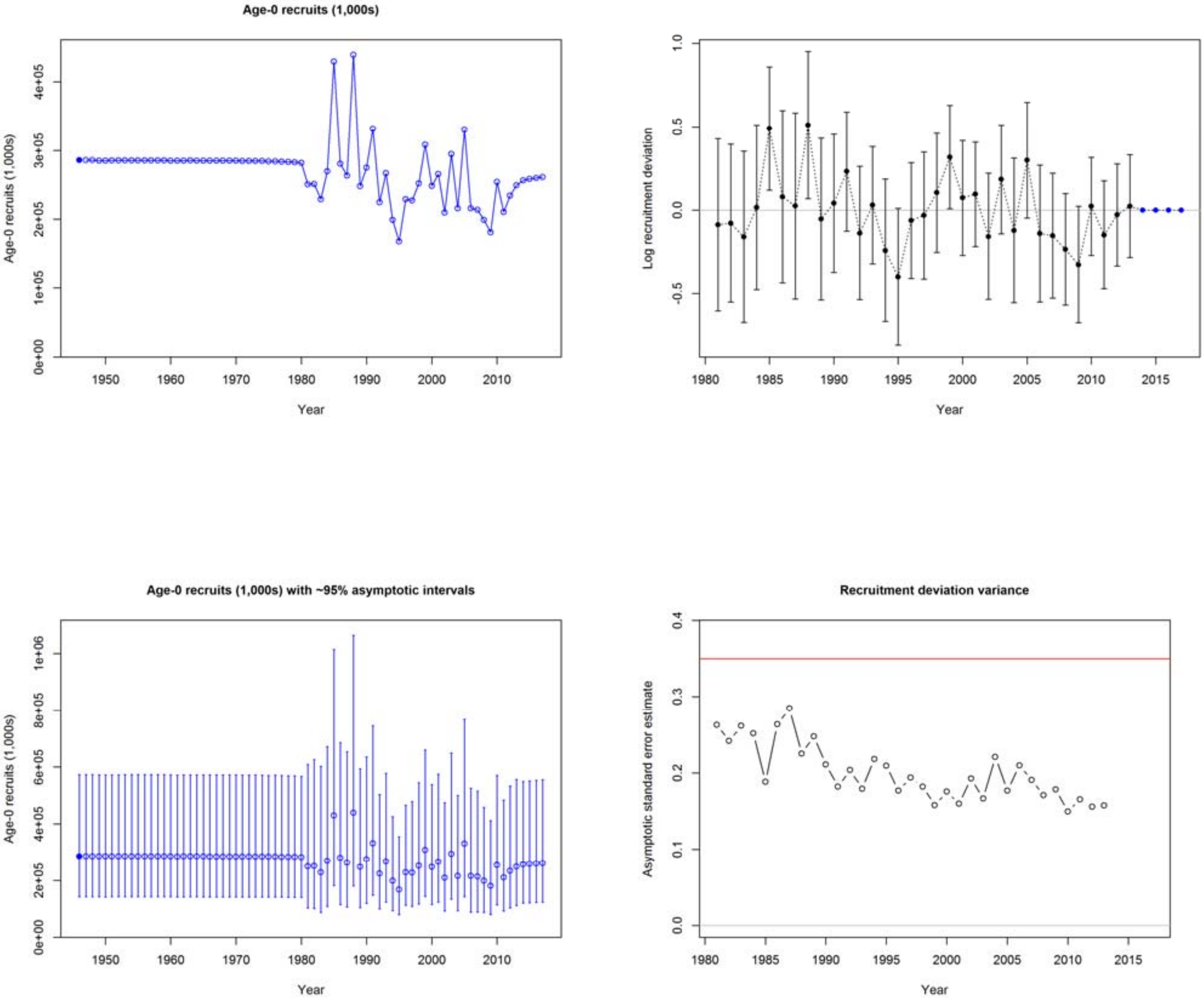


Figure 15.16. Recruitment estimation for the base case analysis. Top left : Time-trajectories of estimated recruitment numbers; top right : time trajectory of estimated recruitment deviations; bottom left : time-trajectories of estimated recruitment numbers with approximate 95% asymptotic intervals; bottom right: the standard errors of recruitment deviation estimates.

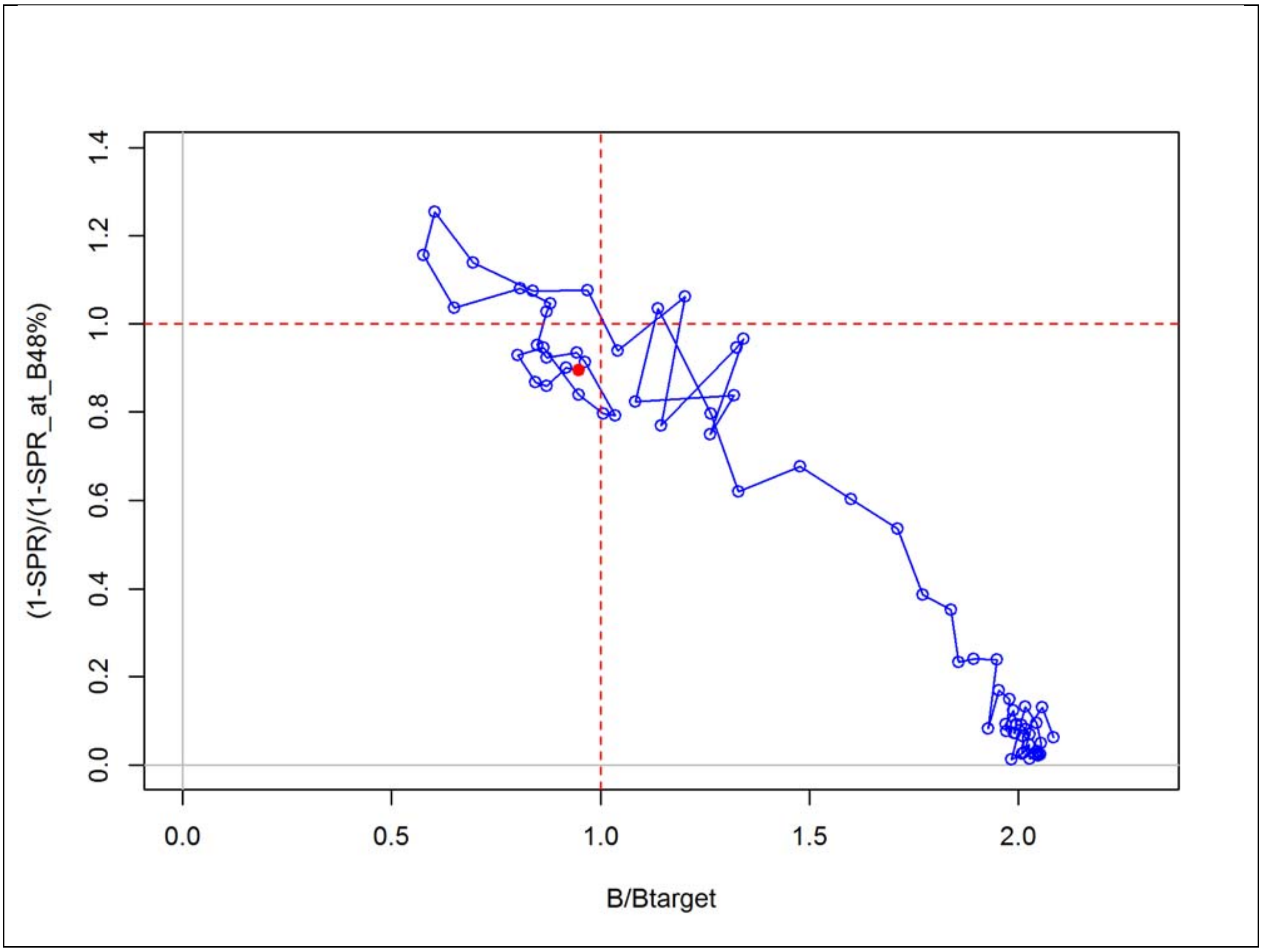


Figure 15.17. Kobe plot base case, showing the trajectory of spawning biomass (relative to B_0) plotted against 1-SPR, which is a proxy for fishing mortality, essentially integrating fishing mortality across fleets in the fishery.

Figure 15.17 shows a Kobe plot for the base case. This plot shows a time series of spawning biomass plotted against spawning potential ratio, which provides a measure of overall fishing mortality, and shows the stepwise movement in this space from the start of the fishery, in the bottom right corner, when there was low fishing mortality and high biomass to the 2017 (the red dot) where the biomass is just below the target (to the left of the vertical red dashed line) and the fishing mortality is below the target fishing level (below the horizontal red dashed line). This trajectory shows an increase in overall fishing mortality as the fishery developed from 1947, with movement from the bottom right corner to the top left corner, when the biomass was well below the target and the fishing mortality was above the target rate. The fishing mortality was gradually reduced from the late 1990s and had been below the “overfishing limit” for the last 13 years, with the spawning biomass generally increasing over this same period.

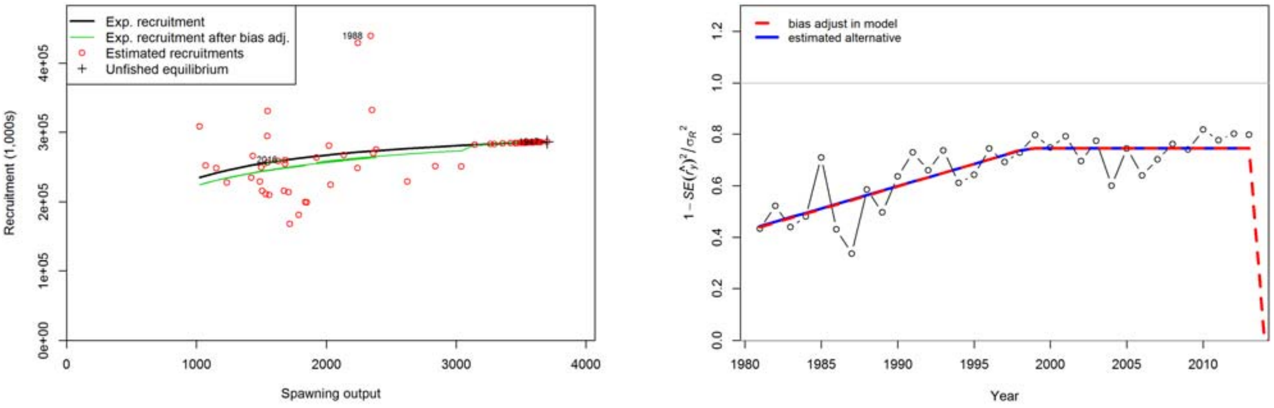


Figure 15.18. Recruitment estimation for the base case analysis. Left: the stock-recruit curve and estimated recruitments; right: bias adjustment.

The time-trajectories of recruitment and recruitment deviation are shown in Figure 15.16. Estimates of recruitments since 1981 are variable with a couple of large recruitment event in the 1980s, two periods of below average recruitment (mid 1990s and late 2000s) with a period of largely above average recruitment in between (from 1998-2005).

The base-case assessment estimates that current spawning stock biomass is 49% of unexploited stock biomass (SSB_0). The 2018 recommended biological catch (RBC) under the 20:35:48 harvest control rule is 1,606 t (Table 15.10) and the long term yield (assuming average recruitment in the future) is 1,641 t (Table 15.12). Averaging the RBC over the three year period 2018-2020, the average RBC is 1,615 t and over the five year period 2018-2022, the average RBC is 1,621 t (Table 15.12). The RBCs for each individual years from 2018-2022 are listed in Table 15.10 for the base case agreed by SERAG in December 2017.

Table 15.10. Yearly projected RBCs (tonnes) across all fleets under the 20:35:48 harvest control rules all assuming average recruitment from 2014 for the agreed base case with January spawning and improved fits to growth (sensitivity 17).

RBCs Year	Jan growth
2018	1,606
2019	1,615
2020	1,623
2021	1,630
2022	1,634

15.4.1.5 Discard estimates

Model estimates for discards for the period 2018-22 with the 20:35:48 Harvest Control Rule are listed in Table 15.11 for the for the base case agreed by SERAG in December 2017, with a range of 119 to 121 t.

Table 15.11. Yearly projected discards (tonnes) across all fleets under the 20:35:48 harvest control rules with catches set to the calculated RBC for each year from 2018 to 2022 for the agreed base case with January spawning and improved fits to growth (sensitivity 17).

Discards Year	Jan growth
2018	119
2019	120
2020	120
2021	121
2022	121

15.4.2 *Sensitivity tests and alternative models*

Results of the sensitivity tests are shown in Table 15.12. Some sensitivities were not able to be completed (halving the weight on age comps, doubling the weight on CPUE, σ_r =0.3) without the model being able to produce results and, in these cases, intermediate sensitivities were conducted, with movement of the respective parameters in the appropriate direction.

As with the 2009 assessment, results are not very sensitive to results are very sensitive to the assumed values for steepness, *h*, von Bertalanffy *k* and σ_r (relative to the base-case), but are quite sensitive to the age at 50% maturity. School whiting become sexually mature at two years of age (Smith and Wayte, 2005), which corresponds to a length of around 16cm. Three year olds are about 18cm long and school whiting reach 14cm at about 1½ years old. One year old fish are around 11-12 cm and are unlikely to be sexually mature. Other reports of length at maturity for school whiting range from 15cm in northern NSW (Kevin Rowling, pers comm. based on an unpublished research by Grey and Barnes) and 17cm in Victoria (Hyndes and Potter, 1997, based on data from Hobday and Wankowski (1986)). The base case value for length at 50% maturity has been left at 16cm.

This assessment is not sensitive to the weighting placed on the length compositions or the CPUE series with the depletion ranging from 47% to 53% in these cases. The assessment is more sensitive to the weightings on the age data, with a depletions around 40% if the weighting on age data is either halved or doubled. This suggested that the age data is well tuned, with the likelihood values also deteriorating in both cases (Table 15.13). Some inconsistencies in the age-at-length data between years, indicate that there could be unrepresentative sampling of the age data (either temporally or spatially) or some other dynamics which are unable to be captured by the model. This is also reflected in the sensitivities altering the weighting on the age data and it indicates that the age data is balanced as well as is possible. The length and age data weightings were set according to standard practice in SESSF stock assessments, using iterative reweighting of this data to match input and output effective sample sizes.

Doubling and halving the discard proportions results in depletion ranging from 47% to 53%, but given these inputs are based on data, there appears to be no evidence based justification for making this alterations.

In addition to the standard sensitivities, (cases 1-14 in Table 15.12), four additional sensitivities were investigated.

The initial sensitivity excluding all catch data north of Barrenjoey Point (S15a) has a different catch series which is shown by fleet (with recent NSW Danish seine catches obscured) in Figure 15.19 and by jurisdiction in Figure 15.20. This results in an estimated depletion below 20%. This model is fully balanced. However, further investigation shows that this should not be considered as a serious sensitivity due to the resulting low estimate of mortality (Table 15.12). With less catch data used in this sensitivity, it appears there may not be enough data to adequately estimate mortality. A variation of this sensitivity, using the same modified catch series excluding all catch north of Barrenjoey, with mortality fixed at 0.6 was also conducted (S15). This produced an estimate of 2018 spawning biomass of 39% (Figure 15.21).

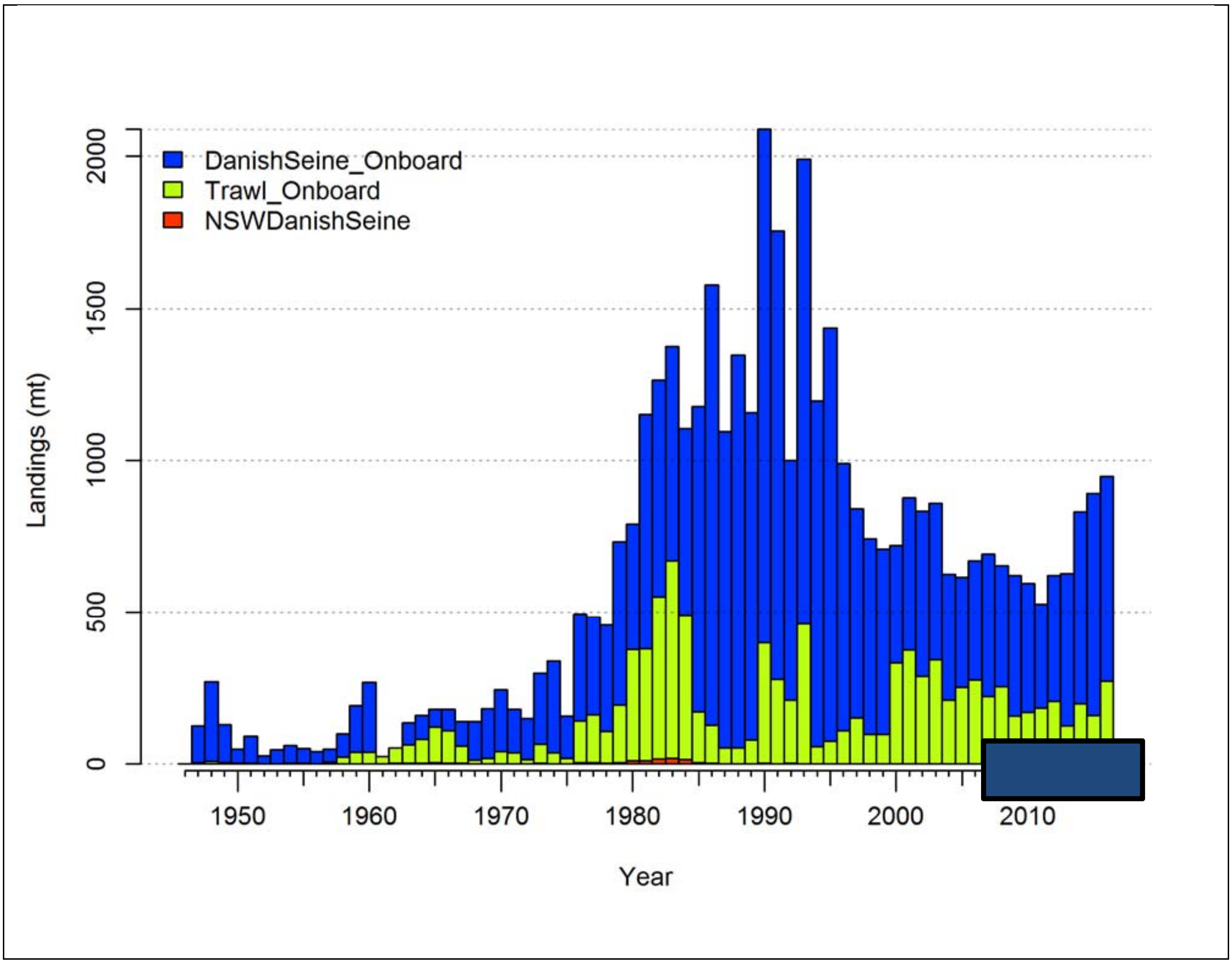

[redacted]

Figure 15.19. Total landed catch (tonnes) of school whiting by fleet (stacked) from 1947-2016 excluding all catches north of Barrenjoey Point. Recent NSW Danish seine catches are not publicly available.

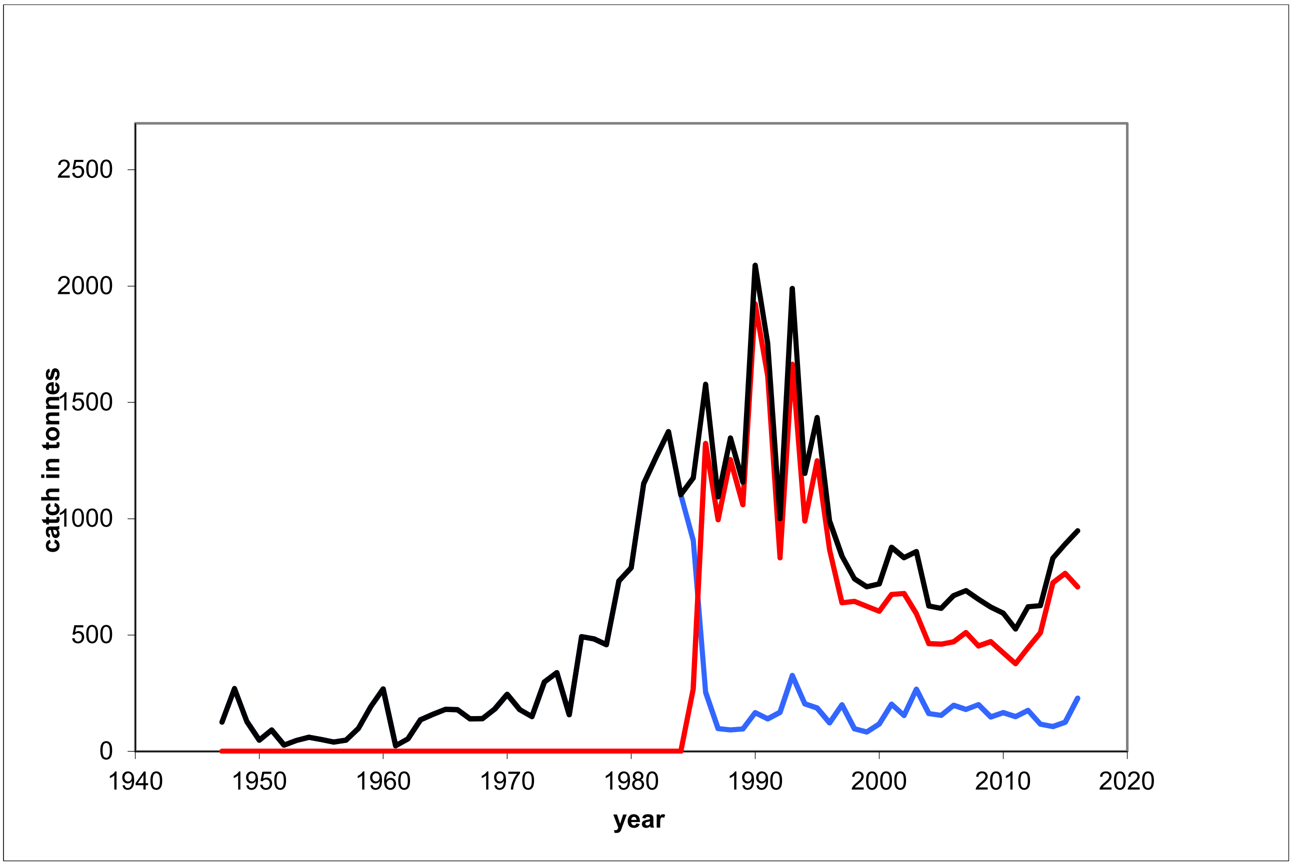


Figure 15.20. Total landed catch of school whiting in the SESSF from 1947-2016 (black line with circles) excluding all catches north of Barrenjoey Point, and this same catch separated into jurisdiction with state catches (blue) and Commonwealth catches (red). The Commonwealth catch south of Barrenjoey Point is considerably larger than the state catch south of Barrenjoey Point from 1987-2016. The state catches (blue) comprise the whole catch until 1985. The Commonwealth catch starts in 1985.

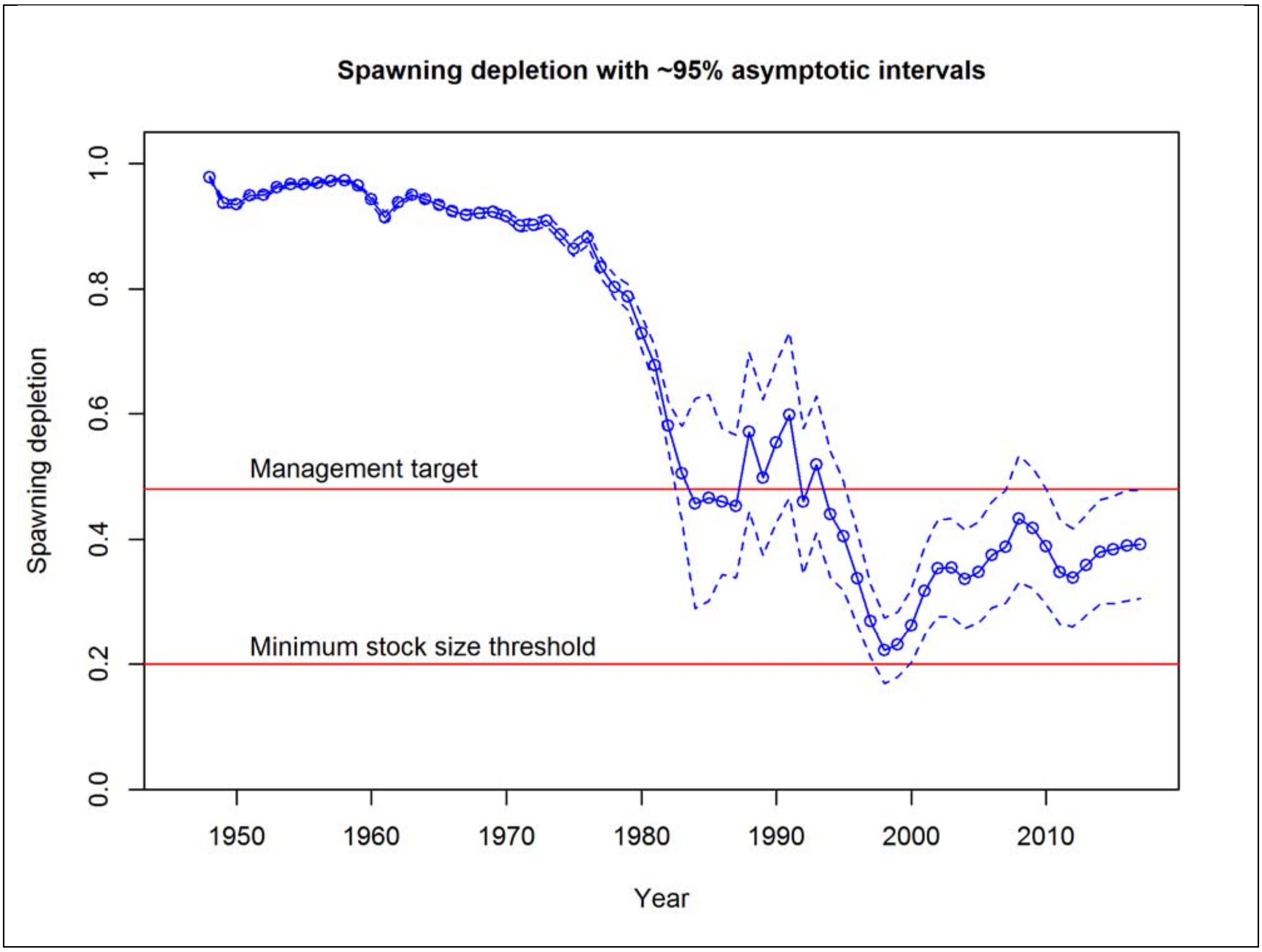


Figure 15.21. Time-trajectory of spawning biomass depletion for school whiting (with approximate 95% asymptotic intervals) corresponding to the MPD estimates for Sensitivity 15, excluding all catches north of Barrenjoey Point.

The sensitivity with winter spawning (S16) produced very similar results to the base case with January spawning (Table 15.12). Improving the fit to the growth (S17) also produced very similar results (Table 15.12). Comparative plots are shown for relative spawning biomass (Figure 15.21) and recruitment series (Figure 15.22) for: the November provisional base case with July spawning (blue); the SERAG suggested base case with January spawning (red); and the model with improved growth estimates and January spawning (green), illustrating the similarities in the results from these three alternative base cases.

Unweighted likelihood components for the base case and differences for the sensitivities reveal several points (Table 15.13). The overall likelihood is only improved for the sensitivity excluding data north of Barrenjoey (S15), but in this case comparison of likelihood is not meaningful due to the difference in data inputs between this sensitivity and the base case. Apart from this one case, none of the sensitivities show an improvement in overall likelihood, indicating that the model is not greatly sensitive to the variations in parameters tested, that the model is remarkably stable and well balanced.

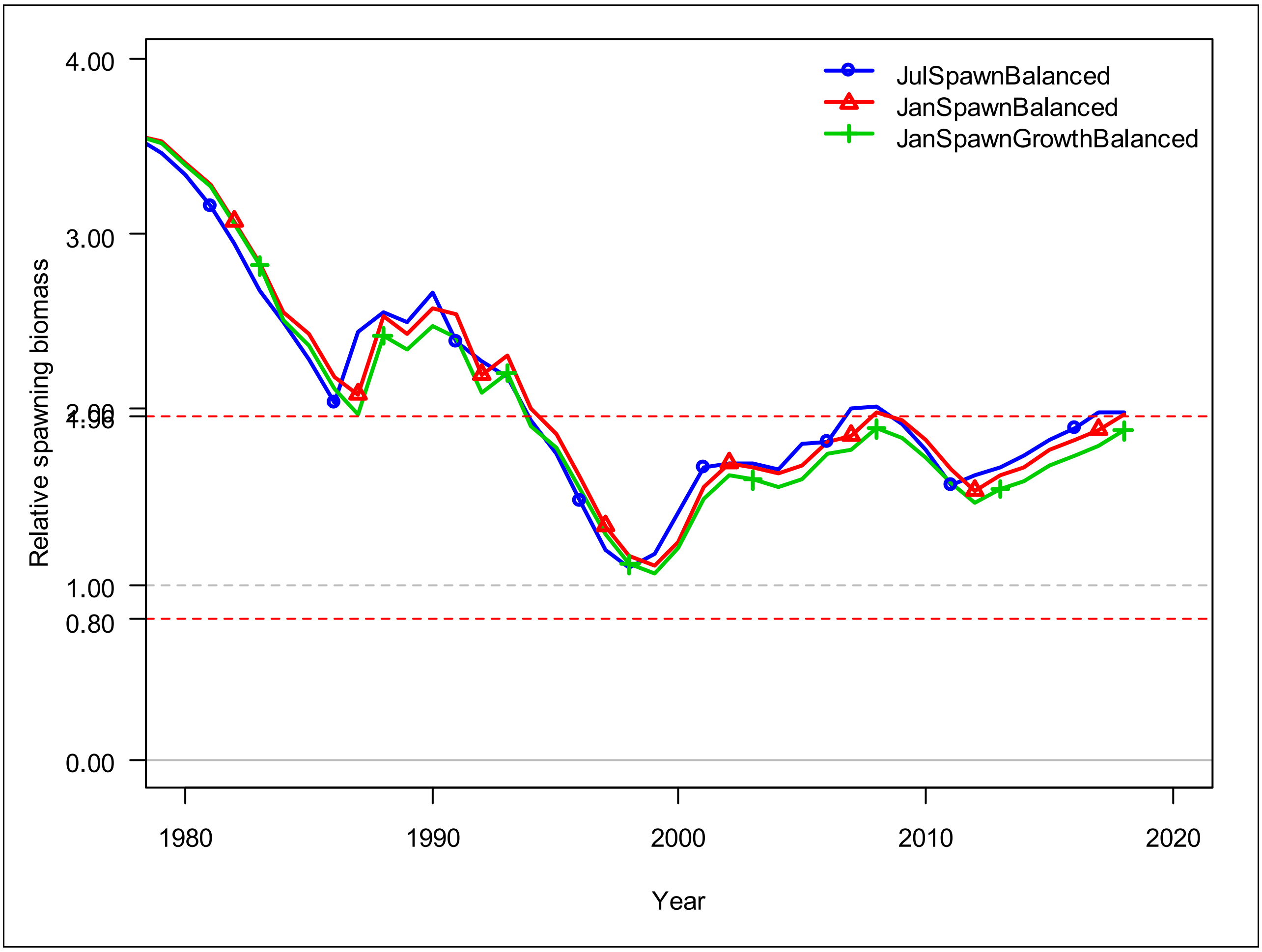


Figure 15.22. Comparative spawning biomass time series for: the November provisional base case with July spawning (blue); the SERAG suggested base case with January spawning (red); and the model with improved growth estimates and January spawning (green). Note the translation of the series to the right for January spawning.

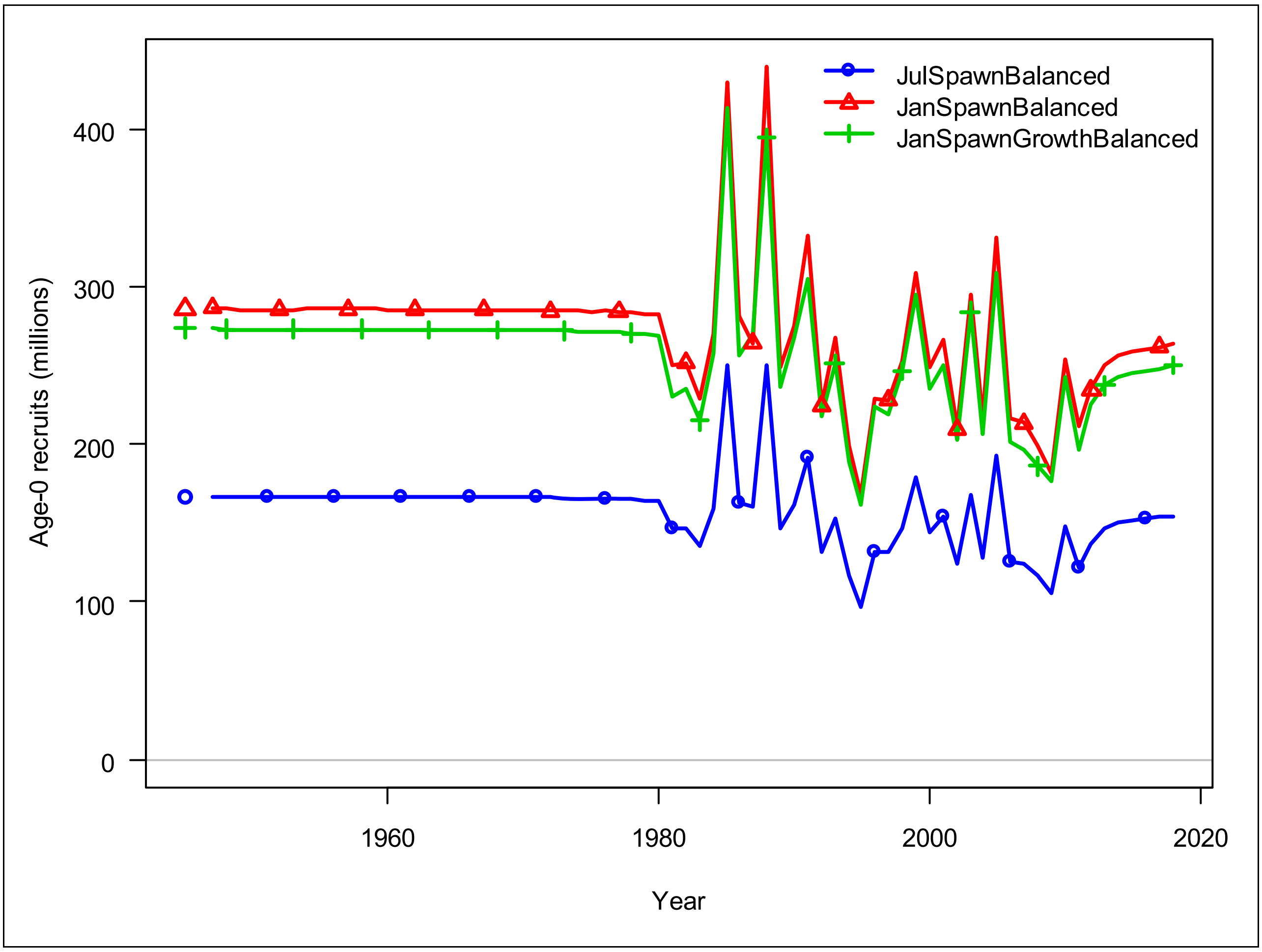


Figure 15.23. Comparative recruitment series for: the November provisional base case with July spawning (blue); the SERAG suggested base case with January spawning (red); and the model with improved growth estimates and January spawning (green). Note the change in absolute value of recruitment when the spawning month is changed. This relates to mortality up to age one being applied to either six months (July spawning) or 12 months (January spawning).

15.4.3 *Future work*

15.4.3.1 Stock structure

Further genetic work to determine any stock structure would be very useful. If such work was to produce clear suggestions recommending geographical separation of stocks, issues relating to separation of the data input to the assessment to match any new stock structure would need to be addressed.

15.4.3.2 2010 age data

The 2010 Danish seine age-at-length data needs to be properly coded so this data can be included in a future assessment. This should be a straightforward addition to the next stock assessment.

15.4.3.3 NSW state data

Provision of NSW state data for a future stock assessment, including discarding rates, length and age composition data and possible catch rate data would be very useful, especially as this would provide more information on the fishery at the northern part the distribution. The current model has limited information on this part of the fishery.

15.4.3.4 Likelihood profiles

A likelihood profile on R_0 would be a useful diagnostic to provide in a future assessment.

15.4.3.5 Retrospective analyses

Retrospective analyses could also be useful diagnostics, although there is no indication of any pathological behaviour with recent estimates of recruitment deviations being close the average.

Table 15.12. Summary of results for the base-case and sensitivity tests. Recommended biological catches (RBCs) are only shown for agreed base case model models (Case 17).

Case		**SSB_0**	**SSB_{2018}**	**SSB_{2018}/SSB_0**	**Mortality**	**RBC_{2018}**	**$RBC_{2018-20}$**	**$RBC_{2018-22}$**	**$RBC_{longterm}$**
0	base case Jan spawn	7,399	3,568	0.48	0.62				
1	h 0.65	7,769	3,758	0.48	0.65				
2	h 0.85	7,131	3,586	0.50	0.60				
3	50% maturity at 14cm	9,086	5,191	0.57	0.61				
4	50% maturity at 18cm	5,415	2,188	0.40	0.65				
5	$\sigma_R = 0.325$	7,379	3,590	0.49	0.61				
6	$\sigma_R = 0.4$	7,451	3,764	0.51	0.63				
7	wt x 2 length comp	7,589	3,667	0.48	0.59				
8	wt x 0.5 length comp	7,387	3,596	0.49	0.63				
9	wt x 2 age comp	7,295	2,983	0.41	0.55				
10	wt x 0.75 age comp	6,959	2,693	0.39	0.55				
11	wt x 1.5 CPUE	7,256	3,820	0.53	0.65				
12	wt x 0.5 CPUE	7,530	3,519	0.47	0.59				
13	discard proportion x 2	8,163	4,334	0.53	0.64				
14	discard proportion x 0.5	7,110	3,361	0.47	0.61				
15a	exclude catch north of BJ	5,551	917	0.17	0.43				
15	BJ with M=0.6	4,287	1,691	0.39	0.60				
16	Jul spawn	7,317	3,624	0.50	0.64				
17	improved growth	7,547	3,539	0.47	0.59	1,606	1,615	1,621	1,641

Table 15.13. Summary of likelihood components for the base-case and sensitivity tests. Likelihood components are unweighted, and cases 1-17 are shown as differences from the base case. A negative value indicates a better fit, a positive value a worse fit.

Case		**Likelihood**						
		TOTAL	**Survey**	**Discard**	**Length comp**	**Age comp**	**Recruitment**	**Parm_priors**
0	base case Jan spawn	95.41	-66.18	23.09	91.60	63.40	-17.30	0.58
1	h 0.65	0.14	-0.19	0.24	-0.27	-0.08	0.18	0.30
2	h 0.85	0.10	0.14	-0.16	0.22	0.05	-0.06	-0.11
3	50% maturity at 14cm	0.00	0.12	-0.14	0.14	0.02	-0.16	0.00
4	50% maturity at 18cm	0.18	-0.11	0.35	-0.27	-0.10	0.35	0.00
5	$\sigma_R = 0.325$	-0.75	0.57	0.00	-0.02	0.01	-1.31	0.00
6	$\sigma_R = 0.4$	1.47	-1.07	0.04	0.10	0.02	2.39	0.00
7	wt x 2 length comp	2.21	3.66	2.70	-4.75	0.54	0.05	0.00
8	wt x 0.5 length comp	1.45	-0.53	-3.08	4.91	-0.11	0.28	0.00
9	wt x 2 age comp	7.05	3.87	-0.83	2.51	1.05	0.10	0.01
10	wt x 0.75 age comp	6.20	2.03	-1.93	1.32	4.20	0.15	0.01
11	wt x 1.5 CPUE	1.48	-5.33	1.03	1.74	1.00	3.08	0.01
12	wt x 0.5 CPUE	1.41	5.23	-0.89	-1.25	-0.39	-1.32	0.00
13	discard proportion x 2	2.02	-0.15	2.02	0.53	-0.33	-0.02	0.00
14	discard proportion x 0.5	-1.12	0.38	-1.00	-0.54	0.20	-0.18	0.00
15a	exclude catch north of BJ	-9.71	-8.77	-2.86	-1.95	-3.22	6.97	0.05
15	BJ with M=0.6	-4.08	-4.82	-1.47	-1.55	-2.02	5.88	0.00
16	Jul spawn	-1.37	0.44	0.13	-0.42	-1.62	0.07	0.05
17	improved growth	2.36	1.04	-0.47	1.20	0.35	0.19	0.05

15.5 Acknowledgements

Age data was provided by Kyne Krusic-Golub (Fish Ageing Services), ISMP and AFMA logbook and CDR data were provided by John Garvey (AFMA). Mike Fuller, Roy Deng, Franzis Althaus and Robin Thomson (CSIRO) pre-processed the data. Karina Hall (NSW DPI) provided NSW catch data and advice on school whiting fisheries in NSW state waters. Malcolm Haddon provided useful code for auto-balancing, Athol Whitten provided R code for organising plots. Geoff Tuck, Malcolm Haddon, André Punt, Robin Thomson, Miriana Sporcic, Claudio Castillo-Jordán and Neil Klaer are thanked for helpful discussions on this work. Ian Taylor and Rick Methot from NOAA are thanked for considerable technical advice on Stock Synthesis and r4ss and other contributions to this assessment.

15.6 References

Anonymous 1992. Length Frequency distributions for south east trawl fish species measurements at Lakes Entrance and Portland, 1991-92. Report from Department of Conservation and Natural Resources, Fisheries Branch, October 1992, 20pp.

Bax NJ, and Knuckey IA 2002. Draft. Evaluation of selectivity in the South-East fishery to determine its sustainable yield. Final Report to the Fisheries Research and Development Corporation. FRDC Project 96/140.

Cui G, Punt, AE and Cope JM 2004. Summary of the stock assessment for school whiting (Sillago flindersi) based on data up to 2003. In: Tuck, G.N. and Smith, A.D.M. (Eds.) Stock assessment for southern and eastern scalefish and shark fishery 2004-2005 and southern shark fishery species. Fisheries Research and Development Corporation and CSIRO Marine Research, Hobart 222 pp.

Day J. 2007. School whiting (Sillago flindersi) stock assessment based on data up to 2006. Unpublished report to Shelf RAG. 55 pp.

Day J. 2008a. Modified breakpoint for the 2008 Tier 1 harvest control rule. Unpublished report to Shelf RAG. 6 pp.

Day J. 2008b. School whiting (Sillago flindersi) stock assessment based on data up to 2007. Unpublished report to Shelf RAG. 63 pp.

Day J. 2017. School whiting (Sillago flindersi) stock assessment based on data up to 2016 – development of a preliminary base case. Unpublished report to SERAG. 48 pp.

Dixon PI, Crozier RH and Black M 1986. School whiting – how many species. Australian Fisheries Journal, 45: 33-38.

Dixon PI, Crozier RH Black M and Church A 1987. Stock identification and discrimination of commercially important whitings in Australian waters using genetic criteria. Final Report, Centre for Marine Science, University of New South Wales.

Haddon M and Sporcic M 2017. Statistical CPUE standardizations for selected SESSF species (data to 2016). Document prepared for SE RAG Meeting November 2017. Hobart. 270 pp.

Hobday DK and Wankowski JWJ 1986. Age determination of school whiting. Internal Report No. 130, Victorian Department of Conservation, Forests and Lands, Fisheries Division, Queenscliff. 21 pp.

Hyndes GA and Potter IC 1997. Age, growth and reproduction of Sillago schomburgkii in south-western Australian, nearshore waters and comparisons of life history styles of a suite of Sillago species. Env. Biol. of Fishes 49: 435–447.

Klaer N and Thomson R 2006. Yield, total mortality and Tier 3 estimates for selected shelf and slope species in the South East Fishery. Presented to the Shelf and Slope Assessment Groups, 2006.

Methot RD 2005. Technical Description of the Stock Synthesis II Assessment Program Version 1.17 – March 2005. NOAA Fisheries Internal Report.

Methot RD 2009. User manual for Stock Synthesis. Model Version 3.03a. NOAA Fisheries Service, Seattle. 143 pp.

Methot RD, A'mar T, Wetzel C and Taylor I 2017. Stock Synthesis User manual. Version 3.30.05. NOAA Fisheries Service, Seattle. 183 pp.

Pease BC and Grinberg A 1995. New South Wales commercial fisheries statistics 1940 to 1992. Fisheries Research Institute report, 351 pp.

Punt AE 1999. ADAPT and integrated analysis assessments of school whiting. Document submitted to the 17-18 June 1999 school whiting workshop 18pp.

Punt AE Smith DC and Koopman MT 2005. Using information for 'data-rich' species to inform assessments of 'data-poor' species through Bayesian stock assessment methods. Final report to Fisheries Research and Development Corporation. FRDC Project 2002/094. Primary Industries Research Victoria, Queenscliff.

Richards LJ, Schnute JT, Kronlund .R and Beamish RJ 1992. Statistical models for the analysis of ageing error. Can. J. Fish. Aquat. Sci. 49: 1801–1815.

Smith ADM, Smith DC, Tuck GN, Klaer N, Punt AE, Knuckey I, Prince J, Morison A, Kloser R, Haddon M, Wayte S, Day J, Fay G, Fuller M, Taylor B and Little LR 2008. Experience in implementing harvest strategies in Australia's south-eastern fisheries. Fish.Res. 94: 373–379.

Smith ADM and Wayte SE (eds) 2005. The Southern and Eastern Scalefish and Shark Fishery 2004, Fishery Assessment Report compiled by the Southern and Eastern Scalefish and Shark Fishery Assessment Group. Australian Fisheries Management Authority, Canberra.

Wankowski JWJ 1983. The Lakes Entrance Danish seine fishery for tiger flathead, school whiting and jackass morwong, 1947-1978. Technical Report No. 30 from Department of Conservation Forests and Lands, Fisheries Branch, July 1983, 30pp.

15.7 Appendix A

15.7.1 *Fits to length composition, implied fits to age composition, and diagnostics for fits to conditional age-at-length data.*

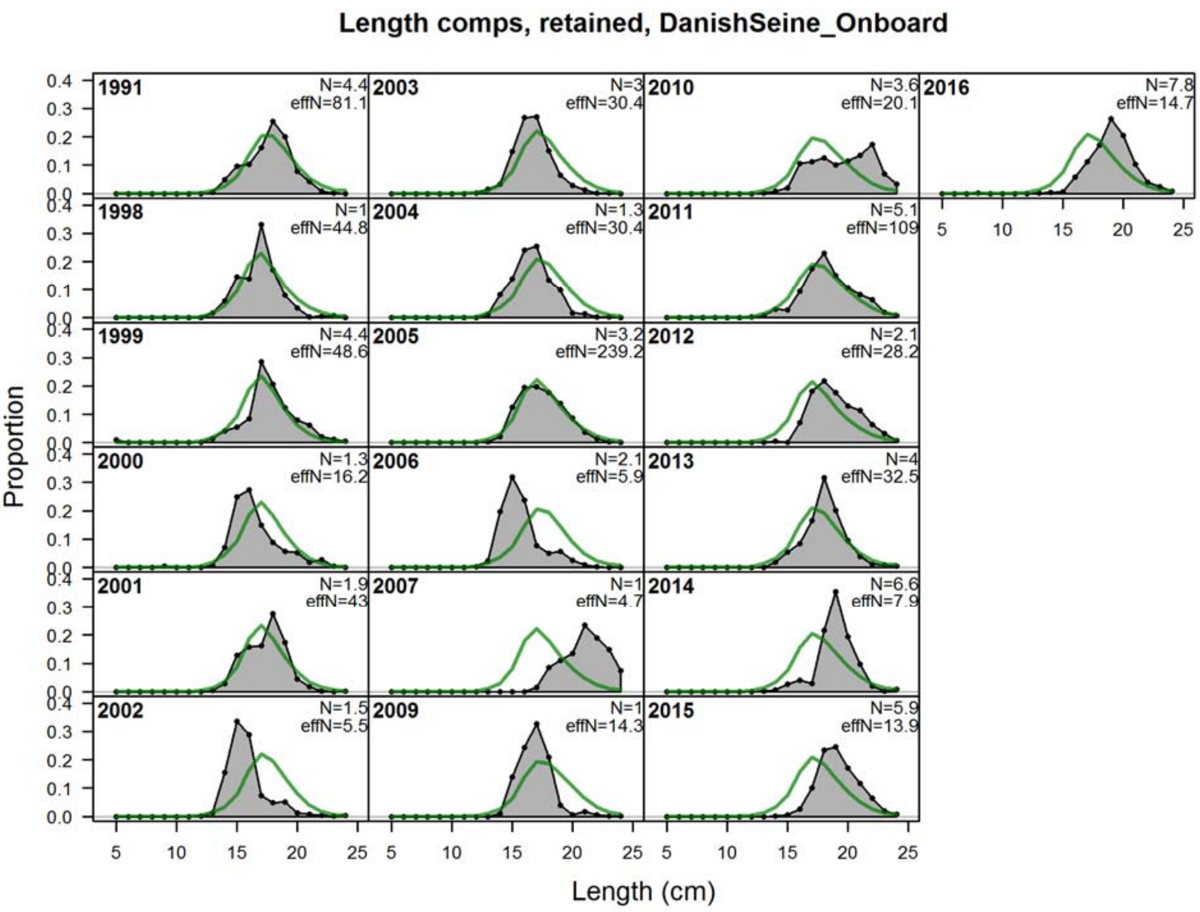


Figure A 15.1. School whiting length composition fits: Danish seine onboard retained..

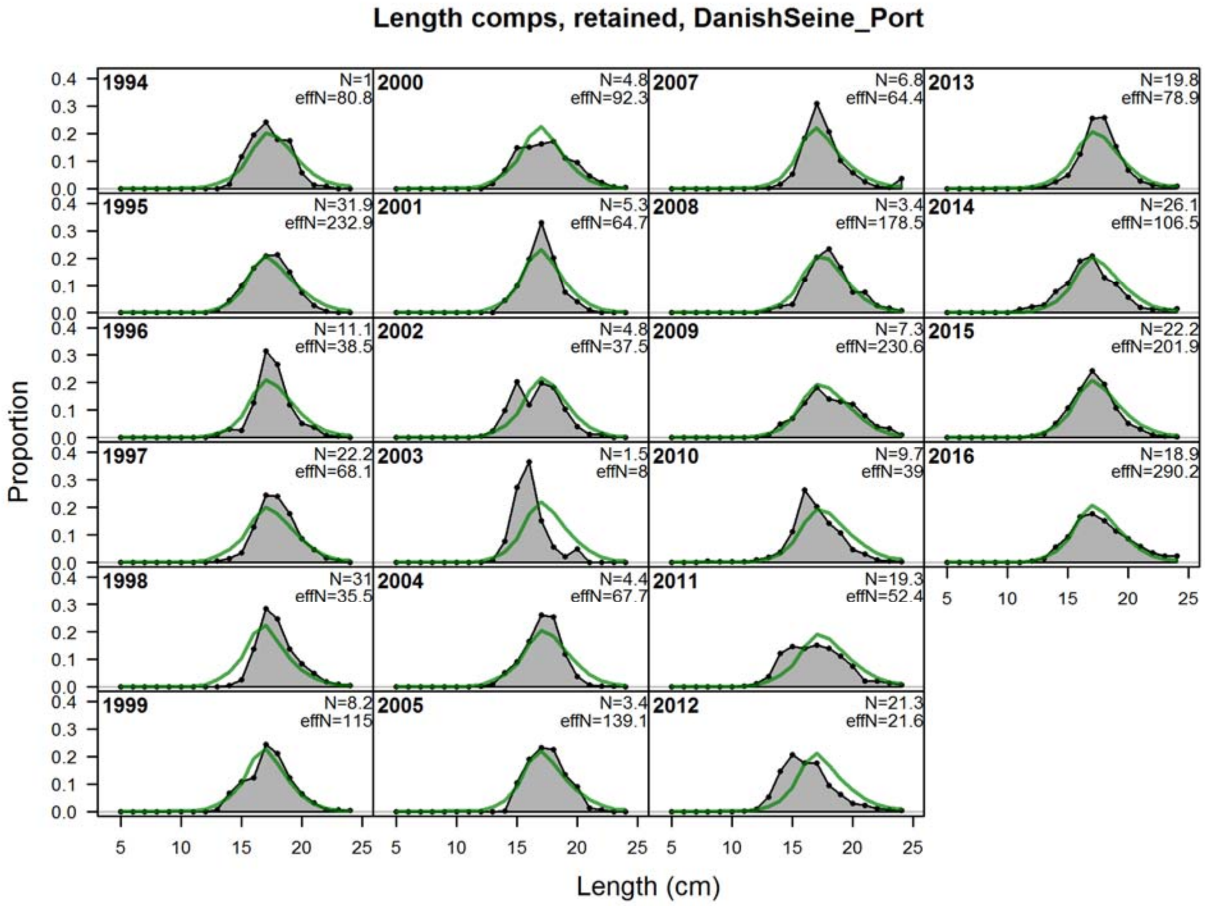


Figure A 15.2. School whiting length composition fits: Danish seine port retained.

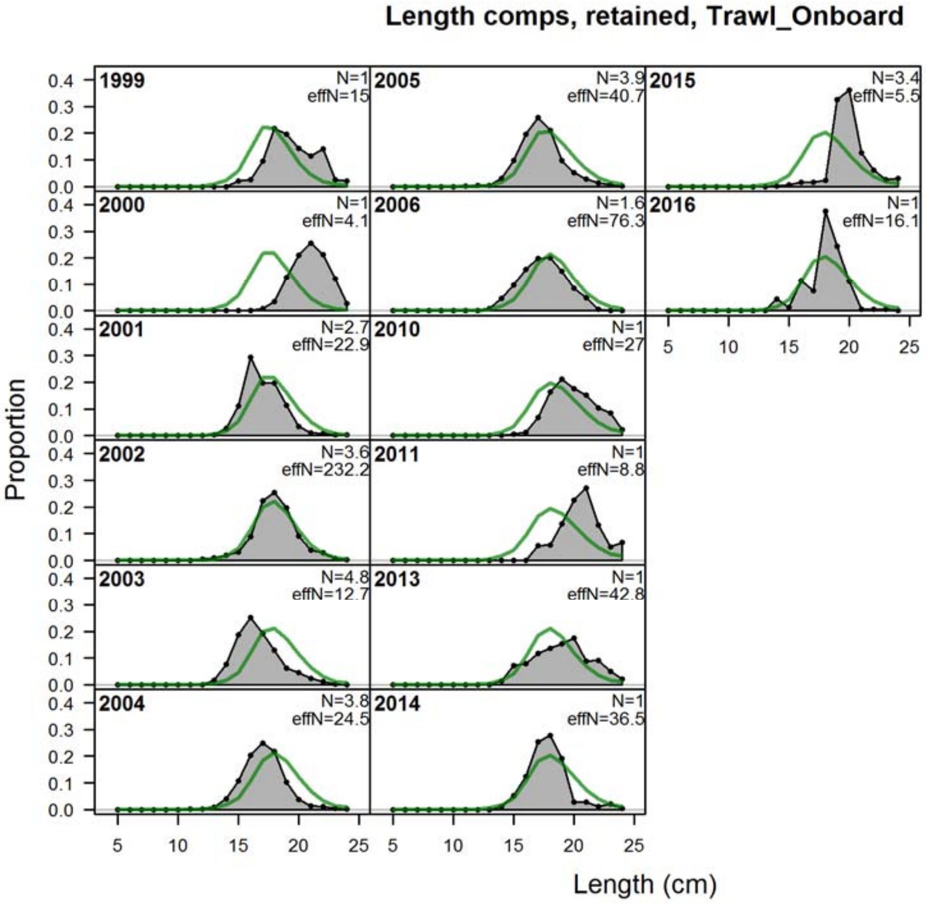


Figure A 15.3. School whiting length composition fits: trawl onboard retained.

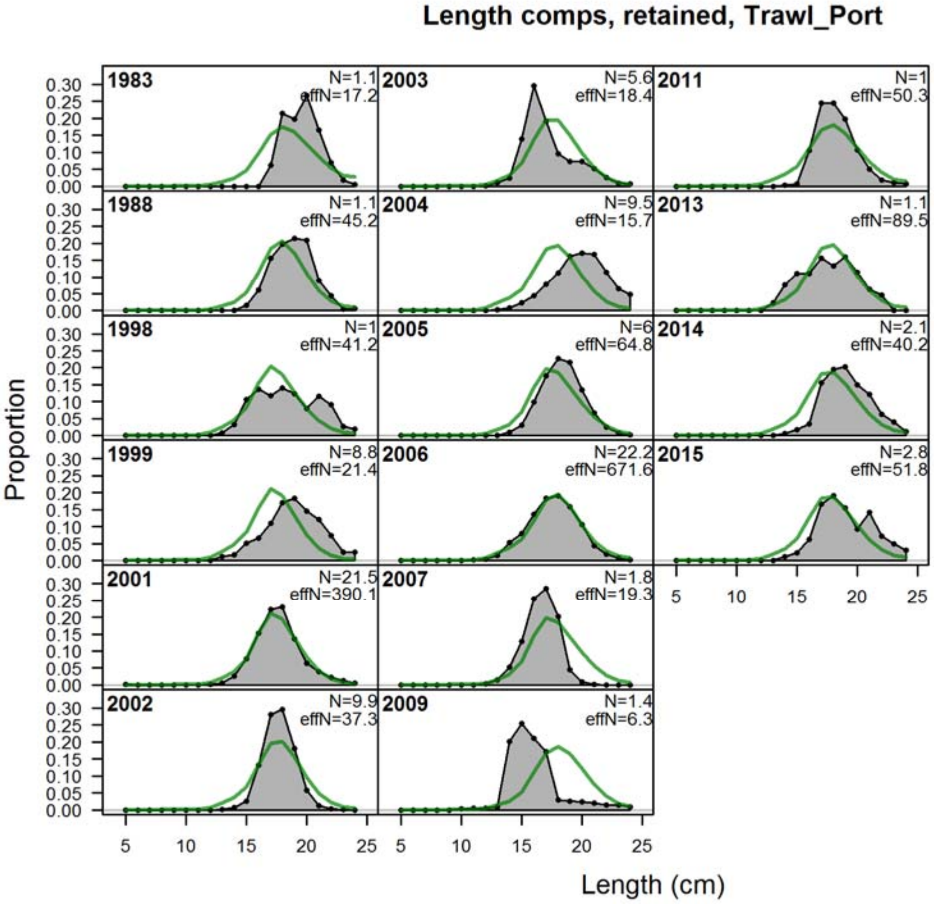


Figure A 15.4. School whiting length composition fits: trawl port retained.

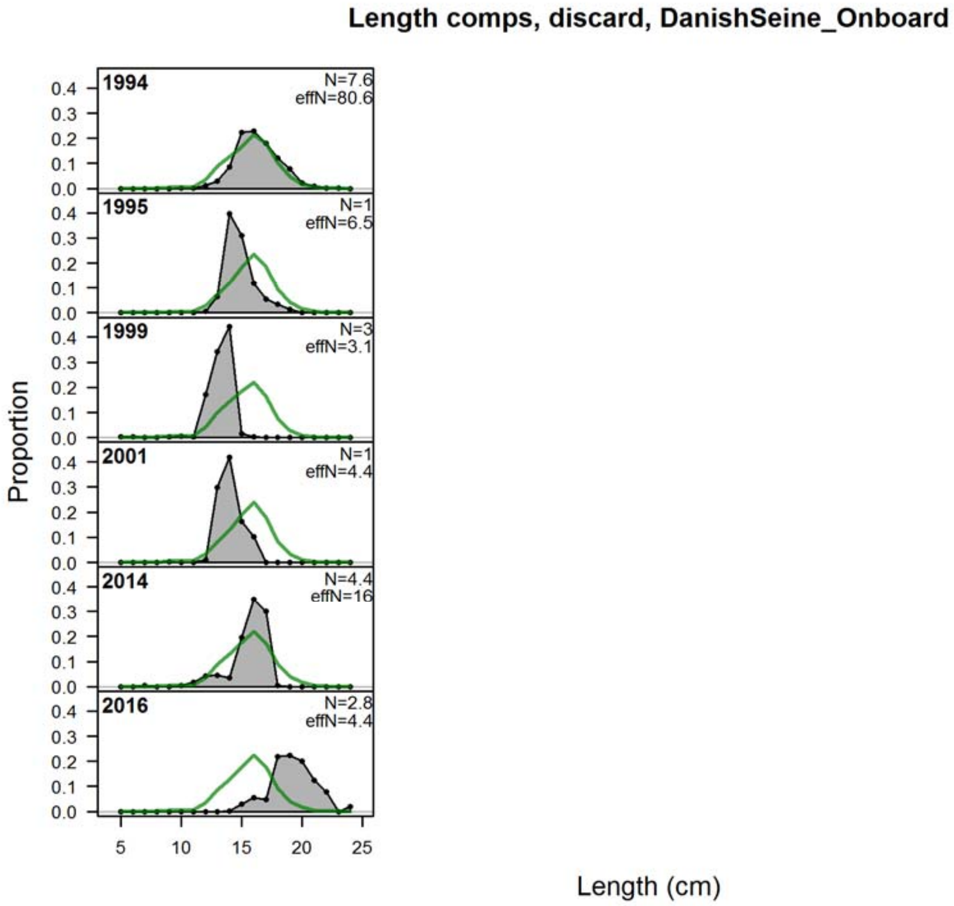


Figure A 15.5. School whiting length composition fits: Danish seine discarded.

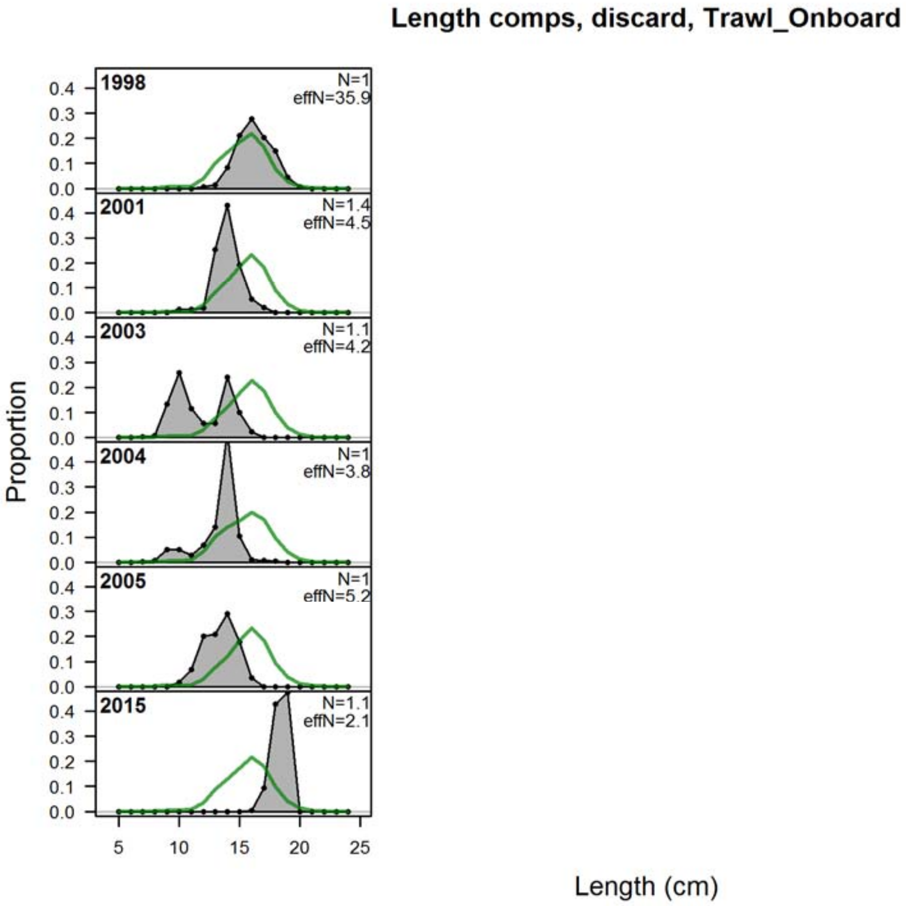


Figure A 15.6. School whiting length composition fits: trawl discarded.

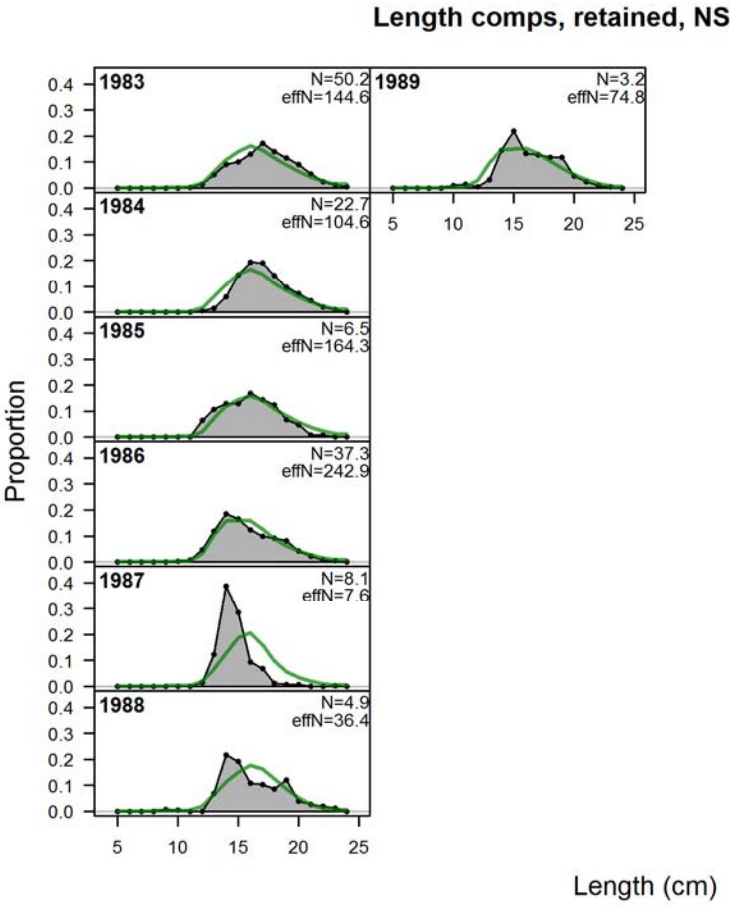


Figure A 15.7. School whiting length composition fits: NSW Danish seine port retained.

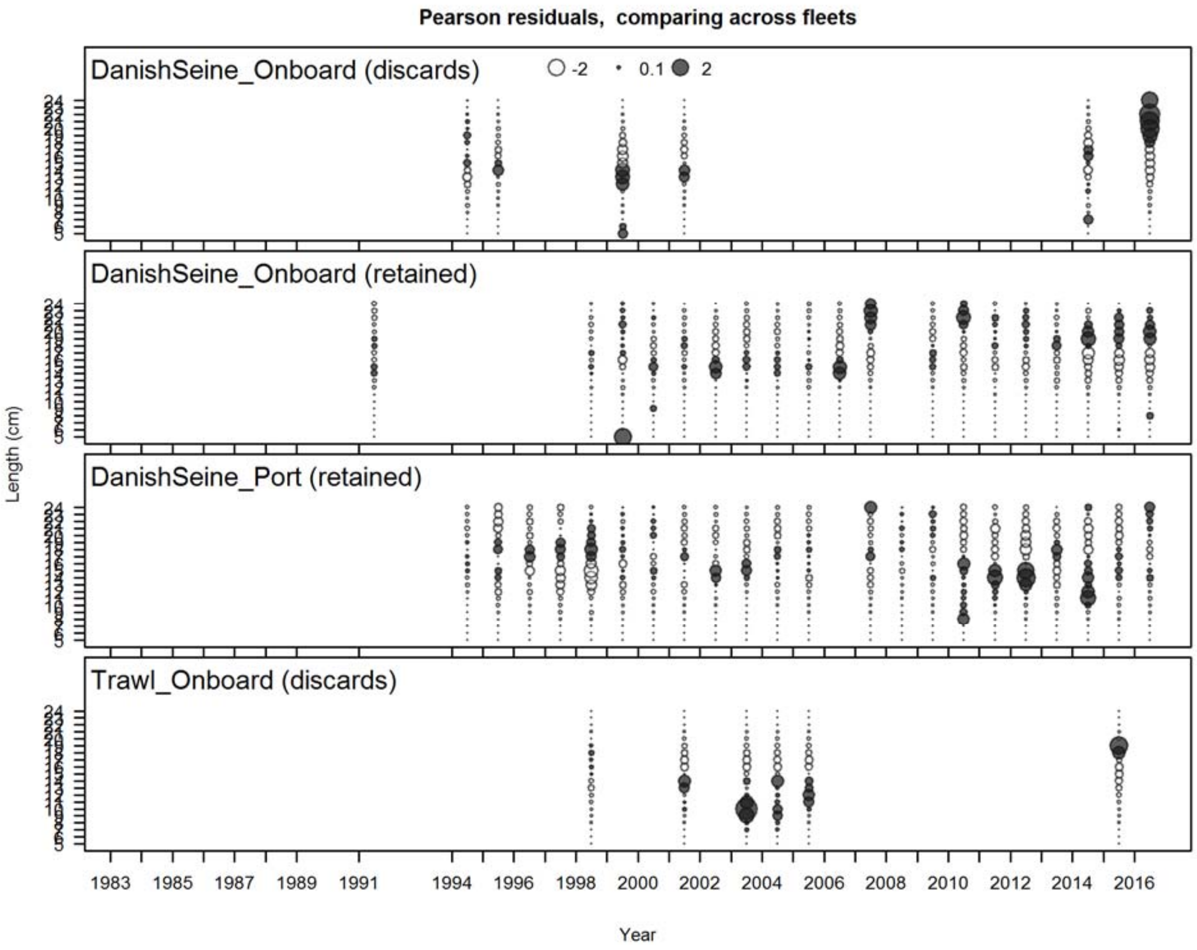


Figure A 15.8. Residuals from the annual length composition data for school whiting displayed by year and fleet for Danish seine fleets(retained and discarded) and trawl discards.

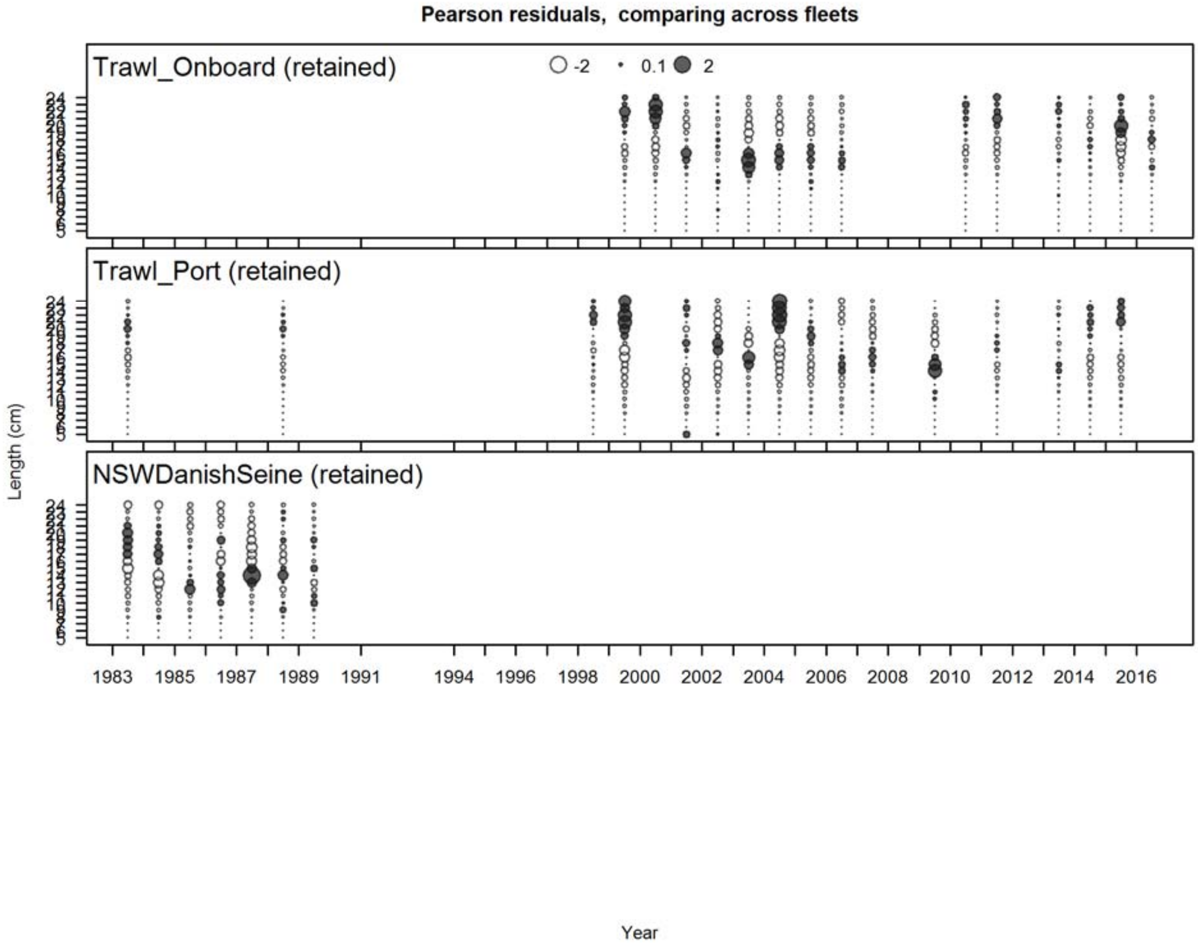


Figure A 15.9. Residuals from the annual length composition data for school whiting displayed by year and fleet for trawl (retained) and NSW Danish seine (retained).

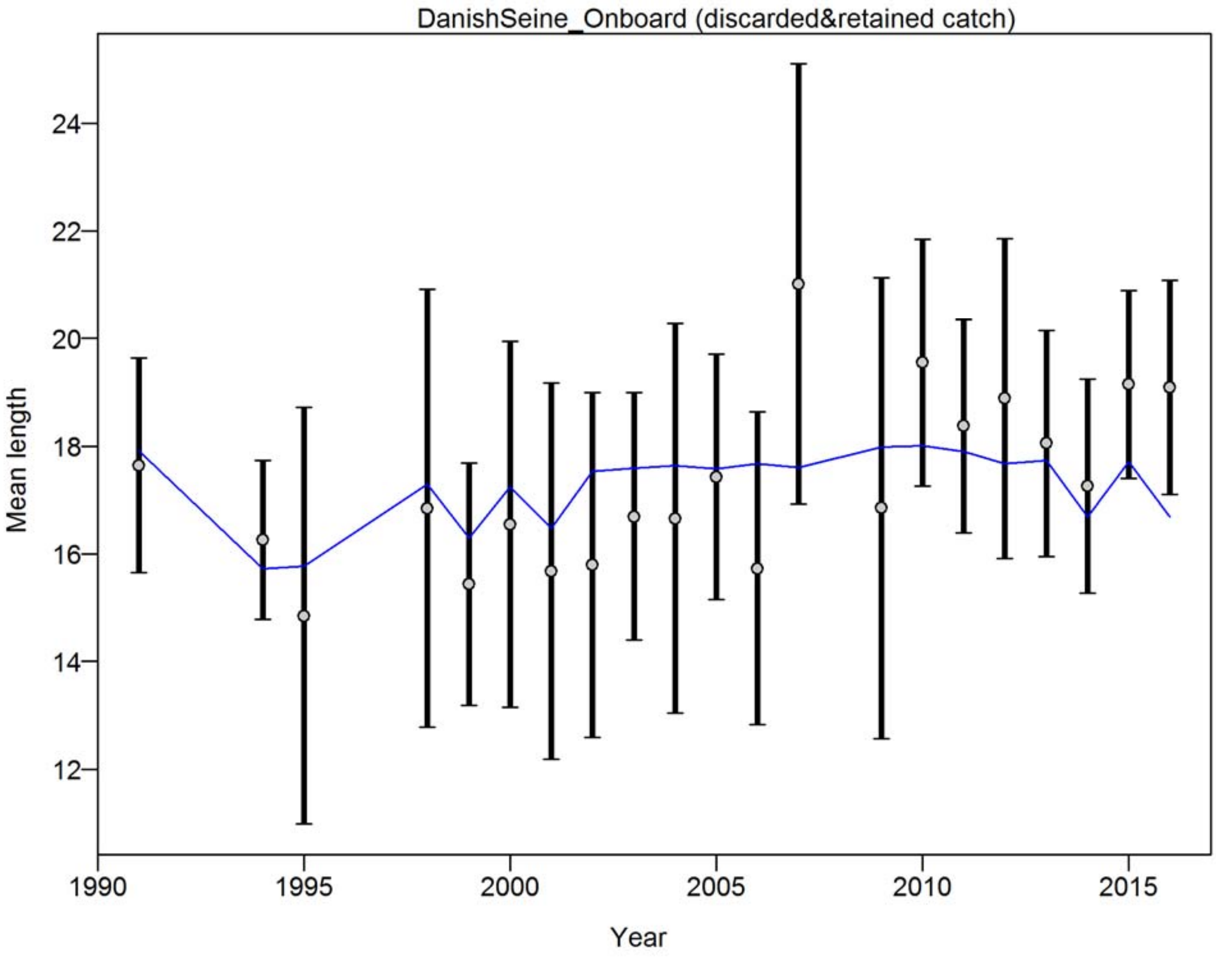


Figure A 15.10. Mean length for school whiting from Danish seine onboard with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.

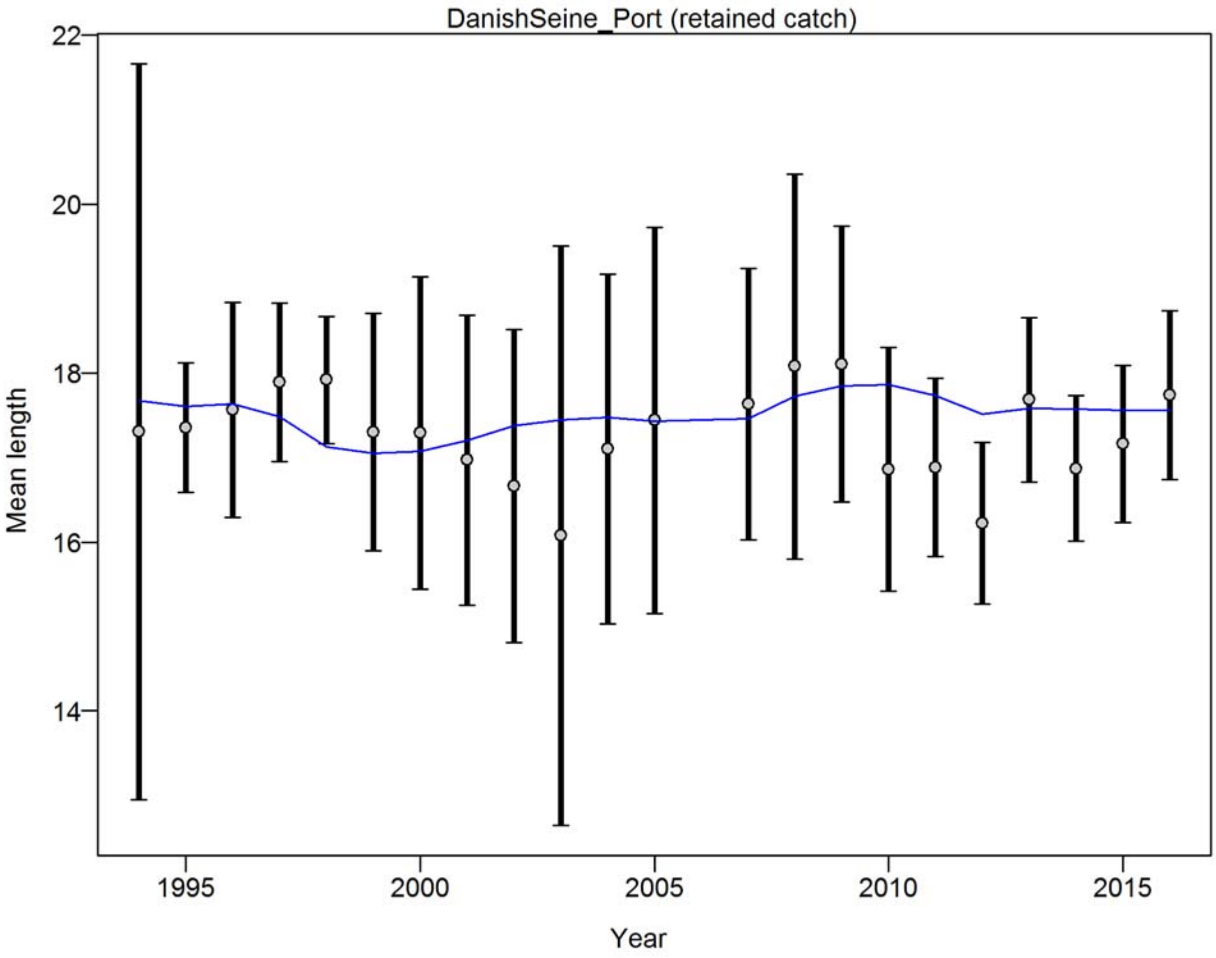


Figure A 15.11. Mean length for school whiting from Danish seine port with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.

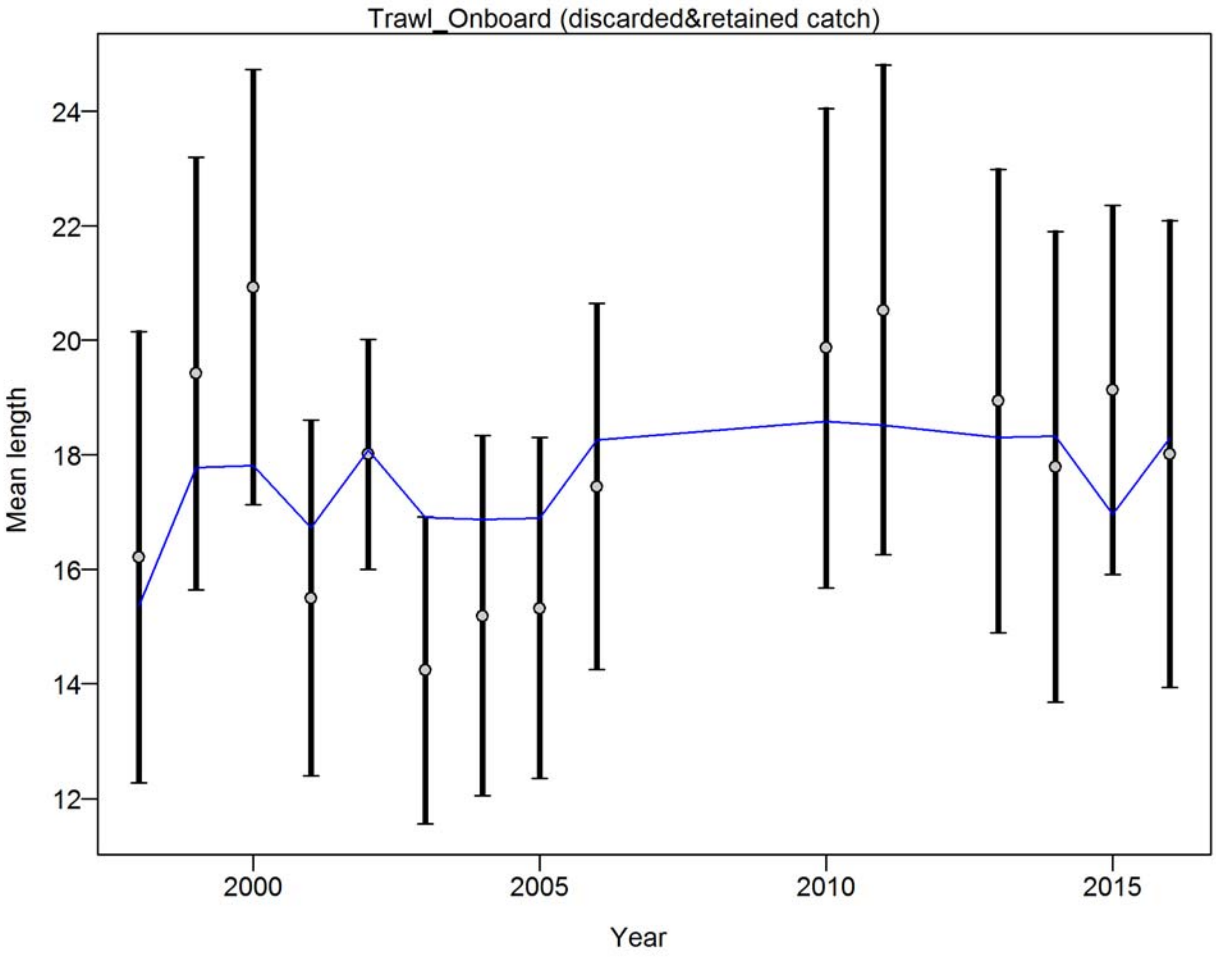


Figure A 15.12. Mean length for school whiting from trawl onboard with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.

