National Research FLAGSHIPS
Wealth from Oceans

CSIRO

Australian Spawning Population of Orange Roughy:

Eastern zone acoustic and biological index fished from 1987 to 2010

Rudy Kloser, Caroline Sutton, Kyne Krusic-Golub

www.csiro.au

Draft report to the South East Trawl Fishing Industry Association

October 2012

SETFIA SOUTH EAST TRAWL FISHING INDUSTRY ASSOCIATION

sustainable fishing practises protect our future

CSIRO

National Library of Australia Cataloguing-in-Publication entry

Author: Kloser, R. J.

Title: Australian spawning population of orange roughy :eastern zone acoustic and biological index fished from 1987 to 2010 / Rudy Kloser ; Caroline Sutton ; Kyne Krusic-Golub.

ISBN: 9780646583594 (pbk.)

Subjects: Orange roughy--Spawning--Australia, Southeastern.
Orange roughy--Monitoring--Australia, Southeastern.
Orange roughy--Australia, Southeastern--Measurement.
Fish populations--Australia, Southeastern--Measurement.
Fish stock assessment--Australia, Southeastern.
Fishing surveys--Australia, Southeastern.
Underwater acoustics--Australia, Southeastern.
Echo sounding in fishing--Australia, Southeastern.

Other Authors/Contributors:
Sutton, Caroline.
Krusic-Golub, Kyne.
CSIRO. Marine and Atmospheric Research

DEWEY NUMBER: 333.95664160994

SUMMARY OF CHANGES TO THE ORANGE ROUGHY FISHERY FROM 1987 TO 2010

Reductions in abundance, mean length, age, age at maturity with corresponding increased fecundity have been observed for the Eastern zone orange roughy spawning population and are well recognised effects of an exploited fishery (e.g. Haedrich and Barnes 1997; Clark *et al.* 2000 provides a good summary). Unfortunately due to changing methods and practices there is uncertainty in all indicators that are highest in the earlier years of the fishery. In recent years there is strong evidence of recruitment of fish to the spawning population where age and length data indicate that younger and smaller fish are entering the spawning population and acoustic surveys report an increase in biomass. Reproductive studies indicate increased fecundity and improved fish condition that may be associated with the decline in fish density.

A summary of the main indicators at the eastern zone spawning region from 1987 to 2010 are as follows:

- **The St Helens snapshot spawning biomass estimate has decreased by 73% from 71497 tonnes in 1990 (hull estimate c.v. 0.49) to 19200 tonnes in 2010 (towed estimate c.v. 0.15).**

- **Eastern Zone acoustic snapshot spawning biomass estimate increased by 7100 t from 18359 t (c.v. 0.15) in 2006 to 25459 tonnes in 2010 (c.v. 0.15). This represents a potential recruitment rate to the fishery of 1800 tonnes per year.**

- **Average standard length of orange roughy has decreased by approximately 1-2 cm variable between sex and grounds.**

- **Average age has decreased by 15 to 25 years variable between sex and grounds**.

- **Age at 50% maturity has shifted downward by up to 2 years from 30 to 28 years for males.**

- **Length standardised fecundity has increased 75% presumably in response to the stock depletion.**

- **The reproduction potential of the stock in 2010 is estimated at 32% of the virgin levels.**

- **Age and Length** d**ata sources differed between years with a mix of port and at sea sampling.**

- **Potentially significant issues regarding representative sampling for age and length data due to differences in the 1992 and 2004 years.**

- **Age data time series has been verified both by re-aging and otolith weight comparisons.**

- **Estimated catch since 1987 at the spawning grounds has been approximately 87 k tonnes.**

Conclusions and Recommendations:

1. That age and length data have not been similarly collected over time and could be biased and used with caution in stock assessment models.

2. Acoustic data has varied in methodology over time and prior to 2006 only broad trends can be drawn with high c.v.’s.

That given the conflict between the acoustic and model (age/stock structure driven) interpretation of the stock size and recovery rate that repeat acoustic surveys and appropriate biological sampling for age, length, weight and reproductive potential are done to provide sustained evidence of the recovery rate and stock size.

1. BACKGROUND AND NEED:

Orange roughy is a deep-sea fish that is long lived, has a late age of maturity and forms large aggregations making it vulnerable to over fishing (Koslow *et al.* 2000). Globally many orange roughy fisheries have reported an initial high catch rate followed by a rapid decline with predicted long response time for recovery (Clark *et al.* 2000; Branch 2001).

The initial large decline in orange roughy biomass due to fishing is well documented with the associated contraction in fishing area (Branch 2001). Associated biological responses to fishing such as change in length, weight and age structure, fecundity, and recruitment variability over a number of generations have not been reported. This is due to the fact that a generation time for orange roughy may be ~50 years and biological records of orange roughy fishing have only been done over the past ~35 yrs. The longest record of fishery catch and biological indicators are from the New Zealand (~1979 – present) and Australian (~1987 – present) fisheries. A within generation study from NZ over a twenty year fishing period (1979 – 1997) documented the effect of fishing on the population (Clark *et al.* 2000). In that study the fishing area contracted and CPUE analysis determined that the fishery declined to 20% of virgin levels. Importantly biological indicators over that time did not show any marked changes in length, age and fecundity leading to predictions there would be a long response time to fishing (Clark *et al.* 2000).

In the Australian fishery there was a marked decrease in catch since the fishery began as a combination of management measures were introduced combined with declining catch rates and stock assessment results (Bax *et al.* 2006). In 2006 orange roughy were classed as conservation dependant by the Australian Government and most fishing areas closed to fishing to allow stocks to rebuild from the estimated ~16% virgin biomass levels (Tuck 2007). As part of the conservation dependant listing a monitoring plan was put in place to determine the effects of fishing on the population and if and at what rate the major spawning site for orange roughy was recovering (AFMA 2006). Monitoring of the spawning site between 2006 and 2010 showed that the biomass at the spawning site had increased by ~7400 t (Kloser *et al.* 2011). The estimated biomass at the spawning site in 2010 was ~2 times greater than that estimated by a subsequent stock assessment model (Upston and Wayte 2011). Data entered into the model include a catch series, age data series, egg survey and acoustic biomass series. The main impact for estimating the biomass and population trajectory within the stock assessment model is due to the age data series 1992 to 2010 and in particular the data from 1992.

As part of the orange roughy assessment process a comprehensive review of the existing data and assumptions for input into the assessment and more broadly to understand the biological changes that have occurred in the population over time was recommended (Stokes 2009). An initial review of the acoustic and biological indices was presented at the AFMA April 2011 orange roughy assessment data meeting (Kloser *et al.* 2011). This initial review highlighted the differences in New Zealand and Australian orange roughy population response to fishing and that careful use needs to be made of catch, proportion spawning, age and acoustic data in the model. In particular the initial review showed how the age data was sensitive to ground and shot biases. The importance of the age data to the assessment model was emphasised at the AFMA orange roughy meeting held in May 2011 and further heightened the need to investigate any potential biases and or errors. The November 2011 slope resource assessment group endorsed a review of the data inputs to the stock assessment model as part of their research plan. This project forms part of that review with the following objective.

Objective:

- Document and review the orange roughy eastern zone acoustic and biological indices 1987 to 2010.

2. BIOLOGICAL DATA SOURCE (SIZE AND AGE)

2.1 LOCATIONS

The Tasmanian Eastern Zone (TEZ) orange roughy spawning grounds are comprised of St Helens Hill and St Patricks Head (Figure 2.1). Both grounds have been heavily exploited since the beginning of the fishery in the early 1980s.

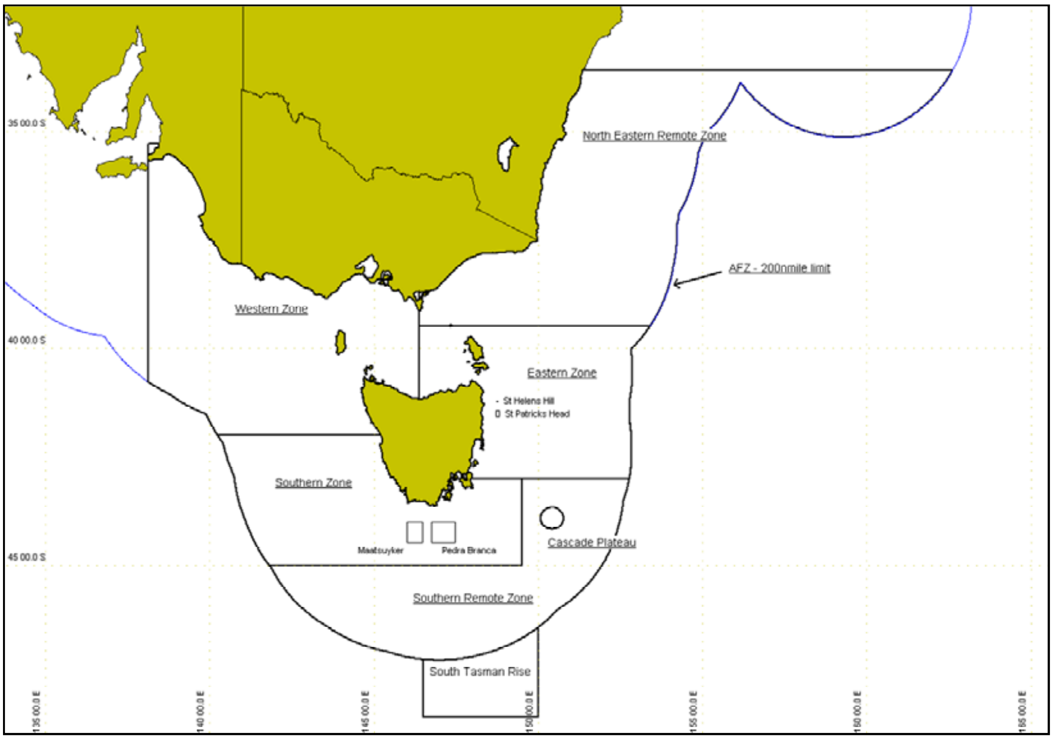


Figure 2.1 Location of the Tasmanian Eastern Zone spawning grounds. Image sourced from Wayte (2006).

2.2 DATA SOURCES

Most data were sourced from research surveys conducted by CSIRO, Biospherics and Fishwell. CSIRO has conducted biological surveys for Orange Roughy since 1987 and many in association with acoustic surveys since 1990 (CSIRO 1991; Kloser *et al.* 2001; Ryan and Kang 2005; Kloser *et al.* 2008; Kloser *et al.* 2011; Diver 2004; Knuckey *et al.* 2007; Knuckey *et al.* 2008). Generally biological samples were collected onboard commercial trawlers by observers or scientists. Two exceptions include the 1987 and 1992 samples which were collected from CSIRO's research vessels *RV Soela* and *RV Southern Surveyor* respectively. From 2004 both the acoustic and biological samples have been collected from commercial trawlers during the same survey.

Between 1989 to 1992 CSIRO used size distribution data from commercial trawls as part of an egg biomass survey and a fecundity analysis (Koslow *et al.* 1995a; Koslow *et al.* 1995b). We have been unable to locate these particular field data sheets or the electronic files to date. Only a subset of the fecundity data has been located which contains female fish that were selected according to size class and therefore not representative of the population (Koslow *et al.* 1995b).

Other data sources (not included in this report)

Other sources of orange roughy data include; Tasmanian Aquaculture and Fisheries Institute (TAFI) and the Australian Fisheries Management Authority (AFMA). AFMA coordinated the Integrated Scientific Monitoring Program (ISMP, formerly SMP), Knuckey *et al.* (1999) provides a good account of the development of the observer program for the South East Fishery. The various groups that worked on Orange Roughy over the years had some significant differences in methodology used for measuring Standard Length (SL, Table 2.1). Key differences were the length measurement technique itself (offset tape, length board or electronic length board), the measurement resolution, the rounding methodology and precisely which parts of the fish was deemed to constitute the SL (Table 2.1).

Table 2.1 Length measuring protocols

Group	Method	Reference
Sea Fisheries (now TAFI)	SL (end of the hypural plate) rounded down to the nearest cm	Lyle et al 1991, J Lyle pers com
CSIRO 1987-96	SL (end of the hypural plate) rounded to the closest cm using an offset tape	Mark Lewis, CSIRO pers com
CSIRO 1996-present	SL (end of the hypural plate) to the closest mm using an electronic board	Mark Lewis, CSIRO pers com
Biospherics	SL (end of the hypural plate) to the closest mm using an electronic board	Mark Lewis, CSIRO pers com
Fishwell	SL (end of the hypural plate) to the closest mm using an electronic board	Mark Lewis, CSIRO pers com
ISMP 1998- present SMP 1993-1998	To the end of the caudal peduncle rounded up into cm size classes	Mark Lewis, CSIRO pers com Knuckey et al 1999

2.2.1 LENGTH AND WEIGHT

An audit was conducted on all Orange Roughy length and weight data held by CSIRO from 1987 to 2010. Datasets from research and commercial vessel based surveys were compiled into a single standardised format excel workbook for Year/ Zone/Area/Survey Name/Date/Operation Number/Length/Weight/Sex/Stage. Similarly the Shot Data was compiled and standardised for Year/Zone/Area/Survey Name/Date/Operation Number/Latitude/ Longitude/Depth/Catch Weight. The data were then imported into an MS Access Database to cross reference biological and shot data using the fields Survey Name/Operation Number.

2.2.2 AGE

All age data (AGE dataset) were obtained directly from Fish Ageing Services (FAS), formally CAF (Kyne Krusic-Golub pers. comms.). Although CSIRO uses this same data for the Stock Assessments, it was necessary to use the original ‘source’ files because over the years fields have been eliminated from the CSIRO age datasets preventing thorough crosschecking. The otoliths used for the AGE dataset are from fish collected during the above mentioned surveys. However the source of the otoliths aged for years 1992 and 1995 is uncertain.

While not conclusive the weight of evidence suggests that AGE data for 1992 and 1995 were from fish collected via Port sampling;

- It is unlikely the otoliths from 1992 are from fish collected on the *RV Southern Surveyor* cruise SS0392. The cruise report makes no mention of otolith collection (CSIRO 1992) and there are more otoliths (542) for 1992 than fish collected (340) during SS0392 (Table 2.3).

- For 1995 there was no acoustic survey and we have no corresponding length data to match the age data.

- For these years otoliths were collected from multiple vessels and shot data are absent. Generally survey data is collected from a single vessel, 2001 is the only exception where the survey involved two vessels. The AGE dataset indicates that for 1992, data were collected from at least two vessels (three if June data are included) and for 1995, data were collected from five vessels.

The Age and the Length/Weight datasets can be fully cross-referenced to the level of Zone/Area/Year/Month/shot for all years but 1992, 1995 and 2004. Unfortunately we cannot locate the shot data for these years despite going back to the original otolith sample envelopes.

Based on crosschecking between, the CSIRO Length/Weight datasets, original field survey sheets and Industry survey dates with station data and the 'Original Client Reference' fields of the AGE dataset, we made some changes to the AGE dataset. Specifically;

1987, SO587:	Spawning ground has been changed from St Helens to St Patricks. Data from the original excel survey dataset were crosschecked with the Original Client Reference in the AGE dataset.
1992, Port samples:	Date change from 7 June 1992 to 6 July 1992 (n = 255) and 7 July (n=291). Survey dates from commercial vessels were crosschecked with dates in the AGE dataset
2001, PE2001:	Station or date data for the following shots were missing from the AGE data base and had to be sourced from the original hard copy field data sheets. Note that these shots have not been included in any of the analyses in this document: Shot 13 (St Helens, 12 July 2001, n = 25) Shot 41 (St Patricks, 28 July 2001 n = 39) Shot 45 (St Patricks, 29 July 2001, n = 42)

2.3 FIELD AND MEASUREMENT PROTOCOLS

Orange Roughy are fished from commercial trawlers using demersal roughy nets fitted with 40 mm cod-end liners using standard industry methodology (Kloser *et al.* 2001; Kloser *et al.* 2008; Kloser *et al.* 2011). Trawl nets and fishing methodology have been modified throughout the life of the fishery to reduce catch size, prevent net losses, and in response to survey objectives. Currently nets are fitted with large windows up from the codend and shots are targeted at the edges of aggregations (Mark Lewis personal communication CSIRO).

2.3.1 LENGTH

All the Standard Length (SL) data presented here were collected using the recommended protocol (Appendix B). Standard Lengths before 1999 were measured and grouped into cm size classes using a fish length board with a 0.5 cm offset. After 1999 lengths were measured to the and standardise between years, all lengths were rounded to the nearest cm.

2.3.2 WEIGHT PROTOCOLS

Weight measuring methods are inconsistent between years and are generally considered less reliable than the length data for between year comparisons. Weights prior to 1999 were measured in the laboratory from frozen specimens. From 1999 fish have been weighed in the field with a high precision motion compensated balance. Weights from frozen specimens are biased low due to the dehydrating effects of the freezing process (Kloser *et al.* 2001).

2.4 FILTERING AND FOCUS/JUSTIFICATION

Spawning ground, sexual dimorphism and spawning aggregations are important aspects of the Orange Roughy fishery and are known contributors to variability in size and age structure. The results of an experiment in 1999 where replicate tows were conducted in and out of spawning aggregations at the spawning areas of St Helens and St Patricks are shown below (Kloser *et al.* 2001). Figure 2.2 shows that for experiments conducted during 1999, population structure was influenced by 1) spawning grounds, 2) sexual dimorphism and 3) spawning aggregations. In summary, female fish were on average larger than males at St Helens. St Helens fish were larger relative to those at St Patricks and fish caught from within spawning aggregations were larger than those caught outside spawning aggregations.

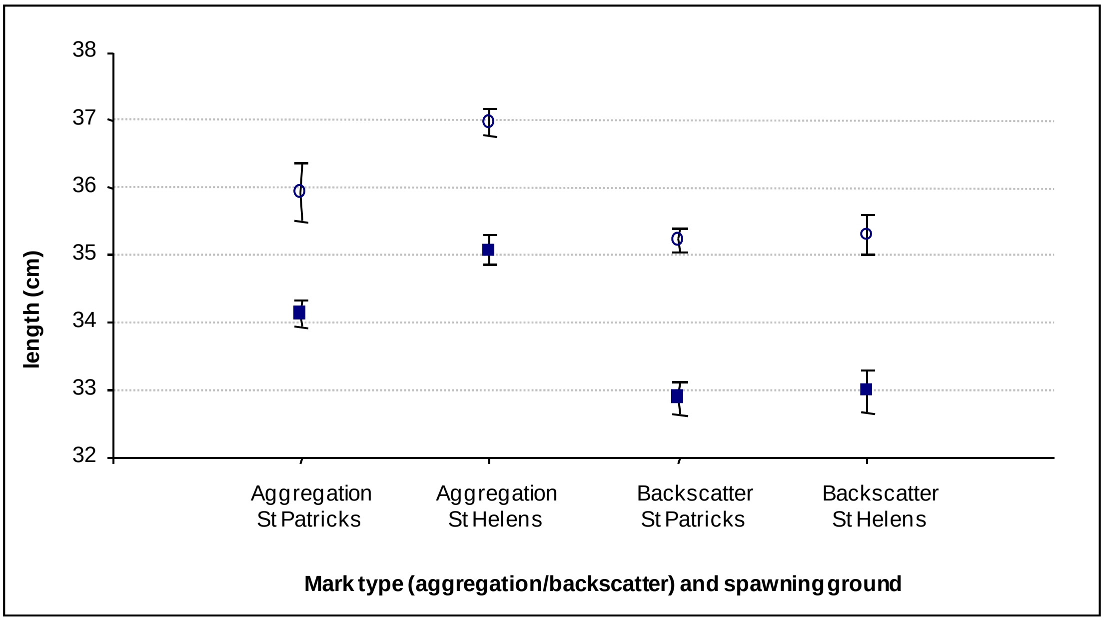


Figure 2.2 Difference in standard length between the Backscatter (non-spawning) population and targeted spawning aggregations for females (circles) and males (squares) at St Helens and St Patricks in July 1999 (SS0399). Error bars are 95% confidence limits.

