Australian Government
Australian Fisheries Management Authority

Meeting of the Tropical Tuna Resource Assessment Group (TTRAG)

FINAL RECORD

TTRAG 38

11-13 JULY 2023

TROPICAL TUNA RESOURCE ASSESSMENT GROUP (TTRAG)

Chair: Dr Cathy Dichmont
Date: 11-13 July 2023
Meeting: 38
Venue: Maroochydore (Maroochy RSL Boardroom 2, 105 Memorial Avenue) and video conference
Attendance:
All members attended the meeting venue, except those identified. Chair, Dr Cathy Dichmont.

Members	Invited Participants	Observers
Dr Ian Knuckey, Science Member	David Ellis, Industry	Laura Tremblay - Boyer, CSIRO
Dr James Larcombe, Science Member	Terry Romaro, Industry	Dr Jason Hartog, CSIRO[1]
Dr Rich Hillary, Science Member (online)[2]		Selina Stoute, AFMA
Dr Ashley Williams, Science Member		Robert Wood, AFMA (online)[3]
Pavo Walker, Industry Member[4]		Dr Steph Brodie, CSIRO (online)[5]
Gary Heilmann, Industry Member[6]		Dr Julie McInnes, AAD (online)[7]
Dr Julian Pepperell, Science/Recreational Fisheries Member (online)		Mandi Livesey, AAD (online)[8]
Robert Curtotti, Economic Member (online)		Andrea Polanowski, AAD (online)[9]
Kate Martin, AFMA Member		Dr Mike Double, AAD (online)[10]
Lachlan Farquhar, Executive Officer, AFMA		

Apologies:
Paul Williams, industry observer

[1] Present Agenda Item 3 only
[2] Present Day 1 (full day), Day 2 (until midday)
[3] Present Agenda Item 6.1 and 6.2 only
[4] Present Day 1 (until 1545), Day 2 (from 0900)
[5] Present Agenda Item 3 only
[6] Present Day 1 (full day), Day 2 (from 0930) and Day 3 (all)
[7] Present Agenda Item 6.1 only
[8] Present Agenda Item 6.1 only
[9] Present Agenda Item 6.1 only
[10] Present Agenda Item 6.1 only

Agenda item 1 - Preliminaries

1.1 Welcome and Apologies

The thirty eighth meeting of the Tropical Tuna Resource Assessment Group (TTRAG 38) was opened at 08:45am on 11 July 2023 by the Chair, Dr Cathy Dichmont. The Chair welcomed members and observers to the meeting and:

a) made an acknowledgement of country;

b) noted the only apology for the meeting from Mr Paul Williams, a regular industry observer who advised he will no longer attending TTRAGs; and

c) advised members the meeting would be recorded to assist with the preparation of the meeting record. The recording will be deleted once the record is finalised.

1.2 Declarations of interest

The standing declaration of interests was reviewed by RAG members and RAG members provided updates as necessary following last TTRAG meeting (meeting 37). The updated declarations of interest are at **Attachment 1.2**.

The RAG agreed that industry members with fishing concession holdings and the industry invited participants held potential conflicts of interest with *Agenda Items 4 – Fishery Indicators*; *Agenda item* 7 – *Coral Sea Zone Hook Trial*. The RAG also agreed that David Ellis and CSIRO employed staff held potential conflicts of interest with *Agenda item* 8 – *Australian Billfish Fisheries Annual and 5-year Research Plans*.

These members were asked to leave the room while the RAG considered the nature of the conflict and appropriate action to be taken when the agenda item is discussed. The RAG members agreed on an inclusive approach to manage the perceived conflicts to make use of the expertise of members. The RAG agreed that all members and participants could be present for discussion and advice on the abovementioned items and excluding the opportunity for an industry member with fishing concessions in the Coral Sea Zone to provide advice regarding discussions on *Agenda Item. 7 – Coral Sea Zone Hook Trial*.

1.3 Adoption of agenda

The RAG adopted the agenda with no amendments and is provided at **Attachment 1.3**. Throughout the meeting the order of agenda items was revisited to ensure presenters had sufficient time for breaks and to meet the availability of invited presenters.

1.4 Actions arising from previous meetings

The RAG noted the status of actions items. The status of actions arising together with RAG advice on the ongoing relevance of certain items, can be found at **Attachment 1.4.**

1.5 Out of session correspondence

The RAG noted the out of session correspondence between TTRAG 37 and TTRAG28 as detailed in the table below.

Date	Description
22 May 2023	Two items distributed to the RAG: 1. Letter to Dr Ashley Williams - regarding ARC's guidance on research proposal - Scientific advice for management of Tropical Tuna and Billfish Fisheries. 2. Final report - EM-Logbook Congruence Report - An evaluation of the reliability of electronic monitoring and logbook data for informing fisheries science and management.
09 June 2023	Update to RAG members that AFMA Management is currently undertaking a review of Fishery Management Paper Number 14 – AFMA's Approach to Ecological Risk Management and its supporting Guide to AFMA's Ecological Risk Management Framework. Feedback or comments on the drafts, to be provided to policycomment@afma.gov.au by COB 31 July 2023.

Agenda item 2 Member updates

2.1 Industry, recreational fishing and scientific member update

The RAG noted the following update from the recreational fishing member:

- That inflated economic conditions have reduced recreational fishing effort, with less boats fishing in tournaments due to fuel prices, however club membership is constant.
- The tournament season ceased at the end of June on the east coast of Australia.
- East coast recreational catches of striped marlin and blue marlin were lower than usual.
- Juvenile black marlin (1-2kg) have been caught around Hervey Bay, Queensland. Anecdotal evidence suggests a spawning event may have occurred outside the normal spawning grounds of the Coral Sea.
    - Fish frames have been retained for aging by CSIRO
- Yellowfin tuna catches were recorded off the shelf of Sydney to Eden. Averaging 60-70kg. Juvenile yellowfin tuna have not been seen in this area.
- Juvenile yellowfin tuna 25cm (350g) have been caught off the coast of Sydney around the NSW Fish Aggregation Devices (FADS), samples from the recreational sector have been sent to CSIRO for aging.
- Large southern bluefin tuna (100kg+) are being caught off Sydney and mid-south coast NSW.
- Targeting for southern bluefin tuna is also occurring in New Zealand and social media content is indicating great recreational catches.

The RAG noted the following updates from the industry members:

- Reasonable catches have been experienced in the Western Tuna and Billfish Fishery (WTBF) and the Eastern Tuna and Billfish Fishery (ETBF). Skipjack tuna have been caught by longline vessels and striped marlin catches increased late in 2022. Additionally, there has been an increase of yellowfin tuna catches early in 2023 off the Sunshine coast, QLD.
- Tuna Australia (TA) advised that the spatial squeeze on the fishery footprint from Marine Parks and various exploration companies such as windfarms, seismic surveys and energy exploration is a major challenge for industry and industry associations. TA has developed an industry position statement and services agreement for engagement with energy companies. TA have been approached by several companies with mixed success on willingness to engage with TA.
- TA noted that the association has made submissions on *Environmental Protection and Biodiversity Conservation Act 1999* review and the Threat Abatement Plan for the incidental catch (bycatch) of seabirds during oceanic longline fishing operations (2018) 5-year review.
- Crew recruitment and retention remains a key challenge for all fleets in both fisheries, particularly around availability of international crew. The industry invited participant raised concerns with visa applications and the Temporary Skilled Migration Income Threshold increasing the minimum wage from $53,900 to $70,000 from 01 July 2023.
- TA and industry have been informed by Australian Maritime Safety Authority (AMSA) of the implementation of new Marine Orders of crew qualifications. Current processes suggest that workers from overseas will require two medicals, two first aid certificates, and two certificates of safety training to meet AMSA and Department of Immigration/Home Affairs requirements.
- Freight and export – freight availability continues to be a challenge for industry. Industry advised that QANTAS has employed a freight logistics coordinator based out of Brisbane and is providing some cost-effective options to industry, such as sending product on partially filled planes. There have been reports the albacore fishery has lost value with the export markets into the European Union due to the EU releasing new export and disease control requirements.
- An industry member noted that his vessels have changed bait type to Vietnamese black squid however are unable to reflect the bait change in logbooks. The member also suggested that their broadbill swordfish catches may influence CPUE standardisation, as their targeting of broadbill swordfish is based on market demand and value, rather than availability.

2.2 AFMA Management and international meetings update

The RAG noted the AFMA Management's update as detailed in the agenda paper outlining outcomes from the Indian Ocean Tuna Commission meeting (IOTC27) held between 8-12 May 2023 and an update on the AFMAs review of Fishery Management Paper Number 14 (FMP 14) – AFMA's Approach to Ecological Risk Management and its supporting *Guide to AFMA's Ecological Risk Management Framework*.

The RAG noted that the IOTC had:

a. adopted an annual TAC of 80,583 tonnes (t) for bigeye tuna for 2024 and 2025, which is consistent with the outcome of the Management Procedure (MP) for the species;

b. agreed to a voluntary fishing closure in the Indian Ocean for the conservation of tropical tunas; and

c. adopted a Regional Electronic Monitoring Program (REMP) to commence by 1 July 2024. The REMP will provide guidance to contracting parties and co-operating non-contracting parties (CPCs) who choose to implement electronic monitoring systems (EMS); and

d. adopted amendments *On Reducing the Incidental Bycatch of Seabirds in Longline Fisheries* to include hook-shielding devices as stand-alone mitigation option in IOTC fisheries operating south of 25 degrees.

e. The IOTC's resolution on an interim plan for rebuilding the Indian Ocean Yellowfin Tuna stock in the IOTC area of competence remains unchanged.