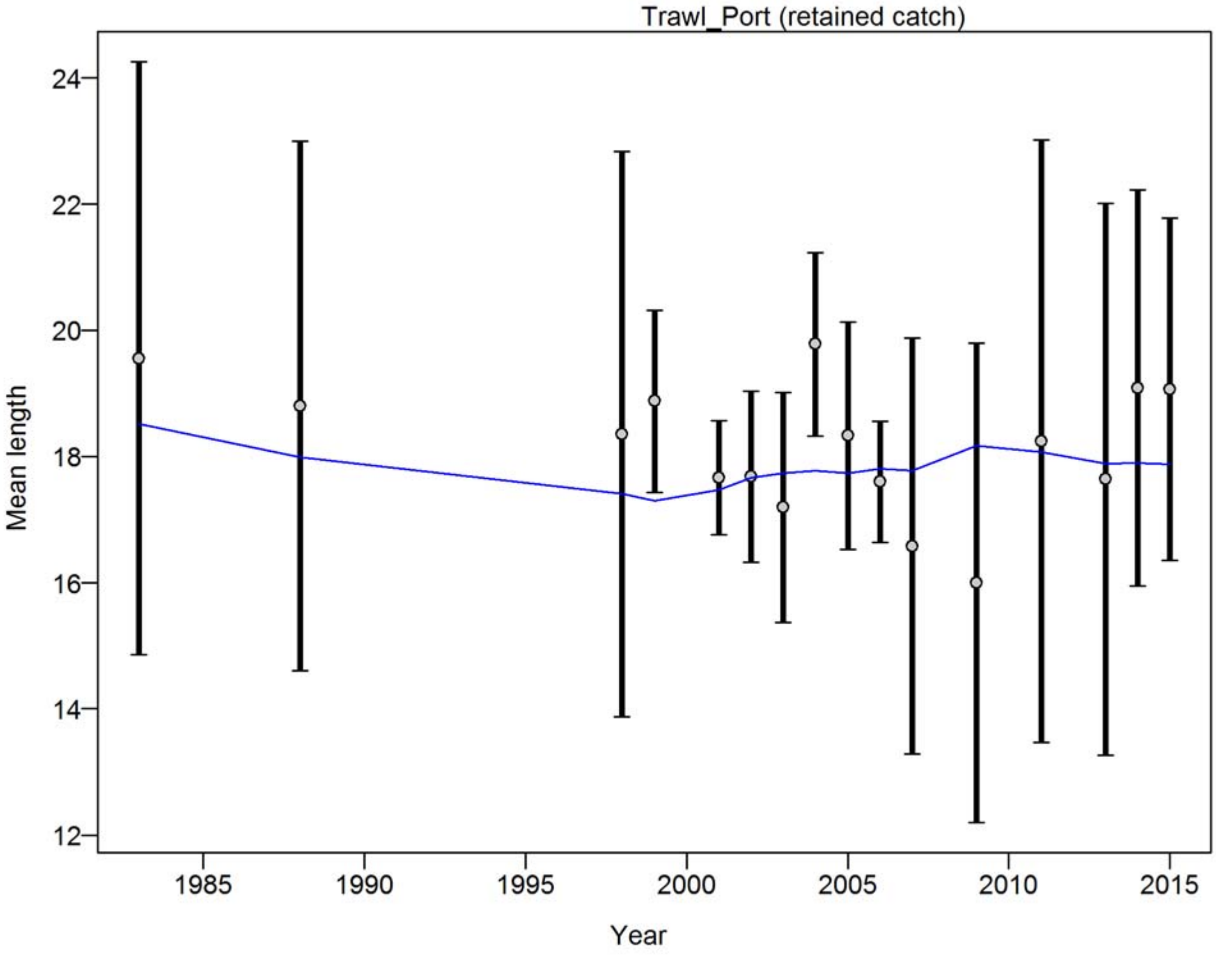


Figure A 15.13. Mean length for school whiting from trawl port with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.

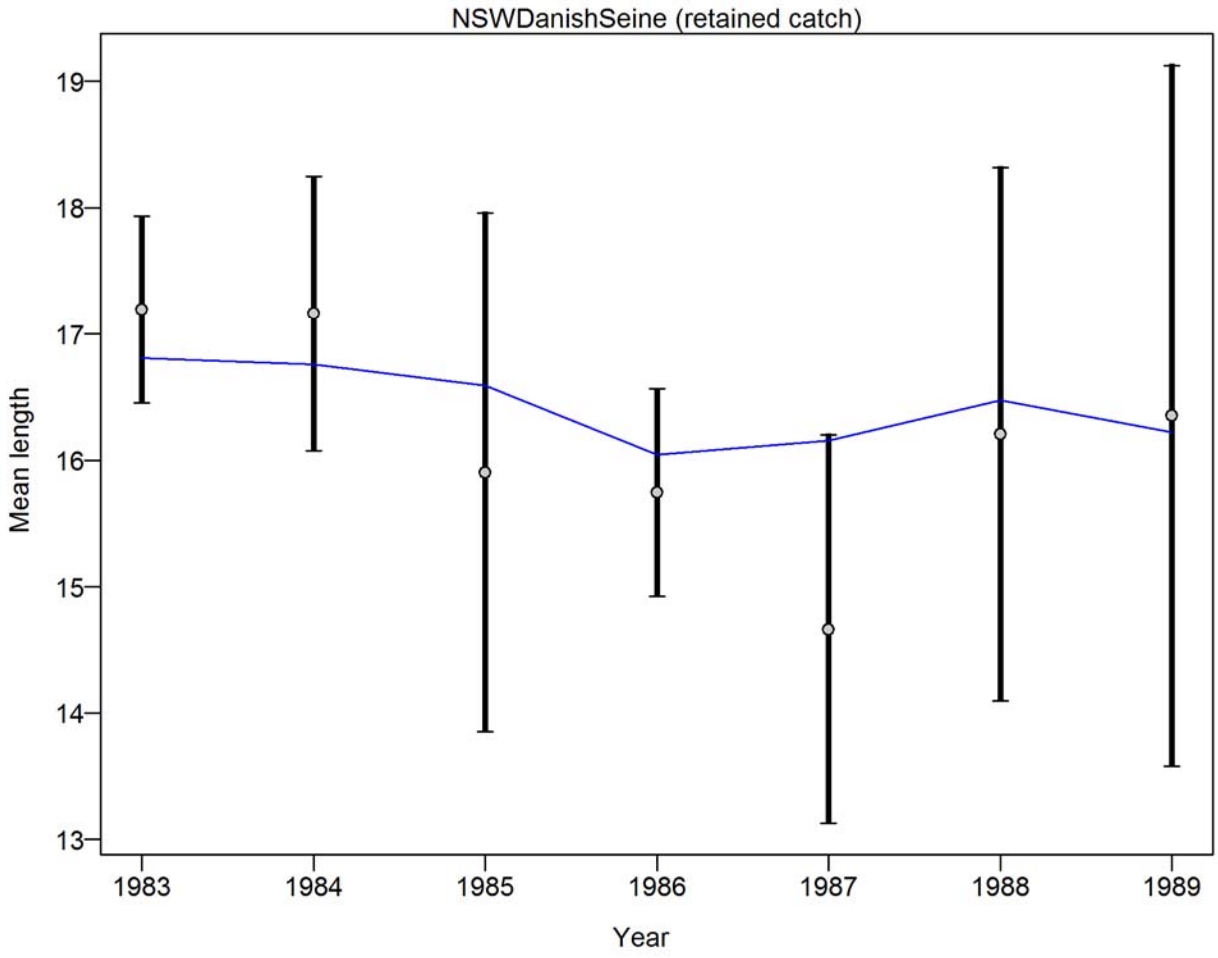


Figure A 15.14. Mean length for school whiting from NSW Danish seine with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced.

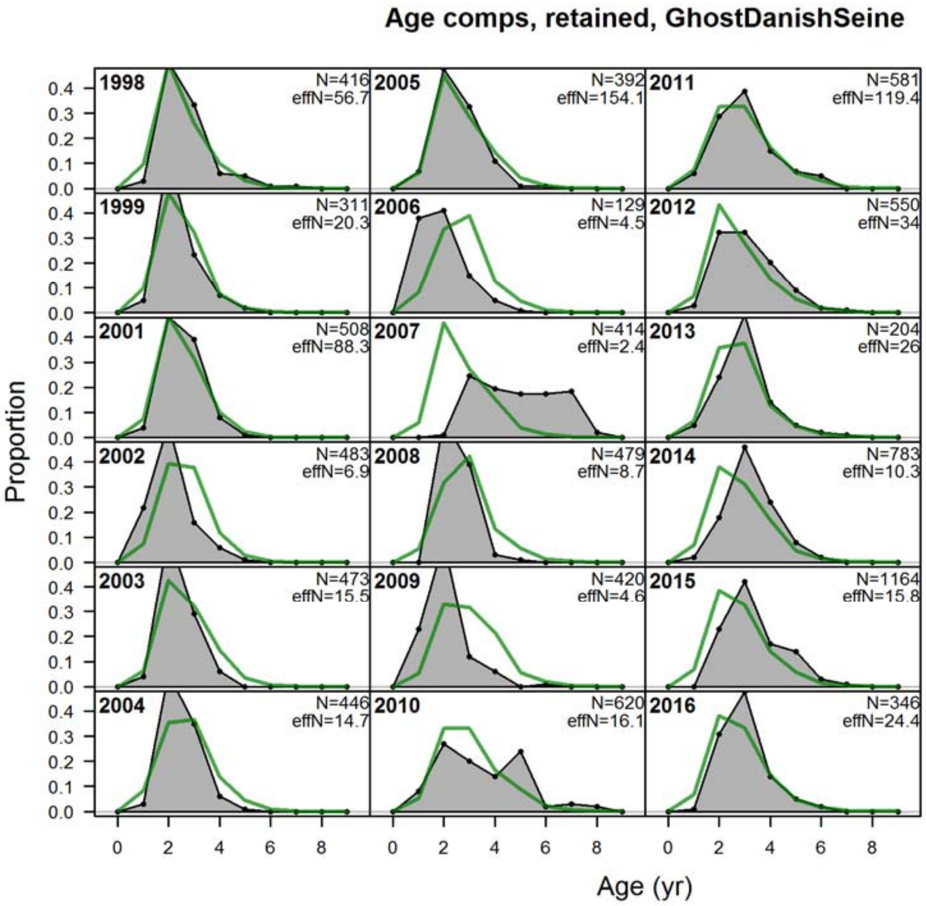


Figure A 15.15. Implied fits to age compositions for school whiting Danish seine onboard (retained).

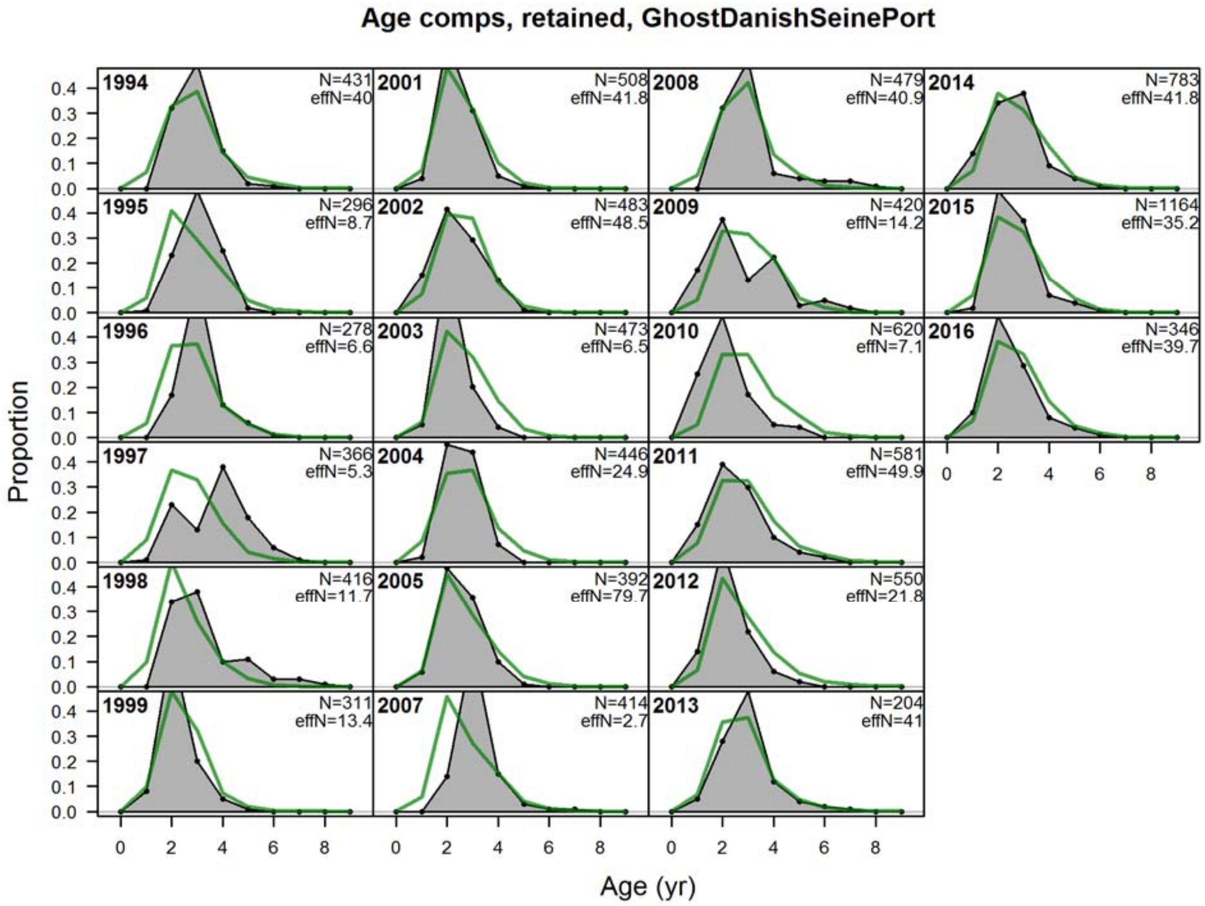


Figure A 15.16. Implied fits to age compositions for school whiting Danish seine port (retained).

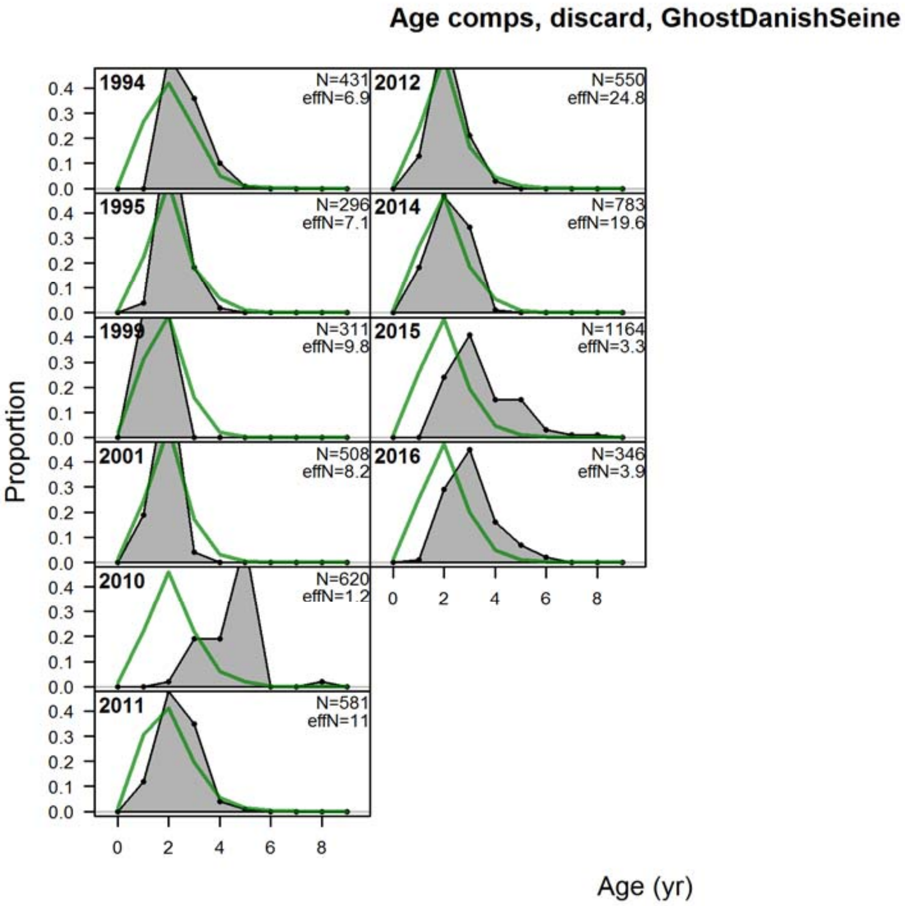


Figure A 15.17. Implied fits to age compositions for school whiting Danish seine (discarded).

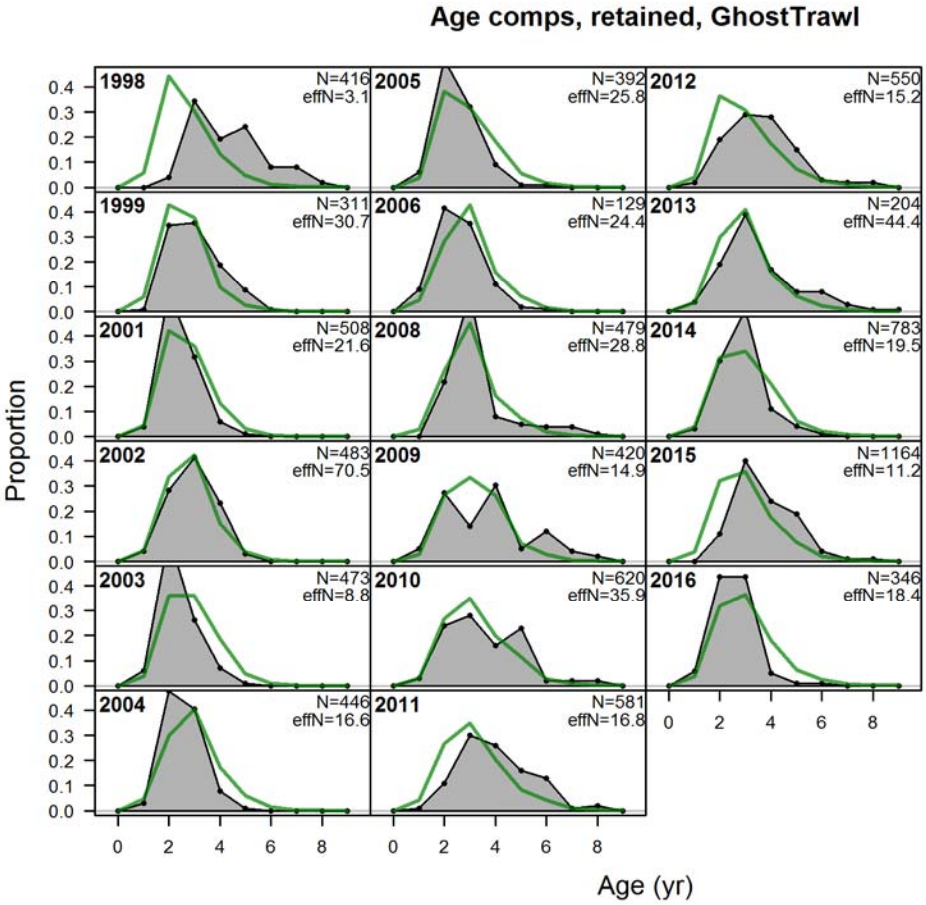


Figure A 15.18. Implied fits to age compositions for school whiting trawl onboard (retained).

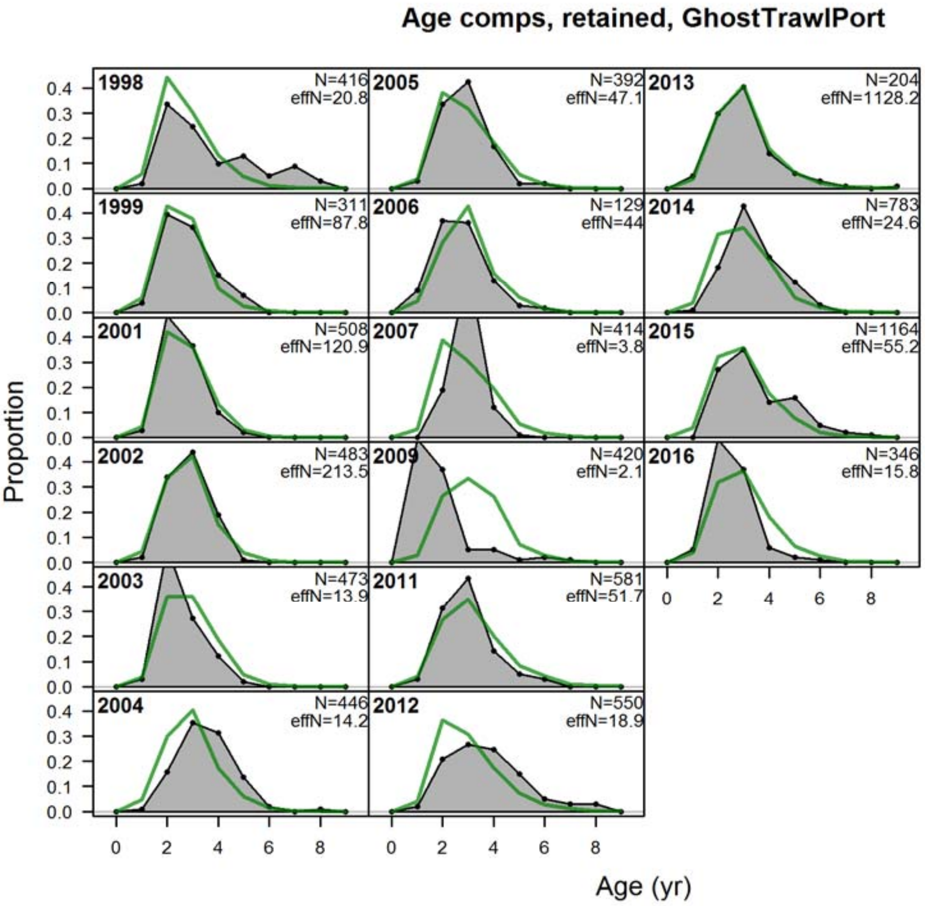


Figure A 15.19. Implied fits to age compositions for school whiting trawl port (retained).

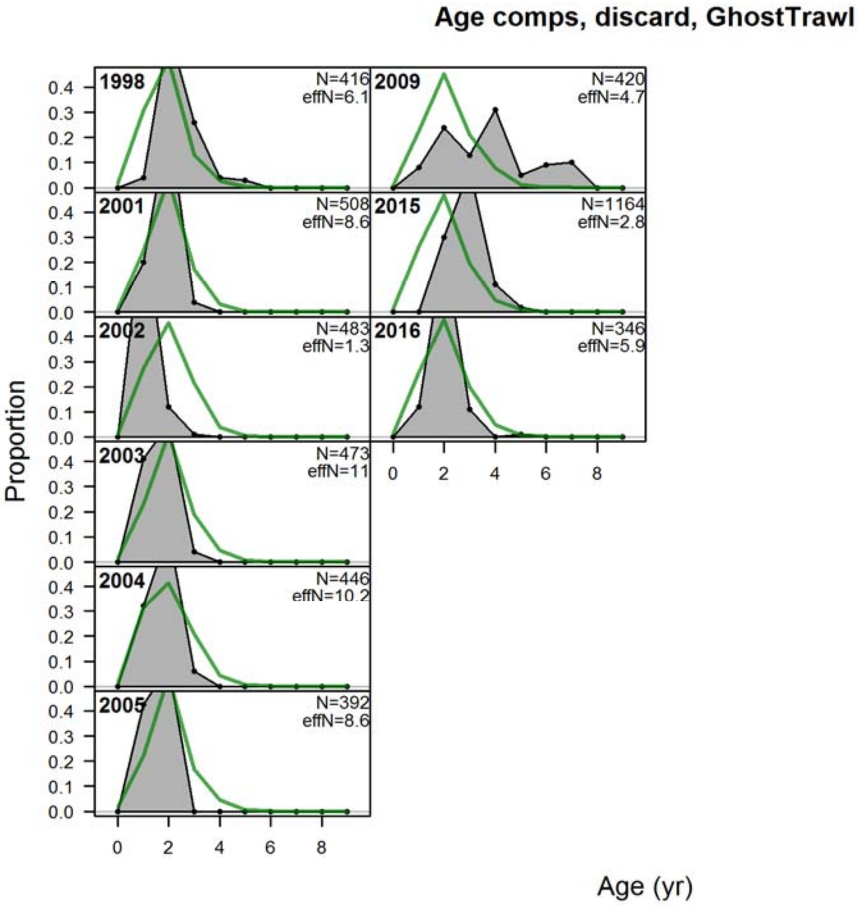


Figure A 15.20. Implied fits to age compositions for school whiting trawl (discarded).

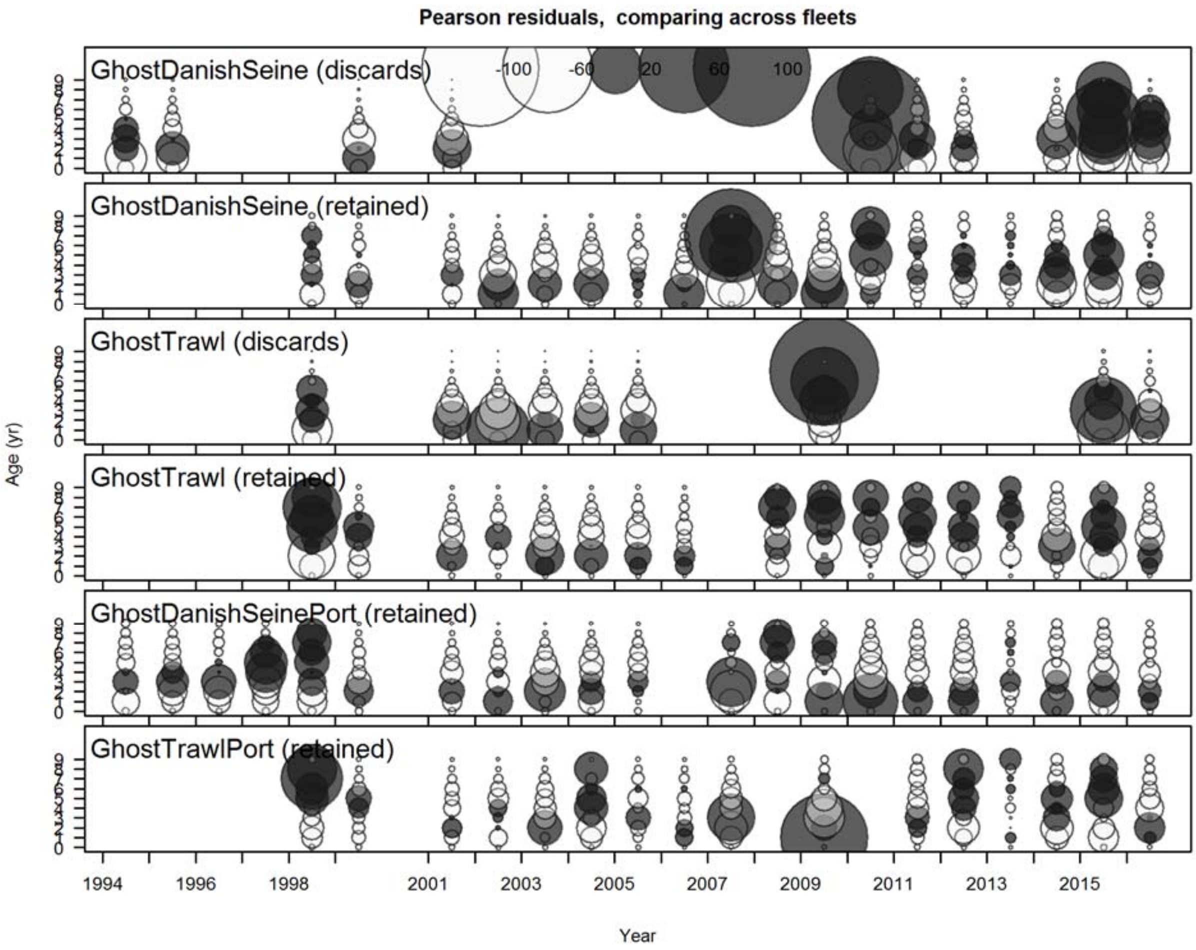


Figure A 15.21. Residuals from the Implied fits to age composition data for school whiting displayed by year and fleet.

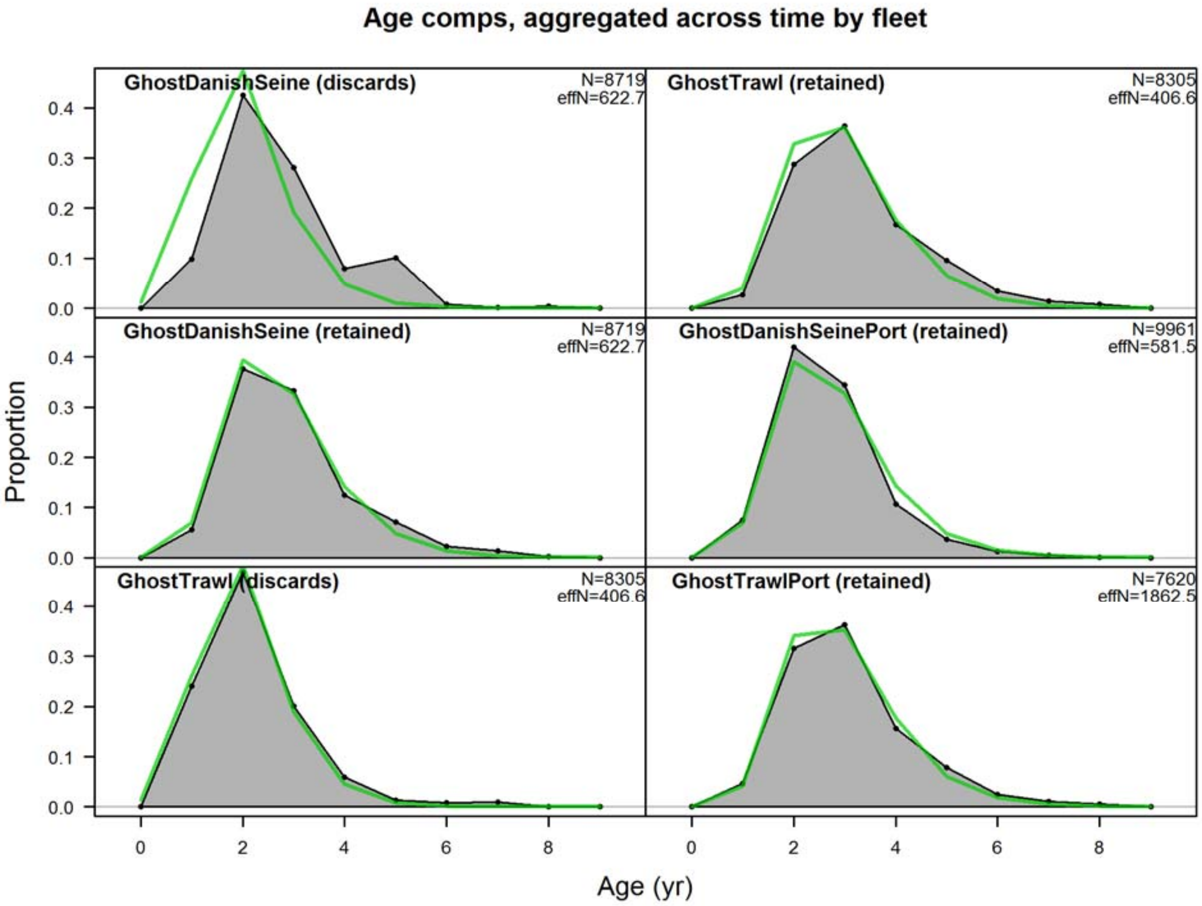


Figure A 15.22. Implied fits to age compositions for school whiting aggregated across time for each fleetl (retained and discarded shown separately).

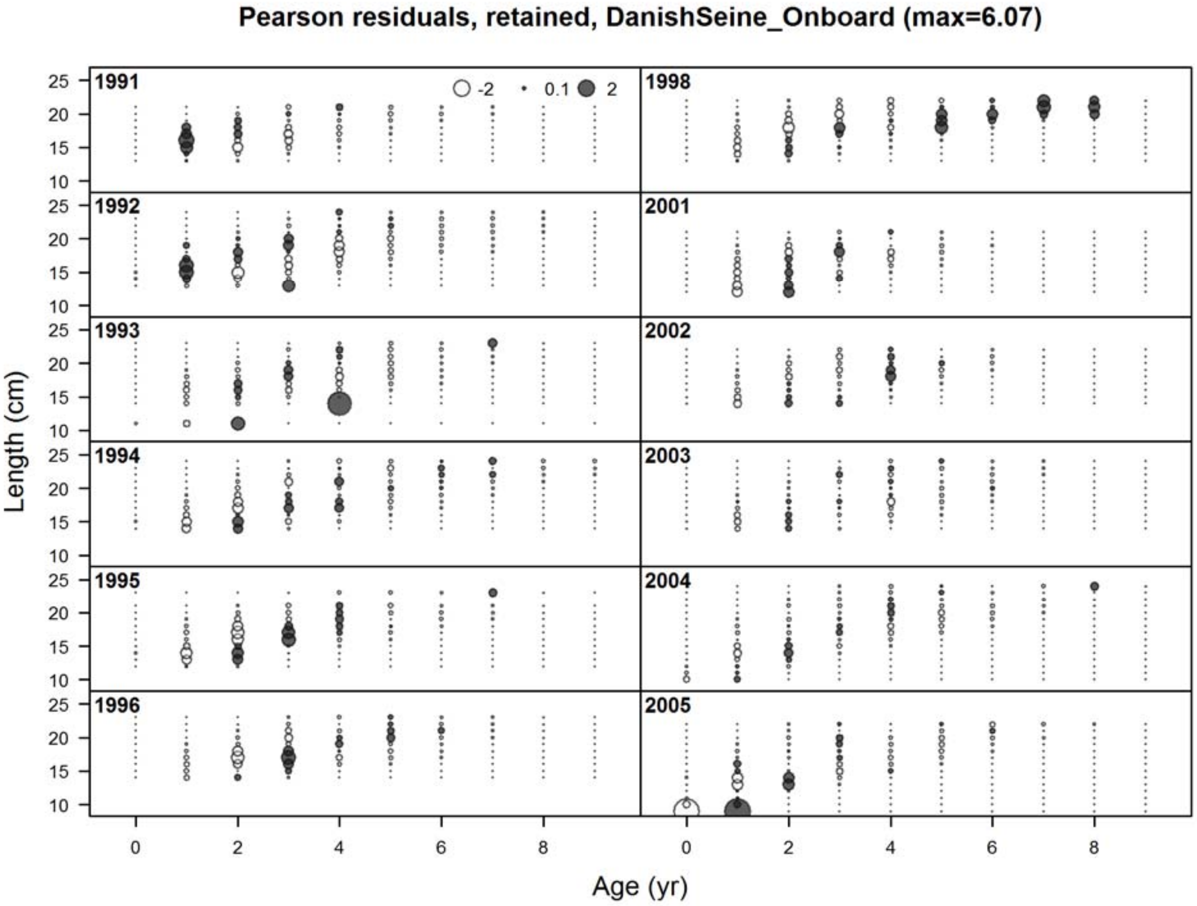


Figure A 15.23. Residuals from the fits to conditional age-at-length for Danish seine to 2005. This plot gives some indication of the variability in the age samples from year to year.

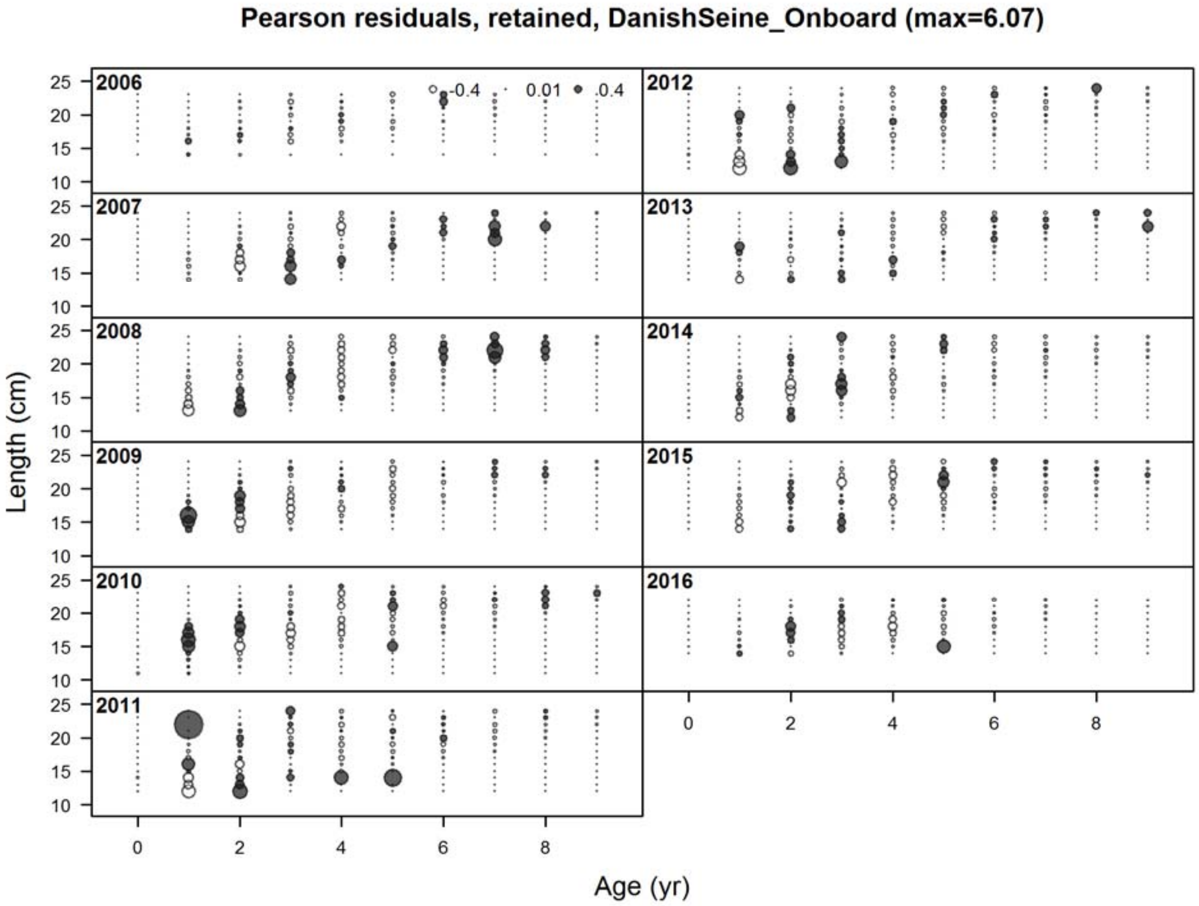


Figure A 15.24. Residuals from the fits to conditional age-at-length for Danish seine from 2006. This plot gives some indication of the variability in the age samples from year to year.

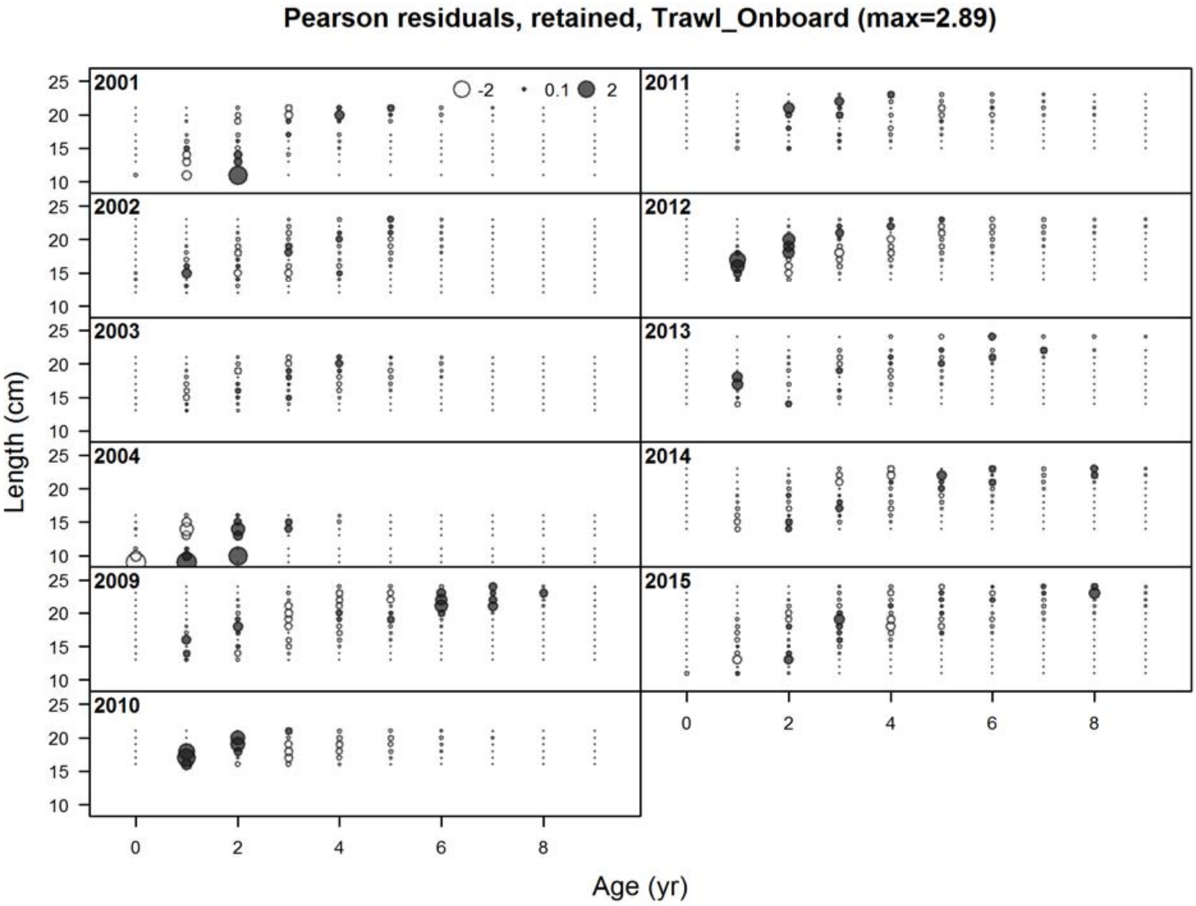


Figure A 15.25. Residuals from the fits to conditional age-at-length for trawl. This plot gives some indication of the variability in the age samples from year to year.

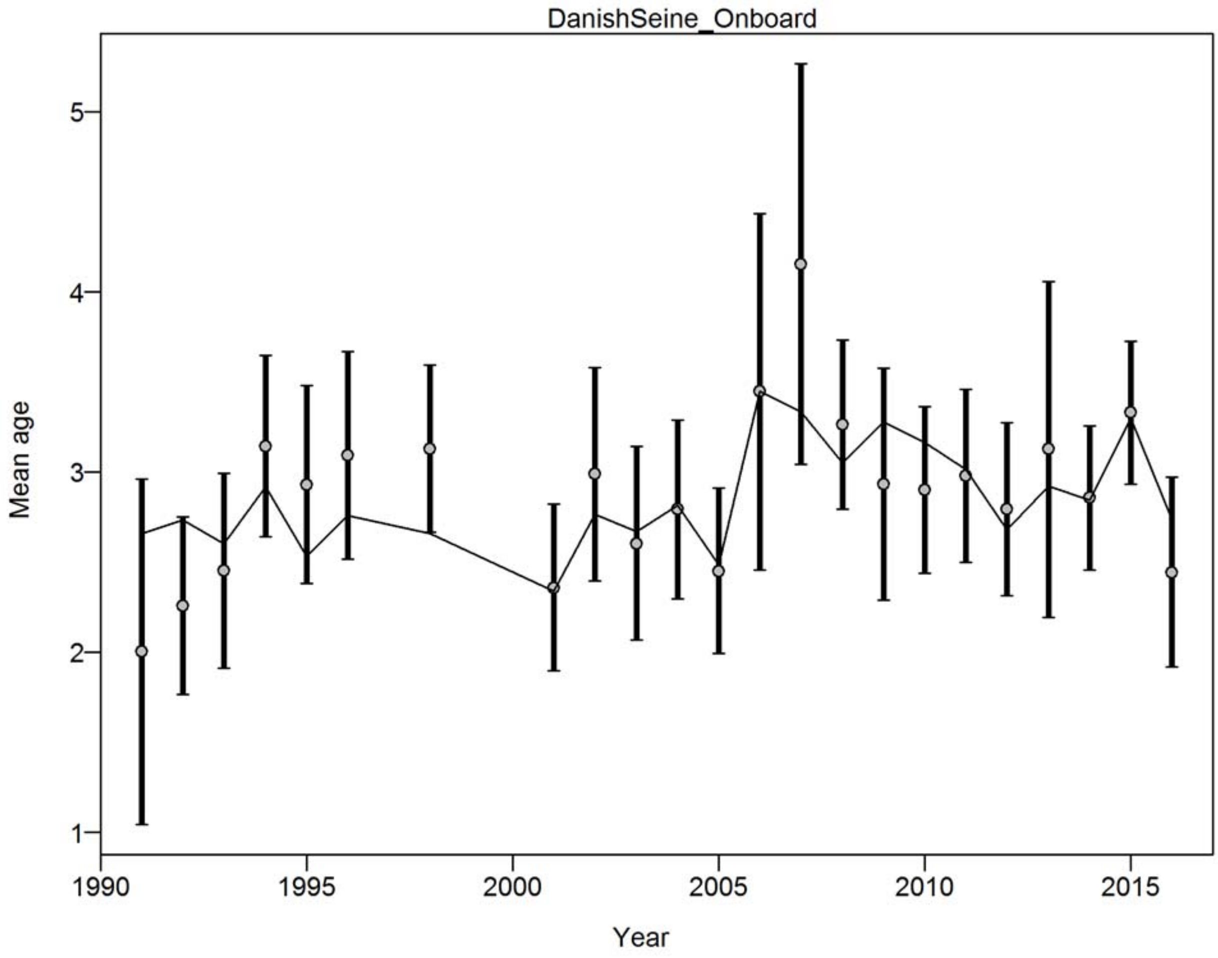


Figure A 15.26. Mean age (aggregated across length bins) for school whiting from Danish seine with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced. Yearly variation in the data is shown in changes in mean age, which can be large over a short period (e.g. 2005-2007).

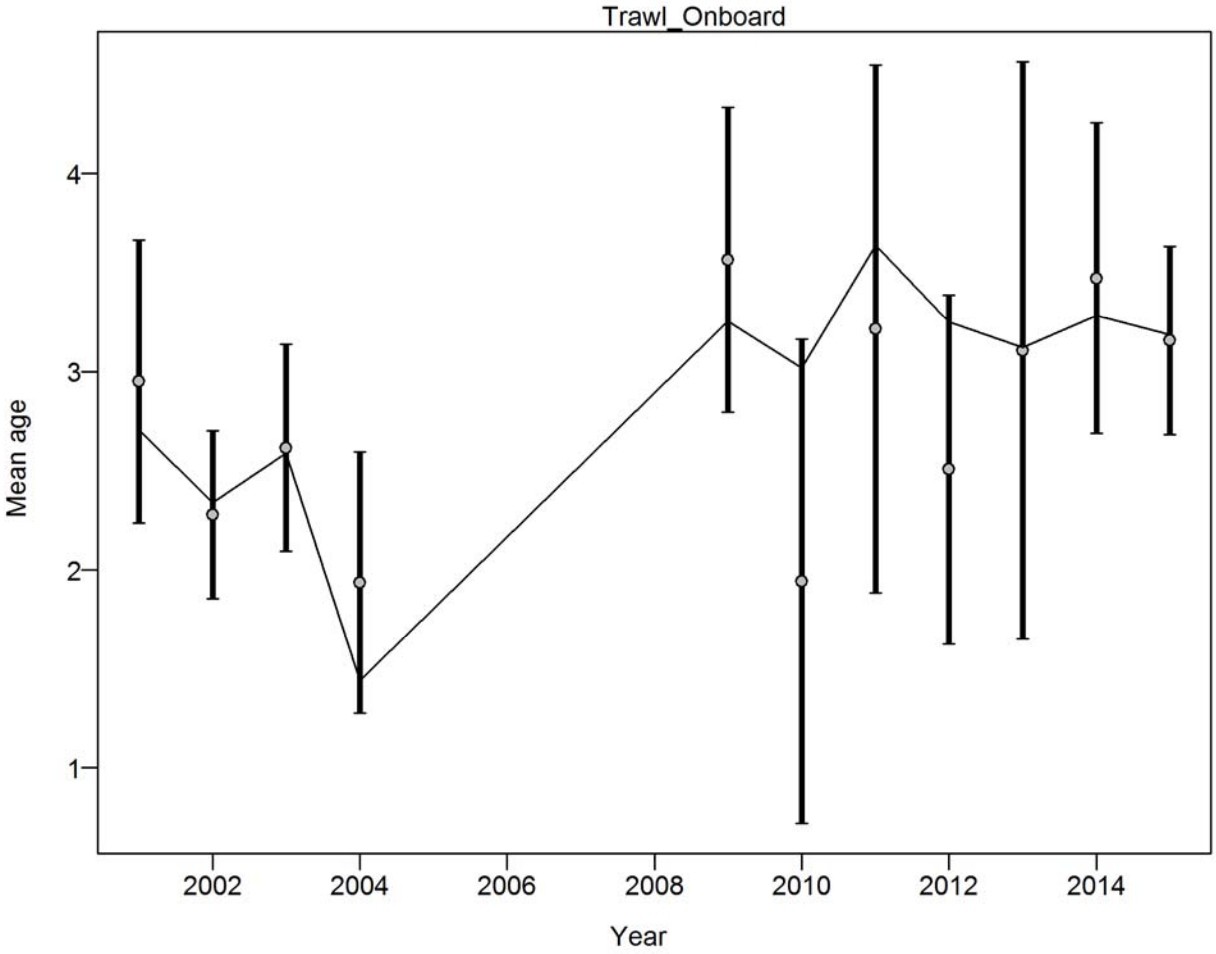


Figure A 15.27. Mean age (aggregated across length bins) for school whiting from trawl with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: Thin capped lines matching thick lines indicate this is well balanced. Yearly variation in the data is shown in changes in mean age, which can be large over a short period (e.g. 2009-2010).

16. Redfish (*Centroberyx affinis*) stock assessment based on data up to 2016 – development of a preliminary base case

Geoff Tuck

CSIRO Oceans and Atmosphere, GPO Box 1538, Hobart, TAS 7001, Australia

16.1 Executive Summary

This document presents a suggested base case for an updated quantitative Tier 1 eastern redfish (*Centroberyx affinis*) assessment for presentation at the first SERAG meeting in 2017. The last full assessment was presented in 2014 (Tuck and Day, 2014; Tuck, 2014). The preliminary base case has been updated by the inclusion of data up to the end of 2016, which entails an additional 3 years of catch, discard, CPUE, length and age data and ageing error updates since the 2014 assessment. This document describes the process used to develop a preliminary base case for redfish through the sequential updating of recent data to the stock assessment, using the stock assessment package Stock Synthesis (SS-V3.30).

The base case specifications agreed by the ShelfRAG in 2014 were maintained into the preliminary base case presented here. The main differences however are: separating length frequencies into onboard and port collected components, weighting length frequencies by shots (onboard) and trips (port) rather than fish measured; and using the latest tuning methods.

Results show reasonably good fits to the catch rate data, length data and conditional age-at-length data. Issues to note include that there is considerable difference between the port and onboard retained length frequencies, with the mode of port lengths generally larger than onboard lengths. The magnitude of the estimated recruitment in 2011 in the 2104 assessment has been greatly reduced in the 2017 preliminary assessment (although estimates of recent recruitment are improved over the poor period during 2002-2010). The 2017 preliminary assessment estimates that the projected 2018 spawning stock biomass will be 8% of virgin stock biomass (projected assuming 2017 catches in 2018), compared to 11% at the start of 2015 from the last assessment (Tuck, 2014).

Further development should include an exploration of the observed differences between port and onboard lengths, differences in length compositions between adjacent years, and refining the model structure (eg years of recruitment estimation, selectivity and retention blocking).

16.2 Introduction

16.2.1 *Bridging from 2014 to 2017 assessments*

The previous full quantitative assessment for redfish was performed in 2014 (Tuck and Day, 2014; Tuck, 2014) using Stock Synthesis (version SS-V3.24f, Methot, August 2012). The 2017 assessment uses the current version of Stock Synthesis (version SS-V3.30.06.02, Methot, 2017).

As a first step in the process of bridging to a new model, the data used in the 2014 assessment was used in the new software (SS-V3.30). This was followed by the inclusion in the model of updated data and new data from 2014-2016. This additional data included new catch, discard, CPUE, length frequency and age-at-length data. The last year of recruitment estimation was extended to 2015 (2012 in the 2014 assessment). The usual process of bridging to a new model by adding new data piecewise and analysing which components of the data could be attributed to changes in the assessment outcome was conducted. Details of this process are provided below.

16.2.2 *Update to Stock Synthesis SSV-3.30*

The 2014 redfish assessment was converted to the most recent version of the software, Stock Synthesis version SS-V3.30. There were negligible changes to the spawning biomass and recruitment time series following conversion (trajectories are overlapping in Figure 16.1 and Figure 16.2).

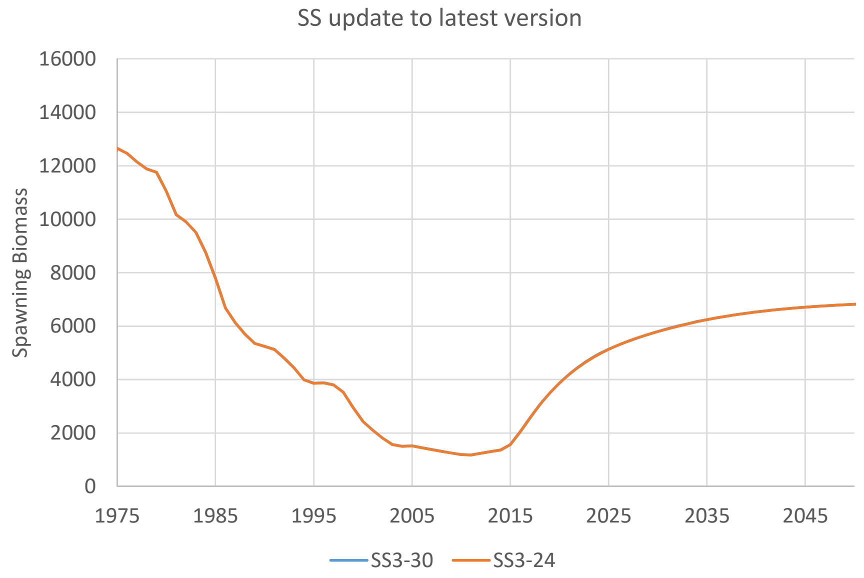


Figure 16.1. Comparison of the spawning biomass time series for the 2014 assessment (SS3-24) and a model converted to SS-V3.30 (SS3-30).

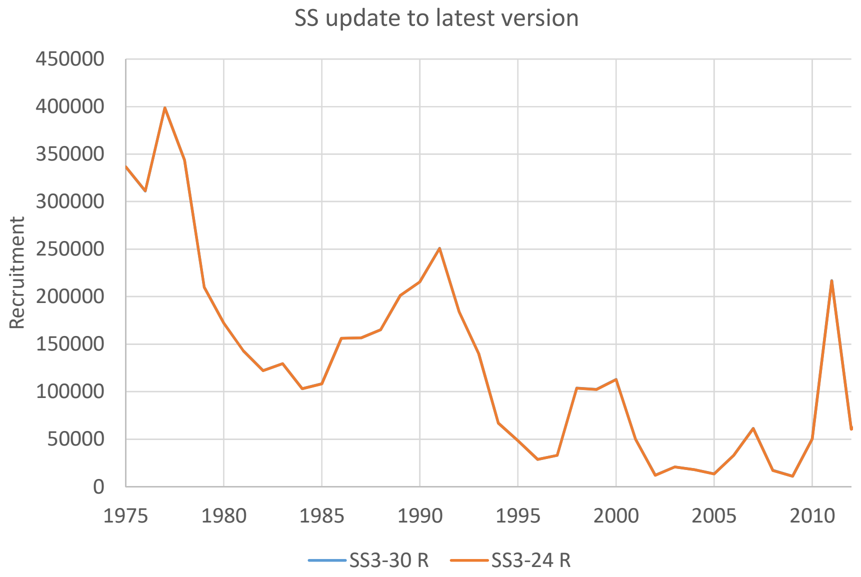


Figure 16.2. Comparison of the recruitment time series for the 2014 assessment (SS3-24 R) and a model converted to SS-V3.30 (SS3-30 R).

16.2.3 *Inclusion of new data*

The data inputs to the assessment come from multiple sources: length and age-at-length data from the trawl fishery, updated standardized CPUE series (Sporcic and Haddon, 2017), the annual total mass landed and discard rates, and age-reading error. Data were formulated by calendar year (i.e. 1 Jan to 31 Dec) and were aggregated across all eastern zones (Zones 10, 20 and 30).

Starting from the converted 2014 base case model, additional and updated data to 2016 were added sequentially to develop a preliminary base case for the 2017 assessment:

1. Change final assessment year to 2016, add catch to 2016 (NewC).
2. Add CPUE to 2016 (from Sporcic and Haddon (2017)) (NewC_CPUE).
3. Add updated discard fraction estimates to 2016 (NewC_CPUE_D).
4. Update length frequency data, including both port and onboard length frequencies (NewC_CPUE_D_POL).
5. Add updated age error matrix and age-at-length data to 2016 (NewC_CPUE_D_POL_A).
6. Change the final year for which recruitments are estimated from 2012 to 2015 (NewC_CPUE_D_POL_A_R).
7. Retune using latest tuning protocols (Tuned17).

16.2.3.1 Catch data

Total annual catches (t) for redfish have been estimated based on a combination of sources, including Sydney Fish Market (SFM) data (to 1986), NSW and Victorian landings and the SEF logbook data (Table 28 of Rowling (1994); Appendix 1 of Rowling (1999); Table 1 of Thomson (2002); Table 1 of Klaer (2005)). The estimated annual tonnages of landings, discard rates and CPUE are provided in Table 16.1. Where available, previously agreed catch tonnages from RAGs were used (Rowling, 1999;

Klaer, 2005). CDR records and NSW state catch data are used from 2005 for the base-case model (referred to as BC4 in Tuck (2014)). Figure 16.3 shows a comparison of the agreed total catch (Commonwealth and NSW combined) from the 2014 assessment and the updated catch estimates for the 2017 assessment. Table 16.1 shows the annual catch values used in the assessment.

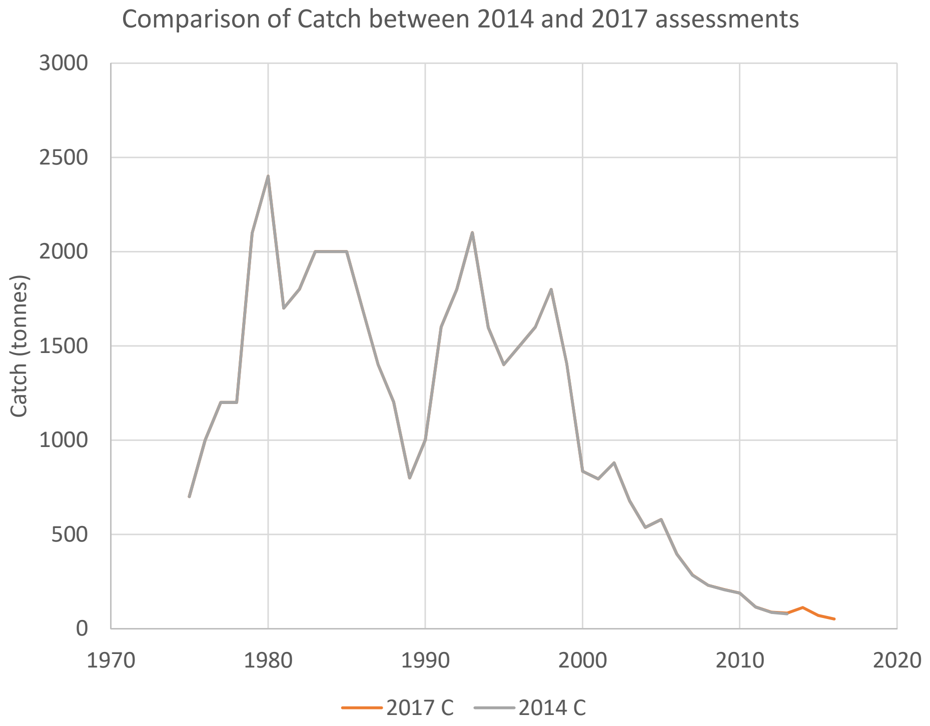


Figure 16.3. A comparison of total annual catches from the 2014 base case assessment (2014 C) and the updated catch used in the 2017 assessment (2017 C).

Table 16.1. Estimated landings (t), discard rates and standardized CPUE (Sporcic and Haddon, 2017) for redfish by calendar year. Total catch (Commonwealth and state) for years 1975 to 2004 were taken from previously agreed catch estimates from redfish assessment group meetings (Rowling, 1999, Appendix 1; Klaer, 2005) and from CDR records for 2005 onwards. Also shown are the NSW state catches from 2005 onwards. State catches exist prior to 2005 but are included in the redfish assessment group agreed catches (Landings column) until 2004.

Year	Landings (t)	NSW	Total Landings (t)	Discard Rates	CPUE
1975	700		700	0.40	
1976	1000		1000	0.40	
1977	1200		1200	0.40	
1978	1200		1200	0.40	
1979	2100		2100	0.40	
1980	2400		2400	0.30	
1981	1700		1700	0.20	
1982	1800		1800	0.20	
1983	2000		2000	0.20	
1984	2000		2000	0.20	
1985	2000		2000	0.20	
1986	1700		1700	0.20	1.81
1987	1400		1400	0.15	1.55
1988	1200		1200	0.15	1.74
1989	800		800	0.15	1.28
1990	1000		1000	0.10	1.62
1991	1600		1600	0.10	1.79
1992	1800		1800	0.25	2.25
1993	2100		2100	0.588	2.70
1994	1600		1600	0.569	1.99
1995	1400		1400	0.767	1.29
1996	1500		1500	0.265	1.16
1997	1600		1600	0.067	1.22
1998	1800		1800	0.213	1.43
1999	1406		1406	0.046	1.20
2000	835		835	0.131	0.80
2001	794		794	0.375	0.76
2002	880		880	0.580	0.71
2003	677		677	0.327	0.61
2004	538		538	0.398	0.54
2005	532	47	579	0.231	0.60
2006	321	76	397	0.038	0.56
2007	230	54	284	0.124	0.55
2008	201	29	231	0.018	0.49
2009	182	26	208	0.357	0.42
2010	166	23	188	0.120	0.41
2011	99	17	115	0.143	0.30
2012	72	16	88	0.021	0.21
2013	66	17	83	0.261	0.27
2014	96	16	112	0.333	0.36
2015	59	11	70	0.429	0.22
2016	43	9	52	0.404	0.17

16.2.3.2 Discard rates

Discard rates prior to 1992 are those estimated by the redfish RAG (Rowling, 1999; Thomson, 2002). Discard rates after 1992 were estimated from on-board data which gives the weight of the retained and discarded component of those shots that were monitored (Thomson and Klaer, 2011). Rowling (1999) provides considerable detail on how the historical discard rates were estimated and the factors that influenced discard practices. Redfish discarding was discussed at a redfish workshop held in Cronulla in April 1997 and at various open redfish assessment group meetings during late 1997 and early 1998. The resulting discard rates are documented in Rowling (1999) and also listed in the last redfish assessment group (Thomson, 2002) and Shelf RAG (Klaer, 2005) assessments of redfish. Here we update the discard estimates by the addition of on-board estimates through to 2016 (Table 16.1).

The assessment model allows an estimation of the probably of retention (which is 1 – P(discard)) as a function of length in order to estimate the annual discard rate and any information on discard length composition. It is apparent that the redfish fishery has undergone numerous changes that may have influenced the behaviour of discarding; these changes are documented in Rowling (1999; Appendix 2). In consultation with K. Rowling (pers. comm.), the following discarding periods have been identified:

1975 – 1985. Market driven discarding

1975 – 1985. Discards largely across all size ranges, but with more small fish discarded

1986 – 2000. Surimi markets period

1986 – 1992. Surimi market. Discarding rates lower, mainly small fish.

1993 – 1995. Quantity of fish sent to surimi market declined, Geelong surimi market closes; consequent increase in discarding.

1996 – 2000. Discarding declined ‘as redfish became less available’. Close of Hacker surimi processor in 2000.

2001 – 2013. Size based discarding period

2001 – 2013. Assume mostly small fish discarded

These changes in discarding behaviour have influenced the large variations in discard rates observed (Table 16.1), as well as the catches, catch rates and discard length composition. The RAG agreed (2014) base case model allows the retention function to vary according to the identified discard period from 1975 to 1985 (market driven), and from 1986 to 2016 (size driven).

16.2.3.3 Catch rates

Sporcic and Haddon (2017) provides the updated catch rate series for redfish (Table 16.1; Figure 16.4). After substantial increases in catch rate in the early and late 1990s, the catch rate has continued to decline since then, and is now less than 10% of levels in 1986. A small increase in catch rate occurred in 2013-14 but has since declined.

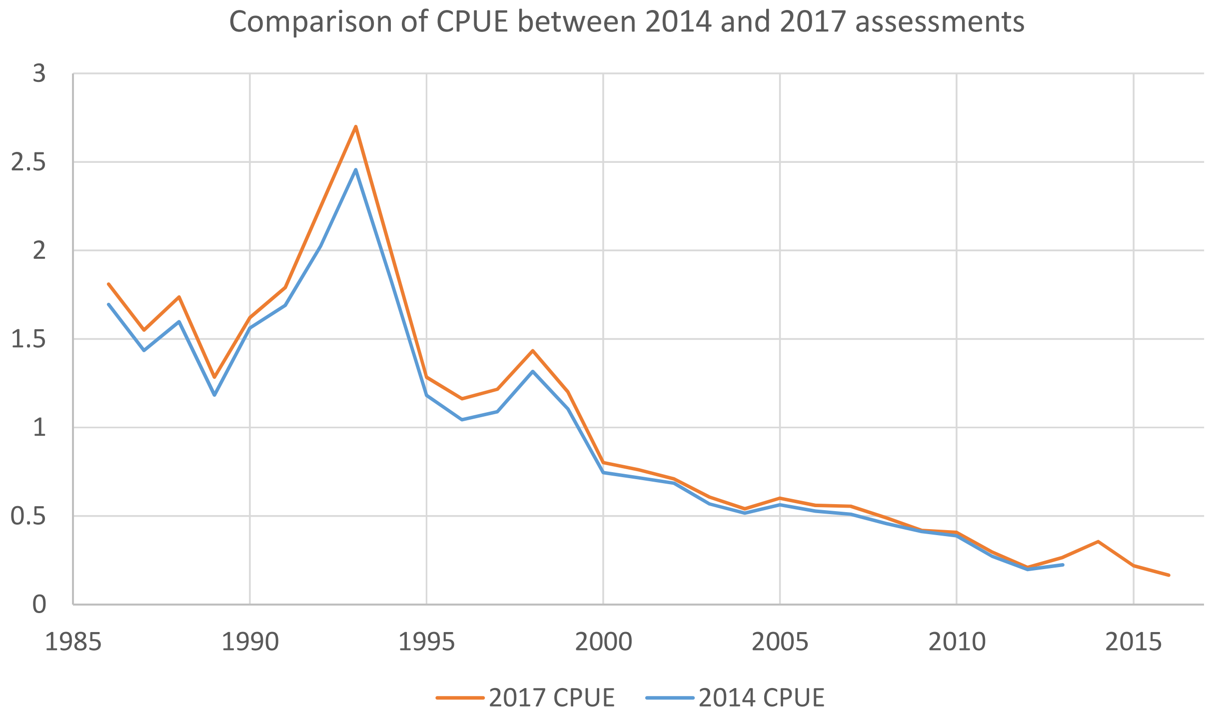


Figure 16.4. A comparison of the annual catch rates series for redfish between 2014 (2014 CPUE) and 2017 (2017 CPUE).

16.2.3.4 Length frequencies and age data

Length and age data have been included in the model as length frequency data and conditional age-at-length data by year and sex (when available). Age composition data is included in diagnostic plots but is not used directly within the fitting procedure. Catch length frequency data were obtained from NSW records of fish measured at the Sydney Fish Markets to 1991. After 1991 length frequencies were obtained from ISMP on-board and port measurements. The observed length and age data are shown in later figures with the corresponding model predicted values. The Kapala length frequencies and Fishery Independent Survey (FIS) abundance indices are not included in the RAG agreed base-case model (Tuck and Day, 2014).

16.2.3.5 Biological parameters and stock structure assumptions

The assessment assumes that length at 50% maturity is 19cm for females (Thomson, 2002). Natural mortality is assumed to be 0.10y^{-1}. Redfish natural mortality is generally assumed to be in the 0.05 and 0.15 y^{-1} range (SEFAG, 2000). Morison and Rowling (2001) calculated natural mortality values between 0.07 and 0.11 y^{-1}. Steepness is assumed to be 0.75. Parameters for the length weight relationship were taken from Klaer (2005; also used by Thomson, 2002). Growth parameters, including the von Bertalanffy growth parameter k, are estimated (Thomson, 2002). Data were formulated by calendar year (i.e. 1 Jan to 31 Dec) and were aggregated across all eastern zones (Zones 10, 20 and 30), as sufficiently strong evidence to suggest a north-south split did not exist (Shelf RAG agreement, September 2014; Haddon, 2014). The 2017 base case model structure follows the RAG agreed base case from 2014 (Tuck and Day, 2014; Tuck, 2014) except that length data are now separated into port and onboard, and updated tuning methods are applied.

16.2.3.6 Age-reading error

Standard deviations for aging error by reader have been estimated, producing the age-reading error matrix of Table 16.2 (A.E. Punt, pers. comm.).

16.2.3.7 Analytic approach

The 2017 preliminary base case assessment of eastern redfish uses an age- and size-structured model implemented in the generalized stock assessment software package, Stock Synthesis (SS) (Version 3.30.06.02, NOAA 2011). The methods utilised in SS are based on the integrated analysis paradigm. SS can allow for multiple seasons, areas and fleets, but most applications are based on a single season and area. Recruitment is governed by a stochastic Beverton-Holt stock-recruitment relationship, parameterized in terms of the steepness of the stock-recruitment function (h), the expected average recruitment in an unfished population (R_0), and the degree of variability about the stock-recruitment relationship (σ_r). SS allows the user to choose among a large number of age- and length-specific selectivity patterns. The values for the parameters of SS are estimated by fitting to data on catches, catch-rates, discard rates, discard and retained catch length-frequencies, and conditional age-at-length data. The population dynamics model and the statistical approach used in fitting the model to the various data types are given in the SS technical documentation (Methot, 2005).

Table 16.2. The standard deviation of age reading error.

Age	St Dev	Age	St Dev
0	0.214	20	0.922
1	0.214	21	0.946
2	0.267	22	0.969
3	0.317	23	0.992
4	0.365	24	1.013
5	0.412	25	1.034
6	0.456	26	1.053
7	0.499	27	1.072
8	0.540	28	1.090
9	0.579	29	1.108
10	0.617	30	1.125
11	0.654	31	1.141
12	0.688	32	1.156
13	0.722	33	1.171
14	0.754	34	1.185
15	0.785	35	1.199
16	0.815	36	1.212
17	0.843	37	1.225
18	0.870	38	1.237
19	0.897	39	1.249
		40	1.260

The base–case model includes the following key features:

a) A single region, single stock model is considered, aggregated across zones 10, 20 and 30 (RAG agreed base-case, 2014).

b) The selectivity pattern for the trawl fleet was assumed to be length-specific and logistic. The parameters of the selectivity function for each fleet were estimated within the assessment. A selectivity pattern is estimated for each of port and onboard lengths due to large differences in length compositions.

c) The model accounts for males and females separately.

d) The initial and final years are 1975 and 2016. Previous models (Thomson, 2002; Klaer, 2005) used 1975 as the initial year due to the generally perceived poorer quality of data prior to this year. An initial fishing mortality is estimated to account for catches prior to the starting year.

e) The CVs of the CPUE indices were initially set at a value equal to the standard error from a loess fit (0.247; Sporcic and Haddon, 2017), before being re-tuned to the model-estimated standard errors within SS.

f) Discard tonnage was estimated through the assignment of a retention function. This was defined as a logistic function of length, and the inflection and slope of this function were estimated where discard information was available. A retention function was estimated for each ‘block’ period: namely 1975 – 1985 and 1986 – 2013.

g) Over the period 1975-1985 include a logistic retention function with a cap less than 1.0 (i.e. larger fish do not reach full retention and can be discarded; fixed at 0.8; Tuck and Day, 2014).

h) The rate of natural mortality, M, is assumed to be constant with age, and also time-invariant. The value for M is 0.1 y^{-1}.

i) Recruitment to the stock is assumed to follow a Beverton-Holt type stock-recruitment relationship, parameterised by the average recruitment at unexploited spawning biomass, R_0, and the steepness parameter, h. Steepness for the base-case analysis is set to 0.75.

j) The initial value of the parameter determining the magnitude of the process error in annual recruitment, σ_r, is set to 0.6.

k) The population plus-group is modelled at age 40 years, as is the maximum age for observations.

l) Growth is assumed to follow a von Bertalanffy type length-at-age relationship, with the parameters of the growth function being estimated separately for females and males inside the assessment model.

m) Retained and discard onboard length sample sizes were capped at 200 and required to have a minimum of 100 fish sampled to be included. For Sydney Fish Market samples (1975 to 1991) numbers of fish were divided by 10 and capped at 200. For port samples, numbers of trips were used as the sampling unit, with a cap of 100 (which was not reached). The sample size is reduced because the appropriate sample size for length frequency data is probably more closely related to the number of shots (onboard) or trips (port) sampled, rather than the number of fish measured.

The values assumed for some of the (non-estimated) parameters of the base case models are shown in Table 16.3.

Table 16.3. Parameter values assumed for some of the non-estimated parameters of the base-case model.

Parameter	Description	Value
M	Natural mortality	0.1
h	“steepness” of the Beverton-Holt stock-recruit curve	0.75
x	age observation plus group	40 years
a	allometric length-weight equations	0.0577 g^{-1}.cm
b	allometric length-weight equations	2.77
l_m	Female length at 50% maturity	19cm

16.2.3.8 Tuning method

Iterative rescaling (reweighting) of input and output CVs or input and effective sample sizes is a repeatable method for ensuring that the expected variation of the different data streams is comparable to what is input. Most of the indices (CPUE, surveys, composition data) used in fisheries underestimate their true variance by only reporting measurement or estimation error and not including process error.

In iterative reweighting, the effective annual sample sizes are tuned/adjusted so that the input sample size was equal to the effective sample size calculated by the model. In SS3.3 there is an automatic adjustment made to survey CVs (CPUE).

1. set the standard error for the relative abundance indices (CPUE, acoustic abundance survey, or FIS) to their estimated standard errors for each survey or for CPUE (and FIS values) to the standard deviation of a loess curve fitted to the original data (which will provide a more realistic estimate to that obtained from the original statistical analysis. SS3.3 then re-balances the relative abundance variances appropriately.

An automated tuning procedure was used for the remaining adjustments. For the recruitment bias adjustment ramps:

2. adjust the recruitment variance (σ_R) by replacing it with the RMSE or a defined set minimum and iterate to convergence (keep altering the recruitment bias adjustment ramps as predicted by SS3.3 at the same time).

Finally for the age and length composition data:

3. multiply the initial sample sizes by the sample size multipliers for the age composition data using Francis weights (Francis, 2011).
4. similarly multiply the initial samples sizes by the sample size multipliers for the length composition data
5. repeat steps 2 to 4, until all are converged and stable (proposed changes are < 1 – 2%).

This procedure may change in the future after further investigations but constitutes current best practice.

16.3 Results

16.3.1 *Transition to the latest version of SS and updated data*

Inclusion of the new data resulted in minimal changes to the estimates of recruitment and the relative spawning biomass time series until length data were included. Including the new length data resulted in a reduced 2011 recruitment estimate and consequent reduced spawning biomass (Figure 16.5 and Figure 16.6). The final tuned preliminary base case model produced spawning biomass that is less in recent years compared to the 2014 assessment, largely due to changes in the length data.

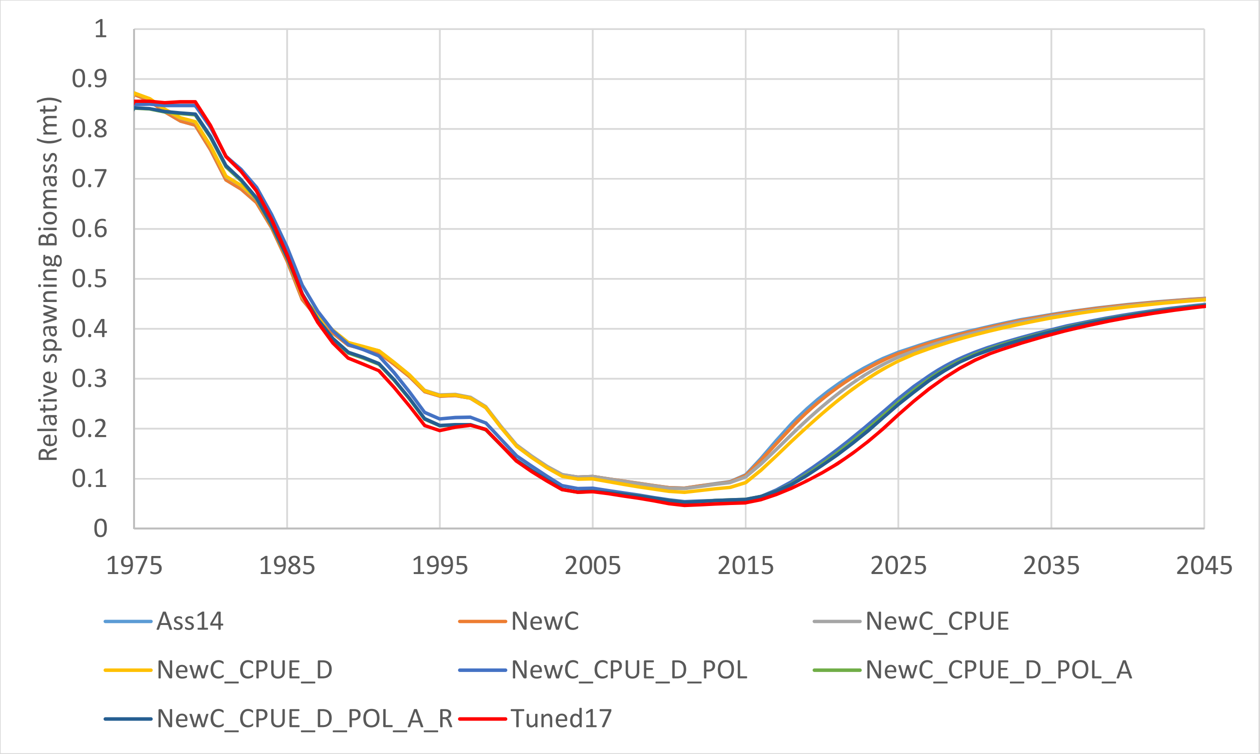


Figure 16.5. A comparison of relative spawning biomass according to the step-wise addition of updated data starting from the 2014 assessment (Ass14) through to the tuned preliminary 2017 assessment (Tuned17). C = Catch, CPUE = catch rates, D = discard, POL = port and onboard lengths, A = age data, R = additional years of recruitment estimation to 2015.

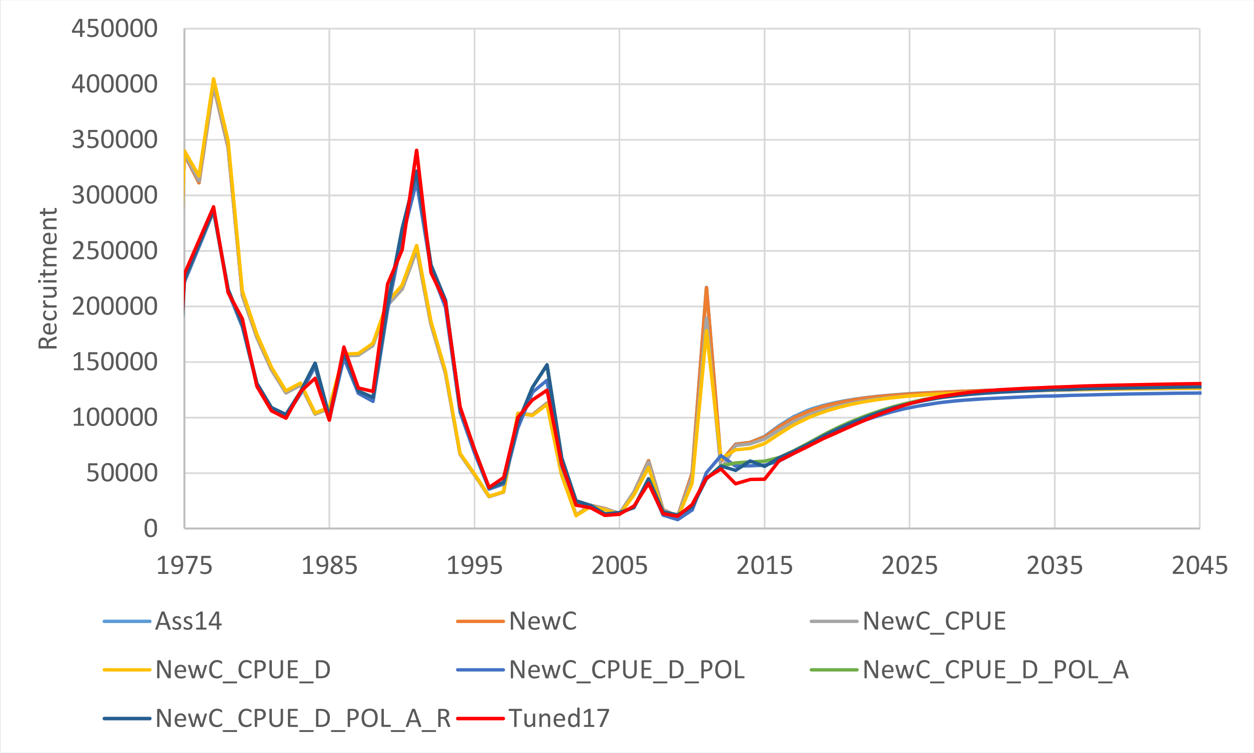


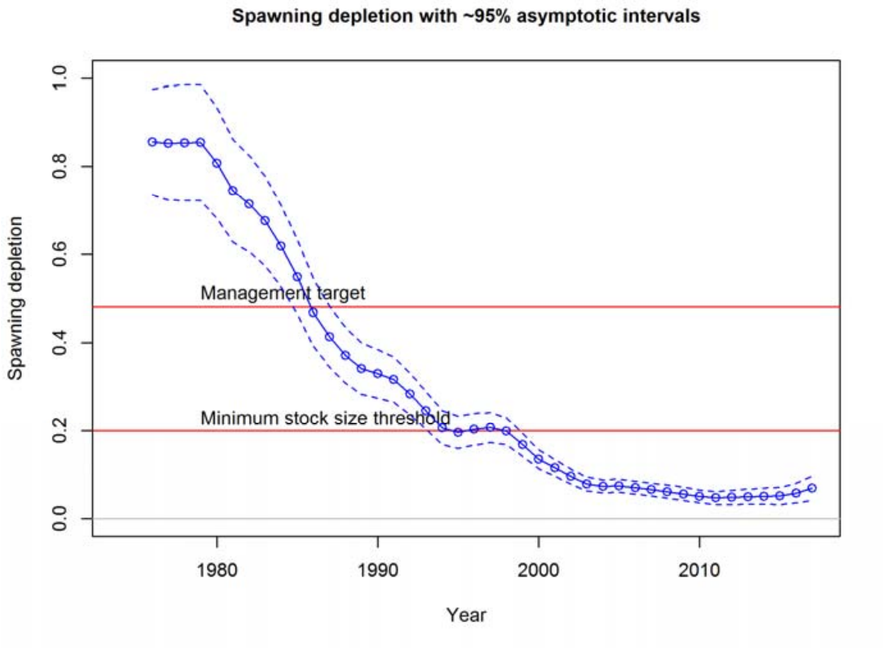
Figure 16.6. A comparison of the estimated annual recruitment according to the step-wise addition of updated data starting from the 2014 assessment (Ass14) through to the tuned preliminary 2017 assessment (Tuned17). C = Catch, CPUE = catch rates, D = discard, POL = port and onboard lengths, A = age data, R = additional years of recruitment estimation to 2015.

16.3.2 *The 2017 preliminary base case*

The base case specifications agreed by the ShelfRAG in 2014 were maintained into the 2017 preliminary base case presented here. The main differences however are: separating length frequencies into onboard and port collected components, weighting length frequencies by shots (onboard) and trips (port) rather than fish measured; and using the latest new tuning methods.

Results show reasonably good fits to the catch rate data, length data and conditional age-at-length data (Appendix). Issues to note include that there is considerable difference between the port and onboard retained length frequencies, with the mode of port lengths generally larger than onboard lengths (Figure A.5). The magnitude of the estimated recruitment in 2011 in the 2014 assessment has been greatly reduced in the 2017 preliminary assessment (although estimates of recent recruitment are improved over the poor period during 2002-2010; Figure 16.6). The 2017 preliminary assessment estimates that the projected 2018 spawning stock biomass will be 8% of virgin stock biomass (projected assuming 2017 catches in 2018; Figure 16.7), compared to 11% at the start of 2015 from the last assessment (Tuck, 2014).

Further development should include an exploration of the observed differences between port and onboard lengths, differences in length compositions between adjacent years, and refining the model structure (eg years of recruitment estimation, selectivity and retention blocking).