Recognising these influences, all the time series data are presented by sex and by spawning ground. Data were included if they were from Eastern Zone spawning aggregations from either St Helens or St Patricks and the fish were sexed, because Orange Roughy are sexually dimorphic.

To select for spawning aggregations from the greater dataset, only July samples were included because mid July is the peak of the spawning season (Bell *et al.* 1992; Koslow *et al.* 1995a). The method of fishing where the skippers targeted "Marks" of >1000kg at the spawning ground (on a hill or significant feature in this case St Helens Hill and St Patricks Head) also ensured that spawning aggregations were targeted (Kloser *et al.* 2008). To further refine the selection we considered only using fish from samples with total catch weights of >1000kg. However we did not use this final filter because in too many cases total catch data was not complete for all survey years and the use of this filter resulted in the loss of too much data. Table 2.2 summarises the impact on sample size of the successive filter selections.

The subset of data used for this document is summarised in Table 2.3

Table 2.2 Eastern Zone Length Data Summary for the three data filtering scenarios. (Note that backscatter samples from 1999 are excluded).

Year	June, July, August	July	July and shot weight > 1000kg
1987	785	327	
1990	2563	1259	
1992	340	340	
1996	1010	1010	427
1999	2095	2095	1519
2001	3492	3492	2177
2002	1080	1080	909
2004	3019	3019	3019
2005	2991	2991	
2006	5406	5406	3667
2007	2788	2788	
2008	3665	3665	
2009	1649	1649	1469
2010	1548	1548	1448

Table 2.3 Data subset: Orange Roughy spawning aggregations (fish caught in July) in the Eastern Zone (St Patricks and St Helens). [A] indicates an associated acoustic survey.

Agency	voyage	year	ground	No. shots	No. SL	No. sexed	No. wts.	No. staged	No. shot wts	Age data
CSIRO	SO587[A]	**1987**	SP	9	327	327	327	327		310
CSIRO	MS190[A]	**1990**	SH	7	1259		1259	1259		
CSIRO	SS0392	**1992**	SH	4	340		340	340		
?	Port									*546
?	Port	**1995**								*1248
CSIRO	SP196 [A]	**1996**	SH	16	793	151	151	793	793	
			SP	5	217	46	46	217	217	
CSIRO	SS0399[A]	**1999**	SH	8	1346	259	1346	1346	1346	444
	SP1999		SP	3	749	151	749	749	749	137
CSIRO	CR2001	**2001**	SH	13	310	310	310	310	293	201
			SP	14	324	324	324	324	285	242
	PE2001		SH	16	1139	1139	1139	1139	1139	234
			SP	21	1719	1719	1719	1719	1719	551
CSIRO	PE2002	**2002**	SH	3	136		136	136	136	
			SP	10	944	79	944	944	944	
Biospherics	AP2004	**2004**	SH	9	1992	1992	1992	1992	1992	463
			SP	7	1356	1356	1356	1356	1356	456
Fishwell	SP2005	**2005**	SH	6	1190	1190	1190	1190		
			SP	9	1801	1801	1801	1801		
CSIRO	AP2006[A]	**2006**	SH	14	2260	2260	2260	2260	2260	
			SP	24	3146	3146	3146	3146	3146	
Fishwell	SP2007	**2007**	SH	7	1736	1736	1736	1736		
			SP	5	1052	1052	1052	1052		
Fishwell	SP2008	**2008**	SH	10	2137	2137	2137	2137		
			SP	7	1528	1528	1528	1528		
CSIIRO	SX2009[A]	**2009**	SH	10	1095	1095	1095	1095	1095	
			SP	7	554	554	554	554	554	
CSIRO	SX2010[A]	**2010**	SH	10	1064	1064	1059	1064	1064	598
			SP	3	389	483	484	484		350

* AGE data for 1992 be from port samples or from fish reported in Koslow 1995 a and b. We have obtained a female_fish_fecundity dataset subset which includes lengths and ages for 1991 (n=109) and 1992 (n = 100) from Tony Koslow (via Luke Pitman) .

Voyage Information: SO = *RV Soela,* MS = *FV Majestic Star*, SS = *RV Southern Surveyor,* SP = *Saxon Progress,* CR = *FV Celtic Rose,* PE = *FV Petunia Explorer,* AP = *Adriatic Pearle,* SX = *Saxon Progress* (note same vessel as above but different voyage reference).

Note: Some age data from the original AGE dataset obtained from Kyne of Fish Aging Services have changed after crosschecking our Length/Weight datasets, original field survey sheets or Industry survey dates with the Original Client reference or station data of the AGE dataset. See Section 2.2.2 for specifics.

3. SIZE DISTRIBUTION

3.1 METHODS

3.1.1 STANDARD LENGTH

All data are filtered according to the criteria described above in Section 2.4 to reduce the likelihood of including data that were not from spawning aggregations. For each survey year length frequencies distribution and average standard length (SL) are presented for males and females at the St Helens and St Patricks spawning grounds.

3.1.2 LENGTH TO WEIGHT RELATIONSHIP

Average weight for males and females captured at St Helens and St Patricks are plotted by year. As with the length data, weight data are filtered according to the criteria described above in Section 2.4 to reduce the likelihood of including data that were not from spawning aggregations.

The estimated weights for each year are calculated with the weight-length equation (Equation 3.1) used for the eastern zone orange roughy stock assessments in (Lyle *et al.* 1991; Wayte 2006).

$$W_{male} = 0.083L^{2.942}$$

$$W_{female} = 0.051L^{2.970}$$

$$W_{combined} = 0.07L^{2.952}$$

Equation 3.1 Length-weight equation (Lyle *et al.* 1991).

Estimated and Observed weights were compared by plotting the results of observed minus expected values with box plots for each year for combined males and females. Lyle (1991) found that there was no significant difference between F-values or intercepts between the male and females and that the equation for the combined sexes adequately described the relationship for the Eastern zone population.

3.2 RESULTS

3.2.1 STANDARD LENGTH

Figure 3.1 plots the orange roughy standard length for males and females at St Helens and St Patricks. Average standard length has decreased by 1 to 2 cm from 1987 to 2010. Average lengths of male fish (1.6 cm - 1.8 cm) have decreased by more than the female fish (1.1 cm - 0.08 cm) at both grounds, St Helens and St Patricks respectively (). Length frequencies for males and female at both grounds have remained unimodal from 1987 to 2010 (Figure 3.2). However, consistent with the decrease in average length there is a downward shift in mode for males and females at both spawning grounds (Table 3.1). The mode for males has shifted from

37 cm to 34 cm at St Patricks and from 36 cm to 33.5 cm at St Helens. The mode for females has shifted from 38 cm to 37 cm at St Patricks and from 38 cm to 36 cm at St Helens.

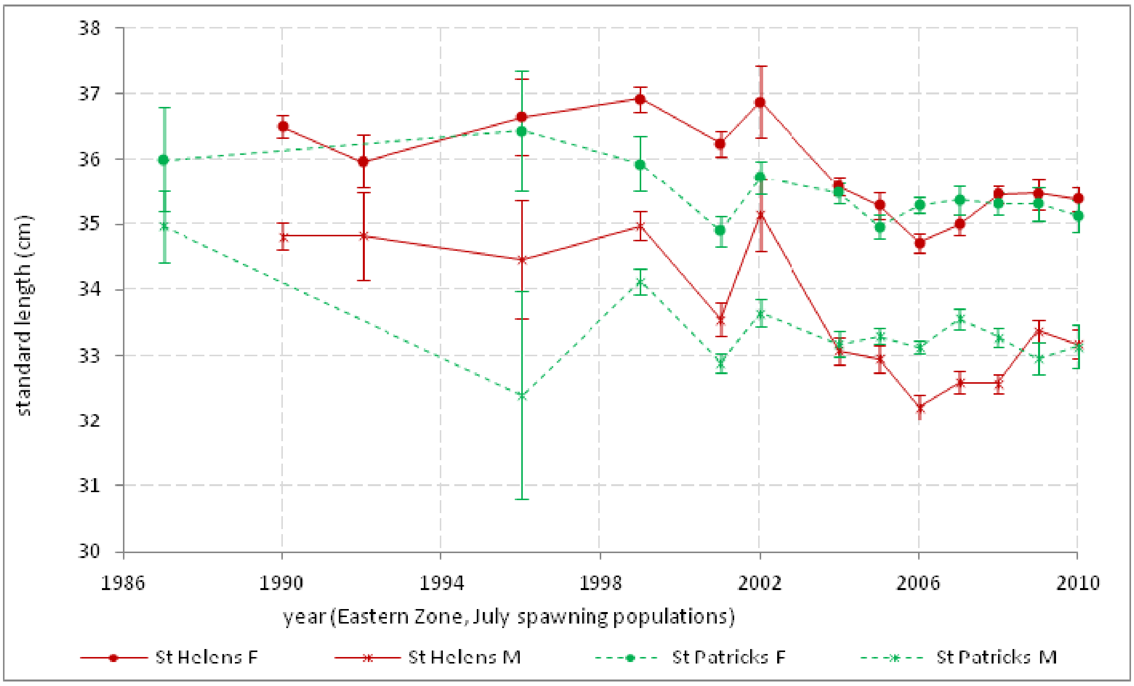


Figure 3.1 Average length for Orange roughy males and females at St Helens and St Patricks from 1987 to 2010. Error bars are 95% confidence intervals.

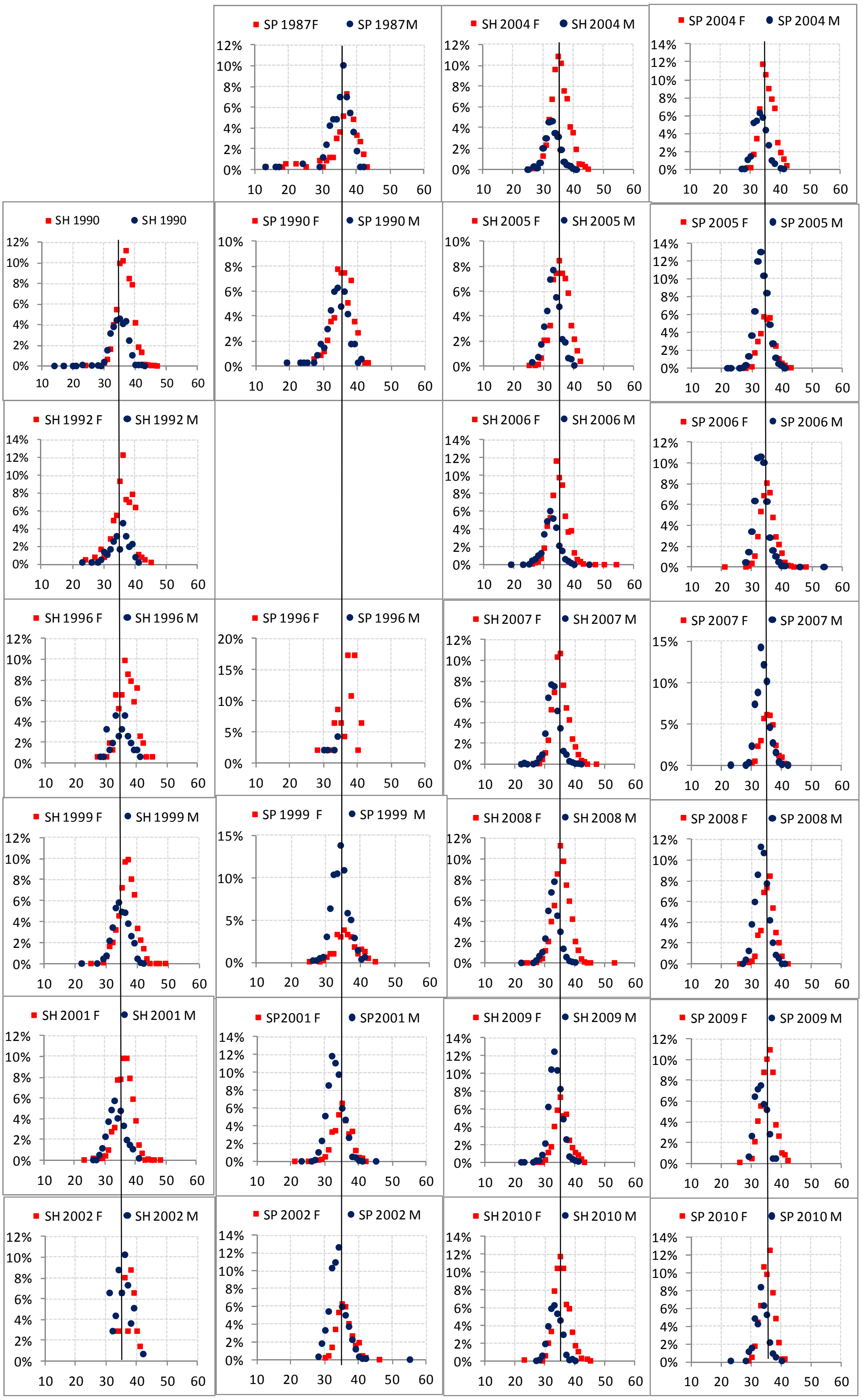


Figure 3.2 Length (cm) frequencies from 1987 to 2010. Data presented as percentage occurrence for each cm length category. Vertical lines set at 35cm length for modal reference.

Table 3.1 Number of fish measured and mode for standard lengths for males and females measured at St Helens and St Patricks from 1987 to 2010. Shots 13, 41 and 45 from PE2001 are not represented (refer to Section 2.2.2). Values in brackets are total numbers of fish including shots 13, 41 and 45 from PE2001 (refer to Section 2.2.2).

	St Helens				St Patricks			
	Females		Males		Females		Males	
Year	No. fish	Mode (cm)	No. fish	Mode (cm)	No. fish	Mode (cm)	No. fish	Mode (cm)
1987					146	38	181	37
1990	800	38	59	36				
1992	248	37	92	37				
1996	104	37	47	37	41	38-40	5	35
1999	840	37-38	506	35	199	36	550	35
2001	800 (971)	37-39	447 (478)	34	487	36	910	33
2002	59	37-39	77	37	332	36-37	612	35
2004	1465	37	527	33-34	886	35	470	35
2005	702	36	488	34	608	36-37	1193	34
2006	1520	35	740	33	1394	36	1752	35
2007	1064	36	672	33-34	362	35-36	690	35
2008	1402	36	735	34	639	37	889	34-35
2009	425	36	670	34	334	37	220	34
2010	704	36	355	33-34	304	37	179	34

Table 3.2 Proportion (percentage) of males and females caught at St Helens and St Patricks from 1987 to 2010.

St Helens													
	1990	1992	1996	1999	2001	2002	2004	2005	2006	2007	2008	2009	2010
% F	69	73	69	62	64	43	74	59	67	61	66	39	66
% M	31	27	31	38	36	57	26	41	33	39	34	61	34
St Patricks													
	1987	1990	1996	1999	2001	2002	2004	2005	2006	2007	2008	2009	2010
% F	45	55	89	27	35	35	65	34	44	34	42	60	63
% M	55	45	11	73	65	65	35	66	56	66	58	40	37

3.2.2 LENGTH - WEIGHT RELATIONSHIP

Average weight declined for males and females at St Patricks and St Helens from 1987 to 2010 but the decline was more subtle than the decline in Standard Lengths (Figure 3.3). Average weight at decreased by 156 g for males and 221 g females at St Patricks. Decrease in average weight was less for fish at St Helens with decreases of 107 g for males and 136 g for females respectively.

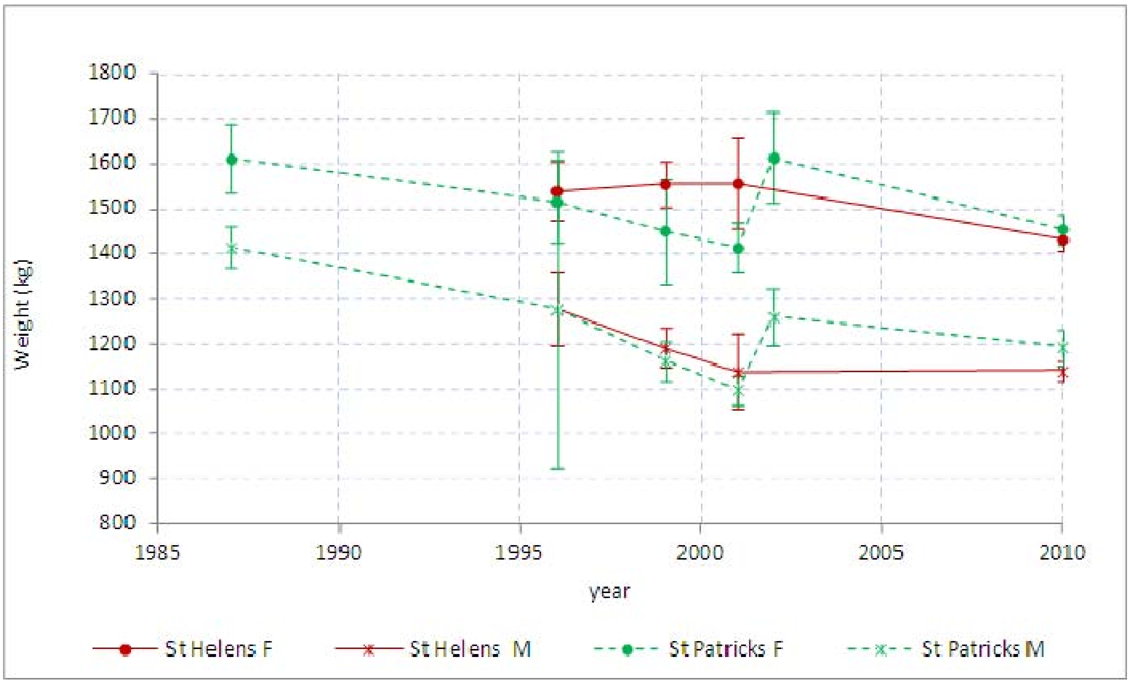


Figure 3.3 Average weight (g) of Orange Roughy females (circles) and males (asterisk) at St Helens and St Patricks from 1987 to 2010. Error bars are 95% confidence intervals.

There does not appear to be a shift in the weight-length relationship over time. The majority of observed weights were within 100 g of the expected weight (Lyle 1991). For most survey years the observed fish were heavier than expected and only 1996 and 1999 survey years were observed weights less than expected (Figure 3.5). However, overall the observed – expected values are generally spread around 0 suggesting a reasonable fit of the data to the Lyle (1991) equation (Figure 3.4).

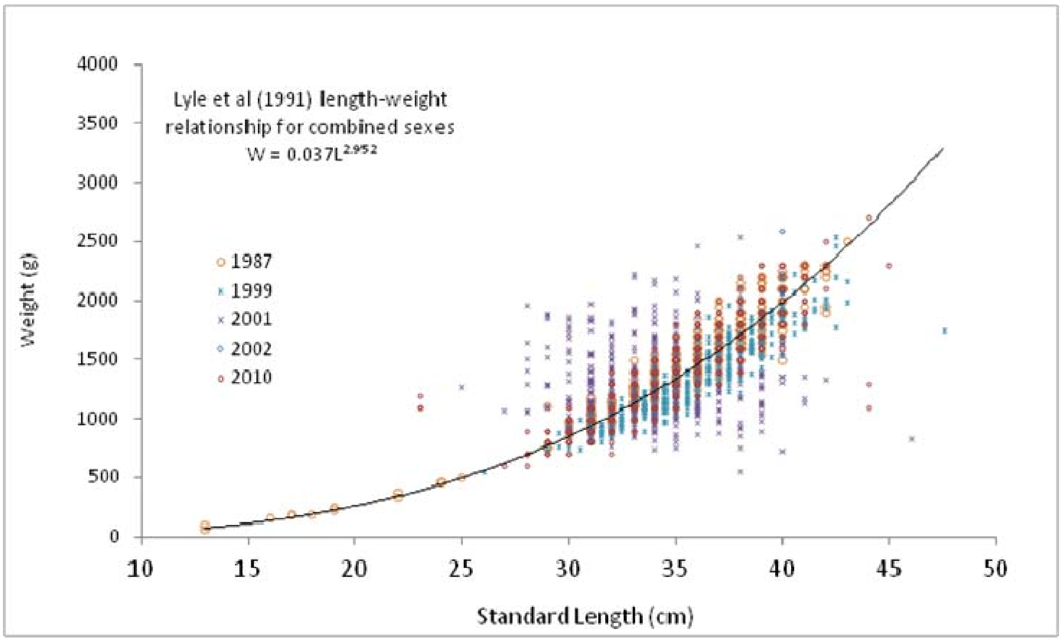


Figure 3.4 The Standard Length (cm) vs Weight (g) of all Orange Roughy from 1987 to 2010. The Lyle (1991) equation is shown.