A Science Member, ABARES, advised the RAG that the Western Central Pacific Fisheries Commission (WCPFC) Scientific Committee will be held in 16-24 August 2023, Palau. The member also provided an update on meetings held with Conformity Assessment Bodies (CABs) regarding Marine Stewardship Council new standard. The member advised that fisheries are assessed by accredited independent certifiers CAB's, to meet the new 3.0 MSC Fisheries Standards to maintain certification. CAB's are currently consulting with 30-40 certified fisheries that are MSC certified for key tuna stocks. The new standard requires members within the WCPFC area of competence, agreeing to allocation and harvest strategies to be implemented and operating in line with specified milestones set by MSC to maintain certification. The Department of Agriculture, Fisheries and Forestry has provided advice to the CAB's through the consultation process.

Agenda item 3 Climate Change – Ecosystem Status Report

The RAG noted the presentation by the AFMA Member on the Climate Science Summary for the ETBF (**Attachment 3a**) and discussed the presentation by Ms Stephanie Brodie (CSIRO) on the draft Climate and Ecosystem Status Report for the ETBF (**Attachment 3b**).

The RAG recalled that AFMA is developing a framework to support the integration of climate impacts and risk into TACs utilising available information. The framework will set out criteria for assessing risk and guidance on integrating into TAC advice. The framework is currently under development, and in the meantime, the AFMA Commission expects that climate impacts and vulnerability have been taken into account by RAGs and MACs in developing recommendations and advice.

The RAG noted that the following climate impact predictions relevant to the ETBF:

a) It is anticipated that ETBF tuna fishing will experience normal shifts in distribution and abundance with the El Niño-Southern Oscillation (ENSO) cycle (i.e. La Niña and El Niño) however, the severity and frequency of ENSO events will continue to increase.

b) Pacific stocks of skipjack and yellowfin tuna are predicted to move eastward by 2050.

c) Declines in abundance of yellowfin tuna, southern bluefin tuna and broadbill swordfish projected for ETBF by 2040.

d) Bigeye tuna is expected to remain relatively stable through to 2050.

e) For albacore, there is uncertainty regarding the effect of warming waters on movement and dissolved oxygen in these oceanic areas. It is thought that dissolved oxygen is likely to decrease when waters warms. This scenario predicts relatively stable abundance and distribution of albacore. However, if dissolved oxygen does not reduce as predicted, then albacore could benefit from the warming waters and increase in abundance across the pacific.

The RAG was able to review the first draft of the ETBF Ecosystem Status Report that will be used as a tool to support the RAG's consideration of climate impacts when providing future management advice.
The RAG recommended the following amendments to the draft ETBF Ecosystem Status Report:

- Sea surface temperature and temperature at depth to be included in separate plots
- Catch to be replaced with CPUE under the Ecosystem and Fishery section.
- Removal of arrows for standardised CPUE trends.

    - Include long term ETBF forecasting projections made in the report *Summary of Commonwealth Fishery Climate Sensitivity* (Fulton et al, 2021) and a summary of the final outcomes of Dr Jason Hartog's Fisheries Research and Development Corporation 2017-004 Project*: Investigate oceanographic and environmental factors impacting on the ETBF.*
    - Inclusion of a section for RAG observations on predictions and considerations on the current climate information.
    - CSIRO to explore the possible inclusion of eddy indicators at the climate scale.
- Inclusion of the following at-sea observations by industry and recreational fishers:
    - There have been ENSO effects on the fishery in 2022 and 2023 which include:
        - Bigeye being targeted at varying depths, especially during pre el-nino events
        - Recreational fishing sector noted a recruitment event may have occurred, due to reported very small juvenile yellowfin tuna and black marlin being caught in early 2023.
        - The predications of SST and conditions may have contributed to a recruitment event.

ACTION ITEM: CSIRO to make TTRAG's recommended amendments to the climate and Ecosystems status report for ETBF and AFMA to provide the update status report out -of – session for comment.

Agenda Item 4. Fishery Indicators

Agenda item 4.1 ETBF and WTBF catch and effort data summaries

The RAG noted the presentation by Laura Tremblay-Boyer on annual data summaries, trends in catches, effort and fishing practices recorded from logbook data of longline operations in the ETBF and WTBF target species for the period of 1998-2022 calendar years.

- Ms Tremblay-Boyer advised that approximately ten per cent of the data is excluded (groomed) from the CPUE calculations each year, as some fields used in the CPUE standardisation were either blank or assumed to be incorrectly filled e-log fields.
- Ms Tremblay-Boyer advised that a higher proportion of data was excluded for 2022 because some sets were reported with 45 hooks between floats. Historically, when calculating CPUE, CSIRO has accepted hook between float numbers of 3-40. Industry members advised no operators would be setting 45 hooks between floats and a more probable figure was 30. The RAG queried whether this was a sole operator or if it is occurring across the fleet. TA offered to contact identified operators and discuss e-log entries.
- The graphs for nominal CPUE and proportion of discards presented exclude data where less than 50 fish have been caught. This threshold can be reviewed or modified if required.

Eastern Tuna and Billfish Fishery

- Vessel numbers have plateaued over the past ten years with retained catch numbers persisting since 2019, however retained catch weights have seen a slight decline across all species. Retained catch numbers for albacore, bigeye tuna, broadbill swordfish and striped marlin have increased since 2019, however have decreased for yellowfin tuna.
- All ETBF target species saw an overall increase in the proportion of discarded individuals compared to total catches. Ms Tremblay-Boyer noted historic observer-based information is still being used to inform the CPUE for discard size. An industry member noted that most discards that occur are due

to depredation rather than an unsuitable size. Members saw benefit in identifying the year in which Electronic Monitoring (EM) was introduced on the proportion of discard graphs, as trends for all species increased around 2015/16, indicating potential influence by EM on reporting.

- The RAG discussed operational trends and industry members advised operators are using combinations of baits on the same set. The RAG discussed modifying the e-logs entries to allow for proportions of mixed bait species to be included. i.e. 90% squid and 10% pilchard. AFMA will explore whether proportions of mixed bait species are included in e-logs and will advise the RAG.
- Ms Tremblay-Boyer shared the catch summary tables by species provided in the report, the table are derived in numbers and weight from three data sources (logbook, processor and Catch Disposal Records (CDR)). Previous iterations of the report only calculated the latest dataset for that year, however it was noted that previously presented catch summary tables do not reflect updated database catches, after the data had been complied each year. This also, prevents a full reproduction of the report's catch tables each year as the catch values have changed through time.
- The RAG was asked to consider whether the catch summary catch values provided in previous iterations of the report, should be updated to reflect the current catch values for those years' or if the figures should remain unchanged. The RAG recommended using revised data each year and accepting minor changes. Any change greater than one per cent will be flagged and brought to the attention of the RAG for discussion and advice.

Western Tuna and Billfish Fishery

- Less than five vessels fished in the WTBF in 2022, with one vessel conducting ~90% of the sets. There is continuing decline in catch numbers and weights as well as mean fishing days per vessel and mean sets per vessel. The primary reason for groomed data in 2022 for the WTBF was low input of bait type.

ACTION ITEM: AFMA to explore whether reporting mixed bait species proportions is included in e-logs and to advise TTRAG.

RECOMMENDATION: The RAG recommended using revised data each year and accepting minor changes for the catch summary tables. Any change greater than 1% will be flagged and brought to the attention of the RAG for discussion and advice.

RECOMMENDATION: Tuna Australia and CSIRO to investigate potential erroneous logbook reporting regarding 45 hooks between floats. Tuna Australia to follow up with operator if error is identified.

Agenda item 4.2 ETBF weight frequency data summary

The RAG noted the presentation by Laura Tremblay-Boyer on weight frequency data summaries in the ETBF between 1998-2022, which is used as an indicator to assess temporal and spatial trends in the distribution of target fish size data, which can be used to examine stock conditions, for example if larger fish become less prevalent or there is an increase in the number of small fish caught (indicating a strong recruitment cohort) **(Attachment 4.2)**.

Albacore

- The mean weight (kg) recorded in 2022 quarters 1, 2 and 3 were marginally smaller than previous years, however there is an increase in mean weight over time, with some variability within the dataset. Size distributions (kg) were presented as quantiles (quartiles) derived from individual fish weights. The median size for 2022 was lower than 2021, with two peaks in the size distribution noted at 10kg and 16kg in 2022. There were no clear trends between regions (Northern Queensland, Southern Queensland, Northern New South Wales and Southern New South Wales) in weight frequency distributions. An industry member noted the albacore caught off the coast of Mooloolaba are generally 12-14kg, however, early 2023 there have been reports of increased fish weights averaging in the higher teens.