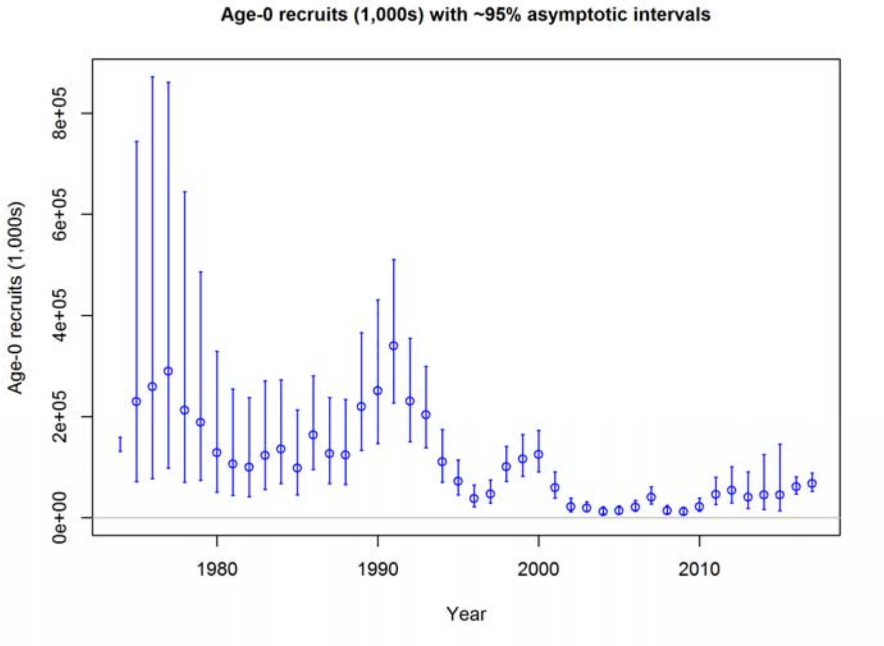


Figure 16.7. The estimated time-series of relative spawning biomass and annual recruitment for the 2017 preliminary base case assessment for redfish.

16.4 Acknowledgements

Age data was provided by Kyne Krusic-Golub (Fish Ageing Services), ISMP and AFMA logbook and CDR data were provided by John Garvey (AFMA). Mike Fuller, Roy Deng and Franzis Althaus (CSIRO) pre-processed the data. Jemery Day, Malcolm Haddon, Andre Punt, Robin Thomson, Rich Little, Miriana Sporcic and Claudio Castillo-Jordan are thanked for helpful discussions on this work.

16.5 References

Francis, R.I.C.C. 2011. Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124-1138.

Haddon, M. 2014. Length at Age for Redfish (*Centroberyx affinis*). CSIRO, Oceans and Atmosphere, Hobart, Australia. 34p.

Haddon, M and Sporcic, M. 2017. Catch Rate Standardizations 2017 (for data 1986 – 2016). Technical paper presented to SESSF Resource Assessment Group. August 2017. Hobart, Tasmania.

Hilborn, R., Maunder, M., Parma, A., Ernst, B., Payne, J. and Starr, P. 2000. Coleraine – A generalized age structured stock assessment model. http://www.fish.washington.edu/research/coleraine/

Methot, R.D. 2005 Technical Description of the Stock Synthesis II Assessment Program. NOAA Fisheries Service, Seattle. 54 pp

Methot, R.D. 2011. User manual for Stock Synthesis Model Version 3.2. NOAA Fisheries Service, Seattle. 165 pp.

Methot, R.D. and C.R. Wetzel. 2013. Stock Synthesis: a biological and statistical framework for fish stock assessment and fishery management. Fisheries Research 142: 86–90.

Rowling, K.R. 1994. Redfish, *Centroberyx affinis* in R.D.J. Tilzey (ed) The South East Fishery, Bureau of Resource Sciences, Canberra.

Rowling, K.R. 1999 Stock Assessment Report for Redfish, 1999. Redfish Assessment Group, South East Fishery Assessment Group, Australian Fisheries Management Authority, Canberra.

Thomson, R.B. 2002. Integrated Analysis of redfish in the South East Fishery, including the 2001 fishing data. Report to Redfish Assessment Group, Bermagui, 27-28 June 2002.

Tuck, G.N. 2014. Stock assessment of redfish *Centroberyx affinis* based on data up to 2013: Supplement to the October 2014 Shelf RAG paper. Technical document presented to the Shelf RAG, 22 November 2014.

Tuck, G.N. and Day, J.R. 2014. Development of a base-case Tier 1 assessment of redfish *Centroberyx affinis* based on data up to 201. Technical document presented to the Shelf RAG, Hobart, 22 September 2014.

16.6 Appendix A

16.6.1 *Preliminary base case diagnostics*

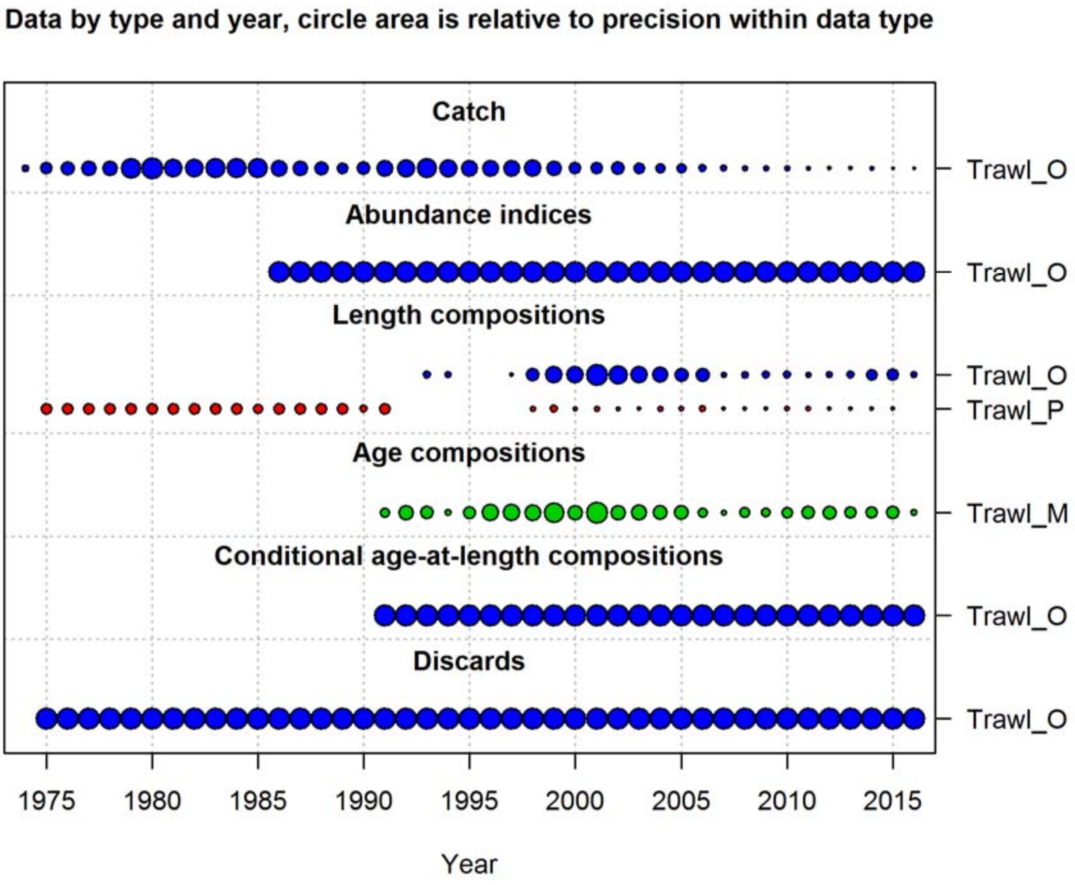
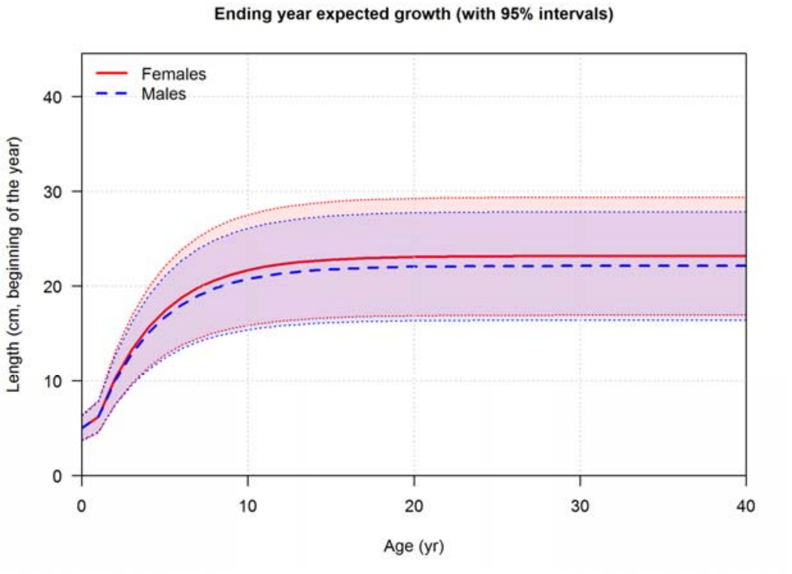


Figure A 16.1. Summary of data sources for the preliminary base case assessment. O = on board, P = port, M = mirrored (used to observe age composition fits).



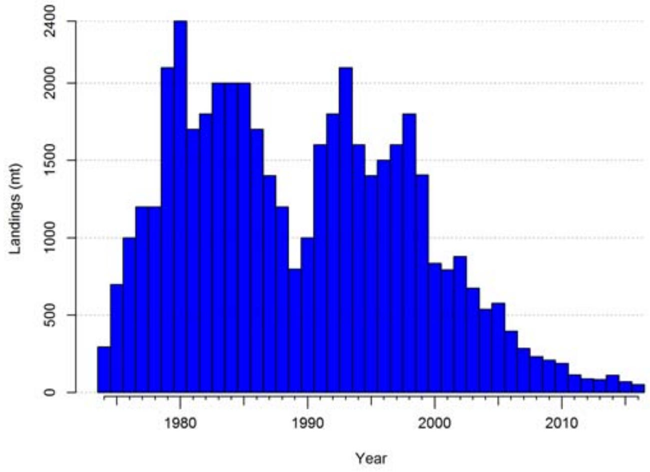


Figure A 16.2. Growth and landings for redfish.

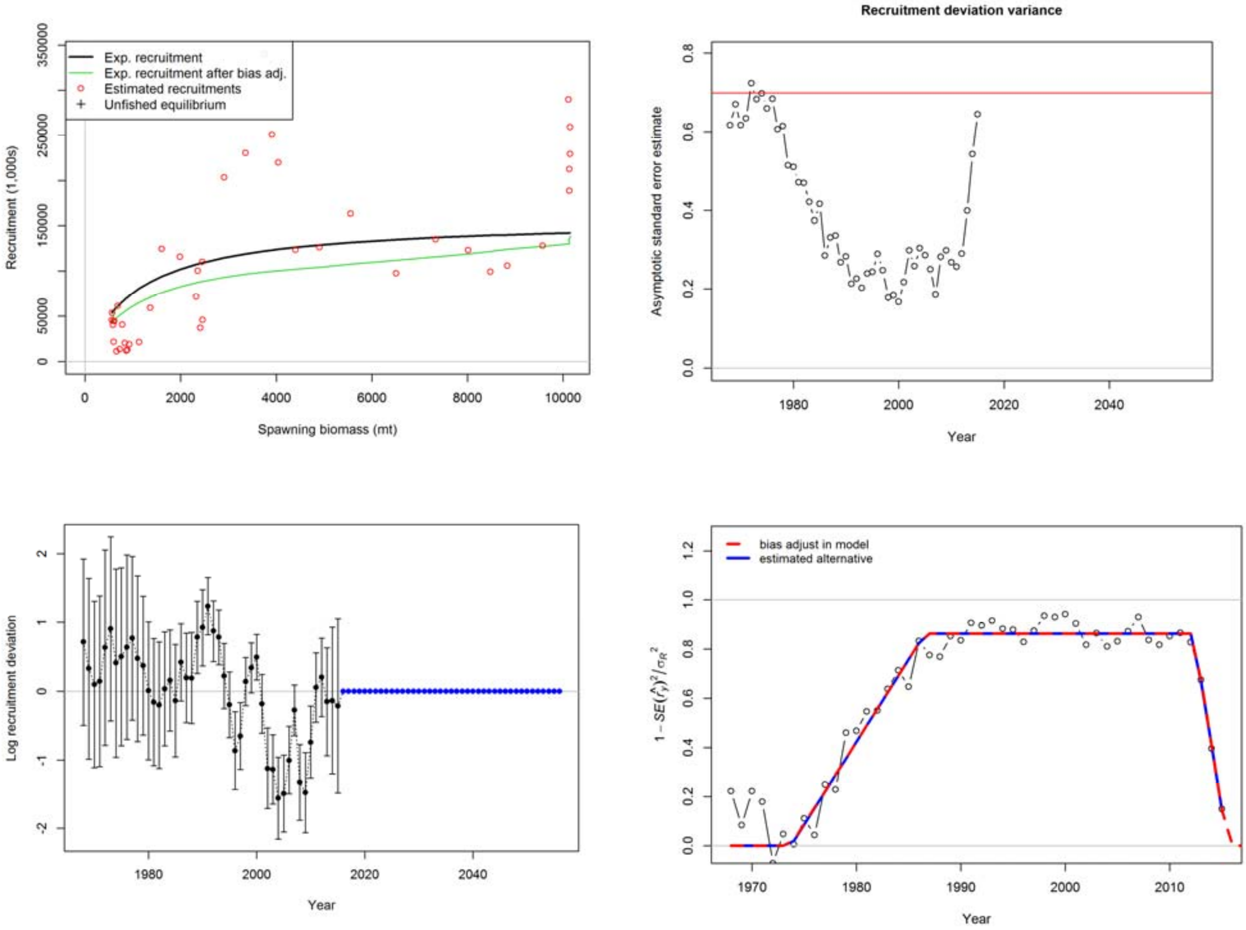


Figure A 16.3. Time series showing the stock recruitment curve, recruitment deviations and recruitment deviation variance check for redfish.

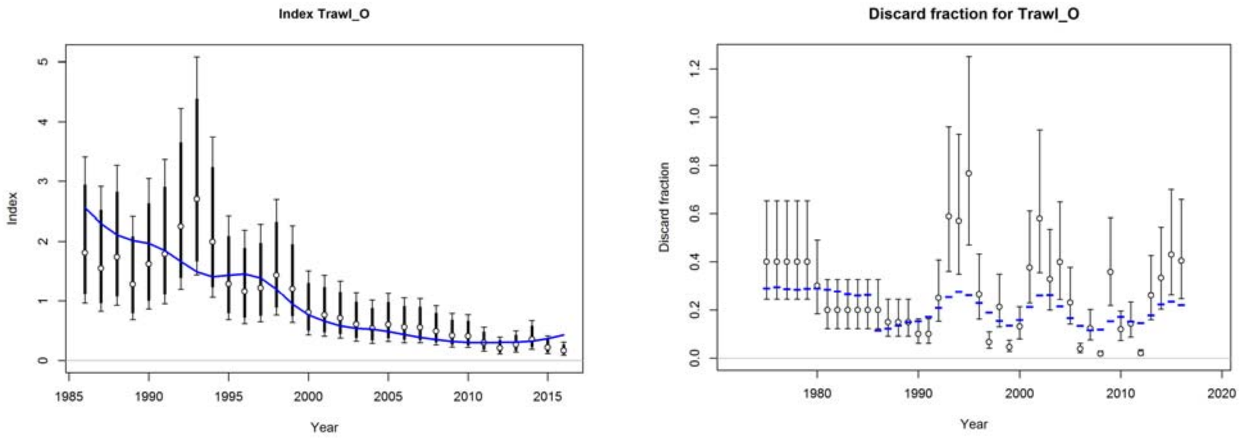


Figure A 16.4. Fits to trawl CPUE and discards for redfish.

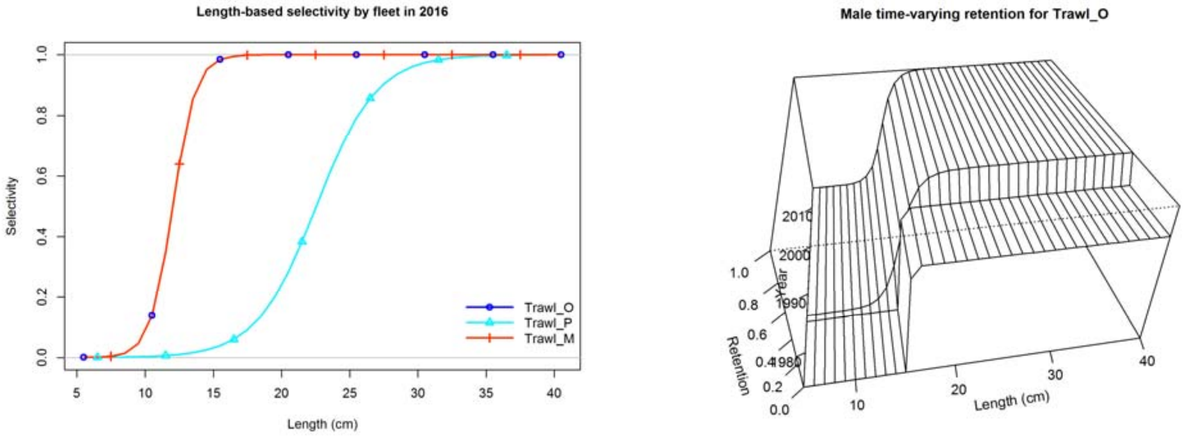


Figure A 16.5. Estimated trawl selectivity for port (P) and onboard (O) and the retention function for redfish.

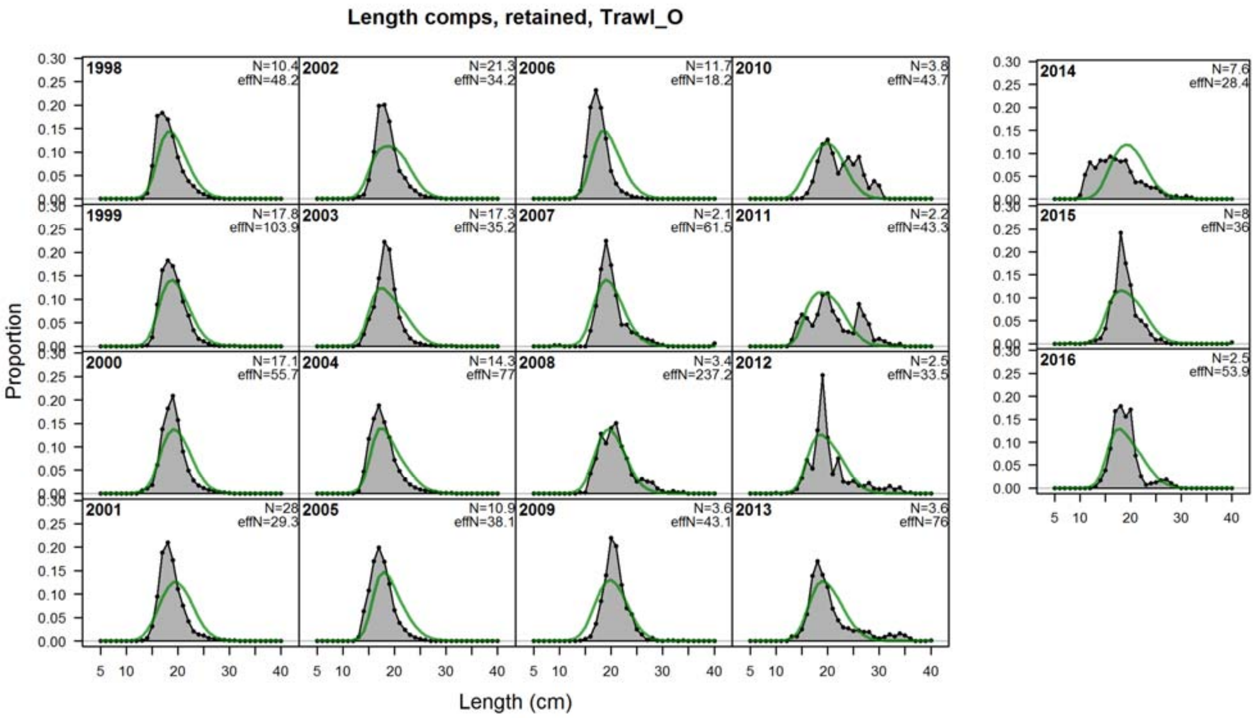


Figure A 16.6. Redfish length composition fits: onboard trawl retained.

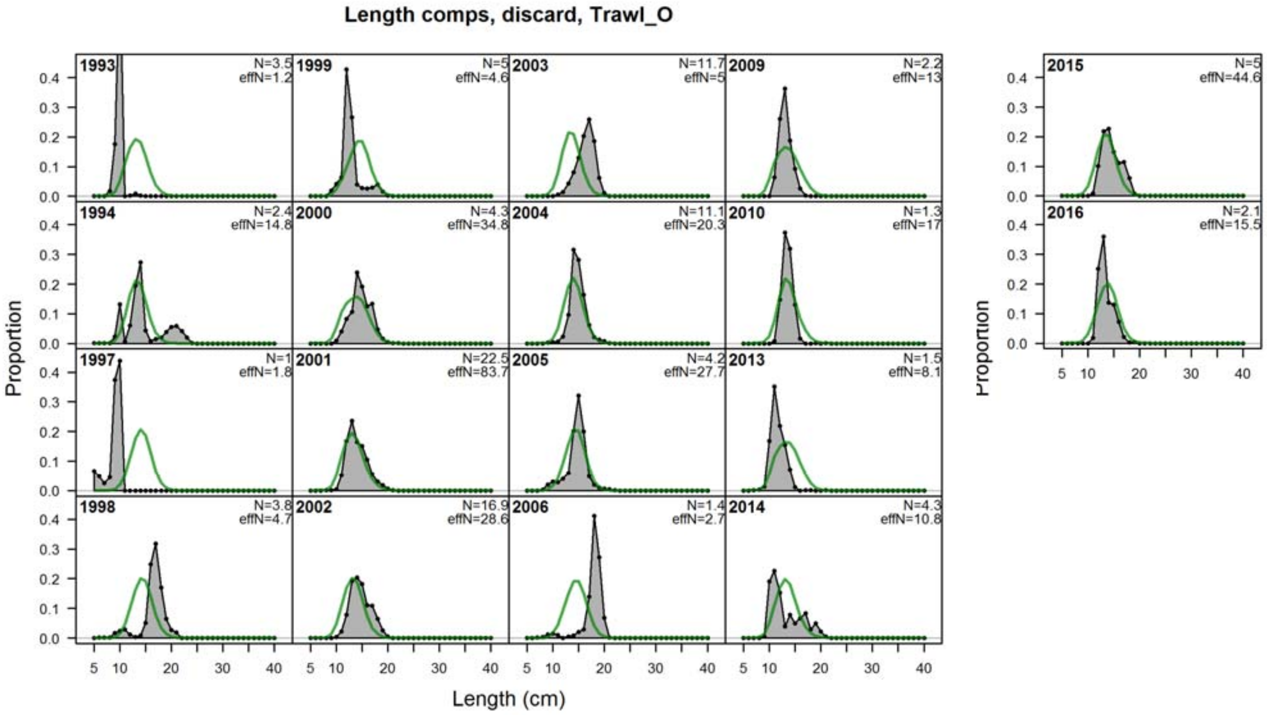


Figure A 16.7. Redfish length composition fits: onboard trawl discard.

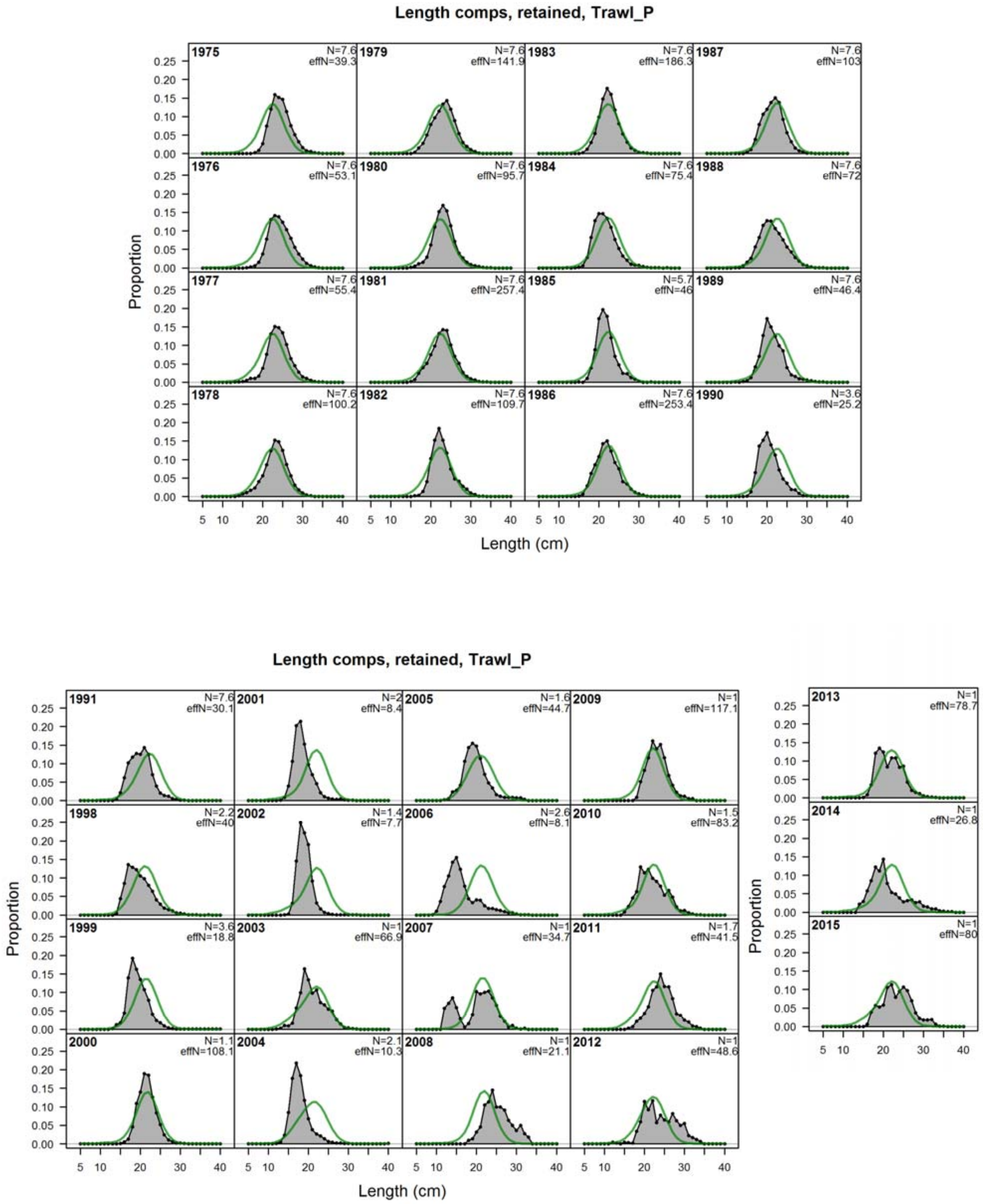


Figure A 16.8. Redfish length composition fits: Port trawl.

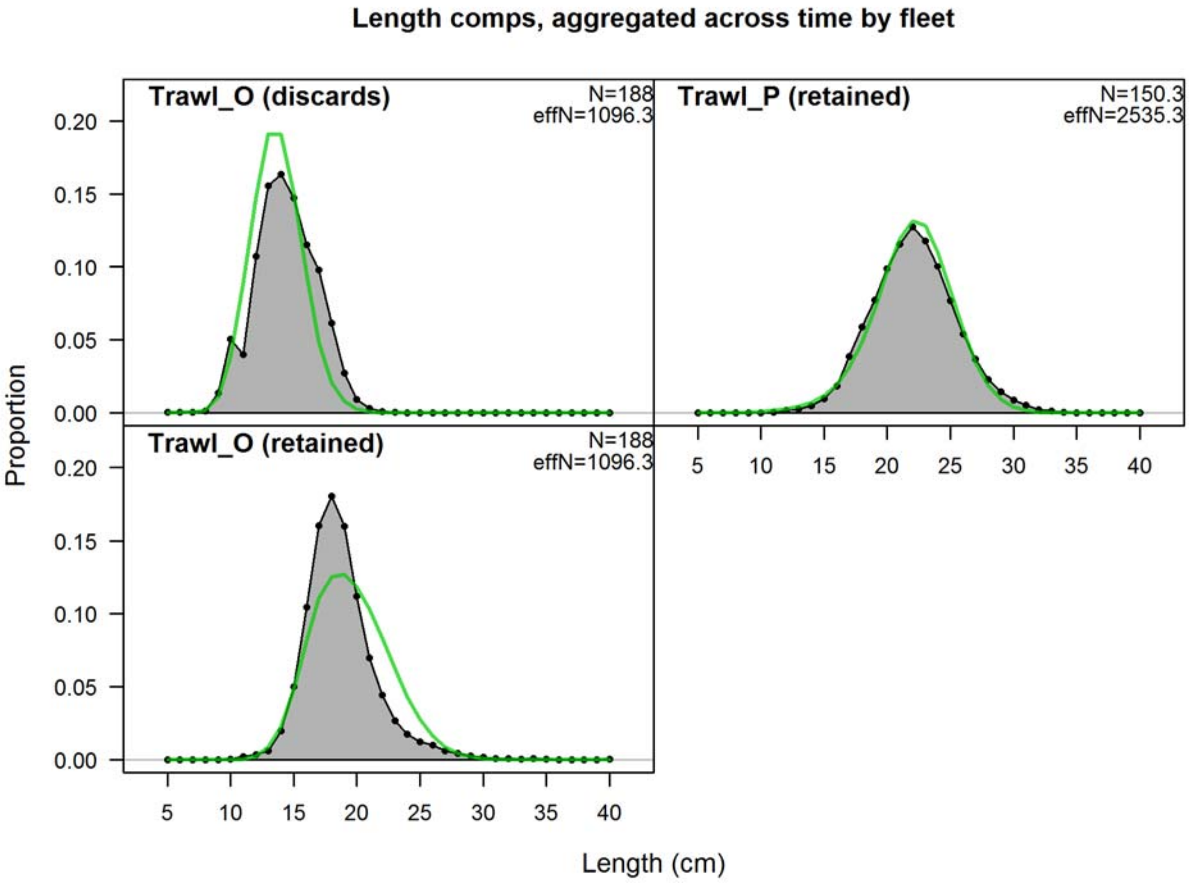


Figure A 16.9. Redfish length composition fits aggregated across years.

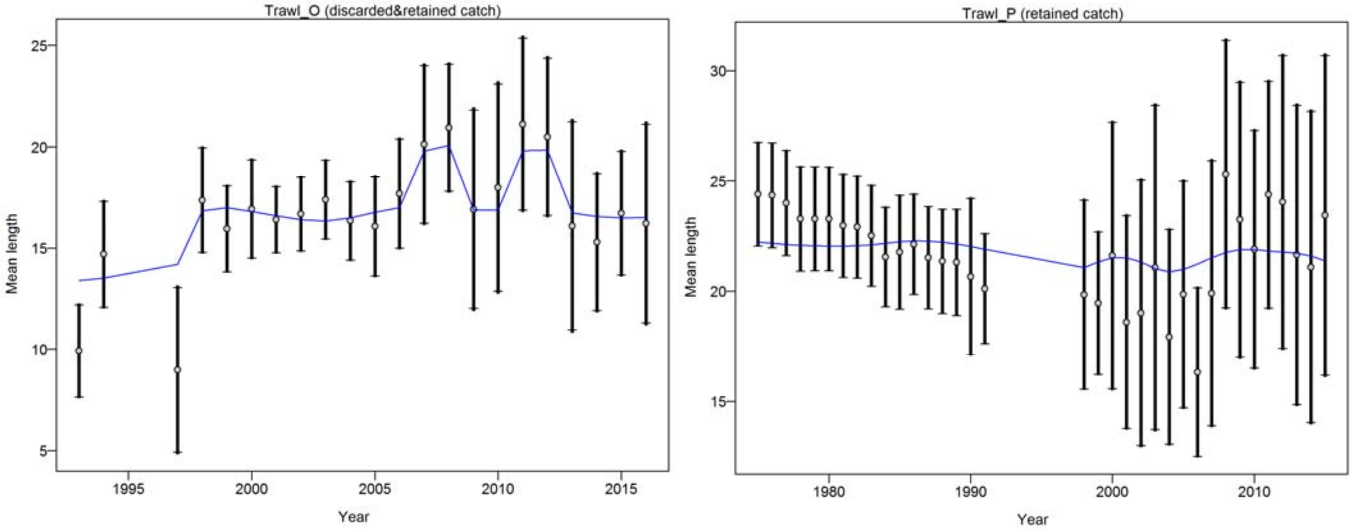


Figure A 16.10. Redfish length composition fit diagnostics from tuning. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data.

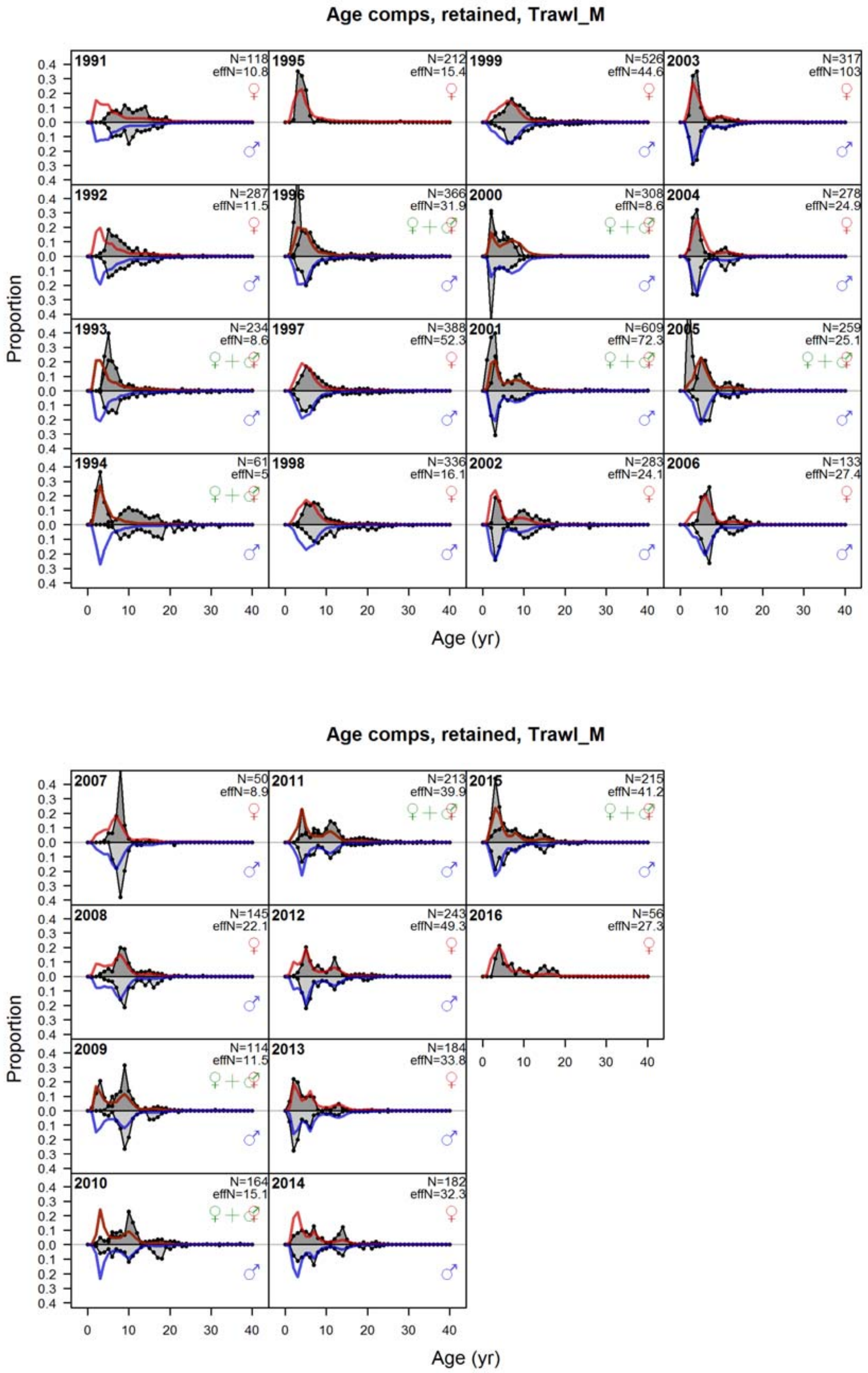


Figure A 16.11. Redfish age composition fits.

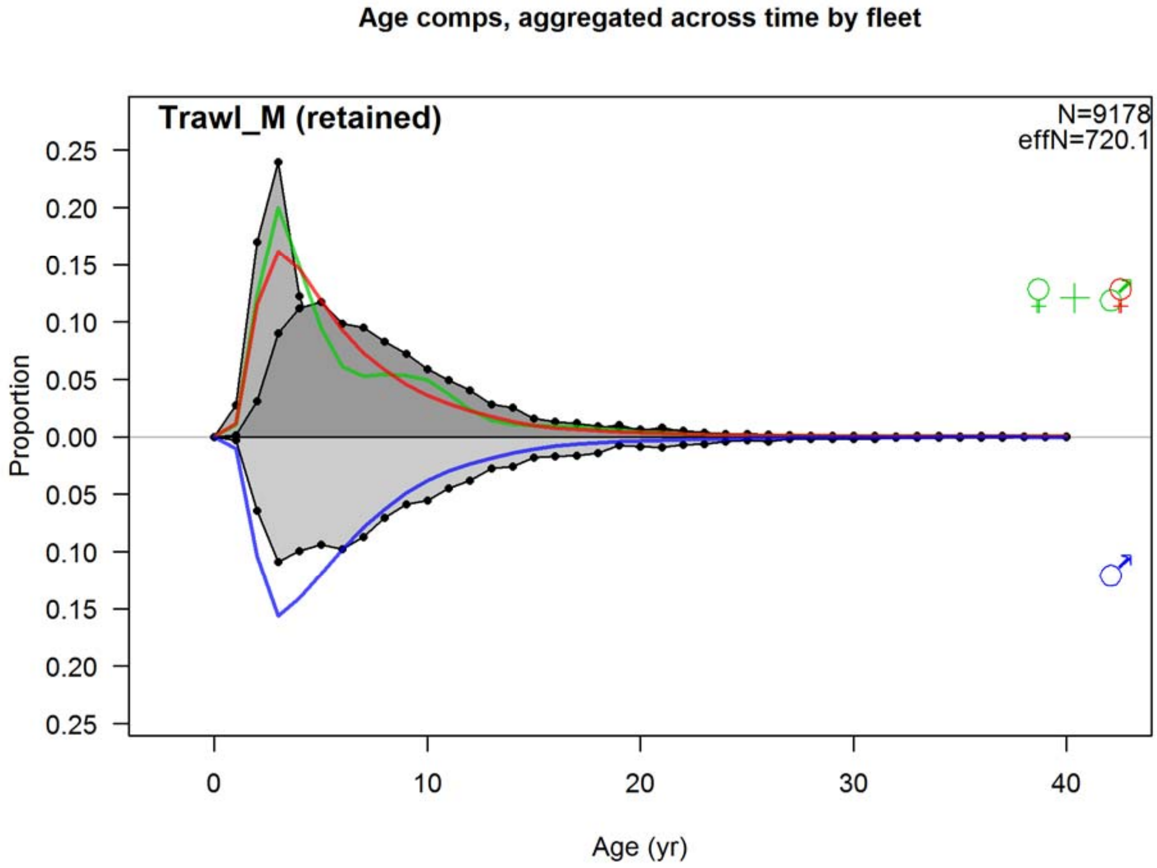


Figure A 16.12. Redfish age composition fit aggregated across years.

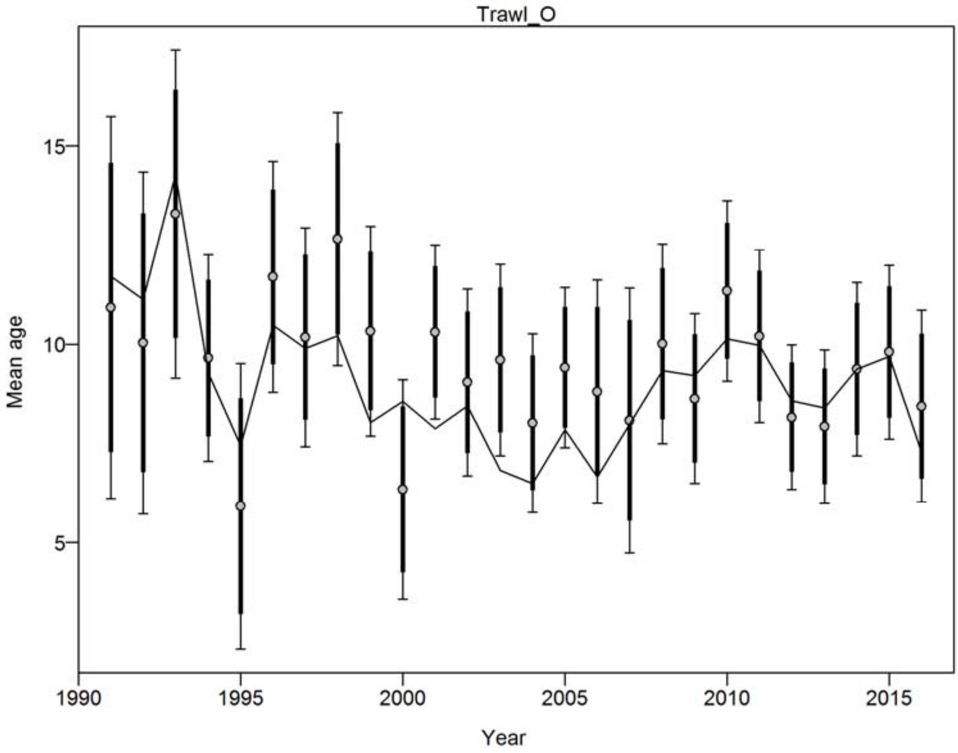
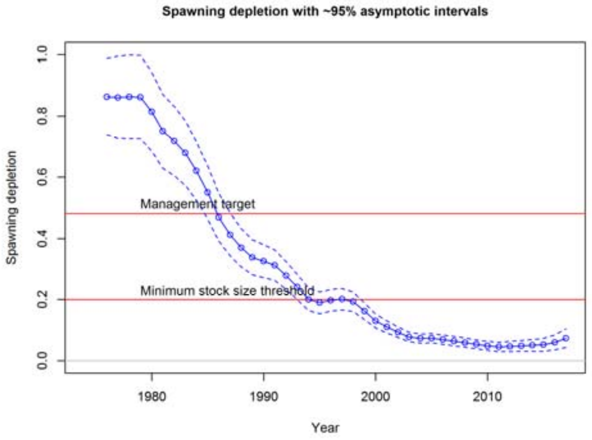


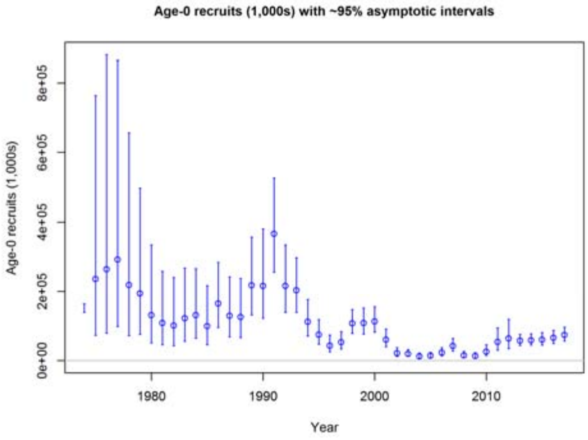
Figure A 16.13. Redfish conditional age at length fit diagnostics from tuning. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data.

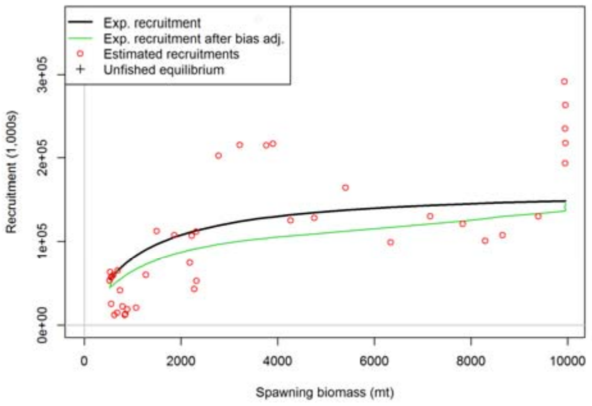
16.6.2 ***Additional diagnostics***

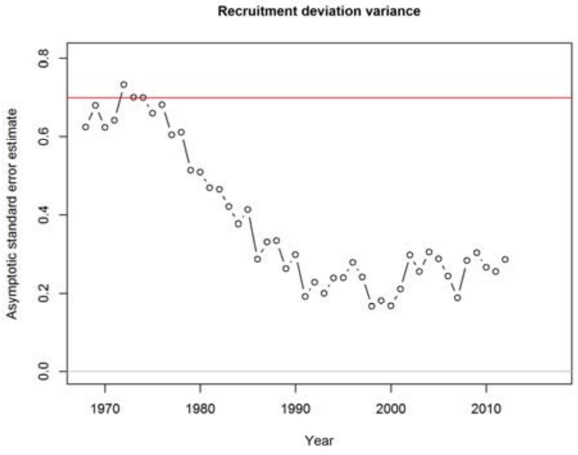
16.6.2.1 Last year of recruitment estimation is 2012

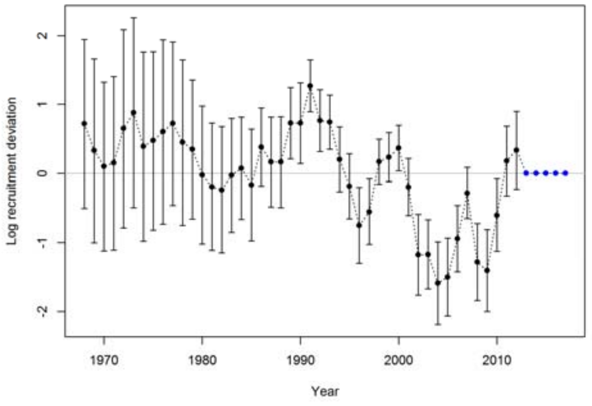
In this sensitivity, the last year of estimated recruitments is 2012 instead of 2015. The stock status in 2018 is 9%.

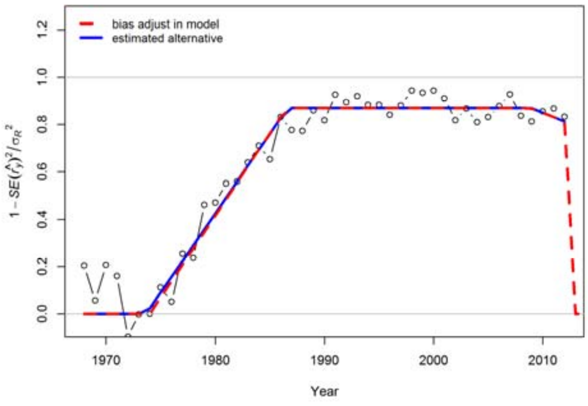






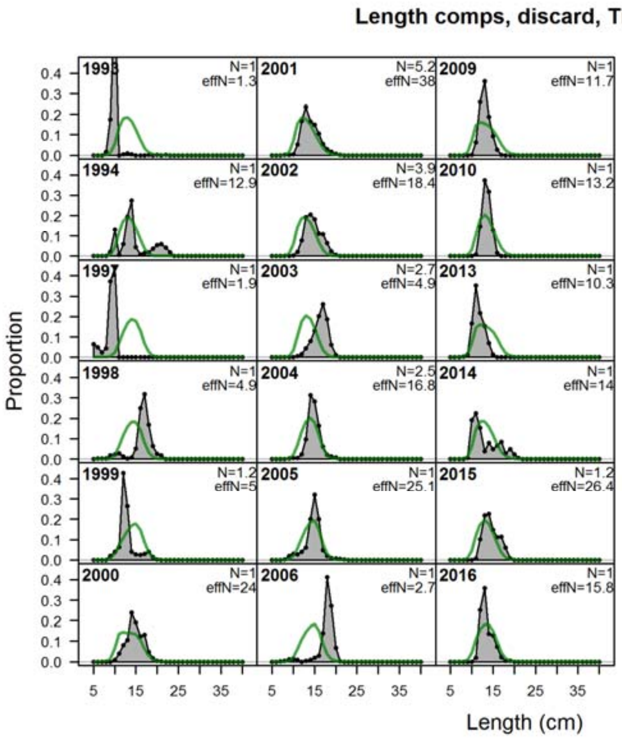


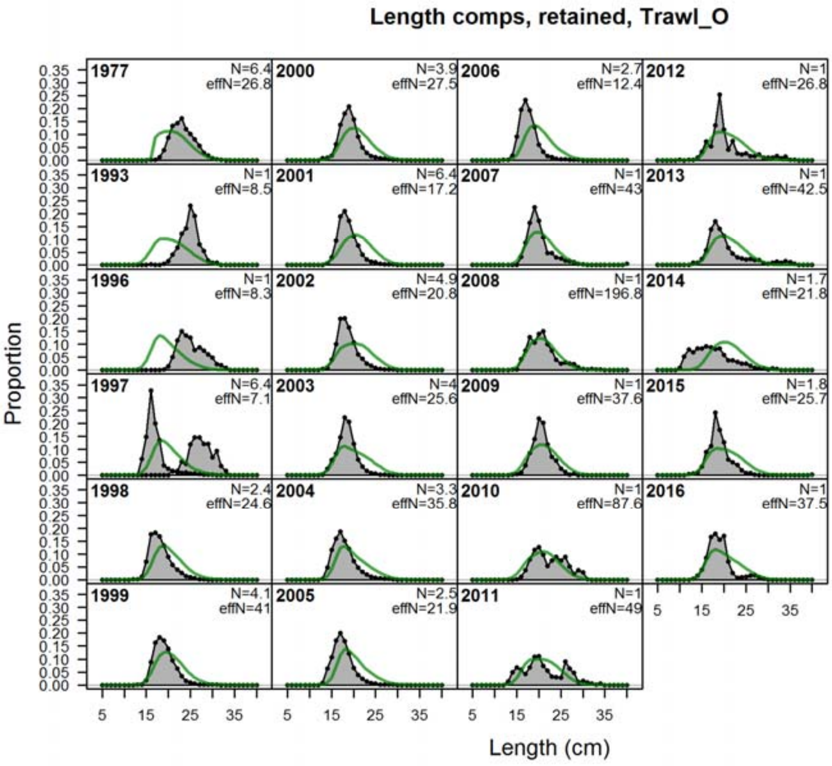


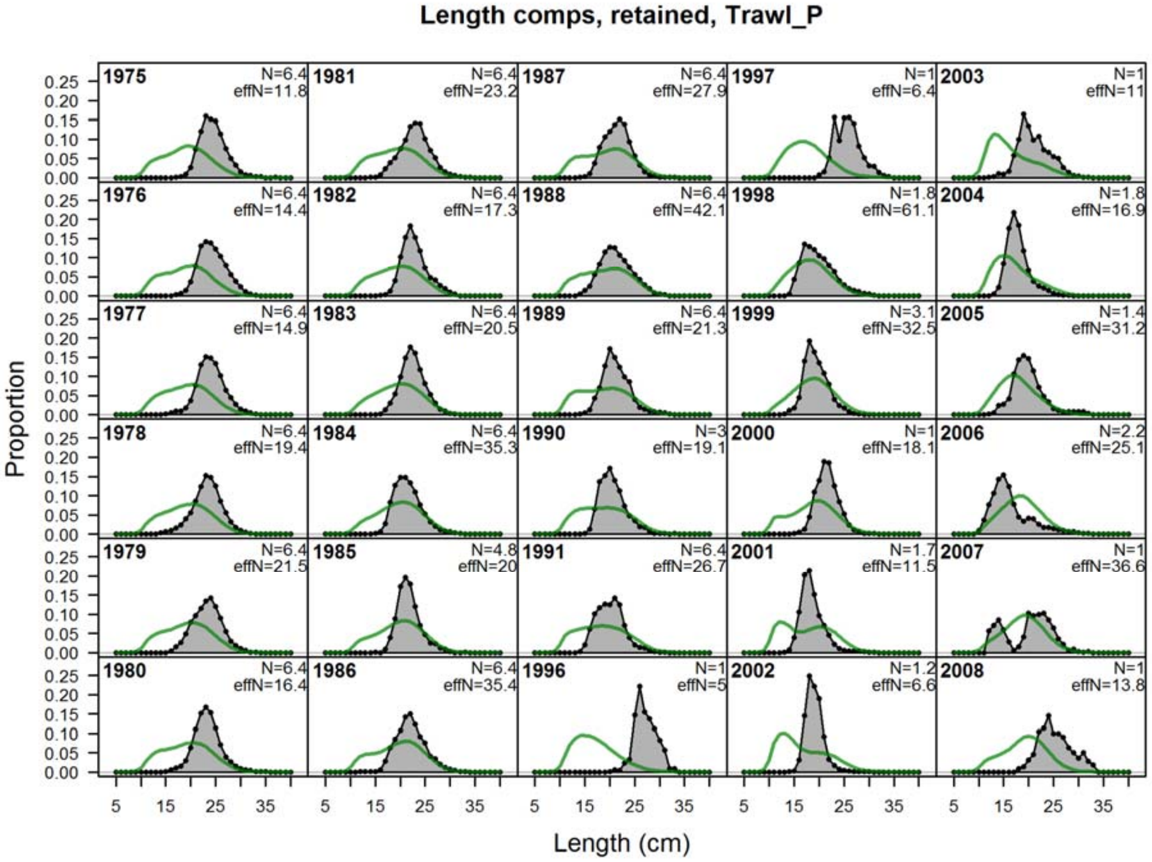


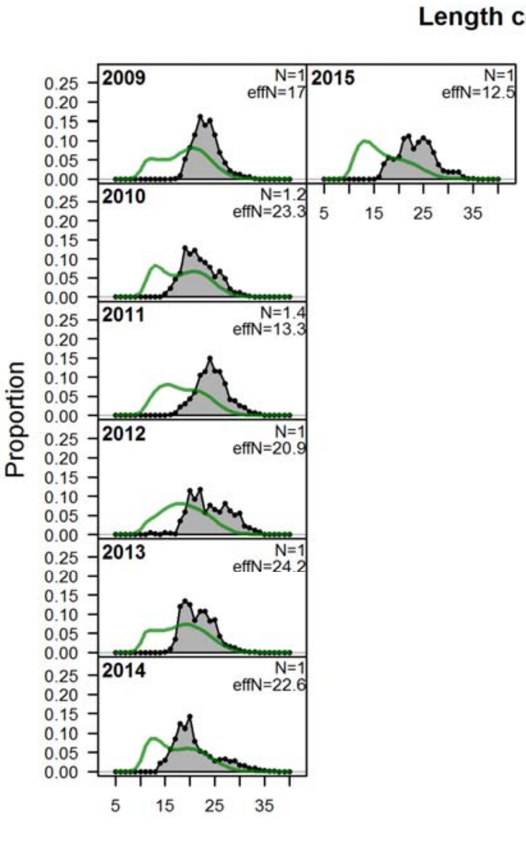
16.6.2.2 Single selectivity for port and onboard lengths

In this sensitivity, only a single selectivity is fit to port and onboard lengths.






Length comps, retained, Trawl_P


Length comps, retained, Trawl_P

17. Redfish (*Centroberyx affinis*) stock assessment based on data up to 2016

Geoff Tuck, Jemery Day, Malcolm Haddon and Caludio Castillo-Jordan

CSIRO Oceans and Atmosphere, GPO Box 1538, Hobart, TAS 7001, Australia

17.1 Executive Summary

This document describes the base case assessment and some of the issues encountered during the development of the quantitative Tier 1 eastern redfish (*Centroberyx affinis*) assessment in 2017. The last full assessment was presented in 2014 (Tuck and Day, 2014; Tuck, 2014). A preliminary base case was presented at the September RAG and was updated from the 2014 assessment by the inclusion of data up to the end of 2016, which entails an additional 3 years of catch, discard, CPUE, length and age data and ageing error updates since the 2014 assessment.

A base case assessment was achieved according to the RAG-agreed model structure that did not separate length data by zone. The model fits to the catch rate data, length data and conditional age-at-length data reasonably well. The magnitude of the estimated recruitment in 2011 in the 2014 assessment has been greatly reduced in the 2017 assessment (although estimates of recent recruitment have increased compared to the period of poor recruitment during 2002-2010). The assessment estimates that the projected 2018 spawning stock biomass will be 8% of virgin stock biomass (projected assuming 2016 catches in 2017). Estimates of recruitment since the early 2000s have been lower than average (except for 2011, 2012), potentially as a consequence of directional environmental change influencing productivity. Low recruitment scenarios using average historical recruitment residuals from 2001 to 2010 for future projections of constant annual catches showed a markedly slow increase in spawning biomass for annual catches of 50t. Catches of 150t were not sustainable under this low recruitment assumption.

Initial difficulties in reaching a tuned base case according to the RAG-agreed model structure led to several attempts at alternative models (such as single and two selectivity models to fit to port and onboard length data, fixing parameters, and removing EBass and Sydney Fish Market length data). As part of the investigation into this issue, a breakdown of the length data by year, month, zone, onboard/port, discarded and retained was conducted. This revealed that there are distinct differences between Eastern Bass (EBass) and NSW port lengths. EBass port lengths are considerably larger than NSW port lengths, with ascending limbs beginning at ~10cm for NSW and ~15-20cm for EBass. This appears to be driven by different discard practices, as the distribution of caught fish lengths from the onboard length data are similar for EBass and NSW. As such, future models should consider data separated by zone, with a different discard function estimated for each zone.

17.2 Introduction

17.2.1 *Data*

Tuck (2017) described the process of moving to the new version of Stock Synthesis (version SS-V3.30.06.02, Methot, 2017) and this is not repeated here. Further minor changes to the Stock Synthesis platform occurred since September 2017 (such as corrections to projection code) and the version used here is V3.30.08.04. For completeness, the data inputs to the model are described. The data inputs to the assessment come from multiple sources: length and conditional age-at-length data from the trawl fishery, updated standardized CPUE series (Haddon and Sporcic, 2017), the annual total mass landed and annual discard rates, and age-reading error. Data were formulated by calendar year (i.e. 1 Jan to 31 Dec) and were aggregated across all eastern zones (Zones 10, 20 and 30).

17.2.1.1 Catch data

Total annual catches (t) for redfish have been estimated based on a combination of sources, including Sydney Fish Market (SFM) data (to 1986), NSW and Victorian landings and the SEF logbook data (Table 28 of Rowling (1994); Appendix 1 of Rowling (1999); Table 1 of Thomson (2002); Table 1 of Klaer (2005)). The estimated annual tonnages of landings, discard rates and CPUE are provided in Table 17.1. Where available, previously agreed catch tonnages from RAGs were used (Rowling, 1999; Klaer, 2005). CDR records and NSW state catch data are used from 2005 for the base-case model development (referred to as BC4 in Tuck (2014)). Figure 17.1 shows a comparison of the agreed total catch (Commonwealth and NSW combined) from the 2014 assessment and the updated catch estimates for the 2017 assessment. Table 17.1 shows the annual catch values used in the assessment.

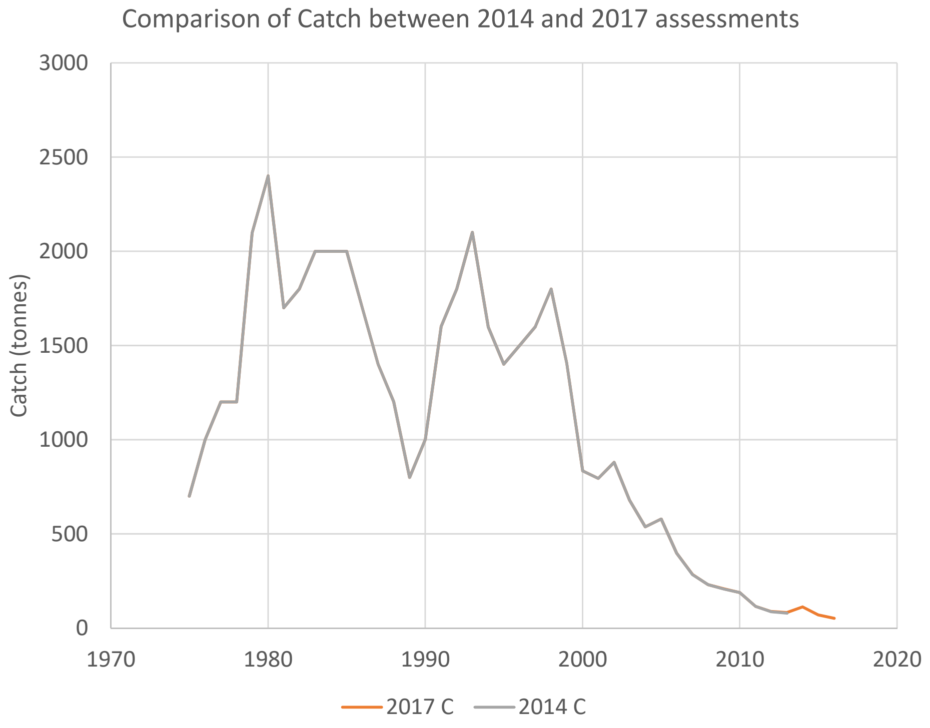


Figure 17.1. Comparison of total annual catches from the 2014 base case assessment (2014 C) and the updated catch used in the 2017 assessment (2017 C).

Table 17.1. Estimated landings (t), discard rates and standardized CPUE (Sporcic and Haddon, 2017) for redfish by calendar year. Total catch (Commonwealth and state) for years 1975 to 2004 were taken from previously agreed catch estimates from redfish assessment group meetings (Rowling, 1999, Appendix 1; Klaer, 2005) and from CDR records for 2005 onwards. Also shown are the NSW state catches from 2005 onwards. State catches exist prior to 2005 but are included in the redfish assessment group agreed catches (Landings column) until 2004.

Year	Landings (t)	NSW	Total Landings (t)	Discard Rates	CPUE
1975	700		700	0.40	
1976	1000		1000	0.40	
1977	1200		1200	0.40	
1978	1200		1200	0.40	
1979	2100		2100	0.40	
1980	2400		2400	0.30	
1981	1700		1700	0.20	
1982	1800		1800	0.20	
1983	2000		2000	0.20	
1984	2000		2000	0.20	
1985	2000		2000	0.20	
1986	1700		1700	0.20	1.81
1987	1400		1400	0.15	1.55
1988	1200		1200	0.15	1.74
1989	800		800	0.15	1.28
1990	1000		1000	0.10	1.62
1991	1600		1600	0.10	1.79
1992	1800		1800	0.25	2.25
1993	2100		2100	0.588	2.70
1994	1600		1600	0.569	1.99
1995	1400		1400	0.767	1.29
1996	1500		1500	0.265	1.16
1997	1600		1600	0.067	1.22
1998	1800		1800	0.213	1.43
1999	1406		1406	0.046	1.20
2000	835		835	0.131	0.80
2001	794		794	0.375	0.76
2002	880		880	0.580	0.71
2003	677		677	0.327	0.61
2004	538		538	0.398	0.54
2005	532	47	579	0.231	0.60
2006	321	76	397	0.038	0.56
2007	230	54	284	0.124	0.55
2008	201	29	231	0.018	0.49
2009	182	26	208	0.357	0.42
2010	166	23	188	0.120	0.41
2011	99	17	115	0.143	0.30
2012	72	16	88	0.021	0.21
2013	66	17	83	0.261	0.27
2014	96	16	112	0.333	0.36
2015	59	11	70	0.429	0.22
2016	43	9	52	0.404	0.17

17.2.1.2 Discard rates

Discard rates prior to 1992 are those estimated by the redfish RAG (Rowling, 1999; Thomson, 2002). Discard rates after 1992 were estimated from on-board data which gives the weight of the retained and discarded component of those shots that were monitored (Thomson and Klaer, 2011). Rowling (1999) provides considerable detail on how the historical discard rates were estimated and the factors that influenced discard practices. Redfish discarding was discussed at a redfish workshop held in Cronulla in April 1997 and at various open redfish assessment group meetings during late 1997 and early 1998. The resulting discard rates are documented in Rowling (1999) and also listed in the last redfish assessment group (Thomson, 2002) and Shelf RAG (Klaer, 2005) assessments of redfish. Here we update the discard estimates by the addition of on-board estimates through to 2016 (Table 17.1).

The assessment model estimates the probably of retention (which is 1 – P(discard)) as a function of length in order to estimate the annual discard rate and to fit to any information on discard length composition. It is apparent that the redfish fishery has undergone numerous changes that may have influenced the behaviour of discarding; these changes are documented in Rowling (1999; Appendix 2). In consultation with K. Rowling (pers. comm.), the following discarding periods have been identified:

1975 – 1985. Market driven discarding

1975 – 1985. Discards largely across all size ranges, but with more small fish discarded

1986 – 2000. Surimi markets period

1986 – 1992. Surimi market. Discarding rates lower, mainly small fish.

1993 – 1995. Quantity of fish sent to surimi market declined, Geelong surimi market closes; consequent increase in discarding.

1996 – 2000. Discarding declined ‘as redfish became less available’. Close of Hacker surimi processor in 2000.

2001 – 2013. Size based discarding period

2001 – 2013. Assume mostly small fish discarded

These changes in discarding behaviour have influenced the large variations in discard rates observed (Table 17.1), as well as the catches, catch rates and discard length composition. The RAG agreed (2014) base case model allows the retention function to vary according to the identified discard period from 1975 to 1985 (market-driven), and from 1986 onwards (size-driven).

17.2.1.3 Catch rates

Haddon and Sporcic (2017) provides the updated catch rate series for redfish (Table 17.1; Figure 17.2). After substantial increases in catch rate during the early and late 1990s, the catch rates have continued to decline since then, and the catch rate is now less than 10% of the levels in 1986. A small increase in catch rate occurred during 2013-14 but has since declined.

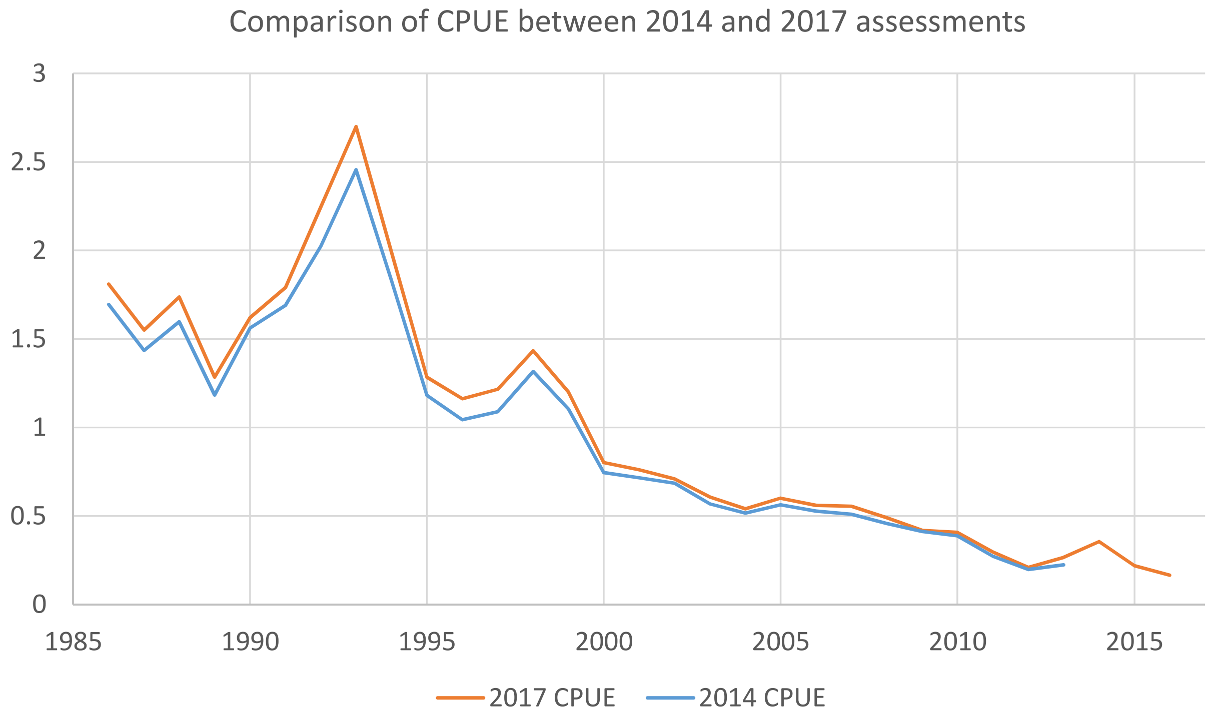


Figure 17.2. Comparison of the annual catch rates series for redfish between 2014 (2014 CPUE) and 2017 (2017 CPUE).

17.2.1.4 Length frequencies and age data

Length and age composition data have been included in the model as length frequency data and conditional age-at-length data by year and sex (when available). Marginal age composition data are included in diagnostic plots but are not used directly within the fitting procedure. Catch length frequency data were obtained from NSW records of fish measured at the Sydney Fish Markets to 1991. After 1991 length-frequencies were obtained from ISMP on-board and port measurements. The observed length and age data are shown in later figures with the corresponding model predicted values. The Kapala length frequencies and Fishery Independent Survey (FIS) abundance indices are not included in the RAG-agreed base-case model (Tuck and Day, 2014).

17.2.1.5 Biological parameters and stock structure assumptions

The assessment assumes that the length at 50% maturity is 19cm for females (Thomson, 2002). Natural mortality is assumed to be 0.10y^{-1}. Redfish natural mortality is generally assumed to be in the 0.05 and 0.15 y^{-1} range (SEFAG, 2000). Morison and Rowling (2001) calculated natural mortality values between 0.07 and 0.11 y^{-1}. Steepness is assumed to be 0.75. Parameters for the length-weight relationship were taken from Klaer (2005; also used by Thomson, 2002). Growth parameters, including the von Bertalanffy growth parameter *k*, are estimated (Thomson, 2002). Data were formulated by calendar year (i.e. 1 Jan to 31 Dec) and were aggregated across all eastern zones (Zones 10, 20 and 30), as there is sufficiently strong evidence to suggest a north-south split did not exist (Shelf RAG agreement, September 2014; Haddon, 2014). The 2017 base case model structure follows the RAG agreed base case from 2014 (Tuck and Day, 2014; Tuck, 2014) except that the length data are now separated into port and onboard, and updated tuning methods are applied. A new feature of SS3.30

allows specification of spawning and settlement month. Here we assume redfish spawn in July and settle in January. Previous versions of SS3 had assumed these events occurred in January.

17.2.1.6 Age-reading error

Standard deviations for aging error by reader have been estimated, producing the age-reading error matrix of Table 17.2 (A.E. Punt, pers. comm.).

17.2.1.7 Analytic approach

The 2017 preliminary base case assessment of eastern redfish uses an age- and size-structured model implemented in the generalized stock assessment software package, Stock Synthesis (SS) (Version 3.30.08.04, NOAA 2017). The methods utilised in SS are based on the integrated analysis paradigm. SS can allow for multiple seasons, areas and fleets, but most applications are based on a single season and area. Recruitment is governed by a stochastic Beverton-Holt stock-recruitment relationship, parameterized in terms of the steepness of the stock-recruitment function (h), the expected average recruitment in an unfished population (R_0), and the degree of variability about the stock-recruitment relationship (σ_r). SS allows the user to choose among a large number of age- and length-specific selectivity patterns. The values for the parameters of SS are estimated by fitting to data on catches, catch-rates, discard rates, discard and retained catch length-frequencies, and conditional age-at-length data. The population dynamics model and the statistical approach used in fitting the model to the various data types are given in the SS technical documentation (Methot, 2005).

Table 17.2. The standard deviation of age reading error.

Age	St Dev	Age	St Dev
0	0.214	20	0.922
1	0.214	21	0.946
2	0.267	22	0.969
3	0.317	23	0.992
4	0.365	24	1.013
5	0.412	25	1.034
6	0.456	26	1.053
7	0.499	27	1.072
8	0.540	28	1.090
9	0.579	29	1.108
10	0.617	30	1.125
11	0.654	31	1.141
12	0.688	32	1.156
13	0.722	33	1.171
14	0.754	34	1.185
15	0.785	35	1.199
16	0.815	36	1.212
17	0.843	37	1.225
18	0.870	38	1.237
19	0.897	39	1.249
		40	1.260

The base–case model includes the following key features:

a) A single region, single stock model is considered, with data aggregated across zones 10, 20 and 30 (RAG agreed base-case, 2014).

b) The selectivity pattern for the trawl fleet was assumed to be length-specific and logistic. The parameters of the selectivity function for each fleet were estimated within the assessment. A selectivity pattern is estimated for each of port and onboard lengths due to large differences in length compositions.

c) The model accounts for males and females separately.

d) The initial and final years are 1975 and 2016. Previous models (Thomson, 2002; Klaer, 2005) used 1975 as the initial year due to the generally perceived poorer quality of data prior to this year. An initial fishing mortality is estimated to account for catches prior to the starting year.

e) The CVs of the CPUE indices were initially set at a value equal to the standard error from a loess fit (0.247; Sporcic and Haddon, 2017), before being re-tuned to the model-estimated standard errors within SS.

f) Discard tonnage was estimated through the assignment of a retention function. This was defined as a logistic function of length, and the inflection and slope of this function were estimated where discard information was available. A retention function was estimated for each 'block' period: namely 1975 – 1985 and 1986 – 2013.

g) Over the period 1975-1985 the logistic retention function has an asymptotic value less than 1.0 (i.e. larger fish do not reach full retention and can be discarded; fixed at 0.8; Tuck and Day, 2014).

h) The rate of natural mortality, M, is assumed to be constant with age, and also time-invariant. The value for M is 0.1 y^{-1}.

i) Recruitment to the stock is assumed to follow a Beverton-Holt type stock-recruitment relationship, parameterised by the average recruitment at unexploited spawning biomass, R_0, and the steepness parameter, h. Steepness for the base-case analysis is set to 0.75.

j) The initial value of the parameter determining the magnitude of the process error in annual recruitment, σ_r, is set to 0.6. This was tuned to an upper bound of 0.7.

k) The population plus-group is modelled at age 40 years, as is the maximum age for observations.

l) Growth is assumed to follow a von Bertalanffy type length-at-age relationship, with the parameters of the growth function being estimated separately for females and males during the model-fitting process.

m) Retained and discard onboard length sample sizes were capped at 200 and required to have a minimum of 100 fish sampled to be included. For Sydney Fish Market samples (1975 to 1991) numbers of fish were divided by 10 and capped at 200. For port samples, numbers of trips were used as the sampling unit, with a cap of 100 (which was not reached). The sample size is reduced because the appropriate sample size for length frequency data is probably more closely related to the number of shots (onboard) or trips (port) sampled, rather than the number of fish measured.

The values assumed for some of the (non-estimated) parameters of the base case models are shown in Table 17.3.

Table 17.3. Parameter values assumed for some of the non-estimated parameters of the base-case model.

Parameter	Description	Value
M	Natural mortality	0.1
h	"steepness" of the Beverton-Holt stock-recruit curve	0.75
x	age observation plus group	40 years
a	allometric length-weight equations	0.0577 g^{-1}.cm
b	allometric length-weight equations	2.77
l_m	Female length at 50% maturity	19cm

17.2.1.8 Tuning method

Iterative rescaling (reweighting) of input and output CVs or input and effective sample sizes is a repeatable method for ensuring that the expected variation of the different data streams is comparable to what is input. Most of the data sets (CPUE, surveys, composition data) used in fisheries underestimate their true variance by only reporting measurement or estimation error and not including process error.

In iterative reweighting, the effective annual sample sizes are tuned/adjusted so that the input sample size is equal to the effective sample size calculated by the model. In SS3.30 there is an automatic adjustment made to survey CVs (CPUE).

1. set the standard error for the relative abundance indices (CPUE, acoustic abundance survey, or FIS) to their estimated standard errors for each survey or for CPUE (and FIS values) to the standard deviation of a loess curve fitted to the original data (which will provide a more realistic estimate to that obtained from the original statistical analysis. SS3.30 then re-balances the relative abundance variances appropriately.

An automated tuning procedure was used for the remaining adjustments. For the recruitment bias adjustment ramps:

2. adjust the recruitment variance (σ_R) by replacing it with the RMSE or a defined minimum (0.3) or maximum (0.7) and iterate to convergence (keep altering the recruitment bias adjustment ramps as predicted by SS3.30 at the same time).

Finally for the conditional age-at-length and length composition data:

3. multiply the initial sample sizes by the sample size multipliers for the age composition data using Francis weights (Francis, 2011).
4. similarly multiply the initial samples sizes by the sample size multipliers for the length composition data.
5. repeat steps 2 to 4, until all are converged and stable (proposed changes are < 1 – 2%).

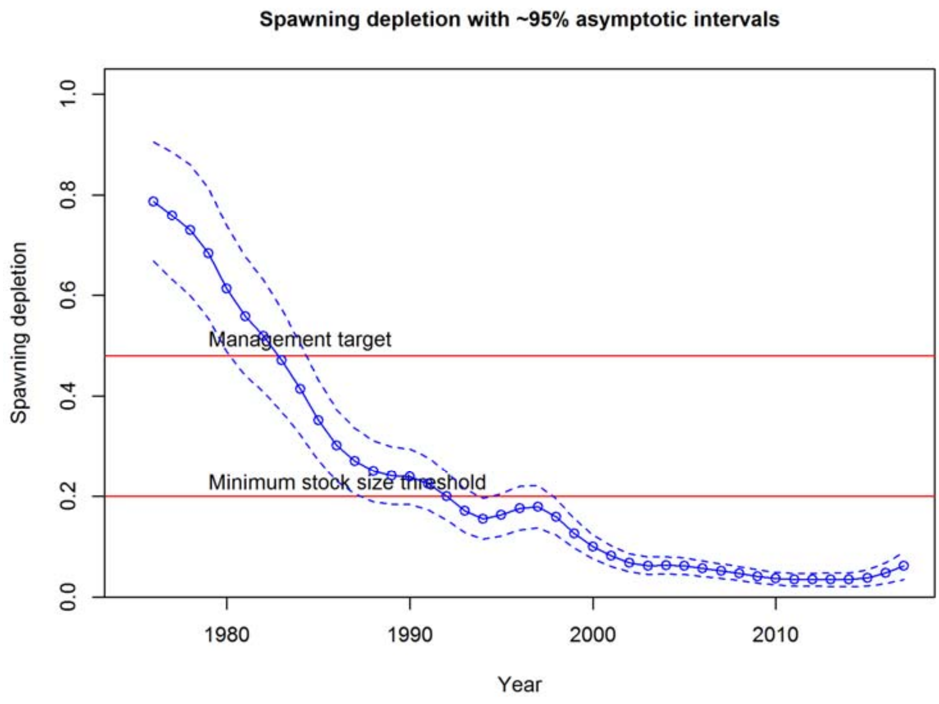
This procedure may change in the future after further investigations but constitutes current best practice.

17.3 Results

17.3.1 The base case assessment model

While the SERAG accepted the model structure of the preliminary base case assessment for redfish presented in September 2017, it also recommended that the 1993, 1996 and 1997 length composition data be included (which had been removed as anomalously large) and that the model estimate recruitment to 2012, rather than 2015. The large length compositions of 1993, 1996 and 1997 were from EBass (Zone 20) and were evident in both onboard and port measurements. While sample sizes are small, they are not sufficiently small to be removed according to current rules that determine acceptable annual length samples. Diagnostics presented at the September 2017 SERAG revealed that recruitments after 2012 were not sufficiently well estimated to be included in the base case assessment model. Investigations by project staff (J Day pers. comm) since the September 2017 SERAG discovered that the model had not been properly tuned to ages. The minimum sample size for ages was not sufficiently small to allow appropriate re-weighting of the age at length data. As a consequence, the model's age-at-length variance adjustment parameters were not balancing. This particular aspect was not identified until 2 November 2017. This paper has corrected this issue and provides the base case assessment results.

Diagnostic figures for the base-case model tuned according to the now agreed tuning methods are provided in Figures 3 to 6 and in Appendix A. Plots of the time-series of the spawning biomass and recruitment residuals (Figure 17.3) are similar to those shown at the September RAG (Tuck, 2017). The 2017 base case model estimates that the female spawning biomass depletion in 2018 is 8% of original biomass levels. The initial (1973) female spawning biomass is estimated to be 12,003 tonnes.



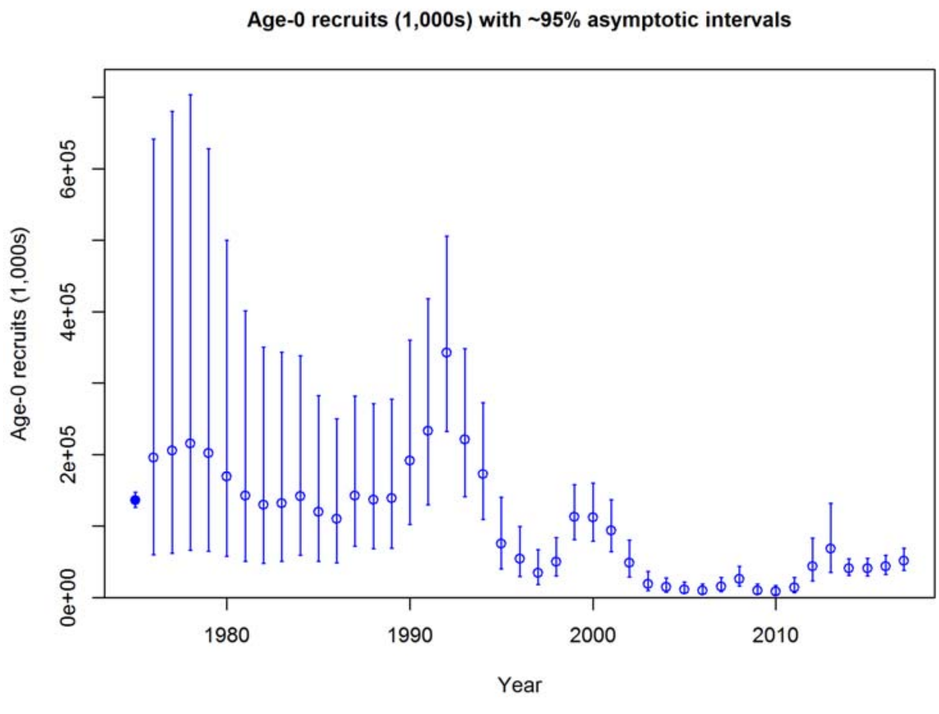


Figure 17.3. The estimated time-series of relative spawning biomass and annual recruitment for the 2017 base case assessment for redfish.

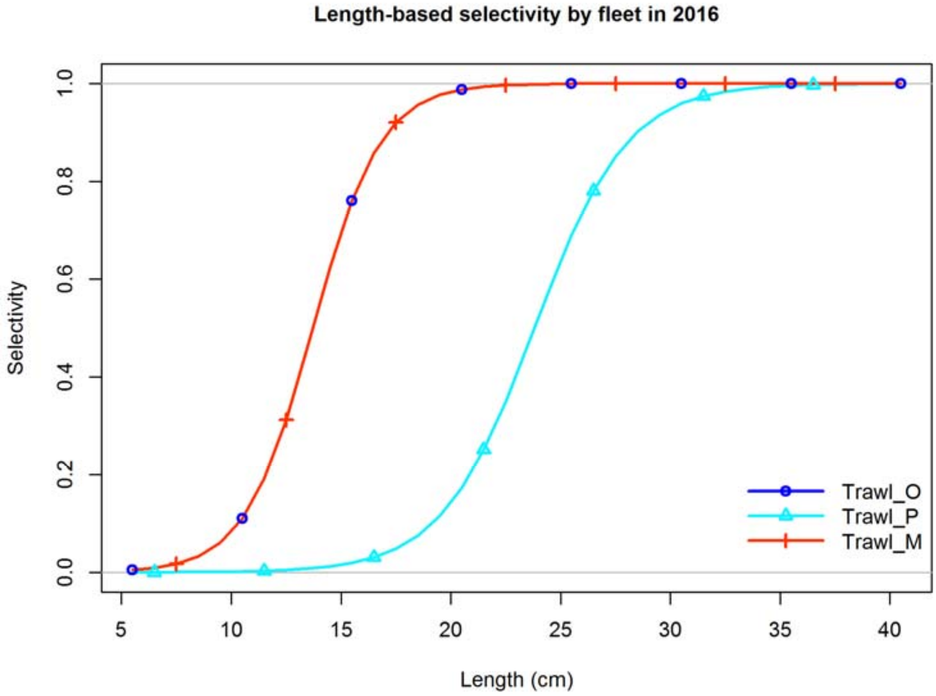


Figure 17.4. The estimated selectivity for onboard (O) and port (P) lengths for the 2 selectivity base case model.

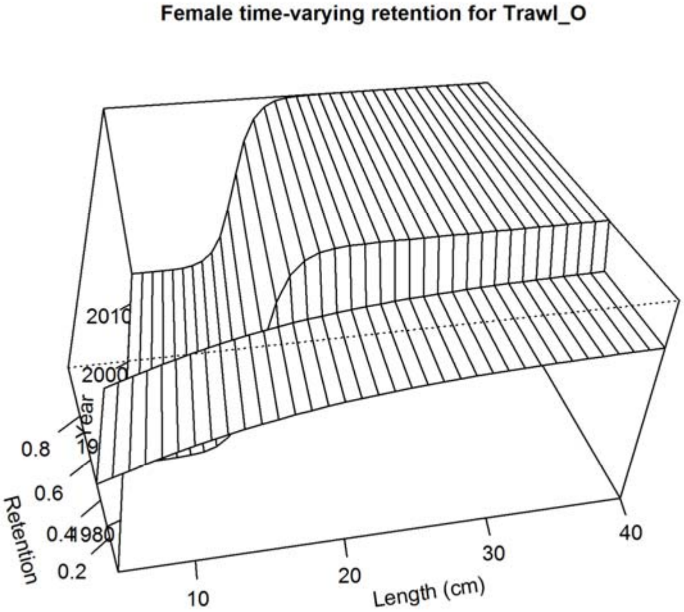


Figure 17.5. The base case estimated retention function for the 2 selectivity base case model.