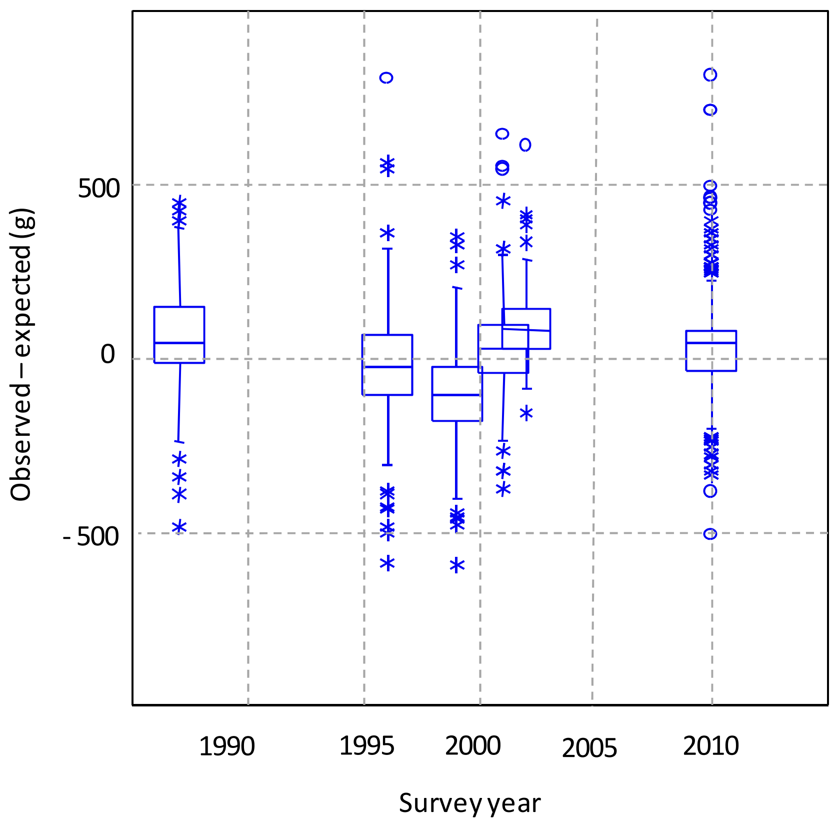


Figure 3.5 Observed minus expected (Lyle *et al.* 1991) values for weight of Orange Roughy from 1987 to 2010.

4. AGE AND MATURITY

4.1 AGE AND MATURITY METHODS

4.1.1 AVERAGE AGE

The age data is presented by year for males and females at St Helens and St Patricks. Age frequencies are plotted for each year. Data were selected for the Eastern zone spawning population following the filtering methods described in Section 2.4.

4.1.2 AGE AT MATURITY

Onset of maturity is consistent with the transition zone, and is defined as the point on the otolith where annulus width decreases markedly and the surface starts to curve (Francis and Horn 1997). Total orange roughy age is determined by and recorded as the number of annuls to the transition zone plus the number of annulus to the otolith edge (Appendix C). Change in age at maturity was assessed by comparing the age at which cumulative proportion of fish for each survey reached maturity. Sex, total age and site biases for age at maturity were also examined.

4.1.3 TESTS FOR AGE DATA REPRESENTATIVENESS

Shot by shot variability

The representativeness of the age data was assessed by examining the shot by shot variability in age estimates. Unfortunately the shot data has not been available for each survey, therefore for some surveys only the day to day variability is examined.

CAF age database comparison with CSIRO measures database

The AGE dataset is a subset of total surveyed population. The representativeness of the AGE data was examined by cross correlating the average standard lengths of AGE database with the lengths from CSIRO's survey database (LENGTH data) for each year, data permitting. Multiple t-tests were used to assess differences in average lengths for year, sex and grounds between the two datasets.

4.2 AGE AND MATURITY RESULTS

4.2.1 AVERAGE AGE

Average age has declined significantly from 1987 to 2010 (Figure 4.1). Decline in age was greater for males than females at both spawning grounds; Females are on average 15 and 16 years younger and males are 25 and 24 years younger at St Helens and St Patricks respectively. It is likely that the discrepancy is a sampling artefact or perhaps a behaviour difference between the sexes that allows males to be preferentially selected over females.

The Age Frequencies show that the population is largely unimodal with a long tail on the right hand side representing older fish (Figure 4.2). The left hand side of the population is truncated for most years due to the targeting of the spawning population and therefore an absence of young non-spawning fish from the samples. The left hand side of the tail is present in1987 suggesting that this survey may not have effectively targeted a spawning aggregation and caught some small non spawning fish. For some years (1987, 1992, 2001 St Helens) there is evidence of a minor mode at the right arm of the distribution around 80-100 years. Despite a large decline in proportion of older fish there is still a suggestion of this secondary mode at St Helens for 2004 and 2010.

There has also been an obvious downward shift of the mode at both spawning grounds for males and females (Figure 4.2, Table 4.1). The shift was greatest for St Helens with a downward shift of 20 and 25 years for females and males respectively. At St Patricks the mode shifted by 10 and 15 years for females and males respectively. The mode shift was greater at St Helens due to the greater proportion of very old fish in the early years.

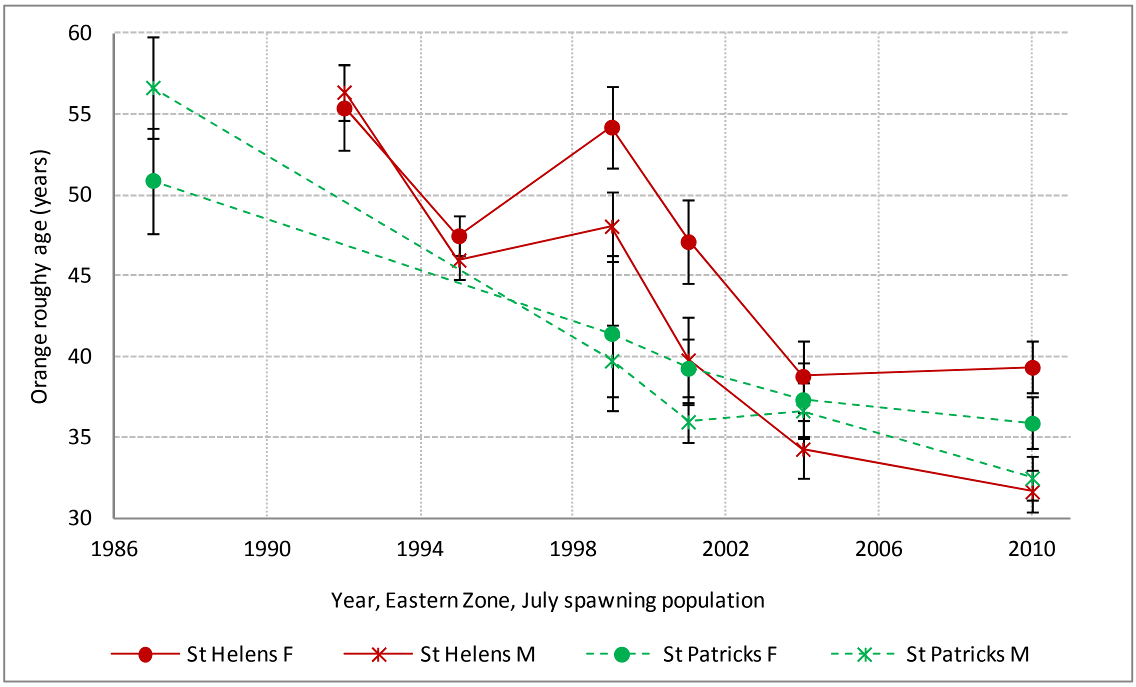


Figure 4.1 Average age of Orange Roughy males and females at St Helens and St Patricks from 1987 to 2010. Selection filtered applied (Eastern Zone, July, spawning population). Error bars are 95% confidence intervals.

Figure 4.2 Age Frequencies for male and female Orange Roughy at St Helens and St Patricks from 1987 to 2010. Selection filtered applied (Eastern Zone, July, spawning population).

Table 4.1 Mode of age for female and male fish at St Helens and St Patricks from 1987 to 2010. Selection filtered applied (Eastern Zone, July, spawning population).

	St Helens		St Patricks	
	Females	Males	Females	Males
1987			36-40	41-45
1992	46-50	56-60		
1995	41-45	41-45	38-40	35
1999	51-55	36-40	26-30	31-35
2001	36-40	26-30	26-30	31-35
2004	26-30	26-30	31-35	31-35
2010	26-30	31-35	26-30	26-30

4.2.2 AGE AT MATURITY

There is a downward shift in age at maturity from 1987 to 2010. Prior to 2004 50% of the population had reached maturity by the age of 30. By 2004 there was a shift to 29 years for both spawning grounds, and by 2010 there was a second shift for fish at St Patricks to 28 years (Figure 4.3). Most of the shift can be attributed to male fish with 50% of the male fish having reached maturity by 27 and 28 years in 2004 and 2010 respectively. Female fish showed evidence of a very minor shift, females matured at a slightly older age of 30.5 years and by 2010 50% of females had matured by 29 years (Figure 4.4).

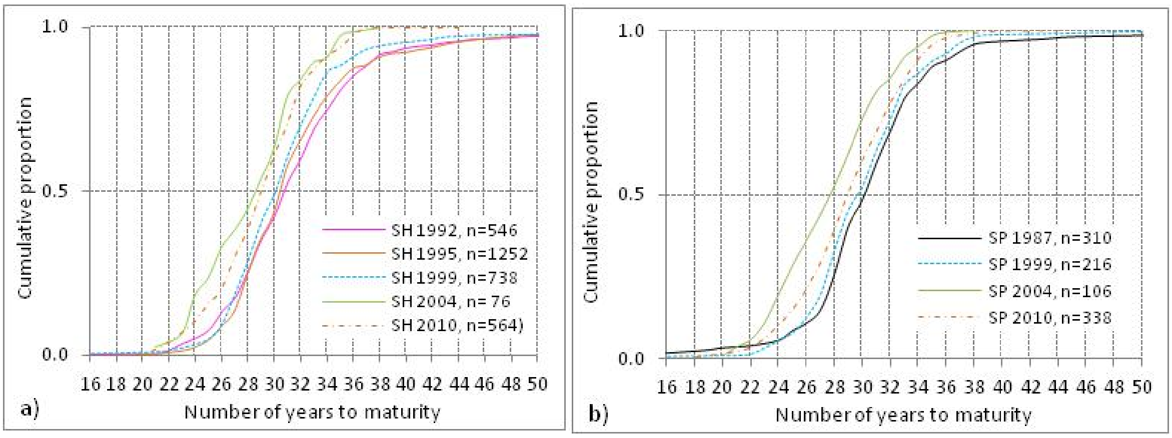


Figure 4.3 Age at maturity for all fish caught at a) St Helens and b) St Patricks from 1987 to 2010. Selection filtered applied (Eastern Zone, July, spawning population).

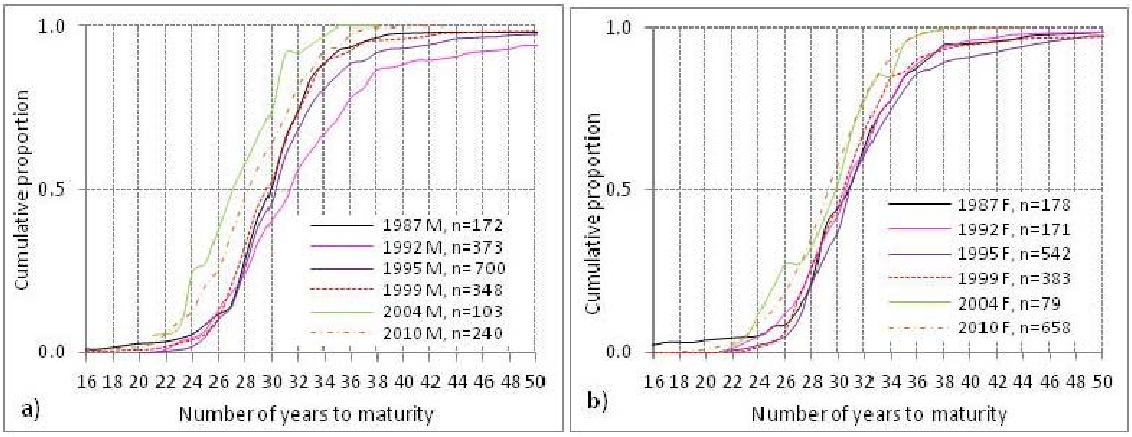


Figure 4.4 Age at maturity for a) male and b) female fish caught at the combined spawning grounds of St Helens and St Patricks. Selection filtered applied (Eastern Zone, July, spawning population).

4.2.3 AGE DATA REPRESENTATIVENESS

Comparison between the CAF and CSIRO datasets

In general the CAF and CSIRO datasets follow the same trend for decreasing average standard lengths over time indicating that generally the AGE data subset representatively samples the LENGTH dataset. There were however some important differences. There were significant differences in standard lengths between the AGE and the LENGTH datasets for 1992 and 2004 surveys. There was potentially up to 1cm difference in SL between females at St Helens in 1992 and females at St Patricks in 2004 (p values < 0.01, Figure 4.5). As discussed in Section 0 there are unresolved data gaps for some years. The AGE data for 1992 most likely came from port samples and not from SS0392 where the length data was sourced. The 2004 samples were collected on one day but there is no station data in the AGE dataset. Cross-referencing with LENGTH dataset shows that on that date there were 9 shots, so the age data could have come from up to 9 shots (Table 2.3). The high between shot variability this might account for the difference if the AGE data come from only a few shot.

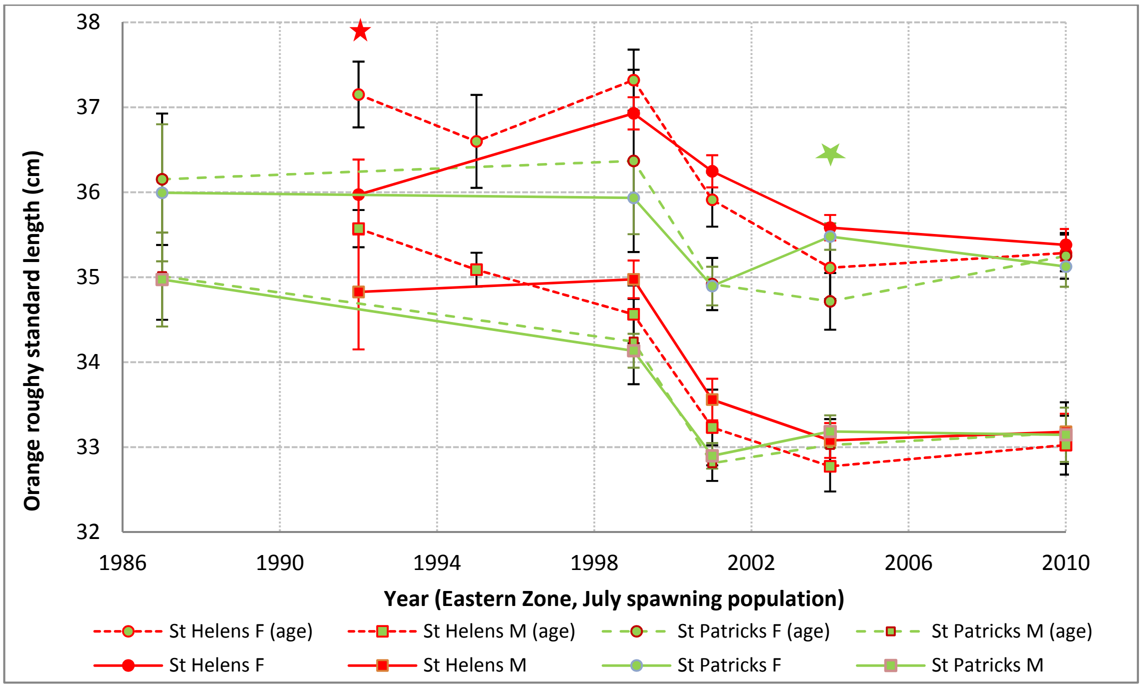


Figure 4.5 Comparison of standard lengths between the CAF and CSIRO datasets. Stars indicate significant different between the datasets ($p < 0.01$). Selection filtered applied (Eastern Zone, July, spawning population). Error bars are 95% confidence intervals.

Shot by shot variability

There was considerable inter shot variability (Figure 4.6). For some surveys average age between shots ranged from 35 to 55 years (St Patricks 1987), 25 to 65 years (St Patricks 2001) and 35 to 70 years (St Helens 2001).

Table 4.2 shows the average age, standard deviation and count for each shot (day if shot data are not available) from 1987 to 2010. Most surveys were conducted over multiple days with the exception of the 1987 and 2004 (Figure 4.6,Table 2.3).

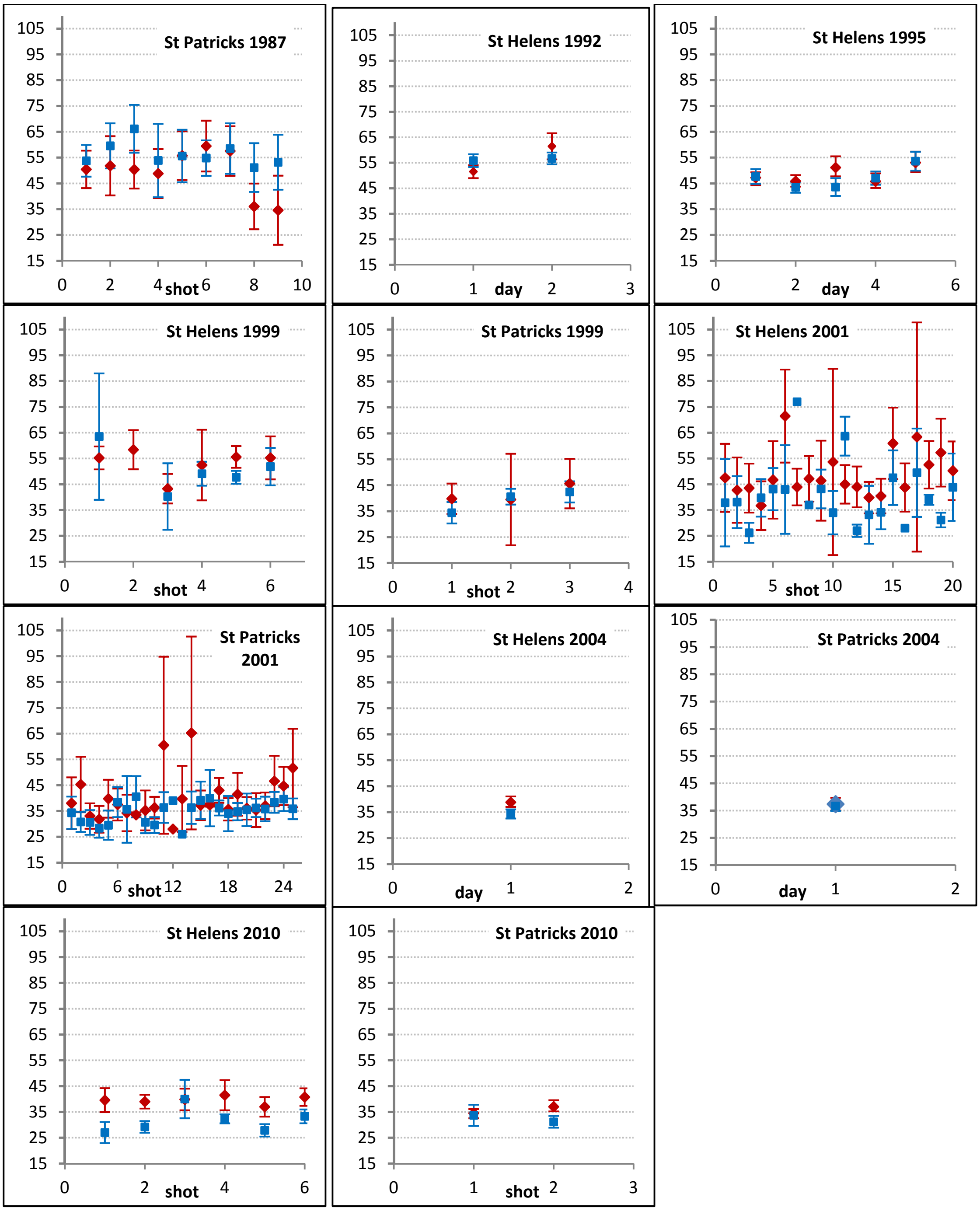


Figure 4.6 Shot variability for the Age data from 1987 to 2010. Selection filtered applied (Eastern Zone, July, spawning population). Error bars are 95% confidence intervals. Where shot data was not available data were plotted by day.