Bigeye Tuna

- There was an increase in mean weights (kg) in quarters 3 and 4 in 2022 to about 35 kg compared with around 30 kg in 2021, while the mean weight in quarters 1 and 2 remained relatively stable. The weight frequency distribution in Southern NSW clearly shows a growth progression throughout the time series, noting many of the samples are from Northern New South Wales and Southern Queensland. An industry member noted that early in 2023 there have been reported catches of large bigeye tuna.

Yellowfin Tuna

- No trends were observed across years with variability across all four quarters in 2022, with fish weight averaging >35kg. Two size distribution peaks were observed at 22kg and 45kg. An industry member advised the data displayed for 2022 of two distinct groups was representative of observations from the fleet. No clear trends were observed through the four regions in 2022 or through the time series.

Broadbill Swordfish

- Mean weights (kg) in quarters 1, 2 and 4 were greater than in the previous year in 2021. The distribution of fish size has shifted in recent years and is gradually showing larger fish with a median weight in 2022 of 43kg. Most samples were taken in Southern Queensland, so no clear trends across other three regions could be made.

Striped Marlin

- Mean weights (kg) have increased across all quarters with steady weight distribution over time, however larger weights of individuals were recorded in quarter 3 at 67kg in 2022. Most samples were taken from Queensland region and no clear trends in the mean size across all regions were observed.

4.3 ETBF CPUE Standardisation

The RAG noted the presentation by Laura Tremblay-Boyer on standardised CPUE indices for target species in the ETBF 1998-2022 (**Attachment 4.3**).

2023 CPUE Standardisation Model

- This year’s update of standardised indices for the ETBF further expanded on the General Additive Model approach developed in 2022 (Tremblay-Boyer et al., 2022a).
- Two key areas of model development were explored for this year’s indices. Firstly, refining the identification of fishing strategies in the ETBF, with the aim to use fishing strategies (metiers) to replace the current targeting covariate based on species composition. Secondly, covariates describing the interaction of fishing sets with eddies were developed based on a database of daily eddy location in the ETBF.

Stepwise Approach

The RAG acknowledged the importance of updating the model in a stepwise approach. Ms Tremblay-Boyer advised the following steps had been taken:

- Rerun of the accepted 1998–2021 model structure on the new dataset extract with the 2022 data removed.
- Rerun of the accepted 1998–2021 model structure on the new dataset extract including 2022, using the same grooming rules as in Tremblay-Boyer et al. (2022)[11.]
- Rerun of the accepted 1998-2021 models on the new dataset extract including 2022.
- Set time covariate removed.
- Model update with distance to shelf: Previous step with addition of a non-linear relationship for the distance of fishing sets to the shelf.
- Implementation of metiers as the targeting variable
- Inclusion of eddy covariates

Ms Tremblay-Boyer compared the nominal time series with last years and the final index for all target species.

Albacore

- The index developed for albacore is developed for all sizes classes. No significant trends were observed over time and high variability was observed in 2020 and 2021. Last year's index was slightly higher than the final model, potentially due to increase in deep setting for albacore. Ms Tremblay-Boyer introduced the stepwise model plots to standardised index which showed the most influential covariates on CPUE, and in the case of Albacore, it was the year/quarter and targeting cluster covariates.

Bigeye Tuna

- Standardised CPUE indices for bigeye tuna were developed for all sizes classes has been declining overtime but showing an increase in the last 5 years. An industry member noted bigeye tuna was targeted off Mooloolaba around 2007 -2008 was reflected in the final model which peaked higher than the nominal. The year/quarter covariate was the most influential on the model. Industry members recommended that inclusion of fish weight be incorporated, rather than just individual counts. The standardised indices were stable for all size groups.

Yellowfin Tuna

- Yellowfin tuna continues to be highly variable in 2022. However, the final model for all size classes presented fewer extreme peaks. Hooks per km of longline were highly influential on the model. The standardised indices increased from 2021 to 2022 for all size groups.
- The RAG queried whether the new information added to the model has represented a potential shrinkage effect as the distance from peaks and troughs were shortening. It was also noted by industry members that 2016 was a significant year for yellowfin tuna catches and queried the nominal CPUE and the standardised CPUE during this period, RAG members were uncertain whether the effect was because of the variability in the species or whether there was from this additional information added to the model. However, Ms Laura Tremblay – Boyler clarified that the data during

[11] Tremblay-Boyer, L., Cooper, S., and Williams, A. (2022a). Standardised CPUE indices for the target species in the Eastern Tuna and Billfish fishery–1998 to 2021. Working Paper presented to the ETBF Data Meeting held 13–14 July 2022, Teleconference.

the 2015-26 fishing season is not based on a calendar year, unlike in recent years and that year has been identified by the model.

Broadbill Swordfish

- Standardised CPUE indices for sub-adult broadbill swordfish have been cyclical since 2016 and the final and last year's model aligned closely. The sub-adults group displays the steepest increase in 2022 in comparison to 2021. It was noted that the standardised index within the last few years does not decline as much as the nominal index.
- The recruit – sub-adult weight category was between ~20kg and ~30kg for broadbill swordfish (quarter dependent). The RAG noted that the year/quarter, use of lights, hooks between floats and hooks per kilometre of line were the most influential on the model. The RAG agreed that the 1998-2021 model for the sub-adult index was the most suitable index to apply to the CPUE standardisation.

Striped Marlin

- The index for all size classes shows a relatively stable standardised index through time. There is an increase in the standardised index from 2021 to 2022. The targeting cluster and hooks per km of mainline were the most influential on the model. The recreational/scientific member noted that some striped marlin was incidentally caught wide of the south coast, however the majority of the has been caught by boats out of Mooloolaba; and that the model did not pick up a strong effect of distance from shelf where the majority of striped marlin would have been caught.

The Chair sought the views of the RAG on the above indices, no objections were raised.

Metier Effect

The RAG recalled at its March meeting TTRAG37, the RAG supported continued work on the new approach to review the modelling approach to identifying ETBF fishing strategies and interaction of fishing sets with eddies, with a further intersessional meeting 15th June 2023, to further review and agree on the appropriateness of fishing strategies (clusters) generated by the model prior to them being included in the CPUE standardisation model as a covariate.

Ms Laura Tremblay Boyler advised both approaches were tested in this year's CPUE standardisation with the following results:

- Refinement of fishing strategies incorporated fishing operational characteristics of fishing sets and moved away from targeting covariates based on species composition. Additionally, covariates describing the interaction between eddies and fishing sets were also considered.
- The replacement of the species composition-based targeting covariate with the metiers-derived one induced a high amount of additional variability in some of the indices. The incorporation of the eddy covariates had little to no effect on the standardised indices.
- Accordingly, due to high variability caused by the metiers-derived covariate, and little to no change in the eddy covariates when used in the CPUE standardisation, neither of the modifications were applied at this time. Further refinement is needed to use the fishing strategy covariate in the future. This approach was supported by the RAG.

The RAG were asked to consider the following four CPUE refinement priorities:

1. Continue the implementation of metiers approach
2. Move from area-based approach to explicit spatial approach
3. Improve inclusion of oceanography covariates eg. Eddies

4. Simulation test of the CPUE standardisation

The RAG supported all priorities, however suggested Priority 4 be revisited for discussion and advice with TTRAG in March 2024.

RECOMMENDATION: TTRAG discuss and provide advice at its meeting in March 2024, on priority need to undertake simulation testing of the CPUE standardisation.

Catch rate of Broadbill Swordfish *per kilometre of mainline graph*

- It was requested at TTRAG 37, that CSIRO develop a graph detailing the approximate catch rate of broadbill swordfish in relation to mean hook density per kilometre of mainline in the ETBF. Ms Tremblay-Boyer presented a model of the effects of hooks per km of mainline on catch rates with all covariates being the mean value of what is contained in the datasets (caveat – may not represent outcomes of a traditional broadbill swordfish set). The model suggested the average catch rate for 1000 hooks was 1.3-2.2 fish.

Agenda item 5. Review the process for recommending total allowable commercial catches for the five key target species in the ETBF.

Agenda items 5.1 Harvest strategy review

The harvest strategy review was presented with two components, firstly, a review of all available information on swordfish stock structure and the second component was for the RAG to discuss and provide advice to the project team on the priority analyses to support the review of the processes for recommending total allowable commercial catches (TACC) for species currently subject to a harvest strategy.

Swordfish stock structure

- Ms Tremblay-Boyer's provided an overview of the geographical area covered by the stock assessment and the boundaries for the nine regions in the Western Central Pacific Ocean (WCPO) and the TTRAG regions of interest map[12]. Each of regions in the WCPO are treated separately and movement amongst the regions is estimated in the stock assessment for target species **(Figure 1)**.
- TTRAG[13] regions of interest map boundaries are used to summarise the proportion of catch taken by the ETBF relative to the total catch in the southwest Pacific Ocean **(Figure 2)**.
- TTRAG's main regions of interest are known as Region 1 for broadbill swordfish and striped marlin, Region 5 for yellowfin tuna, bigeye tuna and albacore and the southwest Pacific region which includes all tuna and billfish species and encompasses ETBF fishing operations, flag state vessels that have fished adjacent to Australian waters.