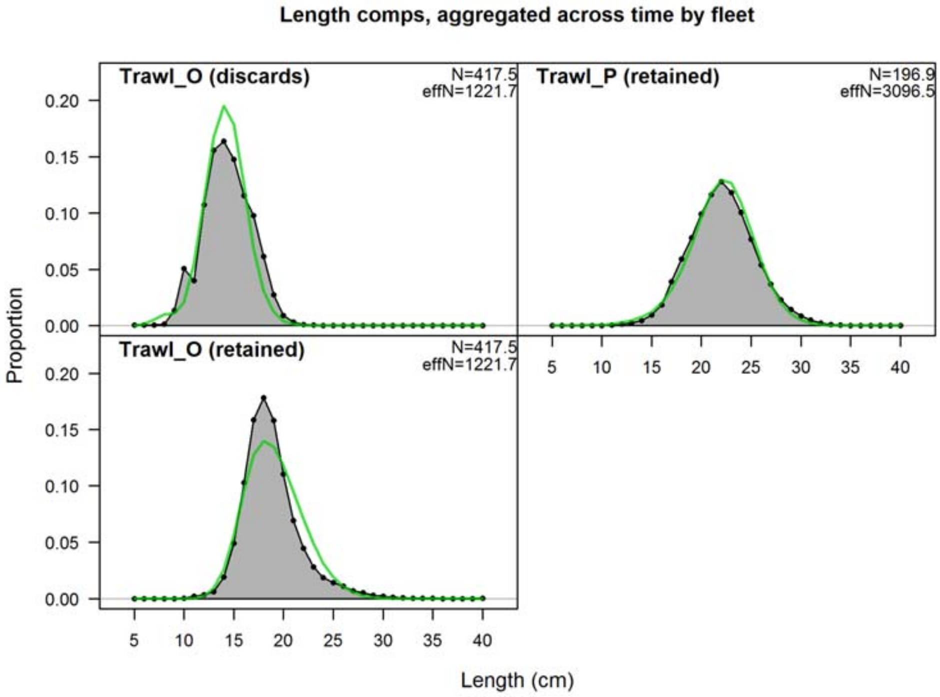


Figure 17.6. Redfish length composition data and fits (green line) aggregated across years for the 2 selectivity base case model.

17.3.2 *Standard and low recruitment projections*

Estimates of recruitment strength for eastern redfish show considerably lower values than average since at least the early 2000s (Figure 17.3 and Figure A 17.3). This could be a consequence of directional environmental change. The base case model assumes that recruitment values are taken from the stock recruitment curve for historical years that are not estimated and for future projections (in our case from 2013 onwards). If there has been an environmental driven change in productivity, this may be an overly optimistic recruitment scenario. The following scenario projects all future recruitments with the average recruitment deviations taken from the 10 year period 2001 to 2010 (average = -1.11; Figure A.3). Constant annual catches are then projected with low recruitments to explore future potential trajectories of biomass. As the low recruitment scenario markedly reduces stock productivity, annual catches of 50t take a considerably long time (beyond the 40 year projection horizon) to recover to the limit reference point (current catch is estimated to be 52t). An annual catch of 150t is unsustainable for the stock (Figure 17.7). Under the standard harvest control rule and recruitment model (that uses recruitments from the stock-recruitment curve), the spawning biomass is estimated to pass 20% of initial biomass levels by approximately 2024. With a fixed annual catch of 100t from 2018 and the standard recruitment model, the spawning biomass is estimated to pass 20% of initial biomass levels by approximately 2026 (Table 17.4). The two year delay in passing 20% of initial biomass is because the standard HCR assumes no retained catch when the biomass is below the limit reference point (compared to a fixed 100t for all future years for the C100 aveR scenario).

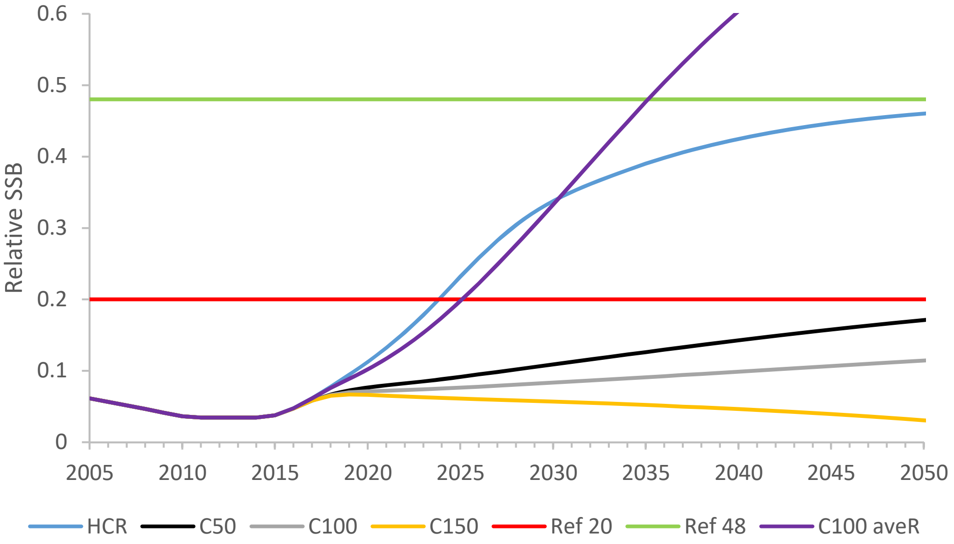


Figure 17.7. Relative spawning biomass time-series for standard SESSF harvest control rule (blue HCR), and four alternative constant catch scenarios: three with low recruitment (catches of 50t, 100t, 150t; black, grey and orange respectively) and one with standard recruitment drawn from the S-R curve with 100t annual catch from 2018 onwards (purple C100 aveR). The red and green lines are the limit (Ref 20) and target (Ref 48) biomass depletion levels.

Table 17.4. The depletion levels corresponding to the projection scenarios of Figure 17.7.

Year	HCR	C50	C100	C150	C100 aveR
2017	0.061	0.058	0.058	0.058	0.061
2018	0.077	0.067	0.066	0.065	0.076
2019	0.094	0.073	0.070	0.067	0.089
2020	0.112	0.076	0.071	0.066	0.102
2021	0.132	0.079	0.072	0.065	0.117
2022	0.154	0.082	0.073	0.064	0.134
2023	0.178	0.085	0.074	0.063	0.153
2024	0.204	0.088	0.075	0.062	0.174
2025	0.232	0.091	0.076	0.061	0.198
2026	0.258	0.095	0.078	0.060	0.222
2027	0.282	0.098	0.079	0.059	0.249
2028	0.304	0.102	0.080	0.058	0.276
2029	0.322	0.105	0.082	0.058	0.304
2030	0.338	0.109	0.083	0.057	0.333

17.3.3 *Sensitivities to the base case model*

Standard sensitivities to alternative natural mortality values (M=0.08, 0.12, and M estimated), steepness (h=0.65, 0.85, and h estimated), and σ_R (0.6, 0.8) were considered (Table 17.5 and Table 17.6). The base-case model and sensitivities all have stock status less than the limit reference point of 20% of virgin spawning biomass, and generally vary between 5% and 12%. Results from a comparison of likelihoods (Table 17.5) suggest that lower values of natural mortality and steepness should be considered in future assessments.

Table 17.5. Summary of sensitivity results for the base-case model.

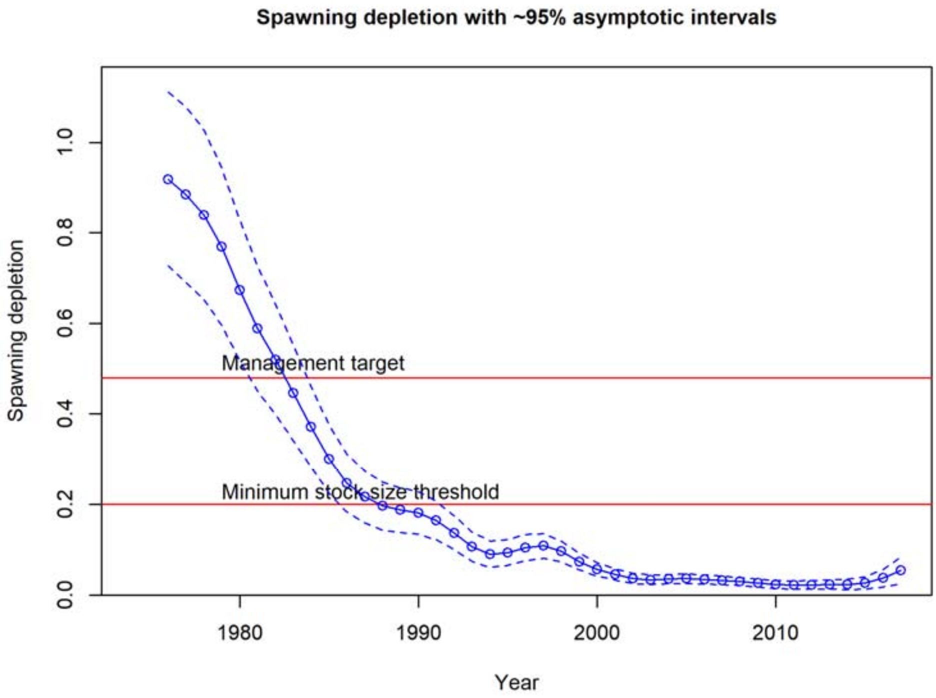
Case		SSB_0	SSB_{2018}	SSB_{2018}/SSB_0
0	base case 20:35:48 *M*=0.10 *h*=0.75	12005	928	0.08
1	*M*=0.08	14604	832	0.06
2	*M*=0.12	9707	1069	0.11
3	estimate *M* (0.077), *h*=0.75	15014	820	0.05
4	steepness, *h* =0.65	13324	820	0.06
5	steepness, *h*=0.85	10244	1208	0.12
6	estimate *h* (0.55), *M*=0.10	15106	760	0.05
7	σ_R = 0.8	12171	898	0.07

Table 17.6. Summary of likelihood components for the base-case model structure and sensitivity tests. Sensitivities from the base case are shown as differences from the base case. A negative value indicates a better fit, a positive value a worse fit.

		TOTAL	CPUE	Discard	Length comp	Age comp	Recruit	Parm priors
0	base case 20:35:48 *M*=0.10 *h*=0.75	630.41	-21.39	93.09	201.97	340.79	14.90	0.05
1	*M*=0.08	-3.13	-0.23	-0.74	-1.56	0.52	-1.16	0.00
2	*M*=0.12	4.62	0.28	-1.74	3.55	-0.83	3.47	-0.01
3	estimate *M* (0.100), *h*=0.75	-3.16	-0.26	-0.88	-1.72	0.77	-1.16	0.04
4	steepness, *h* =0.65	-5.71	-1.25	-1.20	0.87	-1.32	-2.74	-0.01
5	steepness, *h*=0.85	8.49	2.11	-1.92	2.61	-1.08	6.83	-0.01
6	estimate *h* (0.593), *M*=0.10	-7.42	-2.15	-1.75	1.21	-1.14	-4.21	0.77
7	σ_R = 0.8	-3.64	-0.73	-3.01	0.70	0.00	-0.57	0.00

17.3.4 *Single selectivity model sensitivity*

As part of the process of identifying an acceptable base-case when fits to the agreed model structure were poor, a number of alternative model structures were attempted, including having a single selectivity for both port and onboard lengths. This model was able to balance according to the new tuning methods, however the fit to the port lengths was poor as the model cannot fit concurrently to the larger port lengths and the smaller onboard lengths (a model with no EBass port lengths or SFM lengths was able to provide good fits to both port and onboard lengths, but removed much of the data that informs the model about early recruitment). Additional diagnostic plots are in Appendix B. According to this model, the 2018 depletion is 7% of original female spawning biomass levels.



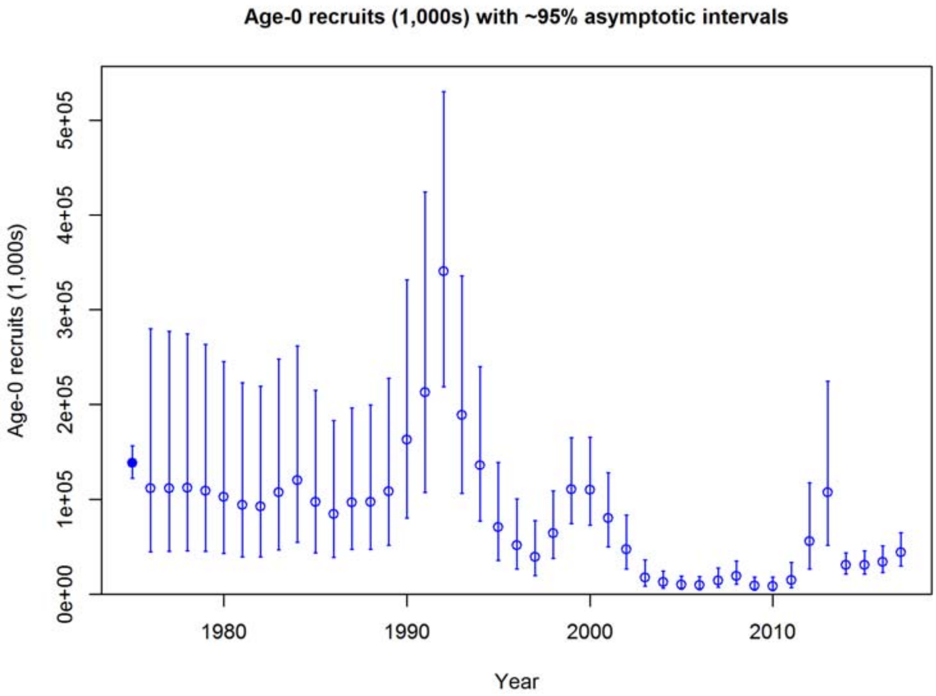


Figure 17.8. The estimated time-series of relative spawning biomass and annual recruitment for the single selectivity model.

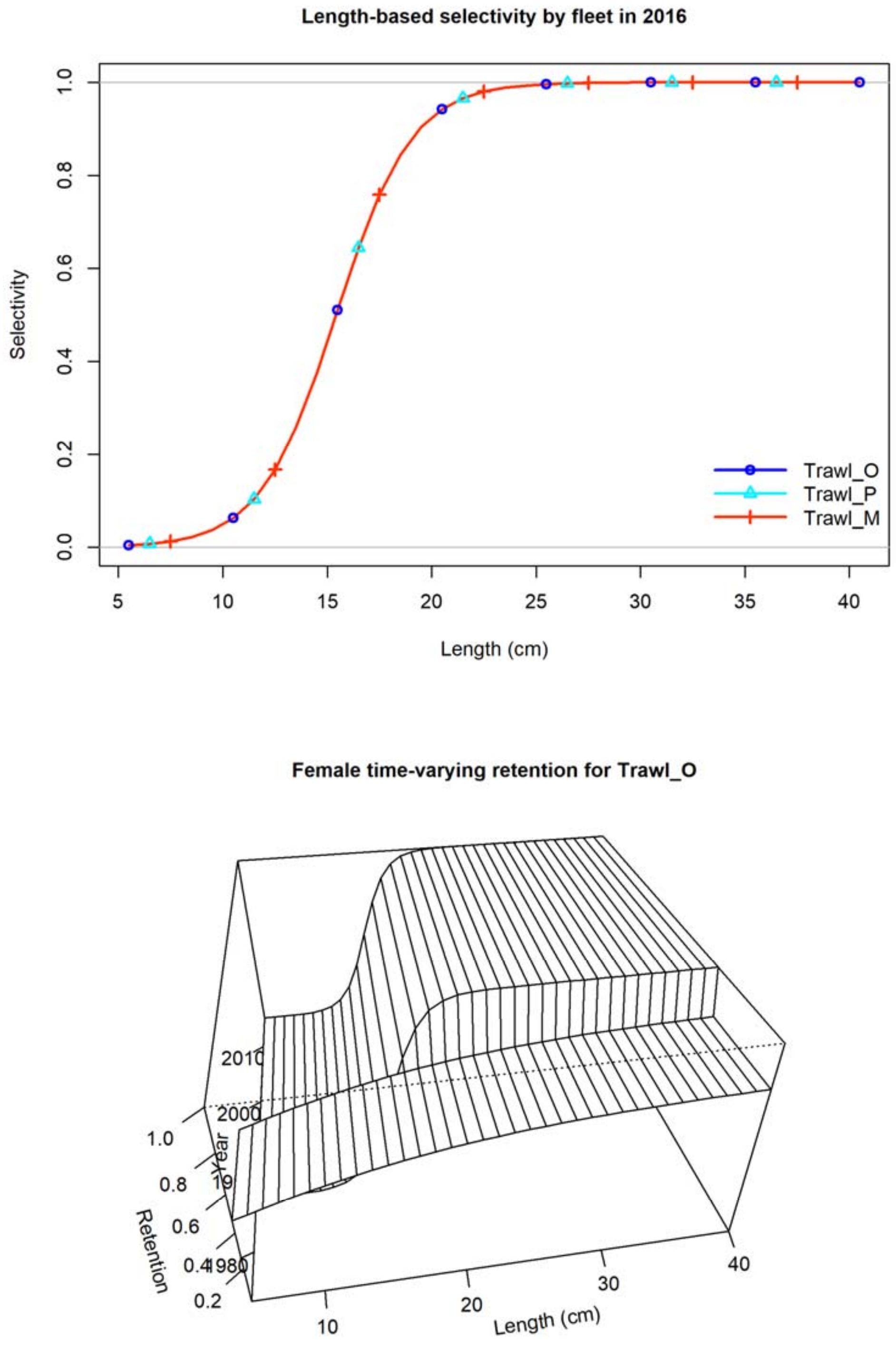


Figure 17.9. The estimated selectivity and retention for lengths for the single selectivity model.

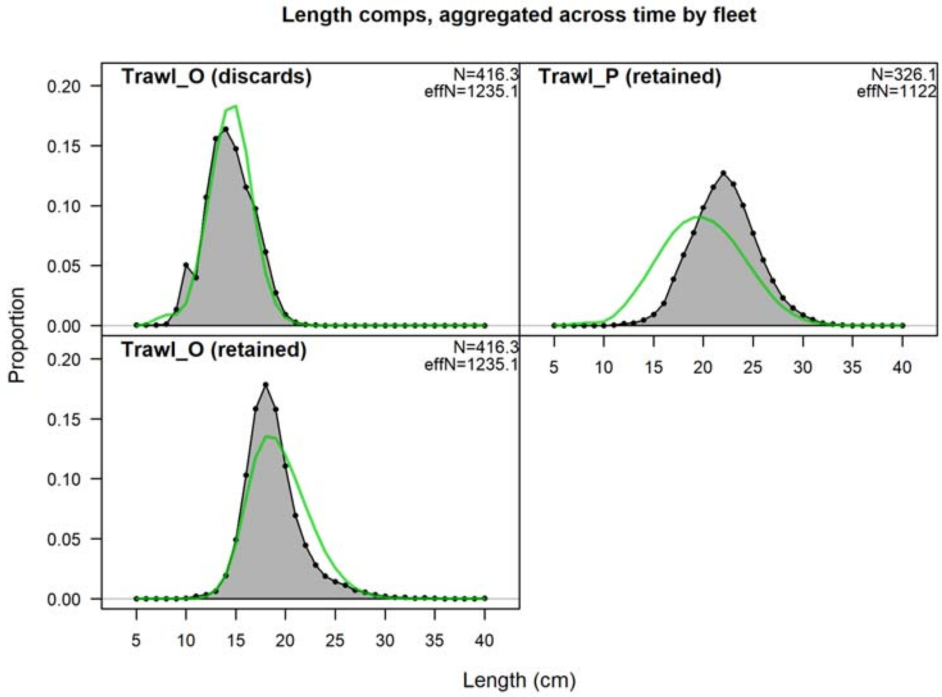


Figure 17.10. Redfish length composition data and fits (green line) aggregated across years for the single selectivity model.

17.4 Future directions

As part of the more detailed exploration of the data brought about by the apparent poor fit to length data, differences were observed between port length compositions from Eastern Bass (EBass, Z20) and NSW (Z10). As can be seen from the Zone by Month figures, even though similar lengths of fish are caught (as seen from the similar onboard length compositions in EBass and NSW; Figure 17.10), the EBass port length compositions appear to suggest that much larger fish are being landed than in NSW (Figure 17.11). This may imply different discarding practices in each zone, whereby a high proportion of fish of lengths less than 15cm are discarded in EBass. However, in NSW some fish below 15cm are landed. Figure 17.12 shows the year aggregated lengths by zone for onboard retained and discarded and port retained lengths. This shows the generally broader distributions of lengths discarded in EBass and that few fish are landed below 15 cm in EBass. It was also evident that Sydney Fish Market lengths (1975 to 1991) were considerably larger than more recent ISMP length samples from NSW (Figure 17.13).

As far as a future Tier 1 assessment is concerned, a model that separates data inputs by zone, including catch, catch rates, discard rates and lengths by zone (to allow alternative discard functions), may be a promising way forward for the redfish assessment.

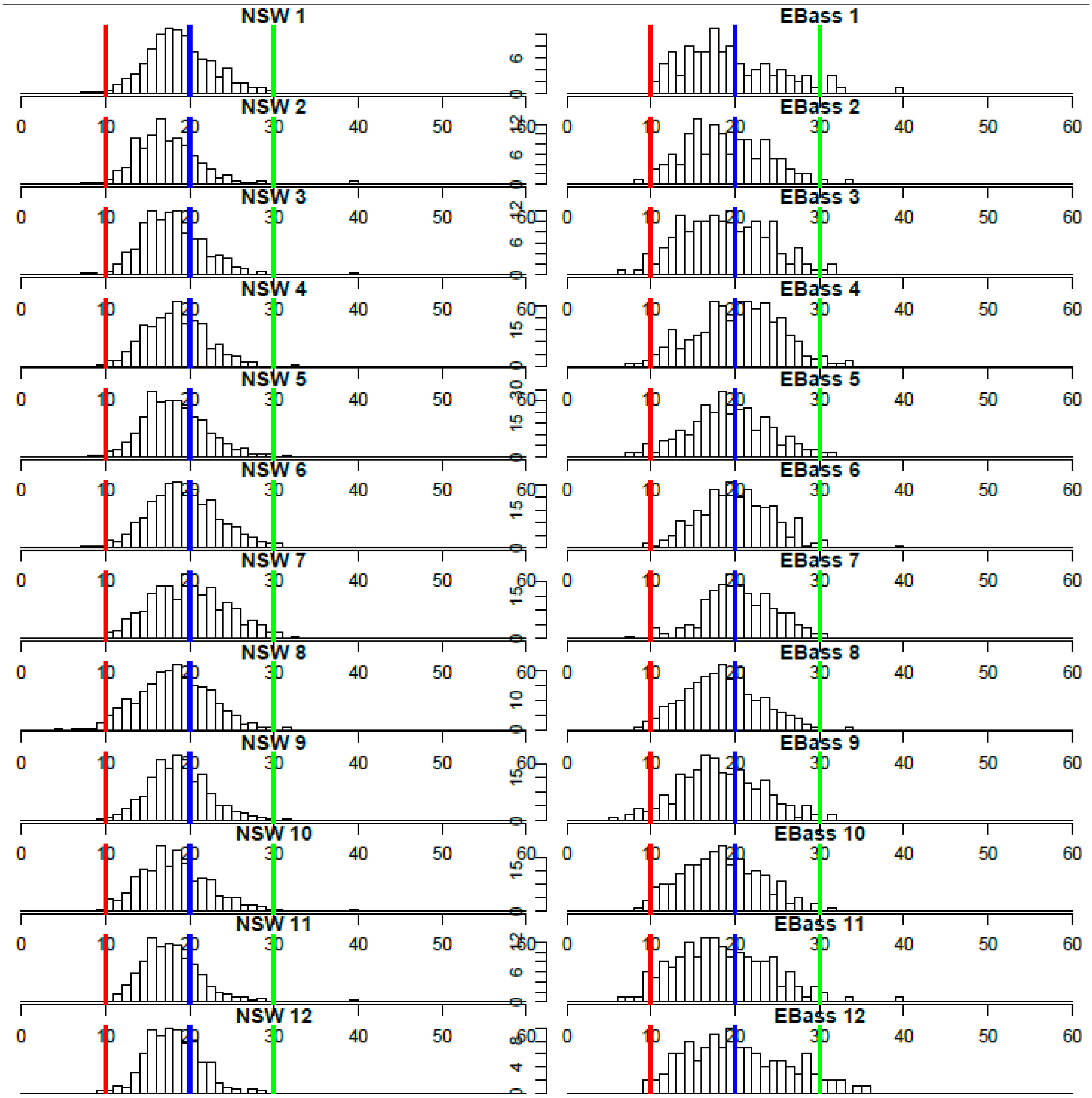


Figure 17.11. Onboard (retained and discard) length distributions of redfish by month and zone (NSW and Eastern Bass). Red (10cm), Blue (20cm) and Green (30cm).

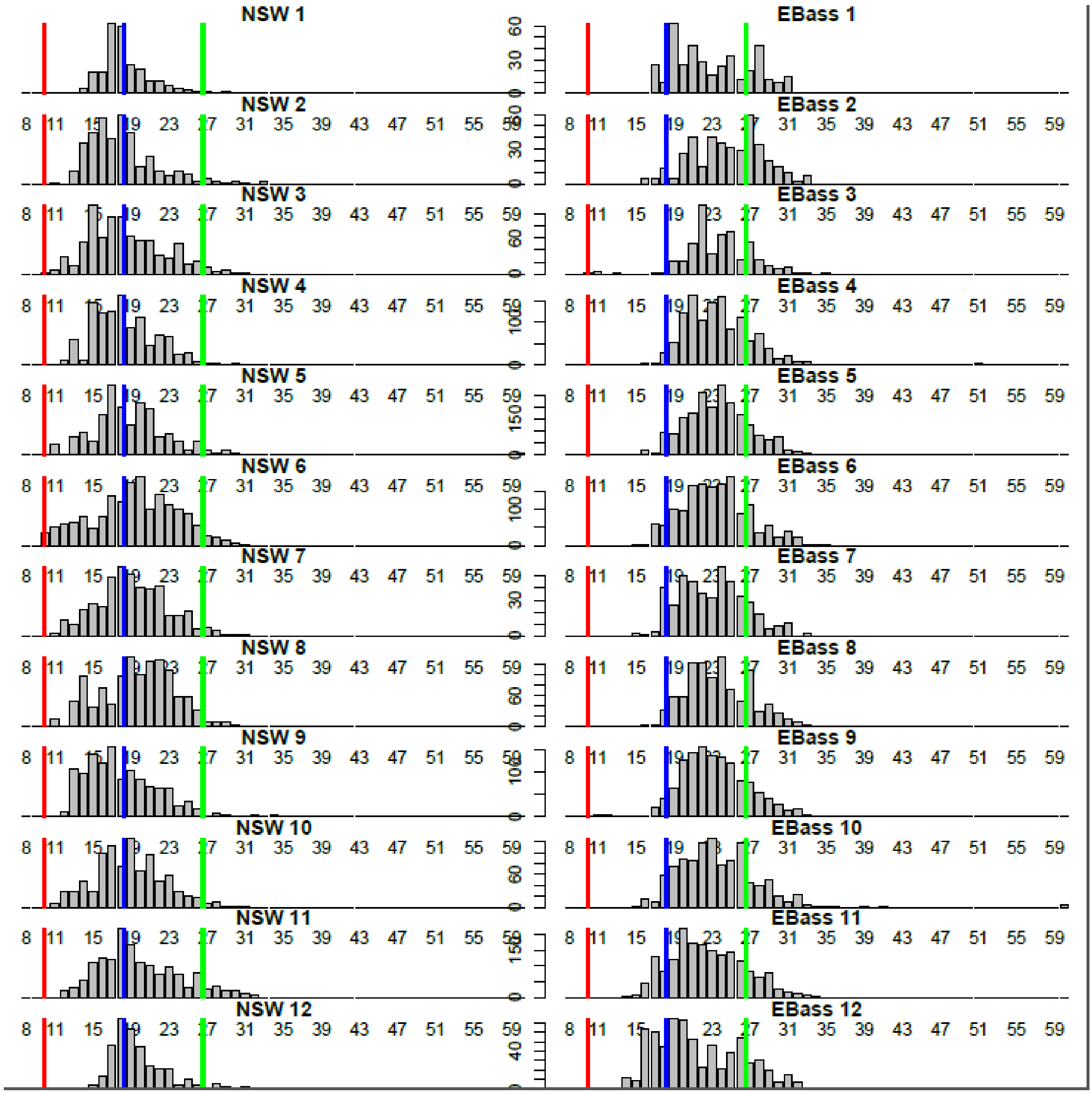
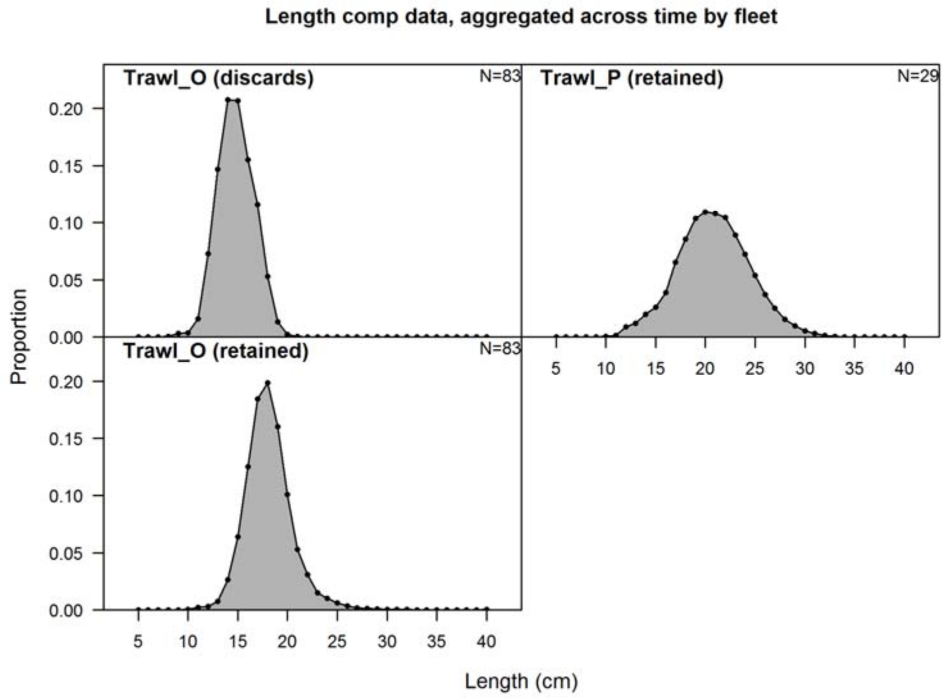


Figure 17.12. Port length distributions of redfish by month and zone (NSW and Eastern Bass). Red (10cm), Blue (20cm) and Green (30cm).



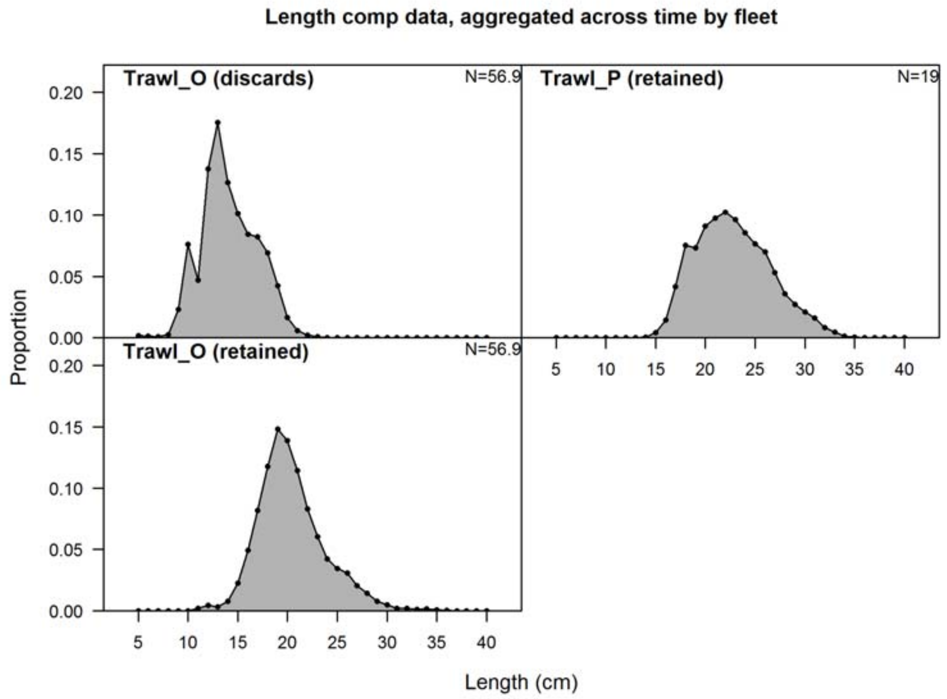


Figure 17.13. The length data aggregated across year for (top) NSW (Zone 10) and (bottom) EBass (Zone 20).

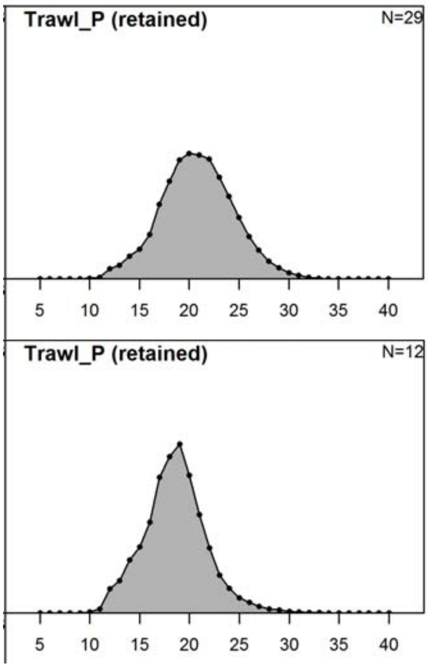


Figure 17.14. The length distribution from port samples from NSW with Sydney Fish Market lengths from 1975 to 1991 (top) and without SFM lengths (bottom).

17.5 Acknowledgements

Age data was provided by Kyne Krusic-Golub (Fish Ageing Services), ISMP and AFMA logbook and CDR data were provided by John Garvey (AFMA). Mike Fuller, Roy Deng and Franzis Althaus (CSIRO) pre-processed the data. The CSIRO SESSF Team and Kev Rowling are thanked for helpful discussions on this work. This work greatly benefitted from the generous help of Ian Taylor and Rick Methot (NOAA).

17.6 References

Francis, R.I.C.C. 2011. Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124-1138.

Haddon, M. 2014. Length at Age for Redfish (*Centroberyx affinis*). CSIRO, Oceans and Atmosphere, Hobart, Australia. 34p.

Haddon, M and Sporcic, M. 2017. Catch Rate Standardizations 2017 (for data 1986 – 2016). Technical paper presented to SESSF Resource Assessment Group. August 2017. Hobart, Tasmania.

Hilborn, R., Maunder, M., Parma, A., Ernst, B., Payne, J. and Starr, P. 2000. Coleraine – A generalized age structured stock assessment model. http://www.fish.washington.edu/research/coleraine/

Methot, R.D. 2005 Technical Description of the Stock Synthesis II Assessment Program. NOAA Fisheries Service, Seattle. 54 pp.

Methot, R.D. 2011. User manual for Stock Synthesis Model Version 3.2. NOAA Fisheries Service, Seattle. 165 pp.

Methot, R.D. and C.R. Wetzel. 2013. Stock Synthesis: a biological and statistical framework for fish stock assessment and fishery management. Fisheries Research 142: 86–90.

Rowling, K.R. 1994. Redfish, *Centroberyx affinis* in R.D.J. Tilzey (ed) The South East Fishery, Bureau of Resource Sciences, Canberra.

Rowling, K.R. 1999 Stock Assessment Report for Redfish, 1999. Redfish Assessment Group, South East Fishery Assessment Group, Australian Fisheries Management Authority, Canberra.

Thomson, R.B. 2002. Integrated Analysis of redfish in the South East Fishery, including the 2001 fishing data. Report to Redfish Assessment Group, Bermagui, 27-28 June 2002.

Tuck, G.N. 2014. Stock assessment of redfish *Centroberyx affinis* based on data up to 2013: Supplement to the October 2014 Shelf RAG paper. Technical document presented to the Shelf RAG, 22 November 2014.

Tuck, G.N. and Day, J.R. 2014. Development of a base-case Tier 1 assessment of redfish *Centroberyx affinis* based on data up to 201. Technical document presented to the Shelf RAG, Hobart, 22 September 2014.

Tuck, G.N. 2017. Redfish (*Centroberyx affinis*) stock assessment based on data up to 2016 – development of a preliminary base case. Technical paper presented to the SERAG, 20-22 September 2017, Hobart, Australia.

17.7 Appendix A

17.7.1 ***Base base (2 Selectivity) model diagnostics***

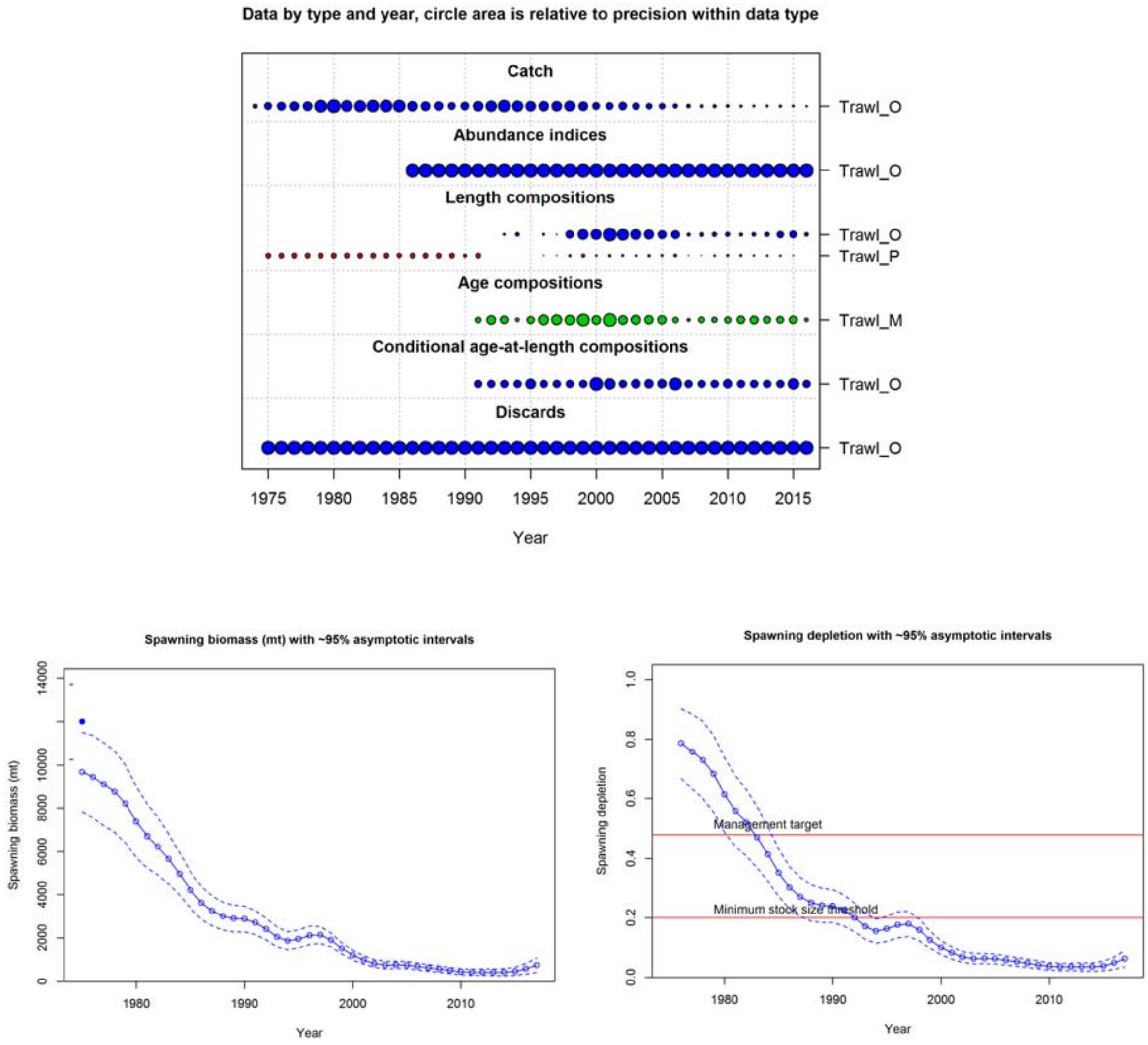
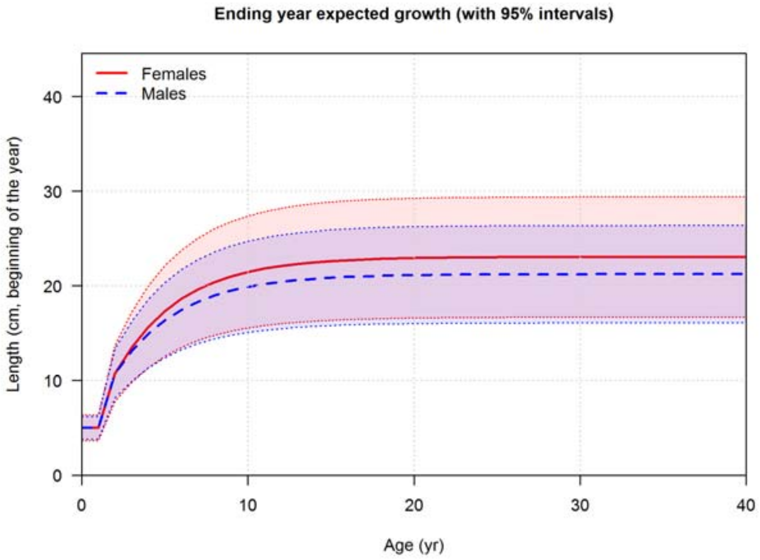


Figure A 17.1. Summary of data sources (top) for the 2 selectivity base case assessment. O = on board, P = port, M = mirrored (used to observe age composition fits). The time-series of absolute and relative female spawning biomass for the redfish base case stock assessment model (bottom).



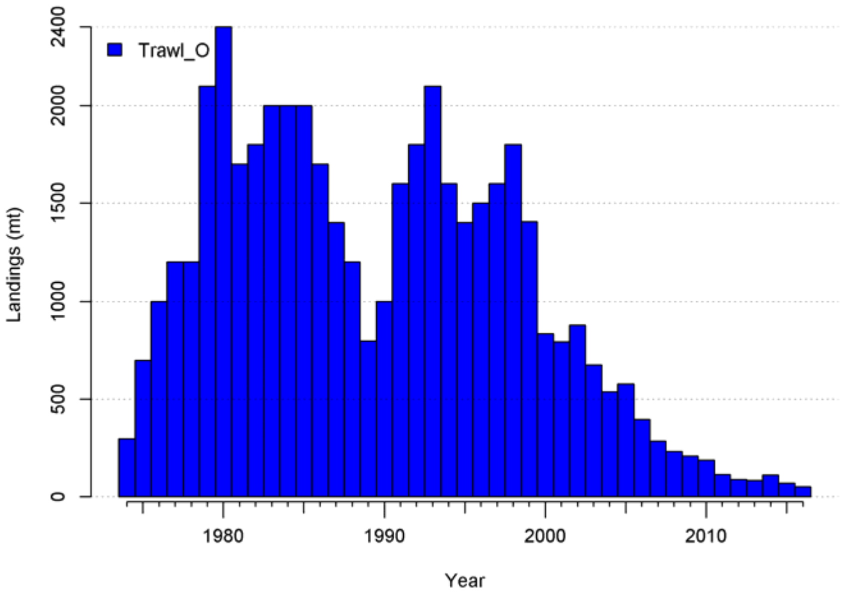


Figure A 17.2. Growth and landings for redfish.

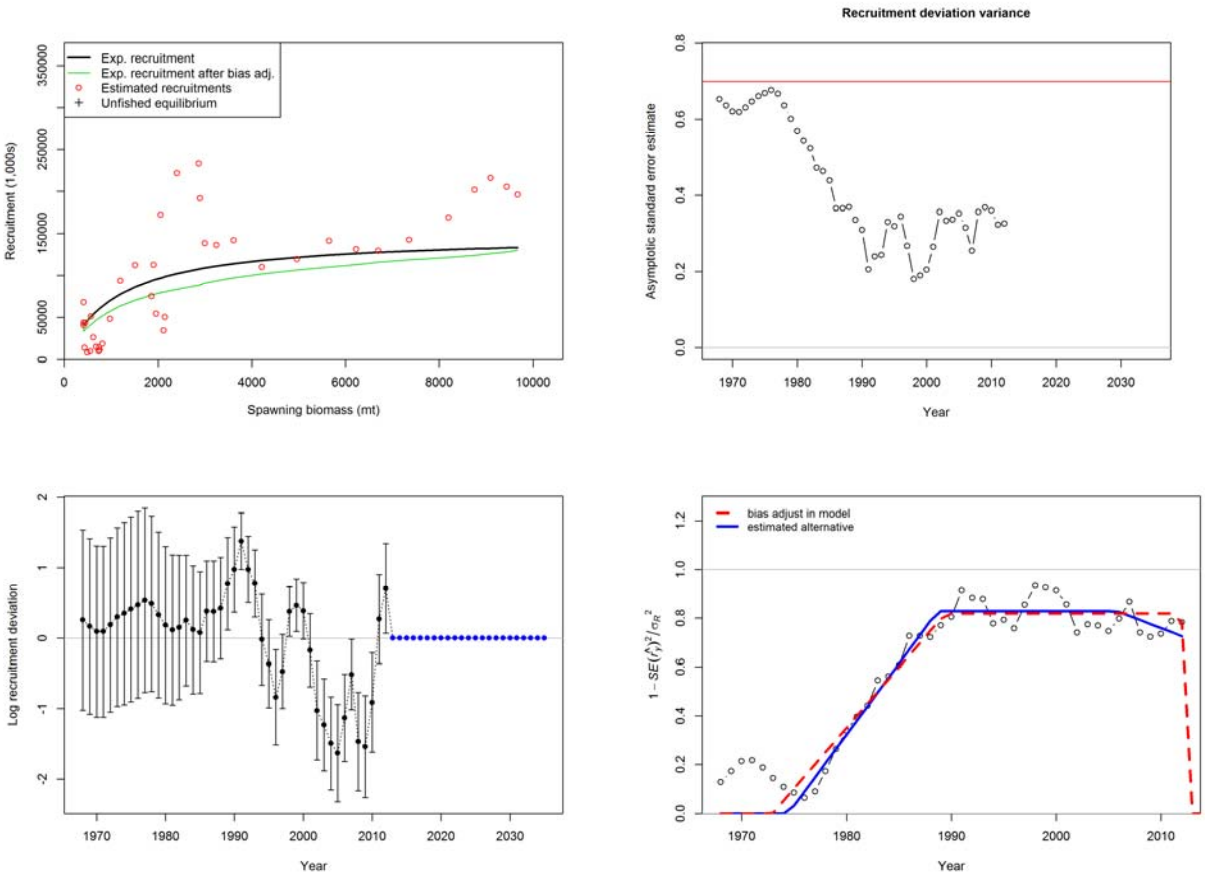


Figure A 17.3. Time series showing the stock recruitment curve, recruitment deviations and recruitment deviation variance check for redfish.

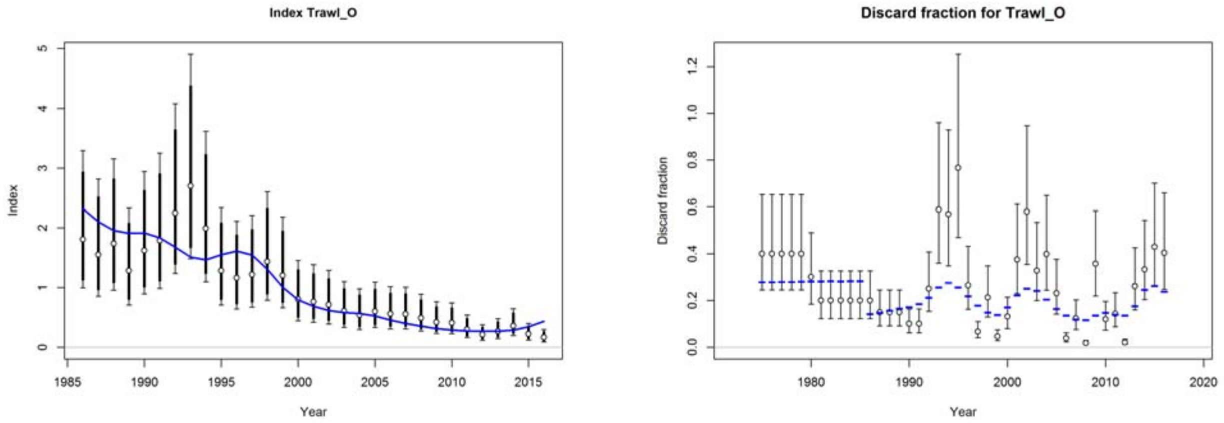


Figure A 17.4. Fits to trawl CPUE and discards for redfish.

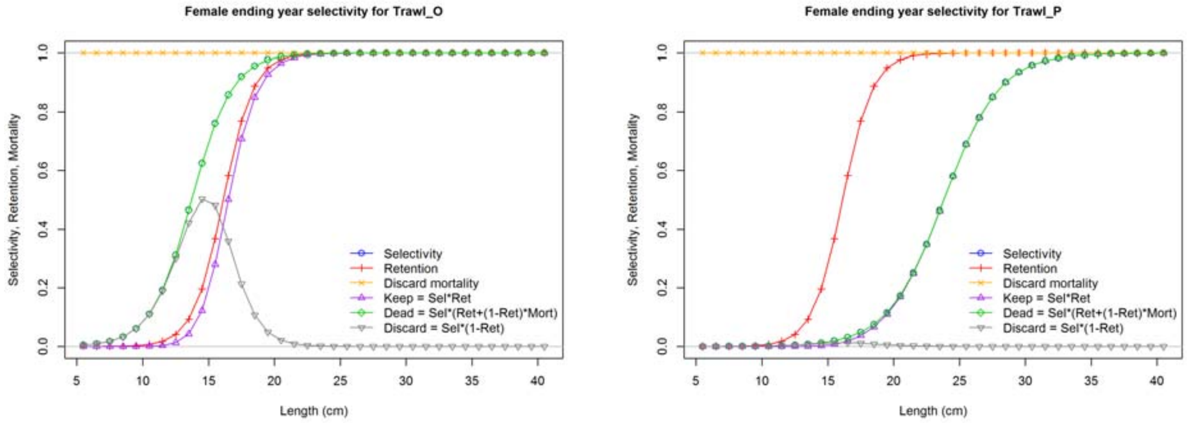


Figure A 17.5. Estimated trawl selectivity for port (P) and onboard (O) and the retention function for redfish.

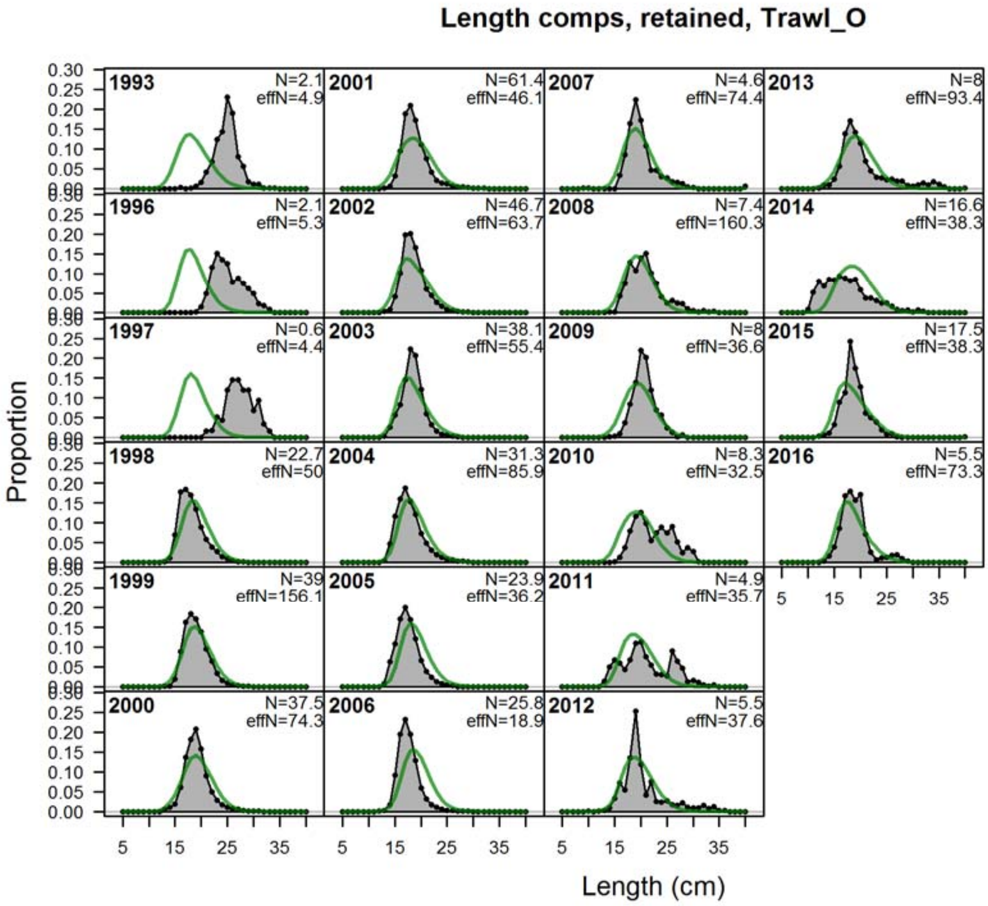


Figure A 17.6. Redfish length composition fits: onboard trawl retained.

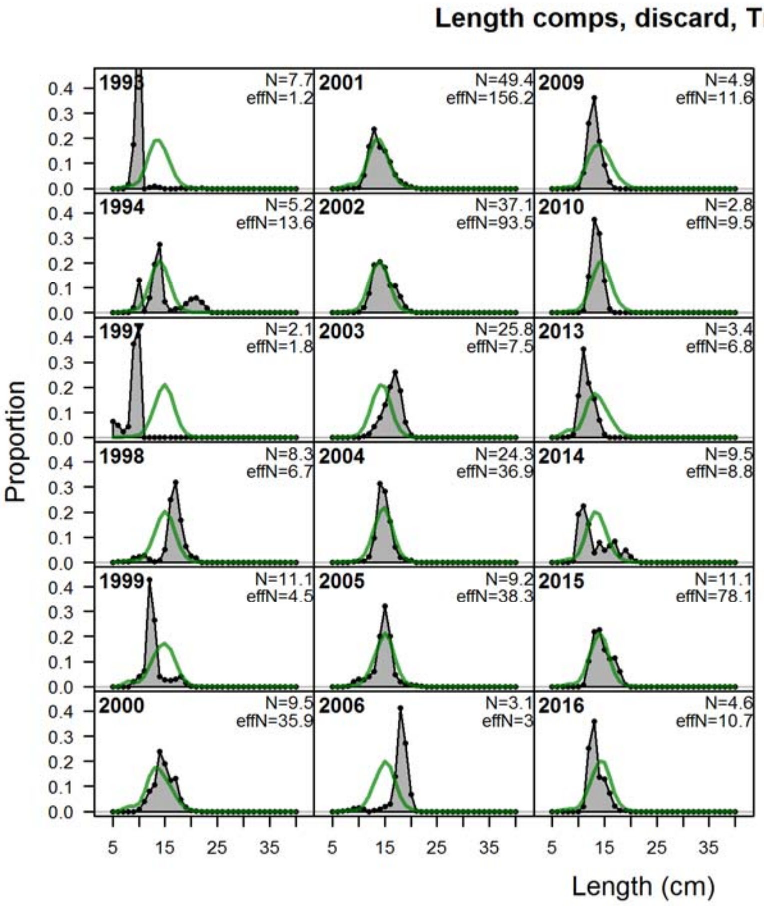


Figure A 17.7. Redfish length composition fits: onboard trawl discard.

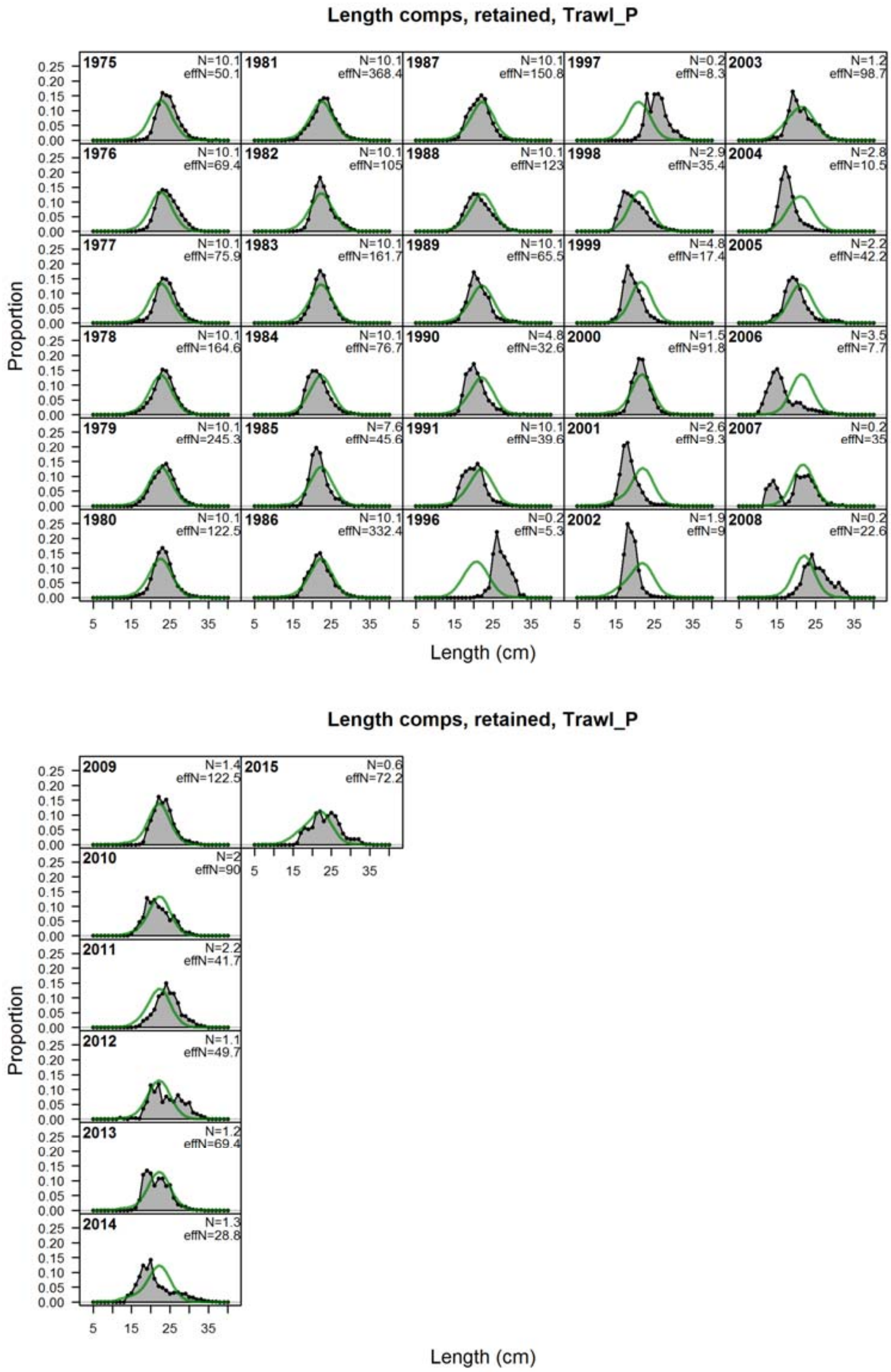


Figure A 17.8. Redfish length composition fits: Port trawl.

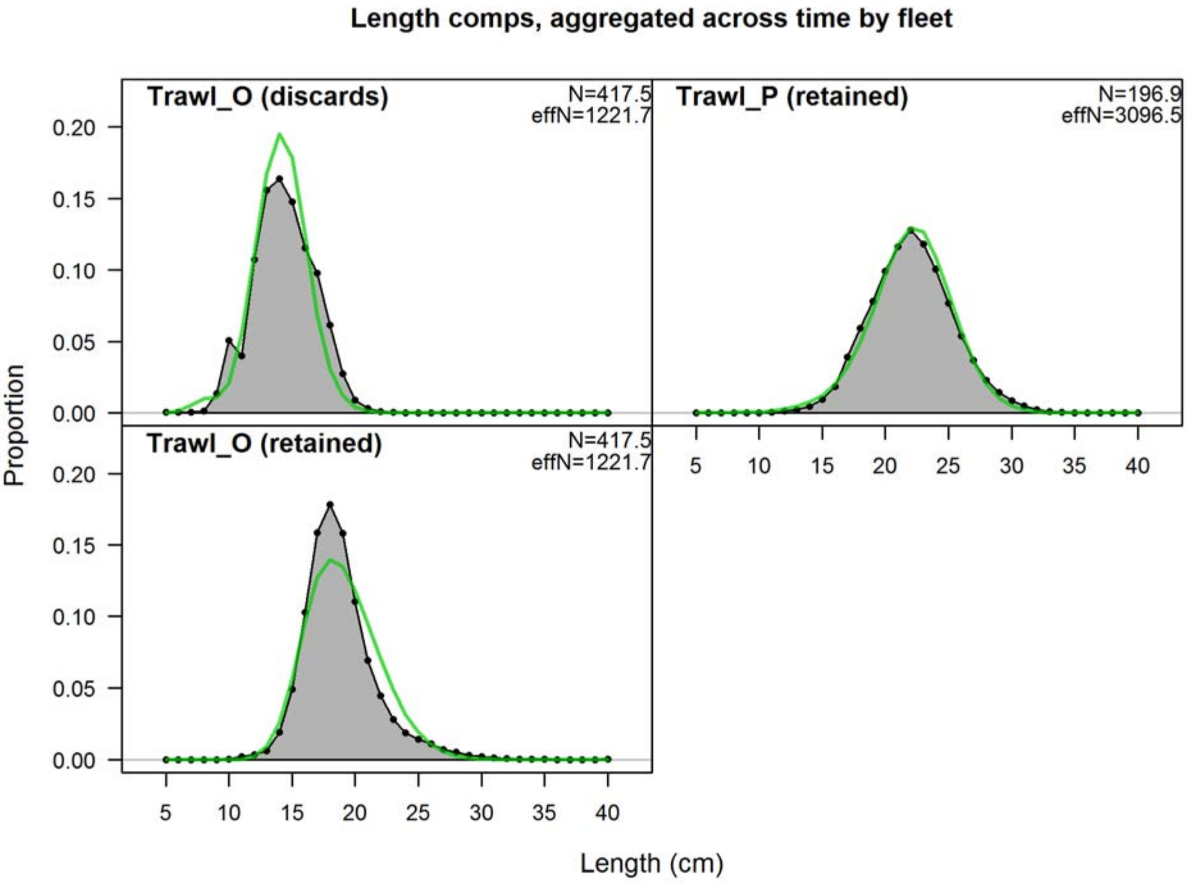


Figure A 17.9. Redfish length composition fits aggregated across years.

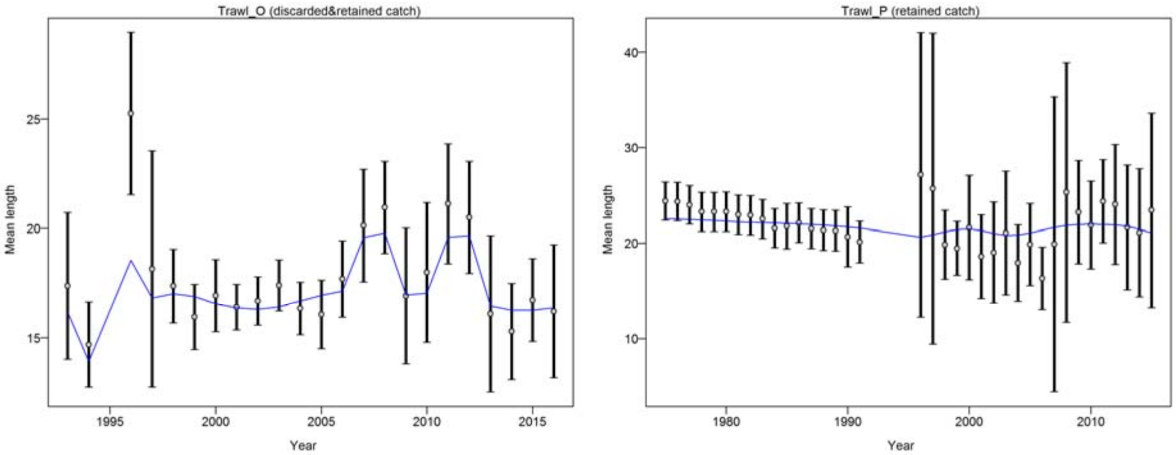


Figure A 17.10. Redfish length composition fit diagnostics from tuning. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data.

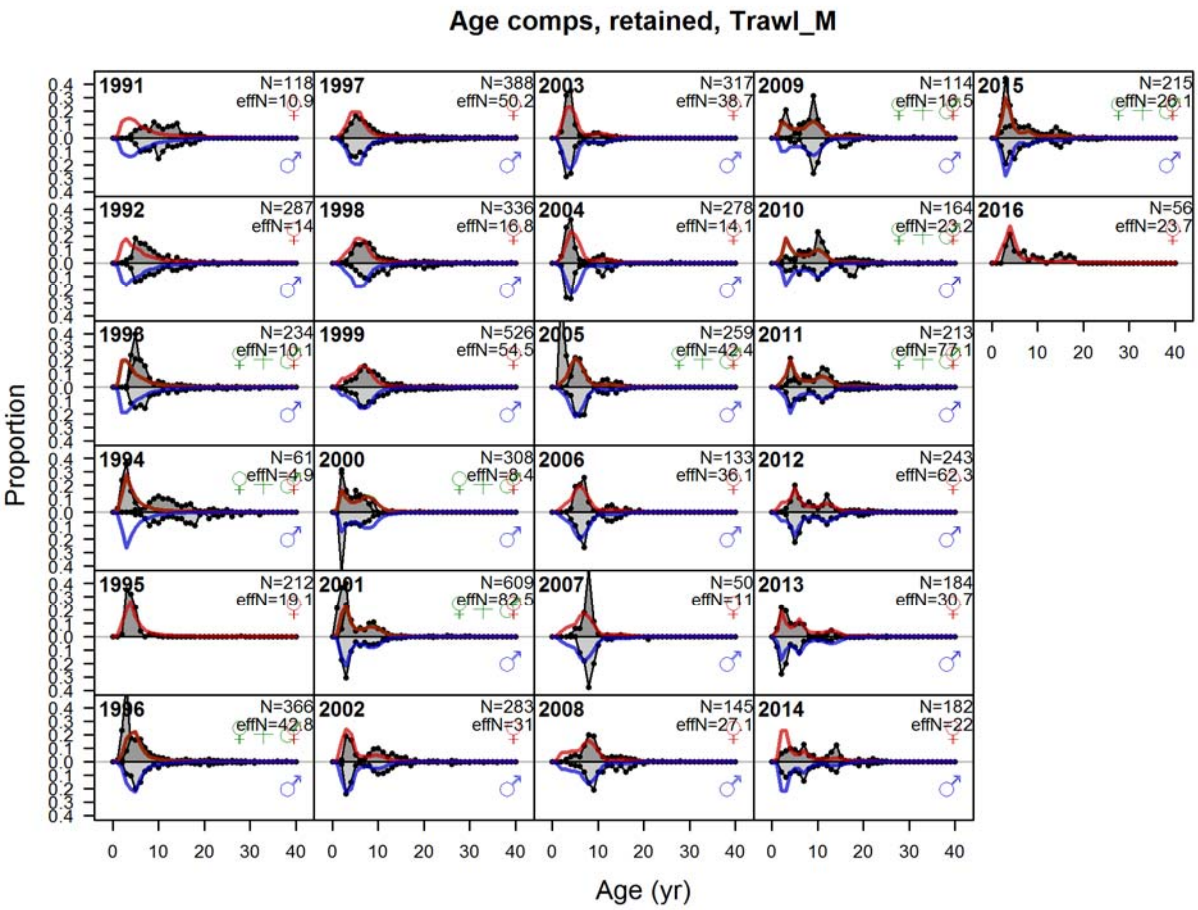


Figure A 17.11. Redfish age composition fits.

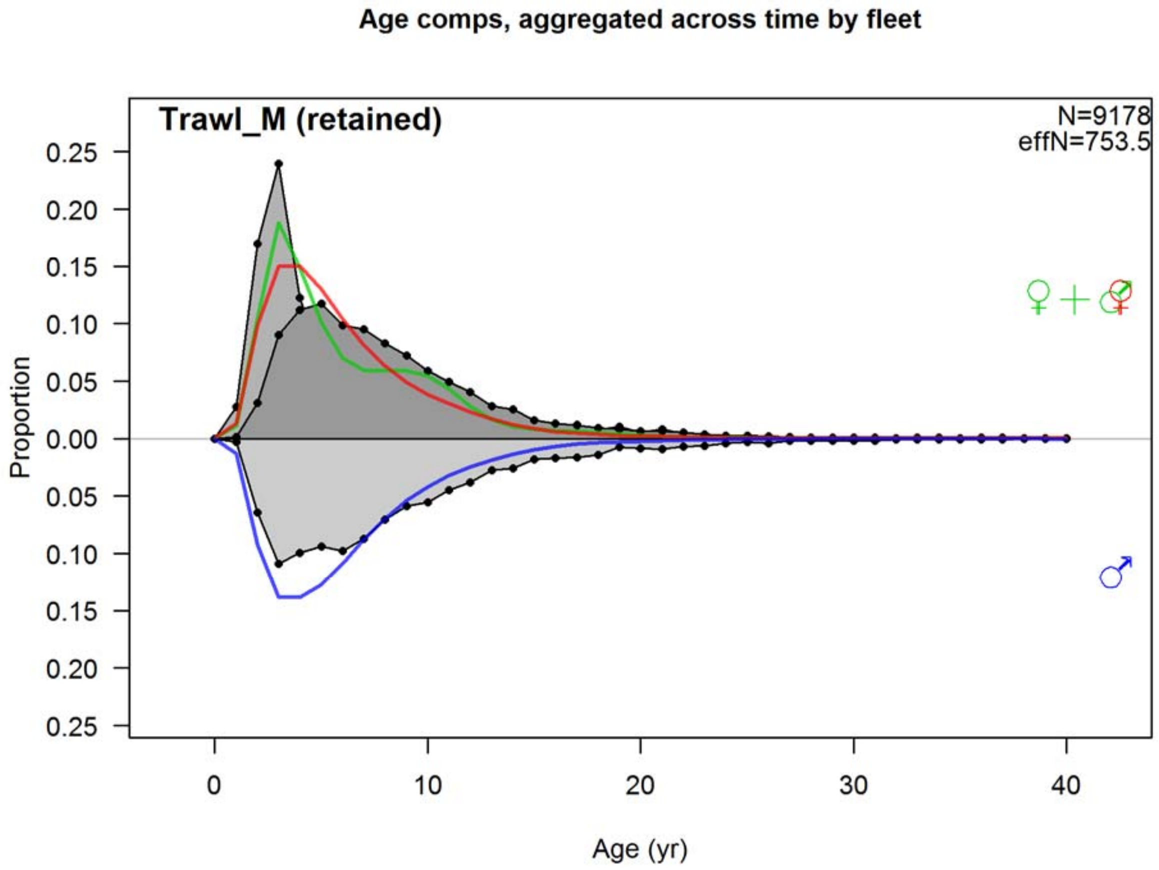


Figure A 17.12. Redfish age composition fit aggregated across years.

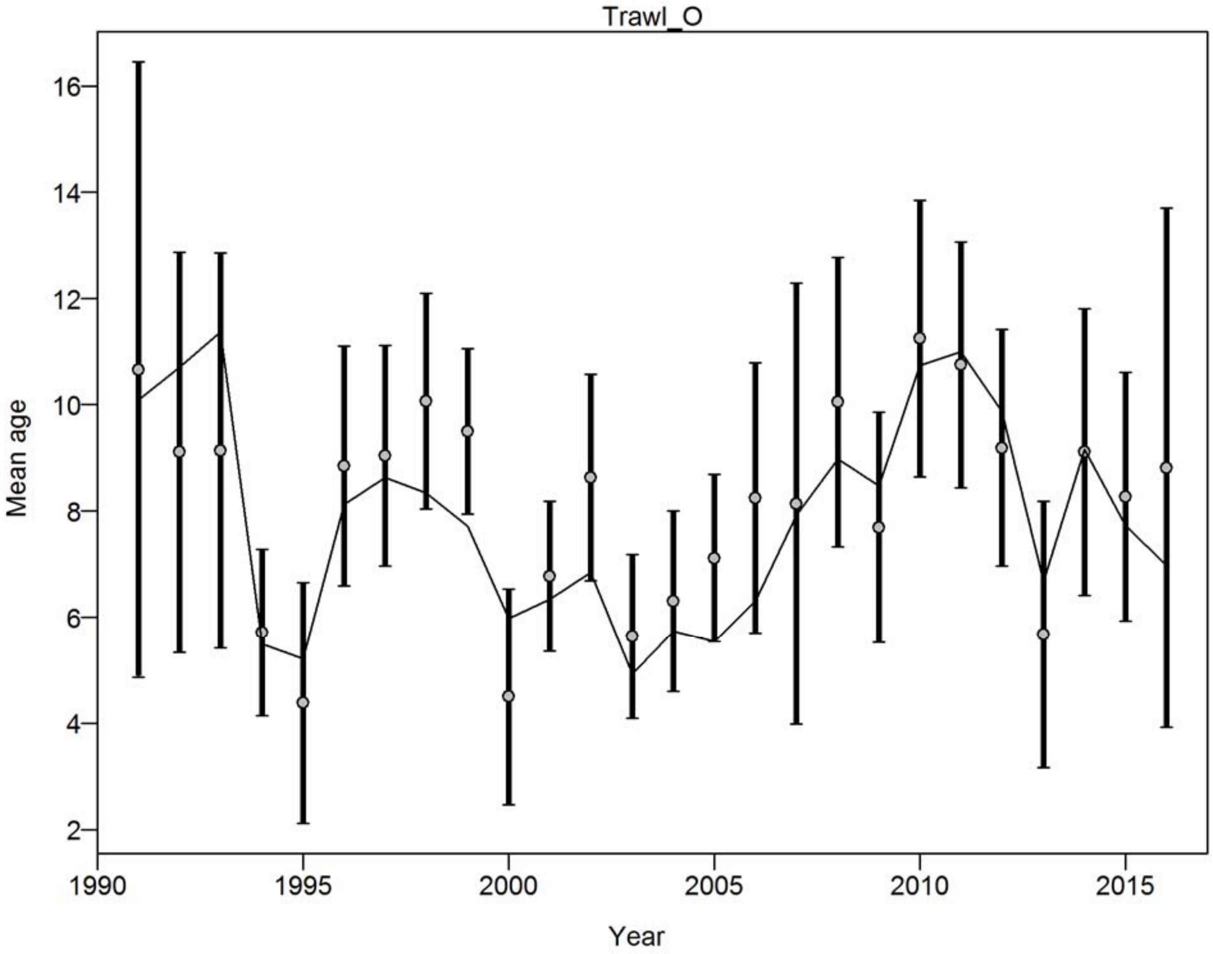


Figure A 17.13. Redfish conditional age at length fit diagnostics from tuning. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data.

17.8 Appendix B

17.8.1 *Single selectivity model diagnostics*

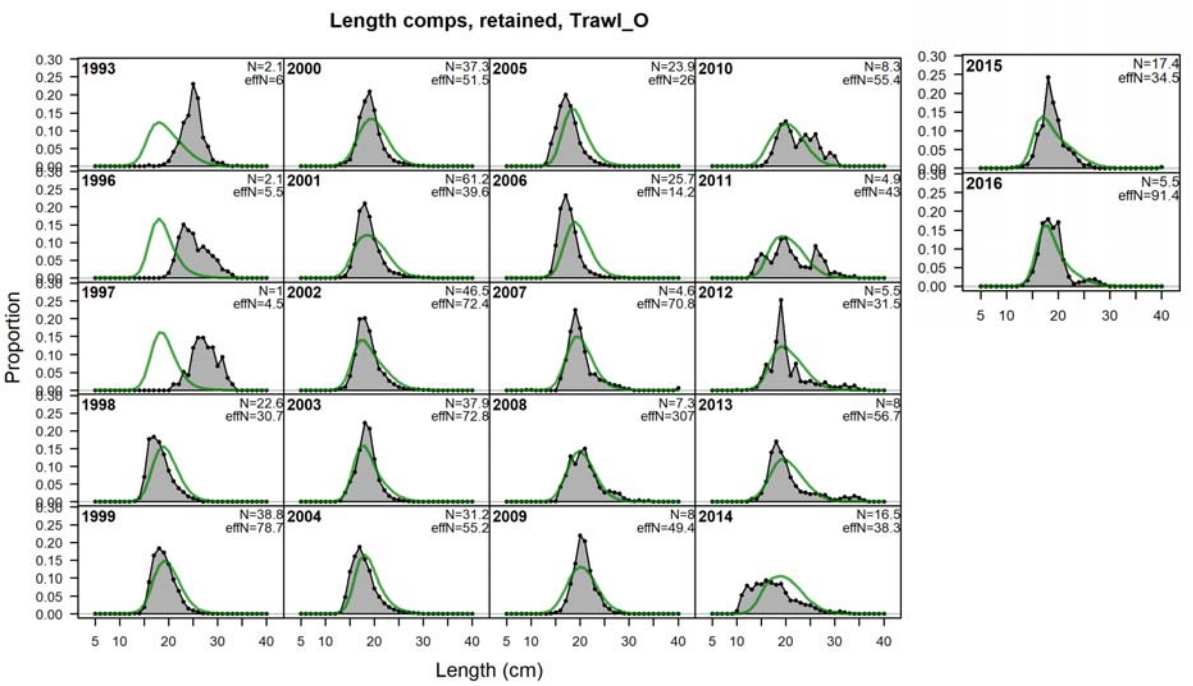
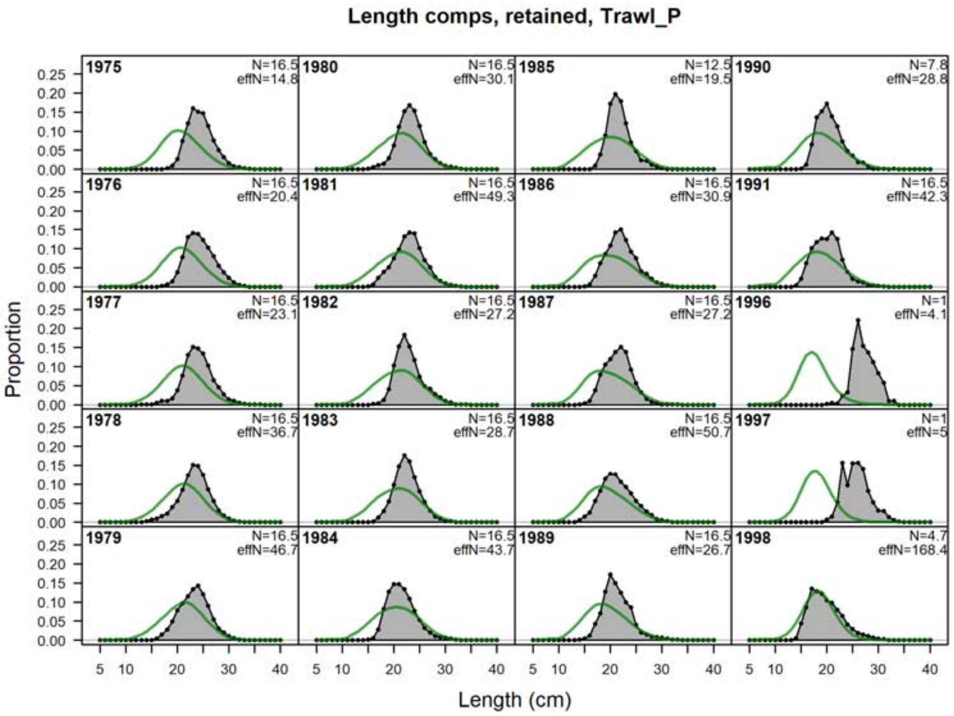


Figure B 17.1. Redfish length composition fits: onboard trawl retained.



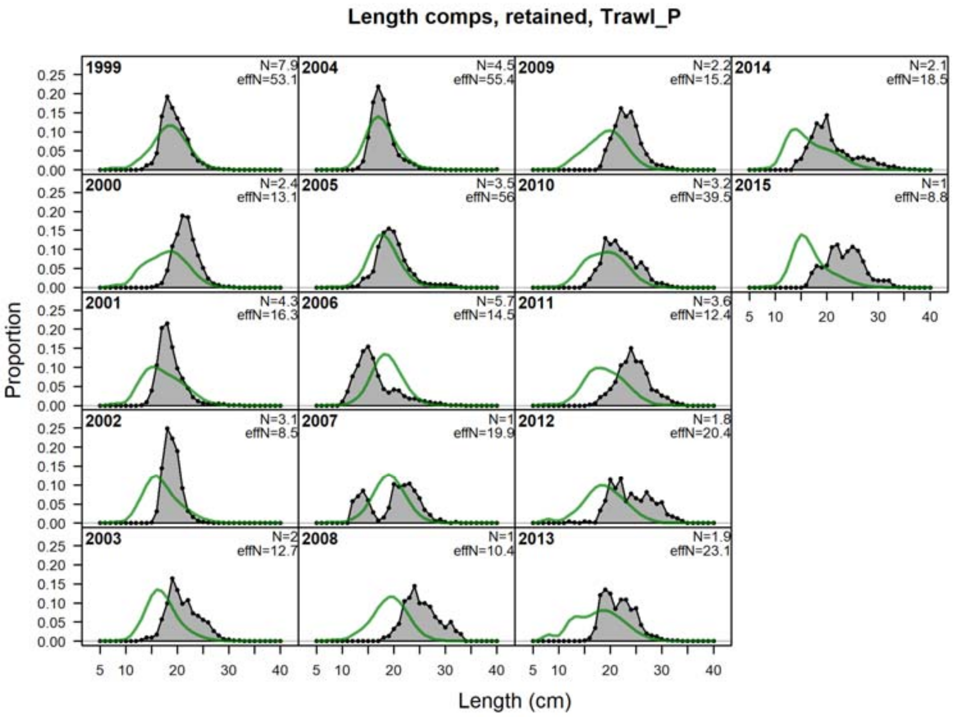


Figure B 17.2. Redfish length composition fits: port trawl.

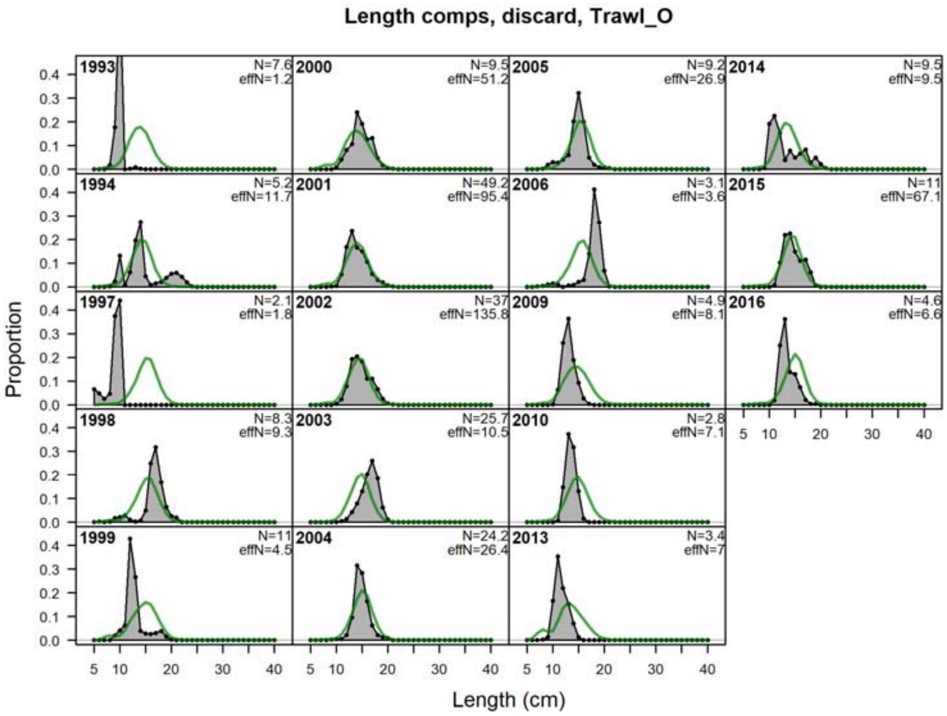


Figure B 17.3. Redfish length composition fits: onboard trawl discard.

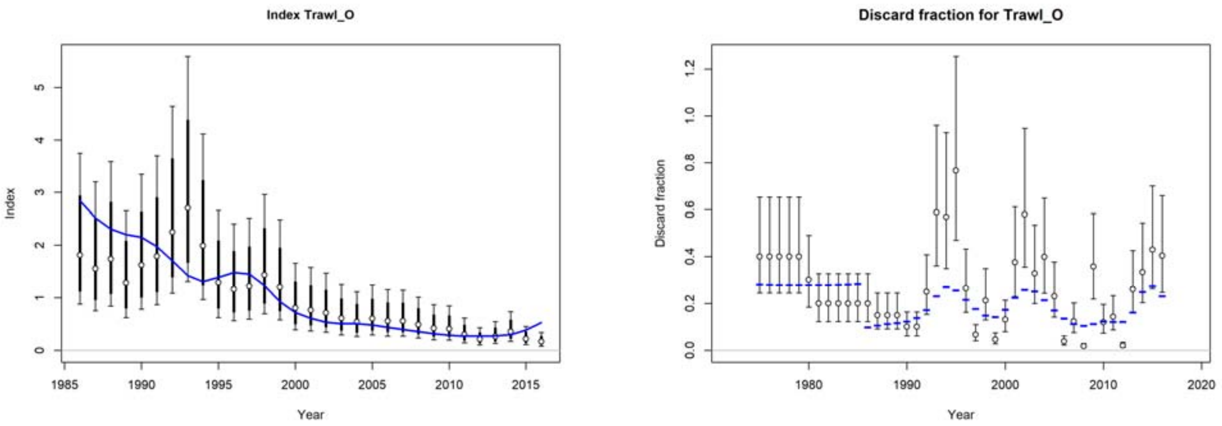


Figure B 17.4. Fits to trawl CPUE and discards for redfish.