Table 4.2 Average Age of Orange Roughy for each shot from CAF AGE data set from 1987 to 2010. Selection filtered applied (Eastern Zone, July, spawning population).

Year	Ground	Vessel	Shot	Nos of fish			Average age			SD age		
				F	M	Total	F	M	Total	F	M	Total
1987	St Patricks	Soela	4	19	20	39	50	54	52	16	14	15
			5	16	24	40	52	60	56	23	22	23
			6	19	21	40	50	66	59	16	22	21
			7	15	8	23	49	54	51	19	21	19
			8	19	21	40	56	56	56	21	24	22
			9	15	29	44	59	55	56	19	19	19
			13	16	20	36	58	59	58	20	22	21
			14	14	24	38	36	51	46	17	24	22
			15	5	5	10	35	53	44	15	12	16
1992	St Helens	L. Dorn		67	224	291	61	57	58	21	18	19
		Monika		105	149	254	52	56	54	13	15	15
1995	St Helens	Bow River		181	142	323	47	48	47	14	18	16
		Megisti Star		87	142	229	46	47	47	15	16	15
		Rosa S		96	198	294	43	42	42	16	15	15
		Suzanne Ritchie		117	124	241	51	52	51	15	19	17
		Teena B		58	93	151	51	44	46	17	17	17
1999	St Helens	Saxon Progress	7	44	2	46	55	64	56	15	18	15
			8	22		22	58		58	18		18
			25	24	15	39	43	40	42	14	25	19
			27	11	38	49	52	49	50	23	15	17
			34	20	27	47	55	52	53	19	19	19
				89	149	238	56	48	51	20	15	18
	St Patricks		16	23	23	46	40	34	37	14	10	13
			19	4	43	47	40	41	40	18	10	11
			41	11	33	44	46	42	43	16	12	13
2001	St Helens	Celtic Rose	2	12	7	19	48	38	44	23	23	23
			4	11	9	20	43	38	41	21	15	19
			13	15	7	22	40	38	39	12	14	12
			14	17	5	22	44	26	40	20	4	19
			15	7	17	24	37	40	39	13	15	14
			33	7	15	22	47	43	44	20	16	17
			34	9	8	17	71	43	58	28	25	29
			43	22	1	23	44	28	43	22	na	22
			45	3	4	7	63	50	55	39	17	27
			66	16	8	24	50	44	48	23	19	22
		Petuna Explorer	11	20	1	21	44	77	46	16	na	17
			12	20	1	21	47	37	47	20	na	20
			13	5	16	21	46	43	44	18	15	16
			14	6	17	23	54	34	39	45	18	28
			15	20	3	23	45	64	47	17	7	17

			16	20	4	24	44	27	41	18	2	18
			17	18	6	24	40	33	38	13	14	13
			18	16	7	23	40	34	39	14	9	13
			19	8	11	19	61	48	53	20	18	19
			25	16	2	18	53	39	51	19	1	18
			27	11	6	17	57	31	48	22	4	22
	St Patricks	Celtic Rose	5	10	15	25	38	34	36	16	12	14
			11	14	9	23	45	31	40	20	6	18
			18	15	7	22	33	31	32	10	6	9
			21	10	11	21	32	28	30	8	6	7
			28	9	10	19	40	30	34	11	9	11
			30	6	13	19	38	38	38	8	11	10
			32	8	12	20	34	36	35	10	23	18
			41	13	7	20	36	30	34	8	4	7
			50	1	1	2	28	39	34	na	na	8
			51	10	1	11	40	26	38	21	na	20
			52	4	14	18	65	36	43	38	12	23
			53	9	13	22	37	39	38	9	13	11
			62	3	15	18	52	36	39	13	8	10
		Petuna Explorer	6	2	15	17	34	41	40	1	16	15
			7	8	14	22	35	31	32	11	8	9
			23	2	14	16	61	36	39	25	11	15
			28	3	15	18	37	40	40	1	22	20
			30	18	44	62	43	36	38	10	10	10
			31	37	16	53	36	34	35	13	14	14
			33	10	23	33	42	35	37	13	8	10
			34	33	32	65	36	35	36	13	18	16
			35	8	24	32	35	36	36	9	9	9
			38	11	25	36	37	36	36	9	12	11
			39	22	38	60	47	38	41	23	13	18
			41	40	65	105	44	40	41	18	14	15
			45	26	6	32	45	44	45	15	19	15
2004	St Helens	Adriatic Pearl		228	234	462	39	34	37	17	14	16
	St Patricks	Adriatic Pearl		186	270	456	37	37	37	16	14	15
2010	St Helens	Saxon Onwards	7	69	11	80	40	27	38	20	7	19
			9	148	20	168	39	29	38	17	5	16
			12	75	11	86	40	40	40	18	13	18
			13	49	39	88	41	32	37	21	6	17
			19	75	15	90	37	28	35	17	5	16
			31	58	25	83	41	33	39	13	7	12
	St Patricks	Saxon Onwards	11	97	70	167	35	34	34	8	8	8
			29	121	60	181	37	31	35	14	7	13
			Total	**2815**	**2943**	**5758**	**44**	**43**	**44**	**18**	**17**	**18**

4.3 AGE VALIDATION AND VERIFICATION

Orange roughy are a slow growing and long-lived species with an age at maturity of approximately 30 years and a maximum age approaching 200 years. Age validation studies have supported these parameters and ranged in their complexity from the use of modal length analysis and edge analysis (Mace *et al.* 1990) radiometric age (Fenton *et al.* 1991; Smith *et al.* 1991; Andrews and Tracey 2003; Andrews and Tracey 2007) and more recently lead 2010 ratio analysis (Andrews *et al.* 2009).

While the longevity of orange roughy are not in question, estimating the age of orange roughy by counting growth zones in orange roughy otoliths is considered difficult and can be open to drift and bias with and between age readers and institutes. Concerns about the poor precision between agers were identified in the NZ-Australian 2004/2005 comparisons of reads on NZ roughy (Francis 2006). This report initiated a working group to develop a set of international ageing protocols for this species (refer to Appendix C). The protocol was completed and tested (Tracey *et al.* 2009) and was used for the estimation of age from the 2010 survey, and a subset of these samples were re-read by a secondary reader from NIWA and produced acceptable precision and indicated no bias between the readings.

Orange Roughy age frequencies are available from 1987 with sampling occurring usually during June/July. Over this period three age readers at the CAF and now FAS have been employed to provide age estimates (Table 4.3).

Table 4.3 Years that age estimates are available and the readers employed.

Year	Reader/s
1987	Reader1
1992	Reader1
1995	Reader1
1999	Reader 1
2001	Reader1, 2 & 3
2004	Reader2
2010	Reader3

Due to the changes in the age frequency (presented later in this section) of the eastern stock over time and the reported inaccuracy between NZ-Australia, it has been questioned whether the interpretation of the otolith zones had remained consistent over time. A summary of recent investigations into the extent of ageing drift and bias in Eastern Zone orange roughy age read is included in Upston & Wayte (2012b). Here we re-state that work and provide further details some images used here (prepared by Kyne Krusic-Golub) also appear in Upston & Wayte (2012b).

To investigate for potential drift or bias a small sub-set of otoliths (n=42) from 1995 (Batch 28; original reader Reader1; age range: 25 to 95), were re-examined by Reader 3 and age was estimated by following the Orange Roughy ageing protocols used to produce the 2010 estimates. From the comparison of age (Figure 4.7) the results suggests that there is no notable age drift/ bias in the sample, certainly not to the extent that is implied by the shift in age compositions between 1992 and 2010 (refer to figure Figure 4.1).

Three other sources of data are available to support the theory that the change in the observed age frequencies is not due to reader drift. These are:

(i) The 2001 age estimates were produced by the three readers, one of which was the 1995 reader and another was Reader 3. Inter-reader testing at that time indicated reasonable precision and no bias between readers (Figure 4.8)

(ii) There is a significant linear relationship between age and otolith weight (Figure 4.9).

(iii) Using otolith weight as a proxy for age, we observe a similar shift to that implied by the age compositions, with less old fish (nominally fish with otoliths weighing more than 0.25 g) in recent years, compared to the early to mid 1990's (Figure 4.10).

(iv) Following from above, preliminary analysis indicates a shift/ decline in orange roughy lengths between 1990 and 2010.

The results shown in this section suggest that the ageing has remained relatively constant over time, nevertheless, a certain degree of age drift/ bias cannot be ruled out without a more extensive study involving re-ageing up to 100's of orange roughy from earlier years. This analysis is proposed and will hopefully be completed by September 2012.

Estimating the age at the transition zone (the point on the otolith section with marked morphological change) is quite subjective and may be open to more personal interpretation. While this will be tested in the proposed re-reading experiment, it is worth noting that the QA/QC protocols used by the CAF insure that at the very least the age estimates provided by the one reader within each year are internally consistent and that any change in the total age or age at transition between survey areas (as seen in section 4.2.2) should be a real observation and not due to age bias. The only year that this may not be the case would be 2001 where three readers provided age estimates.

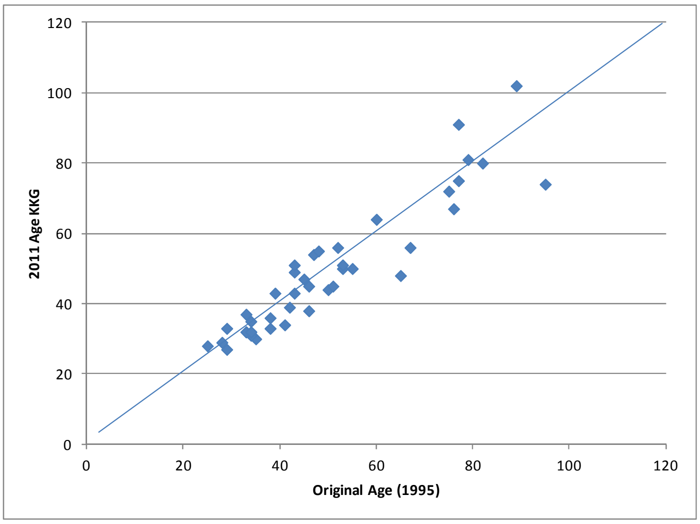


Figure 4.7 Plot of age reads by Reader 3 in 2011 (Reader3 on y-axis) against original age for Eastern Zone orange roughy, recorded by the 1995 reader (n = 42). Image provided by Fish Ageing Services and sourced from Upston & Wayte (Upston and Wayte 2012b).

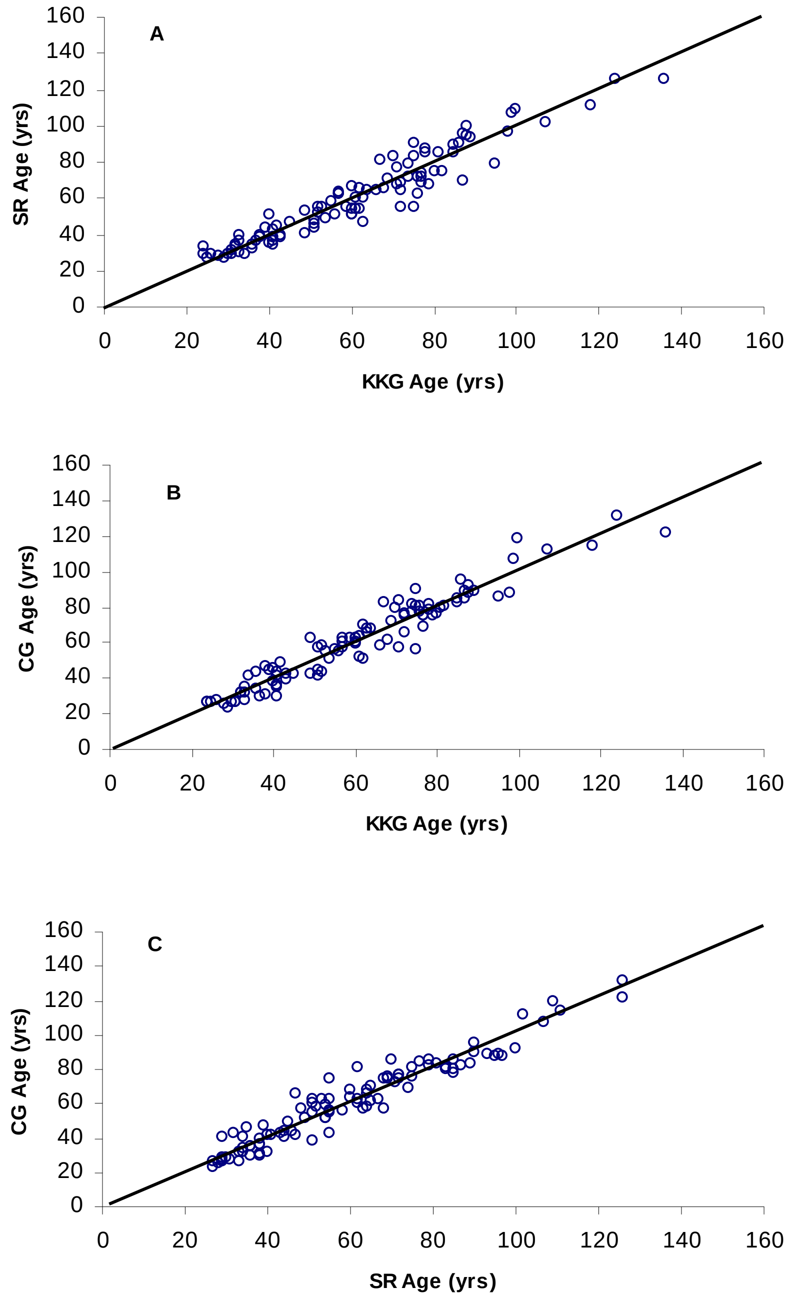


Figure 4.8 Plot of age reads for orange roughy in 2001/ 2002 by the three main CAF readers. A, B, C refer to the different reader comparisons. Key: KKG = Reader3; SR = Reader1 (early years) reader, CG = Reader.

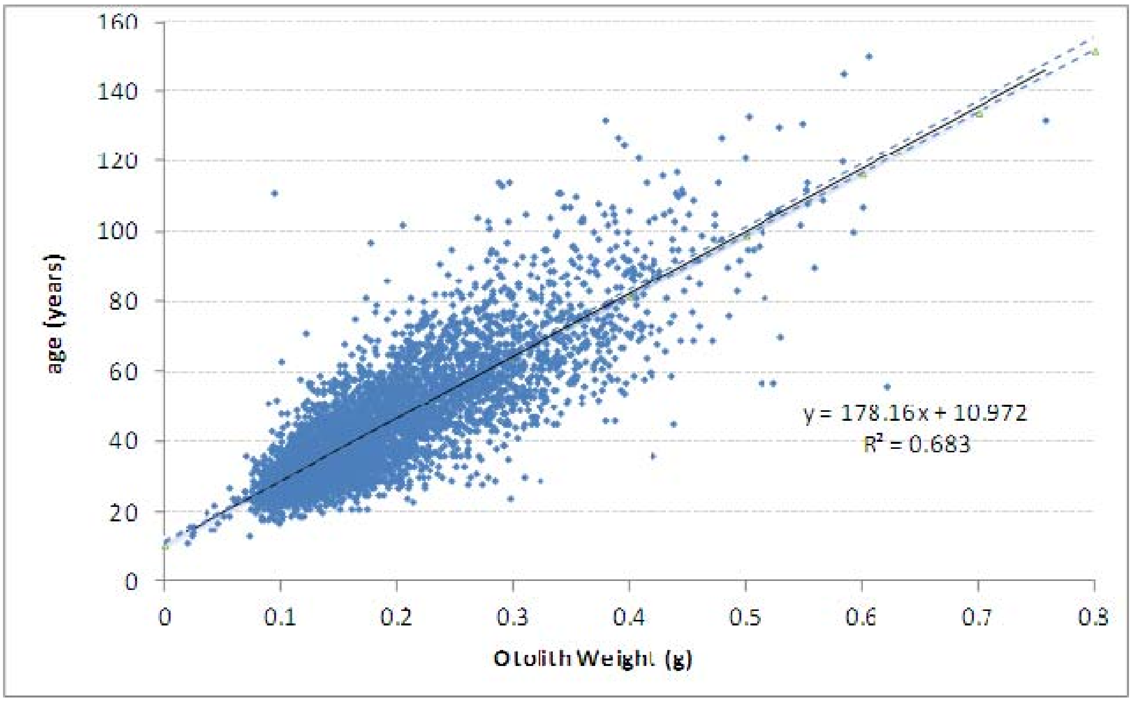


Figure 4.9 The relationship between otolith weight and otolith age estimate (annulus counts).

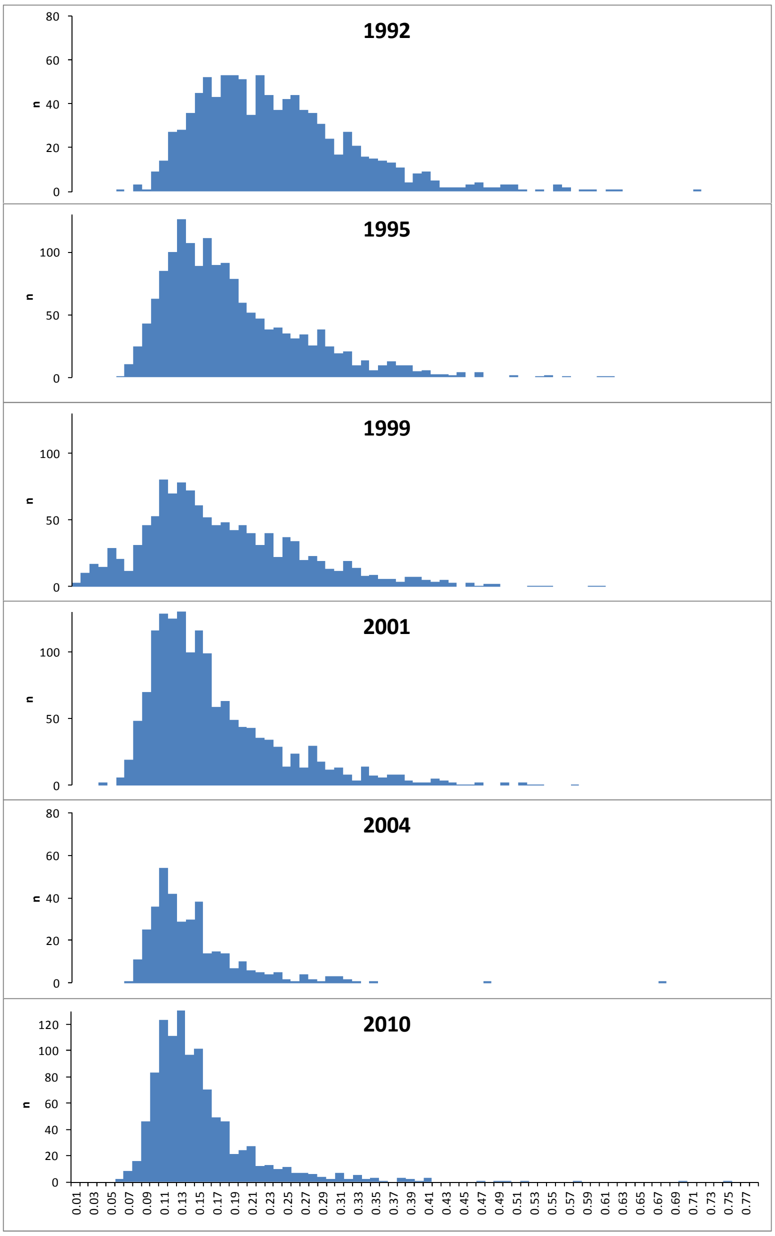


Figure 4.10 Otolith weight as a proxy for orange roughy age – the shift from “older” fish in the early to mid 1990’s compared with recent years corresponds with that implied by the age compositions. Weight in grams on x-axis; frequency on y-axis. Note that the 1999 otolith weights include fish from non-aggregations (hence biased towards the LHS of the plot) and therefore cannot be directly compared with the age compositions from aggregations for that year.