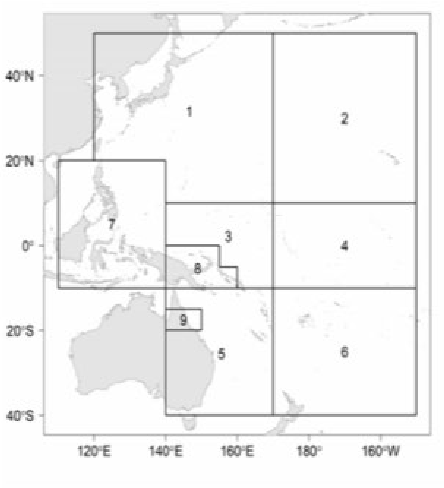


Figure 1 The geographical area covered by the stock assessments for yellowfin tuna and bigeye tuna in the Western and Central Pacific Ocean and the boundaries for the nine areas when using the 2020 regional structure (Vincent *et al.*, 2020).

- Confidentiality requirements do apply for fine scale spatial information of flag states vessels where less than three vessels have been recorded; however, total catch is collected per flag state per-year.

[12] Hill & Williams, (2022), TTRAG Annual catch fleet and fishing method in southwest Pacific working paper.
[13] TTRAG 8 - (2013)

- TTRAG recommended re-labelling the TTRAG’s southwest Pacific region to remove any misunderstanding when discussing the region boundaries between the WCPO stock assessment and the TTRAG region boundaries. The RAG agreed to re-label and refer the southwest Pacific region as the ANZ region.

Figure 2 Map showing the boundaries of the three regions used in this analysis. The exclusive economic zones of each nation are also shown. Region 5 is used for the three tuna species, Region 1 is used for the two billfish species, while the southwest Pacific region is used for all species.

Hill &Williams, (2022), TTRAG Annual catch fleet and fishing method in southwest Pacific working paper

RECOMMENDATION: The RAG agreed to re-label the TTRAG regions of interest map formerly known as southwest Pacific region to ANZ region.

Ms Tremblay-Boyer’s provided an overview on what informs the stock structure for species, along with an overview of outcomes from three technical reports and scientific papers on the stock structure of broadbill swordfish, presented to the Regular session of the Scientific Committee of WCPFC in 2021.

Analysis that can inform stock structure:

- Genetics (long term signal; multiple generations; high sensitivity to low migration rates)
- Tagging (short to medium term signal; small sample size and costly)
- Otolith and muscle microchemistry (individual lifetime): no studies focusing on WCPO
- Parasite community (short term signal): Smith et al. 2007 AU/ NC /NZ, some differences but preliminary study
- Close-Kin Mark Recapture

Scientific Committee of WCPFC presented reports in 2021 include:

- o *Evans et al. (2021) Connectivity of broadbill swordfish targeted by the Australian Eastern Tuna and Billfish Fishery with the broader Western Pacific Ocean. WCPFC-SC17-2021/SA-IP-17*
- o *Moore (2021) Biology, stock structure, fisheries and status of swordfish, Xiphias gladius, in the Pacific Ocean – a regions in the western and central Pacific. WCPFC-SC17-2021/SA-IP-17*
- o *Patterson et al. (2021) Broadbill swordfish movements and transition rates across stock assessment spatial regions in the western and central Pacific. WCPFC-SC17-2021/SA-IP-17*

Other reports since WCFPC Scientific committee meeting:

- *Holdsworth et al (2021): summary of [streamer] tags released/recaptured in NZ billfish recreational fishery*
- *Tracy & Wolfe (2022) Satellite tagging of Swordfish (Xiphias gladius) caught by the recreational fishery in southwest Victoria*

Genetic Analysis – broadbill swordfish

- The genetic analysis undertaken by *Evans et al 2021.* involved collecting genetic samples from multiple locations in Pacific. The results determined there was no differentiation between the stocks for individuals caught in Cook Islands, New Zealand and Australia. However, it was noted there was a very small sample size and genetic analysis has high sensitivity to low migration rates between the regions.

Tagging – broadbill swordfish

- Based on available data, the movement patterns of broadbill swordfish is limited and that conventional tag returns have been limited with very low return rates and electronic tag deployments have largely been limited by short deployment periods. A study undertaken in Australia and New Zealand by *Evans et al 2014.* deployed pop-up satellite tags (PSATs) in swordfish was to determine the connectivity and spatial dynamics of the species. The results of the study determined that swordfish tagged within Australian waters remained in Australian waters and moved south from their tagged location, with very limited movement eastwards towards New Zealand or vice versa.
- A study still in review, has been conducted by *Tracy & Wolfe (2022)*, which includes satellite tagging of swordfish movement behaviour of swordfish provisions connectivity the temperature and tropical southwest Pacific Ocean from the recreational fishery. The study includes a finer scale satellite modelling to assess the fish transiting or foraging, along with the determining the probability of tag retention from the day of release. The results are yet to be published.

Summary

- There are two mixed signals, with one long term signal from genetic studies that currently provides evidence that there is little genetic differentiation between swordfish caught from Cook Island, New Zealand and Australia, however noting there was a very small sample size for individuals in Cook Islands and that this method has high sensitivity to low migration rates.
- The short-term signal from swordfish tagging studies indicate that swordfish do not undertake large scale movement within a year at least.
- An Industry Invited Participant, agreed that the tagged movement trends represented a north movement, however noted that there is limited data and that Close-Kin Mark-Recapture could be used to further remove the uncertainty on swordfish stock structure.
- The Science Member, noted that Australian swordfish harvest Management Strategy Evaluation (MSE) work has accounted the uncertainty of swordfish movements with testing of scenarios which include the relative rate of transfer longitude band 165 degrees east derived from WCPO stock assessment region maps, along with if there was a separate spawning biomass stock in each of the regions either side of longitude 165 degrees east that produced recruits, it was assumed that the adult population produced those recruits stayed within those regions.
- The RAG agreed, although there is limited data on swordfish movements, the current available data suggests the swordfish stock movements are predominantly north/south rather than east/west within the Australian region. The RAG agreed that this information supports the hypothesis that there is a swordfish sub stock within Australia's exclusive economic zone. The RAG recognised that

further research should be undertaken to further reduce the uncertainty of swordfish stock structure. However, the relative priority of doing so needs to be considered against other research needs in the fishery. The RAG noted future research priorities would be considered under agenda item 8.

Harvest Strategy Review

- AFMA noted the status of the Harvest Strategies (HS) for broadbill swordfish and striped marlin, which are due for a routine review following three years of implementation. The RAG was reminded the modified swordfish HS assumes the current low catch levels to cease from 2025 onwards.
- The RAG members noted the main data inputs used for the harvest strategies and indicators (catches, catch-per-unit-effort, size data, assessment outputs).

Swordfish

- Views were sought from the RAG on the performance of the harvest strategies, relevance of existing or alternative indicators and the priority analyses or additional features that may be required to support the review. The RAG discussed stock structure scenarios; updating the datasets for the past five years; undercatch provisions and modelling; if the harvest strategy recommends reducing the catch by 10% then an increase should be of the same proportion of the decrease; consideration of recreational objectives; and multi-year TACCs and potential incorporation of impacts of climate change. The RAG advised the project team on the priority analysis to explore is provided in **Table 1**.
- A Scientific Member provided suggestions in dealing with the undercatch, which could include a multiyear TACC to allow for annual variability to be managed by industry, beyond current overcatch and undercatch provisions. This would need to be evaluated through that period, Industry members, strongly opposed this approach. The other option discussed, was a harvest control rule that explicitly deals with the previous years' undercatch and is accounted within a tested MSE framework and operating models on yearly or two-year approach. The RAG needs project input and analysis to further determine how to deal with undercatch as part of the HS review.
- Scientific Members cautioned against maintaining the current modified swordfish harvest model to account for undercatch going forward, as it may miss-represent a decline in the stock. The RAG agreed that the modified harvest strategy should not be used to explicitly deal with undercatch.
- The RAG noted the current swordfish harvest operating models are separate from WCPFC stock assessments and can be modified/updated for the domestic harvest strategy, if there are scenarios RAG members would like to be explored. The RAG advised the project team on scenarios they wish to explore as priorities, provided in **Table 1**.
- An Industry Member advised that the current management arrangements and harvest strategy system is working effectively, as there is sufficient swordfish quota in circulation amongst operators. The Industry Member additionally, noted that in season management flexibility for his business is not required for swordfish like other species like yellowfin tuna and that swordfish catches are returning to pre-covid levels with demand and fewer price fluctuations.
- The RAG discussed an appropriate timeframe undertake priority analysis. It was suggested that the RAG could review the settings and scenarios in March 2024, with results of the updated MSE presented in July 2024. However, the RAG agreed a contingency plan on an interim approach for recommending the SWO TAC for 2025 season was also needed, whether the modified harvest strategy could be extended for additional two years. Results are yet to be presented to the RAG for consideration and advice.

Striped marlin

- The RAG discussed striped marlin and constant catch annual review of indicators, along with recreational fishing sector objectives.
- The Recreational/Science member noted that striped marlin fishing in Australia is catch and release with a strongly interest on strike rate, rather than size. Catch and effort data is recorded at club level, however there are gaps in recreational catch and effort for those fishers that are not associated with clubs.
- The RAG currently recommended a precautionary approach for striped marlin, due to the stock status and the proportion of catch taken in Australia's waters. The RAG did not recommend any approach. However, agreed it would be valuable to have a presentation on striped marlin recreational objectives from recreational fishing members of TTMAC.