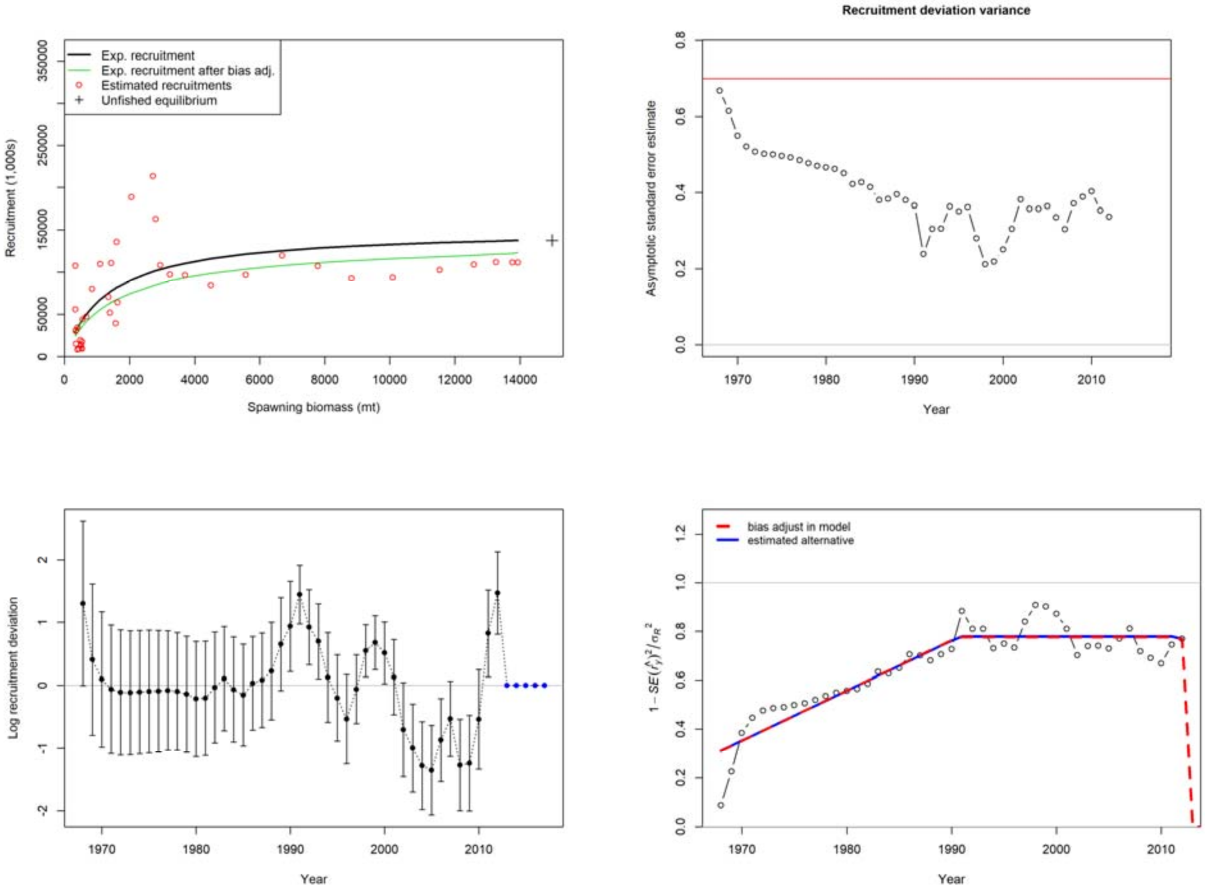


Figure B 17.5. Time series showing the stock recruitment curve, recruitment deviations and recruitment deviation variance check for redfish.

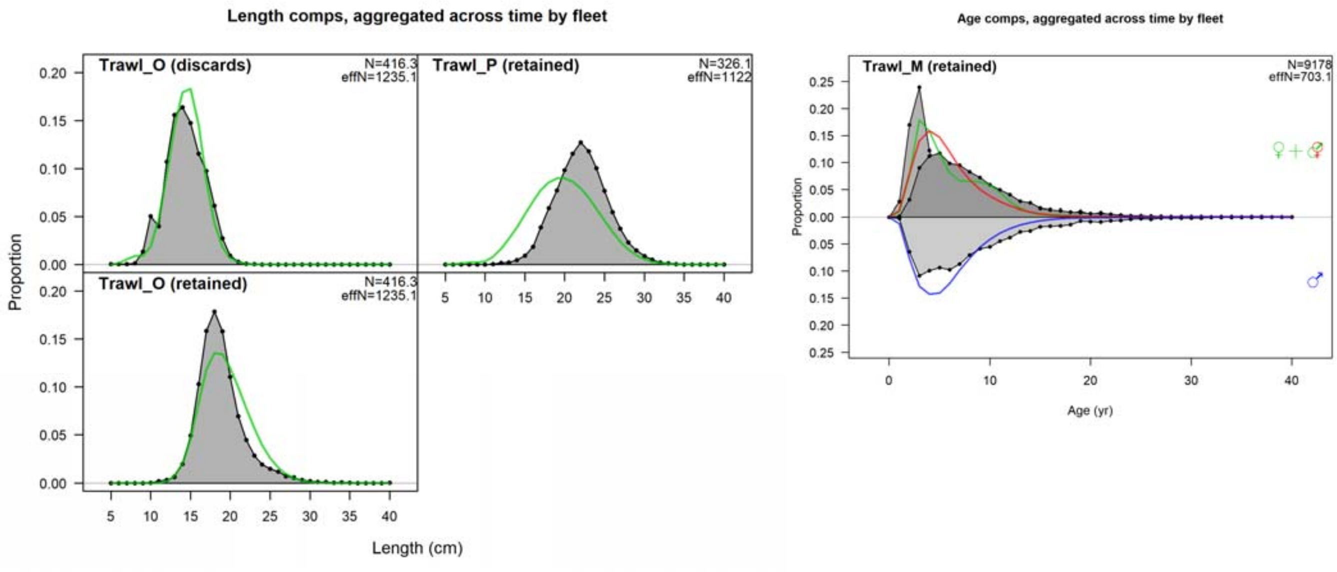


Figure B 17.6. Redfish length and age composition fit aggregated across years.

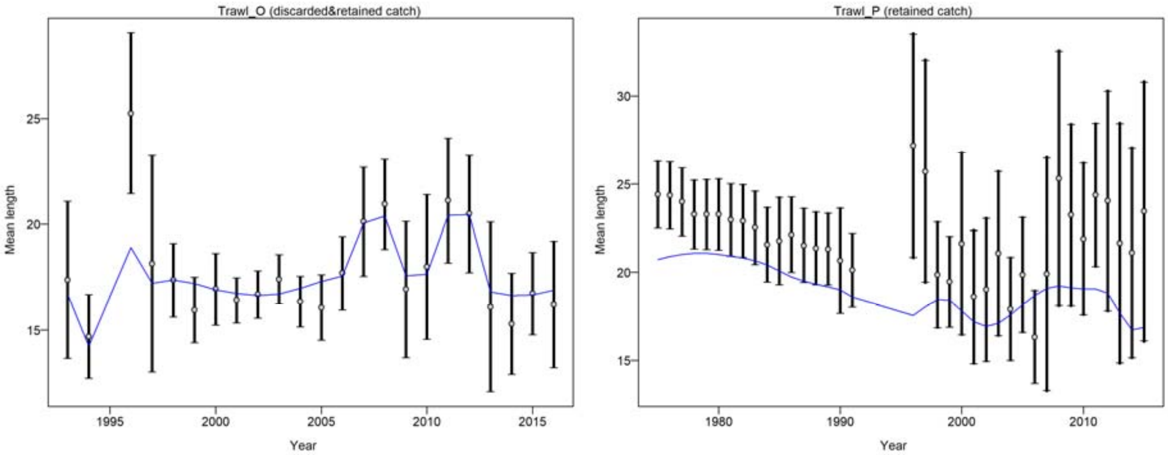


Figure B 17.7. Redfish length composition fit diagnostics from tuning. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for length data.

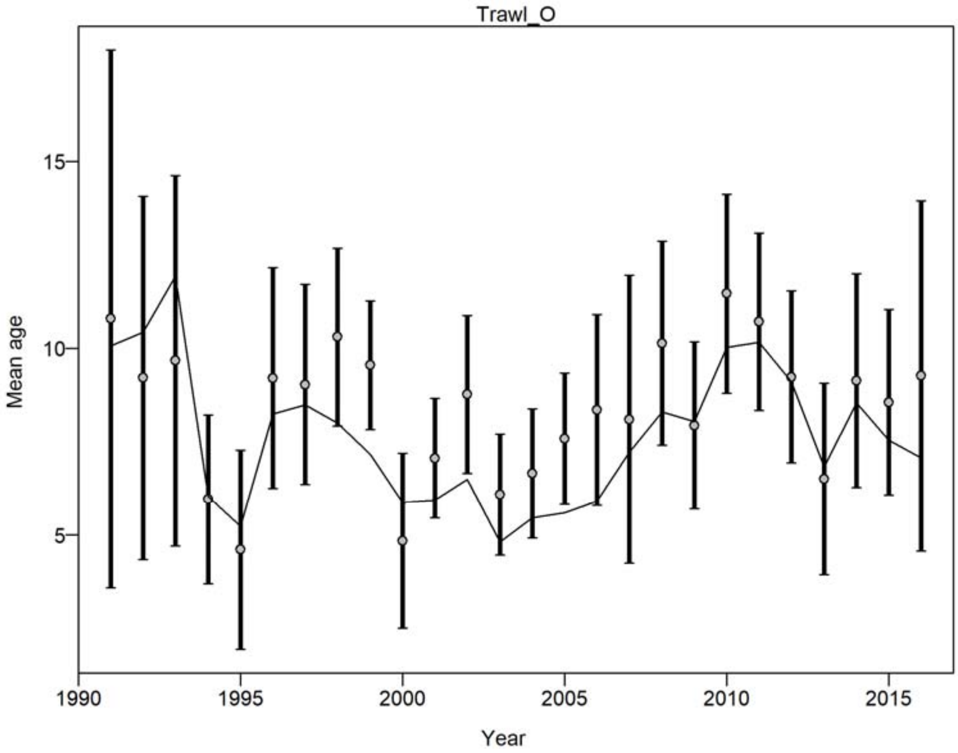


Figure B 17.8. Redfish conditional age at length fit diagnostics from tuning. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data.

18. Orange Roughy East (*Hoplostethus atlanticus*) stock assessment using data to 2016 - development of a preliminary base case

Malcolm Haddon

CSIRO Oceans and Atmosphere, GPO Box 1538, Hobart, TAS 7001, Australia

18.1 Summary

The stock assessment for Eastern Zone orange roughy (*Hoplostethus atlanticus* Collett 1889) described here uses an integrated stock assessment model implemented using the platform Stock Synthesis 3.3 (a revision of the 3.24z version used previously). As in the last assessment it assumes a stock structure that combines the Eastern Zone (primarily St Helens Hill and St Patricks Head) and Pedra Branca from the Southern Zone (all seasons). New data included since the previous stock assessment (Upston et al., 2015) are recent research and commercial catches; relative spawning biomass estimates from the 2016 acoustic towed surveys at St Helens Hill and St Patricks Head, a revised index of spawning biomass from the 2013 towed acoustic survey (which derived from a re-calibration of the survey gear), and new age composition of the catch data from 2012 and 2016. In addition, an extra recruitment residual was included in the analysis. A new base case was generated by adding each of these model changes and data streams sequentially to the previous final base case assessment model to document the effect of each new source of information in a formal bridging analysis.

The acoustic indices are considered to be relative indices in the model in the sense that there are several factors that can lead to the acoustic biomass estimate differing from the biomass available to survey on average. The Francis (2011) data weighting method was applied as is becoming standard practice, to select the weights for the age composition data, which led to more weight being assigned to the acoustic survey indices when the model was fitted. The other new data input was an updated ageing error matrix using data from a recent re-ageing experiment (by Fish Ageing Services). The re-ageing experiment, which was designed to investigate between-year bias in age reads, found no evidence of a major bias in the early age readings for Eastern Zone Orange roughy.

A base-case model was developed that involved including recent catches, a new acoustic survey index from 2016, a revised acoustic survey estimate for 2013, new age composition data for 2012 and 2016, and a new ageing error matrix. Unusual aspects of the model outcome include a pattern of recruitment that switches from predicted high levels of recruitment to low levels rising back up to predicted average levels about six years prior to the start of the fishery. This unusual pattern appears to derive from the extremely high fishing mortality rates imposed.

The model estimates a continuing trend of increases in spawning biomass, whereas the observed acoustic point estimates for 2012 and 2013 are less than the point estimates for the preceding years (Ryan et al. 2014 raise the possibility that the 2013 St Helens acoustic survey may have missed the spawning peak but they cannot be definitive).

The new basecase17 estimated female spawning biomass in 2016 to be about 33% of the unfished level (using maximum likelihood).

18.2 Introduction

18.2.1 *The Fishery*

The three most recent stock assessments for Eastern Zone orange roughy (*Hoplostethus atlanticus* Collett 1889) were completed in 2006 (using data up to July 2006 and using an estimate of catch for calendar 2006; Wayte 2007), in 2011 (using data up to December 2010; Upston & Wayte 2012a, b), and in 2014 (Upston et al, 2015), which used data up to the end of 2013. The stock defined in the 2014 base case as 'orange roughy East' comprised the St Helens Hill, St Patricks Head, and also Pedra Brancha off the south of Tasmania. This assumed stock structure was suggested by an orange roughy workshop held early in 2014 and is continued in this assessment.

The history of the fishery for orange roughy in the Australian Fishing Zone, can be found in CSIRO & TDPIF (1996), Bax (2000), Wayte (2007) and Upston et al. (2015). The important change for the Eastern zone since the 2014 assessment was that the stock had rebuilt to have an estimated median estimate of female spawning depletion at the start of 2015 (SB2015/ SB0) of approximately 0.25B0, which, being above the Commonwealth spawning biomass limit reference point (of 0.2B0), eventually led to a limited re-opening of the eastern fishery starting in 2015 with a three year TAC of 465 t (for the 2015, 2016, and 2017 seasons) in the Eastern zone with a further allocation of 35 t at Pedra Branca in the Southern Zone; this is in contrast with a 25 t TAC in 2014 (AFMA, 2017). An Eastern Orange Roughy Management Area (ORMA) was declared along with a Pedra Branca ORMA (AFMA, 2017, p 83-84), and these declared the specific areas opened to fishing within the 700m deepwater closure.

The fishery had been closed to commercial fishing at end of 2006 with orange roughy listed as conservation dependent using the 'Environment Protection and Biodiversity Conservation Act' (with the exception of a 500 t TAC for the Cascade Plateau Zone, whose stock was deemed to be above the biomass Target Reference Point). A 5-year conservation plan was put in place in 2007 and was reviewed in 2012/13 (AFMA, 2014). A workshop organised by AFMA (including NZ participants) was held at CSIRO Hobart in May 2014 to discuss the fishery and the then upcoming Eastern Zone orange roughy stock assessment, including development of a base-case model specification. That workshop led on to the production of the 2014 stock assessment (Upston et al., 2015). That, in turn led on the production of the current stock assessment that aims to determine whether the Eastern zone orange roughy stock continues to recover and to meet the needs of setting the TAC for 2018 onwards.

18.2.2 *Previous Assessments*

Early stock assessments for the Eastern stock of orange roughy (Bax, 2000) used stock reduction analysis (Kimura et al., 1984) to generate plausible estimates of unfished biomass and current biomass and then considered the outcome of projecting the modelled stock forward under different TAC scenarios. Later stock assessments from after the start of the 2000's used relatively simple age-structured stock assessment models that were fitted using maximum likelihood methods and Bayesian approaches. In 2006 and onwards, fully integrated stock assessments using the stock synthesis software were conducted (Table 18.1).

Table 18.1. A summary of previous integrated stock assessment and their outcomes for Eastern Zone orange roughy. The year of assessment is usually the year after the final year of data collection, while the year listed under Authors is the year the assessment was more formally reported. B0 is the unfished female spawning biomass, except in 2011. The B_0 in 2011 is total spawning biomass rather than just female spawning biomass. The RBC is the potential yield in the following year.

Year	Authors	B0 (t)	Depletion	RBC (LTY) (t)
2001	Wayte & Bax (2002)			
2006	Wayte (2007)	40,746	0.1B_0	0 t
2011	Upston & Wayte (2012a) Upston & Wayte (2012b)	92,675*	~0.165B_0	0 t
2014	Upston et al., (2015)	38,931	0.25B_0	381 t

18.2.3 *Modifications to the Previous 2014 Assessment*

An initial base case has been developed for presentation to the SE RAB in September 2017, and this present describes the changes wrought on the previous assessment by the sequential addition of the new data now available (known as a bridging analysis) along with other structural changes.

One change was the shift to the latest version of the SS3 software (SS3.24z was moved to SS3.3.0.5; Methot and Wetzel, 2013; Methot et al, 2017) and then an array of data updates were made. It is now standard practice in Australia, New Zealand, and at least the west coast USA to place more emphasis on any indices of relative abundance (standardized commercial CPUE and the trawl or acoustic survey indices; Francis, 2011) relative to that placed on age and length composition data. This relates to the proportional emphasis given to the different data streams available when fitting the model and, in this case, different arrangements can lead to different assessment outcomes in terms of estimates of female spawning biomass and depletion levels. The changes are described in a set different manipulations and changes to the old assessment (Table 18.2).

Table 18.2. The 9 sequential changes made to the 2014 assessment model. The final base-case is named basecase17.

N	Name	Description
1	origbase	Repeat the assessment from 2014 using the original software version SS3.24z (Upston et al, 2015)
2	origbalance	Re-balance the variances of the survey indices and eh age composition data.
3	translated	Convert the control and data files to SS3.30.05 version
4	addcatches	Add the landings and discards for 2014 - 2016
5	addsurvey	Add the new 2016 towed body acoustic survey index and the revised index for 2013
6	addnewage	Include new age composition data for 2012 and 2016
7	ageingerror	Include a newly revised ageing error matrix
8	extendrec	estimate one more year of recruitment deviates (three more were initially attempted but the last two had highly uncertain estimates and were rejected).
9	basecase17	Re-balanced variances, with emphasis placed on Survey indices

18.2.3.1 Balancing variances and adjusting biases

As adding significant amounts of new data can alter the relative contribution of different data sets within the model fitting process and thus disturb the apparent model outcomes (depletion and unfished biomass estimation, etc). To stabilize the model fitting and speed up the process some rebalancing of the variances of the different age-composition data sets was conducted prior to translating the control (.ctl), data (.dat), and other SS3.24z files into the new SS3.3 format. SS3.3 now automatically balances the input variances of the survey data with those predicted by the model, but the age-composition data still requires rebalancing manually at each step using the Francis (2011) weights. At the final stage (basecase17) the input variance of the different sets of age composition data were re-balanced relative to the predicted variance until they all reached equilibrium to generate the initial base case.

In addition, the model generates predicted deviations from the expected mean stock recruitment for each year in response to differences in year class strength from the ageing data and changes in the relative abundance indices. Being log-normally distributed these predicted values tend to be biased relative to actual values. Early in the time-frame used by the model to describe the fishery there is less information to inform the values of these predicted recruitment deviates and so any bias is expected to be lower, similarly towards the end of the time-series a ramping down of any bias is also expected (Methot & Taylor, 2011). The model variance balancing and bias adjustment also involves increasing the maximum recruitment variation up to a pre-defined maximum (or down to a pre-defined minimum) as further bias adjustments are required after adjusting the variance estimates on different data streams.

18.2.3.2 Estimation of RBS and long term RBC

Once the base case is approved by the SE RAG (or valid modifications suggested) its dynamics will be projected forwards for a large number of years to estimate the long term RBC that would, at equilibrium, keep the stock to the MEY Commonwealth proxy target of 48%B_0 (DAFF, 2007).

Following the projections, sensitivity analyses will be conducted to provide a test of the structural assumptions made in the formulation of the assessment model. In addition, a number of likelihood profiles around the more influential parameters will be made to clarify the effects of these model parameters.

18.3 Methods

18.3.1 *Biological parameters*

Male and female orange roughy are assumed to have the same biological parameters except for their length-weight relationship (Table 18.3). None of the four parameters relating to the Von Bertalanffy growth equation are estimated within the model-fitting procedure.

Table 18.3. The estimated and pre-specified model parameters for the Eastern Zone Orange roughy preliminary base-case stock assessment. The assumed stock structure includes the Eastern Zone (primarily St Helens Hill and St Patrick's Head) plus Pedra Branca from the Southern Zone. Normal priors are defined by N(mean, standard deviation). There is assumed to be no auto-correlation among the recruitment deviations. 82 parameters are estimated.

Estimated parameters	**Parameters**	**Prior**	**Source**
Unexploited recruitment; log(R0)	1	N(9.3, 10)	Uninformative
Recruitment deviations 1905-1981*	77	N(0, σ_R)	See section 5.3.2.1
Selectivity logistic inflection	1	N(35.0, 99)	Uninformative
Selectivity logistic width	1	N(3.0, 99)	Uninformative
q Acoustic towed catchability	1	N(0.95, 0.3)	Upston et. al. (2015)
q Hull catchability	1	N(0.95, 0.9)	Upston et. al. (2015)
Pre-specified Fixed parameters	**Values**		
Recruitment steepness, *h*	0.75		Annala (1994) cited in CSIRO & TDPIF (1996)
Recruitment variability , σ_R	0.58		
Rate of natural mortality, *M*	0.04 yr^{-1}		Stokes (2009)
Maturity logistic inflection	35.8 cm		Estimated selectivity
Maturity logistic slope	-1.3 cm^{-1}		Smith et al. (1995)
Von Bertalanffy *K*	0.06 yr^{-1}		Smith et al. (1995)
Length at 1 yr Female	8.66 cm		
Length at 70 yrs Female	38.6 cm		
Length-weight scale, *a*	3.51 x 10^{-5}	Female	Lyle et al. (1991)
	3.83 x 10-5	Male	
Length-weight power, *b*	2.97, 2.942	Female, Male	Lyle et al. (1991)
Plus-group age (years)	80		
Length at age CV for young	0.07		Estimated from data
Length at age CV for old	0.07		Expected offset from young
q egg survey catchability	0.9		Bell et al. (1992), Koslow et.al (1995), Wayte (2007)

Maturity is modelled as a logistic function, with 50% maturity at about 35.8 cm. The assumption is made that the maturity would match the selectivity as estimated on the spawning aggregations (which are assumed to be mature).

Fecundity-at-length is assumed to be directly proportional to weight-at-length, which is important for the estimation of the Spawning Potential Ratio, which can act as a proxy for fishing mortality; a requirement for the determination of stock status.

18.3.2 *Available Data*

An array of different data sources are available for the Eastern Zone orange roughy assessment including catch (landings plus discards), three indices of abundance (the egg estimate treated as an absolute abundance, while the two acoustic biomass estimates are treated as relative abundance indices), and age composition data from the acoustic surveys and on-board sampling (Figure 18.1). Length data collected form the acoustic surveys is available now and its inclusion in the stock assessment will be explored as an option.

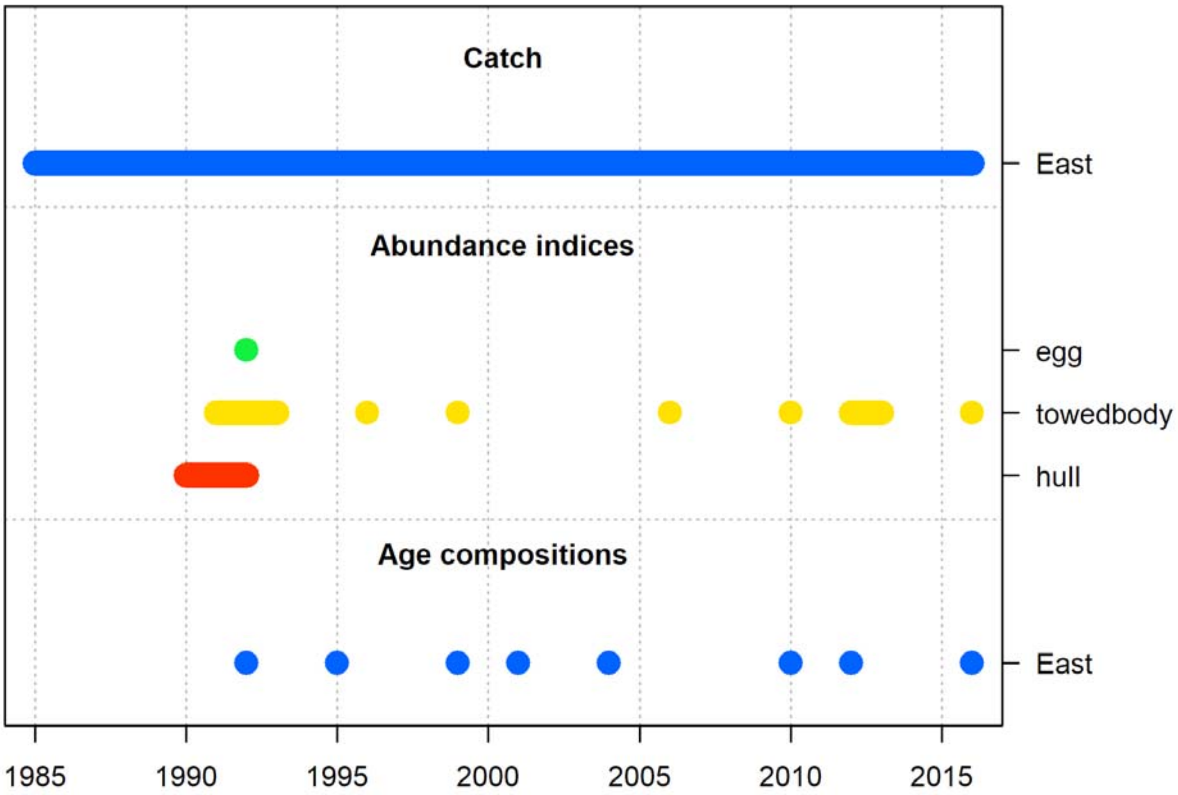


Figure 18.1. Data availability for Orange roughy East by type and year. This illustrates the full data set as used in the basecase17 scenario.

18.3.3 *Catches*

Commonwealth Commercial logbook data for the years 1985 to 1991 and Catch Documentation Records for landings across the years 1992 to 2016 provide information on Orange roughy retained catch in the SESSF (Figure 18.2; Table 18.4).

The Eastern Orange Roughy zone and Pedra Branca (Figure 18.3) catch history is used in the base-case assessment. The catch values reported originally have been adjusted as a result of estimates of burst bags and other initially unreported catches; Wayte (2007) provides details about how the catches from 1989 – 1994 were adjusted. The justification for these adjustments to the catch history leading to the “agreed” catch history are also given in CSIRO & TDPIF (1996) and descriptions of earlier stock assessments (for the years 1995, 1996 and 1997 – see Bax 1997, Bax 2000a and 2000b).

In 2007 the quota year was changed from calendar year to the year extending from 1 May to 30 April the assessment, however, continues to be conducted according to the calendar year as most catches occurred prior to 2007.

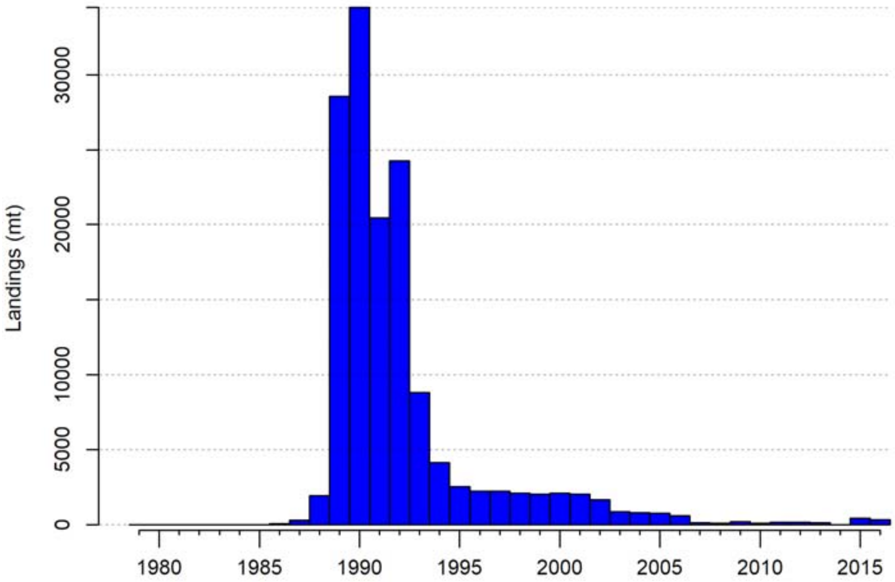


Figure 18.2. Total reported landed catch of Eastern Zone Orange roughy 1985 - 2016; see Table 18.4).

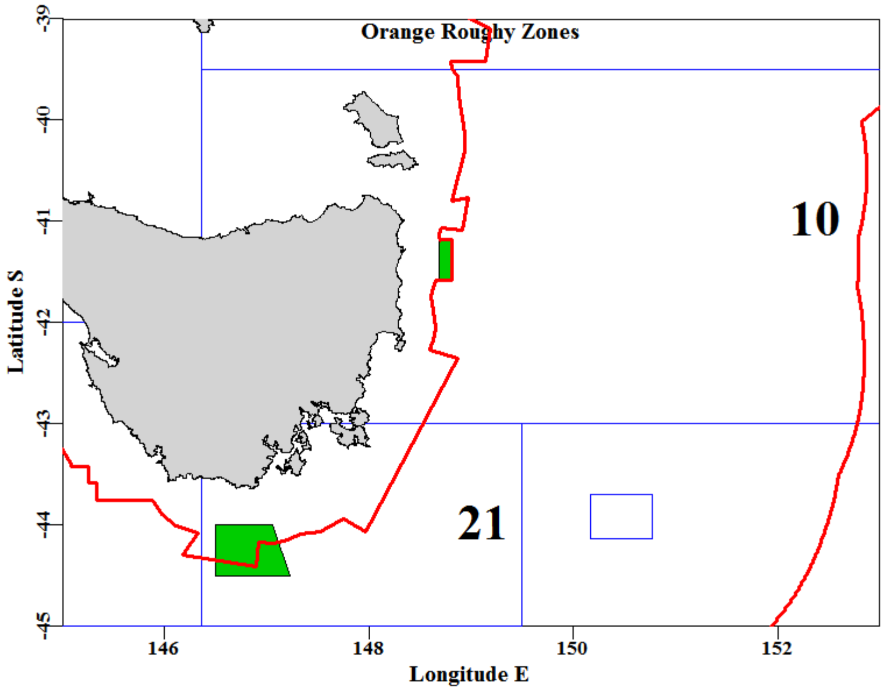


Figure 18.3. A sketch map of the Orange Roughy zones 10 and 21. The red lines denote the current definition of the 700 m deepwater closure and the green regions denote the Orange Roughy Management Areas for Pedra Branca in the south and the Eastern Orange Roughy Management Area in the north, encompassing both St Helen's Hill and St Patrick's Head. The ORMA descriptions are approximate as only measured from AFMA (2017).

Table 18.4. Year agreed catches, in tonnes, of Eastern Zone Orange roughy, where the Eastern Zone stock includes Pedra Branca (PB) from the Southern Zone. The starred years 1989* – 1994* (horizontal shading) denote catches that incorporate adjustments for the proportion lost due to lost gear and burst bags/ burst panels, other losses, and misreporting (CSIRO & TDPIF 1996; Wayte 2007). The shaded column has the catch history included in the Current Eastern Zone Stock Assessment.

Year	Reported	East Agreed	East+PB Agreed	PB Agreed
1985	6	6	6	0
1986	33	33	60	27
1987	310	310	310	0
1988	1949	1949	1949	0
1989*	18365	26236	28575	2339
1990*	16240	23200	34502	11302
1991*	9727	12159	20436	8277
1992*	7484	15119	24265	9146
1993*	1971	5151	8798	3647
1994*	1682	1869	4140	2271
1995	1959	1959	2544	585
1996	1998	1998	2231	233
1997	2063	2063	2250	187
1998	1968	1968	2087	119
1999	1952	1952	2052	100
2000	1996	1996	2109	113
2001	1823	1823	2027	204
2002	1584	1584	1674	90
2003	772	772	877	105
2004	767	767	797	30
2005	754	754	772	18
2006	614	614	615	1
2007	113	113	129	16
2008	98	98	98	0
2009	193	193	193	0
2010	113	113	113	0
2011	160	160	162	2
2012	163	163	163	0
2013	150	150	150	0
2014	7.4	7.3	7.3	0
2015	415	415.8	460.4	44.6
2016	345	340.3	360	19.7

18.3.4 *Age composition data*

Otolith samples have been taken from spawning aggregations in 1992, 1995, 1999, 2001, 2004, 2010, 2012, and 2016. This has permitted the age-composition of the sampled stock to be determined for both males and females. These are included in the assessment and are assumed to be simple random samples of the catch (Figure 18.4; and in Appendix A: Table 18.11). The age-compositions for St Helens Hill and St Patricks Head have been combined and weighted based on either the relative abundance implied by the acoustic estimates or the relative catch (Wayte, 2007). The age samples for 1992 and 1995 are from St Helens only where the major proportion of the catch was taken (Upston & Wayte 2012a).

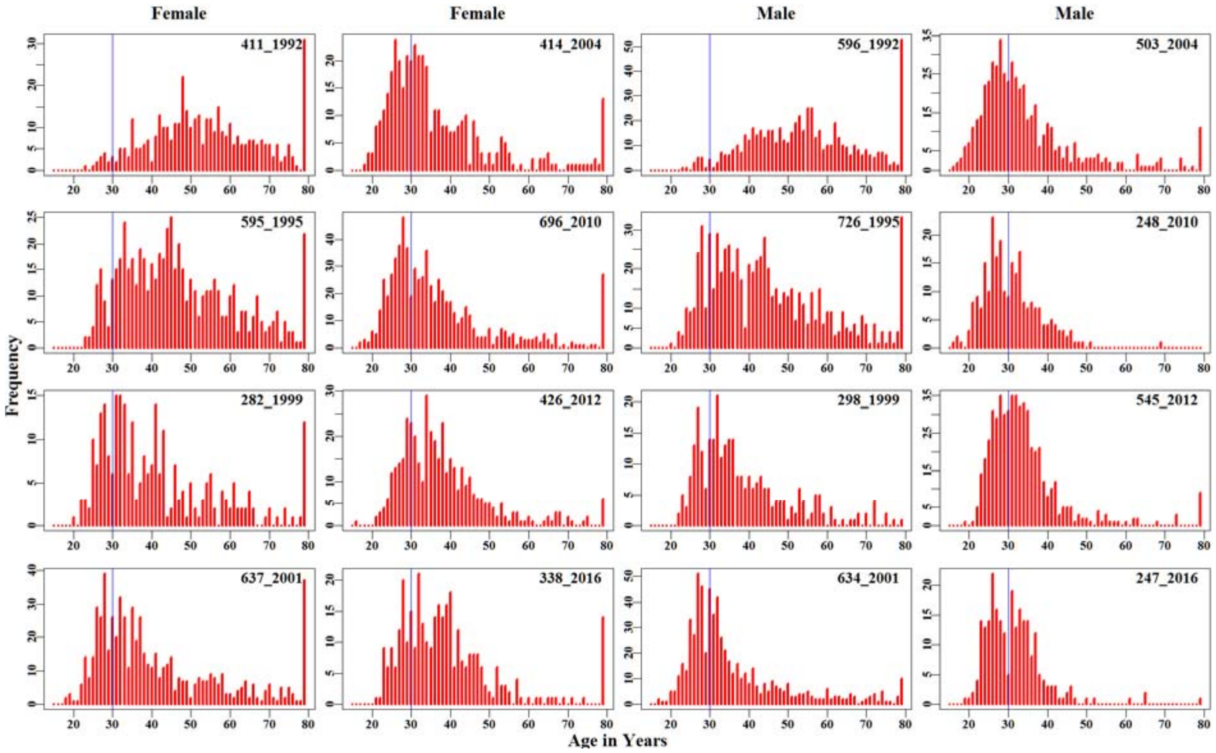


Figure 18.4. All Eastern Zone Orange roughy ageing data used by year and gender. The vertical blue line identifies age 30 to aid comparisons. The numbers at top-right of each plot are the sample size and the year. The age-composition data (the frequency of fish at age) are detailed in Table 18.11.

18.3.4.1 Ageing error

Orange roughy live a long time and reading their otoliths is intrinsically difficult and the possibility of their being ageing errors made up of differences between readers and differences between years brought about by changing experience is a real risk (Francis, 2006). Upston et al, (2015) describe an investigation of this potential risk. It is now standard practice now to include an ageing error matrix into age-structured stock assessments (Francis and Hilborn, 2002), and this is used to adjust the observed distribution of ages in the model fitting process.

An estimate of the standard deviation of age reading error was calculated from data supplied by Kyne Krusic-Golub of Fish Ageing Services (A.E. Punt, pers comm.). The estimate was updated from that used in the 2011 preliminary assessment, to include data from the re-ageing experiment (the difference between the age error matrices was minor).

The age estimates are assumed to be unbiased but subject to random age-reading errors (Punt et al., 2008). Standard deviations for aging error by reader have been estimated from the latest sets of age reading, producing the age-reading error matrix (A.E. Punt, pers. comm.; Table 18.5; Figure 18.5).

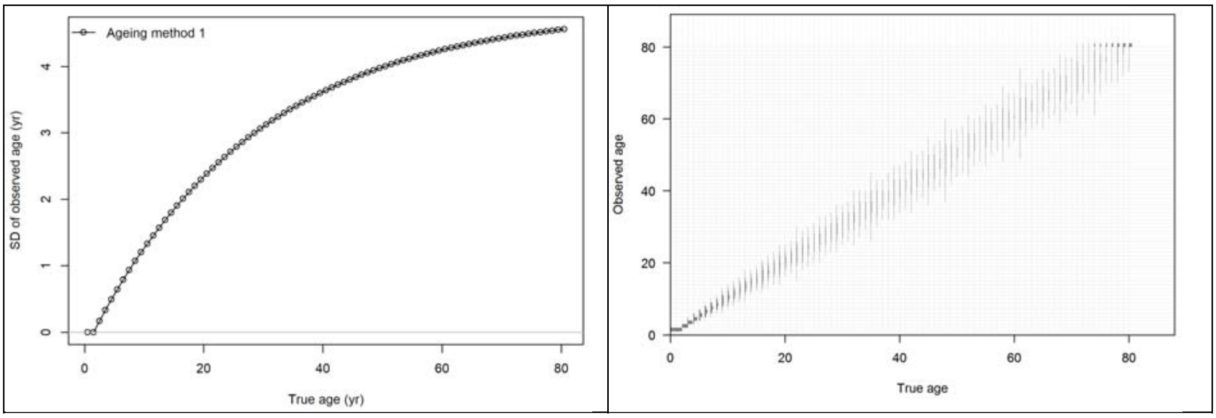


Figure 18.5. Two ways of viewing the increase in ageing error with age (see Table 18.5). The plot on the right illustrates the distribution of observed ages at the agreed true age (ageing error type 1).

Table 18.5. The estimated standard deviation of normal variation (age-reading error) around age-estimates for the different age classes of Eastern Zone orange roughy.

Age	StDev.	Age	StDev.	Age	StDev.	Age	StDev.
0	0.0008	21	2.4719	42	3.7268	63	4.3217
1	0.0008	22	2.5553	43	3.7663	64	4.3404
2	0.1704	23	2.6357	44	3.8044	65	4.3585
3	0.3340	24	2.7133	45	3.8412	66	4.3759
4	0.4920	25	2.7881	46	3.8767	67	4.3928
5	0.6444	26	2.8604	47	3.9110	68	4.4090
6	0.7916	27	2.9302	48	3.9440	69	4.4247
7	0.9336	28	2.9975	49	3.9760	70	4.4398
8	1.0706	29	3.0624	50	4.0068	71	4.4544
9	1.2028	30	3.1251	51	4.0365	72	4.4685
10	1.3305	31	3.1856	52	4.0652	73	4.4821
11	1.4536	32	3.2440	53	4.0928	74	4.4952
12	1.5725	33	3.3004	54	4.1196	75	4.5079
13	1.6872	34	3.3548	55	4.1453	76	4.5201
14	1.7979	35	3.4073	56	4.1702	77	4.5319
15	1.9048	36	3.4579	57	4.1942	78	4.5433
16	2.0079	37	3.5068	58	4.2174	79	4.5543
17	2.1074	38	3.5540	59	4.2398	80	4.5649
18	2.2035	39	3.5995	60	4.2614		
19	2.2962	40	3.6435	61	4.2822		
20	2.3856	41	3.6859	62	4.3023		

18.3.5 *Acoustic survey abundance estimates*

There are now ten estimates of relative abundance, for the St Helens Hill and St Patricks Head area, from the towed body acoustic surveys (Table 18.6). The CV estimates for the individual abundance estimates are initially used in the model fitting process, but when balancing the output variability with that input, these values are slightly modified.

Table 18.6. The three abundance indices used in the Eastern Zone Orange roughy assessment. Values up to 2012 were sourced from Upston et al (2015). The 2013 Towed acoustic survey value was increased by 18% as a result of a recalibration of the equipment (Kloser, pers. comm), and the 2016 estimate is from Kloser et al, (2016). DEPS is the daily egg production survey. The DEPS is treated as an absolute abundance estimate, the others are treated as relative abundance indices.

System	Year	Biomass	CV	Catchability
Hull	1990	120239	0.63	N(0.95, 0.92)
Hull	1991	71213	0.58	N(0.95, 0.92)
Hull	1992	48985	0.59	N(0.95, 0.92)
Towed	1991	59481	0.49	N(0.95, 0.3)
Towed	1992	56106	0.50	N(0.95, 0.3)
Towed	1993	22811	0.53	N(0.95, 0.3)
Towed	1996	20372	0.45	N(0.95, 0.3)
Towed	1999	25838	0.39	N(0.95, 0.3)
Towed	2006	17541	0.31	N(0.95, 0.3)
Towed	2010	24000	0.25	N(0.95, 0.3)
Towed	2012	13605	0.29	N(0.95, 0.3)
Towed	2013	14368*	0.29	N(0.95, 0.3)
Towed	2016	24037	0.17	N(0.95, 0.3)
DEPS	1992	15922	0.50	0.9 (fixed)

18.3.6 *Stock Assessment*

18.3.6.1 Population dynamics model and parameter estimation

A two-sex stock assessment for Eastern Zone orange roughy has been implemented using the software package Stock Synthesis (SS, previously version 3.24z was used now this has been updated to version 3.3; Methot and Wetzel, 2013, Methot et al, 2017). While it is a two-sex model, differences by gender are restricted to weight at length, which, along with the age data being separated by gender, is used to inform the relative biomass of each gender. Spawning biomass, and its depletion levels is thus able to be presented as female spawning biomass. Stock Synthesis is a statistical age- and length-structured model that can be used to fit the various data streams now available for Eastern orange roughy simultaneously. The population dynamics model, and the statistical approach used in the fitting of the model to the various types of data, are described in the SS operating manual (Methot et al, 2017) and the more technical description (Methot and Wetzel, 2013) and, as these are very long, are not reproduced here.

A single stock of orange roughy was assumed to occur Orange Roughy zone 10 and 21 (where 21 is the eastern half of the southern zone; Figure 18.3). The stock was assumed to have been unexploited prior to 1985, initial catches from 1985 – 1987 were relatively minor. The input CVs of the catch rate index and the biomass survey were initially set to fixed values (0.05) which are effectively arbitrary in the final phase of the model fitting as catches are assumed to be known without significant error.

The selectivity pattern for the trawl fleet was modelled as constant through time; although this may change in the future as more recent catch data indicates that the fishery is now spreading across the year rather than being focussed in the spawning season of June - August. This change in fishing behaviour has importance because the modelled selectivity is a combination of both the selectivity of the fishing gear combined with the properties of the fish available to that gear, which will change through the year. Both of the selectivity-at-length parameters were estimated within the assessment.

The rate of natural mortality, M, was assumed to be constant with age and also constant through time. The natural mortality rate is fixed in the base-case analysis (Table 18.3).

Recruitment was assumed to follow a Beverton-Holt type stock-recruitment relationship, parameterised by the average recruitment at unexploited spawning biomass, R_0, and the steepness parameter, h. Steepness for the base-case analysis was assumed to be 0.75. Deviations from the average recruitment at a given spawning biomass (recruitment deviations) were estimated from 1905 – 1980 in the last assessment, with one extra year being included in this assessment. The value of the parameter determining the magnitude of the potential variation in annual recruitment, σ_R (SigmaR) was initially set equal to 0.58. During the rebalancing of variances (Methot and Taylor, 2011) the model continued to suggest increasing the SigmaR value so it could have increased well above 0.7, which was set as an upper limit. This has the appearance of very high variation, which intuitively seems inconsistent with the long-term, inherently stable biology of orange roughy. However, the recruitment dynamics deriving from the model exhibit an unusual large rise implied for the years prior to exploitation. These large positive deviations arise as the model attempts to account for the extremely high catches taken across the early years 1989 - 1993. The recruitment deviates for more recent years cannot be estimated well because it can take decades for larval fish to grow and enter the fishery. Hence, it can take 30+ years before information about relative recruitment levels becomes available to the model.

Age 80 is treated as a plus group into which all animals predicted to survive to ages greater than 80 are accumulated. Growth of orange roughy was also assumed to be time-invariant, that is there has been no change over time in the expected mean size-at-age, with the distribution of size-at-age being determined from the prescribed values entered as fixed values into the model. The potential for age-reading errors (Punt *et al*., 2008) is accounted for within the model by the inclusion of an age-reading error matrix (Table 18.5).

18.3.6.2 Iterative reweighting of data variances

Iterative rescaling (reweighting) of input and output CVs or input and effective sample sizes is a repeatable method for ensuring that the expected variation of the different data streams is comparable to what is input. Most of the indices (CPUE, surveys, composition data) used in fisheries underestimate their true variance by only reporting measurement or estimation error and not including process error.

In iterative reweighting, the effective annual sample sizes are tuned/adjusted so that the input sample size was equal to the effective sample size calculated by the model. In SS3.3 there is an automatic adjustment made to survey CVs once the model has been set up appropriately.

1. set the standard error for the relative abundance indices (CPUE, acoustic abundance survey, or FIS) to their estimated standard errors for each survey (Table 18.6), or for CPUE and FIS values

to the standard deviation of a loess curve fitted to the original data (which will provide a more realistic estimate to that obtained from the original statistical analysis. SS3.3 then re-balances the relative abundance variances appropriately.

An automated tuning procedure was used for the remaining adjustments. For the recruitment bias adjustment ramps:

2. adjust the recruitment variance (σ_R) by replacing it with the RMSE or a defined set minimum (in this case 0.58) and iterating to convergence (keep altering the recruitment bias adjustment ramps as predicted by SS3.3 at the same time).

Finally for the age and length composition data:

3. multiply the initial samples sizes by the sample size multipliers for the age composition data using Francis weights (Francis 2011).
4. similarly multiply the initial samples sizes by the sample size multipliers for the length composition data
5. repeat steps 2 to 4, until all are converged and stable (proposed changes are < 1 – 2%).

This procedure may change in the future after further investigations but constitutes current best practice.

18.3.7 *The Development of the Base-Case Assessment*

Nine sequential changes were made to the 2014 assessment (Table 18.7). It was possible to closely match the original assessment spawning biomass time-series (Upton et al., 2015) using the SS3.24z version and there were only very minor differences to the outcome when the latest version of SS3 (SS3.3.0.5) was used (with any differences generally < 1% and visually unapparent).

Table 18.7. The 9 sequential changes made to the 2014 assessment model. The final base-case is named basecase17.

N	Name	Description
1	origbase	Repeat the assessment from 2014 using the original software version SS3.24z (Upston et al, 2015)
2	origbalance	Re-balance the variances of the survey indices and eh age composition data.
3	translated	Convert the control and data files to SS3.30.05 version
4	addcatches	Add the landings and discards for 2014 - 2016
5	addsurvey	Add the new 2016 towed body acoustic survey index and the revised index for 2013
6	addnewage	Include new age composition data for 2012 and 2016
7	ageingerror	Include a newly revised ageing error matrix
8	extendrec	estimate one more year of recruitment deviates (three more were initially attempted but the last two had highly uncertain estimates and were rejected).
9	basecase17	Re-balanced variances, with emphasis placed on Survey indices

18.4 Results

18.4.1 ***The Base-Case Analysis***

Stepping sequentially through the different scenarios leading from the 2014 assessment to the current 2017 base-case, the general result was that most scenarios, that had an observable influence on the outcome, led to improvements to the estimated spawning biomass depletion level, which has tracked from a maximum likelihood estimate of 0.235B_0 in 2014 to 0.34.3B_0 at the end of 2016. By conducting a variance rebalance at the beginning the effects of adding extra data could become more clear.

Table 18.8. The spawning biomass (B0), at the end of 2016 and the spawning biomass depletion along with the different likelihood components for the Surveys, the age composition, and the recruitment deviates, all obtained during the development of the 2017 variance balanced base-case assessment for Eastern Zone Orange roughy.

Scenario	SB2017	Depletion	Bzero	Total L	Index	Age Comp	Recruit
origbase	9275	0.235	39479	140.13	-8.946	135.472	12.401
origbalance	10953	0.263	41654	30.80	-8.605	35.079	4.073
translated	11654	0.280	41632	30.67	-8.606	34.977	4.048
addcatches	15413	0.360	42764	33.56	-7.160	38.095	2.422
addsurvey	15362	0.360	42699	32.25	-8.609	38.178	2.455
addnewage	14392	0.343	42020	42.80	-9.878	48.899	3.577
ageingerror	14590	0.347	42088	44.74	-9.764	50.829	3.473
extendrec	14555	0.346	42102	44.08	-9.755	50.243	3.389
basecase17	14352	0.343	41844	37.86	-10.456	44.337	3.963

The major improvement in the model fit came from the original rebalancing that greatly improved the fit (negative log-likelihoods getting smaller) to the age-composition data and the recruitment deviations, although losing a little of the fit to the survey data. Addition of new survey data and age composition data improved the fits to the surveys and reduced the contribution from the recruitment deviates while decreasing the fits to the age-composition data. However, the final rebalancing of the input variances to match the expected variances led to improvements in the fitting to all data streams although it led to a slight increase in the contribution from the recruitment deviates (Table 18.8).

Despite catches being relatively low recently (Table 18.4; Figure 18.2) the estimated spawning biomass trajectory suggests a gradual and on-going increase since a stock low point in 2002. The median maximum likelihood estimate of depletion of about 0.34B_0 is now 14% above the limit reference point of 0.2B_0 (Figure 18.6, Figure 18.7; Table 18.9).

The trajectory is essentially parallel to the trajectory obtained in 2014 (Upston et al, 2015), only slightly raised above the previous estimates.

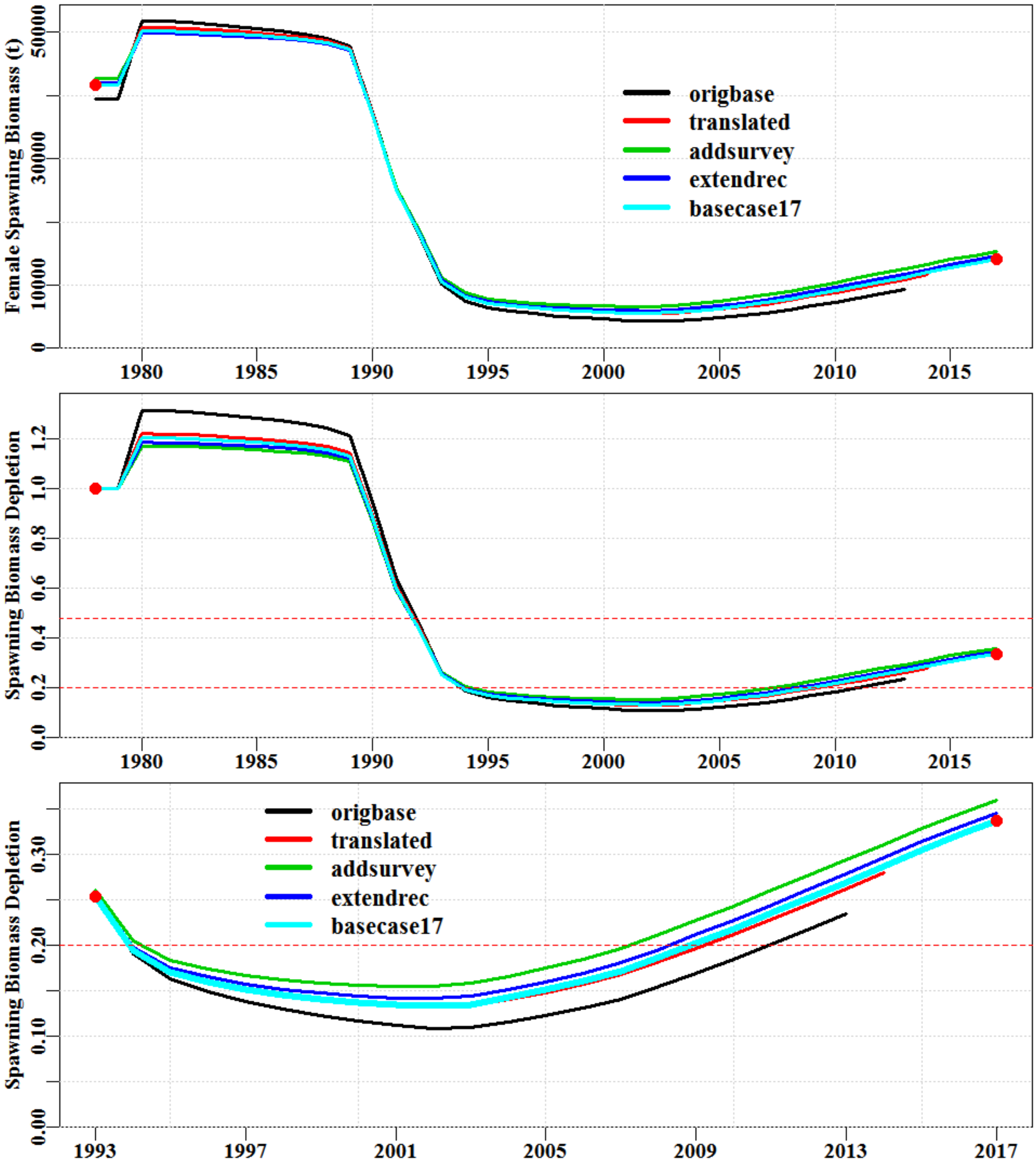


Figure 18.6. The predicted female spawning biomass and relative depletion level for the main scenarios describing the inclusion of different data and alternative assessment software. Some lines sit almost exactly on top of each other (for example the origbase24f and origbase24z), the thicker red line with the black dots is the balanced outcome from the base-case (see Table 18.7 for an explanation of each scenario). In terms of the different bridging analysis scenarios the *translated* curve is visually the same as the *origbalance*, *addsurvey* is visually equivalent to *addcatches*, and *extendrec* is approximately the same as both *ageingerror* and *addnewage*, so the equivalents are omitted from the plot for clarity.

Table 18.9. The predicted female spawning biomass from basecase17 each with its respective asymptotic standard deviation (units = tonnes), depletion level, and total catch for the year.

Year	SpawnB	StDev	Depl	Catch	Year	SpawnB	StDev	Depl	Catch
B0	41845	2102.03	1.000	0	1998	6016.96	908.29	0.144	2087
1980	50289	1851.33	1.202	0	1999	5846.78	938.73	0.140	2052
1981	50211	1749.53	1.200	0	2000	5719.85	975.30	0.137	2109
1982	5008	1650.42	1.197	0	2001	5643.6	1018.19	0.135	2027
1983	49905	1554.84	1.193	0	2002	5665.0	1068.32	0.135	1674
1984	49679	1463.64	1.187	0	2003	5859.5	1127.38	0.140	877
1985	49404	1377.64	1.181	6	2004	6190.6	1194.82	0.148	797
1986	49075	1297.54	1.173	60	2005	6572.8	1267.76	0.157	772
1987	48650	1223.83	1.163	310	2006	7013.0	1345.02	0.168	615
1988	47860	1155.47	1.144	1949	2007	7557.8	1425.90	0.181	129
1989	41850	1069.56	1.000	28575	2008	8192.6	1508.28	0.196	98
1990	30474	979.71	0.728	34502	2009	8852.1	1589.23	0.212	193
1991	21437	913.11	0.512	20436	2010	9536.1	1667.34	0.228	113
1992	13888	899.63	0.332	24265	2011	10243.9	1741.34	0.245	162
1993	9305	855.92	0.222	8798	2012	10959.7	1810.00	0.262	163
1994	7659	846.86	0.183	4140	2013	11682.9	1872.73	0.279	150
1995	6957	851.99	0.166	2544	2014	12421.9	1929.48	0.297	7.3
1996	6565	865.13	0.157	2231	2015	13115.6	1978.67	0.313	460.4
1997	6258	883.99	0.150	2250	2016	13749.2	2020.40	0.329	360

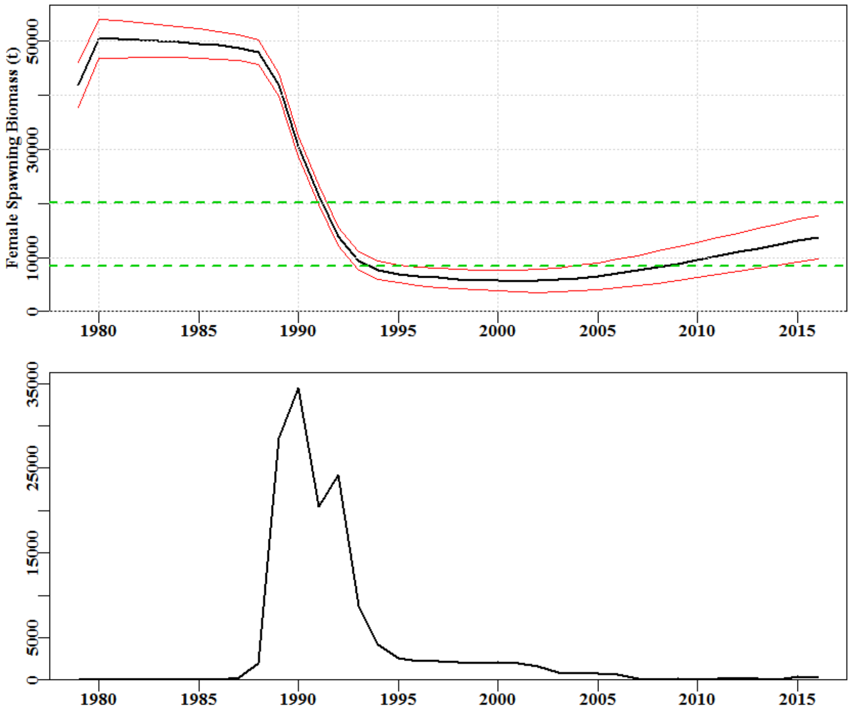


Figure 18.7. The predicted female spawning biomass (top plot) with its 95%CI based on asymptotic standard errors, compared with the limit and target biomass reference points for Eastern zone orange roughy. The equivalent plot for spawning biomass depletion is illustrated in Figure 18.8. The bottom plot compares the biomass trajectory with the catch removals through time.

The length based selectivity was estimated as being about 35.5cm (Table 18.10; Figure 18.8), which, given the relatively slow growth above 30 cm, implies a wide spread of ages from 31 (just) up to the maximum age are selected (Figure 18.8).

Depletion in 2016 is predicted to have been about 0.329*B₀* (Table 18.9; Figure 18.8; predicted to be 0.34*B₀* in 2017)

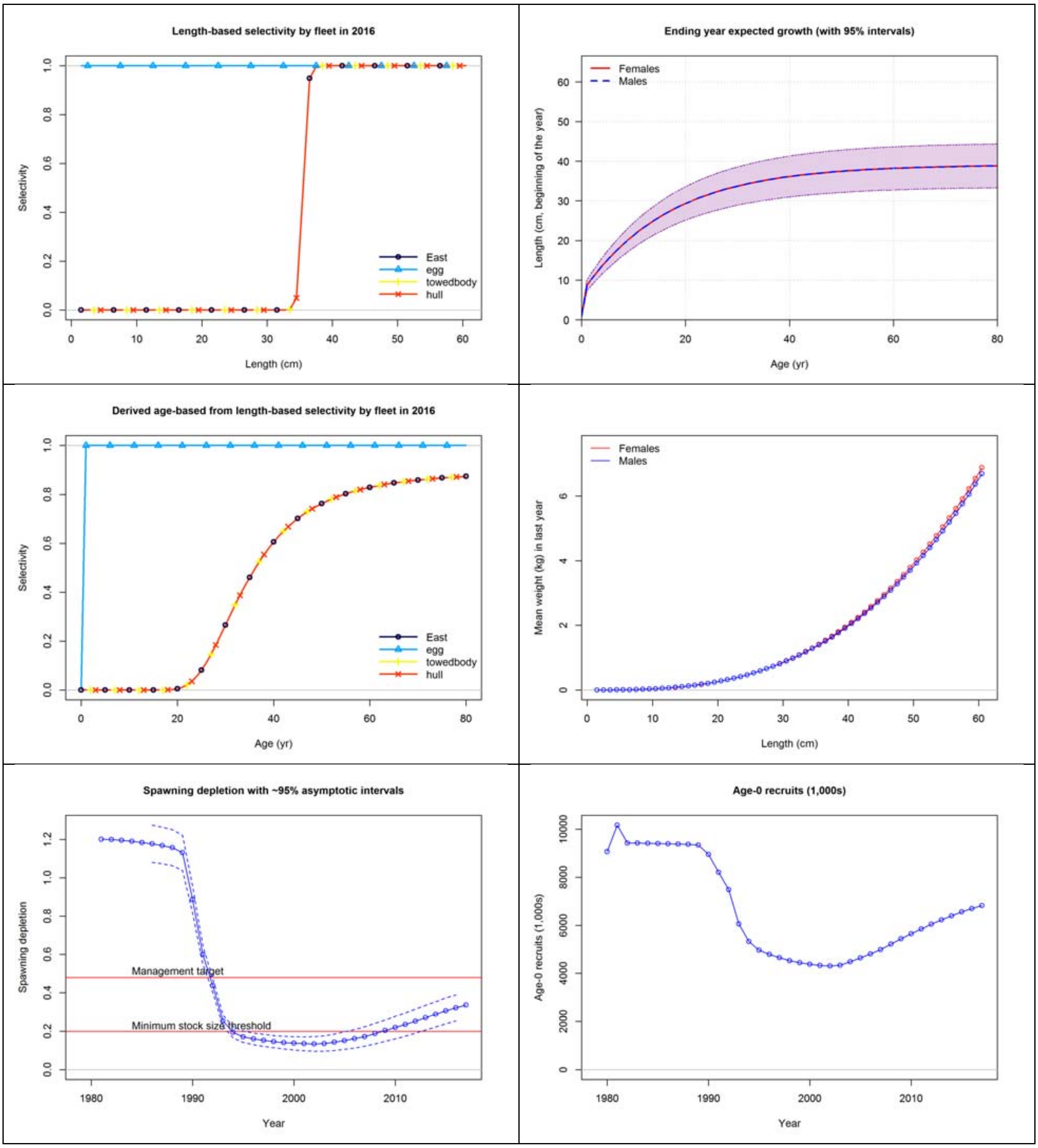


Figure 18.8. The selectivity curves for the trawl fishery and related age-composition data and that assumed for the acoustic surveys, and the predicted expected growth curves for females and males. The predicted mean weight at length, and derived age-based, length-based selectivity, the predicted depletion level of the balanced model with the 95% asymptotic confidence intervals, and the Age-0 recruit levels, again with the 95% asymptotic confidence intervals.

18.4.2 *Recruitment deviates*

Table 18.10. Estimates for parameters other than recruitment deviates. St. Dev is the approximate standard deviation for each estimate.

Parameter/Feature	Value	St. Dev.	C.V.	Comment
Unexploited recruitment; log(R0)	9.0834	0.0502	0.0055	
Recruitment deviations 1905-1981*	Figure 18.9			
Selectivity logistic inflection	35.4932	0.3426	0.0096	
Selectivity logistic width	1.0022	0.0736	0.0734	
q Acoustic towed catchability	1.0276			
q Hull mounted catchability	1.6955			

As suggested by the decrease in the predicted rise above the unfished biomass (B_0) just prior to fishing relative to that predicted in the previous assessment (Figure 18.6), the recruitment residuals in basecase17 are less variable above and below the average expected from the Beverton-Holt relationship than that exhibited in origbase. The original ‘extendrec’ scenario within the bridging analysis extended the recruitment deviates by three years (Figure 18.9) but this was reduced to one year because the uncertainty around the two years that were eventually excluded was so great that they breached the standard error estimates. The final extra year retained only just stayed under the upper limit of SigmaR = 0.7 (Figure 18.10).

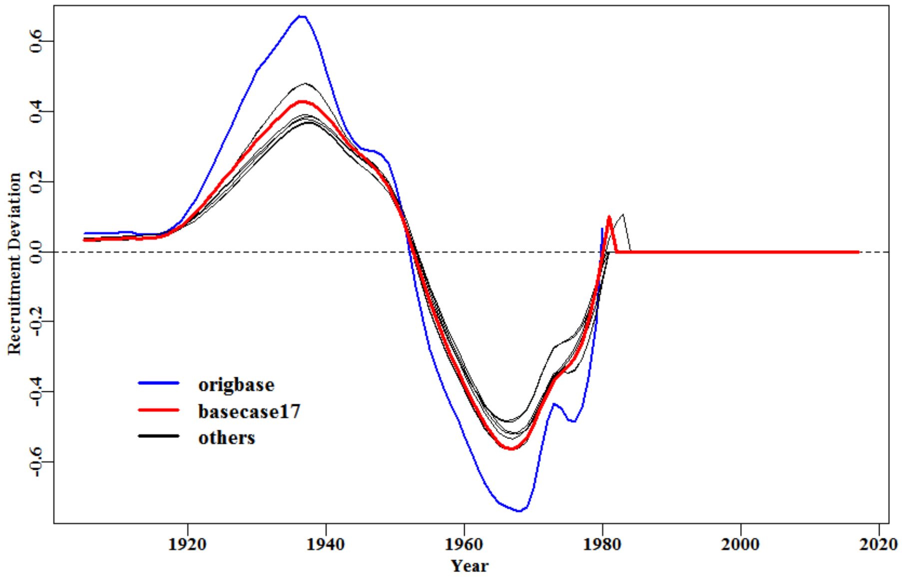


Figure 18.9. The predicted recruitment deviates for each of the bridging analyses. Only the previous assessment (origbase) and the latest basecase (basecase17) are identified clearly to contrast their patterns.

The depletion of the stock through the history of the fishery has provided the contrast required to generate an acceptable estimate of the Beverton-Holt stock recruitment relationship. However, the unexpected period of positive recruitment residuals prior to the advent of fishing remains, even if it is now lower than in previous assessments (Figure 18.10). The final year of assessed recruitment residuals is currently just above the average expected form the Beverton-Holt relationship given the current state of depletion. This is the first positive deviation in 28 years (Figure 18.10).

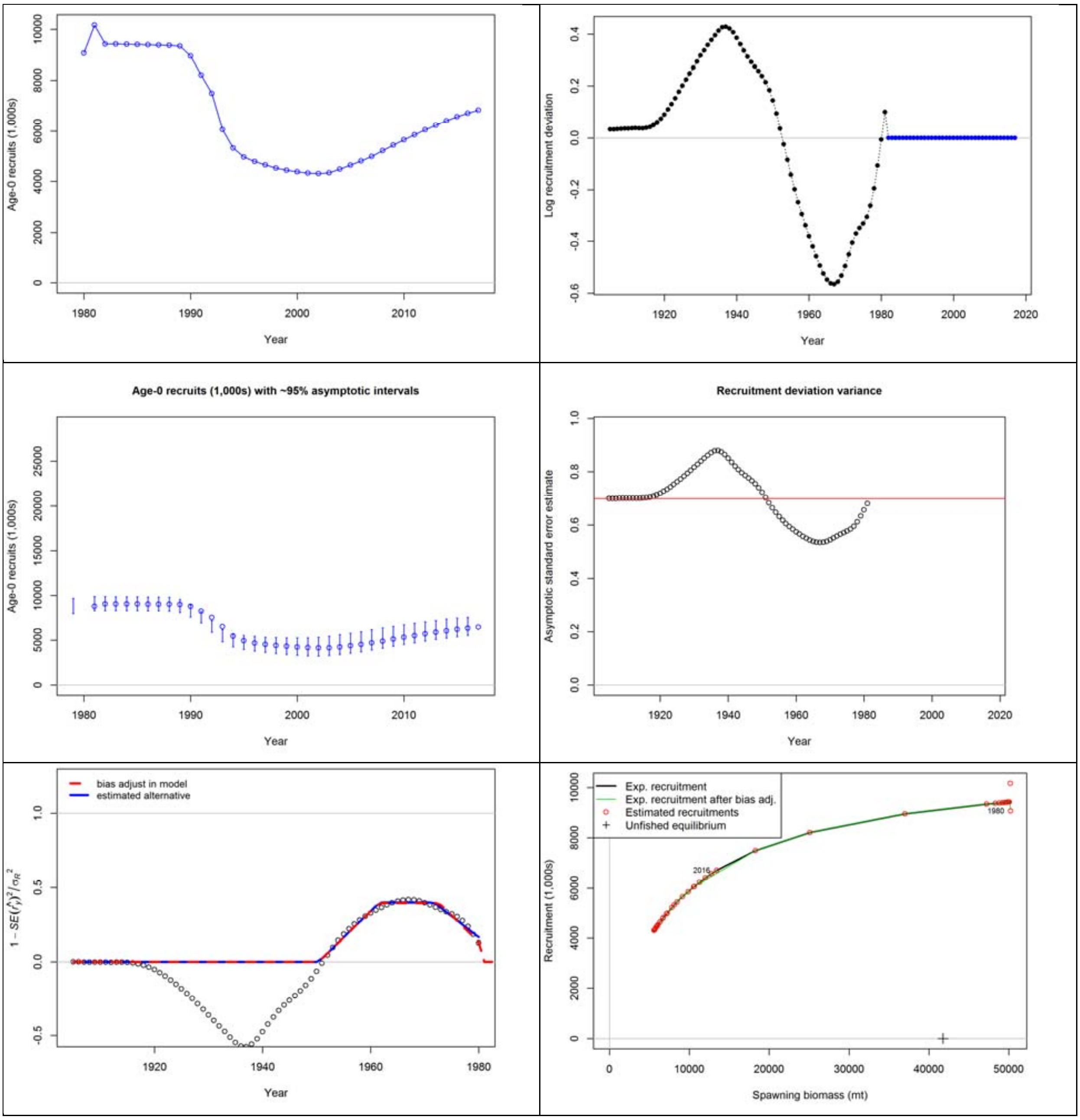


Figure 18.10. Estimation of recruitment and recruitment deviates for the base-case assessment with time trajectories given in both nominal and log-space. The final recruitment deviates from 1982 – 2016 are not estimated but are set at the mean expected recruitment from the Beverton-Holt stock recruitment curve. The asymptotic standard errors of the recruitment deviates (middle left) are exaggerated in 1980 and 1981 to indicate that all estimated deviates have sufficient data to allow for an adequate estimate. The bias-adjustment graph illustrates the degree to which the estimates of recruitment deviates require correction for their level of variation (Methot and Taylor, 2011). The implied stock recruitment curve (bottom right) illustrates that the stock depletion level has not been sufficient to alter the average recruitment levels significantly.

18.4.3 ***Model Fits to the Data***

18.4.3.1 Acoustic survey data

The fit to the hull mounted transducer estimates are as good as might be expected from only three mean observations from relatively early in the fishery during the peak of the catches (Figure 18.2).

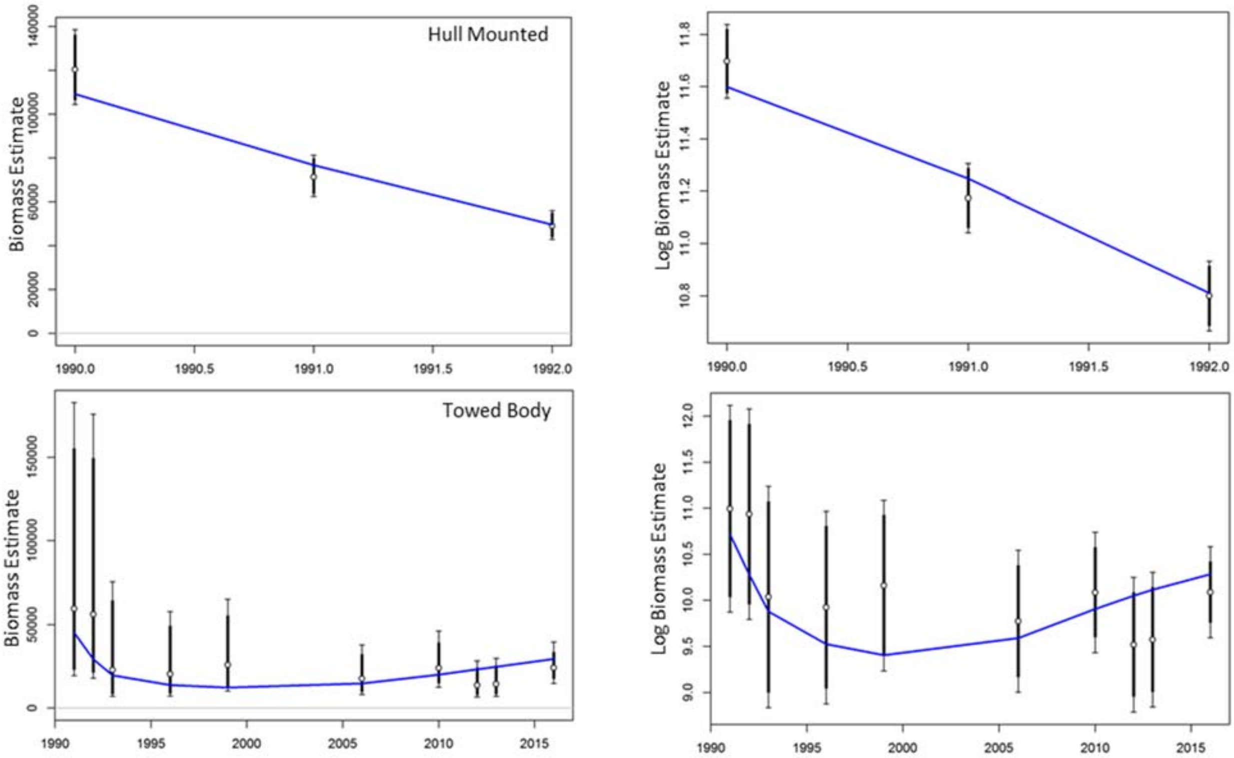


Figure 18.11. The balanced model fit to the hull mounted acoustic survey indices (top panels) and the towed body acoustic surveys (bottom panels), each acts as an index of relative abundance. The plots on the right are of the natural Log Indices because log-normal residual errors were used to fit the model to the abundance index data. The thicker lines are the input variances and the thinner lines with the caps denote the additional variance required to optimize the model fit to the index data.

18.4.3.2 Daily egg production estimate

The so-called 'egg survey' refers to estimate of absolute female spawning biomass made at the St Helens Hill in 1992, calculated using standard daily egg production methods (Koslow et al. 1995). Selectivity for the egg survey was set so that the expected survey abundance was equal to female spawning biomass. The original biomass estimates (Koslow et al 1995) were increased from 13,785 t to 15,922 t following a recommendation from Deriso and Hilborn (1994; referred to in Upston et al, 2015). Other details of the recent treatment of the absolute female spawning biomass estimate are provided in Upston et al (2014).

18.4.3.3 Age composition data

The fit to the age-composition data is reasonable for most years except 1992 and males 2016. In 1992 there is an obvious trend in the residuals with too many predicted to occur at < 40 years of age and too few above 40 years of age. With the males in 2016 there are too few younger fish are predicted and too many older fish. The spikiness of the observed data reflects the fact that there are very many age classes and even though in all cases hundreds of fish were aged, in all cases these were too few to generate a smooth set of observed of different age classes (Figure 18.12). It is not known whether the males age composition in 2016 is a result of non-representative sampling or whether there really is an influx of relatively young new recruits. Only further samples and stock assessments into the future will determine whether the spike of younger males in 2016 will propagate forwards into the future age compositions.

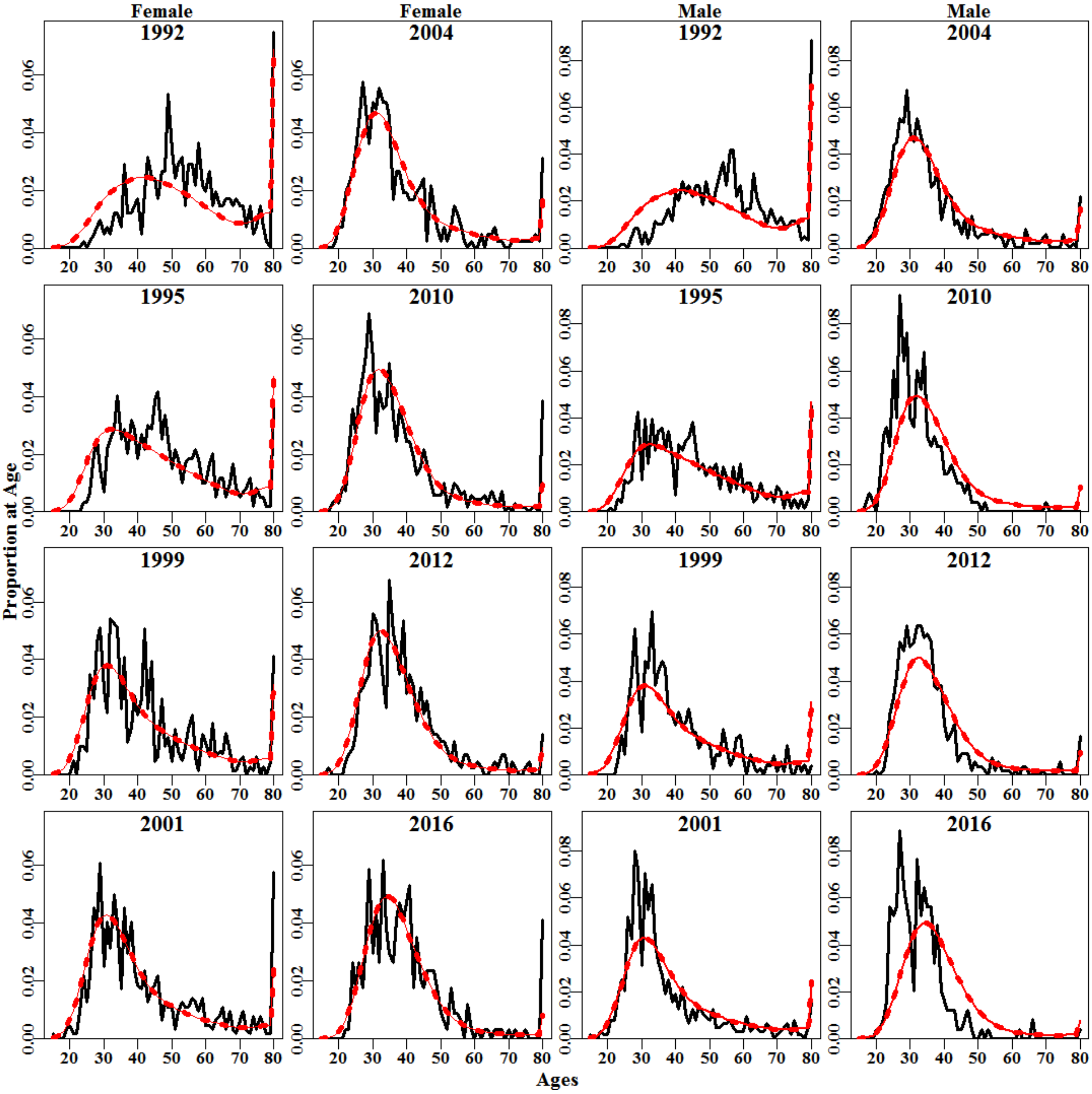


Figure 18.12. The proportional age-composition of the samples from each year (black lines) compared with the fitted age-composition (red lines). The y-axis is on the same scale for each sex.

18.4.3.4 Fishing mortality

An equilibrium analysis of the fishery dynamics as described by the parameter estimates obtained in basecase17 suggests that the Maximum Sustainable Yield (MSY) would be approximately 1700 t, which would be achieved when the stock was close to 29%B_0 and fishing mortality was set at F_{MSY} = 0.02 (Figure 18.13). At the period of peak catches, fishing mortality was somewhat more than 40 times this level. With orange roughy there is only a single fleet, a single gear, and single stock so it would be possible to report fishing mortality directly, which would allow the determination of whether over-fishing were occurring. However, for many fisheries there are multiple fishing gears each with different selectivity making it impossible to generate a composite fishing mortality rate. An alternative would be to use the spawning potential ratio (SPR) or more appropriately 1 – SPR (so that a large value implied a large fishing mortality and vice versa). While the relationship of instantaneous fishing mortality to 1-SPR is not linear it is approximately so across the range of fishing mortality where surplus production is positive (Figure 18.13).

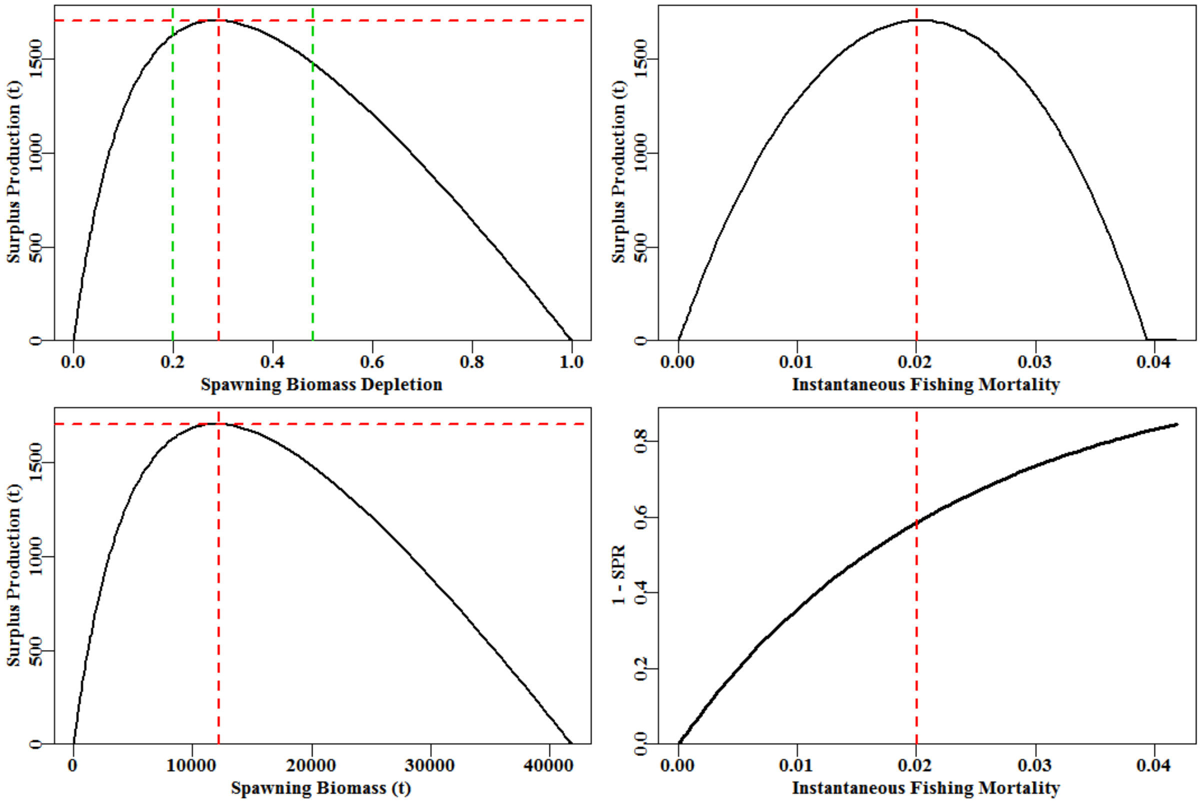


Figure 18.13. The equilibrium surplus production dynamics illustrating the *MSY*, the depletion at *MSY*, B_{MSY}, and F_{MSY}. In the top plot the green lines denote the 0.2B_0 and 0.48B_0 limit and target biomass reference point proxies for orange roughy in the Commonwealth. The red lines denote the MSY and related statistics. The equilibrium estimates for these statistics are MSY = 1707 t, the MEY = 1482 t, depletion at MSY = 0.291B_0, B_{MSY} = 12193 t, and F_{MSY} = 0.02.

Using the relationship between *F* and 1-SPR it is possible to plot an approximation to the classical Kobe phase plot with B_{year}/B_{target} on the x-axis and (1-SPR)/(1-$SPR_{48\%}$) on the y-axis (as a proxy for fishing mortality relative to the target fishing mortality; Figure 18.14).

Such a phase plot (Figure 18.14) suggests that the stock is still below the target (although above the limit) biomass reference point and so is not over-fished. At the same time it is below the $(1\text{-SPR}_{48\%})$ target and so can be claimed that over-fishing is not occurring.

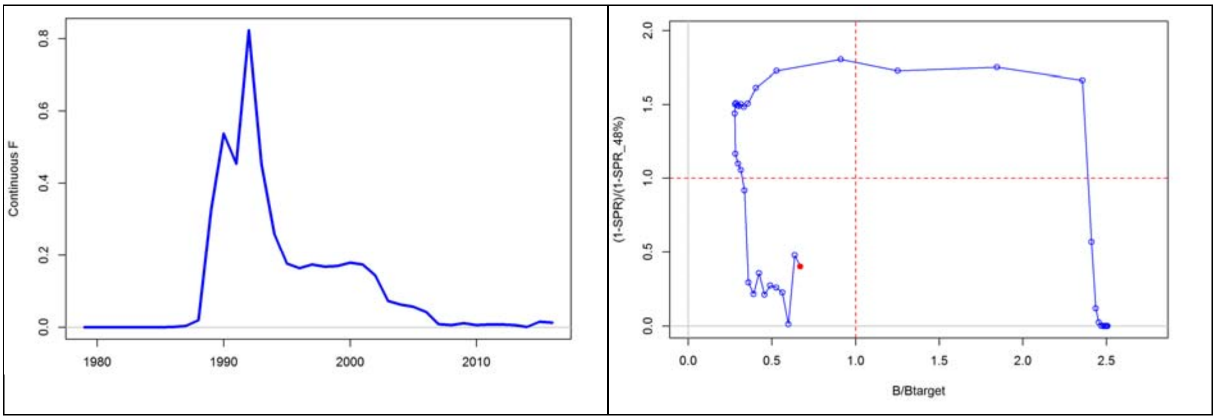


Figure 18.14. Plots of the instantaneous fishing mortality rate and the Spawning Potential Ratio as the complement of the SPR as a ratio with the expected (1-SPR) at a depletion of $0.48B_0$, which acts as a proxy for fishing mortality.