5. SUMMARY OF REPRODUCTIVE STUDIES

The fecundity of orange roughy from eastern Tasmania was reported to have increased 20% during 1987 to 1992 presumably due to a density dependency as the stock reduced by 50% (Koslow *et al* 1995). Kloser *et al* (2011) found that it increased a further 44% from 41 145 ± 1 363 in 1992 to 59 236 ± 1 047 eggs in 2010, representing a total increase of 75% since 1987 (Figure 5.1). Length standardised fecundity is significantly correlated to stock size (r = 0.95, Figure 5.1). If this increase in fecundity is real, based on the 2006 stock assessment and the results demonstrating increased fecundity, the reproductive potential of the stock in 2010 is estimated at 32% of the virgin levels whilst the female spawning stock biomass is estimated to be at 19% (Figure 5.2).

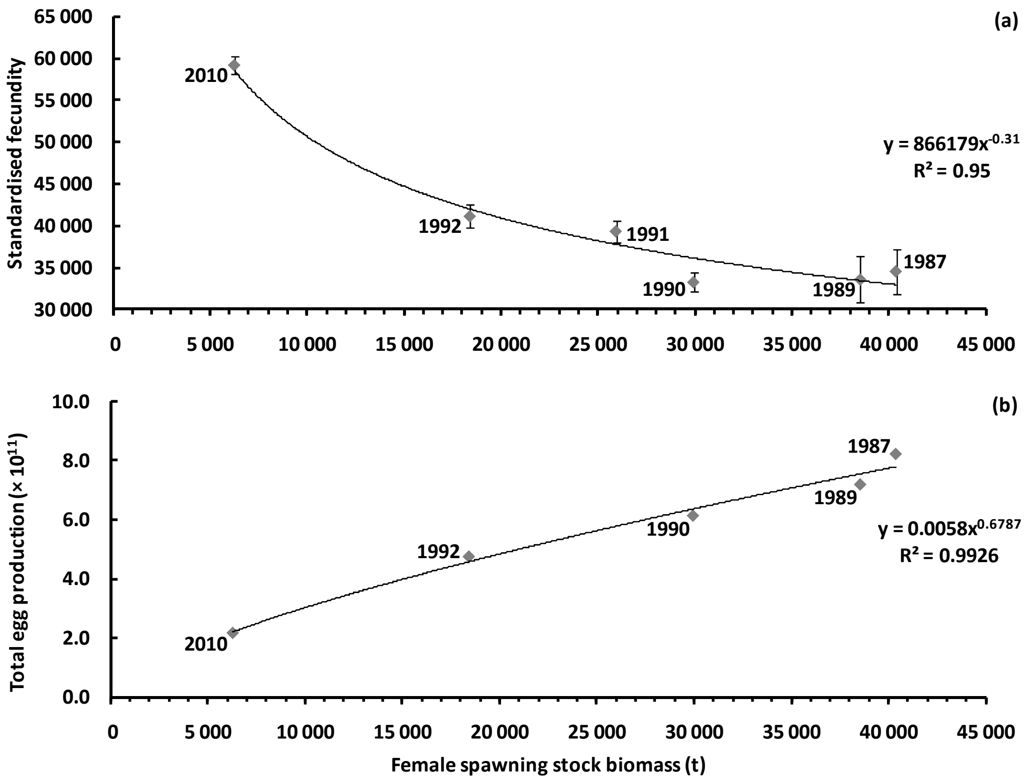


Figure 5.1The relationships of (a) length standardised fecundity (± SE) and (b) total egg production with female spawning stock biomass for orange roughy. Data labels indicate sample year. Image from Kloser et al. (2011).

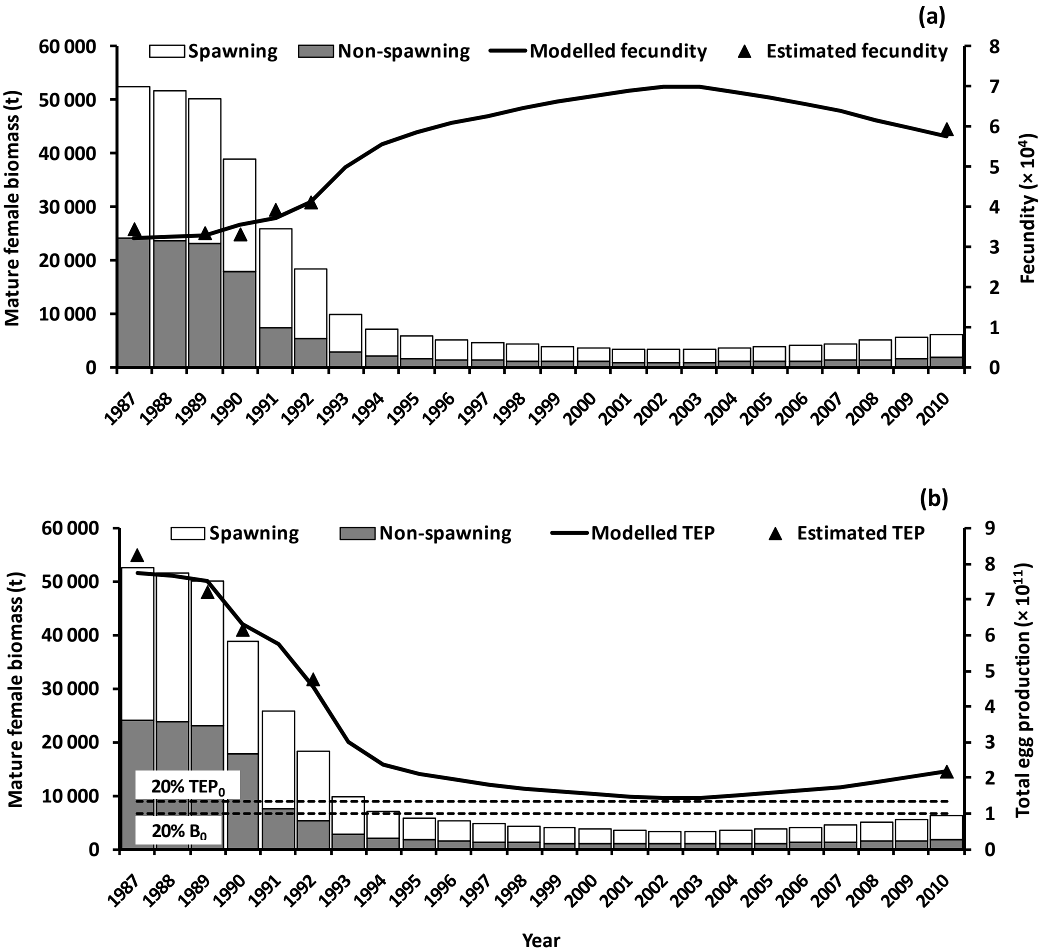


Figure 5.2 Changes in mature female biomass and spawning fraction with modelled and estimated (a) fecundity and (b) total egg production (TEP) for orange roughy since 1987. Dashed lines are the 20% virgin spawning biomass and TEP critical limits (image from Kloser *et al* 2011).

6. DISCUSSION OF BIOLOGICAL DATA

The changes in the size and age structure of Orange Roughy presented in this study are expected impacts of an exploited population. Reductions in abundance, mean length, age, age at maturity with corresponding increased fecundity have been observed for the Eastern zone orange roughy fishery and are well recognised impacts of an exploited fishery (Haedrich and Barnes 1997). Decline in Oran Roughy abundance is well documented and the current stock assessment the female spawning biomass is between 16% and 17% of unfished biomass (Wayte 2006; Upston and Wayte 2012a). Although the uncertainty in these biomass estimates is reliant on the input data and in particular the interpretation and use of age data and to a lesser extent length frequency data.

The standard length frequencies and average length data indicate there has been a small but significant reduction in size of fish at both spawning sites. The length frequencies show a downward shift of the mode for standard length with an overall shift from of 38 cm to 36/37 cm for females and from 36/37 cm to 33/34 cm for males at both spawning grounds. While the large fish are still present in the fishery their proportion is much lower resulting in the downshift of the mode. Bax (1996) reported no change in the size structure because it was not evident until 2002 and the downward trend was first reported in 2006 (Kloser *et al.* 2008).

The most significant change has been in the reduction in mean age over time and a large downward shift in the mode for the age frequencies. The age mode has shifted from around 50 years to around 30 years at both spawning grounds. The shift to younger fish occurred more quickly at St Patricks where mean age for the 2001 survey was significantly lower relative to the fish at St Helens; by 2004 the mean ages were again similar at both grounds. This change in age structure with the loss of old fish from the fishery has been well recognised and is expected outcome of fishing (Smith *et al.* 1998; Koslow *et al.* 2000).

This change in age structure at the spawning site can be interpreted as evidence of recruitment to the fishery. Assuming equal selectivity for all mature spawning fish, with the removal of old fish; the younger more recently recruited fish now dominate the fishery. This result contrasts with the New Zealand fishery where no change in the age structure was observed leading them to infer low recruitment for the New Zealand fishery (Clark *et al.* 2000).

Changes in the length-weight relationship are used as indicators of change in fish condition (Anderson and Neumann 1996). The weight-length relationship has remained stable over time with no apparent shift in the relationship despite an observed increase in fecundity (Kloser *et al.* 2011) over the same time period. Kloser (2011) attributes this apparently conflicting result to the increased density rather than size of the ovarian tissue. The same fish had a corresponding increase in liver and body condition and decreased level of atresia all indicators of improved condition likely resulting from increased resource availability due to reduced densities.

There has been a measured change of Age at Maturity with a shift to a greater proportion of fish maturing earlier. The pre-fishing age at maturity was around 30 years, almost 31 years for female fish at St Helens. The shift was greatest for male fish (30 to 28 years) and slightly greater for fish at St Patricks (30 to 29 years). Our results differ from those of Bell et al. (1992) which found that 50% of fish had matured by the age of 32 years for the Eastern Stock and 28 years for the NSW stock. The downward shift is an indicator that the fishing induced decline in abundance has resulted in the new recruits, naturally those with an earlier age at maturity, contributing proportionately more to the population than previously. With a long lived fish like Orange Roughy the fishery is too young for there to have been an evolutionary change at the genes level for earlier maturing fish.

The overall trends for reduction in size, age and age at maturity are significant when viewed as complete time series although there are year to year variations. Importantly there are between trawl and ground differences that mask this trend. This raises the question of sampling bias. This question becomes important when determining stock relationships and using the data for stock assessments. The dataset comparison indicated that the age data are largely representative of survey data. So the question arises are the survey data representative of the population. Certainly the shot by shot variability in the age data suggests that multiple shots are needed for sound estimates. Of particular concern has been the changing collection protocols of port and at sea sampling. Most importantly, estimates derived from one day (assumed port sampling) and without shot data need to be used cautiously (data from 1992 and 2004).

7. ACOUSTIC INDEX

7.1 BACKGROUND

Acoustic surveys of orange roughy schools at St Helens Hill during their austral winter spawning have been done since 1989 and due to changes in fishers catches included St Patricks Head since 1999. To account for changes in methods and technology these data were reanalysed in 2002 and 2010 to create a consistent procedure (Kloser and Ryan 2002). Corrections to the acoustic data were done for calibration, sound absorption and dead-zone estimation (Kloser 1996; Kloser and Ryan 2002; Ryan and Kang 2005). Echo integration was only carried out on well defined orange roughy schools determined in earlier years by a combination of school dynamics and trawl catch (1990), then in later years including higher resolution deep towed body school structure (1991 to 1996). After 1996 multi-frequency 38 kHz and 120 kHz data from a deeply towed transducer was used to classify orange roughy schools (Kloser *et al.* 2002). During a spawning season several surveys were done to map St Helens and in later years the St Patricks fishing grounds. To ensure that the biomass from both grounds could be summed only surveys that were started within 24 hours were included. Combined surveys where schools of orange roughy were most available to the acoustics were selected assuming that process error dominated observational error. To reduce uncertainty due to signal correction (noise and absorption) and fish biomass estimated into the deadzone the deeply towed acoustic surveys are thought to have less process error and lower survey cv's (Kloser *et al.* 1996; Kloser 1996). Importantly species identification is greatly improved using a deep towed body and deemed essential as the stock declined (Kloser *et al.* 2002). To convert the acoustic echo integration survey data to biomass required an estimate of fish weight and target strength (Simmonds and MacLennan 2005). Estimates of orange roughy target strength have changed over time as different techniques have been used based on *in situ, ex situ* or modelling (Kloser *et al.* 1997; McClatchie and Ye 2000). *In situ* target strength measurements provide the best opportunity for unbiased measures but large differences remain between different approaches (Coombs and Barr 2007; Kloser and Horne 2003). These differences in derived *in situ* target strength are largely attributed to not knowing if the target species is being ensonified and if so are they representative of the schooling population. To ensure the target species is ensonified a recent advance has been the visual verification of the targets with stereo optical measures (Ryan *et al*. 2009). Matching the frequency difference of *in situ* TS and schooling fish measurements is proposed to ensure measurements are representative of the spawning population (Kloser *et al.* 2011). Target strength (TS) of orange roughy used here is base on *in situ* measurements using optical verification and matched to the school scattering at 38 kHz and 120 kHz. Extrapolating the mean tilt averaged target strength, <TS>, to previous years of mean standard length $\overline{L_s}$ fish distribution assumed that;

$$<TS>= A*\log10(\overline{L_s})+B \quad \text{dB} \qquad (2)$$

where A=16.37 is derived from McClatchie *et al.* (1999) and B = -77.1 from Kloser *et al.* (2011). Biological parameters of length, weight and target strength used for the surveys are given in Table 7.1.

Table 7.1 .Biological parameters of length, weight and target strength at 38 kHz used for the surveys.

Year	Length (cm)		Weight (kg)		Target Strength (dB)	
	St Patricks	St Helens	St Patricks	St Helens	St Patricks	St Helens
1990		35.7		*1.49*		-51.8
1991		35.7		*1.49*		-51.8
1992		35.7		*1.49*		-51.8
1993		35.7		*1.49*		-51.8
1996		35.7		*1.49*		-51.8
1999	34.7	36.1	1.41	1.50	-52.0	-51.7
2006	34.3	33.6	1.34	1.27	-52.1	-52.2
2010	34.4	34.6	1.34	1.29	-52.0	-52.0

Historic biomass estimates prior to 2010 were corrected for the revised estimates of target strength of Table 6.1 and also corrected for a calibration error in the Simrad EK500 used in earlier surveys. This calibration error is documented in Kloser and Ryan (2002) and increases earlier biomass estimates by ~24% and 12% for the hull and towed surveys respectively . The target strength corrections have the largest influence by increasing earlier surveys by 51% (Table 7.2).

Table 7.2. Corrections applied to historical data due to a Simrad EK500 TVG software error between 1990 and 1996 and for changes in target strength values used (Table 7.1).

Year	Simrad TVG error		Target strength correction	
	Hull	Towed	St Pats ratio	St Helens ratio
1990	1.23			1.51
1991	1.24	1.10		1.51
1992	1.25	0.93		1.51
1993	1.14	1.12		1.51
1996	1.20	1.12		1.51
1999	1.00	1.00	1.47	1.48
2006	1.00	1.00	1.57	1.56
2010	1.00	1.00	1.01	1.00

7.2 ERROR BUDGET

Accurate estimates of error from acoustic surveys is a non trivial task given the number of sources of potentially correlated errors (Simmonds and MacLennan 2005). For a snapshot biomass estimate an estimate of all significant error sources is done at the 95% confidence interval and then expressed as a CV assuming Gaussian distribution. An estimate of the biomass CV was calculated from the individual estimates of error (e_i) assuming they were not correlated where:

$$CV_{combined} = \sqrt{\sum_{i=1}^{..} e_i^{\,2}}$$ (Lever and Thomas 1974). (3)

Table 7.3 shows the total error budget estimate for the July 2010 surveys. This method of error budget analysis was done in detail for the 2006 and 2010 years.

Table 7.3. Combined error estimate for AOS 38 kHz absolute biomass survey in July 2010 assuming random error is expressed as a CV following Eq. 1 (Kloser *et al.* 2011).

Error	**Random**	**Bias**	**source**	**confidence in estimate being bound**
Target strength	5.0%	0 to -20%	measured	medium
Survey sampling error CI	8.0%		measured	high
Equivalent beam pattern	5.0%		measured	high
Sound absorption estimate	2.5%		measured	high
on-axis calibration	5.0%		measured	high
platform motion	0.0%	-2%	estimated	high
aeration effects	0.0%	0%	estimated	high
species classification	2.5%	0%	estimated	low
exclusion of orange roughy	0.0%	-10%		
inclusion of non-target species	0.0%	10%	estimated	low
area of coverage	2.5%		measured	high
fish weight	2.5%		measured	high
fish migration	5.0%		estimated	low
deadzone estimation	5.0%		estimated	medium
Combined error estimate CV	**14.6%**	**0 to -22%**		

7.3 PROCESS ERROR OR OBSERVATION ERROR DOMINANCE

To interpret the acoustic survey results it is important to understand the sources of error and determine if these are observation or process dominated. Examples of observation error would dominate if the survey sampling CV’s were high due to patchy distributions, fish movement or if there was a large temporal change in the fish target strength or dead zone estimates. Process error is more likely to be an issue for orange roughy surveys for issues such as density detection thresholds, availability of fish to be surveyed in homogeneous schools and schools clear of the seabed echo. Often with acoustic surveys it is necessary to survey the population when they are most available to the acoustic system. For orange roughy this means they are in homogeneous schools well clear of the seabed and they are relatively stationary throughout the survey period. The survey strategy in recent years (2006 and 2010) has been adjusted from earlier years to test if results could be observation or process error biased. In particular surveys measure both spawning grounds (Patricks Head and St Helens) within a 24 hour period to account for any potential fish movement. It is a requirement to do 4 surveys within the spawning period to examine both between survey variability and to capture the stock when they are the most available to the acoustic method.

7.3.1 PROCESS ERROR DOMINATES SURVEY VARIABILITY

In this case it is assumed that process errors of the acoustic surveys dominate and the survey that has the maximum combined biomass between the two grounds conducted within 24 hours is chosen as the best estimate of the stock status for a particular year. This interpretation assumes that the acoustic threshold for detecting schools that are homogeneous is the major temporal variation between surveys as well as fish being well clear of the dead-zone. The multi-frequency method of species identification requires low mixtures of species to be confident that the target species is orange roughy.

Table 7.4. Summary of acoustic surveys at St Helens Hill and Patricks Head using both vessel mounted and towed transducers at 38 kHz. This assumes process error dominates repeat surveys and the c.v. is calculated as shown in Table 7.3.