Summary:

- The RAG recommended priority analysis to be explored as part of the swordfish harvest strategy review, provided in **Table 1**.
- Consider a multi-year single TAC (for example a single TAC that applied over a 3-year period) to give industry greater business flexibility to respond to fluctuating stock availability and to account for uncertainty in estimates of future abundance. Industry members advised that such an approach was not necessary for SWO.
- Accounting for significant events that might undermine the performance of the harvest strategy. For example, in the same way that COVID impacted fishing behaviour (through market impacts) to such an extent that several of AFMA harvest strategies required modification. Aside from undertaking robustness testing, the RAG did not identify any particular approach to deal with significant events at this time.
- Advice from the Project Team and RAG will be needed by March 2024, on an interim approach for recommending the SWO TAC for 2025 season. Subject to considering catch against the TAC for the current season (2023), one approach would be to extend the application of modified harvest control rule (HCR). This would require consideration of relevant MSE results. Alternatively, TAC advice could be derived through the application of the original HCRs. Industry did advise at the meeting that fishing for SWO has returned to pre-covid levels.

The RAG recommended the priority analysis for the swordfish harvest strategy review to be undertaken by the project team:

Table 1: Priority analysis for swordfish harvest strategy review:

MSE testing general scenarios	Include updated information on migration rates
Accounting for cyclical trends in abundance	Explore HCR options that might best account for cyclical trends in abundance that is becoming more apparent from the data.
Accounting for undercatch	Explore options for account for undercatches of the TAC
10% change limit rule	Explore options to ensure equivalency in rate of overall change in TAC reductions and increases.
Climate change adaptation	Project team to meet with Beth Fulton (CSIRO) to understand drivers for predicted changes in abundance and develop potential

	robustness tests for MSE (growth, migration, productivity, recruitment)
Review target reference years	Based on latest stock assessment results determine catch rate proxy for the previously agreed MEY proxy for the fishery (assumed to be B48)
Constant TAC over multiple seasons.	Explore possible constant catch TAC scenarios up to three years.

ACTION: CSIRO to explore the options in the priority analysis in Table 1. MSE testing general scenarios, accounting for cyclical trends in abundance, accounting for undercatch, 10% change limit rule, climate change adaption, review target reference years and constant TAC over multiple seasons. Results to be presented mid-2024.

ACTION: CSIRO to present the MSE results that tested the performance of current modified HS for two additional years to TTRAG by March 2024 and for the RAG to advise whether the modified harvest strategy could be extended beyond 2025.

Agenda item 5. Review the process for recommending total allowable commercial catches for the five key target species in the ETBF.

Agenda Item 5.2 Indicator approach review

The RAG was provided with an overview from AFMA member, the process for recommending total allowable commercial catches for ETBF species (for bigeye, yellowfin and albacore tuna). ETBF TACC recommendations are based on the application of an indicators-based and 'whole of government position' approach. While WTBF TACC recommendations are similarly based on the application of an indicators-based and 'whole of government position' approach (for bigeye tuna, swordfish, striped marlin and yellowfin tuna). The RAG was asked to discuss and provide advice to the project team on the priority analyses required to support the review of the processes for recommending TACC approach on the species above.

- The Chair raised a question to the RAG members on the long standing domestic TACC catch levels for tuna species, in relation to the Regional Fisheries Management Organisation (RFMOs) TACC catch levels for Australian, WCPFC and IOTC. The RAG noted, that historically domestic TACC catch levels aim to achieve sustainability of stocks/economics and additionally, the need to meet AFMA's objectives and international obligations.
- A Scientific Member advised that the paper provided to RAG required a correction on the WCPFC catch levels stated for Australia, corrections include:
    - Yellowfin tuna - historically, was bound by a WCPFC conservation measure in 2016, which ensured that countries did not increase their longline catches beyond the reference period 2001-2004 approximately 3,000t. This measure no longer applies, and Australia currently is not bound by any catch levels within WCPFC for yellowfin tuna.
    - The Scientific Member informed the RAG, that WCPFC Commission have workplans in place to manage the tuna stocks that are in decline to sustainable levels across the WCPO and that it is likely that the above management measures and catch levels are likely to change in the coming years for member countries.
    - Industry members, noted that only one of tropical tuna species requires greater flexibility and potential change in the TACC approach, which is yellowfin tuna (ETBF). Historically this species has met the AFMAs TACC catch limits in 2015-16. Industry members advised that no greater flexibility is would not be required for the other species bigeye tuna and albacore tuna, this is due to the fact that industry has established business arrangements based on the long standing SFR allocations for the species.
    - The RAG discussed options to explore a multiyear TACC advice and noted it would be beneficial to align the formal three-year advice on WCPFC and IOTC stock assessment cycles, as the annual RAG TACC recommendations are in part derived from RFMO species stock assessments. The RAG further noted that this may be problematic with various species planned in different years.
    - The RAG proposed to explore a three-year cycle approach to algin with the yellowfin tuna and bigeye stock assessment cycle, further work may be required to incorporate all species into this framework. The RAG, agreed that the project team explore possible 'breakout rules' and a suite of annual fishery statistics to be considered by the RAG as part of the priority analysis, provided in **Table 2**.
    - The RAG agreed that it would be valuable to review basic data indicators annually for the target species both in ETBF and WTBF for data quality assurance perspective and the RAG further agreed that the project team explore options to identify 'pulse events' for yellowfin tuna (ETBF) that could inform a response, provided in **Table. 2.**

Summary

- The RAG discussed the current WCPFC stock status advice for yellowfin tuna, bigeye tuna and albacore tuna and noted the current catch proportion of ETBF species, relative to total catch in WCPFC. The RAG noted that, the current catch proportion within the ETBF would have limited impact on the overall WCPFC stocks to effect change. The RAG agreed to explore options on the frequency of undertaking a full review of all indicators to move to 3 yearly consideration of all indicators (includes CPUE standardisation for all species).
-
- The RAG agreed to explore multiyear TAC cycle approach for both ETBF and WTBF and aligning the formal review with the WCPFC and IOTC stock assessment schedules, if applicable.
- The RAG members recommended no changes to the TACC setting for all species other than reviewing yellowfin tuna TACC to allow greater within year flexibility and potential change in the TACC approaches. AFMA and the project team to explore options to recognise a YFT pulse event and possible HCR that could apply in response. Noting mostly likely indicator will be cumulative catch within season.
- The RAG recommended that TTMAC recreational fishing sector members be invited to present at an upcoming RAG to provide further insight on the objectives of the recreation striped marlin sector which could potentially inform harvest strategy revisions.

Table 2. The RAG recommended the priority analysis to be undertaken by the project team:

Frequency of undertaking a full review of all indicators (multiyear TAC)	Explore options to move to 3 yearly consideration or multiyear TAC of all indicators (includes CPUE standardisation for all species) In support of a potential 3-yearly approach, explore possible ‘breakout rules’ and suite of annual fishery statistics to be considered by the RAG. The annual review will ensure any data issues are resolve in a timely manner and RAG’s understand of fishery trends remains current.
YFT pulse	AFMA and Project team to explore options to recognise a YFT pulse event and possible HCR that could apply in response. Noting mostly likely indicator will be cumulative catch within season.

ACTION: AFMA and CISRO to explore options on the frequency of undertaking a full review of all indicators to move to 3 yearly consideration of all indicators (includes CPUE standardisation for all species).

ACTION: AFMA and Project team to explore options to recognise a YFT pulse event and possible HCR that could apply in response. Noting mostly likely indicator will be cumulative catch within season.

ACTION: AFMA to invite Ian Bladin and Grahame Williams to provide recommendations on recreational sector objectives of targeting Striped Marlin.

ACTION: CSIRO to develop possible 'break out rules', for the each of species yellowfin tuna, bigeye tuna, albacore and striped marlin in the ETBF and WTBF for the RAGs consideration.

Agenda item 6. Seabird interactions

Agenda Item 6.1 Development of DNA Markers to Identify Seabird bycatch using feathers

- The RAG noted a presentation (**Attachment 6.1**) and report from the Australian Antarctic Division (AAD) on the development of DNA markers to identify seabirds from feather samples collected in the ETBF and discussed the utility of the information to guide future advice on seabird mitigation arrangements in the Eastern and Western Tuna and Billfish Fisheries.
- AFMA, AAD and industry jointly implemented a Seabird Feather Kit Collection program in the ETBF and WTBF. Through fishing concessions conditions, AFMA requires fishers operating in the ETBF and WTBF to collect feathers using the Guide to collecting feather samples from dead seabirds for genetic analysis.
- AAD provided an overview of the range of simple and short genetic markers used to assess the feathers of 36 albatross and petrel species incidentally caught in the ETBF and WTBF. AAD emphasised the utility of these methods even with poor-quality DNA samples.
- AAD advised the development of genetic markers for species identification was driven in recognition of the challenges in identifying many bycaught seabird species including closely related species, juveniles and damaged birds. AAD advised that the genetic methods provide a streamlined framework for the molecular identification of seabird bycatch, and are recommended for use in fisheries within and outside Australian waters to improve identification to species level.
- The RAG noted the identification to family level is quite good from operators (16/17 correct from genetic analyses), but there remains limited success at genus level (4/17 correct) and no success at species level (0/17 correct).
- An industry member suggested the operators provide photos of seabirds to AAD while at sea via messaging applications (in addition to current reporting). AAD has developed a Guide to photographing dead seabirds for this purpose. AAD advised that visually identifying seabirds can be challenging that the most appropriate method is still genetic sampling.
- The RAG discussed the cost of the program and it was noted that it was currently funded by AAD. To reduce costs on future analysis of feather samples, it was suggested that samples collected and stored at AAD then sequenced in batches (e.g. 48 samples).
- The RAG agreed that it is appropriate for AFMA to determine arrangements for dissemination of information generated by the Seabird Feather Kit Collection program. AAD highlighted the importance of these data to implementation of the Threat Abatement Plan and for updating TEP reports that are provided by AFMA to DCCEEW, to ensure the best information is available about bycaught seabirds.