18.5 Discussion

It was possible to extend the integrated stock assessment for Eastern zone orange roughy implemented using the software Stock Synthesis (Methot and Wetzel, 2013) conducted in 2014 to generate a new base case for the stock in 2017. In the previous assessment multiple stock structure hypotheses were examined but here only the single assumption is made of a stock encompassing the Eastern zone (Orange Roughy zone 10) and the Eastern side of the Southern zone (Orange Roughy zone 21; Pedra Branca). This reflects the previous three year TAC set for this management unit/stock.

The stock has continued to rebuild along a trajectory very similar to that predicted in the 2014 stock assessment (Upston et al, 2015). This entailed the inclusion of catches from 2014 – 2016, new age composition data from 2012 and 2016, a revised estimate of the 2013 towed-body acoustic biomass survey from 2013, and a new acoustic biomass survey estimate from 2016.

The stock is predicted to have reached a depletion level of about $33\%B_0$ in 2016, with the expected depletion in 2017 at about $34.3\%B_0$. Catches and implied fishing mortality rates remain low enough that stock rebuilding is continuing relatively rapidly. The changes in the depletion level have been brought about by a combination of both a revised variance rebalancing process and the increase in the 2013 acoustic survey estimate, which kept much of the estimated improvement in the depletion level after the second variance rebalancing in the final basecase17 step of the bridging analysis.

18.6 Acknowledgements

Thanks to the members of the SE resource assessment group. Thanks also to the providers of data for this work: Robin Thomson for the landings and discard data, André Punt for processing the ageing error calculations; Kyne Krusic-Golub (Fish Ageing Services Pty Ltd) for the provision of ageing data. Thanks also to other members of CSIRO SESSF Assessment team for their helpful discussion during the assessment process during the year. Dr Fay Helidoniotis of ABARES is thanked for discussions regarding the determination of over-fishing status.

18.7 References

AFMA (2014) *Orange Roughy (Hoplostethus atlanticus) Stock Rebuilding Strategy 2014.* Australian Fisheries Management Authority, Canberra, 20 p.

AFMA (2017) *Southern and Eastern Scalefish and Shark Fishery Management Arrangements Booklet 2017.* Australian Fisheries Management Authority, Canberra, 92 p.

Annala, J.H. (Comp.) (1994) Report from the Special Fishery Assessment Plenary, 27 May 1994: stock assessments and yield estimates for ORH 2A, 2B, and 3A. (Cited in CSIRO and TDPIF, 1996) 17 p.

Anon (1995) Trial studies of alternate techniques for stock delineation of orange roughy. FRRF Project 1992/93 no. 18. Final report to AFMA. (Cited in Smith et al., 1998).

Bax, N. (1997). Stock Assessment Report 1997: Orange roughy. Report for the South East Fishery Stock Assessment Group. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 64 p. (Unpublished report held by CSIRO, Hobart).

Bax, N. (2000). Stock Assessment Report 2000: Orange roughy. Report for the South East Fishery Stock Assessment Group. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 81 p. (Unpublished report held by CSIRO, Hobart).

Bax, N. (2000a). Stock Assessment Report: Orange roughy 1995, Stock Assessment Report, South East Fishery Stock Assessment Group, Australian Fisheries Management Authority, Canberra, 55 p. (Unpublished report held by AFMA, Canberra).

Bax, N. (2000b). Stock Assessment Report: Orange roughy 1996, Stock Assessment Report, South East Fishery Stock Assessment Group, Australian Fisheries Management Authority, Canberra, 37 p. (Unpublished report held by AFMA, Canberra)

Bell, J.D., Lyle, J.M., Bulman, C.M., Graham, K.J., Newton, G.M. and Smith, D.C. (1992) Spatial variation in reproduction, and occurrence of non-reproductive adults, in orange roughy, *Hoplostethus atlanticus* Collett (Trachichthyidae), from south-eastern Australia. Journal of Fish Biology 40: 107-122.

Clarke, M.R. and M.R. Dunn (2012) Spatial management of deep-sea seamount fisheries: balancing sustainable exploitation and habitat conservation. *Environmental Conservation* **39**: 204 – 214

CSIRO and TDPIF (1996). Orange roughy 1994, Stock Assessment Report, South East Fishery Assessment Group. Australian Fisheries Management Authority, 204 p. (Unpublished report held by AFMA, Canberra).

Cordue, P.L. (2011) Review of the 2011 Orange roughy Eastern Zone Stock Assessment. ISL Client Report for South East Trawl Fishing Industry Association. 1 September 2011. 10p.

Cordue, P.L. (2014) The 2014 orange roughy stock assessments. New Zealand Fisheries Assessment Report 2014/50. September 2014. Ministry for Primary Industries, Wellington, New Zealand. 137 p.

DAFF (2007) Commonwealth Fisheries Harvest Strategy. Policy and Guidelines. Department of Agriculture, Fisheries and Forestry. 55p.

Deriso, R. and Hilborn, R. (1994). A Review of the 1994 Stock Assessment for Orange roughy. Review completed for the Australian Fisheries Management Authority, 28 p. (Unpublished report held by AFMA, Canberra).

Diver, G. (2004). Data Collection for the Eastern Zone Orange roughy Survey, July 2004. Report completed by Diversity – Sustainable Development Consultants, W.A. 23 p. (Unpublished report held by CSIRO, Hobart).

Dunn, M.R. and Devine, J.A. (2010) An holistic approach to determining stock structure of orange roughy on the Chatham Rise. New Zealand Fisheries Assessment Report 2010/17, 65 p.

Francis, R.I.C.C. (1992) Recommendations concerning the calculation of maximum constant yield (MCY) and current annual yield (CAY). New Zealand Fisheries Assessment Research Document 92/8, 27 p.

Francis, R.I.C.C. (2006) Some recent problems in New Zealand orange roughy assessments. New Zealand Fisheries Assessment Report 2006/43. 65 p.

Francis, C. and Hilborn, R. (2002). A Review of the 2002 Orange roughy Stock. Review completed for the Australian Fisheries Management Authority, 14 p. (Unpublished report held by AFMA, Canberra).

Francis, C. (2011) Data weighting in statistical fisheries stock assessment models. Canadian Journal of Fisheries and Aquatic Science **68**: 1124-1138.

Gelman, A., Carlin, J.B., Stern, H.S. and Rubin, D.B. (2003) Bayesian Data Analysis. 2nd Edition. Chapman & Hall/CRC Press, Florida. 668 p.

Kimura, D., Balsiger, J. and Ito, D. (1984) Generalized stock reduction analysis. *Canadian Journal of Fisheries and Aquatic Sciences* **41**: 1325–1333.

Kloser, R. J., T. E. Ryan, et al. (2001). Development and application of a combined industry/scientific acoustic survey of orange roughy in the eastern zone. Final report to Fisheries Research and Development Corporation 99/111. Available from Fisheries Research and Development Corporation, P.O. Box 222, Deakin West, ACT 2600, Australia.

Kloser & Ryan (2002) *Review of Analysis methodologies and data holdings for acoustic assessments of orange roughy on St Helens Hill, 1989 - 1999.* CSIRO Marine Research 40p

Kloser, R., Ryan, T. and Daley, R. (2008) *2006 Eastern Zone orange roughy acoustic survey.* Report to the South East Trawl Fishery Association, CSIRO Marine and Atmospheric Research, Hobart, 92 p.

Kloser, R.J., Knuckey, I.A., Ryan, T.E., Pitman, L.R. and Sutton, C. (2011) *Orange roughy conservation program: Eastern Zone surveys and trials of a cost-effective acoustic headline system.* Final report to the South East Trawl Fishing Industry Association, CSIRO Marine and Atmospheric Research, Hobart, 153 p.

Kloser, R., Sutton, C. and Krusic-Golub, K. (2012) *Australian spawning population of orange roughy: Eastern zone acoustic and biological index fished from 1987 to 2010.* Report to the South East Trawl Fishing Industry Association, CSIRO Marine and Atmospheric Research, Hobart, 64 p.

Kloser, R.J., Macaulay, G., Ryan, T.E. and M. Lewis (2013) Identification and target strength of orange roughy (*Hoplostethus atlanticus*) measured in situ. *Journal of the Acoustical Society of America* **134**: 97 – 108

Kloser, R.J., Sutton, C., Krusic-Golub, K., and T.E. Ryan (2015) Indicators of recovery for orange roughy (*Hoplostethus atlanticus*) in eastern Australian waters fished from 1987. *Fisheries Research* **167**: 225 – 235

Kloser, R., Sutton, C., Kunnath, H. and R. Downie (2016) *Orange roughy eastern zone spawning biomass 2016.* [Draft] Report for South East Trawl Industry Association. CSIRO Oceans and Atmosphere, Hobart. 34 p.

Koslow, J.A., Bulman, C.M., Lyle, J.M. and Haskard, K. (1995) Biomass Assessment of a Deep-water Fish, the Orange roughy (*Hoplostethus atlanticus*), based on an Egg Survey. Mar. Freshwater Res., 46: 819-830.

Lyle, J.M., Evans, K. & Wilson, M.A. (1989) A summary of orange roughy biological information 1981 – 1986. Technical report 39, Department of Sea Fisheries Tasmania (Cited in Prince & Hordyk, 2011).

Lyle, J.M., Kitchener, J. & Riley, S.P. (1991) An assessment of orange roughy resource off the coast of Tasmania. Final report to FIRDC, Project 87/65.

McAllister, M.K. and J.N. Ianelli. (1997). Bayesian stock assessment using catch-at-age data and the sampling-importance-resampling algorithm. *Canadian Journal of Fisheries and Aquatic Sciences* 54: 284-300.

Methot, R.S., A'mar, T., Wetzel, C. and I. Taylor (2017) Stock Synthesis User Manual Version 3.30.05. NOAA Fisheries, Seattle, WA, USA. 178p.

Methot, R.D. and I.G. Taylor (2011) Adjusting for bias due to variability of estimated recruitments in fishery assessment models. *Canadian Journal of Fisheries and Aquatic Sciences* **68**:1744-1760.

Methot, R.D. and C.R. Wetzel (2013) Stock Synthesis: a biological and statistical framework for fish stock assessment and fishery management. Fisheries Research 142, 86-99.

MFSWG (2009) Report from the Fisheries Assessment Plenary, May 2009: stock assessments and yield estimate, Orange roughy, Ministry of Fisheries Science Working Group: 474-479.

Norse, E.A., Brooke, S., Cheung, W.W.L., Clark, M.R., Ekeland, I., Froese, R., Gjerde, K.M., Haedrich, R.L., Heppell, S.S., Morato, T., Morgan, L.E., Pauly, D., Sumaila, R. and R. Watson (2012) Sustainability of deep-sea fisheries. *Marine Policy* **36**: 307 – 320

Pitman, L.R., Haddy, J.A. and R.J. Kloser (2013) Fishing and fecundity: The impact of exploitation on the reproductive potential of a deep-water fish, orange roughy (*Hoplostethus atlanticus*) *Fisheries Research* **147**: 312 – 319

Pitman, L.R., Haddy, J.A. and R.J. Kloser (2014) Response to comment on "fishing and fecundity: The impact of exploitation on the reproductive potential of a deep-water fish, orange roughy (*Hoplostethus atlanticus*)" *Fisheries Research* **155**: 196 – 197

Prince, J. and Hordyk, A. (2011 Draft) Observation of the 2009 Cascade Roughy Spawning Season and drafting of a DeepRAG synthesis paper on orange roughy stock structure in the southern Australia. AFMA Project No. 2009/808, 23 p.

Punt, A.E. (2014) User manual: Age-reading error matrix estimator (AGEMAT). School of Aquatic and Fishery Sciences, University of Washington, USA. 9 p.

Ryan, T. E., Sutton, C. and R. Kloser (2013) *Biomass estimates of orange roughy at the Tasmanian Eastern Zone spawning grounds in July 2012 using a net attached acoustic optical system.* Report to South East Trawl Fishing Industry Association. CSIRO Marine and Atmospheric Research Laboratories, Hobart, Australia: 40 p.

Ryan, T. E., Sutton, C. and R. Kloser (2014) *Biomass estimates of orange roughy at the Tasmanian Eastern Zone spawning grounds in July 2013 using a net attached acoustic optical system.* Report to South East Trawl Fishing Industry Association. CSIRO Marine and Atmospheric Research Laboratories, Hobart, Australia. 41p.

Smith, D.C., Fenton, G.E., Robertson, S.G. and Short, S.A. (1995) Age determination and growth of orange roughy (Hoplostethus atlanticus): a comparison of annulus counts with radiometric ageing. *Canadian Journal of Fisheries and Aquatic Sciences* **52**: 391-401.

Smith, D.C., Robertson, S.G. and Morrison, A.K. (1998) Age composition of orange roughy in the Eastern and Southern Management Zones. Report to Fisheries Research & Development Corporation, Project No. 95/032. Marine and Freshwater Resources Institute, Victoria, Australia. 40 p.

Smith, A.D.M, Punt, A.E., Wayte, S.E., Starr, P.J., Francis, R.I.C.C., Stokes, T.K., Hilborn, R., Langley, A. (2001) Stock assessment for the northeast Chatham Rise orange roughy for 2001. *New Zealand Fisheries Assessment Report 2002/25*. 30 p.

Stokes, K. (2009). Orange roughy Assessment Review. Report completed for the Australian Fisheries Management Authority, 33 p. (Unpublished report held by AFMA, Canberra).

Taylor, I., Stewart, I., Hicks, A., Garrison, T., Punt, A., Wallace, J., Wetzel, C., Thorson, J., Takeuchi, Y., Ono, K., Monnahan, C., Stawitz, C.C., A'mar, Z.T., Whitten, A.R., Johnson, K.F., Emmet, R.L., Anderson, S.C., Lambert, G.I., Stachura, M.M., Cooper, A.B., Stephens, A. and Neil Klaer. (2017) *R code for Stock Synthesis (r4ss)*. NOAA Fisheries, Northwest Fisheries Science Centre, Seattle, WA.

Tracey, D., Horn, P., Marriott, P., Krusic-Golub, K., Green, C., Gili, R., Mieres, L.C. (2007) Orange roughy ageing workshop, otolith preparation and interpretation. Report to the Deepwater Fisheries Assessment Group. Report contributors: NIWA, Wellington (New Zealand), DPI, Victoria (Australia), and CEPES, Valparaíso (Chile) 26 p.

Upston, J. and S. Wayte (2012) Orange roughy (*Hoplostethus atlanticus*) Eastern Zone preliminary stock assessment incorporating data up to 2010 – definition of the base-case model. pp 180 – 217 *in* Tuck, G.N. (*ed*) (2012) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2011. Part 1.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 377p.

Upston, J. and S. Wayte (2012b) Orange roughy (*Hoplostethus atlanticus*) Eastern Zone preliminary stock assessment incorporating data up to 2010 – future work. pp 218 – 225 *in* Tuck, G.N. (*ed*) (2012) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2011. Part 1.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 377p.

Upston, J., Punt, A.E., Wayte, S., Ryan, T., Day, J. and M. Sporcic (2015) Orange roughy (*Hoplostethus atlanticus*) Eastern Zone stock assessment incorporating data up to 2014. pp 10 – 81 *in* Tuck, G.N. (*ed*) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2014. Part 1.* Australian Fisheries Management Authority and CSIRO Oceans and Atmosphere Flagship, Hobart. 170p.

Wayte, S. and Bax, N. (2002) Orange roughy Stock Assessment pp 167 – 208 *in* Smith, A.D.M. and S. Wayte (*eds*) (2002) *The South East Fishery 2002*, Fishery Assessment Report compiled by the South East Fishery Assessment Group. Australian Fisheries Management Authority, Canberra.

Wayte, S.E. (2002). Southern Zone Orange roughy Stock Assessment. Report to Orange roughy Stock Assessment Group. Australian Fisheries Management Authority, Canberra.5 p. (Unpublished report held by CSIRO, Hobart).

Wayte, (2006) Stock assessment of the Cascade Plateau orange roughy (*Hoplostethus atlanticus*). pp 148 – 172. *in* Tuck, G.N. (*ed*) (2006) *Stock assessment for the South East Scalefish and Shark Fishery 2004-2005.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 222 p.

Wayte, (2006b) Analysis of Orange roughy (Hoplostethus atlanticus) Catch Data from the Southern Zone. pp 173 – 179. *in* Tuck, G.N. (*ed*) (2006) *Stock assessment for the South East Scalefish and Shark Fishery 2004-2005.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 222 p.

Wayte, (2006c) Analysis of Orange roughy (Hoplostethus atlanticus) Catch Data from the Western Zone. pp 180 – 186. *in* Tuck, G.N. (*ed*) (2006) *Stock assessment for the South East Scalefish and Shark Fishery 2004-2005.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 222 p.

Wayte, (2006d) Stock assessment of the Cascade Plateau orange roughy (*Hoplostethus atlanticus*). pp 206 – 228. *in* Tuck, G.N. (*ed*) (2006) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2005-2006.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 292 p.

Wayte, (2006e) SESSF harvest strategy framework applied to deepwater species. pp 229 – 246. *in* Tuck, G.N. (*ed*) (2006) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2005-2006.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 292 p.

Wayte, S. (2007) Eastern Zone Orange roughy. pp 429 – 447 *in* Tuck, G.N. (*ed*) (2007) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2006-2007. Volume 1: 2006.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 570 p.

Wayte, S. and N. Bax (2007) Stock Assessment of the Cascade Plateau Orange roughy 2006. pp 411 – 428 *in* Tuck, G.N. (*ed*) (2007) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2006-2007. Volume 1: 2006.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 570 p.

18.8 Appendix A

Table 18.11. The observed age frequency in samples of Eastern zone Orange roughy. 'F' is female and 'M' is male. There were no observations of fish younger than 8 years old.

	F	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**
N	**411**	**595**	**282**	**637**	**414**	**696**	**426**	**338**	**596**	**726**	**298**	**634**	**503**	**248**	**545**	**247**
Age	**1992**	**1995**	**1999**	**2001**	**2004**	**2010**	**2012**	**2016**	**1992**	**1995**	**1999**	**2001**	**2004**	**2010**	**2012**	**2016**
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
13	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
14	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0
17	0	0	0	0	0	2	0	0	0	0	0	2	2	2	0	0
18	0	0	0	2	1	3	0	0	0	0	0	1	3	1	0	0
19	0	0	0	3	3	2	0	0	0	0	0	1	6	0	1	1
20	0	0	1	1	3	6	0	0	0	1	0	5	7	3	0	1
21	0	0	0	1	8	5	2	1	0	0	0	5	11	8	1	2
22	0	0	3	6	9	14	3	1	0	4	2	11	13	9	5	4
23	1	2	3	14	11	25	4	9	1	3	5	16	14	7	14	14
24	0	2	2	8	14	19	6	6	1	10	3	13	22	15	18	13
25	1	4	10	14	18	27	12	9	0	9	8	33	23	10	23	14
26	2	12	7	29	24	33	13	6	3	10	13	27	28	23	31	22
27	3	15	13	26	20	38	14	12	5	24	19	51	27	16	29	16
28	4	9	14	39	15	48	15	20	5	31	12	46	34	19	35	14
29	2	4	8	16	21	37	24	10	1	10	6	20	25	10	30	12
30	3	13	6	26	20	19	23	15	4	29	14	45	23	9	31	5
31	2	15	15	20	23	29	20	9	1	15	14	35	28	15	35	19
32	5	17	15	32	21	25	14	21	3	29	21	42	24	13	35	13
33	5	24	14	26	21	26	10	13	7	19	11	26	21	17	32	16
34	3	15	6	11	19	36	29	10	6	25	13	21	22	8	33	14
35	12	17	12	29	7	23	21	9	6	26	14	17	13	7	31	14
36	5	12	3	19	11	17	19	14	8	19	14	12	14	8	21	8
37	5	19	5	26	11	25	15	16	10	25	8	16	17	7	20	12
38	6	17	8	15	8	21	23	14	7	17	8	10	6	7	21	5
39	7	11	6	12	8	17	12	16	14	5	6	12	9	4	12	4
40	2	16	7	11	7	17	15	18	12	21	8	8	12	4	8	3
41	8	13	14	15	7	13	13	6	17	19	6	14	11	5	10	3
42	13	18	6	8	8	9	8	12	14	22	7	7	5	4	12	3
43	10	17	11	11	9	11	13	7	16	23	8	4	6	3	3	1
44	10	23	1	12	10	15	9	6	13	28	6	8	3	3	5	1
45	7	25	2	14	1	12	11	8	16	20	6	5	6	2	5	2
46	11	15	7	4	9	7	7	8	16	13	3	9	2	3	5	3
47	11	20	3	8	6	4	6	8	11	15	4	7	7	1	1	1
48	22	15	4	7	3	4	6	6	17	11	4	6	3	1	3	0
49	14	9	1	7	1	4	5	3	12	14	4	5	2	1	2	0
50	10	13	5	2	3	7	5	2	11	13	1	8	3	0	2	1
51	12	11	2	6	1	1	4	1	15	15	3	3	3	1	1	0
52	13	6	1	8	3	4	2	6	19	7	2	3	3	0	0	1
53	6	10	3	7	6	7	5	3	22	14	6	4	4	0	4	0
54	12	11	5	7	5	6	2	3	16	11	4	4	2	0	1	0
55	12	11	6	9	3	4	1	2	25	6	1	5	3	0	3	0

cont. The observed age frequency in samples of Eastern zone Orange roughy. ‘F’ is female and ‘M’ is male. There were no observations of fish younger than 8 years old.

Age	F 1992	F 1995	F 1999	F 2001	F 2004	F 2010	F 2012	F 2016	M 1992	M 1995	M 1999	M 2001	M 2004	M 2010	M 2012	M 2016
56	9	13	2	8	1	5	3	0	25	14	2	3	2	0	1	0
57	15	11	0	6	0	1	3	4	13	7	5	2	0	0	1	0
58	9	6	4	9	1	4	1	1	16	15	5	2	2	0	1	0
59	8	6	3	3	0	3	1	0	8	6	2	2	2	0	0	0
60	11	10	2	3	0	3	2	1	10	9	0	6	0	0	1	0
61	6	12	5	2	2	3	1	0	10	9	3	2	0	0	0	1
62	8	3	2	4	0	4	0	1	19	3	1	3	0	0	2	0
63	6	7	2	5	2	2	0	1	13	4	0	3	4	0	2	0
64	6	7	2	7	2	5	1	0	10	9	1	2	1	0	0	0
65	7	3	4	2	3	3	2	1	9	5	0	2	1	0	0	2
66	7	6	2	6	1	1	1	1	6	4	1	4	1	0	0	0
67	6	10	0	2	1	5	3	1	10	6	1	3	1	0	0	0
68	7	5	0	1	0	0	3	0	8	3	2	0	2	0	1	0
69	6	3	1	4	0	1	0	1	6	8	0	1	3	1	0	0
70	6	4	2	6	1	0	2	0	8	6	2	2	0	0	0	0
71	3	5	0	2	1	2	1	1	6	1	0	3	0	0	0	0
72	6	7	1	1	1	1	0	0	5	6	4	4	0	0	0	0
73	2	1	0	5	1	1	0	0	7	1	0	1	0	0	3	0
74	3	5	2	2	1	1	1	1	7	4	0	5	3	0	0	0
75	6	3	0	5	1	0	2	0	6	1	2	1	1	0	0	0
76	3	3	1	3	1	1	0	0	2	4	0	1	0	0	0	0
77	1	1	0	1	2	1	0	0	3	1	1	0	1	0	0	0
78	0	1	1	1	1	0	0	0	2	4	0	3	0	0	0	0
79	31	22	12	37	13	27	6	14	53	33	1	10	11	0	9	1

19. Orange Roughy East (*Hoplostethus atlanticus*) stock assessment using data to 2016

Malcolm Haddon

CSIRO Oceans and Atmosphere, GPO Box 1538, Hobart, TAS 7001, Australia

19.1 Summary

The stock assessment for Eastern Zone Orange Roughy (*Hoplostethus atlanticus*, Collett 1889) uses an integrated stock assessment model implemented using the Stock Synthesis 3.3 software (SS3.30.07, a revision of the 3.24z version used previously). As in the last assessment it assumes a stock structure that combines the Eastern Zone (primarily St Helens Hill and St Patricks Head) and Pedra Branca from the Southern Zone (all seasons), because the Total Allowable Catch was set for this combination and needs updating. New data included since the previous stock assessment (Upston et al., 2015) are recent research and commercial catches; relative spawning biomass estimates from the 2016 acoustic towed surveys at St Helens Hill and St Patricks Head, a revised index of spawning biomass from the 2013 towed acoustic survey (which derived from a re-calibration of the survey gear), and new age composition data from catches taken in 2012 and 2016. In addition, further changes were made to the assessment and these were to include an extra recruitment residual in the analysis and a revised ageing error matrix. A new base-case was generated by adding each of these model changes and data streams sequentially to the previous final base-case assessment model to document the effect of each new source of information in a formal bridging analysis.

The acoustic indices are considered to be relative indices in the model in the sense that there are several factors that can lead to the acoustic biomass estimate differing from the biomass available to survey on average. The Francis (2011) data weighting method was applied, as is becoming standard practice, to select the weights for the age composition data, which led to more weight being assigned to the acoustic survey indices and reduced weight to the age-composition data when the model was fitted. The other new data input was an updated ageing error matrix using data from the new ageing data from 2012 and 2016. This ageing error found no evidence of a major bias in the early age readings for Eastern Zone Orange Roughy.

An initial base-case model was developed that involved including recent catches, a new acoustic survey index from 2016, a revised acoustic survey estimate for 2013, new age composition data for 2012 and 2016, a new ageing error matrix, and an increase in the variability that the recruitment deviates could express. Unusual aspects of the model outcome include a pattern of recruitment that switches from predicted high levels of recruitment to low levels rising back up to predicted average levels about six years prior to the start of the fishery. This unusual pattern appears to derive from the extremely high fishing mortality rates imposed at the start of the fishery leading to a very rapid decline in available biomass. The model attempts to partially explain this rapid decline by implying the recruitment prior to fishing was lower than average. This effect should decrease as the time series of ageing data increases which will discount this effect.

The model estimates a continuing trend of recent increases in spawning biomass. The revised acoustic point estimates for 2013 (revised upwards) reduces the difference between the observed abundance

and that predicted by the model and that, combined with the more recent 2016 estimate reinforces the estimates of recent increases in stock biomass.

After examination of the likelihood profiles around the fixed parameters of natural morality (*M*) and the stock recruitment relationships steepness (*h*), a better fit and more plausible biological model was used as a final base-case that used an $M = 0.036$ rather than 0.04 and an $h = 0.6$ instead of 0.75. In the end after rebalancing of variances and effective sample sizes this had only minor effects on the model fit to the data (although minor improvements did occur). However, the productivity of the model was reduced so that the implied increase in the stock between 2014 and 2017 was no longer so great and yet still constituted a 5% increase in stock biomass from about 25%B_0 to about 30%B_0.

Even though the model fits to the available data were reasonable the model remains uncertain with relatively wide confidence intervals the fitted data time-series and consequently around the median stock estimates. This reflects the uncertainties in the available data. The indices of abundance are variable with significant inter-annual variation in abundance estimates. The ageing data is intrinsically noisy, especially as the sample sizes are typical of SESSF fisheries but there are 80 year classes and samples of up to 600 fish still generate age-composition distributions with a very spiky appearance. Despite the limited data available the outcome from the model is relatively robust and stable although highly dependent upon the assumptions made about natural mortality and the steepness of the stock recruitment relationship (Table 19.1). Two base-cases were developed and presented. The first used a natural mortality of 0.04 and steepness of 0.75 (M=0.04, h=0.75) and the second less productive version used a natural mortality of 0.036 and steepness of 0.6 (M=0.036, h=0.6).

In both base-cases over-fishing was not occurring and neither was over-fished. In addition, in both cases the stock was continuing to recover. Where they did differ was in their current state of depletion with the two base-cases following a nearly parallel spawning biomass recovery trajectory with the more productive base-case being about 4% above the less productive case (Table 19.1). A dip in recruitment due to the severe depletion that occurred in the mid-1990s is predicted to have an impact of recovery rates from about 2025 onwards, slowing recovery until it starts to climb again in about 2051.

Applying the projected catches from one base-case into the other base-case enables a test of the potential risk of applying the catches from one model when the other model is more correct. However, according to the predictions made by the current assessment model (within the precision of estimates currently possible), any differences derived from applying either predicted RBC time series (or average) over the next three years would be difficult to distinguish from applying the correct catches. Prolonged application of the wrong catches would lead to either a cessation of recovery and on-going depletion from about 2027 should the higher catches be applied but the lower productivity model be more correct. Or, conversely, if the lower catches are applied to the higher productivity model then stock recovery would be speeded up and the target achieved possibly by 2050.

Table 19.1. The predicted RBCs (tonnes) from forecasting the initial base-case and the final base-case model forward under the 20:35:48 HCR.

Year	M=0.036, h=0.6	M=0.04, h=0.75
2018	709	1314
2019	776	1347
2020	834	1375
Average next 3 years	773	1345
MSY	1472	2314
Long term at $0.48B_0$	1276	1784
Depletion start of 2017	$0.298B_0$	$0.338B_0$

19.2 Introduction

19.2.1 *The Fishery*

The three most recent stock assessments for Eastern Zone Orange Roughy (*Hoplostethus atlanticus* Collett 1889) were completed in 2006 (using data up to July 2006 and using an estimate of catch for calendar year 2006; Wayte 2007), in 2011 (using data up to December 2010; Upston & Wayte 2012a, b), and in 2014 (Upston et al, 2015), which used data up to the end of 2013 (Table 19.2). The stock defined in the 2014 base-case as ‘Orange Roughy East’ was primarily comprised of the St Helens Hill, St Patricks Head, and also Pedra Branca off the south of Tasmania. This stock structure was suggested by an Orange Roughy workshop held early in 2014, and is used in this assessment as management, including Orange Roughy Management Areas and TACs, have been set for this stock arrangement (AFMA, 2017).

The history of the fishery for Orange Roughy in the Australian Fishing Zone, can be found in CSIRO & TDPIF (1996), Bax (2000), Wayte (2007) and Upston et al. (2015). The important change for the Eastern zone described in the 2014 assessment was that the stock had rebuilt to have an estimated median estimate of female spawning depletion at the start of 2015 (SB_{2015}/SB_0) of approximately $0.25B_0$, which, being above the Commonwealth spawning biomass limit reference point (of $0.2B_0$), eventually led to a limited re-opening of the eastern fishery starting in 2015 with a three year TAC of 465 t (for the 2015, 2016, and 2017 seasons) in the Eastern zone with a further allocation of 35 t at Pedra Branca in the Southern Zone; this is in contrast with a 25 t TAC in 2014 (AFMA, 2017), of which only about 7 tonnes were caught. An Eastern Orange Roughy Management Area (ORMA) was declared along with a Pedra Branca ORMA (AFMA, 2017, p 83-84), and these declared the specific areas opened to fishing within the 700m deepwater closure.

The fishery had been closed to commercial fishing at the end of 2006 with Orange Roughy listed as conservation dependent using the ‘Environment Protection and Biodiversity Conservation Act’ (with the exception of a 500 t TAC for the Cascade Plateau Zone, whose stock was deemed to be above the biomass Target Reference Point). A 5-year conservation plan was put in place in 2007 and was reviewed in 2012/13 (AFMA, 2014). A workshop organised by AFMA (including NZ participants) was held at CSIRO Hobart in May 2014 to discuss the fishery and the then upcoming Eastern Zone Orange Roughy stock assessment, including the development of a potential base-case model specification. That workshop preceded the production of the 2014 stock assessment (Upston et al., 2015). That, in turn led on the production of this current stock assessment that aims to determine whether the Eastern zone Orange Roughy stock continues to recover and to meet the needs of setting the TAC for 2018 onwards.

19.2.2 *Previous Assessments*

Early stock assessments for the Eastern stock of Orange Roughy (Bax, 2000) used stock reduction analysis (Kimura et al., 1984) to generate plausible estimates of unfished biomass and current biomass and then considered the outcome of projecting the modelled stock forward under different TAC scenarios. Later stock assessments from after the start of the 2000's used relatively simple age-structured stock assessment models that were fitted using maximum likelihood methods and Bayesian approaches. In 2006 and onwards, fully integrated stock assessments using the stock synthesis software were conducted (Table 19.2), though their structure remained relatively simple.

Table 19.2. A summary of previous integrated stock assessment and their outcomes for Eastern Zone Orange Roughy. The year of assessment is usually the year after the final year of data collection, while the year listed under Authors is the year the assessment was more formally reported. B0 is the unfished female spawning biomass, except in 2011. The B_0 in 2011 is total biomass rather than just female spawning biomass. The RBC is the potential yield in the following year.

Year	Authors	B0 (t)	Depletion	RBC (t)
2001	Wayte & Bax (2002)			
2006	Wayte (2007)	40,746	0.1B_0	0 t
2011	Upston & Wayte (2012a) Upston & Wayte (2012b)	92,675*	~0.165B_0	0 t
2014	Upston et al., (2015)	38,931	0.25B_0	381 t

19.2.3 *Modifying the September 2017 Initial Base-Case*

An initial base-case was developed for presentation to the SE RAG in September 2017 (Haddon, 2017), and this present document describes the changes made to that initial base-case following further exploration of sources of variation and the implications of the various assumptions regarding the biological properties affecting productivity. These adjustments derived mainly from conducted a series of likelihood profiles on parameters that have significant influence on the stock dynamics. Some exploration of the effects of the iterative re-weighting of the different data streams was also undertaken.

It is now standard practice in Australia, New Zealand, and at least the west coast USA to place more emphasis on any indices of relative abundance (standardized commercial CPUE and the trawl or acoustic survey indices; Francis, 2011) relative to the weight placed on age and length composition data. This relates to the proportional emphasis given to the different data streams available when fitting the model and, in this case, different arrangements can lead to different assessment outcomes in terms of estimates of female spawning biomass and depletion levels. The changes are described in a set different manipulations and changes to the old assessment (Haddon, 2017). For Orange Roughy East there are no length samples currently considered to represent a random sample from the whole stock. Although length data from the acoustic surveys are available they were not included in this assessment as what they represent still needs to be clarified before they can be usefully included.

19.2.3.1 Balancing variances and adjusting biases

As adding significant amounts of new data can alter the relative contribution of different data sets within the model fitting process and thus disturb the apparent model outcomes (depletion and unfished biomass estimation, etc). SS3.3 now automatically balances the input variances of the survey data with those predicted by the model, but the age-composition data still requires rebalancing using the Francis (2011) weights in an iterative process outside of the model fitting process. At the final stage of the September base-case (basecase17) the input variance of the different sets of age composition data were re-balanced relative to the predicted variance until they all reached equilibrium to generate the initial base-case. Equilibrium in this case was taken to be changes in the variance multipliers or replacements of < 1.0%.

In addition, the model generates predicted deviations from the expected mean stock recruitment for each year in response to differences in year class strength from the ageing data and changes in the relative abundance indices. Being log-normally distributed these predicted values tend to be biased relative to actual values. Early in the time-frame used by the model to describe the fishery there is less information to inform the values of these predicted recruitment deviates and so any bias is expected to be lower, similarly towards the end of the time-series a ramping down of any bias is also expected (Methot & Taylor, 2011). The model variance balancing and bias adjustment of the recruitment deviates also involves changing the maximum recruitment variation (the so-called $\square_{R}$). Such changes in recruitment variability can be directional and to maintain biological plausibility are given pre-defined maxima and minima. With Orange Roughy the upper limit of 0.7 was required otherwise it would have continued increasing to implausible levels. The recruitment bias adjustment was deemed to have reached equilibrium when the changes were either < 1% or, with regard the estimates of in which years changes occurred absolute differences less than 0.75 of a year. While these thresholds are arbitrary any changes to the assessment become insignificant once the adjustments reach this minor degree of change in likelihoods. The key character being searched for is stability and such small thresholds lead to stability.

The transfer to Stock Synthesis 3.30.07 turned out to be both valuable (automating the variance balancing of the index data) and problematic (where the in-practice methods for balancing some of the data streams had changed and took both time, some experimentation, and interacting with the authors of SS3.3 in the USA to solve. Nevertheless, this is now streamlined and relatively straightforward in its application.

19.2.3.2 Estimation of RBC and long term RBC

Once the final base-case is approved by the SE RAG (or valid modifications suggested) its dynamics are projected forwards for a large number of years (55 for Orange Roughy). This enable estimates of both the RBCs for the next few years, that would match the Commonwealth Harvest Control Rule for Tier 1 assessments, and usually would produce the long term RBC that would, at equilibrium, keep the stock to the MEY Commonwealth proxy target of 48%B_0 (DAFF, 2007). In the case of Orange Roughy 55 years were not enough for it to recover to $B_{48\%}$ so equilibrium surplus production estimates were used instead to estimate the long term yield.

In addition, it is standard to conduct sensitivity analyses on those parameters that are assumed to be fixed in the base-case assessment. These are conducted to provide a test of the structural assumptions made in the formulation of the assessment model. In the case of Orange Roughy East the parameters of interest include the natural mortality (M), the stock recruitment curve's steepness (h), and the length at which 50% of fish are selected (S_{50}). Rather than conduct sensitivity analyses where single values above and below the fixed value in the model, likelihood profiles are made to clarify the effects of these model parameters and determine whether they are having a major influence on the model fit or its outputs. These likelihood profiles highlighted concerns over some of the more important constants within the assessment leading eventually to biologically more plausible values to be used, although the selection of such constants remains in need of a detailed review.

19.3 Methods

19.3.1 *Biological parameters*

In the September 2017 original base-case (Haddon, 2017) the biological parameters were originally set the same as in Upston et al (2015); the estimated values are naturally rather different (Table 19.3) because of the new data included. Male and female Orange Roughy are assumed to have the same biological parameters except for their length-weight relationship (Table 19.3). In the absence of representative length data none of the four parameters relating to the Von Bertalanffy growth equation are estimated within the model-fitting procedure.

Table 19.3. The estimated and pre-specified model parameters for the Eastern Zone Orange Roughy preliminary base-case stock assessment (Sep 2017; Haddon 2017). The assumed stock structure includes the Eastern Zone (primarily St Helens Hill and St Patrick's Head) plus Pedra Branca from the Southern Zone. Normal priors are defined by N(mean, standard deviation). There is assumed to be no auto-correlation among the recruitment deviations. 82 parameters were estimated.

Estimated parameters	**Pars**	**Estimate**	**Prior**	**Source**
Unexploited recruitment; log(R0)	1	9.0773	N(9.3, 10)	Uninformative
Recruitment deviations 1905-	77		N(0, σ_R)	See section 5.3.2.1
Selectivity logistic inflection	1	35.456	N(35.0, 99)	Uninformative
Selectivity logistic width	1	1.0021	N(3.0, 99)	Uninformative
q Acoustic towed catchability	1	0.97659	N(0.95, 0.3)	Upston et. al. (2015)
q Hull catchability	1	1.68159	N(0.95, 0.9)	Upston et. al. (2015)
Fixed parameters		**Values**		
Recruitment steepness, h		0.75		Annala (1994) cited in CSIRO & TDPIF (1996)
Recruitment variability , σ_R		0.58		
Rate of natural mortality, M		0.04 yr^{-1}		Stokes (2009)
Maturity logistic inflection		35.8 cm		Estimated selectivity
Maturity logistic slope		-1.3 cm^{-1}		Smith et al. (1995)
Von Bertalanffy K		0.06 yr^{-1}		Smith et al. (1995)
Length at 1 year Female		8.66 cm		
Length at 70 years Female		38.6 cm		
Length-weight scale, a		3.51×10^{-5}	Female	Lyle et al. (1991)
		3.83 x 10-	Male	
Length-weight power, b		2.97,	Female,	Lyle et al. (1991)
Plus-group age (years)		80		
Length at age CV for young		0.07		Estimated from data
Length at age CV for old		0.07		Expected offset from young
q egg survey catchability		0.9		Bell et al. (1992), Koslow et.al (1995), Wayte

Maturity is modelled as a logistic function, with 50% maturity at 35.8 cm. The assumption is made that the maturity would approximately match the selectivity as estimated on the spawning aggregations (which are assumed to be mature).

Fecundity-at-length is assumed to be directly proportional to weight-at-length, which is important for the estimation of the Spawning Potential Ratio, which can act as a proxy for fishing mortality; a requirement for the determination of stock status.

19.3.2 *Available Data*

No changes have been made to the data available since September 2017, however, tables and plots relating to the data are included here for ease of reference.

An array of different data sources are available for the Eastern Zone Orange Roughy assessment including catch (landings plus discards, which are minor and included in the catches), three indices of abundance (the egg estimate treated as an absolute abundance, while the two acoustic biomass estimates are treated as relative abundance indices), and age composition data from the acoustic surveys and on-board sampling (Figure 19.1). Length data collected form the acoustic surveys is now available now but was not included in this assessment and remain a possible option for future exploration.

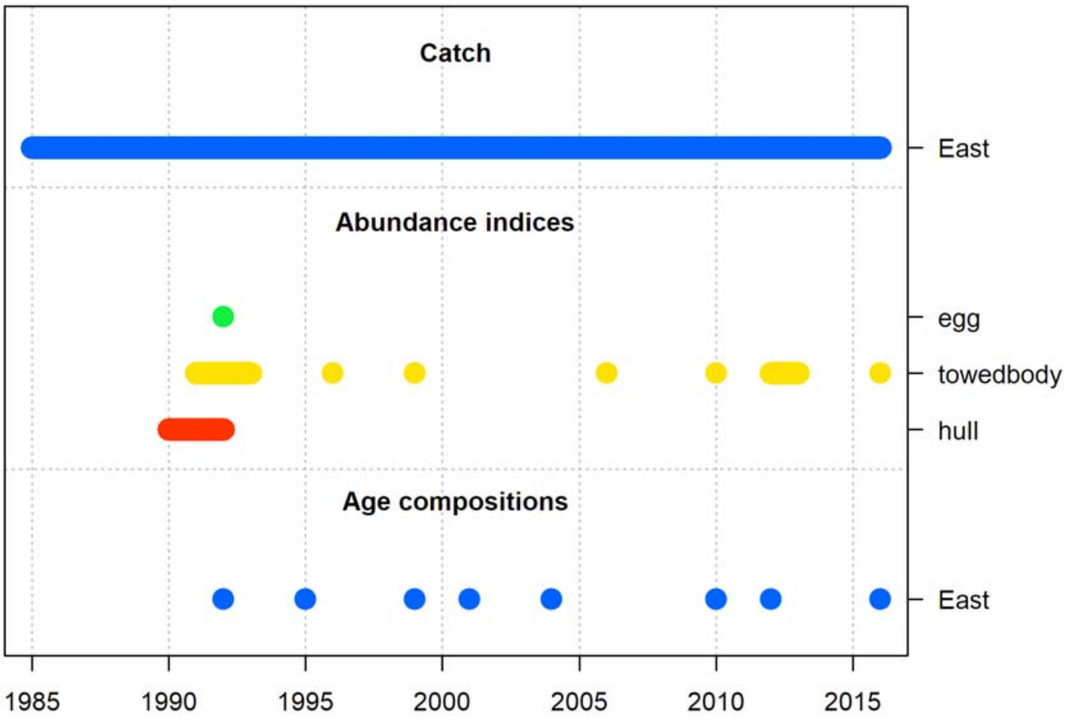


Figure 19.1. Data availability for Orange Roughy East by type and year. This illustrates the full data set as used in the basecase17 scenario.

19.3.3 *Catches*

Commonwealth Commercial logbook data for the years 1985 to 1991 and Catch Documentation Records for landings across the years 1992 to 2016 provide information on Orange Roughy retained catch in the SESSF (Figure 19.2; Table 19.4).

The Eastern Orange Roughy zone and Pedra Branca (Figure 19.3) catch history is used in the base-case assessment. The catch values reported originally have been adjusted as a result of estimates of burst bags and other initially unreported catches; Wayte (2007) provides details about how the catches from 1989 – 1994 were adjusted. The justification for these adjustments to the catch history leading to the “agreed” catch history are also given in CSIRO & TDPIF (1996) and descriptions of earlier stock assessments (for the years 1995, 1996 and 1997 – see Bax 1997, Bax 2000a and 2000b). The extreme catches that occurred during 1989 – 1993 (Figure 19.2) had a disruptive influence on the stock and such rapid changes are both difficult to model appropriately and add an extra source of uncertainty to the assessment.

In 2007 the quota year was changed from calendar year to the year extending from 1 May to 30 April, the assessment, however, continues to be conducted according to the calendar year as most catches occurred prior to 2007.

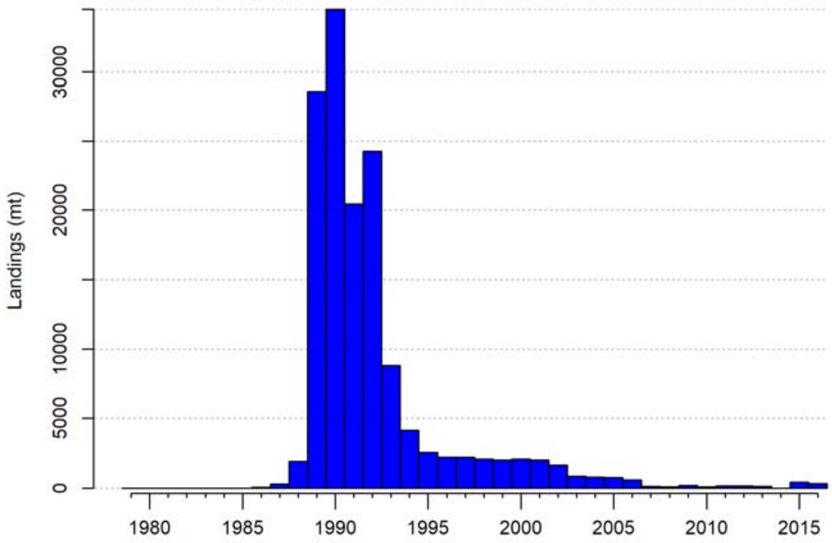


Figure 19.2. Total reported landed catch of Eastern Zone Orange Roughy 1985 - 2016; see Table 19.4).

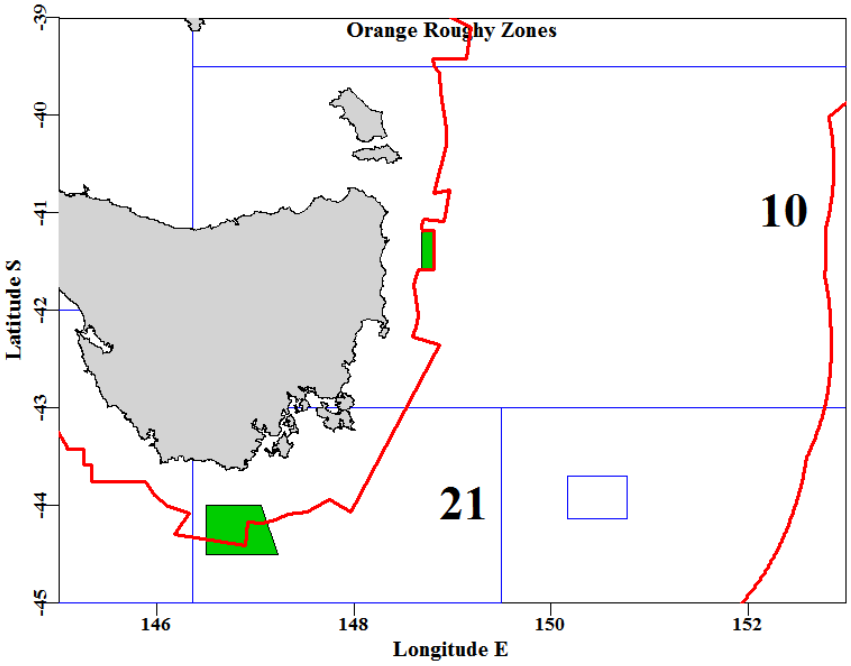


Figure 19.3. A sketch map of the Orange Roughy zones 10 (Eastern Zone) and 21 (part of Southern Zone) around Tasmania. The red lines denote the current definition of the 700 m deepwater closure and the green regions denote the Orange Roughy Management Areas for Pedra Branca in the south and the Eastern Orange Roughy Management Area in the north, encompassing both St Helen's Hill and St Patrick's Head. Some low catches also occur in other open areas but mostly in the green regions.

Table 19.4. Year agreed catches, in tonnes, of Eastern Zone Orange Roughy, where the Eastern Zone stock includes Pedra Branca (PB) from the Southern Zone. The starred years 1989 – 1994 (horizontal shading) denote catches that incorporate adjustments for the proportion lost due to lost gear and burst bags/ burst panels, other losses, and misreporting (CSIRO & TDPIF 1996; Wayte 2007). The shaded column has the catch history included in the Current Eastern Zone Stock Assessment.

Year	Reported	East Agreed	East+PB Agreed	PB Agreed
1985	6	6	6	0
1986	33	33	60	27
1987	310	310	310	0
1988	1949	1949	1949	0
1989*	18365	26236	28575	2339
1990*	16240	23200	34502	11302
1991*	9727	12159	20436	8277
1992*	7484	15119	24265	9146
1993*	1971	5151	8798	3647
1994*	1682	1869	4140	2271
1995	1959	1959	2544	585
1996	1998	1998	2231	233
1997	2063	2063	2250	187
1998	1968	1968	2087	119
1999	1952	1952	2052	100
2000	1996	1996	2109	113
2001	1823	1823	2027	204
2002	1584	1584	1674	90
2003	772	772	877	105
2004	767	767	797	30
2005	754	754	772	18
2006	614	614	615	1
2007	113	113	129	16
2008	98	98	98	0
2009	193	193	193	0
2010	113	113	113	0
2011	160	160	162	2
2012	163	163	163	0
2013	150	150	150	0
2014	7.4	7.3	7.3	0
2015	415	415.8	460.4	44.6
2016	345	340.3	360	19.7

19.3.4 *Age composition data*

Otolith samples with useable numbers of observations have been taken from spawning aggregations in 1992, 1995, 1999, 2001, 2004, 2010, 2012, and 2016. This has permitted the age-composition of the sampled stock to be estimated for both males and females. These are included in the assessment and are assumed to be simple random samples of the catch (Figure 19.4; and in Appendix A:Table 19.15). The age-compositions for St Helens Hill and St Patricks Head have been combined and weighted based on either the relative abundance implied by the acoustic estimates or the relative catch (Wayte, 2007). The age samples for 1992 and 1995 are from St Helens only where the major proportion of the catch was taken (Upston & Wayte 2012a).

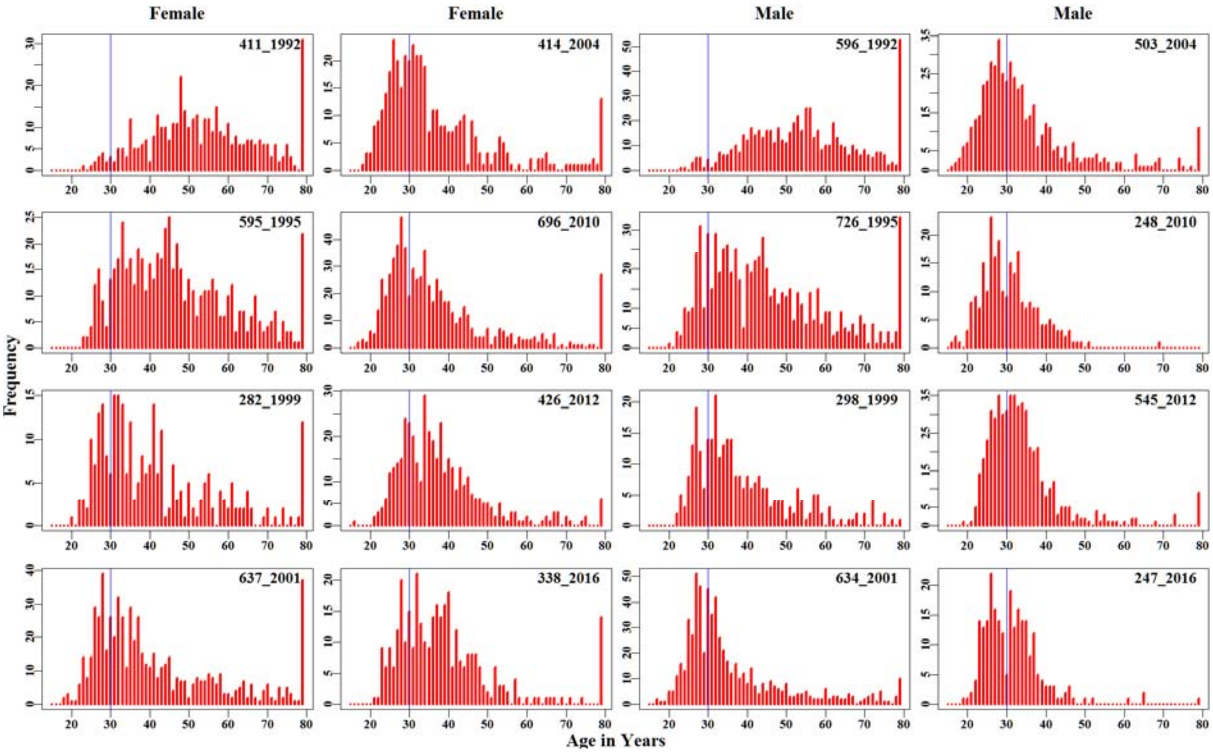


Figure 19.4. All currently available Eastern Zone Orange Roughy ageing data by year and gender. The vertical blue line identifies age 30 to aid comparisons. The numbers at top-right of each plot are the sample size and the year. The age-composition data (the frequency of fish at age) are detailed in Table 19.15. Note the large numbers in the plus group in different years, more so with the females than the males.

19.3.4.1 Ageing error

Orange Roughy live for such long time that reading their otoliths is intrinsically difficult and the presence of ageing errors, made up of differences between readers and differences between years brought about by changing experience, is a real risk (Francis, 2006). Upston et al, (2015) describe an investigation of this potential risk. It is now standard practice to include an ageing error matrix into age-structured stock assessments (Francis and Hilborn, 2002), and this is used to adjust the observed distribution of ages in the model fitting process. An estimate of the standard deviation of age reading error was calculated from data supplied by Kyne Krusic-Golub of Fish Ageing Services (A.E. Punt, pers comm.). The estimate was updated from that used in the 2011 preliminary assessment, to include data from the new ageing data from 2012 and 2016 (the difference between the age error matrices was minor).

The age estimates are assumed to be unbiased but subject to random age-reading errors (Punt et al., 2008). Standard deviations for ageing error by reader have been estimated from the latest sets of age reading, producing the age-reading error matrix (A.E. Punt, pers. comm.; Table 19.5; Figure 19.5).

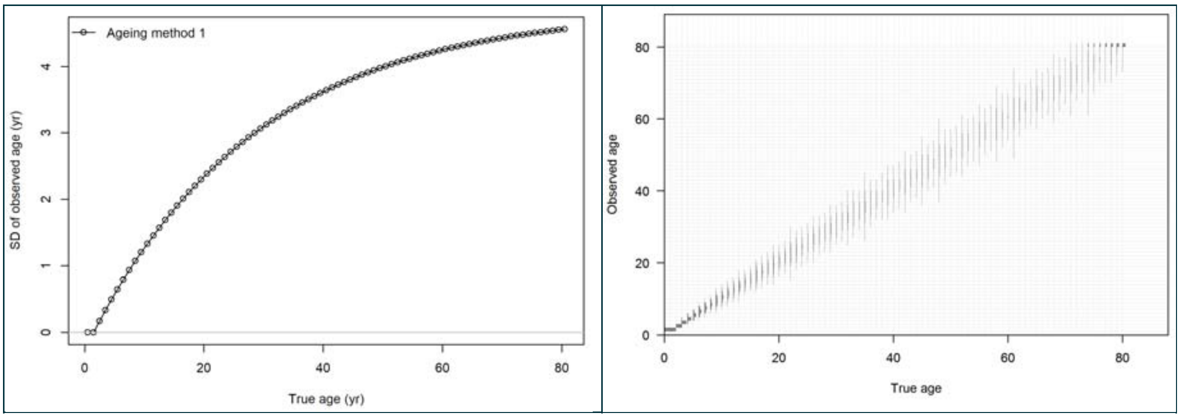


Figure 19.5. Two ways of viewing the increase in ageing error with age (see Table 19.5). The plot on the right illustrates the distribution of observed ages at the agreed true age (ageing error type 1). The plus group is set at 80 years and hence the truncation at the top of the matrix.

Table 19.5. The estimated standard deviation of normal variation (age-reading error) around age-estimates for the different age classes of Eastern Zone Orange Roughy.

Age	StDev.	Age	StDev.	Age	StDev.	Age	StDev.
0	0.0008	21	2.4719	42	3.7268	63	4.3217
1	0.0008	22	2.5553	43	3.7663	64	4.3404
2	0.1704	23	2.6357	44	3.8044	65	4.3585
3	0.3340	24	2.7133	45	3.8412	66	4.3759
4	0.4920	25	2.7881	46	3.8767	67	4.3928
5	0.6444	26	2.8604	47	3.9110	68	4.4090
6	0.7916	27	2.9302	48	3.9440	69	4.4247
7	0.9336	28	2.9975	49	3.9760	70	4.4398
8	1.0706	29	3.0624	50	4.0068	71	4.4544
9	1.2028	30	3.1251	51	4.0365	72	4.4685
10	1.3305	31	3.1856	52	4.0652	73	4.4821
11	1.4536	32	3.2440	53	4.0928	74	4.4952
12	1.5725	33	3.3004	54	4.1196	75	4.5079
13	1.6872	34	3.3548	55	4.1453	76	4.5201
14	1.7979	35	3.4073	56	4.1702	77	4.5319
15	1.9048	36	3.4579	57	4.1942	78	4.5433
16	2.0079	37	3.5068	58	4.2174	79	4.5543
17	2.1074	38	3.5540	59	4.2398	80	4.5649
18	2.2035	39	3.5995	60	4.2614		
19	2.2962	40	3.6435	61	4.2822		
20	2.3856	41	3.6859	62	4.3023		

Table 19.6. The number of observations made of the ages of the two sexes in different.

Year	Female	Male
1992	411	596
1995	595	726
1999	282	298
2001	637	634
2004	414	503
2010	696	248
2012	426	545
2016	338	247

19.3.5 *Acoustic survey abundance estimates*

There are now ten estimates of relative abundance, for the St Helens Hill and St Patricks Head area, from the towed body acoustic surveys (Table 19.7). The CV estimates for the individual abundance estimates are initially used in the model fitting process, but when balancing the output variability with that input, these values are slightly modified.

Table 19.7. The three abundance indices used in the Eastern Zone Orange Roughy assessment. Values up to 2012 were sourced from Upston et al (2015). The original 2013 Towed acoustic survey value was increased by 18% as a result of a recalibration of the equipment (Kloser, pers. comm), and the 2016 estimate is from Kloser et al, (2016). DEPS is the daily egg production survey. The DEPS is treated as an absolute abundance estimate while the others are treated as relative abundance indices.

System	Year	Biomass	CV	Catchability
Hull	1990	120239	0.63	N(0.95, 0.92)
Hull	1991	71213	0.58	N(0.95, 0.92)
Hull	1992	48985	0.59	N(0.95, 0.92)
Towed	1991	59481	0.49	N(0.95, 0.3)
Towed	1992	56106	0.50	N(0.95, 0.3)
Towed	1993	22811	0.53	N(0.95, 0.3)
Towed	1996	20372	0.45	N(0.95, 0.3)
Towed	1999	25838	0.39	N(0.95, 0.3)
Towed	2006	17541	0.31	N(0.95, 0.3)
Towed	2010	24000	0.25	N(0.95, 0.3)
Towed	2012	13605	0.29	N(0.95, 0.3)
Towed	2013	14368*	0.29	N(0.95, 0.3)
Towed	2016	24037	0.17	N(0.95, 0.3)
DEPS	1992	15922	0.50	0.9 (fixed)

19.3.6 *Stock Assessment*

19.3.6.1 Population model and parameter estimation

A two-sex stock assessment for Eastern Zone Orange Roughy has been implemented using the software package Stock Synthesis (SS, previously version 3.24z was used now this has been updated to version 3.3; Methot and Wetzel, 2013, Methot et al, 2017).While it is a two-sex model, differences by gender are restricted to weight at length, which, along with the age data being separated by gender, is used to inform the relative biomass of each gender. Spawning biomass, and its depletion levels is thus able to be presented as female spawning biomass. Stock Synthesis is a statistical age- and length-structured model that can be used to fit the various data streams now available for Eastern Orange Roughy simultaneously. The population dynamics model, and the statistical approach used in the fitting of the model to the various types of data, are described in the SS operating manual (Methot et al, 2017) and the more technical description (Methot and Wetzel, 2013) and these are not reproduced here.

A single stock of Orange Roughy was assumed to occur across Orange Roughy zone 10 and 21 (where 21 is the eastern half of the southern zone; Figure 19.3). The stock was assumed to have been unexploited prior to 1985, initial catches from 1985 – 1987 were relatively minor. The input CVs of the catch rate index and the biomass survey were initially set to the survey estimates (Table 19.7), while the CVs for the catches were set to 0.05, which is effectively an arbitrary small value as catches are assumed to be known without significant error.

The selectivity pattern for the trawl fleet was modelled as constant through time; although this may change in the future as recent (2016) catch data indicates that the fishery is now spreading across the year rather than being focussed in the spawning season of June - August. This change in fishing behaviour has importance because the modelled selectivity is a combination of both the selectivity of the fishing gear combined with the properties of the fish available to that gear, which will change through the year, so this may need attention in future assessments. Both selectivity-at-length parameters were estimated within the assessment. It is also possible that the availability (which affects selectivity in the model) may be better modelled by time blocking the early years of the fishery to allow for larger older fish to be more available. This was deemed suitable for future work and may help address some unusual aspects of the recruitment patterns exhibited by the model.

The rate of natural mortality, M, was assumed to be constant with age, and also constant through time. The natural mortality rate is fixed in the initial base-case analysis to be the same as that used in 2014 (Table 19.3) but after the likelihood profiles was changed to 0.036 (Table 19.11).

Recruitment was assumed to follow a Beverton-Holt type stock-recruitment relationship, parameterised by the average recruitment at unexploited spawning biomass, R_0, and the steepness parameter, h. Steepness for the initial base-case analysis was assumed to be 0.75. While changing steepness had little effect on the model fit it was very influential on the productivity and in the final base-case a steepness of 0.6 was used as being biologically more plausible. Like the natural mortality the value of this constant requires further more detailed review.

Deviations from the average recruitment at a given spawning biomass (recruitment deviations) were estimated from 1905 – 1980 in the last assessment, with only one extra year being included in this assessment; more were attempted but their estimation proved too uncertain and were dropped. The value of the parameter determining the magnitude of the potential variation in annual recruitment, σ_R (SigmaR) was initially set equal to 0.58. During the rebalancing of variances (Methot and Taylor, 2011) the model continued to suggest increasing the SigmaR value so it could have increased well above 0.7, which was set as an upper limit. This has the appearance of very high variation, which intuitively seems inconsistent with the long-term, inherently stable biology of Orange Roughy. However, the recruitment dynamics derive from the model exhibiting an unusual large rise implied for the years prior to exploitation. These large positive deviations arise as the model attempts to account for the extremely high catches taken across the early years 1989 - 1993. The recruitment deviates for more recent years cannot be estimated well because it can take decades for larval fish to grow and enter the fishery. Hence, it can take 30 - 40 years before information about relative recruitment levels becomes available to the model.

Age 80 is treated as a plus group into which all animals predicted to survive to ages greater than 80 are accumulated. Growth of Orange Roughy was also assumed to be time-invariant, that is there has been no change over time in the expected mean size-at-age, with the distribution of size-at-age being determined from the prescribed values entered as fixed values into the model. The potential for age-reading errors (Punt *et al*., 2008) is accounted for within the model by the inclusion of an age-reading error matrix (Table 19.5).

19.3.6.2 Iterative reweighting of data variances

Iterative rescaling (reweighting) of input and output CVs or input and effective sample sizes is a repeatable method for ensuring that the expected variation of the different data streams predicted by the assessment model is comparable to what is input. Most of the indices (CPUE, surveys, age- and length-composition data) used in fisheries underestimate their true variance by only reporting measurement or estimation error and not including process error (e.g. between year and between area variation). With composition data an important source of variation occurs because samples are necessarily limited in their coverage across the fishery and fish caught together in the same shot are often more similar to each other (in terms of age or length) than samples from separate shots. Often such total samples have a lower variance than expected in the stock assessment model. Iterative re-weighting is the process used to adjust for such self-correlated sampling. With composition data (ages, lengths, or conditional age-at-length) this adjustment entails reducing the apparent sample size, which increases the variance of the sample (when the multinomial statistical distribution is used to describe the proportional distribution of data among age or length classes, the larger the sample the smaller the variance). This is what is meant in discussions of reducing the ‘effective sample size’. In iterative reweighting, the effective annual sample sizes are tuned/adjusted so that the input sample size was equal to the effective sample size calculated by the model (the multinomial variances are matched).

In SS3.3 there is now an automatic adjustment made to survey or CPUE CVs enabled through selecting a particular option in the control file. The process used for Orange Roughy East in SS3.3 entailed the following steps:

1. set the standard error for the relative abundance indices (CPUE, acoustic abundance survey, or FIS) to their estimated standard errors for each survey (Table 19.7), or for CPUE and FIS values to the standard deviation of a loess curve fitted to the original data (which will provide a more realistic starting estimate to that obtained from the original statistical analysis. Software procedures within SS3.3 then adjust the relative abundance variances appropriately (by adding to, or more rarely subtracting from, the input standard deviation or CV).

The present standard is to apply the Francis weighting procedure (Francis, 2011), which has three guiding principles:

2. do not let other data stop the model from fitting abundance data well;
3. when weighting age or length composition data, allow for correlations; and
4. do not down-weight abundance data because they may be unrepresentative.

An automated tuning procedure was used for the remaining adjustments. For the recruitment bias adjustment ramps:

5. adjust the recruitment variance (σ_R) by replacing it with the RMSE or a defined set minimum or maximum (in the final base-case the maximum was set to 0.7) and iterating to convergence (keep altering the recruitment bias adjustment ramps as predicted by SS3.3 at the same time). A set maximum was necessary because in an attempt to account for the unusual early predicted rise in recruitment the assessment continually recommended larger and larger values for σ_R.

Finally for the age and length composition data

6. multiply the initial samples sizes by the sample size multipliers for the age composition data using Francis weights (Francis 2011) generated by the R4SS package.
7. similarly multiply the initial samples sizes by the sample size multipliers for the length composition data (not needed with Orange Roughy East).
8. repeat steps 4 to 6, until all are converged and stable (proposed changes are < 1 – 2%).

This procedure may change in the future after further investigations but constitutes current best practice (see Results section). Future assessments may use the Dirichlet distribution (named after Dirichlet, a German mathematician who died in 1859) rather than the multinomial distribution to describe composition data (it is in fact, a conjugate prior of the multinomial distribution). This has the advantage that the effective sample size should no longer be a problem.

19.3.7 *Estimate RBC through Forecasting the Model Forward*

To estimate the RBC for the next few years (assuming a multi-year TAC) requires the optimally fitting model to be projected forward a number of years. In addition, if the likely long-term yield is also wanted for future planning then the projection needs to go forward a large number of years. Here a projection of 55 years from 2018 onwards was used during which the usual 20:35:48 Tier 1 harvest control rule (HCR) was applied. The 20:35:48 format, starting from the right hand side implies a 48% target reference point above which a constant fishing mortality ($F_{48\%}$) is applied. The 35% is where the change in fishing mortality with changes in stock size is altered, below 35% the fishing morality is dropped below the $F_{48\%}$ while above the 35% fishing mortality is fixed at the maximum, finally there is the 20% limit reference point after which no targeted fishing occurs. The origin of the 20:35:48 HCR is described in Day (2009).

Once completed the predicted catches that if taken would project the dynamics along the expected biomass recovery trajectory can be read from the output files.

Because the year 2017 is not complete the total catch within that year is unknown so it was assumed that 465 t would be taken in 2017 even if that turns out not the case.

19.4 Results

19.4.1 *The Initial Base-Case Analysis*

Details of the September initial base-case are given in Haddon (2017), however, in summary the median female spawning biomass was estimated as being recovered to a level of about 33%B_0, although this includes the assumptions about natural mortality, steepness, and other structural assumptions (Figure 19.6; Haddon, 2017).

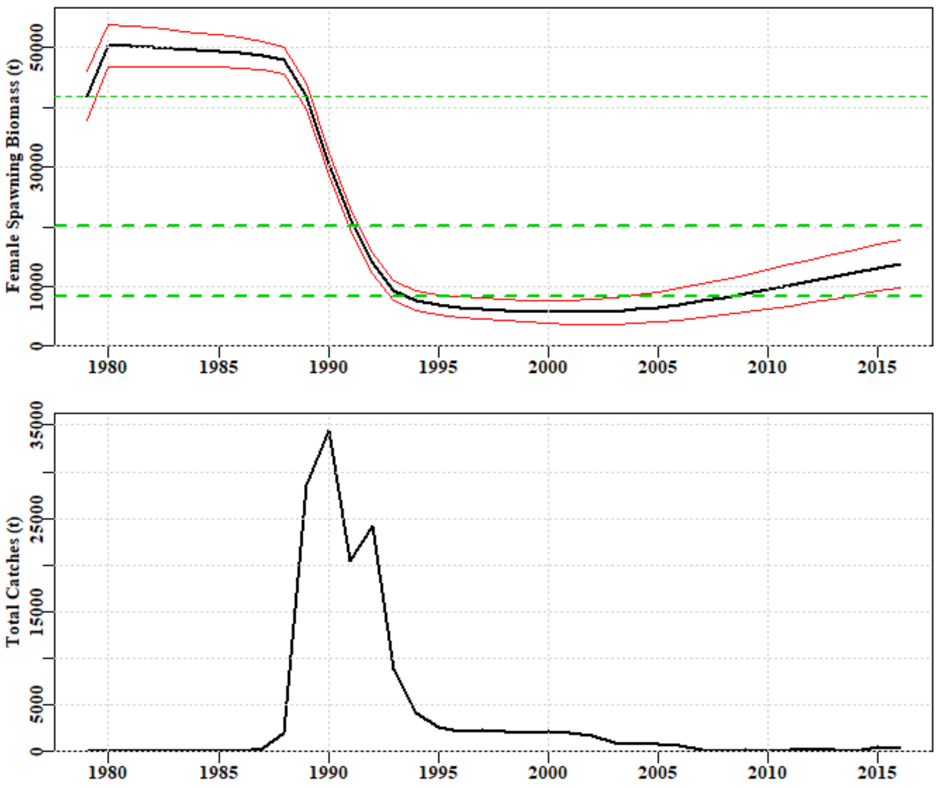


Figure 19.6. The predicted female spawning biomass (top plot) with its 95%CI based on asymptotic standard errors, compared with the limit and target biomass reference points for Eastern zone Orange Roughy. The bottom plot allows a comparison of the biomass trajectory with the catch removals through time.

19.4.1.1 Fishing mortality

In addition, using the relationship between *F* and 1-SPR it is possible to plot an approximation to the classical Kobe phase plot with B_{year}/B_{target} on the x-axis and (1-SPR)/(1-SPR$_{48\%}$) on the y-axis (as a proxy for fishing mortality relative to the target fishing mortality; Figure 19.7).

Such a phase plot (Figure 19.7) suggests that the stock is still below the biomass target (although above the limit) biomass reference point and so is not over-fished. At the same time it is below the (1-SPR$_{48\%}$) target and so it can be claimed that over-fishing is not occurring.

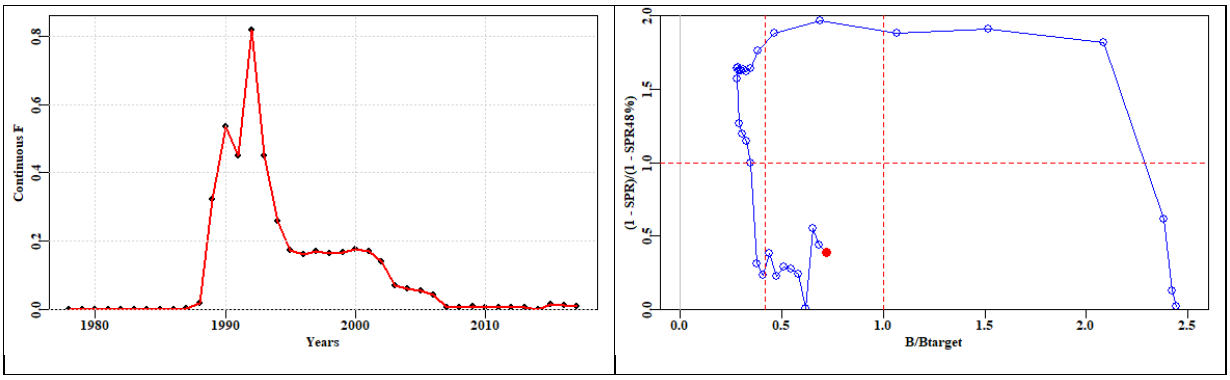


Figure 19.7. Plots of the instantaneous fishing mortality rate and the Spawning Potential Ratio as the complement of the SPR as a ratio with the expected (1-SPR) at a depletion of 0.48B_0, which acts as a proxy for fishing mortality. The horizontal dashed line indicates the target fishing mortality SPR proxy, and the two vertical dashed lines are the target biomass and limit reference points.

19.4.2 *Iterative Re-weighting*

19.4.2.1 Age-composition data

The relative weights attributed to the different data sets, which in Orange Roughy East are limited to the different indices of abundance (egg-estimate, hull-mounted acoustic estimates, and tow-body acoustic estimates) and the age samples taken from the fished aggregations. The iterative re-weighting the indices of abundance are now conditioned automatically within SS3.3 so there is only the age-composition data to work with (Table 19.6). The effect of the iterative re-weighting can be seen by comparing the relative fits to the data streams and recruitment residuals (Table 19.8).

Table 19.8. Statistics from each iteration of the Orange Roughy East initial base-case assessment model in which the effective sample size of the age-composition data was reduced sequentially until all changes in the likelihoods were reduced to within less than 1% of the previous iteration. A postfix ‘L’ implies a likelihood, the other rows are derived statistics. The multiplier is applied to derive the effective sample size.

Statistic	Iteration 0	Iteration 1	Iteration 2	Iteration 3	Iteration 4
Priors L	1.2104	0.2099	0.1989	0.1970	0.1965
Softbounds L	0.0103	0.0073	0.0073	0.0073	0.0073
Catch L	1.11E-09	1.64E-10	1.48E-10	1.44E-10	1.43E-10
TOTAL L	877.2390	38.5853	40.6316	39.1266	38.9495
Survey L	-10.0348	-10.1655	-10.0682	-10.0732	-10.0778
Age_comp L	866.5760	46.7998	46.1524	44.8979	44.6976
Recruitment L	19.4772	1.7338	4.3412	4.0976	4.1259
Multiplier	1	0.04803	0.04697	0.04555	0.04530
Depletion	0.3035	0.3297	0.3388	0.3388	0.3388
B_0	36582	42182	41585	41606	41591
1-SPR	0.217	0.186	0.187	0.187	0.187

The re-weighting which moves from naïve use of sample sizes as effective sample sizes to an optimized and balanced variance (see methods) has a clear and marked effect on the estimates of B_0 and the depletion level. The de-emphasis of the age-composition data led to a shift from 30.4%B_0 to 33.9%B_0.

The first suggested adjustment from the original starting point (iteration 0) to iteration 1, made the largest and most significant change to the likelihoods and derived statistics, while the following changes made relatively minor changes in iteration three and four relative to that in iteration 1. When the relative fits to the age-composition data are examined for each year and sex (Figure 19.8) the most marked differences were in the years 1992 and 1995. In the other years there were minor changes primarily around the peak of observations.

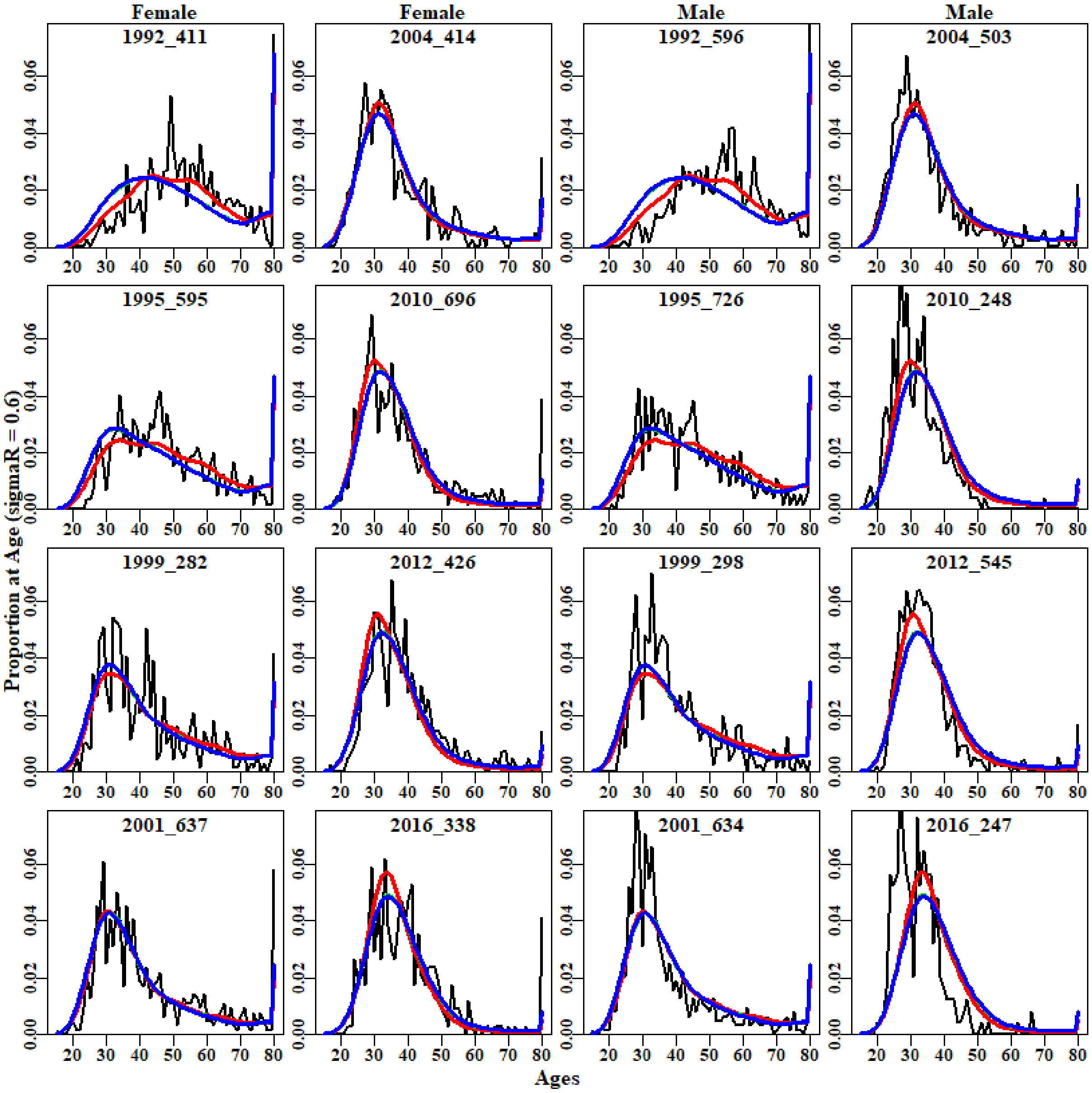


Figure 19.8. A comparison of the expected age-composition from the five stages of the iterative re-weighting process. The black lines are the observed data, the red line is the starting point for the re-weighting process and green and blue lines (essentially on top of each other) represent the third and fifth (final) iteration steps. The spikiness of the observed data derives from there being so many ages classes with sample numbers ranging from about 250 – 726. The legends include the year and original sample size.

In some years, however, for example in 1999 and 2001, only minor changes occur. In other years differences are more obvious although visually it is not always clear which is a better fit; the great noisiness of the data makes visual comparisons especially difficult. In 1995 males the revised predicted ages appear to find more of the observations but the original fits in 1992 and 1995 females are clearly closer to more data points than the later fits. The fit to the 2016 males mimics that to the 2012 males but ignores an apparent mode of fish from 25 – 30 cm. Whether this is a reflection of the relatively small sample size or some other aspect of un-representative sampling is unknown. The difference between males and females in 2016 is marked with females having many more fish older than 40 years, but given reports of Orange Roughy schools not being well mixed by sex such differences between males and females should not be unexpected.

19.4.2.2 Recruitment deviates

That the quality of fits to age-composition declines when the effective sample size is reduced is not surprising, what is surprising is that the fits in some of the years barely change. Unfortunately, the Orange Roughy East age-composition data is relatively noisy, which is a direct reflection of the sample sizes. Such sample sizes (Table 19.6) would usually provide a representative age-composition for many species but with 80 year classes such numbers will only ever provide noisy age distributions. This is also apparent in the variation visible in the plus-group (age 80) counts, as well as in the differences between the age distributions of the females and males (Figure 19.4). The predicted age-composition data will generally be a smoothed version of what is observed, but such noisy age-composition observations can still influence the predicted recruitment dynamics (Figure 19.9).

If the age-composition data are given a great deal of weight (which they are when their observed sample sizes are treated as their effective sample sizes) then anomalies such as the spike of recruits in 1937 can occur as well as the bumps up and down in the 1930s, the 1950s, and the 1970s. However, once the weighting on the age-composition is reduced then the recruitment deviates become less variable even though they retain the unusual pattern of a sequence of elevated recruitment followed by a sequence of reduced recruitment all before any fishing began.

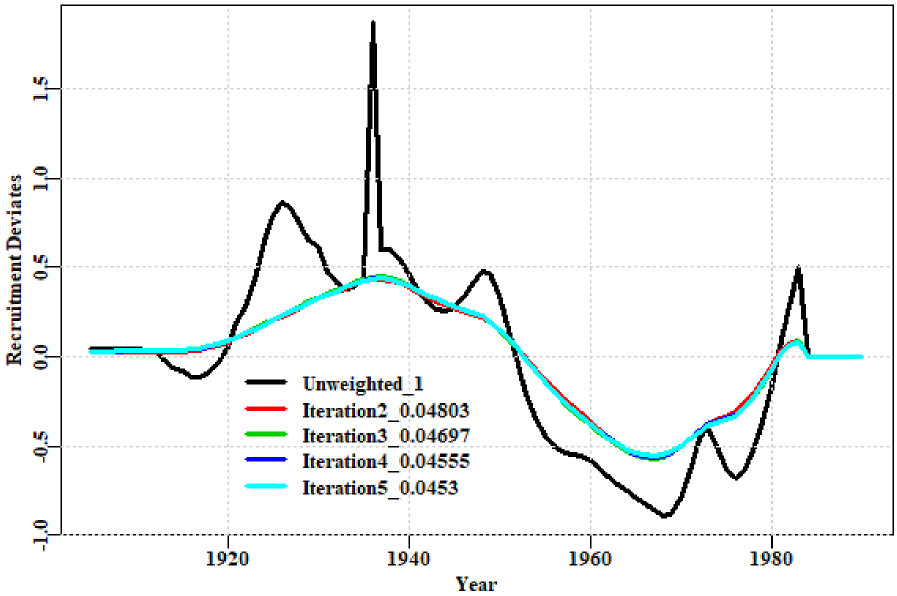


Figure 19.9. The recruitment residuals from each iteration of the re-weighting process. The black line is from the initial state where the age-composition data is given its maximum weight of 1.0.

19.4.2.3 Indices of abundance

Within integrated assessments altering the relative weighting attributed to one data series, such as the age-composition data, influences the fits to other data series at the same time. In the case of the indices of abundance the relative fit to each series does indeed alter but not in a simple manner. The fit the egg-production estimate improves with down-weighting the age-composition data. Out of 10 towed body biomass estimates four were improved by changing the age-composition weighting while six became worse, whereas with the hull mounted estimates two improved while one became worse.

The relative model fits in the original base-case (and the final base-case) require relatively wide confidence intervals around the acoustic spawning biomass survey estimates to obtain an adequate model fit (Figure 19.11). These bounds encompass the differences in model fit exhibited following the application of variance re-weighting (Figure 19.10).