		Hull (tonnes)					Towed (tonnes)				Combined (tonnes)	
Year	**Date**	**St Patricks**	**c.v.**	**St Helens**	**c.v.**	**Date**	**St Patricks**	**c.v.**	**St Helens**	**c.v.**	**Towed**	**c.v.**
1990	**16-Jul**			71497	0.49	**16-Jul**						
1991	**26-Jul**			55048	0.41	**30-Jul**			*45979*	*0.28*		
1992	**17-Jul**			37866	0.41	**17-Jul**			43370	*0.28*		
1993	**25-Jul**			13856	0.41	**25-Jul**			17633	*0.35*		
1996	**20-Jul**			15183	0.41	**20-Jul**			17107	*0.28*		
1999	**18-Jul**	23425	0.49			**18-Jul**	21748	0.63	5728	0.28	27476	0.56
2006	**20-Jul**			15269	0.38	**20-Jul**	2293	0.15	16066	0.15	18359	0.15
2010	**18-Jul**	6048	0.33	4700	0.38	**18-Jul**	6259	0.15	19200	0.15	25459	0.15

Details of survey results are outlined in Appendix A and summarised in Table 7.4 for process error dominated interpretation where the maximum survey combination between Patricks Head and St Helens Hill is used. The variation in the surveys using the deep towed transducer declined 59% from 46 k tonnes in 1991 to 19 k tonnes in 2010 (Figure 7.1). Note that the 1991 sampling year was later than normal and may not be representative of the entire stock. Based on this trend the biomass at St Helens Hill has reduced 73% between 1990 (71 k tonnes) and 2010 (19 k tonnes). Note there is a high c.v. for the hull mounted 1990 survey due to poor species composition and that this decline does not account for the proportion of orange roughy that were at Patricks Head which was not measured in 1990. In some years 80% of the orange roughy biomass has been at the Patricks Head ground.

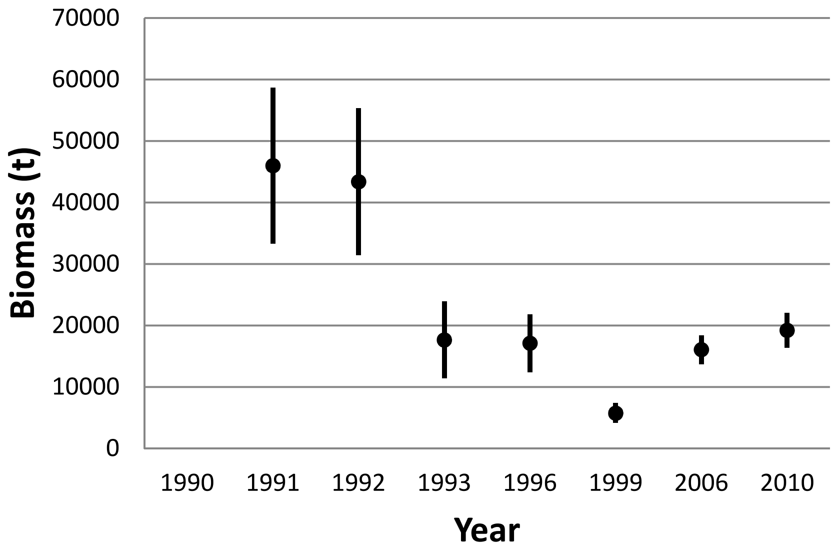


Figure 7.1. Biomass of orange roughy as measured at St Helens Hill for the towed body surveys from 1991 to 2010, error bars are one s.d. (Table 3).

7.3.2 OBSERVATION ERROR DOMINATES SURVEY VARIABILITY

In this case it is assumed that sampling error dominates the error within and between surveys and a number of surveys are conducted to evaluate a mean. This analysis method would reduce bias from the extrapolation of fish within the dead-zone. Hence the mean from a survey ground is calculated for each year (Appendix A) and the combined biomass is the addition of the mean from each ground (Table 7.5). This method assumes that all fish are equally available to the acoustics for each survey. Hence if fish are below acoustic detection or unable to be classified as within a homogeneous school the survey estimate would be reduced.

Table 7.5. Summary of acoustic surveys at St Helens Hill and Patricks Head using both vessel mounted and towed transducers at 38 kHz. This assumes observation error dominates repeat surveys and the c.v. is calculated as shown in Table 7.3.

	Hull (tonnes)				**Towed (tonnes)**				**Combined (Tonnes)**			
Year	**St Patricks**	**c.v.**	**St Helens**	**c.v.**	**St Patricks**	**c.v.**	**St Helens**	**c.v.**	**Hull**	**c.v.**	**Towed**	**c.v.**
1990			71497	0.49								
1991			55048	0.41			*45979*	*0.28*				
1992			37866	0.41			43370	*0.28*				
1993			13856	0.41			17633	*0.35*				
1996			11924	0.41			15748	*0.39*				
1999	14109	0.85	4879		*21748*	0.63	5190	0.61	18988	0.72	26938	0.63
2006			15269	0.51	2882	0.45	14608	0.15	15269	0.59	17490	0.20
2010	6305	0.33	14800	1.02	4694	0.49	19350	0.12	21105	0.82	24044	0.19

As expected this method reduces the overall mean for the years where there were multiple surveys and the c.v. increases. Of note is that there is only minimal variation (not statistically significant) between the biomass estimates from the process or observation dominated error interpretation of the data.

7.4 RECOVERY RATE SURVEYS

Orange roughy were listed as conservation dependant in Dec. 2006 and a requirement of that listing was the development and implementation of a monitoring plan to determine if and at what rate the orange roughy were recovering at the dominant spawning site. To test this in an economical way (self funding using research quota) using available resources a project was developed and carried out to use a net attached acoustic optical system (Kloser et al. 2011). It should be noted that the fishery was closed in 2006 with only minimal bycatch provisions and no commercial targeting of orange roughy. Hence the monitoring strategy needed to detect variation in spawning stock size with high precision (Kloser et al. 2011).

Based on the 2006 and 2010 acoustic survey results there is a 7100 t (c.v. 0.21) increase between years assuming process error dominance (Figure 7.2). This can be compared with the 6554 t (c.v. 28) increase assuming observation error dominance (Table 7.5). The significance of the biomass increase can be tested using a t-test where for St Helens Hill there is an increase of 4768 t (t=4.4, v = 7) between 2006 (7 surveys) and 2010 (2 surveys) that is significant at the 99% confidence interval. Similarly for the combined St Patricks and St Helens surveys there is an increase of 6444 t (t=6.4, v = 4) between 2006 (4 combined surveys) and 2010 (2 combined surveys) that is significant at the 99% confidence interval.

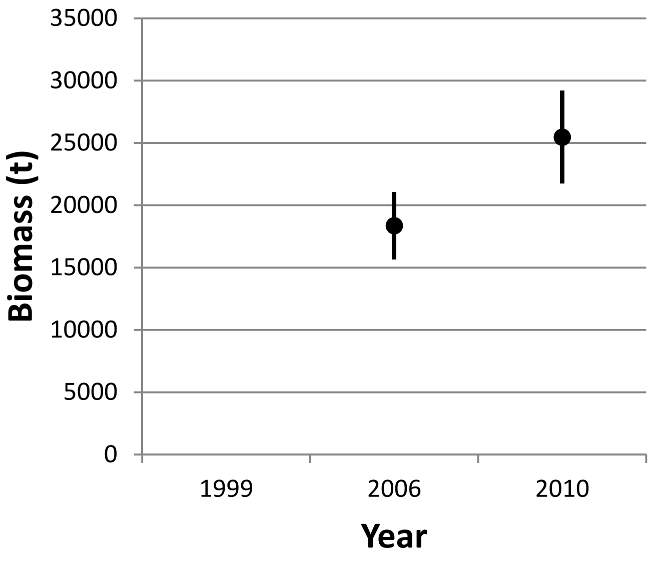


Figure 7.2 Acoustic survey snapshot biomass estimates of the combined St Helens and Patricks Head spawning sites designed to monitor the recovery rate of orange roughy (process error estimate, error bars s.d.).

The spawning fish recovery rate as inferred from the acoustic surveys between 2006 and 2010 is approximately 1800 t per annum. This can be compared to the base case B stock assessment estimating a mature fish recovery rate of ~530 t per annum over the same time frame. Note over this time ~ 100-150 tonnes of fish have been extracted each year for monitoring (Table 6.5). This is due to a large difference between the recent base case B stock assessment of mature biomass (~11482 tonnes, c.i. range 10200 to 13300) compared to the spawning acoustic survey biomass estimate (25400 tonnes, c.i. 18000 to 32800 tonnes) and the estimate of the total stock taking into account proportion spawning (48800 t, c.i. 21100 to 76600 tonnes) (Kloser et al. 2011; Upston and Wayte 2011). This difference in perceived recovery rate could be due to observation bias in the acoustic and proportion spawning data or bias in the model input data (mainly age data) or underlying stock structure hypotheses.

Potential biases in the acoustic data include target strength and dead-zone compensation. Target strength estimation is well advanced and is now reported for two frequencies. By reporting the biomass estimate at multiple frequencies it should be possible to reduce this source of potential bias. The 2010 estimate of biomass at 38 and 120 kHz were within 5% and it is recommended that the biomass at 120 kHz is estimated for the 2006 year and future surveys. Estimate of biomass into the dead-zone can vary by 3% to 26% for surveys in 2010. No estimates were available for 2006. It is recommended that dead-zone biomass estimates are consistently reported for each year so that Appendix A can be updated and a sensitivity test to changes in biomass done.

7.5 SUMMARY OF CATCH FROM GROUNDS

The catch of orange roughy since 1985 was recently updated in Upston and Wayte (2010) and incorporates historic agreed corrections for burst bags lost gear and misreporting (Table 7.6). Catch corrections add 37% to the east catch total and 33% to the south catch total. The current base case stock assessment has an agreed stock structure hypothesis for the Eastern Zone spawning site that combines the Eastern catch and part of the Southern Zone catch (up to Pedra Branca). Approximately 52% of the Southern Zone catch comes from East of the Pedra Branca region (Table 7.7).

Table 7.6. Total recorded logbooks catches (t) 1985 - 1991, recorded landed catches (t) 1992 – 2010, and agreed catch history of Orange Roughy for East, South and West Management Zones and area Pedra Branca (PB). All seasons are included. Agreed catch history (incorporates adjustments for proportion lost due to gear los and burst bags/ panels etc, and misreporting (CSIRO & TDPIF 1996; Wayte 2007).

	EAST		EAST(PB)	SOUTH		WEST
Year	Reported	Agreed	Agreed	Reported	Agreed	Reported
1985	6	6	6	58	58	129
1986	33	33	60	631	631	3970
1987	310	310	310	353	353	5128
1988	1949	1949	1949	469	469	4765
1989*	18365	26236	28575	7620	10886	1386
1990*	16240	23200	34502	24801	35430	802
1991*	9727	12159	20436	11541	14426	628
1992*	7484	15119	24265	7947	16054	1141
1993*	1971	5151	8798	7602	5486	1031

1994*	1682	1869	4140	4345	4828	927
1995	1959	1959	2544	2157	2157	1055
1996	1998	1998	2231	802	802	1320
1997	2063	2063	2250	454	454	352
1998	1968	1968	2087	250	250	360
1999	1952	1952	2052	174	174	244
2000	1996	1996	2109	311	311	192
2001	1823	1823	2027	357	357	248
2002	1584	1584	1674	167	167	294
2003	772	772	877	210	210	243
2004	767	767	797	80	80	321
2005	754	754	772	99	99	281
2006	614	614	615	5	5	159
2007	113	113	129	22	22	31
2008	98	98	98	0	0	5
2009	193	193	193	10	10	16
2010	113	113	113	18	18	27
Total	**76534**	**104799**	**143609**	**70483**	**93737**	**25055**

Based on the SEF log book data (1985-2004 and not correcting for under-reporting and misreporting in 1992 and 1993 (Bax, 1996)) there is a significant winter effect of where the dominant catch was derived. Within the Eastern Zone 83% (~87 k tonnes) of the catch was derived from the winter months (month 6, 7 and 8). This compares to the Southern Zone and Pedra Branca Southern zone where only 12% of catch in any given year was caught in winter months. Based on this catch history it adds weight to the hypothesis that the Eastern and Southern Zones are combined with fish in the South moving to the Eastern Spawning zone to spawn.

Table 7.7. Proportion of the catch for east year caught in winter (months 6, 7 and 8) from the total catch in the Eastern, Southern and Pedra regions (SEF trawl data base). The proportion of the catch in the Pedra region as of the total Southern Zone catch. (under-reporting and misreporting in years 1992 and 1993 not corrected (Bax 1996)).

	East	**South**	**South**	**South**
Year	winter /total	winter /total	Pedra /Total	winter /Pedra
1985				
1986	96%	9%	94%	5%
1987	57%	11%	0%	0%
1988	59%	0%	0%	
1989	92%	22%	34%	10%
1990	90%	11%	38%	10%
1991	77%	11%	70%	12%
1992	56%	6%	70%	7%
1993	91%	33%	59%	37%
1994	86%	18%	50%	21%
1995	76%	7%	30%	17%
1996	81%	16%	34%	8%

1997	85%	8%	49%	12%
1998	91%	35%	72%	48%
1999	90%	5%	63%	3%
2000	86%	4%	55%	0%
2001	95%	4%	72%	4%
2002	96%	10%	63%	13%
2003	82%	10%	60%	16%
2004	94%	1%	65%	0%
Total	**83%**	**12%**	**52%**	**12%**

Within the Eastern Zone most of the catch was caught in the winter months between the St Helens and St Patricks spawning sites (Figure 7.3).

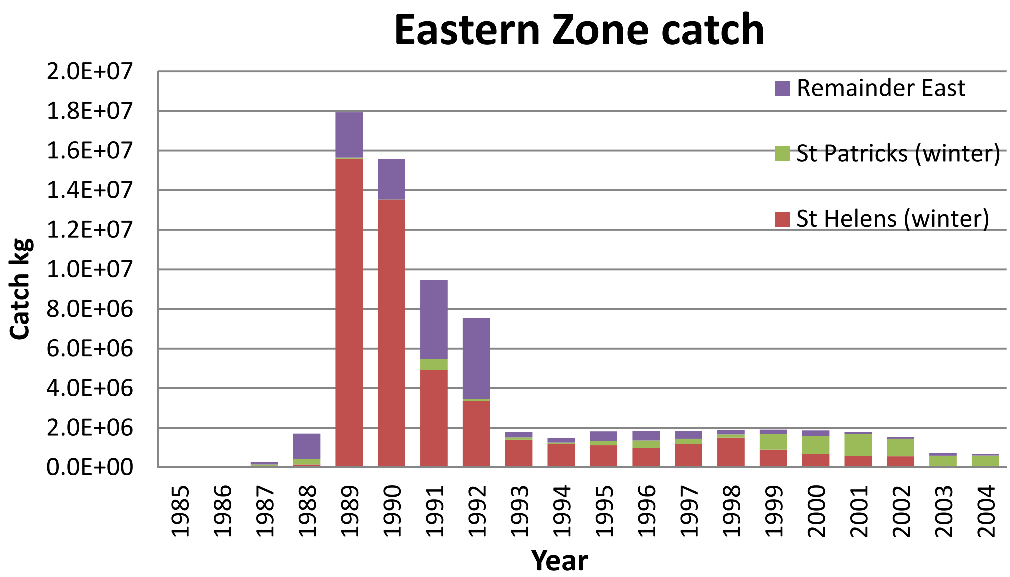


Figure 7.3. Orange roughy catch within the Eastern Zone for the St Helens and St Patricks region in winter (months 6, 7 and 8) and the remainder of the catch for that year.

The difference in the catch between the acoustic surveys is estimated in **Error! Reference source not found.**. It is assumed that on average 87% of the fish are caught prior to the survey in the east for that catch year and that 50% of catch in the south is derived from the previous year and 50% from the current year. There appears to be very little correlation between the differences observed in the acoustic surveys and the catches for either stock hypothesis. This may be due to natural variation in the proportion of orange roughy that spawn or errors in the acoustic estimates.

Table 7.8 estimated catc in tonnes of orange roughy between acoustic surveys at St. Helens Hill and Patricks Head for two scenarios of stock structure being East and East plus South derived from Table 7.6. Between year difference in estimated biomass (tonnes) at the Eastern zone spawning grounds for the acoustic sureys using the vessel mounted and towed acoustic systems derived from Table 7.4. Survey differences in italic highlight surveys with large c.v.s.

	Catch between surveys		**St Helens**		**St Helens + Patricks Head**
Year	**East**	**East + South**	**Hull**	**Towed**	**Towed**
1990	51447	81558			
1991	12446	37374	*16449*		
1992	8694	23934	17182	*2609*	
1993	10947	21717	24010	25737	
1996	6312	16441	-1327	526	
1999	5877	7069	15183	11379	
2006	8478	9794	-15269	-10338	*9117*
2010	581	624	10569	--3134	-7100

8. RECOMMENDATIONS FOR FUTURE SURVEYS AND REPORTING

Following acoustic surveys in 2006 and 2010 the status and recover rate of the eastern zone orange roughy fishery is now under question. This is due to a large difference between the recent base case B stock assessment of mature biomass (~11482 tonnes, c.i. range 10200 to 13300) compared to the spawning acoustic survey biomass estimate (25400 tonnes, c.i. 18000 to 32800 tonnes) and the estimate of the total stock taking into account proportion spawning (48800 t, c.i. 21100 to 76600 tonnes) (Kloser et al. 2011; Upston and Wayte 2011). Importantly the spawning fish recovery rate as inferred from the acoustic surveys between 2006 and 2010 is approximately 1800 t per annum. This can be compared to the base case B stock assessment estimating a mature fish recovery rate of ~530 t per annum over the same time frame. Note over this time ~ 100-150 tonnes of fish have been extracted each year for monitoring. This difference in perceived recovery rate could be due to observation bias in the acoustic and proportion spawning data or bias in the model input data (mainly age data) or underlying stock structure hypotheses. Resolution of the conflicting views of the status and recovery rate of orange roughy could be determined with ongoing monitoring of the spawning population.

Acoustic surveys

For future acoustic surveys it is necessary to establish sustained evidence that the fishery is recovering at a faster rate and higher biomass that predicted in the stock assessment model. To do this high precision surveys are required and we recommend AOS surveys at 3 frequencies for species identification, reporting biomass estimates at 2 frequencies 38 kHz and 120 kHz. The estimate of dead-zone biomass should also be reported. Further evidence to support the currently adopted target strength should be done.

Both process and observation error analyses of the acoustic data should be reported to quanitfy the difference in approaches. Noting that to date there has not been a significant difference between the methods for the 2006 and 2010 years. To facilitate this at least 4 surveys at each ground should be done.

Age and length data

The analysis of the age data presented in this report highlights both between trawl tow and spawning ground variability. To minimise this variability it is suggested that at least 6-8 trawl tows are taken on each ground of high catch rates (~10 t) during the acoustic surveys. Subject to further review we recommend at least 50 otoliths are retained and 200 lengths measured from each trawl.

There has been inconsistent collection of age data over the time series (1987 to 2010) with a mixture of port and at sea sampling. There has also been inconsistent collection of length data over that period. For a critical year, 1992, age data appear to be collected from port samples and age length frequencies were statistically different from length frequencies of the same year (collected from a research vessel). Given the inconsistent sampling no test can be done of the port sampled data concerning population representativeness. Current stock assessment analysis place a high weight on age data and this needs to be justified given the potential sources of bias in the inconsistent collection methods.

An issue not considered here is the impact on biological data collections of length and age due to changing targeting of the fish depending on the commercial quota available or the survey objectives for a given year. Future years surveying need to be as repeatable and systematic as possible collecting and recording appropriate trawl tow data.

9. REFERENCES

AFMA 2006. Orange roughy conservation program. http://www.afma.gov.au/wp-content/uploads/2010/07/n20061207.pdf, date last viewed 08/08/12.