The RAG raised concerns on the verification process of GenBank, and the uncertainties associated with DNA sequencing stored within the database. AAD have developed their own verification sequencing process to verify the DNA sequences and reference database of the bird species. AAD are encouraging ACAP to become the managers of the AAD verified reference database.

Agenda Item 6.2 Summary of seabird interaction and options for future analysis

- The RAG reviewed results of the incidental bycatch of seabirds from 2018 – 2022 within the Eastern and Western Tuna and Billfish Fisheries. The RAG provided advice on the utility of the information to guide further analysis and management actions required to further assist in reducing seabird interactions within the Eastern and Western Tuna and Billfish Fisheries.

- The RAG noted the value in statistically analysing low rates of interactions with low effort. A scientific member advised a report had recently been completed by ABARES on standardising low effort and interaction rates *Parsa et al. 2019* **(Attachment 6.2)**.
- The RAG and AFMA agreed that formal updates on seabird interactions should be provided back to operators, so operators are fully informed, along when they are approaching the bycatch rate.
- It was recommended that incorporating temporal morphological and behavioural aspects of seabirds to assist in identifying trends in interactions.
- It was also suggested by the RAG that the inclusion of heat maps with catch data overlayed with interaction data could assist in identifying areas of low catch/high interactions to assist in informing management responses.
- The RAG and AFMA advised the summary of seabird interactions to be a standing agenda item at TTRAGs.

<u>Summary</u>

- The RAG recommended amendments to the paper and AFMA will be provided out of session to RAG members.
- The summary of interactions will be a standing agenda item for the RAG to review and discussed by TTRAG.
- AFMA formal updates on seabird interactions should be provided back to operators, so operators are fully informed, but also when they are approaching the interaction rates.

Agenda item 7. Coral Sea Zone Hook Trial

The RAG discussed scientific advice developed out-of-session by the scientific members of the Coral Sea Zone (CSZ) trial. The RAG supported a small tactical project be funded as part of the annual research priorities (noted this will be through the levy base) to analyse the trial data and determine what, if any, further sampling is necessary to detect any impacts during the middle of 2024.

The analysis will also assist the RAG to determine the sampling size (via power analysis) to detect the level of confidence and detect the level of change in mortality on blue and black marlin and TEPS in the CSZ.

Industry and scientific members supported the continuation of the trial to collect further data into 2024 and in the meantime AFMA will continue monitoring catches and triggers already designed by TTRAG.

ACTION: AFMA to outsource analysis of the Coral Sea hook trial data and present findings to the TTRAG mid-2024.

Agenda item 8. Australian Tuna and Billfish Fisheries Annual and 5-year Research Plans

The RAG discussed and provided advice on the five-year strategic fishery research plan for the ETBF and WTBF for the period 2023/24 to 2027/28 **(Attachment 8a)**; and the annual research plan for the ETBF and WTBF for 2024 including an evaluation of any new priorities. At the commencement of the discussion the Chair, reminded the RAG that she remains the Chair of COMRAC however did not consider this to be conflict of interest for the agenda item.

Agenda Item 8.1 Australian Tuna and Billfish Fisheries Annual Research Statement (annual plan)

1. The Chair introduced five topics that had been discussed throughout the meeting that might underpin a future research priority (in no particular order) and invited members to make further research priority suggestions. The topics identified by the Chair included:

2. Improving our understanding of eddie oceanography through temperature depth recorders to assist in further defining fishing strategies.

3. Updating size composition data for discards.

4. Coral Sea hook trial analysis and power analysis

5. Close-Kin Mark-Recapture (CKMR) for Swordfish stock structure

6. Survey of the recreational fishing sector to better understand their objectives (key priorities) when fishing for Striped marlin

In addition to the above priorities, a research priority identified during TTRAG 33 (July 2021) was discussed:

- Assessment of ETBF fishing depth strategies to assist standardisation of fishing strategies of key commercial and protected species management approaches (time depth recorders).
- AFMA encouraged RAG members to consider potential funding avenues from the AFMA electronic monitoring program as the scope for potential projects funded under this program are electronic related, and not specific to cameras.
- The RAG agreed for the research items listed to be prioritised out of session.

1. Improving our understanding of eddie oceanography through temperature depth recorders to assist in further defining fishing strategies.

- The Chair noted the potential similarities in collection methods for the research items between eddy behaviour and fishing depth strategies, which both influence fishing targeting strategies. There were differing views from RAG members on whether the priorities could be amalgamated into one project. However, RAG members noted that fishing depth strategies have prescriptive components in determining the proximity of gear set to improve CPUE analysis, whereas analysing eddie behaviour requires further analysis in determining the oceanography features whilst fishing.

- The RAG recommended that AFMA coordinate a small working group to determine the components and objectives of the research projects and seek advice from the RAG whether project 1 and project 6 can be amalgamated or remain separate.

- The RAG members agreed on an inclusive approach to manage the perceived conflicts to make use of the expertise of members. The RAG members agreed that David Ellis (Invited Industry Member - Tuna Australia), Ian Knuckey (Science Member) and James Larcombe (Science Member - ABARES) would be involved in the discussion and scoping of the project, however, would be managed closely by AFMA.

ACTION: AFMA coordinate a small working group out of session to determine to scope improving our understanding of eddie oceanography through temperature depth recorders to assist in further defining fishing strategies.
ACTION: AFMA to determine whether the project 1; improving our understanding of eddie oceanography through temperature depth recorders and project 6; assessment of ETBF fishing depth strategies to assist standardisation of fishing strategies, can run concurrently or must remain separate.

2. Updating size composition data for discards.

- The RAG discussed CPUE indices developed for specific species size-classes, namely adults and recruits for bigeye and yellowfin tuna, and adults, sub-adults and recruits for broadbill swordfish derived from the historical onboard observer collection program. The dataset up until 2012, assumes that fishing behaviour would not have changed in the last decade. Additionally, the model assumes that a high proportion of discards are recruits, especially for bigeye tuna and swordfish. Industry members advised that discarding is because of economic reasons, rather than availability or size, using the example of discarding albacore when the value is low, and retaining the remaining portions of damaged swordfish when values are high. The RAG members agreed this wasn't a priority for the 2023/24 annual research plan, however, is a priority for the RAG to consider options to update the data over the next five years. To do so a power analysis would need to be undertaken to determine the sampling size required to update the dataset.

- Tuna Australia offered to liaise with CSIRO's pending the sampling size required and determine whether Tuna Australia can undertake the at-sea measurements of fish. Additionally, AFMA advise that it would explore the potential to use electronic monitoring to collect the length samples.

3. Coral Sea Zone Hook Trial analysis and power analysis

- The RAG supported undertaking a small tactical project to analysis of all available trial data in 2024. Pending the analysis outcomes and RAG advice, the project could also be used to undertake a power analysis to determine future sampling requirements to detect changes in interactions with blue and black marlin against varying levels of confidence.

4. Close-Kin Mark-Recapture (CKMR) for Swordfish stock structure

- The RAG discussed improving the understanding regional connectivity of swordfish, following the presentation on swordfish longitudinal tagging movement and unresolved movement uncertainties. The RAG, also noted there are challenges with using the population genetics approach to measure connectivity of different ETBF target species noting it can detect barriers to gene flow, however is limited in identifying finer levels of connectivity to determine population structure. Due to complexities of high-level mixing in the ETBF stocks, it was suggested that CKMR was the most suitable method to detect connectivity for these stocks.
- Scientific members advised there is a project funded through Western and Central Pacific Fisheries Commission (WCPFC) to undertake the scoping of swordfish abundance, not stock structure, the swordfish abundance funding includes determining epigenetic aging from tissue samples. Sampling requirements to undertake stock structure connectivity may differ to stock abundance work. RAG members noted that it is important to complement to the WCPFC project and to determine the feasibility of the stock structure research domestically and whether the research would meet project outcomes.
- The RAG recommended that a working group be formed out of session to scope the stock structure analysis needed along with potential similarities with the WCPFC funded project.
- The RAG members agreed on an inclusive approach to manage the perceived conflicts to make use of the expertise of members. The RAG members agreed that CSIRO science members would be involved in the discussion and scoping of the project however, would be managed closely by AFMA.

ACTION: AFMA coordinate a small working group out of session to determine to scope the stock structure analysis and determine if it can align or complement the WCPFC project swordfish abundance project.