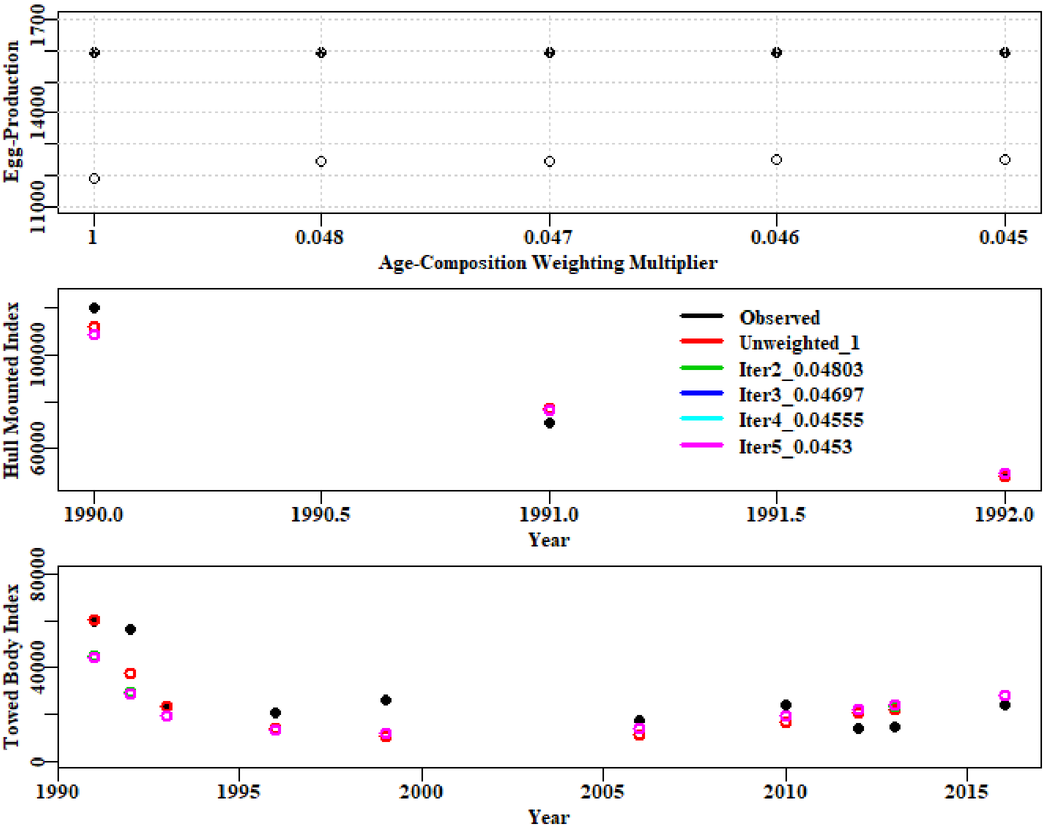


Figure 19.10. The effect of altering the weighting allocated to the age-composition data on the fits to the indices of abundance.

Table 19.9. The predicted CPUE/indices relative to the observed indices from the daily egg production estimate, the hull mounted and towed body estimates. For each of the different relative weightings ascribed to the age-composition data. The optimum fit in each case is highlighted in yellow, although the differences between the predicted values for the different age-composition weightings that are < 1 is generally only a tiny proportional change.

Index	Year	Observed	1	0.04815	0.04296	0.04061	0.03996
egg	1992	15922	11867	12441	12470	12476	12477
towed	1991	59481	60258	45149	44398	44283	44263
towed	1992	56106	37298	29166	28764	28708	28701
towed	1993	22811	23336	19441	19248	19229	19229
towed	1996	20372	14060	13539	13504	13518	13522
towed	1999	25838	10740	11894	11935	11966	11974
towed	2006	17541	11062	13910	14064	14102	14117
towed	2010	24000	16753	19048	19202	19223	19231
towed	2012	13605	20314	22031	22155	22166	22168
towed	2013	14368	22197	23571	23674	23679	23678
towed	2016	24037	27866	28102	28110	28099	28090
hull	1990	120239	111953	108935	108720	108674	108658
hull	1991	71213	77245	76549	76506	76495	76492
hull	1992	48985	47812	49451	49566	49592	49600

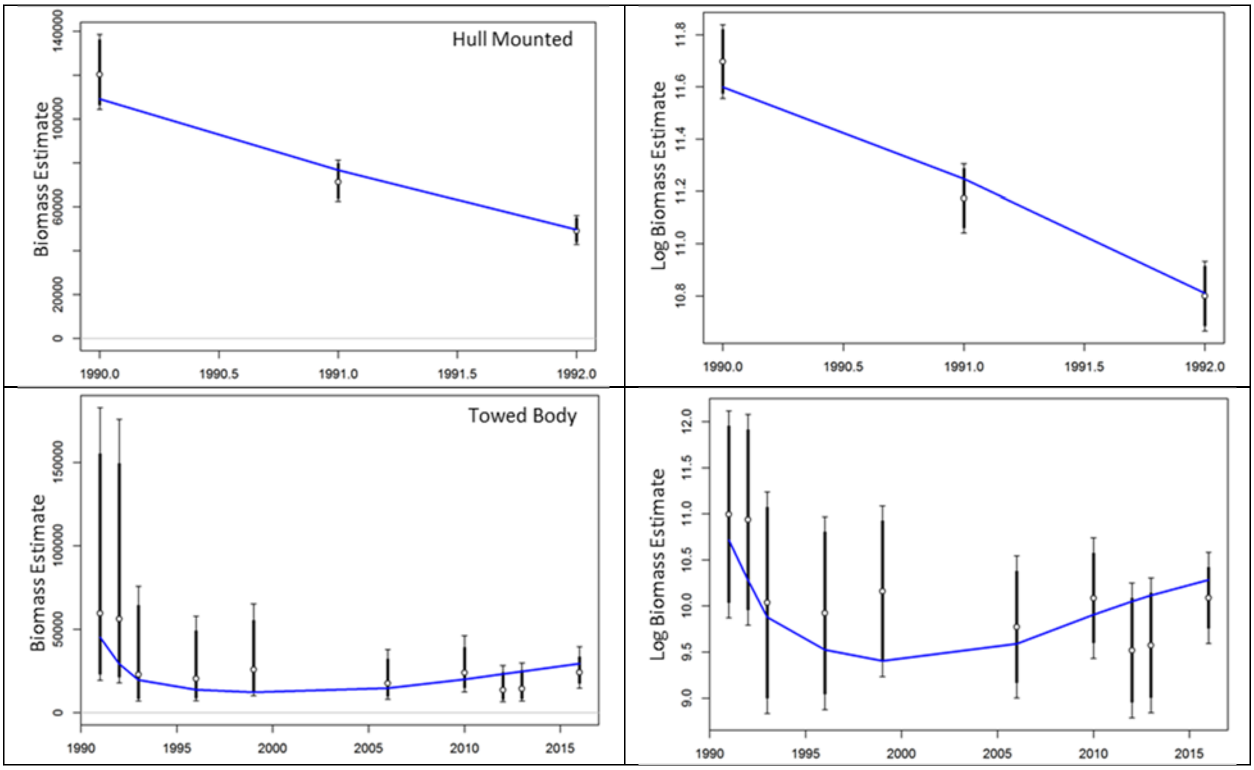


Figure 19.11. The balanced initial base-case model fit to the hull mounted acoustic survey indices (top panels) and the towed body acoustic surveys (bottom panels), each acts as an index of relative abundance. The plots on the right are of the natural-log Indices because log-normal residual errors were used to fit the model to the abundance index data. The thicker lines are the input variances and the thinner lines with the caps denote the additional variance required to optimize the model fit to the index data.

19.4.3 *Likelihood Profiles*

Rather than conduct sensitivity analyses on natural mortality, steepness, and selectivity characteristics, which are currently fixed parameters within the model, there are advantages to generating likelihood profiles for each so as to characterize how the model would perform across a given range of values for each parameter rather than just two or three. The basic idea behind generating a likelihood profile is to fix a given parameter at an array of different values and for each value repeat the model fitting so that all the other fitted parameters can be optimized under the constraint of the new value for the parameter that has been fixed. Such profiles were generated for natural morality *M*, the stock recruitment relationship steepness value, *h*, and the size at 50% selectivity, *S50*.

19.4.3.1 Natural mortality

Following Upston *et al*. (2015) natural mortality in the initial base-case assessment (Haddon, 2017) was fixed at 0.04. It is recognized that Orange Roughy is a long lived species with reports of fish living to ages between about 90 – 190 years (FAO workshop on Orange Roughy, Auckland, New Zealand, June 6 – 10, 2016; the original draft report Tingley, In Prep). In New Zealand, generally, a value for *M* of 0.045 is now used in stock assessments, but other estimates cited in Tingley (In Prep) include 0.045 (0.03 – 0.06), and 0.037 (0.025 – 0.062) from New Zealand, between 0.03 – 0.058 in Chile, and between 0.025 to 0.045 in the Northeast Atlantic. Values used for natural mortality have also varied in stock assessments of different areas within Australia with a minimum value of 0.02 being used for the Cascade Plateau (Wayte and Bax, 2007) and a maximum value of 0.042 being used by Wayte (2007) for the Eastern Zone Orange Roughy. Stokes (2009) recommended that 0.04 be used consistently across Australia, although made allowances for particular cases to be made.

A likelihood profile was generated across values of *M* from 0.023 up to 0.047 in steps of 0.001 (Figure 19.12). The total likelihood exhibits a minimum at 0.032 rather than closer to the assumed value of 0.04. This minimum is driven by the different trends expressed by the age-composition data likelihoods and those deriving from the index data and the recruitment deviates. The age-composition data likelihoods exhibit a minimum at *M* = 0.039 whereas both the index and the recruitment deviate likelihoods exhibit steady declines with minima at the smallest value of *M* used (0.023; Table 19.10).

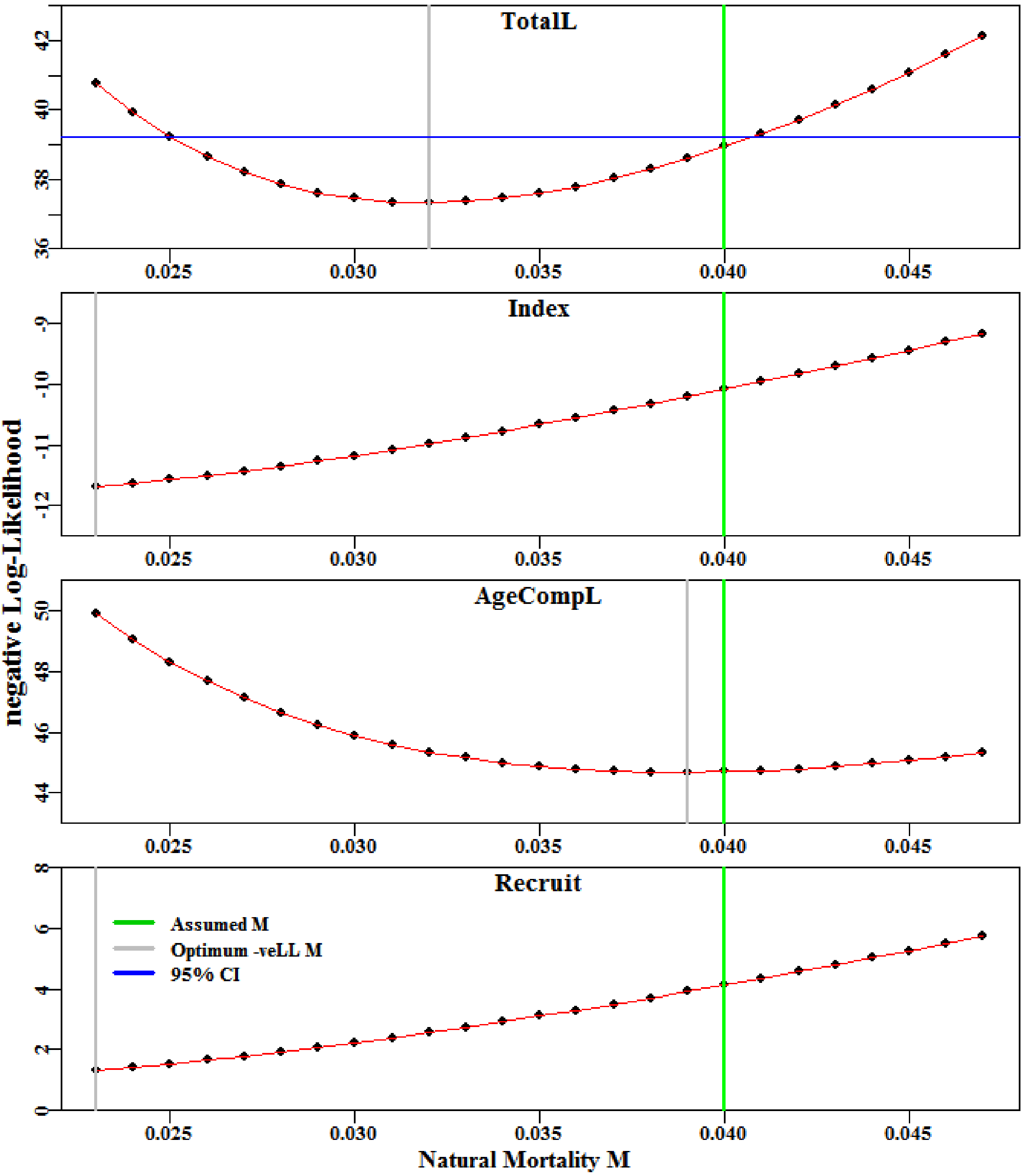


Figure 19.12. Likelihood profiles on natural morality for values of *M* from 0.023 to 0.047 in steps of 0.001. The top plot illustrates the effect on the total likelihood (the sum of the three likelihoods below plus some other very minor contributions), and the three plots below that illustrate the three main components of that total likelihood. The blue horizontal line depicts a likelihood equal to the minimum + 1.92, which provides approximate 95% confidence intervals. The grey lines in each case denote the *M* value corresponding to the minimum likelihood for each series and the green lines depict the current assumed *M* value. The four plots all have different vertical scales.

The question arises whether the value assumed for natural mortality in the stock assessment should be changed. The value used (0.04) is very close to the approximate 95% confidence bounds (Venzon and Moolgavkar, 1988; Haddon, 2011) and the previous value assumed for *M* of 0.042 (Wayte, 2007) is above the 95% confidence limits. The shift to 0.04 from 0.042 in Upston et al (2015) would appear to have been a minimum reduction and a further reduction would appear to be appropriate given the fact that the confidence bounds in Figure 19.12 only approximate those based on asymptotic standard errors and the true intervals are likely to be wider.

Moving the assumed value of *M* to that corresponding to the minimum of the Total Likelihood is an option especially since the analysis has other sources of uncertainty with the assessment outcomes and implications being significantly influenced by the stock recruitment steepness value, and the SigmaR value that constrains the variability of the recruitment residuals. Both the age-composition data and the indices of abundance are variable as illustrated by the spikiness of the age-composition values relative to the predicted age-composition values (Figure 19.8), and the broad 95% confidence intervals of the difference abundance indices (Haddon, 2017).

Table 19.10. The outputs from conducting a likelihood profile on natural mortality, *M*. Depletion, B_0, and 1-SPR are all derived statistics while the other four columns are the total likelihood and the three main components. The minimum likelihood value in each case is highlighted in yellow.

M	Depletion	B_0	1-SPR	TotalL	Index	AgeCompL	Recruit
0.023	0.189	44540	0.2713	40.7829	-11.6812	49.8850	1.34092
0.024	0.198	44197	0.2648	39.9365	-11.6316	49.0409	1.42943
0.025	0.207	43880	0.2586	39.2385	-11.5726	48.3062	1.53304
0.026	0.216	43587	0.2526	38.6716	-11.5056	47.6681	1.6498
0.027	0.225	43318	0.2469	38.2213	-11.4314	47.1157	1.7781
0.028	0.233	43071	0.2413	37.8748	-11.3510	46.6396	1.91665
0.029	0.242	42847	0.236	37.6214	-11.2652	46.2315	2.06439
0.03	0.251	42644	0.2309	37.4515	-11.1744	45.8845	2.22043
0.031	0.26	42461	0.2259	37.3569	-11.0793	45.5921	2.38408
0.032	0.269	42298	0.2211	37.3305	-10.9802	45.3490	2.55473
0.033	0.278	42154	0.2164	37.3659	-10.8774	45.1502	2.73188
0.034	0.287	42029	0.2119	37.4576	-10.7714	44.9915	2.91513
0.035	0.295	41921	0.2075	37.6006	-10.6623	44.8691	3.10412
0.036	0.304	41831	0.2032	37.7906	-10.5504	44.7797	3.29854
0.037	0.313	41758	0.199	38.0238	-10.4358	44.7204	3.49815
0.038	0.322	41701	0.1949	38.2967	-10.3187	44.6884	3.70271
0.039	0.33	41660	0.1909	38.6062	-10.1993	44.6815	3.91201
0.04	0.339	41634	0.187	38.9495	-10.0778	44.6976	4.12586
0.041	0.347	41623	0.1832	39.3242	-9.95409	44.7347	4.3441
0.042	0.356	41627	0.1795	39.7279	-9.82844	44.7913	4.56655
0.043	0.364	41645	0.1759	40.1588	-9.7009	44.8658	4.79304
0.044	0.373	41677	0.1723	40.6148	-9.57154	44.9570	5.02343
0.045	0.381	41723	0.1689	41.0945	-9.44045	45.0635	5.25755
0.046	0.389	41782	0.1654	41.5961	-9.30769	45.1845	5.49524
0.047	0.397	41855	0.1621	42.1184	-9.17333	45.3189	5.73634

With a maximum observed age of 162 in the Eastern zone stock (Figure 19.13) it may be that the current assumed value of 0.04 may be implying too high a productivity. Rather than reduce it all the way down to the apparent optimum of 0.032, in the face of the many sources of uncertainty in this assessment a compromise of *M* = 0.036 was adopted for further analysis.

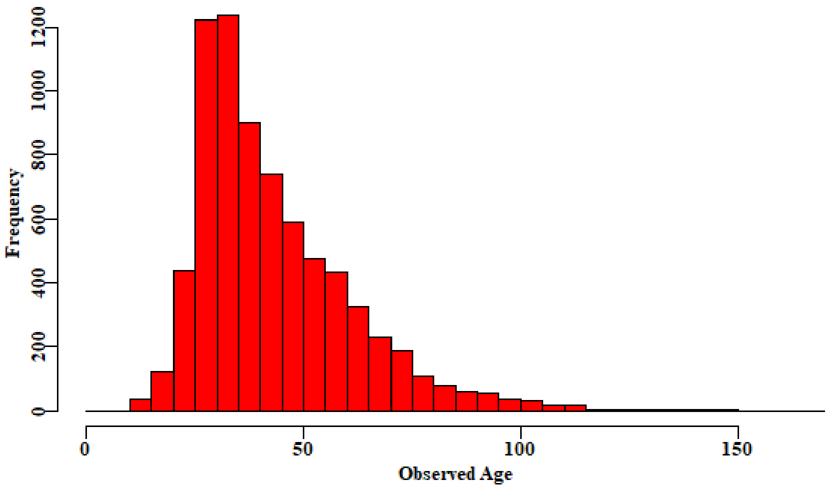


Figure 19.13. The combined Orange Roughy age data available for the Eastern Zone across years 1992 - 2010, presented in age-classes of 5 years. Approximately 10% are 65 years or older and 5% 75 years and older, with a maximum observed age of 162.

19.4.3.2 Steepness

With most species the steepness assumed for the stock recruitment relationship has important implications for a species' productivity and hence for any stock assessment. In the previous assessment (Upston et al., 2015) and the initial base-case (Haddon, 2017), a value of $h = 0.75$ was adopted. Consistent with the sensitivities conducted in the last assessment (Upston et al, 2015) the likelihood profile on steepness has little influence on the fit of the current assessment to the available data (Figure 19.14). This would appear to be because the recruitment into the fishery currently occurring would still be about at unfished levels. If they continue to recruit at about the age of 30 – 35 then the depressing effects of the fishery on subsequent recruitment (see Figure 19.9) should start to influence recruitment within the next few years.

However, even though the current stock assessment is barely altered by changing the steepness value currently set at 0.75, the influence on the implied productivity of the stock is very great (Figure 19.15; it must be remembered this is also using a natural mortality of 0.04). The implied *MSY* for a steepness of 0.55 is more than doubled by increasing steepness to 0.95. Even a steepness of 0.75 suggest that B_{MSY} would occur around 20%B_0 with an *MSY* about 150% that with a steepness of 0.55.

The steepness of the stock recruitment relationship is an important influence on stock dynamics that needs further discussion. Intuitively, the large aggregations needed in Orange Roughy for effective spawning suggests that depletion should impose large impacts on recruitment dynamics. If that really is the case then a steepness of 0.75 may suggest a biologically implausible productivity. In a manner similar to natural mortality a steepness of 0.6 will be adopted for this assessment, which is more in line with a relatively low productivity stock. However, steepness in Orange Roughy also needs to be reviewed as 0.6 may not be low enough for a species with such low productivity.

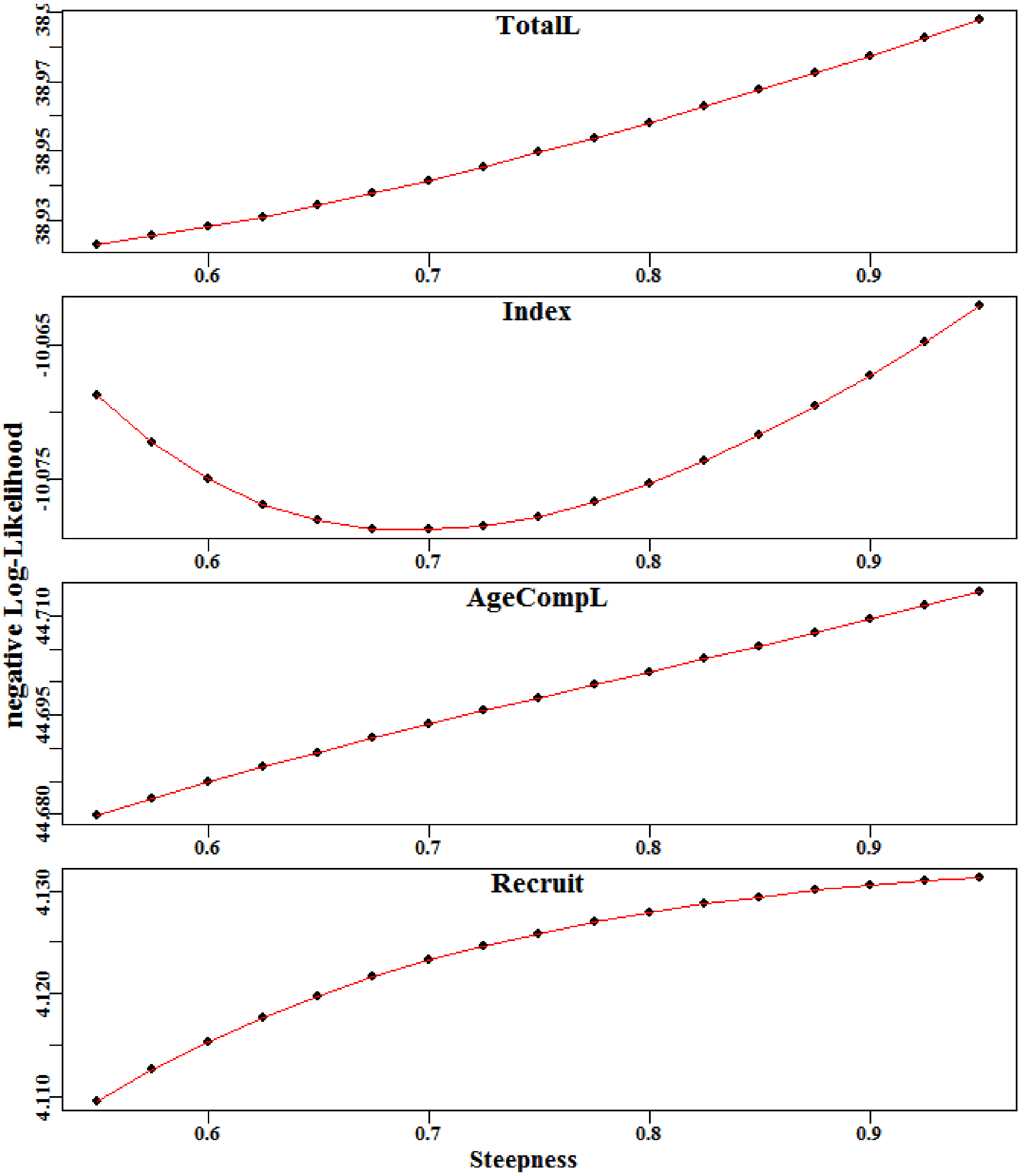


Figure 19.14. The likelihood profile derived for the Beverton-Holt stock recruitment relationships steepness, which ranged from values of 0.55 – 0.95. The strong trends apparent in the plots are misleading because the vertical scales in each case are very small only varying at the second decimal place. The maximum difference generates in the total likelihood was from about 38.925 – 38.99.

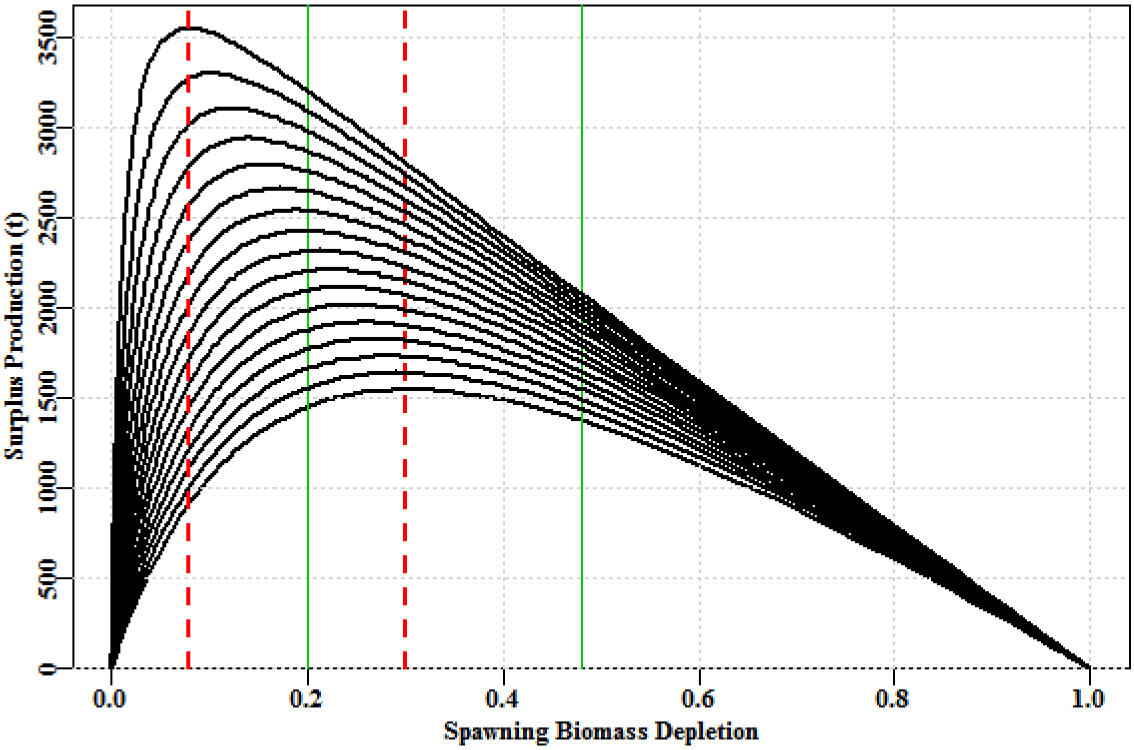


Figure 19.15. The influence of changing the steepness in the likelihood profile. The green lines are the current Harvest Strategy Policy biomass depletion reference points. The right hand red line at about 30% is the implied B_{MSY} with a steepness of 0.55, where the red line on the left is that for a steepness of 0.95, with the lines in between representing steepness values of 0.575 – 0.925.

19.4.3.3 Selectivity

The selectivity for the fishery is estimated (that for the acoustic surveys is fixed), with the optimum value for S50%, the size at which 50% of fish are selected, was 35.456 cm. This value closely matches the optimum when a profile was generated for values between 34.0 to 37.0 in steps of 0.25. after about 35.75 the likelihood profiles for the indices and the recruitment contribution do not follow a typical smooth trajectory (Figure 19.16). The selectivity is highly influential on the model outcomes and the relative weighting of the different data streams becomes unbalanced as the size of 50% selectivity increases. This appears to be why the right-hand limb of the total likelihood curve is not as steep as the left-hand limb. It would be possible to rebalance the variances at each step in the likelihood profile, although this is not generally done in sensitivities but it could be added to the list of options to explore in the future.

Whatever the case, the likelihood profile suggests that the estimated value appropriately reflects the available data and at least the left-hand limb suggests that the selectivity would not need to change much to have a large effect on the outcome.

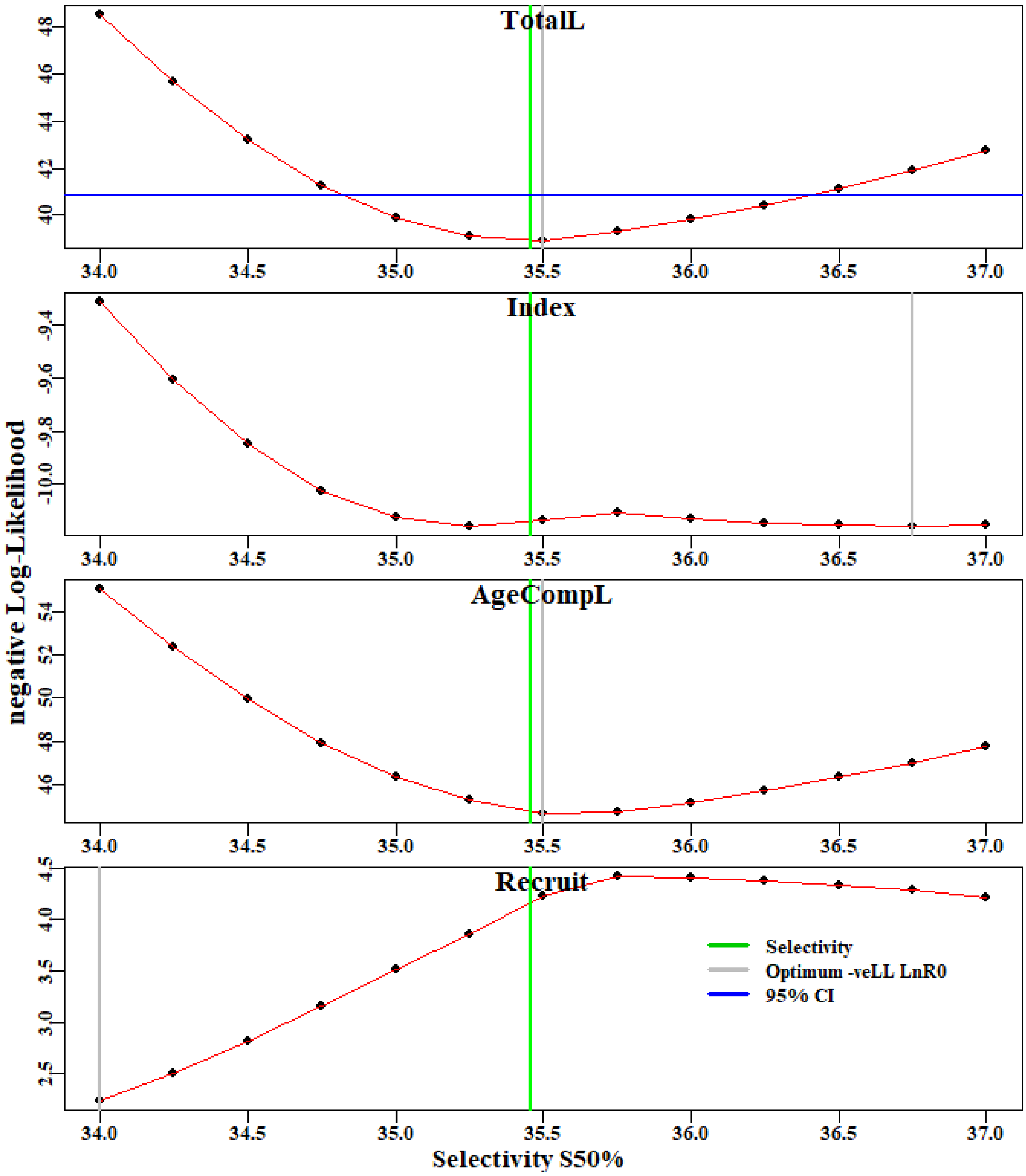


Figure 19.16. Likelihood profiles varying the selectivity parameter for the size at 50% selection between 34.0 and 37.0 in steps of 0.25. Likelihoods for the total, the combined indices of abundance, and age-composition data, and the contribution from the recruitment deviates are plotted. The green line is the optimum estimated value while the grey lines are the optimum for each likelihood.

19.4.4 ***Final Base-Case***

19.4.4.1 SPR phase plot

So as to characterize the current stock status with respect to the current harvest strategy policy limit and target reference points the complement of the Spawning Potential Ratio (1 - SPR) was plotted against the expected SPR at the respective biomass and fishing mortality targets (Figure 19.17). Fortunately, the current status indicates both that the stock is not over-fished nor is over-fishing occurring, although the stock is still below the target of $B_{48\%}$. It was only when catches dropped below 200 t that over-fishing stopped and stock recovery made serious increases.

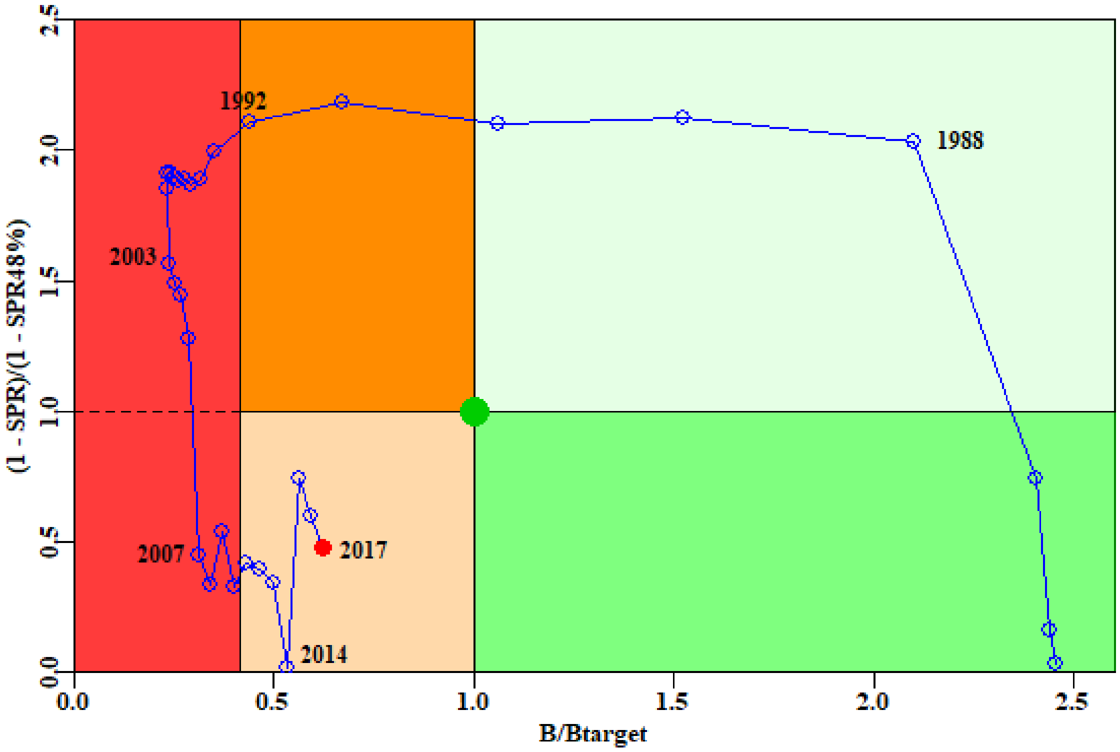


Figure 19.17. A phase plot of the female spawning biomass as a ratio with the proxy for $B_{MEY} = B_{48\%}$, against (1 – SPR)/(1 – $SPR_{48\%}$), which is used as a proxy for fishing mortality. The blue line and dots represent the status trajectory through the history of the fishery. The red dot represents the current status and the large green dot the ideal target. The red block constitutes a state of being overfished and if above the 1.0 on the y-axis also over-fishing. The light-green area is above the biomass target but over-fishing is occurring, although if that is part of a planned fish-down this is not a bad outcome. The years 1989 – 1992 bracket the highest catches (Table 19.4).

19.4.4.2 Comparison with the initial base-case

The final base-case for Orange Roughy East uses a natural mortality of 0.036, a steepness of 0.6, and the iterative re-weighting of sample variances (effective sample sizes) led to a recruitment variability of 0.7. These are the only parameters that changed from the initial base-case (Table 19.11; and see Table 19.3). The changes to the fitted parameters were relatively minor.

A comparison of the initial base-case with the final base-case illustrates the effect of the change in productivity implied by the changes to natural mortality and steepness. The female spawning biomass trajectory is lower in the final base-case, although the 95% confidence intervals strongly overlap

(Figure 19.18). The asymptotic confidence intervals invariably underestimate the full variability and uncertainty, so they also serve to illustrate the uncertainty behind the median assessment outcomes.

Table 19.11. The estimated and changed pre-specified model parameters for the Eastern Zone Orange Roughy initial and final base-case stock assessment (Haddon 2017, and current document).

Parameter	Initial Base-Case	Final Base-Case
Unexploited recruitment; log(R0)	9.0773	8.8286
Selectivity logistic inflection	35.456	35.502
Selectivity logistic width	1.0021	1.0023
q Acoustic towed catchability	0.97659	1.15853
q Hull catchability	1.68159	1.74029
B_0	41591	41348
Depletion	0.337	0.298
Fixed parameters	Values	Values
Recruitment steepness, h	0.75	0.6
Recruitment variability , σ_R	0.59	0.7
Rate of natural mortality, M	0.04	0.036

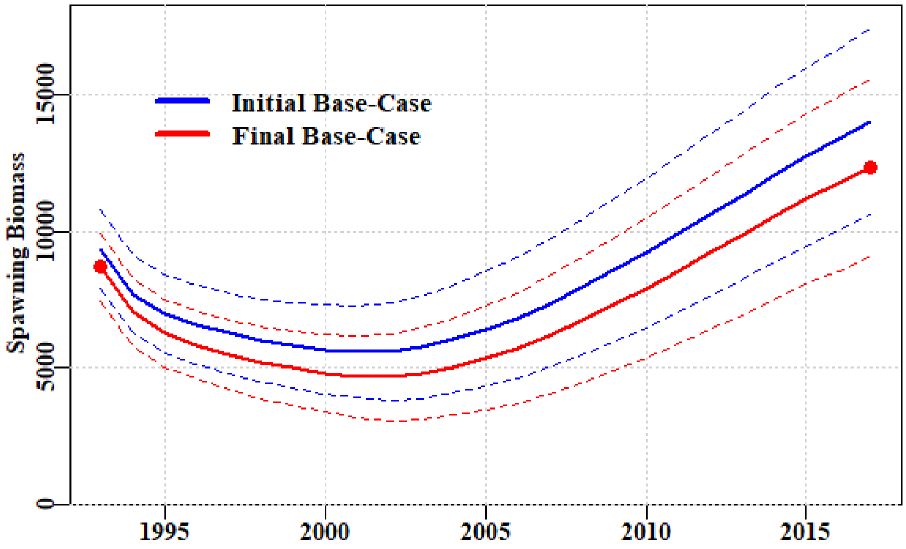


Figure 19.18. A comparison of the female spawning biomass trajectories from the initial and final base-cases over the years 1993 – 2017, along with the asymptotic 95% confidence intervals (the dashed lines). The intervals for the final base-case were from 21.9% - 37.7%B_0 and for the initial base-case from 25.6% - 41.9%B_0.

The recruitment residuals describe very similar trajectories although the bias-adjustment in the initial base-case is greater in the earlier years than in the final base-case and the extra recruitment residual added to the assessment (in 1981) rises further above the zero line in the final base-case (Figure 19.19).

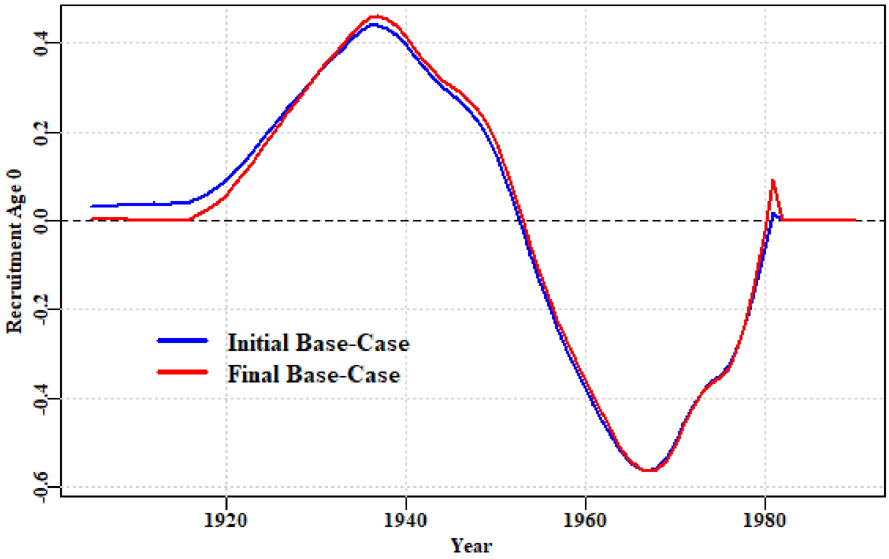


Figure 19.19. A comparison of the initial and final base-case recruit deviates from 1905 – 1990.

Finally, the depletion levels also exhibit almost parallel trajectories with a gradual deviation during the stock recovery phase (Figure 19.20).

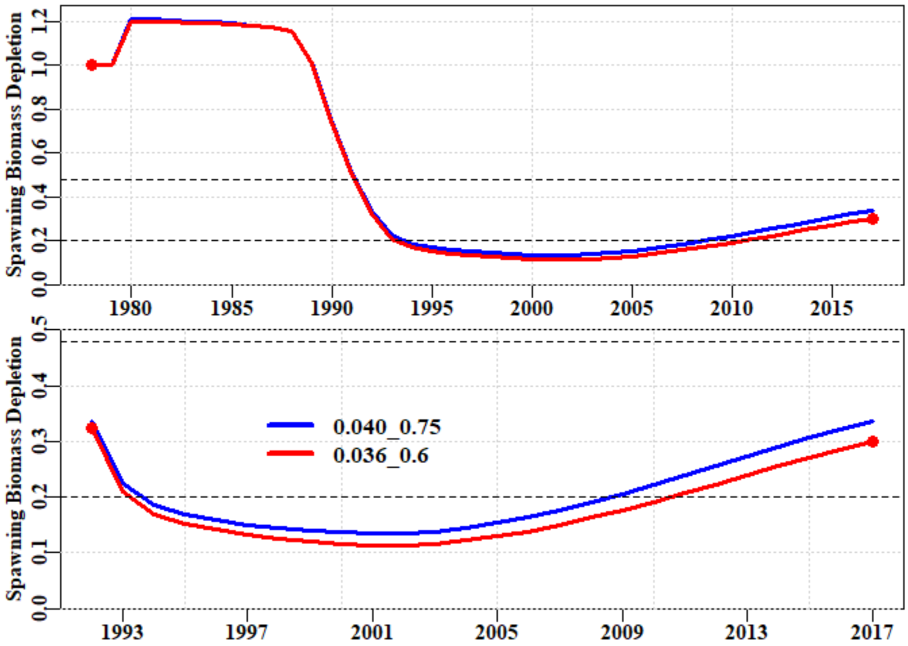


Figure 19.20. A comparison of the complete trajectory of the female spawning biomass depletion along with a magnified version focussed on the years 1992 – 2017. The dashed black lines are the limit and target reference points. The 0.040_0.75 refer to the initial base-case M=0.04 and h=0.75, while the final base-case has M=0.036 and h=0.6.

Likelihood profiles remain essentially the same as before except, of course, that the fixed values of M and h are in different locations closer to the total likelihood optimum (though still not identical to it). Further examination of the assumptions behind fixing these parameters is required. The information available in the stock assessment is insufficient for the assessment to converge when attempts are made to estimate *M*. Only assessments with many years of data and contrasting periods of depletion and recruitment are capable of generating an estimate of steepness, *h*, so no attempt was made with Orange Roughy.

19.4.5 *Forecasts and Cross-Catch Risk Assessment*

To obtain the RBCs it is necessary to project the optimum fitting model forwards into the future. As there was debate in the RAG as to which of the two base-cases should be accepted both were projected forward and results presented. The dynamics are projected forwards 55 years under the standard 20:35:48 harvest control rule for SESSF tier 1 species (Day, 2009), and then the predicted catches taken in the years 2018 onwards are detailed (Figure 19.21). In addition, to the standard projections the predicted catches for each series, from 2018 – 2040, were transferred to a projection of the alternative base-case to provide for a cross projected-catch risk assessment. Thus, the predicted catches from the initial base-case (*M*=0.04 and *h*=0.75) for years 2018 – 2040 are used in a projection of the final base-case (*M*=0.036 and *h*=0.6) and vice-versa. In this way the implications of applying the different catches if the model specification is incorrect can be determined. This is only done so as to facilitate the choices to be made by fishery managers over which base-case to adopt.

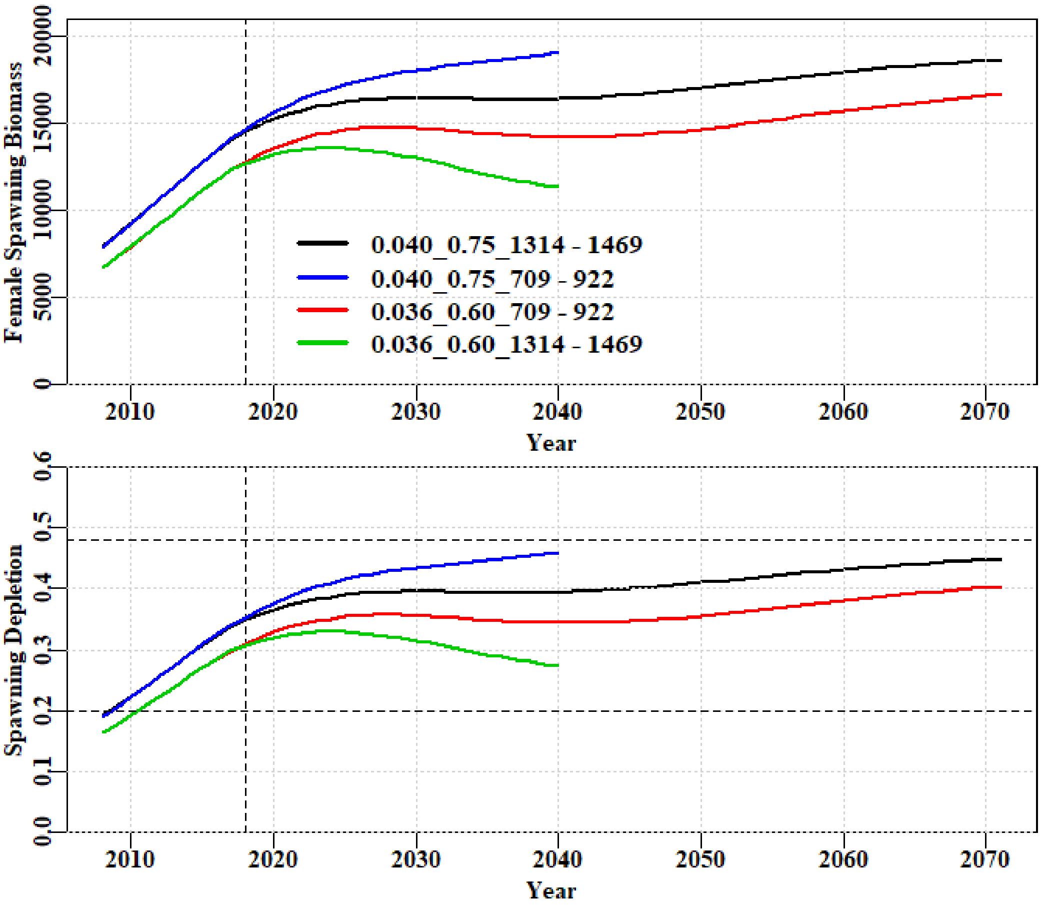


Figure 19.21. The predicted spawning biomass of Orange Roughy East projected for 55 years for the initial base-case (black line) and the final base-case (red line), using the standard 20:35:48 HCR. In addition, there is a projection to 2040 (24 years) of the initial base-case using he predicted catches from the final base-case (blue line) and of the final base-case using the predicted catches from the initial base-case (green line).

There is an unexpected dip in the recovery of both primary trajectories from about 2030 – 2050, after which they both continue on almost parallel upward trajectories (Figure 19.21), although neither achieves the target reference point by the end of 55 years (in 2071). This reduction in recovery has been brought about by the forward projection of age-0 recruitment expectations off the stock recruitment relationship for the years 1982 onwards (Figure 19.22). While the two recruitment trajectories are effectively parallel the higher intrinsic productivity implied by the initial base-case's *M* and *h* values leads directly to the higher numbers of recruits at age-0. The depletion of the spawning stock that occurred from the beginning of the 1990s leads in turn to an immediate drop in the expected recruitment in both base-cases which lasts through to the 2010s. If these low recruitment levels of age-0 fish are projected forwards for 30 or 40 years this accounts for the dip in female spawning biomass from the 2030s – 2050s.

While the predicted dip in recovery could be viewed as contrary to any strict rebuilding strategy, the projected dip is only predicted to begin after about 2027 onwards and continue until about 2051 (Figure 19.21; Table 19.12). Given the relatively high level of uncertainty in the current assessment (e.g. Figure 19.11), management would only need to become concerned after about 2025 should the predicted dip still occur in any projections.

The predicted RBCs from the final base-case for the next three years 2018 – 2020 are 709, 776, and 834, which have a mean of 773 tonnes for the 20:35:48 HCR (Table 19.13). The average yield from 2068 – 2071 is about 1,100 t, and is generated by an instantaneous fishing mortality rate of 0.0315 (equivalent to an annual harvest of 3.1%). For the initial base-case the RBCs are 1314, 1347, and 1375 t, with an average of 1345 t (Table 19.14), and the average yield in the later years is about 1665 t at an *F* of 0.042. Even after 55 years the Eastern Orange Roughy stock is not predicted to have achieved the biomass target reference point of $B_{48\%}$ in either base-case version.

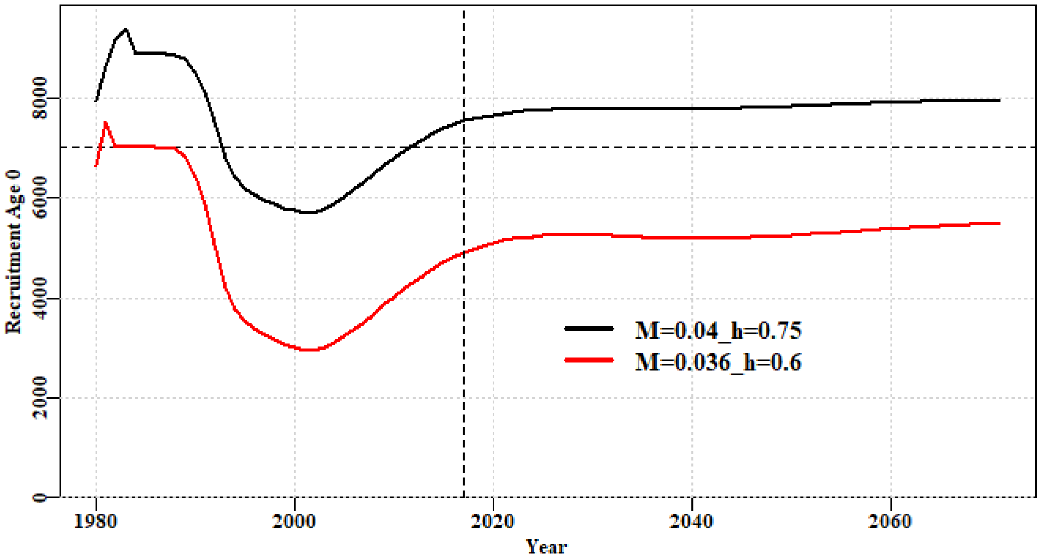


Figure 19.22. The predicted recruitment estimated from the stock recruitment relationship projected forward out for 55 years after 2017. The marked dip in expected recruitment between the early 1990s and about 2010 reflects the high degree of depletion in the spawning stock starting back in the 1990s.

While it would be possible to project the model much further than 2071, the uncertainty of such projections makes them unreliable, especially in the face of a directionally changing marine environment. Instead it is possible to revert to equilibrium methods that determine the expected production curve when the fishery is allowed to achieve equilibrium at each level of depletion (Figure 19.23).

Table 19.12. The projected female spawning biomass from the final base-case out to 2071, including the spawning biomass and the related depletion level. The highlighted years denote the period where the rebuilding stalls and even reverses until 2051.

Year	SpB	Depl	Year	SpB	Depl	Year	SpB	Depl
2015	11176	0.270	2034	14494	0.351	2053	14996	0.363
2016	11759	0.284	2035	14428	0.349	2054	15103	0.365
2017	12320	0.298	2036	14368	0.347	2055	15211	0.368
2018	12812	0.310	2037	14317	0.346	2056	15320	0.371
2019	13232	0.320	2038	14276	0.345	2057	15430	0.373
2020	13599	0.329	2039	14246	0.345	2058	15538	0.376
2021	13911	0.336	2040	14230	0.344	2059	15645	0.378
2022	14168	0.343	2041	14226	0.344	2060	15750	0.381
2023	14374	0.348	2042	14235	0.344	2061	15852	0.383
2024	14532	0.351	2043	14257	0.345	2062	15951	0.386
2025	14647	0.354	2044	14290	0.346	2063	16047	0.388
2026	14723	0.356	2045	14335	0.347	2064	16140	0.390
2027	14765	0.357	2046	14391	0.348	2065	16229	0.392
2028	14778	0.357	2047	14455	0.350	2066	16314	0.395
2029	14765	0.357	2048	14528	0.351	2067	16396	0.397
2030	14733	0.356	2049	14609	0.353	2068	16474	0.398
2031	14685	0.355	2050	14698	0.355	2069	16548	0.400
2032	14626	0.354	2051	14792	0.358	2070	16619	0.402
2033	14561	0.352	2052	14892	0.360	2071	16687	0.404

The equilibrium yield curve identifies MSY values of about 1472 and 2314 t but of more interest to the Commonwealth harvest strategy is the potential yield at 48% B_0. The equilibrium calculations that give rise to the production curve estimate the equilibrium surplus production at $B_{48\%}$ to be 1276 and 1784 t respectively (Figure 19.23).

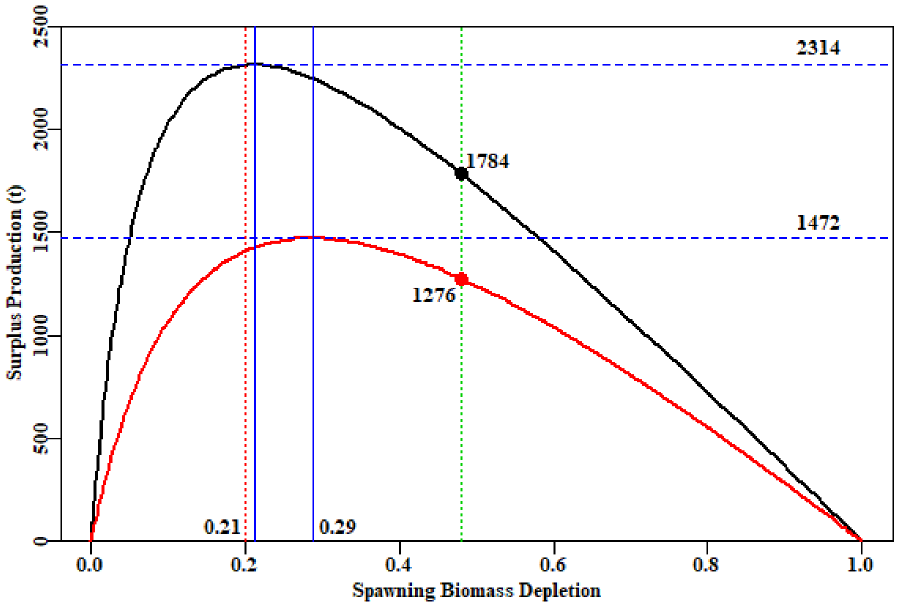


Figure 19.23. The surplus production plot for the initial (black line) and final base-cases (red line) indicating equilibrium maximum sustainable yields of 2314 t and 1472 t respectively. The long term equilibrium yield at $B_{48\%}$ was 1784 t and 1276 t in the final base-case. B_{MSY} occurred at $0.21B_0$ and $0.29B_0$ respectively.

Table 19.13. Predicted female spawning biomass, age-0 recruits, fishing mortality, and depletion across the years of projection of the final base-case (M=0.036, h=0.6).

Year	FemSpB	Recruit_0	Catch (t)	F	Depletion
Unfished	41349	0	0	0.0000	1.000
2011	8562	4009	162	0.0090	0.207
2012	9206	4167	163	0.0084	0.223
2013	9862	4315	150	0.0072	0.239
2014	10539	4456	7	0.0003	0.255
2015	11176	4590	460	0.0194	0.270
2016	11759	4708	360	0.0144	0.284
2017	12320	4809	465	0.0178	0.298
2018	12812	4902	709	0.0260	0.310
2019	13232	4978	776	0.0276	0.320
2020	13599	5041	834	0.0288	0.329
2021	13911	5094	883	0.0298	0.336
2022	14168	5137	924	0.0306	0.343
2023	14374	5173	956	0.0313	0.348
2024	14532	5200	975	0.0315	0.351
2025	14647	5221	982	0.0315	0.354
2067	16396	5436	1091	0.0315	0.397
2068	16474	5445	1096	0.0315	0.398
2069	16548	5454	1101	0.0315	0.400
2070	16619	5462	1106	0.0315	0.402
2071	16687	5470	1110	0.0315	0.404

Table 19.14. Predicted female spawning biomass, age-0 recruits, fishing mortality, and depletion across the years of projection of the Initial base-case (*M*=0.04, *h*=0.75).

Year	FemSpB	Recruit_0	Catch (t)	F	Depletion
Unfished	41634	0	0	0.0000	1.000
2011	9960	6789	162	0.0076	0.239
2012	10659	6928	163	0.0072	0.256
2013	11371	7055	150	0.0062	0.273
2014	12107	7173	7	0.0003	0.291
2015	12805	7283	460	0.0168	0.308
2016	13454	7379	360	0.0125	0.323
2017	14086	7461	465	0.0154	0.338
2018	14582	7535	1314	0.0420	0.350
2019	14941	7590	1347	0.0420	0.359
2020	15259	7628	1375	0.0420	0.367
2021	15535	7660	1400	0.0420	0.373
2022	15770	7687	1421	0.0420	0.379
2023	15965	7710	1438	0.0420	0.383
2024	16122	7728	1451	0.0420	0.387
2025	16244	7742	1461	0.0420	0.390
2067	18459	7929	1651	0.0420	0.443
2068	18516	7933	1656	0.0420	0.445
2069	18569	7938	1661	0.0420	0.446
2070	18619	7941	1665	0.0420	0.447
2071	18668	7945	1669	0.0420	0.448

19.4.5.1 Cross-catch projection risk analysis

Two assessments were generated for Orange Roughy East, the initial base-case, with *M* = 0.04 and *h* = 0.75 and the final base-case with *M* = 0.036 and *h* = 0.6. While the likelihood profile on *M*, the natural mortality (Figure 19.12), was sufficient to justify a reduction in the assumed natural mortality rate. How far to reduce it was less clear. The change from a minimum total log-likelihood occurring at 0.031 in the initial base-case to a minima at 0.032 in the final base-case indicates there is an interaction between *M* and the steepness, *h*, which is not surprising as both are related to stock productivity. Many more such analyses would be required however, to appropriately characterize this interaction.

Changing the steepness value for the stock recruitment relationship was less simple. Some RAG members felt that despite Orange Roughy being well recognized as being a low productivity species this would not necessarily require a reduction in the steepness used. The argument was made that as a species that forms dense spawning aggregations Orange Roughy would not suffer greatly from density dependent reductions in recruitment success as stock size declined and so a reduction in steepness from 0.75 to 0.6 was not warranted. On the other hand, the steepness of Orange Roughy stock recruitment relationships has never been estimated well and so the *h*=0.75 used in the initial base-case is merely a repeat of the assumptions used in many stock assessments conducted on shallower water, more productive species; this does not mean 0.75 is correct for Orange Roughy. Agreement over the issue of the contribution of steepness to Orange Roughy stock productivity was not reached in the November SE RAG and so two base-cases with their projections are presented.

One way of determining the relative risk of the management implications derived from the different base-cases is to transfer the predicted catches from each base-case to the other base-case's projections (Figure 19.21).

This was done for both base-cases and the implied trajectories included with the spawning biomass and depletion trajectories for the full projections of the two base-cases. When the predicted future catches from the initial base-case (*M*=0.04, *h*=0.75) are used to project forward the dynamics of the final base-case (*M*=0.036, *h*=0.6), the spawning biomass and depletion both began to decline reaching $0.274B_0$ by 2040 after a peak of about $0.329B_0$ in 2024 (Figure 19.21). When the predicted catches from the final base-case are used in the initial base-case projections the stock is predicted to recover at a faster rate achieving approximately $0.46B_0$ by 2040 and avoiding the 2030 - 2050 dip in stock biomass (Figure 19.21).

If only the first three years are taken account of (to reflect the impact of a three year TAC) then irrespective of which set of catches are applied to which base-case stock recovery is predicted to continue, fastest with the lower catches and more productive base-case, the two base-cases recover at about the same rate, and the higher catches in the least productive base-case still improve in terms of depletion only not so much as with the lower catches.

The lower RBC values are therefore of lower risk than the higher values, although even with a multi-year TAC from 2018 – 2020 the impact of applying the wrong catches to the wrong model is predicted to be minor (Figure 19.21).

19.5 Discussion

It was possible to extend the integrated stock assessment for Eastern zone Orange Roughy implemented using the software Stock Synthesis (Methot and Wetzel, 2013) conducted in 2014 to generate a new final base-case for the stock in 2017. In the previous assessment multiple stock structure hypotheses were examined but here only the single assumption is made of a stock encompassing the Eastern zone (Orange Roughy zone 10) and the Eastern side of the Southern zone (Orange Roughy zone 21; Pedra Branca). This reflects the previous three year TAC set for this management unit/stock.

The stock has continued to rebuild along a trajectory very similar to that predicted in the 2014 stock assessment (Upston et al, 2015). This entailed the inclusion of catches from 2014 – 2016, new age composition data from 2012 and 2016, a revised estimate of the 2013 towed-body acoustic biomass survey from 2013, and a new acoustic biomass survey estimate from 2016.

Once an initial base-case had been fitted the production of a series of likelihood profiles on some of the more important fixed parameters within the model relating to stock productivity along with the plot of stock status against catches shed doubt on the validity or plausibility of the assumed values for natural mortality, *M*, and of the steepness of the stock recruitment relationship, *h*. When the stock was depleted down to about $12\%B_0$ catches of 600 – 700 tonnes were enough to for over-fishing to be occurring and it was only once catches dropped down to about 160 t (during the acoustic surveys) that serious rebuilding occurred. This suggested the stock was not as resilient as suggested by an *M*=0.04 and a steepness of *h*=0.75. Similarly, the likelihood profile on natural mortality suggested a significant improvement in model fit given a lower value for *M* and the distribution of ages found in the Eastern zone also suggest a lower value would be more appropriate (Figure 19.12, Figure 19.13). In a similar manner the profile on steepness indicated an overall model inclination towards a much lower value than 0.75, even the Index data were slightly improved by a steepness of 0.7 (Figure 19.14). While changing the steepness had very little effect on the model fitting it had a large effect on the relative productivity (Figure 19.15).

An alternative base-case, termed the final base-case, was produced by implementing lower but plausible values of M=0.036 and h=0.06. While this improved the model fit slightly it also leads to lower levels of productivity. However, at the November SE RAG some members were not convinced that there was sufficient justification for such reductions so both base-cases are presented with their forecasts and with cross-catch risk projections. Whatever the outcome of management, the values selected for M and h need a more thorough review than was possible here before the next stock assessment. Many stock assessments in the southern hemisphere have origins from the 1990s when the growth and maximum age of Orange Roughy was still under intense debate. Given the maximum ages observed, and the occasional large plus group at 80 years the changes made in the current assessment may require further adjustment.

The stock is predicted to have reached a depletion level of about 29.8%B_0 or 33.8%B_0 in 2017. Catches and implied fishing mortality rates currently remain low enough that stock rebuilding should continue relatively rapidly over at least the next three years given the predicted RBCs from either base-case (Figure 19.21; Table 19.13, Table 19.14).

Neither base-cases predicted that the stock would recover to the biomass target reference point of 0.48B_0 within 55 years (out to 2071; the approximate generation time is estimated at about 57 years). Recovery progress was slowed in both cases by a pronounced dip in predicted recruitment produced by the rapid decline in spawning biomass that occurred in the very early 1990s (Figure 19.7, Figure 19.17, and Figure 19.22).

A cross-catch risk assessment was conducted on both base-cases indicating that in the long term allocating the higher catches to the wrong model structure could lead to a failure to recover (Figure 19.21). However, while, not surprisingly, the lower predicted RBCs (average 773 t relative to 1314 t) have a lower risk, the outcome that the application of either time series (or average) over the next three years would be difficult to distinguish according to the predictions made by the current assessment model and the precision of the estimates possible from the stock assessment model.

Using (1 – SPR), the spawning potential ratio, it was possible to assert that with either base-case the stock is neither over-fished nor is over-fishing occurring (Figure 19.7, Figure 19.17).

19.5.1 *Future developments*

Further investigations using the likelihood profile approach may have value in identifying the parameters to which the assessment is most sensitive. By generating multiple likelihood profiles with each re-weighted to a different base-line value, a comparison of these curves would indicate the variability induced by the iterative re-weighting process. If it were large it would mean that the optimum values of parameters in any one likelihood profile may depend upon what constituted the starting point within the stock assessment. Whatever the case, it is clear that the assumptions used in any assessment where there is limited data available (as in the Orange Roughy assessment) can be very influential on the final outcomes of the stock assessments and could contribute to inter-annual variations between stock assessments for the same stocks (Punt et al, 2017).

With regard to future data collection, when further age-composition data are collected consideration should be given to increasing the sample sizes in an effort to reduce the noisiness (spikiness) of the age-compositions obtained. Some consideration to obtaining relatively balanced samples between the sexes might also be made. A continuation of the acoustic surveys will also always have value.

19.6 Acknowledgements

Thanks go to Rudy Closer and Caroline Sutton for details of the Orange Roughy acoustic surveys and the recent re-calibration of the transducers, which had important implications. Thanks also to the providers of other data for this work: Robin Thomson for the landings and discard data, André Punt for processing the ageing error calculations; Kyne Krusic-Golub (Fish Ageing Services Pty Ltd) for the provision of ageing data. Thanks also to other members of CSIRO SESSF Assessment team for their helpful discussion during the assessment process during the year. Dr Fay Helidoniotis of ABARES is thanked for discussions regarding the determination of over-fishing status, which has led to the inclusion of the (1 – SPR) phase plot.

19.7 References

AFMA (2014) *Orange Roughy (Hoplostethus atlanticus) Stock Rebuilding Strategy 2014.* Australian Fisheries Management Authority, Canberra, 20 p.

AFMA (2017) *Southern and Eastern Scalefish and Shark Fishery Management Arrangements Booklet 2017.* Australian Fisheries Management Authority, Canberra, 92 p.

Annala, J.H. (Comp.) (1994) Report from the Special Fishery Assessment Plenary, 27 May 1994: stock assessments and yield estimates for ORH 2A, 2B, and 3A. (Cited in CSIRO and TDPIF, 1996) 17 p.

Anon (1995) Trial studies of alternate techniques for stock delineation of orange roughy. FRRF Project 1992/93 no. 18. Final report to AFMA. (Cited in Smith et al., 1998).

Bax, N. (1997). Stock Assessment Report 1997: Orange roughy. Report for the South East Fishery Stock Assessment Group. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 64 p. (Unpublished report held by CSIRO, Hobart).

Bax, N. (2000). Stock Assessment Report 2000: Orange roughy. Report for the South East Fishery Stock Assessment Group. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 81 p. (Unpublished report held by CSIRO, Hobart).

Bax, N. (2000a). Stock Assessment Report: Orange roughy 1995, Stock Assessment Report, South East Fishery Stock Assessment Group, Australian Fisheries Management Authority, Canberra, 55 p. (Unpublished report held by AFMA, Canberra).

Bax, N. (2000b). Stock Assessment Report: Orange roughy 1996, Stock Assessment Report, South East Fishery Stock Assessment Group, Australian Fisheries Management Authority, Canberra, 37 p. (Unpublished report held by AFMA, Canberra)

Bell, J.D., Lyle, J.M., Bulman, C.M., Graham, K.J., Newton, G.M. and Smith, D.C. (1992) Spatial variation in reproduction, and occurrence of non-reproductive adults, in orange roughy, *Hoplostethus atlanticus* Collett (Trachichthyidae), from south-eastern Australia. Journal of Fish Biology 40: 107-122.

Clarke, M.R. and M.R. Dunn (2012) Spatial management of deep-sea seamount fisheries: balancing sustainable exploitation and habitat conservation. *Environmental Conservation* **39**: 204 – 214

CSIRO and TDPIF (1996). Orange roughy 1994, Stock Assessment Report, South East Fishery Assessment Group. Australian Fisheries Management Authority, 204 p. (Unpublished report held by AFMA, Canberra).

Cordue, P.L. (2011) Review of the 2011 Orange roughy Eastern Zone Stock Assessment. ISL Client Report for South East Trawl Fishing Industry Association. 1 September 2011. 10p.

Cordue, P.L. (2014) The 2014 orange roughy stock assessments. New Zealand Fisheries Assessment Report 2014/50. September 2014. Ministry for Primary Industries, Wellington, New Zealand. 137 p.

DAFF (2007) Commonwealth Fisheries Harvest Strategy. Policy and Guidelines. Department of Agriculture, Fisheries and Forestry. 55p.

Day, J. (2009) Modified breakpoint for the 2008 Tier 1 harvest control rule. Pp 198 – 202 *in* Tuck, G.N. (*ed.*) 2009. *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2008.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 645 p.

Deriso, R. and Hilborn, R. (1994). A Review of the 1994 Stock Assessment for Orange roughy. Review completed for the Australian Fisheries Management Authority, 28 p. (Unpublished report held by AFMA, Canberra).

Diver, G. (2004). Data Collection for the Eastern Zone Orange roughy Survey, July 2004. Report completed by Diversity – Sustainable Development Consultants, W.A. 23 p. (Unpublished report held by CSIRO, Hobart).

Dunn, M.R. and Devine, J.A. (2010) An holistic approach to determining stock structure of orange roughy on the Chatham Rise. New Zealand Fisheries Assessment Report 2010/17, 65 p.

Francis, R.I.C.C. (1992) Recommendations concerning the calculation of maximum constant yield (MCY) and current annual yield (CAY). New Zealand Fisheries Assessment Research Document 92/8, 27 p.

Francis, R.I.C.C. (2006) Some recent problems in New Zealand orange roughy assessments. New Zealand Fisheries Assessment Report 2006/43. 65 p.

Francis, C. and Hilborn, R. (2002). A Review of the 2002 Orange roughy Stock. Review completed for the Australian Fisheries Management Authority, 14 p. (Unpublished report held by AFMA, Canberra).

Francis, C. (2011) Data weighting in statistical fisheries stock assessment models. Canadian Journal of Fisheries and Aquatic Science **68**: 1124-1138.

Gelman, A., Carlin, J.B., Stern, H.S. and Rubin, D.B. (2003) Bayesian Data Analysis. 2nd Edition. Chapman & Hall/CRC Press, Florida. 668 p.

Haddon, M. (2011) *Modelling and Quantitative Methods in Fisheries*. 2nd Chapman & Hall, CRC, Boca Raton, 449 p.

Haddon, M. (2017) Orange Roughy East (*Hoplostethus atlanticus*) stock assessment using data to 2016 Report to September 2017 SE RAG meeting. CSIRO, Oceans and Atmosphere, Australia. 32p.

Kimura, D., Balsiger, J. and Ito, D. (1984) Generalized stock reduction analysis. *Canadian Journal of Fisheries and Aquatic Sciences* **41**: 1325–1333.

Kloser, R. J., T. E. Ryan, et al. (2001). Development and application of a combined industry/scientific acoustic survey of orange roughy in the eastern zone. Final report to Fisheries Research and

Development Corporation 99/111. Available from Fisheries Research and Development Corporation, P.O. Box 222, Deakin West, ACT 2600, Australia.

Kloser & Ryan (2002) *Review of Analysis methodologies and data holdings for acoustic assessments of orange roughy on St Helens Hill, 1989 - 1999.* CSIRO Marine Research 40p

Kloser, R., Ryan, T. and Daley, R. (2008) *2006 Eastern Zone orange roughy acoustic survey.* Report to the South East Trawl Fishery Association, CSIRO Marine and Atmospheric Research, Hobart, 92 p.

Kloser, R.J., Knuckey, I.A., Ryan, T.E., Pitman, L.R. and Sutton, C. (2011) *Orange roughy conservation program: Eastern Zone surveys and trials of a cost-effective acoustic headline system.* Final report to the South East Trawl Fishing Industry Association, CSIRO Marine and Atmospheric Research, Hobart, 153 p.

Kloser, R., Sutton, C. and Krusic-Golub, K. (2012) *Australian spawning population of orange roughy: Eastern zone acoustic and biological index fished from 1987 to 2010.* Report to the South East Trawl Fishing Industry Association, CSIRO Marine and Atmospheric Research, Hobart, 64 p.

Kloser, R.J., Macaulay, G., Ryan, T.E. and M. Lewis (2013) Identification and target strength of orange roughy (*Hoplostethus atlanticus*) measured in situ. *Journal of the Acoustical Society of America* **134**: 97 – 108

Kloser, R.J., Sutton, C., Krusic-Golub, K., and T.E. Ryan (2015) Indicators of recovery for orange roughy (*Hoplostethus atlanticus*) in eastern Australian waters fished from 1987. *Fisheries Research* **167**: 225 – 235

Kloser, R., Sutton, C., Kunnath, H. and R. Downie (2016) *Orange roughy eastern zone spawning biomass 2016.* [Draft] Report for South East Trawl Industry Association. CSIRO Oceans and Atmosphere, Hobart. 34 p.

Koslow, J.A., Bulman, C.M., Lyle, J.M. and Haskard, K. (1995) Biomass Assessment of a Deep-water Fish, the Orange roughy (*Hoplostethus atlanticus*), based on an Egg Survey. Mar. Freshwater Res., 46: 819-830.

Lyle, J.M., Evans, K. & Wilson, M.A. (1989) A summary of orange roughy biological information 1981 – 1986. Technical report 39, Department of Sea Fisheries Tasmania (Cited in Prince & Hordyk, 2011).

Lyle, J.M., Kitchener, J. & Riley, S.P. (1991) An assessment of orange roughy resource off the coast of Tasmania. Final report to FIRDC, Project 87/65.

McAllister, M.K. and J.N. Ianelli. (1997). Bayesian stock assessment using catch-at-age data and the sampling-importance-resampling algorithm. *Canadian Journal of Fisheries and Aquatic Sciences* 54: 284-300.

Methot, R.S., A'mar, T., Wetzel, C. and I. Taylor (2017) Stock Synthesis User Manual Version 3.30.05. NOAA Fisheries, Seattle, WA, USA. 178p.

Methot, R.D. and I.G. Taylor (2011) Adjusting for bias due to variability of estimated recruitments in fishery assessment models. *Canadian Journal of Fisheries and Aquatic Sciences* **68**:1744-1760.

Methot, R.D. and C.R. Wetzel (2013) Stock Synthesis: a biological and statistical framework for fish stock assessment and fishery management. Fisheries Research 142, 86-99.

MFSWG (2009) Report from the Fisheries Assessment Plenary, May 2009: stock assessments and yield estimate, Orange roughy, Ministry of Fisheries Science Working Group: 474-479.

Norse, E.A., Brooke, S., Cheung, W.W.L., Clark, M.R., Ekeland, I., Froese, R., Gjerde, K.M., Haedrich, R.L., Heppell, S.S., Morato, T., Morgan, L.E., Pauly, D., Sumaila, R. and R. Watson (2012) Sustainability of deep-sea fisheries. *Marine Policy* **36**: 307 – 320

Pitman, L.R., Haddy, J.A. and R.J. Kloser (2013) Fishing and fecundity: The impact of exploitation on the reproductive potential of a deep-water fish, orange roughy (*Hoplostethus atlanticus*) *Fisheries Research* **147**: 312 – 319

Pitman, L.R., Haddy, J.A. and R.J. Kloser (2014) Response to comment on "fishing and fecundity: The impact of exploitation on the reproductive potential of a deep-water fish, orange roughy (*Hoplostethus atlanticus*)" *Fisheries Research* **155**: 196 – 197

Prince, J. and Hordyk, A. (2011 Draft) Observation of the 2009 Cascade Roughy Spawning Season and drafting of a DeepRAG synthesis paper on orange roughy stock structure in the southern Australia. AFMA Project No. 2009/808, 23 p.

Punt, A.E., Smith, D.C., Krusic Golub, K. and S. Robertson (2008) Quantifying age-reading error for use in fisheries stock assessments, with application to species in Australia's southern and eastern scalefish and shark fishery. *Canadian Journal of Fisheries and Aquatic Science* **65**: 1991–2005

Punt, A.E. (2014) User manual: Age-reading error matrix estimator (AGEMAT). School of Aquatic and Fishery Sciences, University of Washington, USA. 9 p.

Punt, A.E., Day, J., Fay, G., Haddon, M., Klaer, N., Little, L.R., Privitera-Johnson, K., Smith, A.D.M., Smith, D.C., Sporcic, M., Thomson, R., Tuck, G.N., Upston, J., and S. Wayte (2017) Retrospective investigation of assessment uncertainty for fish stocks off southeast Australia *Fisheries Research* **198**: 117-128.

Ryan, T. E., Sutton, C. and R. Kloser (2013) *Biomass estimates of orange roughy at the Tasmanian Eastern Zone spawning grounds in July 2012 using a net attached acoustic optical system.* Report to South East Trawl Fishing Industry Association. CSIRO Marine and Atmospheric Research Laboratories, Hobart, Australia: 40 p.

Ryan, T. E., Sutton, C. and R. Kloser (2014) *Biomass estimates of orange roughy at the Tasmanian Eastern Zone spawning grounds in July 2013 using a net attached acoustic optical system.* Report to South East Trawl Fishing Industry Association. CSIRO Marine and Atmospheric Research Laboratories, Hobart, Australia. 41p.

Smith, D.C., Fenton, G.E., Robertson, S.G. and Short, S.A. (1995) Age determination and growth of orange roughy (Hoplostethus atlanticus): a comparison of annulus counts with radiometric ageing. *Canadian Journal of Fisheries and Aquatic Sciences* **52**: 391-401.

Smith, D.C., Robertson, S.G. and Morrison, A.K. (1998) Age composition of orange roughy in the Eastern and Southern Management Zones. Report to Fisheries Research & Development Corporation, Project No. 95/032. Marine and Freshwater Resources Institute, Victoria, Australia. 40 p.

Smith, A.D.M, Punt, A.E., Wayte, S.E., Starr, P.J., Francis, R.I.C.C., Stokes, T.K., Hilborn, R., Langley, A. (2001) Stock assessment for the northeast Chatham Rise orange roughy for 2001. *New Zealand Fisheries Assessment Report 2002/25*. 30 p.

Stokes, K. (2009). Orange roughy Assessment Review. Report completed for the Australian Fisheries Management Authority, 33 p. (Unpublished report held by AFMA, Canberra).

Taylor, I., Stewart, I., Hicks, A., Garrison, T., Punt, A., Wallace, J., Wetzel, C., Thorson, J., Takeuchi, Y., Ono, K., Monnahan, C., Stawitz, C.C., A'mar, Z.T., Whitten, A.R., Johnson, K.F., Emmet, R.L., Anderson, S.C., Lambert, G.I., Stachura, M.M., Cooper, A.B., Stephens, A. and Neil Klaer.

(2017) *R code for Stock Synthesis (r4ss)*. NOAA Fisheries, Northwest Fisheries Science Centre, Seattle, WA.

Tingley, G. and M. Dunn (In preparation) *Global Review of Orange Roughy* (Hoplostethus atlanticus)*, their Fisheries, Biology, and Management.* Report of the Auckland, June 2016 Meeting. FAO, Rome

Tracey, D., Horn, P., Marriott, P., Krusic-Golub, K., Green, C., Gili, R., Mieres, L.C. (2007) Orange roughy ageing workshop, otolith preparation and interpretation. Report to the Deepwater Fisheries Assessment Group. Report contributors: NIWA, Wellington (New Zealand), DPI, Victoria (Australia), and CEPES, Valparaíso (Chile) 26 p.

Upston, J. and S. Wayte (2012) Orange roughy (*Hoplostethus atlanticus*) Eastern Zone preliminary stock assessment incorporating data up to 2010 – definition of the base-case model. pp 180 – 217 *in* Tuck, G.N. (*ed*) (2012) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2011. Part 1.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 377p.

Upston, J. and S. Wayte (2012b) Orange roughy (*Hoplostethus atlanticus*) Eastern Zone preliminary stock assessment incorporating data up to 2010 – future work. pp 218 – 225 *in* Tuck, G.N. (*ed*) (2012) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2011. Part 1.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 377p.

Upston, J., Punt, A.E., Wayte, S., Ryan, T., Day, J. and M. Sporcic (2015) Orange roughy (*Hoplostethus atlanticus*) Eastern Zone stock assessment incorporating data up to 2014. pp 10 – 81 *in* Tuck, G.N. (*ed*) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2014. Part 1.* Australian Fisheries Management Authority and CSIRO Oceans and Atmosphere Flagship, Hobart. 170p.

Venzon, D.J. and S.H. Moolgavkar (1988) A method for computing profile-likelihood-based confidence intervals. Applied Statistics, 37: 87-94.

Wayte, S. and Bax, N. (2002) Orange roughy Stock Assessment pp 167 – 208 *in* Smith, A.D.M. and S. Wayte (*eds*) (2002) *The South East Fishery 2002*, Fishery Assessment Report compiled by the South East Fishery Assessment Group. Australian Fisheries Management Authority, Canberra.

Wayte, S.E. (2002). Southern Zone Orange roughy Stock Assessment. Report to Orange roughy Stock Assessment Group. Australian Fisheries Management Authority, Canberra.5 p. (Unpublished report held by CSIRO, Hobart).

Wayte, (2006) Stock assessment of the Cascade Plateau orange roughy (*Hoplostethus atlanticus*). pp 148 – 172. *in* Tuck, G.N. (*ed*) (2006) *Stock assessment for the South East Scalefish and Shark Fishery 2004-2005.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 222 p.

Wayte, (2006b) Analysis of Orange roughy (Hoplostethus atlanticus) Catch Data from the Southern Zone. pp 173 – 179. *in* Tuck, G.N. (*ed*) (2006) *Stock assessment for the South East Scalefish and Shark Fishery 2004-2005.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 222 p.

Wayte, (2006c) Analysis of Orange roughy (Hoplostethus atlanticus) Catch Data from the Western Zone. pp 180 – 186. *in* Tuck, G.N. (*ed*) (2006) *Stock assessment for the South East Scalefish and Shark Fishery 2004-2005.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 222 p.

Wayte, (2006d) Stock assessment of the Cascade Plateau orange roughy (*Hoplostethus atlanticus*). pp 206 – 228. *in* Tuck, G.N. (*ed*) (2006) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2005-2006.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 292 p.

Wayte, (2006e) SESSF harvest strategy framework applied to deepwater species. pp 229 – 246. *in* Tuck, G.N. (*ed*) (2006) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2005-2006.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 292 p.

Wayte, S. (2007) Eastern Zone Orange roughy. pp 429 – 447 *in* Tuck, G.N. (*ed*) (2007) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2006-2007. Volume 1: 2006.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 570 p.

Wayte, S. and N. Bax (2007) Stock Assessment of the Cascade Plateau Orange roughy 2006. pp 411 – 428 *in* Tuck, G.N. (*ed*) (2007) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2006-2007. Volume 1: 2006.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 570 p.

19.8 Appendix A

Table 19.15. The observed age frequency in samples of Eastern zone Orange Roughy. ‘F’ is female and ‘M’ is male. There were no observations of fish younger than 8 years old.

	F	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**
N	**411**	**595**	**282**	**637**	**414**	**696**	**426**	**338**	**596**	**726**	**298**	**634**	**503**	**248**	**545**	**247**
Age	**1992**	**1995**	**1999**	**2001**	**2004**	**2010**	**2012**	**2016**	**1992**	**1995**	**1999**	**2001**	**2004**	**2010**	**2012**	**2016**
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
13	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
14	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0
17	0	0	0	0	0	2	0	0	0	0	0	2	2	2	0	0
18	0	0	0	2	1	3	0	0	0	0	0	1	3	1	0	0
19	0	0	0	3	3	2	0	0	0	0	0	1	6	0	1	1
20	0	0	1	1	3	6	0	0	0	1	0	5	7	3	0	1
21	0	0	0	1	8	5	2	1	0	0	0	5	11	8	1	2
22	0	0	3	6	9	14	3	1	0	4	2	11	13	9	5	4
23	1	2	3	14	11	25	4	9	1	3	5	16	14	7	14	14
24	0	2	2	8	14	19	6	6	1	10	3	13	22	15	18	13
25	1	4	10	14	18	27	12	9	0	9	8	33	23	10	23	14
26	2	12	7	29	24	33	13	6	3	10	13	27	28	23	31	22
27	3	15	13	26	20	38	14	12	5	24	19	51	27	16	29	16
28	4	9	14	39	15	48	15	20	5	31	12	46	34	19	35	14
29	2	4	8	16	21	37	24	10	1	10	6	20	25	10	30	12
30	3	13	6	26	20	19	23	15	4	29	14	45	23	9	31	5
31	2	15	15	20	23	29	20	9	1	15	14	35	28	15	35	19
32	5	17	15	32	21	25	14	21	3	29	21	42	24	13	35	13
33	5	24	14	26	21	26	10	13	7	19	11	26	21	17	32	16
34	3	15	6	11	19	36	29	10	6	25	13	21	22	8	33	14
35	12	17	12	29	7	23	21	9	6	26	14	17	13	7	31	14
36	5	12	3	19	11	17	19	14	8	19	14	12	14	8	21	8
37	5	19	5	26	11	25	15	16	10	25	8	16	17	7	20	12
38	6	17	8	15	8	21	23	14	7	17	8	10	6	7	21	5
39	7	11	6	12	8	17	12	16	14	5	6	12	9	4	12	4
40	2	16	7	11	7	17	15	18	12	21	8	8	12	4	8	3
41	8	13	14	15	7	13	13	6	17	19	6	14	11	5	10	3
42	13	18	6	8	8	9	8	12	14	22	7	7	5	4	12	3
43	10	17	11	11	9	11	13	7	16	23	8	4	6	3	3	1
44	10	23	1	12	10	15	9	6	13	28	6	8	3	3	5	1
45	7	25	2	14	1	12	11	8	16	20	6	5	6	2	5	2
46	11	15	7	4	9	7	7	8	16	13	3	9	2	3	5	3
47	11	20	3	8	6	4	6	8	11	15	4	7	7	1	1	1
48	22	15	4	7	3	4	6	6	17	11	4	6	3	1	3	0
49	14	9	1	7	1	4	5	3	12	14	4	5	2	1	2	0
50	10	13	5	2	3	7	5	2	11	13	1	8	3	0	2	1
51	12	11	2	6	1	1	4	1	15	15	3	3	3	1	1	0
52	13	6	1	8	3	4	2	6	19	7	2	3	3	0	0	1
53	6	10	3	7	6	7	5	3	22	14	6	4	4	0	4	0
54	12	11	5	7	5	6	2	3	16	11	4	4	2	0	1	0
55	12	11	6	9	3	4	1	2	25	6	1	5	3	0	3	0

cont. The observed age frequency in samples of Eastern zone Orange Roughy. ‘F’ is female and ‘M’ is male. There were no observations of fish younger than 8 years old.