Anderson, R. O., and Neumann, R. M. 1996. Length, weight, and associated structural indices., American Fisheries Society, Maryland USA.

Andrews, A. H., and Tracey, D. M. 2003. Age validation of deepwater fish species, with particular reference to New Zealand orange roughy, black oreo, smooth oreo, and black cardinalfish. Final Research Report for Ministry of Fisheries Research Project DEE2000/02 Objective 1. 25 pp.

Andrews, A. H., and Tracey, D. M. 2007. Age validation of orange roughy and black cardinalfish using lead-radium dating. . 42 pp.

Andrews, A. H., Tracey, D. M., and Dunn, M. R. 2009. Lead–radium dating of orange roughy (Hoplostethus atlanticus): validation of centenarian life span. Canadian Journal of Fisheries and Aquatic Science, 66: 1130-1140.

Bax, N. 1996. Stock Assessment Report 1996: Orange Roughy (Hoplostethus Atlanticus). South East Fishery Stock Assessment Group; CSIRO Division of Fisheries, GPO Box 1538, Hobart, Tas., Australia.: 36pp.

Bax, N., Tilzey, R., Lyle, J., Kloser, R., and … 2006. Providing management advice for deep-sea fisheries: lessons learned …. Deep Sea 2003: ….

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 Nonreproductive Adults, in Orange Roughy, Hoplostethus-Atlanticus Collett (Trachichthyidae), from South-Eastern Australia. Journal of Fish Biology, 40: 107-122.

Branch, T. A. 2001. A review of orange roughy Hoplostethus atlanticus fisheries, estimation methods, biology and stock structure. South African Journal of Marine Science-Suid-Afrikaanse Tydskrif Vir Seewetenskap, 23: 181-203.

Clark, R. M., Anderson, O. F., Francis, R. I. C., and Tracey, D. M. 2000. The effects of commercial exploitation on orange roughy (*Hoplostethus atlanticus)* from the continental slope of the Chatham Rise, New Zealand, from 1979-1997. Fisheries Research, 45: 217-238.

Coombs, R. F., and Barr, R. 2007. In situ measurements of orange roughy (Hoplostethus atlanticus) target strength. Ices Journal of Marine Science, 64: 1220-1234.

CSIRO. 1991. The abundance, distribution, movements and population dynamics of orange roughy (Hoplolostethus antlanticus) in south east Australian waters.

CSIRO. 1992. Cruise Report SS3/92.

Diver, G. 2004. Data Collection for the Eastern Zone Orange Roughy Survey, July 2004. Report presented to the Deepwater Assessment Group, Hobart.

Fenton, G. E., Short, S. A., and Ritz, D. A. 1991. Age determination of orange roughy, Hoplostethus atlanticus (Pisces: Trachichthyidae) using super(210)Pb: super(226)Ra disequilibria. Marine biology. Berlin, Heidelberg [MAR. BIOL.], vol. 109, no. 2, pp. 197-202, 1991.

Francis, R., and Horn, P. L. 1997. Transition zone in otoliths of orange roughy (Hoplostethus atlanticus) and its relationship to the onset of maturity. Marine Biology [Mar. Biol.], 129: 681-687.

Francis, R. I. C. C. 2006. Some recent problems in New Zealand Orange Roughy assessments. 43. 63 pp.

Haedrich, R. L., and Barnes, S. M. 1997. Changes over time of the size structure in an exploited shelf fishcommunity. Fisheries Research, 31: 229-239.

Kloser, R. J. 1996. Improved precision of acoustic surveys of benthopelagic fish by means of a deep-towed transducer. Ices Journal of Marine Science, 53: 407-413.

Kloser, R. J., and Horne, J. K. 2003. Characterizing uncertainty in target-strength measurements of a deepwater fish: orange roughy (Hoplostethus atlanticus). ICES Journal of Marine Science, 60: 516-523.

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.

Kloser, R. J., Koslow, J. A., and Williams, A. 1996. Acoustic assessment of the biomass of a spawning aggregation of orange roughy (Hoplostethus atlanticus, Collett) off south-eastern Australia, 1990-93. Marine and Freshwater Research, 47: 1015-1024.

Kloser, R. J., Ryan, T., Sakov, P., Williams, A., and Koslow, J. A. 2002. Species identification in deep water using multiple acoustic frequencies. Canadian Journal of Fisheries and Aquatic Sciences, 59: 1065-1077.

Kloser, R. J., and Ryan, T. E. 2002. Review of analysis methodologies and data holdings for asoustic assessments of orange roughy on St. Helens Hill, 1989-1999. CSIRO Marine Research internal report.

Kloser, R. J., Ryan, T. E., and Daley, R. K. 2008. 2006 Eastern Zone orange roughy acoustic survey. Final report to South East Trawl Fishery Association (SETFIA), Copy held at CSIRO Marine and Atmospheric Research Laboratories, Castray Esplanade, Hobart 7001, Australia. ISBN: 9781921232985.

Kloser, R. J., Ryan, T. E., Williams, A., and Lewis, M. E. 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, R. J., Williams, A., and Koslow, J. A. 1997. Problems with acoustic target strength measurements of a deepwater fish, orange roughy (Hoplostethus atlanticus, Collett). Ices Journal of Marine Science, 54: 60-71.

Knuckey, I., Hadson, R., Diver, G., and Ford, B. 2007. Survey of orange roughy spawning aggregation at St Helens Hill and St Patricks Head - 2007. AFMA Project 2007/809. 42 pp.

Knuckey, I., Hudson, R., and Koopman, M. 2008. Survey of orange roughy spawning aggregation at St Helens Hill and St Patricks Head - 2008. AFMA Project 2008/829. 48 pp.

Knuckey, I. A., Grieve, C., and Smith, D. C. 1999. Evoloution fo the integrated scientific monitoring programme in Australia's South East Fishery. *In* The International Conference on Integrated Fisheries Monitoring. Sydney, Australia.

Koslow, J. A., Bell, J., Virtue, P., and Smith, D. C. 1995a. Fecundity and its variabliity in orange roughy: effects of populations density , condition, egg size adn senescence. Journal of Fish Biology, 47: 1063-1080.

Koslow, J. A., Boehlert, G. W., Gordon, J. D. M., Haedrich, R. L., Lorance, P., and Parin, N. 2000. Continental slope and deep-sea fisheries: implications for a fragile ecosystem. ICES Journal of Marine Science, 57: 548-557.

Koslow, J. A., Bulman, C. A., Lyle, J. L., and Haskard, K. A. 1995b. Biomass assessment of a deep-water fish, the Orange Roughy (Hoplostethus atlanticus), based on an egg survey. Australian Journal of Marine and Freshwater Research, 46: 819-830.

Lever, and Thomas 1974. Analysis and presentation of experimental results, Macmillan Press Ltd.

Lyle, J. M., Kitchener, J. A., and Riley, S. P. 1991. An assessment of the Orange Roughy Resource off the coast of Tasmania. Final report to the Fishing and Industry Research and Development Council. Project 87/65.

Mace, P. M., Fenaughty, J. M., Coburn, R. P., and Doonan, I. J. 1990. Growth and productivity of orange roughy (Hoplostethus atlanticus) on the north Chatham Rise. New Zealand Journal of Marine and Freshwater Research [N.Z. J. MAR. FRESHWAT. RES.], 24: 105-119.

McClatchie, S., Macaulay, G., Coombs, R. F., Grimes, P., and Hart, A. 1999. Target strength of an oily deep-water fish, orange roughy (Hoplostethus atlanticus) I. Experiments. Journal of the Acoustical Society of America, 106: 131-142.

McClatchie, S., and Ye, Z. 2000. Target strength of an oily deep-water fish, orange roughy (Hoplostethus atlanticus) II. Modeling. Journal of the Acoustical Society of America, 107: 1280-1285.

Ryan, T. E., and Kang, M. 2005. Biomass estimation of Eastern Zone orange roughy based on winter 2004 industry acoustic surveys. CSIRO Marine Research internal report.

Simmonds, E. J., and MacLennan, D. N. 2005. Fisheries Acoustics Theory and Practice, Blackwell Science, Oxford.

Smith, D. C., Robertson, S. G., and Morison, A. K. 1998. Age composition of orange roughy in the eastern and southern management zones. Final report to FRCD on project 9/032.

Smith , J. N., Nelson, R., and Campana, S. E. 1991. The use of Pb-210/Ra-226 and Th-228/Ra-228 disequilibria in the ageing of otoliths of marine fish., Elsevier, New York.

Stokes, K. 2009. Orange Roughy Assessment Review. Report completed for the Australian Fisheries Management Authority. 33 pp.

Tracey, D., Horn, P. L., and Krusic-Golub, K. 2009. Orange Roughy againg study application of otolith reading protocol and analysis of between agency age data. 16 pp.

Tuck, G. N. 2007. Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2006-2007. Ausralian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart, 1: 570 p.

Upston, J., and Wayte, S. 2011. Orange Roughy (Hoplostethus atlanticus) Eastern Zone preliminary stock assessment incorporating data up to 2010 – definition of the base-case model. 33 pp.

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. .

Upston, J., and Wayte, S. E. 2012b. Orange Roughy (Hoplostethus atlanticus) Eastern Zone 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. 218 -225 pp.

Wayte, S. 2006. Eastern Zone Assessment October 2006 Report to the Deepwater Assessment Group. Document DAG2006_23

APPENDIX A – REPORTED BIOMASS ESTIMATES

Biomass estimates as reported for each year and the derivation of a mean survey c.v for the year. Note changes to survey biomass to correct for target strength, weight and calibration done to derive final estimates not included in these estimates. DZ = deadzone proportion, s.d. = standard deviation.

St Helens											
Hull	**Surveys**			**Reported**	**Sampling**		**Mean**				
Year	**Done**	**Used**	**Date**	**Biomass**	**CV**	**DZ%**	**Year**	**#**	**mean**	**s.d.**	**cv**
1990	1	1	16-Jul	38604		33					
1991	3	1	26-Jul	29483		34					
1992	2	1	17-Jul	20118		38					
1993	1	1	25-Jul	8072		55					
1996	3	2	17-Jul	4795		41					
1996	3	2	20-Jul	8403		33	1996	2	6599	2551	0.39
1999	3	3	19-Jul	NaN							
1999	3	3	20-Jul	NaN							
1999	3	3	31-Jul	3300		35	1999	1	3300		
2006	7	1	22-Jul	9770							
2010	4	2	18-Jul	4700							
2010	4	2	22-Jul	24900			2010	2	14800	14284	0.97
Towed	**Surveys**			**Reported**	**Sampling**		**Mean**				
Year	**Done**	**Used**	**Date**	**Biomass**	**CV**	**DZ%**	**Year**	**#**	**mean**	**s.d.**	**cv**
1991	1	1	30-Jul	27760		25					
1992	1	1	19-Jul	30971		37					
1993	1	1	25-Jul	10456		22					

1996	3	2	17-Jul	8532		15					
1996	3	2	20-Jul	10144		20	**1996**	2	9338	1140	0.12
1999	5	5	19-Jul	NaN							
1999	5	5	20-Jul	5186		35					
1999	5	5	20-Jul	2562		34					
1999	5	5	31-Jul	5200		22					
1999	5	5	31-Jul	1093		42	**1999**	4	3510	2034	0.58
2006	7	7	15-Jul	9016	0.12	23					
2006	7	7	16-Jul	10453	0.14	24					
2006	7	7	18-Jul	9896	0.09	31					
2006	7	7	19-Jul	8266	0.1	25					
2006	7	7	20-Jul	10280	0.11	22					
2006	7	7	22-Jul	8876	0.13	16					
2006	7	7	25-Jul	8645	0.09	22	**2006**	7	9347	855	0.09
2010	3	2	18-Jul	19200	0.08	26					
2010	3	2	22-Jul	19500	0.08	25	**2010**	2	19350	212	0.01
St Patricks											
Hull	**Surveys**			**Reported**	**Sampling**		**Mean**				
Year	**Done**	**Used**	**Date**	**Biomass**	**CV**	**DZ%**	**Year**	**#**	**mean**	**s.d.**	**cv**
1999	4	4	18-Jul	1780							
1999	4	4	18-Jul	14815							
1999	4	4	29-Jul	5830							
1999	4	4	29-Jul	15912			**1999**	5	9584	6890	0.72
2006	4	0									
2010	3	2	19-Jul	6500							

2010	3	2	22-Jul	5991			**2010**	2	6246	360	0.06
Towed	**Surveys**			**Reported**	**Sampling**		**Mean**				
Year	**Done**	**Used**	**Date**	**Biomass**	**CV**	**DZ%**	**Year**	**#**	**mean**	**std**	**cv**
1999	4	1	18-Jul	14773							
2006	4	4	18-Jul	1373		23					
2006	4	4	20-Jul	1456		12					
2006	4	4	23-Jul	1479		8					
2006	4	4	25-Jul	3011		7	**2006**	4	1830	789	0.43
2010	3	2	19-Jul	6200	0.13	3					
2010	3	2	22-Jul	3100	0.17	16	**2010**	2	4650	2192	0.47

APPENDIX B – A GUIDE TO MEASURING FISH LENGTHS

CSIRO Marine Research January 2003
Mark Lewis

The purpose of this document is to clarify the various methods and interpretations for measuring fish. The problem of standardization of fish measurements is well recognized (Howe 2002), even basic measures such as ‘Total Length’ and ‘Standard Length’ have several interpretations. Even if you follow this guide it is important to fully document the collection method of any length data.

- Measurements should be to the nearest mm.
- If rounding is used this should be noted on the data sheets, any electronic file and all subsequent reports using the data.

All bony fishes are measured from the tip of the snout to the tip of the medial caudal-fin ray, (Figure 1) Overall Length, “OL” on data sheet.

Previously these measurements would have been split into Fork Length (FL) and Total Length (TL) depending on the presence of a fork in the caudal fin.

Caudal-fin must be in a **natural** position.

- gently flatten it on the measuring board with a swipe of your fingers, or
- gently 'open' the fin with your thumb and index finger

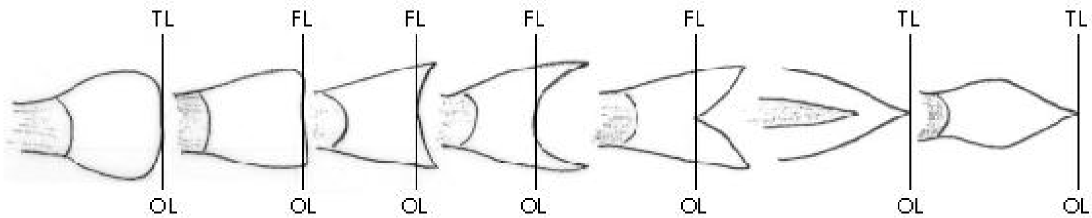


Figure 1 The approximate position of the medial caudal fin ray in several tail shapes.

EXCEPTIONS:

- Whiptails, only whole fish are measured.
- Tip of the snout **does not** include the bill on the garfish, measure from the tip of the upper jaw.
- **Orange roughy** and Blue grenadier are measured as **standard length, SL** on data sheet, (tip of snout to posterior margin of hypural bone or last caudal vertebrae when no enlarged hypural bone is present, (Rojo, 1991).
- Tuna are measured to the middle of the caudal fin **(LCF)** and Billfish are measured from the back of the eye (orbit) to the caudal fork **(OFL)** and the measurements are in centimetres.

ORANGE ROUGHY AND BLUE GRENADIER

The orange roughy assessment group is documenting the methods required to measure and monitor changes in biological parameters. Several methods of measuring SL have been applied in the past and it is preferred that future measurements conform to this method.

It would also be suitable to provide other length measures (fully documented) but it is requested that a conversion factor is supplied to enable the assessment group to incorporate these measurements into a long-term time series.

Standard Length (SL), is measured from the tip of the snout to the distal end of the hypural bone (that supports the rays of the tail fin), () and is recognized externally in the orange roughy by a fold in the skin, after the tail has been flexed back and forth laterally (Figure 2), (Gomon *et al* 1994, Howe, 2002).

A second way of finding the end of the hypural bone in an orange roughy is to insert the knife in the tail in the approximate location and work back to the distal end of the hypural bone. This is particularly useful when using puncture tapes as this marks the tape as well.

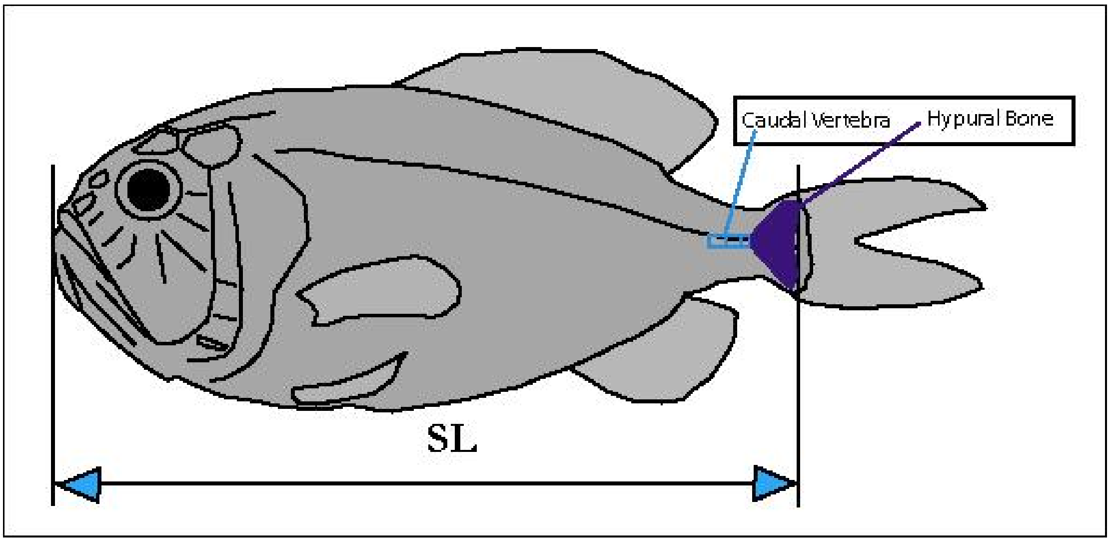
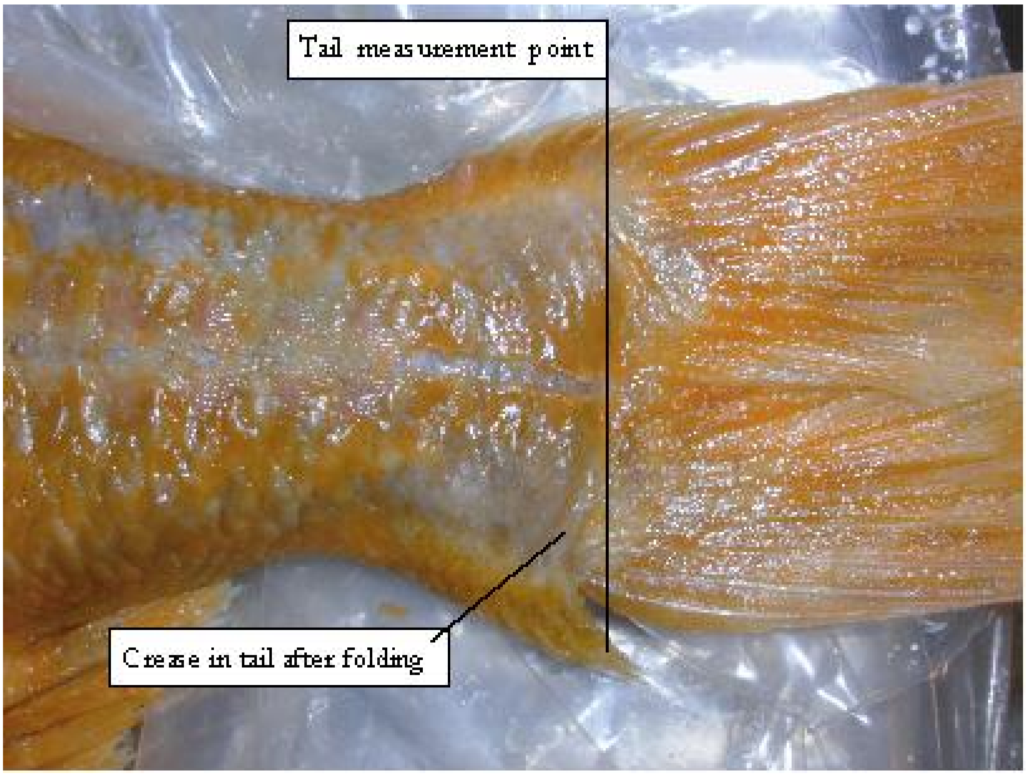
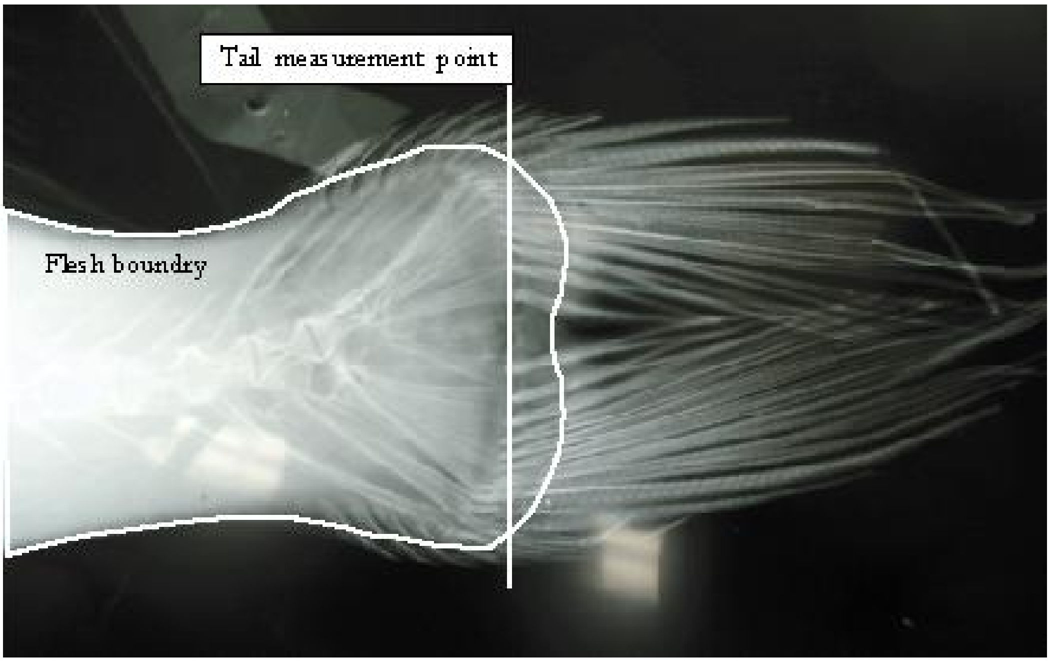