5. Considering recreational objectives of striped marlin (STM) – TTMAC members objectives or survey

- The RAG considered whether the objectives of the recreational fishing sector should be used to inform a STM harvest strategy. The RAG recommended that recreational fishing sector members from the Tropical Tuna Management Advisory Committee present a future RAG meeting to provide insights on recreational objectives for STM in the ETBF, prior to determining whether additional recreational fishing sector surveys are required for STM. TTMAC recreational members provide presentations TTRAG and for TTRAG to determine whether this remains as priority for the TTRAG going forward.

ACTION: Recreational fishing members from the TTMAC to be invited to a future RAG to provide insights on recreational fishing objectives for STM in the ETBF.

Other potential research priorities

Seabird feather sampling and analysis

- The RAG discussed the seabird feather sampling program run by AAD and concluded it did not constitute research and should therefore not be included in the annual plan.

Agenda Item 8.2 - Australian Tuna and Billfish Fisheries 5-year Research Plan

- The RAG reviewed the current ATBF 5-year Research Plan and provided advice on any necessary revisions or inclusions. The RAG discussed the potential of including health and safety including mental health in the 5-year plan, however it was recommended by the RAG that although highly important, was out of scope for an AFMA research plan. The RAG recognised the need for Indigenous views to be considered and recommended that Indigenous interests are included under social aspects of the 5-year plan. The RAG agreed that the remaining contents are current and meet the management goals for the tropical tuna fisheries.

Summary:

- The RAG agreed for the research items listed to be prioritised out of session.
- AFMA to convene a small working group out of session to scope for Close-Kin Mark-Recapture (CKMR) for Swordfish stock structure. Along with coordinating a small working group out of session to scope improving our understanding of eddie oceanography through temperature depth recorders to assist in further defining fishing strategies and determine whether depth strategies project can run concurrently with the eddie project or remain separate.
- Updating size composition data for discards, the RAG agreed this wasn't a priority for the 2023/24 annual research plan, however, is a priority for the RAG to consider options to update the data over the next five years.
- The RAG supported undertaking a small tactical project to analysis Coral Sea trial data in 2024.
- TTMAC recreational members to provide presentation on the recreational objectives of striped marlin to the RAG and for the RAG to determine whether this remains as priority for the RAG going forward.
- The RAG provide advice on five-year strategic fishery research plan for the ETBF and WTBF for the period 2023/24 to 2027/28 **(Attachment 8a)**, with the inclusion of Indigenous interests included under social aspects.

Agenda Item 9 Other Business

There was no other Business identified for the meeting.

Agenda Item 10 Next Meeting

The RAG was invited to agree on a date for the next meeting. The RAG agreed for TTRAG 39 to be held via videoconference between 12-13 September 2023.

Attachment 1.2

Table 1. TTRAG member, invited participants and observer's declarations of interests.

Position	Membership	Declared Interests
Dr Cathy Dichmont	Chair	Has a consulting company but has no pecuniary interests in the tuna fisheries. Is the current Commonwealth Research Advisory Committee (ComRAC) chair.
Ms Kate Martin	AFMA Member	Employee of AFMA, which includes a salary. Is the Manager of the tropical tuna fisheries. No pecuniary interest in tropical tuna fisheries.
Ms Selina Stoute	AFMA, Senior Manager, Tuna and International Fisheries	Employee of AFMA, which includes a salary. Is the Senior Manager of the Tuna and International section. No pecuniary interest in tropical tuna fisheries.
Mr Lachlan Farquhar	Executive Officer	Employee of AFMA, which includes a salary. Is a Senior Management Officer in the tropical tuna fisheries team. No pecuniary interest in tropical tuna fisheries.
Ms Laura Tremblay Boyer	Scientific Invited Participant	Employee of CSIRO, no pecuniary interest in Australian tropical tuna fisheries. Is the PI for the Management Strategy Evaluation (MSE) project for the tropical tuna and billfish species.
Dr Julian Pepperell	Scientific Member	Independent fisheries research consultant and representative of the recreational fishing sector. Is involved in projects including monitoring and research on pelagic fish landed at game fishing tournaments, analysis of gamefish tagging data and assessing current data and alternate data collection methods relating to recreational catches of tropical tuna and billfishes.
Dr James Larcombe	Scientific Member	Employee of ABARES, involved in fisheries research, primarily through engagement with the Western Central Pacific Fisheries Commission. Has no pecuniary interest in the Australian Tropical Tuna Fisheries.
Dr Ian Knuckey	Scientific Member	Has a consulting company with interests in electronic reporting in the tuna fisheries, and is a member on several other AFMA Committees. Is working on a recreational and indigenous capacity building project with DAWE.
Dr Ashley Williams	Scientific Member	Employee of CSIRO, no pecuniary interest in Australian tropical tuna fisheries. Is the PI for the project - *Scientific advice for management of Tropical Tuna and Billfish Fisheries*
Mr David Ellis	Industry Invited Participant	Is currently the CEO of the industry association, TunaAustralia which includes a salary paid by industry. Is the PI on the following projects: - FRDC Project 2020-041. Improving the effectiveness, efficiency and safety of mitigation tools for protected species interactions in the Eastern Tuna and Billfish Fishery - FRDC Project 2021-078. Improving the management of wildlife interactions in pelagic longline fisheries - FRDC Project 2021-063. Future Proofing: Integrating community quota, product supply, product innovation and market diversification in Australia's Tropical Tuna Industry.

Mr Gary Heilmann	Industry Member	Industry member, director of a processing company, no longer holds ETBF boat or quota SFRs.
Mr Terry Romaro	Industry Invited Participant	Director of a company that owns Eastern Tuna and Billfish Fishery (ETBF) boat statutory fishing rights (SFRs), minor line SFRs, ETBF longline SFRs, Western Tuna and Billfish Fishery (WTBF) boat SFRs, WTBF longline SFRs, Western Skipjack Tuna Fishery (WSTF) purse seine permit, Small Pelagic Fishery (SPF) purse seine, mid-water trawl SFRs, and SPF quota SFRs. Shareholder of a company that owns shares in a proposal to fish with foreign longliners in the WTBF. Industry member on Southern Bluefin Tuna (SBT) and Tropical Tuna MAC, Invited participant for TTRAG, and industry representative at the Commission for the Conservation of SBT (CCSBT) & IOTC. Invited participant for squidRAG and squid SFR holder. Director of a company who owns a fish processing facility in Port Lincoln, & a Director of Tuna Australia.
Mr Robert Curtotti	Economics Member	Employee of ABARES, involved in fisheries economic research related to the Eastern Tuna and Billfish Fishery. Has no pecuniary interest in the Australian tropical tuna fisheries.

Attachment 1.3

Tropical Tuna Resource Assessment Group

Meeting 38 — 11-13 July 2023

Venue – Maroochy RSL – Boardroom
105 Memorial Avenue, Maroochydore QLD

Tuesday 11 July – Thursday 13 July 2023

Day 1. Tuesday: 0900 – 1700 hrs

Day 2. Wednesday 0900 – 1700 hrs

Day 3. Thursday 0900 – 1200hrs

1. Preliminaries

1.1 Welcome and apologies

1.2 Declaration of interests

1.3 Adoption of agenda

1.4 Actions arising from previous meetings

1.5 Out of session correspondence

2. Member updates

2.1 Industry, recreational fishing and scientific member update

2.2 AFMA Management and International meeting outcomes update

3. Climate Change - Ecosystem Status Reports

The RAG will be invited to discuss and provide advice on a draft Ecosystem Status Report for the ETBF. The aim of developing an Ecosystem Status Report is to assist the RAG incorporate climate change impacts in its advice.

4. Fishery Indicators

The RAG will be invited to review the latest data and CPUE standardisations for each target species. These inputs are used to inform the application of harvest strategies and indicator assessments for species where relevant.

4.1 ETBF and WTBF catch and effort data summary

4.2 ETBF weight frequency data summary

4.3 ETBF CPUE standardisation

5. Review the process for recommending total allowable commercial catches (i.e harvest strategies and indicators) for the five key target species

The RAG will be invited to discuss and provide advice to the CSIRO project team for the approved project: '*Scientific advice for management of tropical tuna and billfish fisheries*' on priority analysis and timing (having regard for the agreed project resourcing). It is recommended that the RAG consider the harvest strategy reviews separately to the indicator-based approach.

5.1 Harvest strategy review (Broadbill Swordfish stock connectivity)

5.2 Indicator-based approach

6. Seabird interactions

6.1 Results from the Seabird Feather Kit Collection Program

The RAG will be invited to consider a presentation from the Australian Antarctic Division on the development of DNA markers to identify seabirds from feather samples taken from seabirds interacted with by the fishery.

6.2 Summary of interactions and options for future analysis

The RAG will be invited to discuss and provide advice on latest trends in seabird interactions across the ETBF and ETBF. RAG advice will also be sought on options for future ongoing analysis of seabird interactions.

7. Coral Sea Zone Hook Trial

The RAG will be invited to consider advice from the TTRAG Scientists on how an appropriate sampling design may be determined to quantify the impacts of increasing the CSZ hook limit on interactions with marlin species and TEPS (in particular turtles) and likely sampling requirements.

8. Australian Tuna and Billfish Fisheries Annual and 5-year Research Plans

The RAG will be invited to update the annual and 5-year research plans for the ETBF and WTBF. These plans identify and prioritise research needs in the fishery and are considered in the formulation of AFMA's annual research call.