	F	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**
Age	**1992**	**1995**	**1999**	**2001**	**2004**	**2010**	**2012**	**2016**	**1992**	**1995**	**1999**	**2001**	**2004**	**2010**	**2012**	**2016**
56	9	13	2	8	1	5	3	0	25	14	2	3	2	0	1	0
57	15	11	0	6	0	1	3	4	13	7	5	2	0	0	1	0
58	9	6	4	9	1	4	1	1	16	15	5	2	2	0	1	0
59	8	6	3	3	0	3	1	0	8	6	2	2	2	0	0	0
60	11	10	2	3	0	3	2	1	10	9	0	6	0	0	1	0
61	6	12	5	2	2	3	1	0	10	9	3	2	0	0	0	1
62	8	3	2	4	0	4	0	1	19	3	1	3	0	0	2	0
63	6	7	2	5	2	2	0	1	13	4	0	3	4	0	2	0
64	6	7	2	7	2	5	1	0	10	9	1	2	1	0	0	0
65	7	3	4	2	3	3	2	1	9	5	0	2	1	0	0	2
66	7	6	2	6	1	1	1	1	6	4	1	4	1	0	0	0
67	6	10	0	2	1	5	3	1	10	6	1	3	1	0	0	0
68	7	5	0	1	0	0	3	0	8	3	2	0	2	0	1	0
69	6	3	1	4	0	1	0	1	6	8	0	1	3	1	0	0
70	6	4	2	6	1	0	2	0	8	6	2	2	0	0	0	0
71	3	5	0	2	1	2	1	1	6	1	0	3	0	0	0	0
72	6	7	1	1	1	1	0	0	5	6	4	4	0	0	0	0
73	2	1	0	5	1	1	0	0	7	1	0	1	0	0	3	0
74	3	5	2	2	1	1	1	1	7	4	0	5	3	0	0	0
75	6	3	0	5	1	0	2	0	6	1	2	1	1	0	0	0
76	3	3	1	3	1	1	0	0	2	4	0	1	0	0	0	0
77	1	1	0	1	2	1	0	0	3	1	1	0	1	0	0	0
78	0	1	1	1	1	0	0	0	2	4	0	3	0	0	0	0
79	31	22	12	37	13	27	6	14	53	33	1	10	11	0	9	1

20. Western Orange Roughy

Malcolm Haddon

CSIRO Oceans and Atmosphere, GPO Box 1538, Hobart, TAS 7001, Australia

20.1 Summary

The recovery of the Eastern zone (roughy zone 10) Orange Roughy (*Hoplostethus atlanticus*) has raised interest in the current status of other Orange Roughy stocks, in particular that in the Western zone (zone 30). Previous stock assessments primarily used standardized CPUE but only analysed data to 2001. At an Orange Roughy workshop held during the March 2017 SESSF RAG meeting in Canberra it was decided to attempt an updated CPUE standardization for catch and effort data from Orange Roughy zone 30 up to the beginning of the deep water closure that was installed in 2007.

Orange Roughy data were obtained from the CSIRO version of the AFMA catch and effort log book by selecting only on the CAAB code (37255009), that is across all fisheries, methods and areas. After correcting some negative Longitudes the data were selected for those records from zone 30, between the years 1989 - 2006, in depths > 500m, from Longitudes > 100, and Latitudes between -42 and -36. After testing the effect of selecting for different durations of effort a full analysis was conducted on records with <= 1 Hour of trawling effort.

The statistical model used the log of CPUE rather than of catches, as were used in the last stock assessment as this improved the statistical properties of the data and subsequent analysis:

log(catch/effort) = Year + Vessel + Month + unitLat

where unitLat was each degree of latitude rounded to the lowest whole number. This model only described about 17% of the variation in the available data, which is a reflection of high levels of variation at the start and end of the time series, much of which was due to low numbers of observations. Nevertheless, between 2002 - 2006 there was a three-fold increase in the standardized CPUE. While the variation around each of the increasing mean estimates also increased, nevertheless, the change in CPUE across those years appears to represent a significant increase sufficient to warrant further investigations.

20.2 Introduction

The western Orange Roughy Zone (zone 30) in the SESSF was the first region to be fished intensely for Orange Roughy (*Hoplostethus atlanticus*) in the late 1980s through to the mid-1990s (Table 1); between 1986 - 1989 over 15000 tonnes were removed. The southern zones (20 and 21), however, started serious exploitation from 1989 onwards and while from 1986 - 2006 there were 21573 tonnes reported as taken from the Western zone, over the same period 67585 tonnes were taken from the Southern zone and about 59282 t reported from the eastern zone (Table 20.1; Figure 20.1).

Table 20.1. Reported catches of Orange Roughy from the Orange Roughy zones 20, 21, and 30 for the years 1986 - 2015. Catches even in zone 30 were greatly reduced following the introduction of the 700m closure in 2007, with slight increases following adjustment of the 700m boundary in 2009. (Figure 20.1).

Year	20	21	30	Year	20	21	30
1986	604.056	26.700	3924.912	2001	142.215	198.857	200.843
1987	320.800	31.750	5117.988	2002	67.215	90.543	255.735
1988	468.915		4722.200	2003	94.151	114.935	217.502
1989	4993.746	2626.002	1365.128	2004	42.140	97.095	283.110
1990	14898.681	9897.745	801.567	2005	55.917	37.550	264.607
1991	3496.314	8025.082	625.407	2006	4.272	1.230	139.316
1992	2412.841	5241.587	1108.241	2007	4.884	16.937	28.571
1993	2484.272	4758.372	964.409	2008	0.232		3.331
1994	2165.089	2307.755	800.618	2009	9.724	0.064	13.859
1995	1430.519	613.521	962.399	2010	18.278	0.094	21.440
1996	503.075	278.364	1180.349	2011	15.026	16.750	31.426
1997	217.591	232.528	297.003	2012	20.112	0.028	17.253
1998	80.477	215.115	316.131	2013	9.467		35.940
1999	69.888	95.009	210.529	2014	30.372	0.004	22.087
2000	156.547	130.749	169.337	2015	7.943	44.564	16.206

Associated with the rapid depletion of the stocks in the South-East, in 2006 Orange Roughy was declared as conservation dependent and the first version of the deepwater (700m) closure was introduced in 2007 (Figure 20.2). This closure and greatly reduced non-target TACs reduced catches markedly. After the deepwater closure was revised in 2009 some byproduct catches of Orange Roughy began to occur, with further changes documented in the Septmeber 2016 revision of the marine closure (DAFF, 2016). While these most recent openings imply there could be greater catches of Orange Roughy, the current catches remain minor (Table 20.1; Figure 20.1, Figure 20.2).

The assessment of the eastern stock in 2011 (Upston and Wayte, 2012) demonstrated that the Eastern stock had recovered to close to the Commonwealth Limit Reference Point of 20%B0, and it was clear that the median estimates of female spawning stock size stock would soon be significantly above the limit. The most recent stock assessment confirmed this expectation with an estimate of current depletion being approximately 26%B0. This in turn led to the re-commencement of some limited targeted fishing. The rebuilding of Orange Roughy in the East was expected because of the late maturity and long time-scale in relation to its recruitment dynamics. The recruitment to the stock that has occurred since the fish-down in the 1990s derives from cohorts spawned prior to the main fishery starting. Hence such rebuilding is not surprising. Whether there is now going to be a dearth of recruitment as a result of the reduction in spawning biomass has yet to be determined. Whatever the case, the rebuilding in the east raises the question of whether Orange Roughy stocks fished elsewhere, for example in the Western Zone, have also rebuilt. It seemed reasonable therefore to consider what was known about the western stock in a recent workshop held in Canberra in March 2017.

20.3 Objectives

One of the outcomes of the 2017 Canberra workshop was a decision to consider what data was available and whether any of it showed indications of recovery. Earlier assessments in the Western Zone had used CPUE as a measure of fishery performance and so included in the search for signs or recovery (or otherwise) a standardization of available catch and effort data was requested. Hence the objective of this document is:

- Produce a preliminary analysis of CPUE (as catch-per-shot) for Orange Roughy taken in the Western Zone (Orange Roughy Zone 30; Figure 20.2).

20.4 Results

Before conducting any analyses it is best to characterize the properties of what data are available (see also Appendix 1). This includes a consideration of any data selections made (which mostly mirror what was done in the past). Such selections are very important as they can have large influences on the outcome of any analysis. In addition, there were some oddities in the data base such as some records with negative Longitudes, which only made sense when they were made positive.

In the earlier assessments the standardizations were based upon data that had some filtering applied:

- only use data from 1989 onwards so that fishing was no longer focused on large aggregations of roughy,
- a recent addition is to reject data after 2006 so as to exclude catches after the 700m deep-water closure had come into effect,
- only use data with effort < 1 hour to exclude shots targeted at deep water sharks (this will be examined in some detail by comparing the outcome when effort is restricted to < 1.5 and < 2 hours),
- exclude records with no catch, no effort, or depths < 500m.

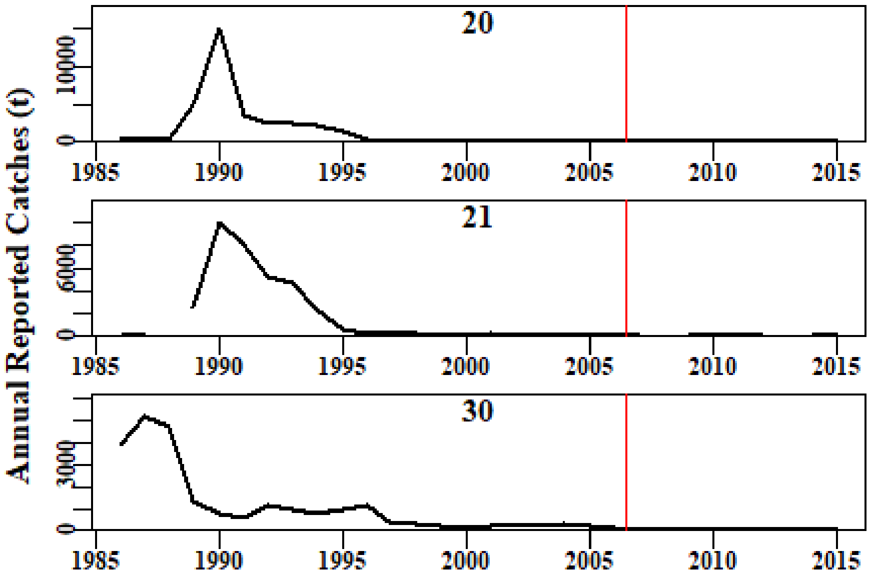


Figure 20.1. The catches reported from Orange Roughy zones 20, 21, and 30.

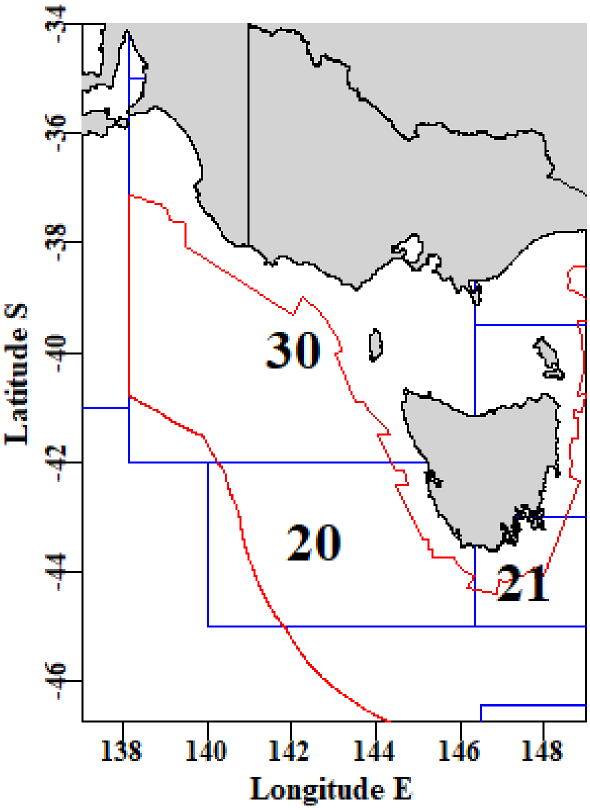


Figure 20.2. A schematic map of the three Orange Roughy zones. The latest deepwater closure definition (September 2016) is included as the red line. Zone 30 is the Western Orange Roughy zone.

20.4.1 *The Characteristics of the Effort Data*

The target species in the western deepwater fishery included both Orange Roughy but also deepwater sharks. These two fisheries operate differently with the length of trawl tows in the deepwater shark fishery being expected to be much longer than shots aimed at Orange Roughy. This is apparent when one examines the effort data from 1989 - 2006 from Orange Roughy 30 (Figure 20.3). In the 2000 and 2002 assessments the data selection was based on shots of <= 1 hour, however, it would appear that there are many shorter shots up to two hours in length (Figure 20.3). If we consider all shots < 2.5 hours in duration we see spikes of reported effort at half-hourly intervals. These specific durations may have been the intent but how precisely they were adhered to in reality, rather than in the reporting, is unknown. Whatever the case, they make the statistical distribution of such data difficult to model well. Here we will compare the outcome of the CPUE standardization when we compare shots <= 1h, <= 1.5h, and <=2h.

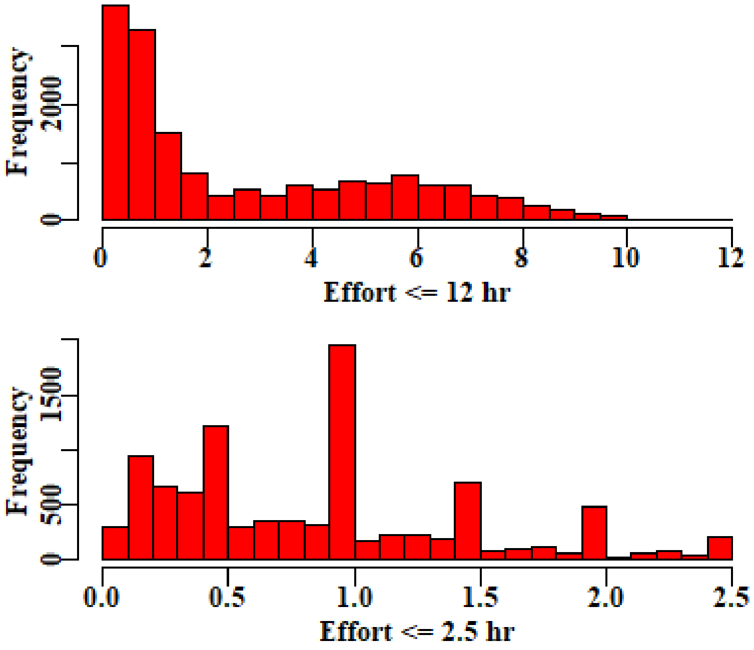


Figure 20.3. The relative frequency of different effort levels in Orange Roughy zone 30, for the years 1989 - 2006, and from Longitudes East of 100.0 and between latitudes -42 and -36. The top plot is all data while the bottom only considers tows less than 2.5 hours.

As the data were rounded and variable there was no obvious cut off point of effort so it was decided to examine the outcome of selecting records with <= 1hour, <= 1.5 hours, and <= 2 hours.

20.5 The Statistical Analysis

The 2002 stock assessment (Wayte and Smith, 2002) followed the 2000 assessment and both were dependent upon the use of catch-per-shot as an index of relative abundance. It was decided to attempt an extension of that time series of CPUE using the more recent data to the end of 2006.

A comparison of the analysis with and without the second two conditions was made.

The model used in the 2000 and 2002 assessments was relatively simple:

log(catch) = Year + Vessel + Quarter + log(effort)

Here we will repeat the analysis only using Month of fishing rather than quarter, and adding another categorical factor by using *unitlat*, which is merely the latitude of fishing truncated to the lowest integer latitude value.

log(catch/effort) = Year + Vessel + Month + unitLat

Importantly, rather than standardizing on catch, whose distribution and variance structure are atypical, catch rates were calculated (as kg/hr) and log-transformed, which generated a more statistically workable distribution (Figure 20.4). This provides an illustration of the potential issues raised by standardizing with log(catch) as the dependent variable instead of log(CPUE), and keeping log(Effort) on the side of the independent variables.

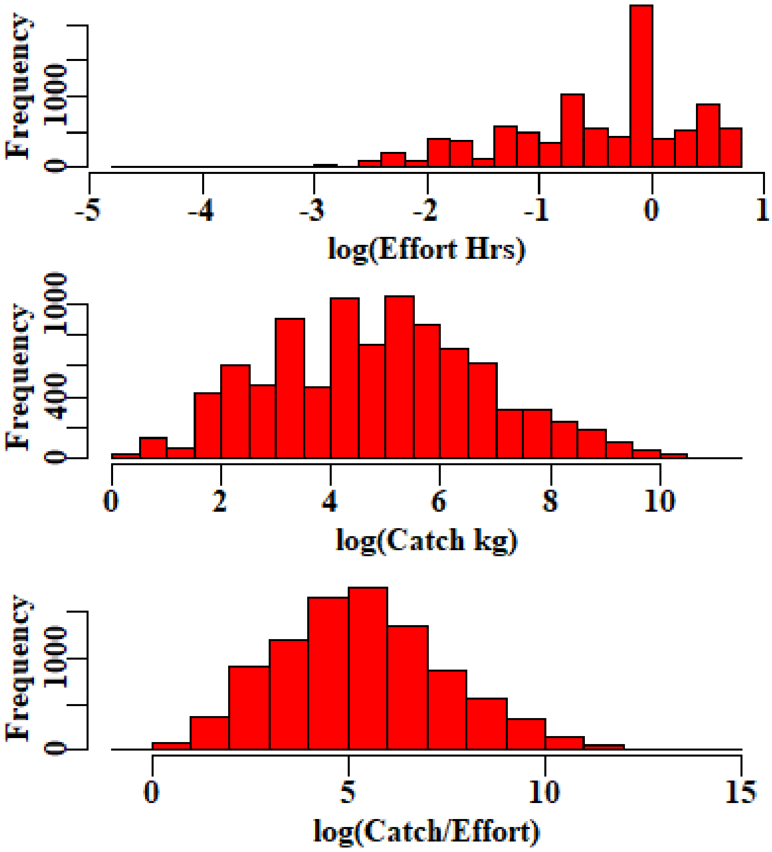


Figure 20.4. The distributions of the log-transformed effort, catch, and catch-per-hour in Orange Roughy zone 30, for the years 1989 - 2006, and from Longitudes East of 100.0 and between latitudes -42 and -36; restricted to records where effort was <= 2.0 hours.

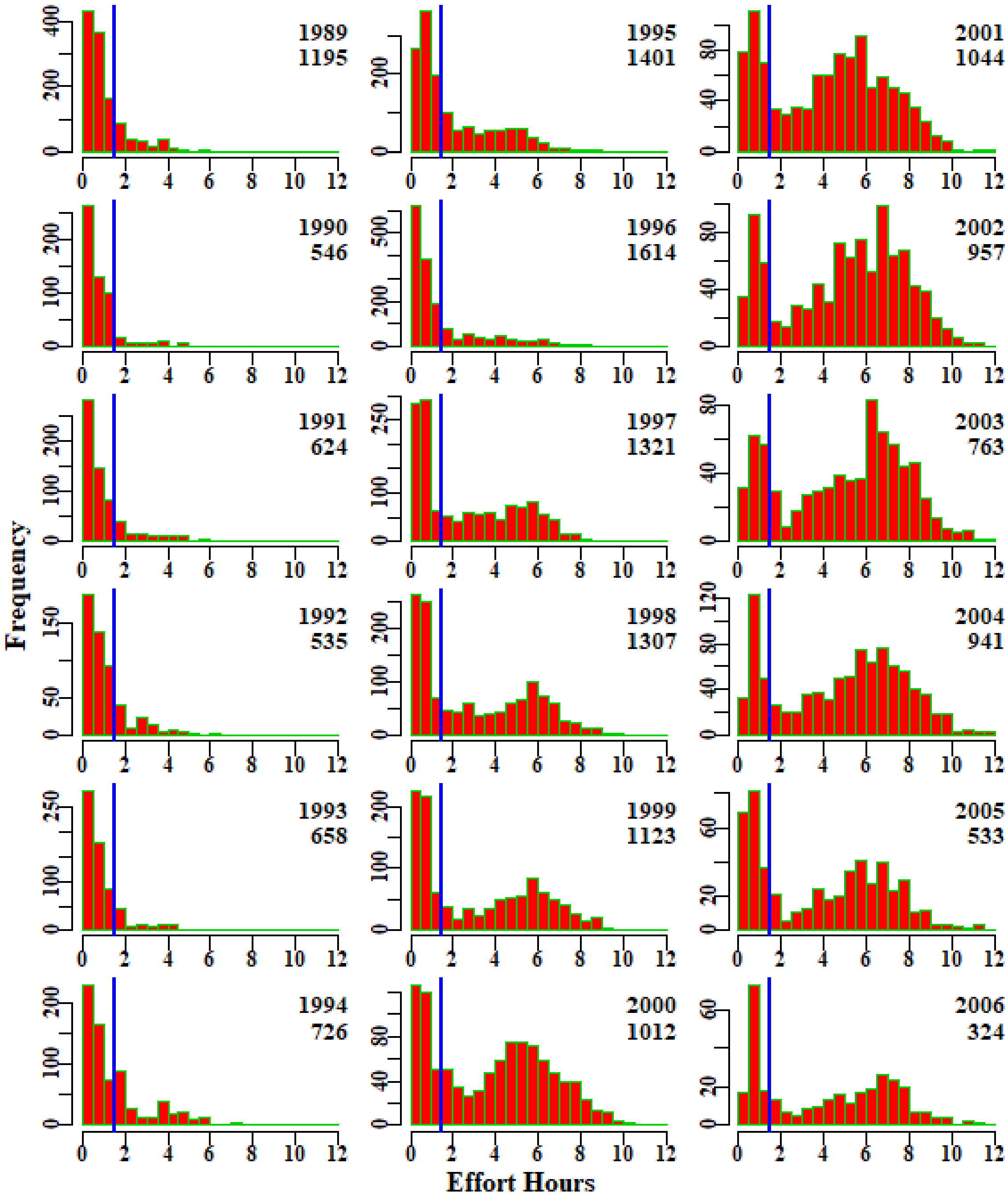


Figure 20.5. The distributions of the Effort in hours trawled in Orange Roughy zone 30, for the years 1989 - 2006, and from Longitudes East of 100.0 and between latitudes -42 and -36; restricted to records where effort was <= 12.0 hours. The vertical Blue line is at 1.5 hours.

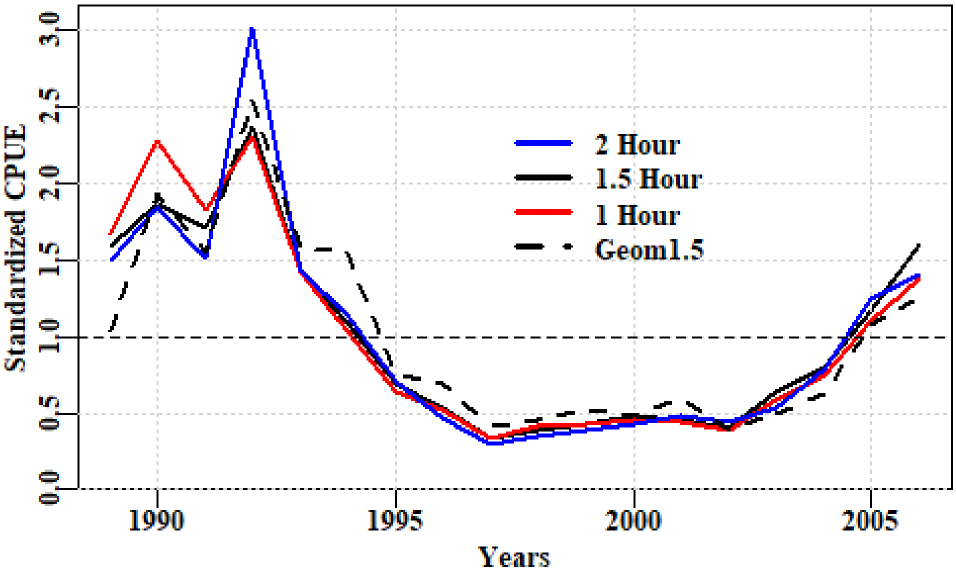


Figure 20.6. The standardized CPUE for zone 30 Orange Roughy (western zone), for the years 1989 - 2006. Three different effort levels were considered in terms of maximum duration of a tow (see Figure 20.3), there were 1 hour, 1.5 hours, and 2 hours.

Table 20.2. The estimated standardized year coefficients for the series of models fitted to the CPUE data from zone 30 from 1989 - 2006. The optimum statistical model was the full model in the last column.

	Year	Vessel	Month	unitlat
1989	1.003	1.277	1.416	1.497
1990	2.059	1.742	1.742	1.847
1991	1.324	1.260	1.423	1.495
1992	2.944	2.850	2.944	3.018
1993	1.478	1.333	1.391	1.442
1994	1.490	1.180	1.142	1.145
1995	0.767	0.760	0.704	0.710
1996	0.673	0.474	0.479	0.475
1997	0.357	0.298	0.298	0.301
1998	0.416	0.394	0.371	0.352
1999	0.485	0.442	0.434	0.391
2000	0.446	0.487	0.468	0.434
2001	0.665	0.567	0.506	0.487
2002	0.461	0.479	0.455	0.447
2003	0.485	0.602	0.563	0.536
2004	0.628	0.886	0.829	0.779
2005	1.219	1.369	1.346	1.241
2006	1.101	1.600	1.489	1.401

Table 20.3. The relative statistical performance of each model fitted to the CPUE data from zone 30 from 1989 - 2006.

	Year	Vessel	Month	unitlat
AIC	10206.964	9518.195	9475.182	9465.622
RSS	29950.743	26609.687	26363.340	26297.193
MSS	2300.136	5641.192	5887.538	5953.685
Nobs	6990.000	6990.000	6990.000	6990.000
Npars	18.000	87.000	98.000	102.000
adj_r2	6.906	16.464	17.105	17.265
%Change	0.000	9.558	0.641	0.160

From 1993 onwards until 2005 the trends in the standardized CPUE are essentially the same but there are differences between 1989 - 1992 and 2006 also differs between maximum effort levels (Figure 20.5). Of course there are more records available the larger the maximum limit of effort with the number of records being 7069, 8599, 9432 respectively for the 1, 1.5, and 2.0 hour maxima.

Given the initial variation of the CPUE is less with the 1 hour effort maximum selection this will be used in subsequent standardizations.

The performance of the different statistical models can be summarized by comparing the variance described by the addition of each new factor (Table 20.3).

The optimal model can be plotted relative to the unstandardized geometric mean trend to see the effect of the standardization (Figure 20.6). A consideration of Table 20.3 and Figure 20.7 indicates that from 2002 to 2006 here was a large increase in CPUE (2002:2006 was 0.431:1.426 = 1:3.29). However, there was an equally large increase in the variation around the estimated mean year coefficients, so clearly uncertainty was also growing. Nevertheless, the increase appears to represent a significant increase sufficient to warrant further investigations. A comparison is made below of the two selection criteria for Effort where either 1.0 or 1.5 hours was the upper limit of effort for consideration.

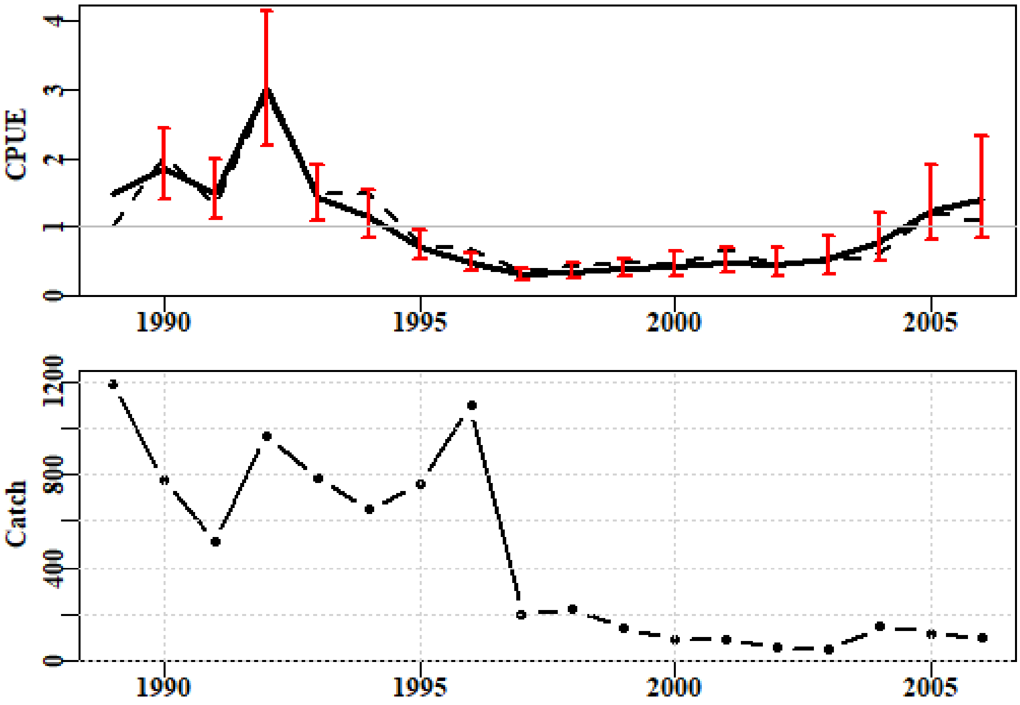


Figure 20.7. The standardized CPUE for zone 30 Orange Roughy (western zone), for 1989 - 2006 when only Effort <= 1.0 hours is used. The dashed line is the geometric mean CPUE, the red bars are the log-normal 95% confidence intervals. Lower plot is total catches in zone 30 by year.

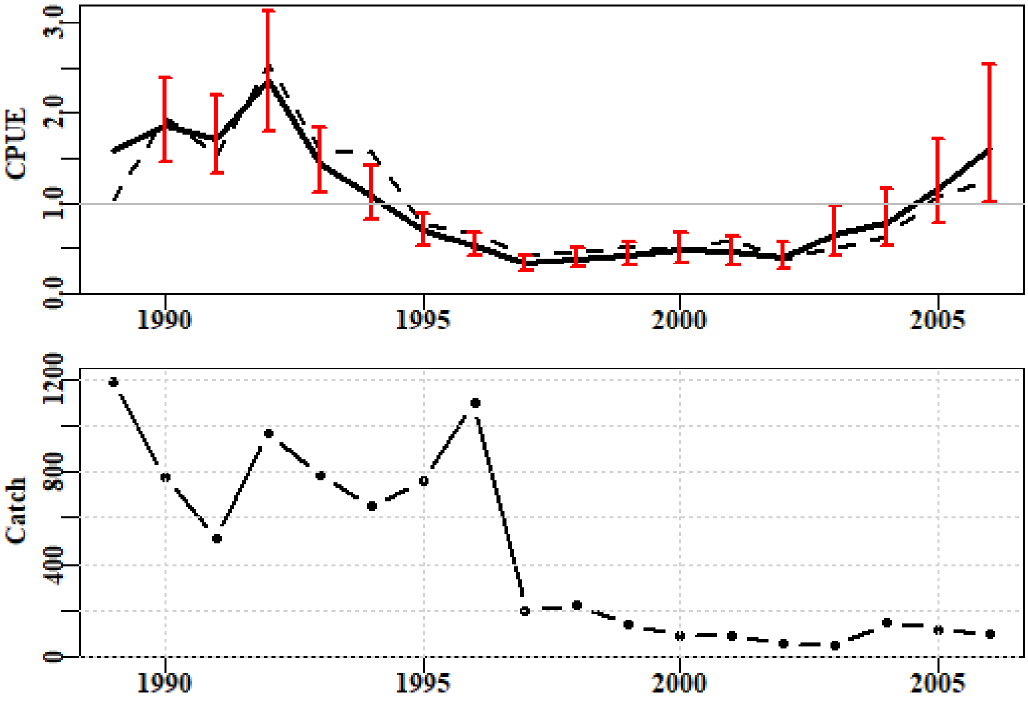


Figure 20.8. The standardized CPUE for zone 30 Orange Roughy (western zone), for 1989 - 2006 when only Effort <= 1.5 hours is used. The dashed line is the geometric mean CPUE, the red bars are the log-normal 95% confidence intervals. Lower plot is total catches in zone 30 by year.

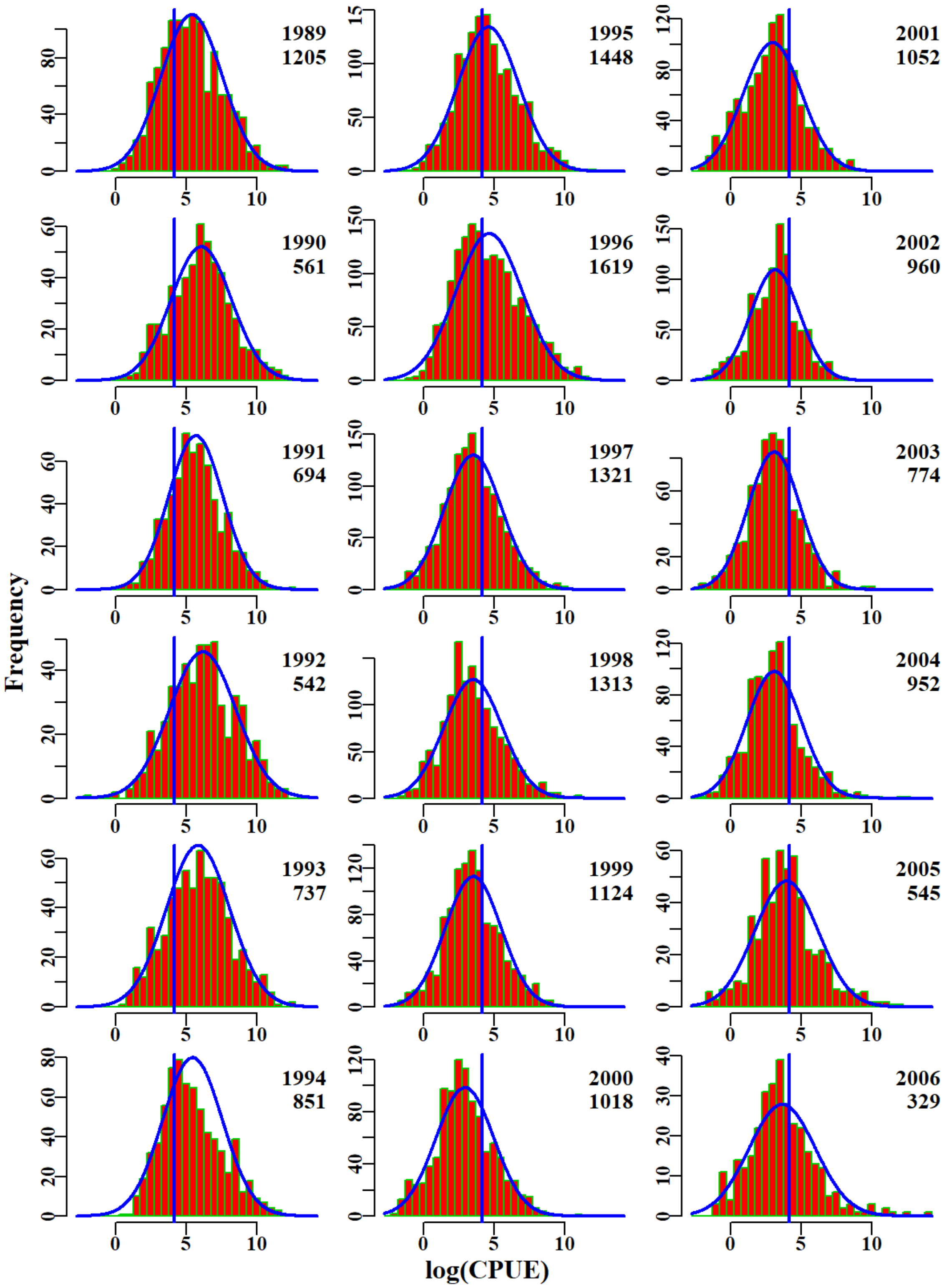


Figure 20.9. The annual distribution of CPUE for zone 30 Orange Roughy (western zone), for 1989 - 2006. The vertical Blue line os the overall arithmetic average across years.

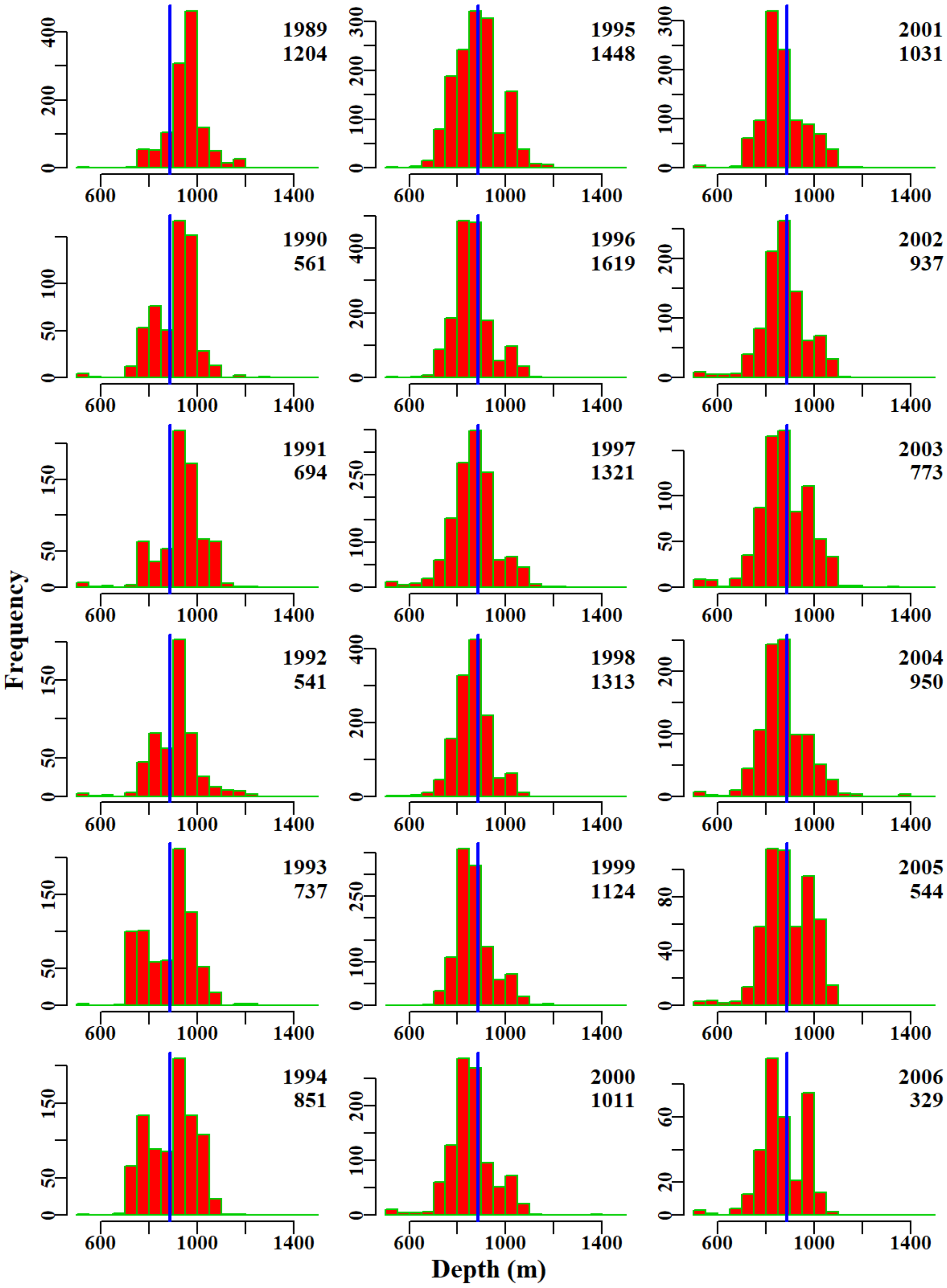


Figure 20.10. The annual distribution of the Depth of each trawl shot for zone 30 Orange Roughy (western zone), for 1989 - 2006. The vertical Blue line os the overall arithmetic average across years. The two numbers are the year and the number of records.

20.6 Acknowledgements

Thanks goes to the CSIRO database team for their preliminary processing of the catch and effort data as received from the Australian Fisheries management Authority. In addition, one author (MH) is indebted to FRDC for funding the project 2012/201 'Improving Catch Rate Standardizations', which provided the time to explore ways of making the mass production of CPUE standardizations more efficient and defensible.

20.7 References

Bax, N. (1997). Stock Assessment Report 1997: Orange Roughy. Report for the South East Fishery Stock Assessment Group. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 64 p. (Unpublished report held by CSIRO, Hobart).

Bax, N. (2000). Stock Assessment Report 2000: Orange Roughy. Report for the South East Fishery Stock Assessment Group. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 81 p. (Unpublished report held by CSIRO, Hobart).

Bax, N. (2000a). Stock Assessment Report: Orange Roughy 1995, Stock Assessment Report, South East Fishery Stock Assessment Group, Australian Fisheries Management Authority, Canberra, 55 p. (Unpublished report held by AFMA, Canberra).

Bax, N. (2000b). Stock Assessment Report: Orange Roughy 1996, Stock Assessment Report, South East Fishery Stock Assessment Group, Australian Fisheries Management Authority, Canberra, 37 p. (Unpublished report held by AFMA, Canberra)

Bell, J.D., Lyle, J.M., Bulman, C.M., Graham, K.J., Newton, G.M. and Smith, D.C. (1992) Spatial variation in reproduction, and occurrence of non-reproductive adults, in orange roughy, *Hoplostethus atlanticus* Collett (Trachichthyidae), from south-eastern Australia. *Journal of Fish Biology* **40**: 107-122.

Deriso, R. and Hilborn, R. (1994). A Review of the 1994 Stock Assessment for Orange Roughy. Review completed for the Australian Fisheries Management Authority, 28 p. (Unpublished report held by AFMA, Canberra).

Burnham, K.P. and D.R. Anderson (2002) *Model Selection and Inference. A Practical Information-Theoretic Approach.* Second Edition Springer-Verlag, New York. 488 p.

Diver, G. (2004). Data Collection for the Eastern Zone Orange Roughy Survey, July 2004. Report completed by Diversity – Sustainable Development Consultants, W.A. 23 p. (Unpublished report held by CSIRO, Hobart).

Francis, C. and Hilborn, R. (2002). A Review of the 2002 Orange Roughy Stock. Review completed for the Australian Fisheries Management Authority, 14 p. (Unpublished report held by AFMA, Canberra).

Francis, C. (2011) Data weighting in statistical fisheries stock assessment models. *Can. J. Fish. Aquat. Sci.*, **68**: 1124-1138.

Gelman, A., Carlin, J.B., Stern, H.S. and Rubin, D.B. (2003) *Bayesian Data Analysis.* 2nd Edition. Chapman & Hall/CRC Press, Florida. 668 p.

Kloser, R. J., T. E. Ryan, et al. (2001). Development and application of a combined industry/scientific acoustic survey of orange roughy in the eastern zone. Final report to Fisheries Research and

Development Corporation 99/111. Available from Fisheries Research and Development Corporation, P.O. Box 222, Deakin West, ACT 2600, Australia.

Kloser & Ryan (2002) Review of Analysis methodologies and data holdings for acoustic assessments of orange roughy on St Helens Hill, 1989 - 1999. CSIRO Marine Research 40p

Kloser, R., Ryan, T. and Daley, R. (2008) 2006 Eastern Zone orange roughy acoustic survey. Report to the South East Trawl Fishery Association, CSIRO Marine and Atmospheric Research, Hobart, 92 p.

Kloser, R.J., Knuckey, I.A., Ryan, T.E., Pitman, L.R. and Sutton, C. (2011) Orange roughy conservation program: Eastern Zone surveys and trials of a cost-effective acoustic headline system. Final report to the South East Trawl Fishing Industry Association, CSIRO Marine and Atmospheric Research, Hobart, 153 p.

Kloser, R., Sutton, C. and Krusic-Golub, K. (2012) Australian spawning population of orange roughy: Eastern zone acoustic and biological index fished from 1987 to 2010. Report to the South East Trawl Fishing Industry Association, CSIRO Marine and Atmospheric Research, Hobart, 64 p.

Koslow, J.A., Bulman, C.M., Lyle, J.M. and Haskard, K. (1995) Biomass Assessment of a Deep-water Fish, the Orange Roughy (Hoplostethus atalanticus), based on an Egg Survey. *Marine and Freshwater Research* **46**: 819-830.

Lyle, J.M., Evans, K. & Wilson, M.A. (1989) A summary of orange roughy biological information 1981 – 1986. Technical report 39, Department of Sea Fisheries Tasmania (Cited in Prince & Hordyk, 2011).

Lyle, J.M., Kitchener, J. & Riley, S.P. (1991) An assessment of orange roughy resource off the coast of Tasmania. Final report to FIRDC, Project 87/65.

Methot, R.D. and Wetzel, C.R. (2013) Stock Synthesis: a biological and statistical framework for fish stock assessment and fishery management. *Fisheries Research* **142**, 86-99.

Neter, J., Kutner, M.H., Nachtsheim, C.J, and W. Wasserman (1996) *Applied Linear Statistical Models.* Richard D. Irwin, Chicago. 1408 p.

Prince, J. and Hordyk, A. (2011 Draft) Observation of the 2009 Cascade Roughy Spawning Season and drafting of a DeepRAG synthesis paper on orange roughy stock structure in the southern Australia. AFMA Project No. 2009/808, 23 p.

R Core Team (2017). *R: A language and environment for statistical computing.* R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Ryan.T.E, Sutton.C, et al. (2013). Biomass estimates of orange roughy at the Tasmanian Eastern Zone spawning grounds in July 2012 using a net attached acoustic optical system. Report to South East Trawl Fishing Industry Association. Copy held at CSIRO Marine and Atmospheric Research Laboratories, Hobart, Australia: 40 p.

Ryan, T. E., C. Sutton, et al. (2014). Biomass estimates of orange roughy at the Tasmanian Eastern Zone spawning grounds in July 2013 using a net attached acoustic optical system. Report to South East Trawl Fishing Industry Association. Copy held at CSIRO Marine and Atmospheric Research Laboratories, Hobart, Australia.

Smith, D.C., Fenton, G.E., Robertson, S.G. and Short, S.A. (1995) Age determination and growth of orange roughy (Hoplostethus atlanticus): a comparison of annulus counts with radiometric ageing. *Can. J. Fish. Aquat. Sci.* **52**: 391-401.

Smith, D.C., Robertson, S.G. and Morrison, A.K. (1998) Age composition of orange roughy in the Eastern and Southern Management Zones. Report to Fisheries Research & Development

Corporation, Project No. 95/032. Marine and Freshwater Resources Institute, Victoria, Australia. 40 p.

Smith, A.D.M, Punt, A.E., Wayte, S.E., Starr, P.J., Francis, R.I.C.C., Stokes, T.K., Hilborn, R., Langley, A. (2001) Stock assessment for the northeast Chatham Rise orange roughy for 2001. New Zealand Fisheries Assessment Report 2002/25. 30 p.

Stokes, K. (2009). Orange Roughy Assessment Review. Report completed for the Australian Fisheries Management Authority, 33 p. (Unpublished report held by AFMA, Canberra).

Upston, J. and Wayte, S.E., (2012a). Orange Roughy (Hoplostethus atlanticus) Eastern Zone preliminary stock assessment incorporating data up to 2010 - definition of the base-case model. *In*: Tuck, G.N. (Ed.) (2012). *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2011. Part 1.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. pp 180-217.

Upston, J. and Wayte, S.E., 2012b. Orange Roughy (Hoplostethus atlanticus) Eastern Zone preliminary stock assessment incorporating data up to 2010 – future work. In: Tuck, G.N. (Ed.) (2012) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2011. Part 1.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. pp 218-225.

Wayte, S.E. and Bax, N. (2002 Draft). Orange Roughy 2002. Stock Assessment Report, South East Fishery Stock Assessment Group. Australian Fisheries Management Authority, Canberra. 57 p. (Unpublished report held by CSIRO, Hobart).

Wayte, S.E. (2002). Southern Zone Orange Roughy Stock Assessment. Report to Orange Roughy Stock Assessment Group. Australian Fisheries Management Authority, Canberra.5 p. (Unpublished report held by CSIRO, Hobart).

Wayte, S.E. (2007). Eastern Zone Orange Roughy. In: Tuck, G.N. (Ed.) (2007) *Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2006-2007. Volume 1: 2006.* Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 570 p.

20.8 Appendix 1: Orange Roughy Data

The CSIRO genlog database was used and data extracted solely on the requirement for a CAAB code of 37255009, which relates to Orange Roughy (Table A 20.1)

Table A 20.1. Properties of the Orange Roughy data held within the genlog database within CSIRO when no filtering is applied. There were 94,896 records found in the database.

	Index	isNA	Unique	Class	Min	Max	Example
Year	1	0	32	numeric	1985	2016	1988
Month	2	0	12	numeric	1	12	3
Day	3	0	31	numeric	1	31	9
Vessel	4	0	175	numeric	2	3841	454
catch_kg	5	0	1210	numeric	0.2	130000	320
discard	6	72268	34	numeric	0	15000	
Long	7	73	2752	numeric	39.38	169.88	142.7
Lat	8	70	1639	numeric	-49.15	-0.01	-39.46
LongE	9	6513	2836	numeric	0.01	169.88	
LatE	10	6513	1671	numeric	-49.25	-1.93	
Depth	11	1111	970	numeric	4	9873	896
DayNight	12	0	4	character	0	0	N
Effort	13	2673	837	numeric	0	23.98	1
Method	14	0	5	character	0	0	TW
Fishery	15	0	10	character	0	0	SET
Unit	16	0	4	character	0	0	TTS
SubUnit	17	0	3	character	0	0	
UnitValue	18	2439	717	numeric	0	4100	1
SubUnitValue	19	73143	3	integer	0	9	
ORzone	20	4219	9	numeric	10	70	30

21. On the Potential Effects of a Seismic Survey on Commercial Fishery Catch Rates in the Great Australian Bight

Malcolm Haddon

CSIRO Oceans and Atmosphere, GPO Box 1538, Hobart, TAS 7001, Australia

21.1 Introduction

Up until 2015 there have been seven fishery independent surveys (FIS) conducted on Bight Redfish (*Centroberyx gerrardi*) and Deepwater Flathead (*Platycephalus conatus*) in the Great Australian Bight (GAB). The first six surveys approximated the same trajectory as the commercial catch-per-unit-effort (CPUE; Figure 21.1). This approximate coincidence between the trajectories failed with the survey that occurred during March and April 2015, which ended rather lower than the commercial CPUE so that the two trajectories began to diverge (Figure 21.1)

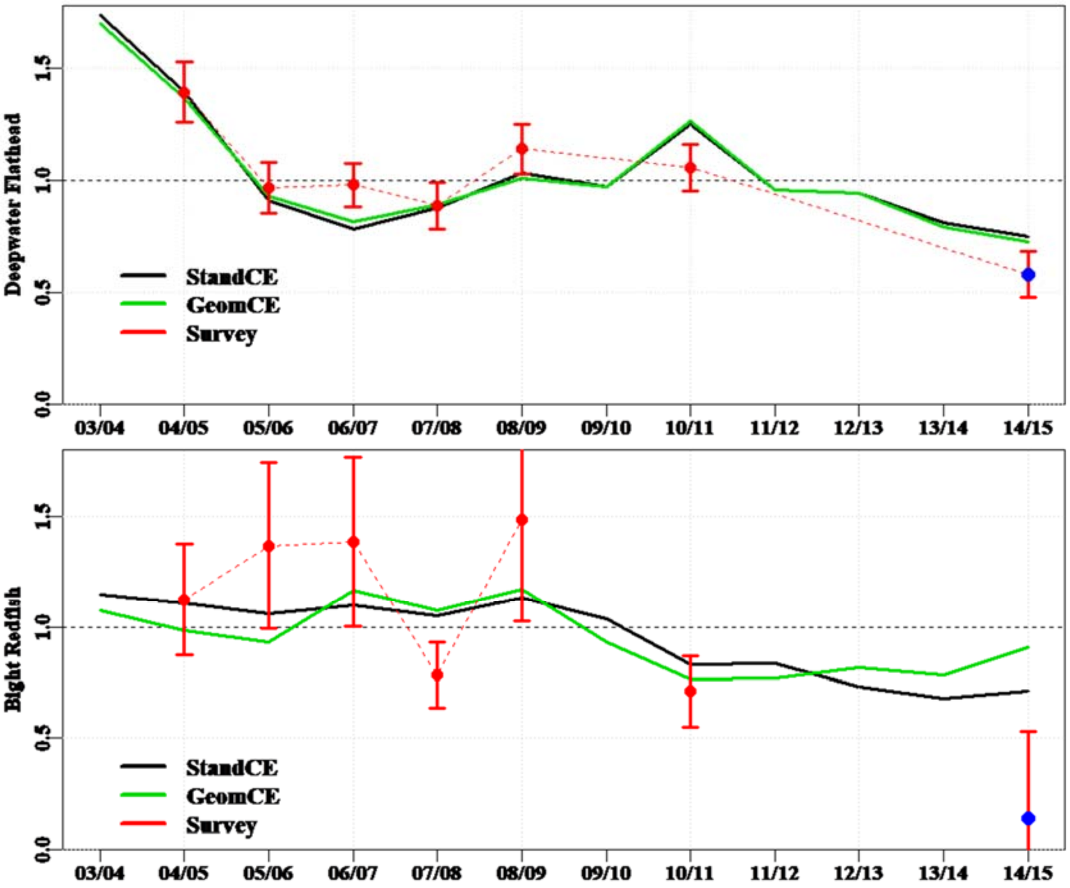


Figure 21.1. A comparison of the indices from the standardized commercial CPUE and the trawl survey indices for Deepwater Flathead (Platycephalus conatus) and Bight Redfish (Centroberyx gerrardi) from the GAB. The red lines represent Â± 1.96 Ã— StDev in each year for the FIS mean estimates. GeomCE is the scaled geometric mean CPUE; each time series has been scaled to have a mean of 1.0 across years 2004/2005 - 2008/2009, 2010/2011, and 2014/2015.

Unfortunately, the 2015 FIS occurred at the same time as a seismic survey approximately in the center of the GAB (PGS Australia, 2014). So the suspicion was raised that the seismic survey, which entails the use of large scale transducers that couple a large amount of acoustic energy into the ocean, had led to the results of the 2015 FIS being biased low. However, before assuming that the seismic survey was having a negative effect on the fishery survey further evidence, in the form of the commercial catch and effort data were examined to determine whether there were other unexpected or unusual effects occurring at the same time.

An initial analysis considered the raw CPUE (using bias-corrected geometric means) as experienced by the commercial fleet and that concluded that the unstandardized CPUE across the fishery was unusually depressed during March and April 2015. The average unstandardized CPUE during March and April across the years 2010 - 2016 (excluding 2015) is 10 - 20 kg/hr greater than occurred in the March and April 2015 (Table 21.1).

Table 21.1. Bias-corrected geometric mean estimates for each month, 1 - 12, for the years 2010 - 2016. The averages for March and April 2015 (highlighted) are markedly lower that the other March and April CPUE levels.

	2010	2011	2012	2013	2014	2015	2016	Average
1	60.28	85.03	46.42	54.60	42.57	42.80	47.27	56.03
2	53.79	71.76	47.99	48.42	42.64	43.91	45.08	51.61
3	34.79	46.77	44.33	33.44	37.10	30.34	45.37	40.30
4	38.37	87.02	43.58	43.50	32.81	24.92	37.36	47.11
5	81.98	63.72	51.70	42.05	49.91	48.34	45.27	55.77
6	58.11	60.37	30.70	48.85	37.91	36.47	47.31	47.21
7	46.77	41.52	30.74	31.68	29.11	32.07	25.32	34.19
8	38.77	38.12	31.34	26.38	29.04	42.15	33.22	32.81
9	43.97	47.33	44.16	36.42	39.91	45.15	48.78	43.43
10	72.34	49.57	54.37	53.78	47.15	64.83	71.06	58.05
11	96.00	53.71	66.92	63.00	59.73	65.93	66.61	67.66
12	81.72	58.78	66.56	49.45	54.97	69.46	57.13	61.43

The monthly catches in March and April 2015 were also depressed (Table 21.2) relative to the monthly averages but so was the amount of effort expended (Table 21.3), hence the lowered CPUE.

This initial CPUE analysis was at least consistent with the seismic survey having a negative effect upon the 2015 FIS results.

Since the time of that analysis more details of the seismic survey have become available (PGS Australia, 2014). Importantly these include a specification of the areal extent of the seismic survey (Figure 21.2). The summed catches across 2010 - 2016 are also illustrated for each degree of longitude across the distribution of the Deepwater Flathead fishery (Figure 21.2). It is clear that about 65% of the fishery occurs between the longitudes of 128 - 132 degrees East, which may have been directly influenced by the seismic survey (if it had any effect at all).

The specification of the seismic survey boundary is given in the *Appendix - Survey Coordinates*. The large kink in the seismic survey boundary coincides with a space or gap that also occurs with the fishery data that appears to have started some time in 2001 and has continued to the present day (Figure 21.3).

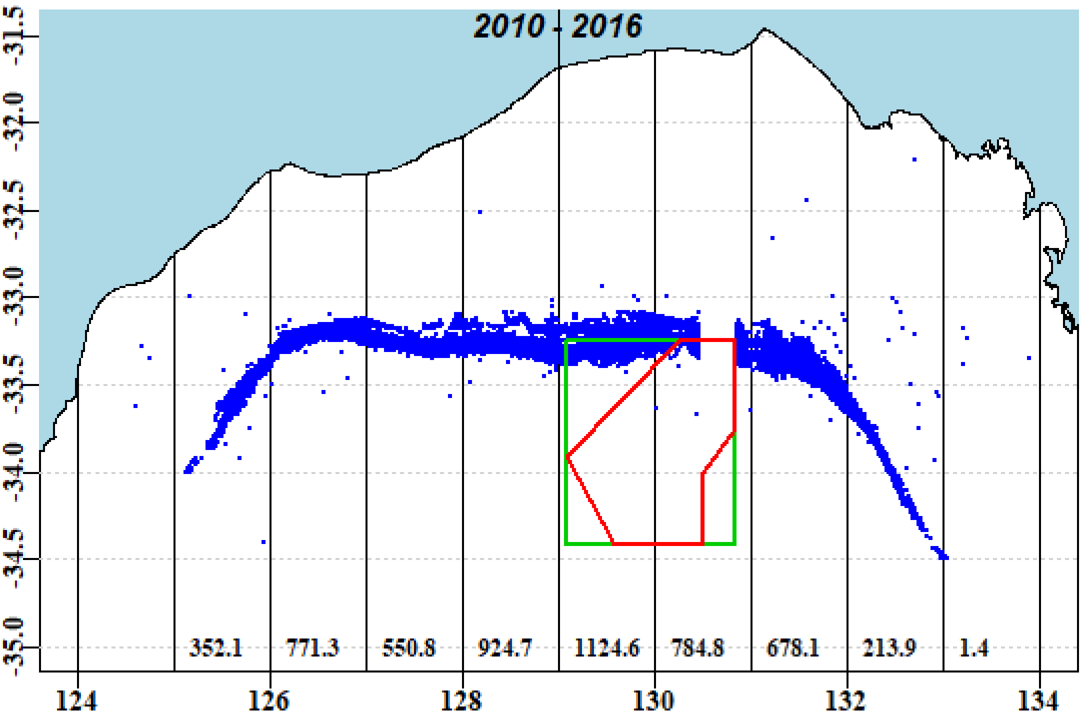


Figure 21.2. Plot of the seismic survey boundary (red line) as defined in PGS Australia (2014). The green lines are the longitudinal and latitudinal bounds of the survey. Also included are the reported locations of every shot that caught Deepwater Flathead from 2010 - 2016 (blue dots) with the numbers at the base being the cumulative catch over that same time period.

Table 21.2. Monthly reported catches for the years 2010 - 2016. March and April 2015 are highlighted.

	2010	2011	2012	2013	2014	2015	2016	Average
1	86.705	100.561	92.746	115.842	66.242	52.792	61.997	87.349
2	81.691	56.330	86.098	88.681	68.777	55.838	55.679	72.876
3	57.231	54.550	83.052	64.435	67.241	33.632	57.289	63.966
4	64.510	128.522	57.162	80.412	56.719	31.534	49.378	72.784
5	95.695	97.498	83.572	78.839	98.043	56.595	26.318	79.994
6	61.455	64.446	27.742	74.094	59.497	16.317	26.681	52.319
7	30.747	46.577	26.980	31.109	32.756	13.626	3.900	28.678
8	20.445	73.015	47.620	39.257	36.540	25.095	13.904	38.463
9	65.670	82.162	50.686	58.021	34.323	35.862	29.571	53.406
10	91.396	90.049	106.952	81.755	61.145	60.500	32.485	77.297
11	127.803	108.677	123.015	86.333	82.034	79.282	47.871	95.956
12	102.941	99.527	131.979	60.358	68.917	82.291	57.038	86.793

Table 21.3. Monthly reported Effort (hours trawled) for the years 2010 - 2016. March and April 2015 are highlighted.

	2010	2011	2012	2013	2014	2015	2016	Average
1	1451	1242	1828	1948	1624	1412	1499	1598
2	1579	819	1508	1910	1718	1403	1394	1488
3	1653	1276	1474	1764	1930	1289	1408	1584
4	1723	1579	1349	1940	1819	1319	1460	1645
5	1204	1500	1489	1924	2032	1229	620	1462
6	1070	1128	897	1489	1647	464	585	1136
7	678	1018	898	1047	1205	431	153	833
8	544	1683	1029	1594	1269	707	466	1097
9	1506	1543	1079	1666	871	993	720	1231
10	1362	1537	1872	1634	1342	957	508	1376
11	1450	1772	1648	1326	1227	1321	866	1381
12	1312	1512	1839	1252	1419	1290	1235	1428

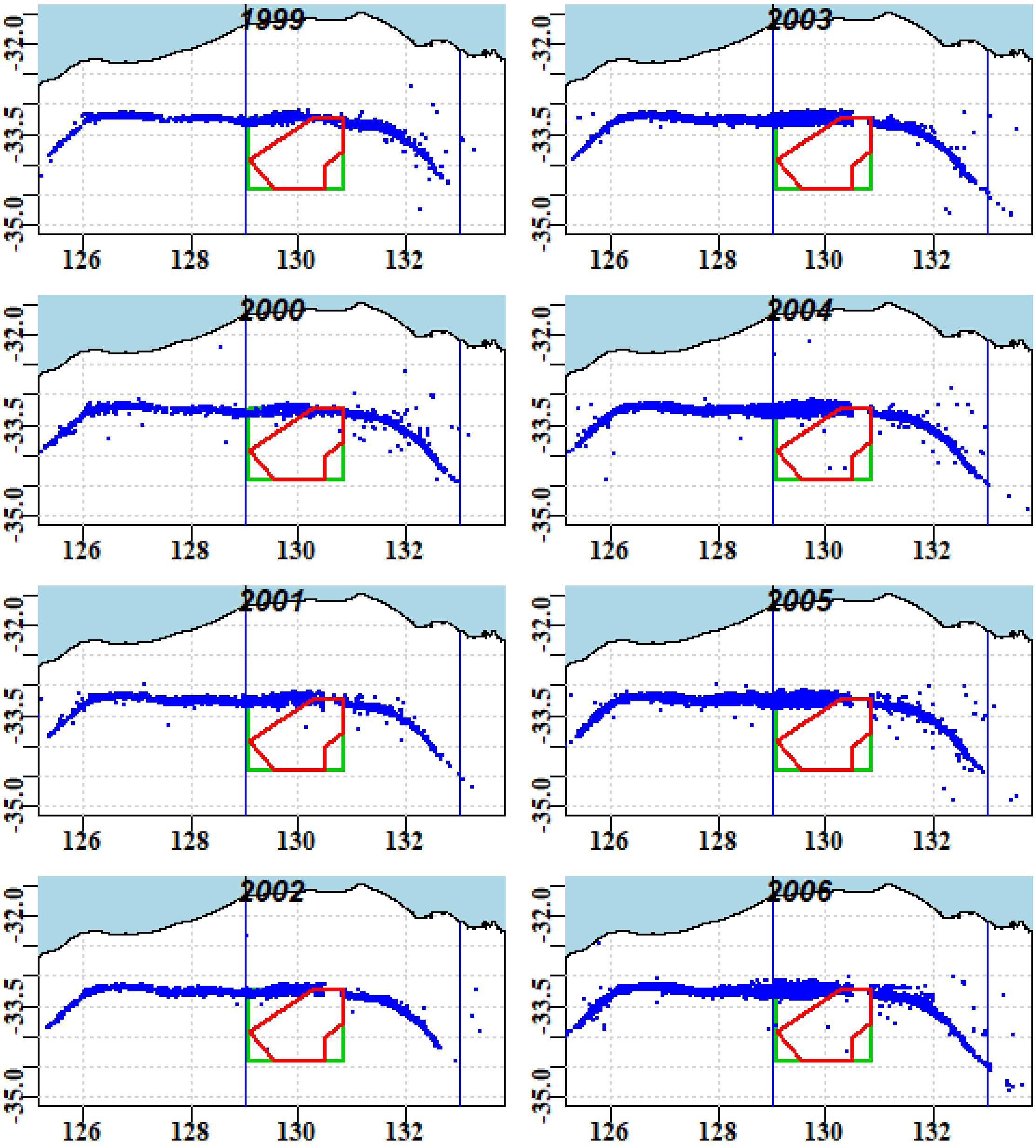


Figure 21.3. Plots of the distribution of Deepwater Flathead catches from 1999 - 2006 (blue dots) relative to the location of the survey boundary (red lines) and longitudinal boundary (green lines). Note the gap that arises part way through 2001 and then continues in all following years.

21.1.1 *Standardized CPUE*

The effects of the seismic survey are expected to occur both within and outside the strict boundary of the survey. while there is attenuation of sound intensity with distance powerful sounds can still be transmitted very long distances from a major source.

The un-standardized commercial CPUE indicates that the months of March and April 2015 were exceptional. However, before stronger conclusions can be made it would be better to put the commercial catch and effort data through a process of statistical standardization in an attempt to remove the effects of which vessels were fishing, what depths they were fishing, at what time of day they were fishing, and the location of fishing (see methods in Haddon and Sporcic, 2017). In this case we can include the truncated longitude as a categorical factor and, as an alternative separate the group from 128 - 132 degree longitude from the rest. The standardization also differs from that described for Deepwater Flathead in Haddon and Sporcic (2017) so that the effects of individual months within each year can be considered. This is done through making a new variable which combines the year and month into a single ordered factor.

The model used in the end was:

LnCE = constant + yrmth + Vessel + DepCat + longzone

the raw CPUE data is natural log-transformed and where all variables are treated as categorical factors.

21.2 Results

The optimum statistical model included all four terms and described over 38% of the variability within the CPUE data (Table 21.4). The actual values from the statistical models are listed in *Appendix - Standardization Results*.

Table 21.4. The summary diagnostic statistics from the standardization of the year x month CPUE for Deepwater Flathead taken in the GAB. Data from 1987 - 2016 were used. The smallest Akaike's Information Criterion and largest adjusted R-squared denote the optimum model (longzone). There are very many parameters because of the numerous year x month combinations.

	yrmth	Vessel	DepCat	longzone
AIC	-45657.015	-52369.072	-53815.688	-58646.052
RSS	44468.111	40830.681	39382.413	37033.247
MSS	16564.424	20201.854	21650.123	23999.288
Nobs	79613.000	79613.000	78831.000	78831.000
Npars	355.000	396.000	446.000	455.000
adj_r2	26.815	32.767	34.297	38.209
%Change	0.000	5.952	1.530	3.912

The results can be visualized by plotting the unstandardized CPUE along with the optimum statistical model to illustrate the effect of the standardization and the extent to which the seasonal cycle exhibited by the CPUE is changed, if at all, in the months March and April 2015 (Figure 21.4).

21.3 Discussion and Summary

The standardization of the commercial CPUE puts the months of March and April 2015 in the context of the complete fishery while taking into account the differences in expected CPUE that fishing in the different degrees of longitude would entail. The unstandardized CPUE (Figure 21.4 and Table 21.1) already indicates a negative influence on catches and CPUE. This is confirmed and reinforced by the standardization (Figure 21.4). The circles in the plot demonstrate that both March and April 2015 were exceptional in terms of both CPUE and catches. However, they also demonstrate that both of these can quickly recover once the seismic survey is over.

It would thus appear that the significant drop in the observed CPUE from the fishery independent survey of the fishery in the GAB, conducted in 2015, was very likely negatively influenced by it being run coincidently with the seismic survey. Fortunately, the seismic survey does not appear to have had a lasting impact on Deepwater Flathead CPUE, which returned to typical values in the first month following the seismic survey (Figure 21.4). Catches, on the other hand, took on a different pattern from usual, which may indicate that the drop off in commercial CPUE altered the fleet's fishing behaviour. Landings from all fisheries, however, are influenced by many factors other than the availability of fish so no conclusions will be drawn over changes in the patterns of reported catches.

21.4 Recommendations

It is recommended that future Fishery Independent Surveys of fish stocks should never be undertaken at the same time as a proximate seismic survey (where proximate could mean within 60 or possibly many more nautical miles). Given the scale of the bias in CPUE from the 2015 seismic survey, the results from the 2015 FIS should not be included in future stock assessments of either Deepwater Flathead or Bight Redfish.

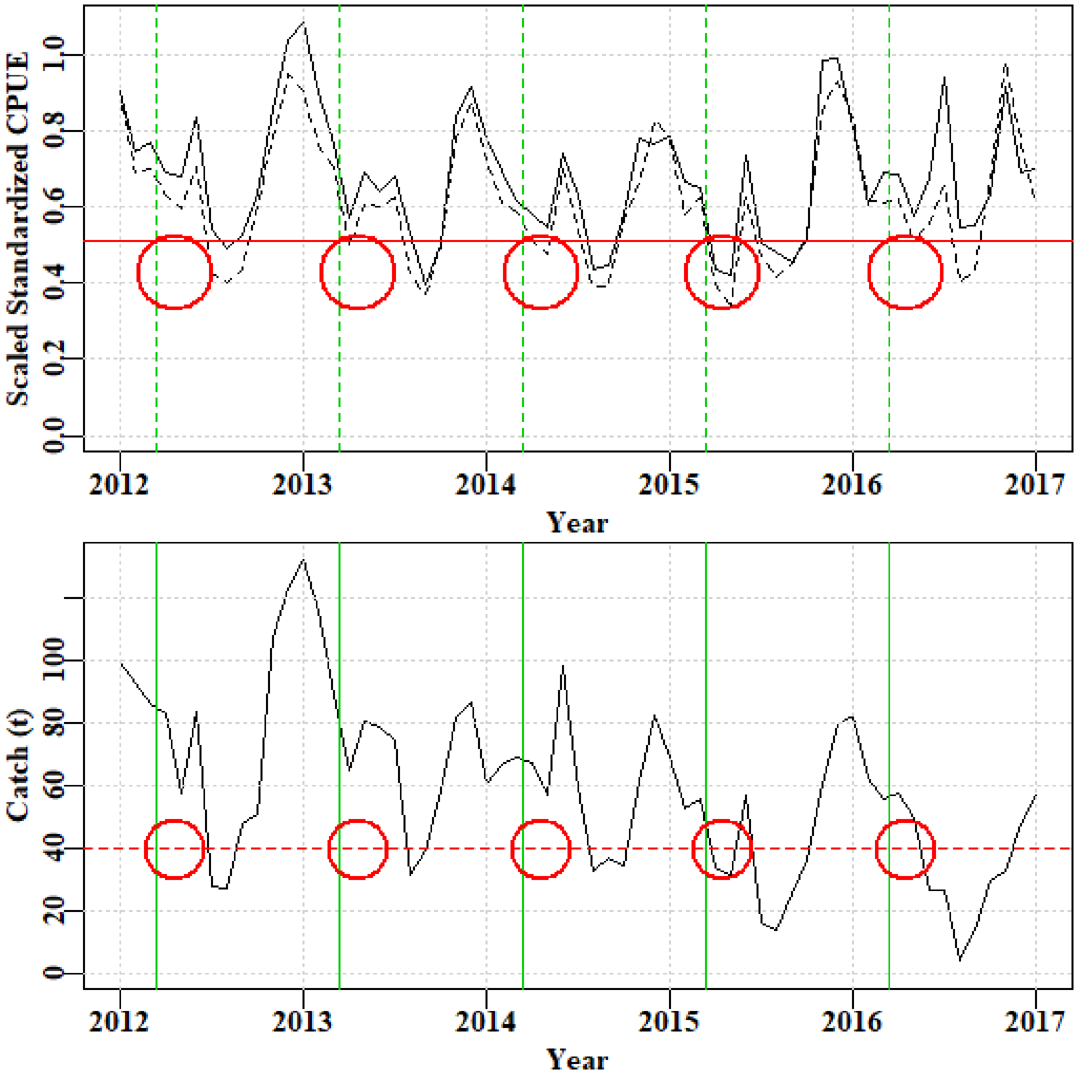


Figure 21.4. A plot of the un-standardized (dashed line) and the optimum standardized CPUE (solid black line) for Deepwater Flathead in the GAB restricted to the years 2012 - 2016. The red circles surround the months March and April in each year with the dashed green lines passing through the point for February. Horizontal red lines are also added to assist comparisons across years.

21.5 Acknowledgements

Thanks go to Christian Pyke who pointed me to the web site containing specific information relating to the seismic survey of 2015. Thanks also to the other members of the Great Australian Bight Resource Assessment Group for their interest in this issue.

21.6 References

Haddon, M. and M. Sporcic (2017) Catch rate standardizations for selected GAB Species (data to 2016). CSIRO Oceans and Atmosphere, Hobart. 52 p.

PGS Australia (2014) *Ceduna Multi-Client 3D Marine Seismic Survey, Environment Plan Summary*, November 2014, Rev 3. PGS Australia Pty Ltd. 87 pp.

21.7 Appendix – Survey Coordinates

Table 21.5. The longitude and latitude of the survey boundary, as depicted in the previous plots. These were copied directly from PGS Australia (2014).

Long	Lat
130.8347	-33.24862
130.8347	-33.74863
130.5014	-33.99863
130.5014	-34.41530
129.5848	-34.41531
129.0848	-33.91531
130.2514	-33.24863
130.8347	-33.24862

21.8 Appendix – Standardization Results

Table 21.6. The standardized year x month parameters, where each year is represented by row-names from, for example, for the 2013 calendar year: 2013.083 (end of January) â€“ 2014 (end of December).

	yrmth	Vessel	DepCat	longzone
2012.083	0.6927	0.7307	0.7193	0.7437
2012.167	0.6991	0.7401	0.7323	0.7683
2012.25	0.6319	0.6740	0.6782	0.6928
2012.333	0.5952	0.6335	0.6560	0.6805
2012.417	0.7050	0.7489	0.7873	0.8367
2012.5	0.4245	0.4640	0.4906	0.5423
2012.583	0.4003	0.4380	0.4636	0.4902
2012.667	0.4342	0.4886	0.4752	0.5258
2012.75	0.6008	0.6524	0.5973	0.6335
2012.833	0.7870	0.8261	0.8159	0.8559
2012.917	0.9511	1.0006	0.9915	1.0415
2013	0.9036	0.9755	0.9708	1.0846
2013.083	0.7629	0.8566	0.8562	0.8982
2013.167	0.7073	0.7222	0.7214	0.7647
2013.25	0.4951	0.5201	0.5059	0.5727
2013.333	0.6060	0.5925	0.5966	0.6894
2013.417	0.5995	0.5875	0.6018	0.6402
2013.5	0.6276	0.6267	0.6622	0.6796
2013.583	0.4259	0.4474	0.4950	0.5320
2013.667	0.3675	0.3806	0.3731	0.3959
2013.75	0.4967	0.4798	0.4804	0.5036
2013.833	0.7783	0.7557	0.7549	0.8403
2013.917	0.8765	0.8808	0.8744	0.9149
2014	0.7261	0.7159	0.7076	0.7796
2014.083	0.6098	0.6527	0.6421	0.6953
2014.167	0.5855	0.5673	0.5543	0.6139
2014.25	0.5099	0.4950	0.4871	0.5818
2014.333	0.4779	0.4723	0.4651	0.5478
2014.417	0.7015	0.6906	0.7090	0.7422
2014.5	0.5437	0.5580	0.5803	0.6333
2014.583	0.3926	0.4339	0.4533	0.4371
2014.667	0.3934	0.4112	0.4332	0.4464
2014.75	0.5638	0.5675	0.5732	0.5831
2014.833	0.6614	0.6445	0.6453	0.7793
2014.917	0.8305	0.8097	0.8007	0.7633
2015	0.7783	0.7297	0.7280	0.7845
2015.083	0.5798	0.5659	0.5594	0.6664
2015.167	0.6273	0.5922	0.5402	0.6505
2015.25	0.3964	0.3946	0.3639	0.4384
2015.333	0.3397	0.3582	0.3577	0.4211
2015.417	0.6280	0.6624	0.6952	0.7333
2015.5	0.4726	0.4808	0.4963	0.5083
2015.583	0.4169	0.4192	0.4760	0.4795

2015.667	0.4532	0.4781	0.4644	0.4546
2015.75	0.5243	0.5450	0.4794	0.5157
2015.833	0.8484	0.8749	0.8547	0.9871
2015.917	0.9287	0.9017	0.8745	0.9920
2016	0.8351	0.8246	0.7869	0.8103
2016.083	0.6152	0.6082	0.5717	0.6040
2016.167	0.6092	0.6011	0.5671	0.6927
2016.25	0.6216	0.6234	0.5880	0.6836
2016.333	0.5123	0.5105	0.4742	0.5787
2016.417	0.5577	0.6185	0.6125	0.6763
2016.5	0.6584	0.8091	0.8377	0.9409
2016.583	0.4010	0.5390	0.5578	0.5476
2016.667	0.4346	0.5320	0.5456	0.5531
2016.75	0.6747	0.6819	0.6671	0.6373
2016.833	0.9816	0.8586	0.8710	0.9175
2016.917	0.7731	0.7972	0.7663	0.6918
2017	0.6160	0.6824	0.6629	0.7024

22. Benefits

The results of this project have had a direct bearing on the management of the Southern and Eastern Scalefish and Shark Fishery. Direct benefits to the commercial fishing industry in the SESSF have arisen from improvements to, or the development of, assessments under the various Tier Rules of the Commonwealth Harvest Strategy Policy for selected quota and non-quota species. Information from the stock assessments has fed directly into the TAC setting process for SESSF quota species. As specific and agreed harvest strategies are being developed for SESSF species (a process required by and agreed to under EPBC approval for the fishery), improvements in the assessments developed under this project have had direct and immediate impacts on quota levels or other fishery management measures (in the case of non-quota species).

Participation by the project's staff on the SESSF Resource Assessment Groups has enabled the production of critical assessment reports and clear communication of the reports' results to a wide audience (including managers, industry). Project staff's scientific advice on quantitative and qualitative matters is also clearly valued.

The stock assessments presented in this report have provided managers and industry greater confidence when making key commercial and sustainability decisions for species in the SESSF. These assessments have provided the most up-to-date information, in terms of data and methods, to facilitate the management of the Southern and Eastern Scalefish and Shark Fishery.

23. Conclusion

- Provide quantitative and qualitative species assessments in support of the four SESSFRAG assessment groups, including RBC calculations within the SESSF harvest strategy framework.

The 2017 assessment of the stock status of key Southern and Eastern Scalefish and Shark fishery species is based on the methods presented in this report. Documented are the latest quantitative assessments (Tier 1) for key quota species (orange roughy, redfish, school whiting), as well as cpue standardisations for shelf, slope, deepwater and shark species and Tier 4 analyses. Typical assessment outputs provided indications of current stock status and an application of the Commonwealth Harvest Strategy framework. This framework is based on a set of assessment methods and associated harvest control rules, with the decision to apply a particular combination dependent on the type and quality of information available to determine stock status (Tiers 1 to 4).

The assessment outputs from this project are a critical component of the management and TAC setting process for these fisheries. The results from these studies are being used by SESSFRAG, industry and management to help manage the fishery in accordance with agreed sustainability objectives.

Stock status and Recommended Biological Catch (RBC) conclusions:

The 2017 assessment school whiting was updated to provide estimates of stock status in the SESSF at the start of 2018. The 2009 stock assessment was updated with the inclusion of data up to the end of 2016, comprising an additional eight years of catch, discard, CPUE, length and age data and ageing error updates. The base-case assessment estimates that current spawning stock biomass is 47% of unexploited stock biomass (SSB_0). Under the agreed 20:35:48 harvest control rule, the 2018 recommended biological catch (RBC) is 1,606 t, with the long term yield (assuming average recruitment in the future) of 1,641 t. The average RBC over the three year period 2018-2020 is 1,615 t and over the five year period 2018-2022, the average RBC is 1,621 t.

The base case assessment for eastern redfish was updated from the last full assessment in 2014. A base case assessment was achieved according to the RAG-agreed model structure that did not separate length data by zone. The model fits to the catch rate data, length data and conditional age-at-length data reasonably well. The magnitude of the estimated recruitment in 2011 in the 2014 assessment has been greatly reduced in the 2017 assessment (although estimates of recent recruitment have increased compared to the period of poor recruitment during 2002-2010). The assessment estimates that the projected 2018 spawning stock biomass will be 8% of virgin stock biomass (projected assuming 2016 catches in 2017). Estimates of recruitment since the early 2000s have been lower than average (except for 2011, 2012), potentially as a consequence of directional environmental change influencing productivity. Low recruitment scenarios using average historical recruitment residuals from 2001 to 2010 for future projections of constant annual catches showed a markedly slow increase in spawning biomass for annual catches of 50t. Catches of 150t were not sustainable under this low recruitment assumption.

The stock assessment for Eastern Zone Orange Roughy (*Hoplostethus atlanticus*) was updated from the last assessment in 2015. As in the last assessment it assumes a stock structure that combines the Eastern Zone (primarily St Helens Hill and St Patricks Head) and Pedra Branca from the Southern Zone (all seasons). New data included since the previous stock assessment were recent research and commercial catches; relative spawning biomass estimates from the 2016 acoustic towed surveys at St

Helens Hill and St Patricks Head, a revised index of spawning biomass from the 2013 towed acoustic survey (which derived from a re-calibration of the survey gear), and new age composition data from catches taken in 2012 and 2016. After examination of the likelihood profiles around the fixed parameters of natural morality (*M*) and the stock recruitment relationships steepness (*h*), a better fit and more plausible biological model was used as a final base-case that used an $M = 0.036$ rather than 0.04 and an $h = 0.6$ instead of 0.75. The ageing data is intrinsically noisy, especially as the sample sizes are typical of SESSF fisheries but there are 80 year classes and samples of up to 600 fish still generate age-composition distributions with a very spiky appearance. The 2018 RBC was 709t for (M=0.036, h=0.6) and 1314t for (M=0.04, h=0.75). The respective depletions in 2017 were 0.298 and 0.338.

A Tier 3 analysis was conducted for John dory. Recent average total mortality was estimated from catch curves constructed from length frequency information. Length frequency data were from ISMP port and/or onboard measurements. New ageing data were available for John Dory in 2017, the previous sampling was from 2011. Including the new ageing data (2010 to 2016), the 2018 RBC for John Dory is 485t, compared to the 2013 RBC of 203t.

The Tier 4 harvest control rule is applied to species for which there is no reliable information on either current biomass levels or current exploitation rates. Tier 4 assessments were conducted on Blue Eye, Mirror Dory East and West, Western Gemfish, Silver Trevally, Deepwater sharks, Ocean Perch, Mixed oreos, Elephant fish and Sawshark. The Mirror Dory analyses treat the west and east as separate stocks, and also include the high levels of discards that occur in the east. Estimated RBCs for Mirror Dory East were 201t (199 t with discards), Mirror Dory West 123t (112t with discards), Western Gemfish Z4050 436t, silver trevally 445 t, Eastern Deepwater Sharks was 9t, Western Deepwater Sharks was 313 t, Offshore Ocean Perch was 344 t, Inshore Ocean Perch was 248t, Mixed Oreos was 135 t (256 t with discard 256 t), Ribaldo was 430t and Royal Red Prawn 431 t. The Blue eye estimated RBC was 482 t. The RBC estimate for elephant fish (excluding discards) was 293 t. This corresponds to a 12.36 t decrease compared to the 2015 RBC estimate. The estimated RBC for sawshark was 519 t, an approximate 16.4 t reduction compared to the RBC estimated in 2015.

24. Appendix: Intellectual Property

No intellectual property has arisen from the project that is likely to lead to significant commercial benefits, patents or licenses.

25. Appendix: Project Staff

Franzis Althaus	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Claudio Castillo-Jordan	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Jemery Day	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Mike Fuller	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Malcolm Haddon	CSIRO Oceans and Atmosphere, Hobart, Tasmania
André Punt	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Miriana Sporcic	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Robin Thomson	CSIRO Oceans and Atmosphere, Hobart, Tasmania
Geoff Tuck	CSIRO Oceans and Atmosphere, Hobart, Tasmania