Figure 2 The recommended length measurement method and the shape and position of the hypural bone in orange roughy



(a)



(b)

Figure 3 Showing the measurement point at the tail after flexing for orange roughy showing the position on an a) fresh fish and b) an X-Ray.

TUNA AND BILLFISHES

Tuna are measured from the tip of the snout (mouth closed) to the middle of the caudal fin, as shown in Figure 4, (**LCF** on data sheet).

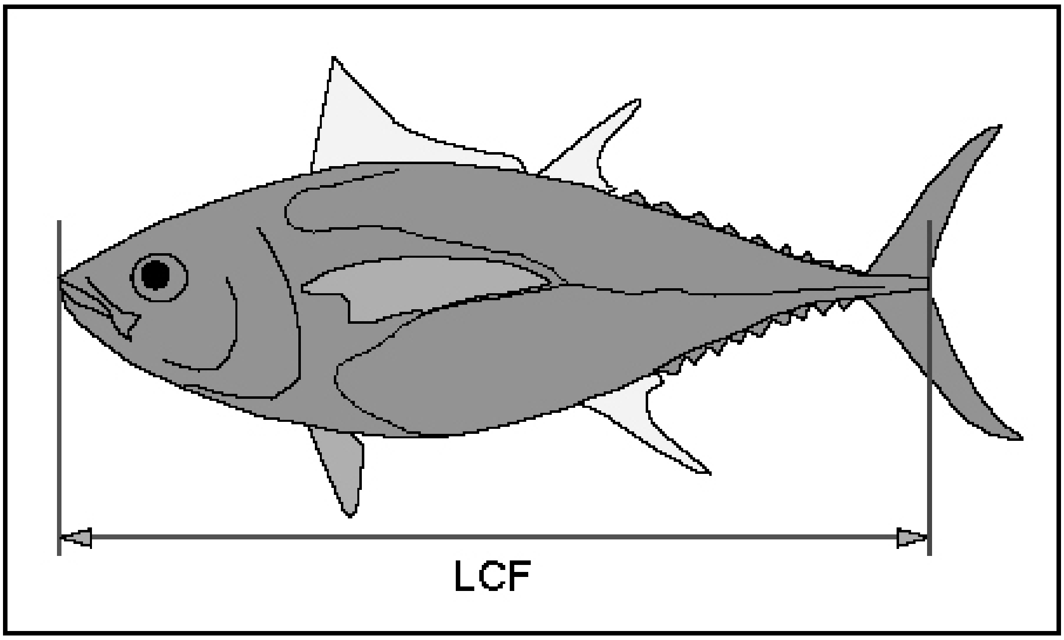


Figure 4 Measurement method for Tuna

Billfish are measured from the back of the eye (orbit) to the caudal fork (**OFL** on data sheet) (Figure 5).

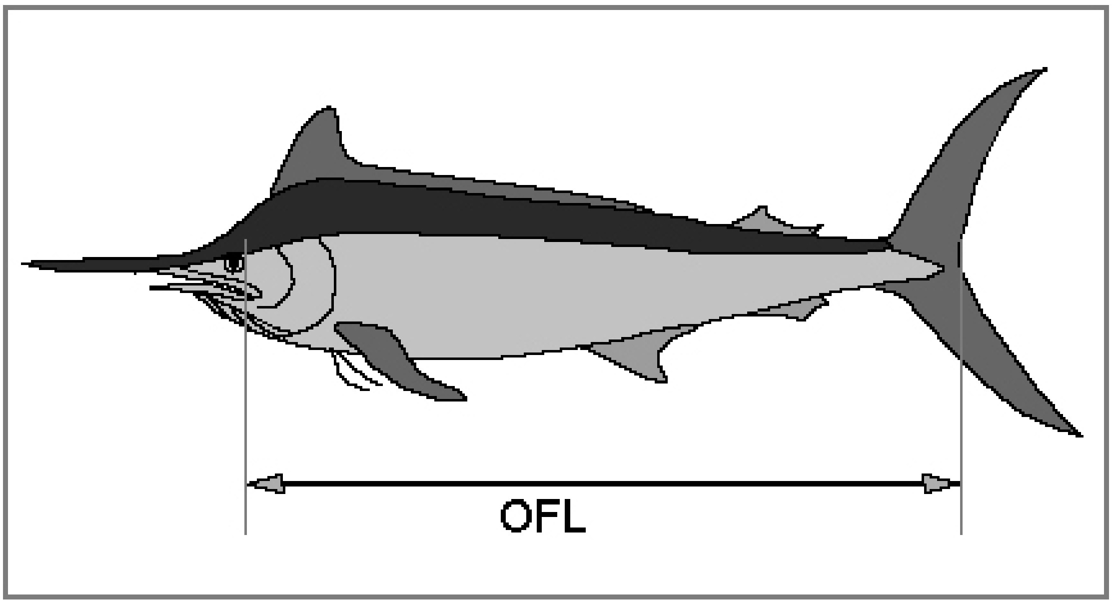


Figure 5 Measurement method for Billfish

SHARKS AND RAYS

Sharks and rays are measured from the tip of the snout to the tip of the upper caudal-fin lobe when the tail is in the ‘natural’ position (Figure 6), they are recorded in millimetres’ and as total length, TL, on data sheet. If the caudal-fin is measured in the **extended** position use the term (ExTL).

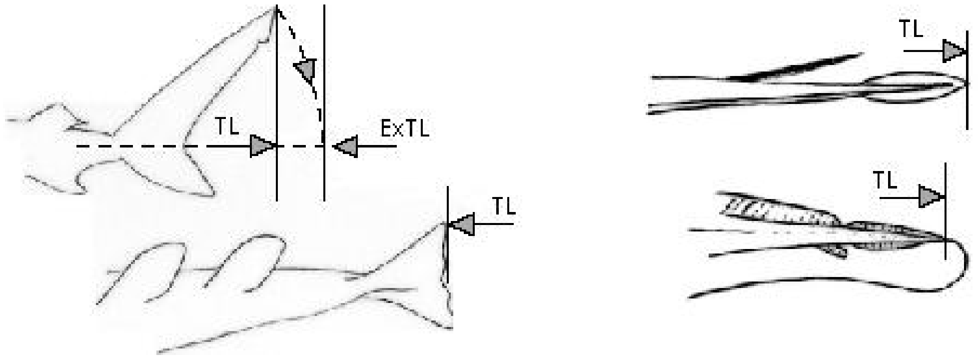


Figure 6 Showing the position of the tip of the upper caudal fin lobe after the fin has been placed in the ‘natural’ position.

EXCEPTIONS

- **chimaeras** –the caudal filament is not included in TL
- **stingrays** (with filamentous tails)– measure max. **disc width,** (Figure 7) **DW** on data sheet.

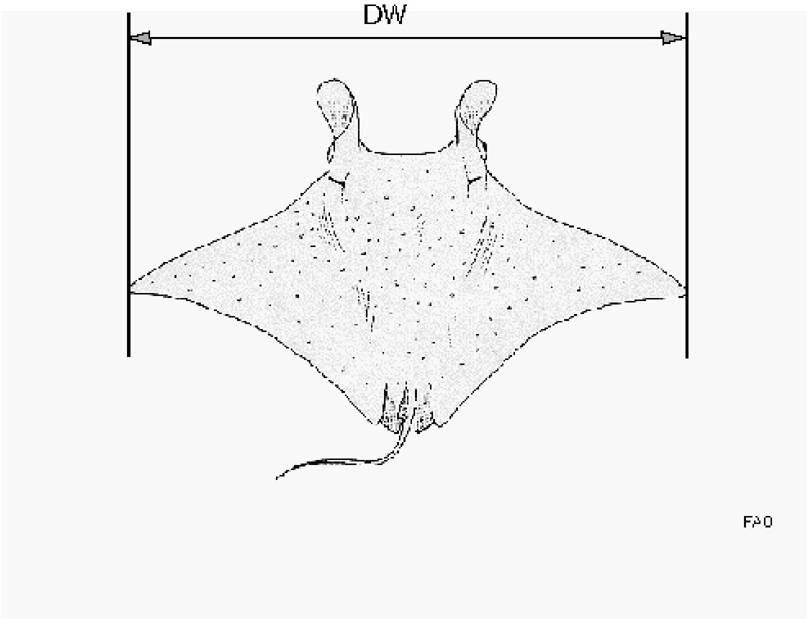


Figure 7 The correct position to measure disc width on a ray with a filamentous tail

REFERENCES:

Rojo. A. L. (1991). Dictionary of Evolutionary Fish Osteology . *CRC Press.* Florida. 273pp.

Gomon, M. F., Glover, J. C. M. and Kuiter, R. H. (eds) (1994). The Fishes of Australias South Coast. *State Print,* Adelaide. 992pp.

Last, P. R. and Stevens, J. D. (1994). Sharks and Rays of Australia. CSRIO Australia. 600pp.

Howe, J. C. (2002). Standard Length: not quite so standard. *Fisheries Research*. **56** 1-7.

APPENDIX C – ORANGE ROUGHY OTOLITH SAMPLING AND AGEING PROTOCOLS

Prepared for slopeRAG , 10-12 November 2010, Hobart, Australia
Fish Ageing Services, 15 Alison St Portarlington Victoria Australia

ABSTRACT

This report is a short communication that summarises the work that has already been completed for orange roughy (*Hoplostethus atlanticus*) in relation to selection of appropriate sample size and age estimation processes. The protocols adopted by Fish Ageing Services (FAS) for the routine age estimation of orange roughy otoliths have been largely taken from the orange roughy ageing workshop report: otolith preparation and interpretation, which was prepared for the Deepwater Fisheries Assessment Working Group 7-9 February 2007 Wellington, New Zealand.

This document also provides a brief background in orange roughy age estimation and lists past and current published work that supports the use of otoliths as the preferred ageing structures for this species.

BACKGROUND

The general consensus is that orange roughy are slow growing, late maturing and long lived. A summary of ageing studies have previously been provided by Tracey & Horn (1999) and Paul et al. (2002). These studies have included determining the appropriate methods to age orange roughy from otoliths (Smith 1992), studies of juvenile orange roughy age (Mace et al. 1990) and studies looking at the transition zone in otoliths and age at maturity (Horn et al. 1998). Age validation studies have used modal length and edge analysis (Mace et al. 1990), radiometric age determination (Fenton et al. 1991, Smith et al. 1991 and Andrews & Tracey 2003; 2007).

The sample size required for the collection of otoliths has remained at N=1000 since 1996/97. Sample size analysis was conducted for a range of SESSF species during 1995/96 (appendix 1), however this analysis didn't include orange roughy. Orange roughy were first routinely aged as part of the FRDC Project (No. 95/032) on the age composition of orange roughy catches. Otolith collection targets were set at approximately 1000 per area per season, although no reference to how the sampling numbers were estimated could be found. The otolith collection target has since remained at 1000.

The sample size analysis was again performed in 2006 using updated age data and included additional species not analysed previously. Again orange roughy were not included because at the time they were not considered a priority species for the Integrated Scientific Monitoring Program collection targets.

Concerns about the assumed productivity of orange roughy were again raised at the 2006 NZ stock assessment for the East Chatham Rise; it was acknowledged that orange roughy productivity, and in particular recruitment pattern are poorly known. Recruitment patterns are usually estimated from age frequency distributions. Recent analysis between reader-and lab ageing errors for orange roughy otoliths aged at the CAF and NIWA indicated that estimates had poor precision. Of more concern was that Francis (2006) noted bias in the most recent (2004/05) age samples. As a result the Deepwater Fisheries Working group (NZ) and the deepwater resource assessment group (AUS) held little confidence in the age frequency data.

Routine ageing of orange roughy has been conducted by the Central Ageing Facility (CAF) in Australia, the National Institute of water and Atmospheric Research (NIWA) in New Zealand and Instituto de Formento Pesquero (IFOP) in Chile. A review on the methods from each laboratory indicated that although the three laboratories had consensus on the plane of sectioning and the area of otolith sectioned, preparation methods and reading protocols were different.

Orange roughy ageing workshop 7-9 February 2007, Wellington NZ

To address the potential issues with reader and laboratory bias, a workshop was held in February 2007 at NIWA (Wellington - NZ) with the overall objective to determine whether orange roughy otoliths can be aged with sufficient accuracy and precision for the data to be of use in stock assessments. Specifically, the potential to use orange roughy age data to provide reliable estimates of changes in age frequency and recruitment patterns.

The specific goals of the workshop were to:

Determine the current (at that time) between reader and laboratory accuracy.

Review the current otolith preparation and reading protocols used by various organisations to age orange roughy and to determine the best practise.

Prepare and age orange roughy samples.

Prepare and report a standardised ageing protocol.

During the workshop scientists from four agencies described preparation methods and examined reading protocols that may have lead to differences in zone counts from the same otolith. A principal focus of the workshop was on refining identification of the transition zone (TZ). The experts agreed on a revised protocol that should provide more reliable and consistent readings.

A larger scale orange roughy cross-ageing study followed to test the protocols and determine accuracy and precision between and within readers and institutions. Two readers from NIWA and two from CAF aged about 400 orange roughy otoliths (sister otoliths from 200 fish) from the Chatham Rise and covering the size range of orange roughy in this area.

The new protocol solved some inter-institute problems, but it was found that there is still some relative reader bias, our ageing imprecision remains relatively high compared to other species, and identification of a TZ still has a 30% effect on the perceived age of the fish. As a result of this research, the Ministry of Fisheries (NZ) Deepwater Working Group is prepared to include age data back into the stock assessment process.

SAMPLE SIZE

The rationale behind the sample size for orange roughy collection remains unclear. However simulation analysis on other long lived species (>30 years) or for a species where the fishery is based on a relatively large range of age classes, a sample size of 1000 to 12000 should be considered as an absolute minimum. For the above reasons we suggest that the minimum sample size for orange roughy remain at 1000, with a view to revising this estimate when new data becomes available.

On the occasions that the sample size target is exceeded, otolith samples will be selected so that the length frequency of the age sample is reflective of the total survey length frequency.

OTOLITH PREPARATION AND AGEING

The ageing protocol used by FAS to age orange roughy from sagittal otoliths follows the agreed protocol decided at the orange roughy working group.

A summary of the overall approach is:

<u>Preparation</u>

- Sagittal otoliths are preferred.
- Otoliths are sectioned along a longitudinal plane from the primordium to the posterior arm on the longest path.
- FAS prepare multiple sections of the same otolith.

<u>Age estimation</u>

- View preparations under transmitted light.
- Use the longest path along the posterior arm of the otolith for ageing.
- Count dark growth zones
- View under 36-40x magnification for count out to the TZ (transition zone).
- View under 36-40x magnification for counts immediately post TZ.
- View under 64-100x magnification for the fine zones post-TZ to otolith margin.

<u>Data recorded</u>

Zone counts are recorded from:

1. the primordium to the TZ.
2. TZ to the marginal edge.

A readability score is assigned to:

1. 0 to TZ counts
2. The relative readability of TZ.
3. TZ to the margin counts

On a side note, the Ministry of Fisheries NZ have called for expressions of interest for the targeted ageing of otoliths from selected deepwater stocks, including orange roughy. The analysis of the age reading experiment conducted post orange roughy ageing workshop identified Peter Horn and Kyne Krusic-Golub as the two readers with the highest precision. Therefore the submission for ageing includes a provision for FAS (Kyne) to provide the secondary reads for age error comparisons.

For the Australian samples it is recommended that a secondary reader is also utilised. In this case the ideal scenario is that Kyne Krusic-Golub provides the primary reads and Dr Peter Horn (NIWA) provides the secondary reads. I have already approached Peter Horn and he has indicated that NIWA/Peter would be willing to provide this service if required. Funding to secure this service could be covered by the current ageing workplan contract.

REFERENCES

Smith DC, Fenton GE, Robertson SG, Short SE (1995) Age determination and growth of orange roughy (Hoplostethus atlanticus): a comparison of annulus counts with radiometric ageing. *Can J Fish of Aquatic Sciences* 52: 391-401

Smith DC, Robertson SG (1992) The problem of ageing orange roughy. In: Hancock DA (ed) The measurement of age and growth in fish and shellfish. Australian Society for Fish Biology. Workshop, Lorne, 22±23 August 1990. Australian Department of Primary Industry and Energy, Bureau of Rural Resources, Canberra, pp 116±120 (Proc Bur Rural Resources No. 12)

Fenton GE, Short SA, Ritz DA (1991) Age determination of orange roughy, Hoplostethus atlanticus (Pisces: Trachichthyidae) using 210Pb:226Ra disequilibria. *Mar Biol* 109: 197-202

Mace PM, Fenaughty JM, Coburn RP, Doonan IJ (1990) Growth and productivity of orange roughy (Hoplostethus atlanticus) on the north Chatham Rise. *NZ Journal of Marine and Freshwater Research* 24: 105-119

Francis, R.I.C.C.; Horn, P.L. (1997). The transition zone in otoliths of orange roughy (*Hoplostethus atlanticus*) and its relationship to age at maturity. *Marine Biology 129(4)*: 681-687.

Contact Us

Phone: 1300 363 400
+61 3 9545 2176

Email: enquiries@csiro.au

Web: www.csiro.au