9. Other Business

Members will be invited to raise any other Business agreed by the Chair. Note there is no meeting paper for this item.

10. Next Meeting

The RAG will be asked to agree the date for the next TTRAG meeting and confirm meeting priorities. The next meeting is planned to be held online. At its meeting in March (March 2023), the RAG agreed a meeting schedule and short-medium term priorities.

Attachment 1.4

Table 1. Actions Items as at TTRAG 38

Number	Action	Meeting Raised	Responsibility	Status at TTRAG 38
1.	ABARES to pursue options to take account of Southern Bluefin Tuna in the catch figures and calculations of GVP and NER for the ETBF and include Southern Bluefin Tuna in future ETBF economic indicators for TTRAG considerations.	TTRAG 33	ABARES / Economics Member	**IN PROGRESS:** Economics Member Robert Curtotti to provide update at TTRAG 39.
2.	AFMA to investigate, if possible, whether bait changes have been experienced by NZ and the Spanish.	TTRAG 33	AFMA	**NOT YET ACTIONED**: AFMA is still investigating.
3.	TTRAG to be provided an update in the new year on the Management Procedure for big eye tuna.	TTRAG 35	ABARES/AFMA	**NOT YET ACTIONED:** Management Procedure for bigeye tuna to be presented.
4.	To collate comments for the Draft Five-Research Strategic Document and Annual Research Plan and provide an update at TTRAG 36.	TTRAG 35	AFMA	**No longer applicable:** TTRAG considered the ETBF and WTBF 5-year Strategic Research Plan and Annual Research Priorities under Agenda Item 8, TTRAG 38 (July, 2023).
5.	AFMA and CSIRO to investigate the differences and potential inconsistencies in set times, including auto-time adjustments from what is being recorded in electronic logs entries and the AFMA database.	TTRAG 35	AFMA/CSIRO	**COMPLETE:** AFMA has investigated the inconsistencies in set times relating to the AFMA database. Update sent to the RAG on 14 August 2023.
6.	TTRAG to revisit the regions used in considerations of TACC for ETBF target species to ensure they are consistent with the needs of the RAG.	TTRAG 36	TTRAG	**COMPLETE:** TTRAG discussed the regions of interest map boundaries are used to summarise the proportion of catch taken by the ETBF relative to the total catch in the southwest Pacific Ocean. At its July 2023 (TTRAG 38) recommended re-labelling the TTRAG's southwest

				Pacific region to remove any misunderstanding when discussing the region boundaries between the WCPO stock assessment and the TTRAG region boundaries. The RAG agreed to re-label and refer the southwest Pacific region as **ANZ region**.
7.	ABARES to examine congruence between logbook and CDR data in the ETBF over time to determine if there is a need to alter the calculation of CPUE to ensure a consistent factor for GVP calculations.	TTRAG 36	ABARES / Economics Member	**IN PROGRESS:** Economics Member Robert Curtotti to provide update at TTRAG 39.
8.	CSIRO to provide a graph detailing the approximate catch rate of Broadbill Swordfish in relation to mean hook density per kilometre of mainline in the ETBF.	TTRAG 37	CSIRO	**COMPLETE:** Graph presented by CSIRO under Agenda Item 4.3 at July 2023, TTRAG38.
9.	CSIRO to make TTRAG's recommended amendments to the climate and Ecosystems status report for ETBF and AFMA to provide the update status report out -of – session for comment.	TTRAG 38	CSIRO	**COMPLETE:** CSIRO provided an updated report to AFMA in August 2023. Member comments were incorporated. To be presented at TTRAG39.
10.	AFMA to explore whether reporting mixed bait species proportions is included in e-logs and to advise TTRAG.	TTRAG 38	AFMA	**COMPLETE:** AFMA confirmed this is not currently an option available to fishers, however the licencing team at AFMA can initiate the change to the e-logs to make this option available. TTRAG to discuss at March TTRAG to determine needs.
11.	CSIRO to explore the options in the priority analysis in **Table 1**. Which include, MSE testing general scenarios, accounting for cyclical trends in abundance, accounting for undercatch, 10% change limit rule, climate change adaption, review target reference years and constant TAC over multiple seasons. Results to be presented mid-2024.	TTRAG 38	CSIRO	
12.	CSIRO to present the MSE results that tested the performance of current modified HS for	TTRAG 38	CSIRO	

	two additional years to TTRAG by March 2024 and for the RAG to advise whether the modified harvest strategy could be extended beyond 2025.			
13.	CISRO to explore options on the frequency of undertaking a full review of all indicators to move to 3 yearly consideration of all indicators (includes CPUE standardisation for all species in the ETBF and WTBF).	TTRAG 38	CSIRO	
14.	To explore options to recognise a YFT pulse event and possible HCR that could apply in response. Noting mostly likely indicator will be cumulative catch within season.	TTRAG 38	AFMA and CSIRO	
15.	AFMA to invite Ian Bladin and Grahame Williams to provide recommendations on recreational sector objectives of targeting Striped Marlin	TTRAG 38	AFMA	
16.	CSIRO to develop possible 'break out rules', for the each of species yellowfin tuna, bigeye tuna, albacore, swordfish (WTBF) and striped marlin in the ETBF and WTBF for the RAGs consideration	TTRAG 38	CSIRO	
17.	AFMA to outsource analysis of the Coral Sea hook trial data and present findings to the TTRAG mid-2024	TTRAG 38	AFMA	
18.	AFMA coordinate a small working group out of session to determine to scope improving our understanding of eddie oceanography through temperature depth recorders to assist in further defining fishing strategies.	TTRAG 38	AFMA	
19.	AFMA to determine whether the project 1; improving our understanding of eddie	TTRAG 38	AFMA	

	oceanography through temperature depth recorders and project 6; assessment of ETBF fishing depth strategies to assist standardisation of fishing strategies, can run concurrently or must remain separate.			
20.	AFMA coordinate a small working group out of session to determine to scope the stock structure analysis and determine if it can align or complement the WCPFC project swordfish abundance project.	TTRAG 38	AFMA	**COMPLETE:** CSIRO provided a research scoping for close-kin mark recapture design study to detect broadbill swordfish stock structure to assess the scoping, feasibility and logistics of different sampling needs based on consultation with July 2023, TTRAG 38 and fishing industry and determine sampling program i.e. Provide scientific advice and support to AFMA and TTRAG on CKMR simulation model to assess sampling needs (number of individuals per year, number of years, location of samples) to detect stock structure for broadbill swordfish in the southern Western Central Pacific Ocean. TTRAG agreed to out of session (August 9th, 2023) that this project be prioritised as the annual research funding cycle 2024/25 and be presented to the AFMA Research Committee.

Table 2. Action Items relating to CPUE as of TTRAG 38.

Number	Item	Meeting Raised	Responsibility	TTRAG comments
1.	The RAG recommended using revised data each year and accepting minor changes for the catch summary tables. Any change greater than 1% will be flagged and brought to the attention of the RAG for discussion and advice.	TTRAG 38	CSIRO	
2.	TTRAG discuss and provide advice at its meeting in March 2024, on priority need to undertake simulation testing of the CPUE standardisation. The RAG identified the following four CPUE refinement priorities: Priority refinement (1-3), further discussion needed for priority 4 simulation testing of CPUE. 1. Continue the implementation of metiers approach 2. Move from area-based approach to explicit spatial approach 3. Improve inclusion of oceanography covariates eg. Eddies 4. Simulation test of the CPUE standardisation-To be discussed in March TTRAG during research gaps.	TTRAG 38	CSIRO, TTRAG	
3.	Tuna Australia and CSIRO to investigate potential erroneous logbook reporting regarding 45 hooks between floats. Tuna	TTRAG 38	CSIRO, Tuna Australia	**ONGOING:** Tuna Australia contacted all ETBF operators however did not receive a response. AFMA and CSIRO to investigate further.

	Australia to follow up with operator if error is identified.			
4.	CSIRO will look to explore potential changes in fishing practices (particularly with the start of set location) associated with the introduction of Marine Parks, and determine potential implications for CPUE standardisations.	TTRAG 23	CSIRO	**ONGOING:** At TTRAG 37 (March meeting 2023), the RAG agreed to keep this as an ongoing action item, due to work being undertaken with CPUE standardisation and noted this agenda item may inform future data priorities.
5.	TTRAG to consider development of Time Temperature Depth Recorder (TDR) based research and/or data collection in the ETBF to better understand and account for (in CPUE analyses) the relationship between fishing strategies (including vessel log speed, shooter speed and dropper lengths etc) and fishing depth.	TTRAG 23	CSIRO, Ian Knuckey, AFMA	**ONGOING:** At TTRAG 37 (March meeting 2023), the RAG agreed to keep this as an ongoing action item, due to work being undertaken with CPUE standardisation and noted this agenda item may inform future data priorities.
6.	AFMA to examine VMS data to check and verify sets reported on logbooks as having mainline lengths greater than 100km.	TTRAG 24	CSIRO, AFMA	**ONGOING:** At TTRAG 37 (March meeting 2023), CSIRO presented distributions of variables used in the CPUE standardisation to identify appropriate thresholds for outliers/erroneous entries.
7.	TTRAG 29 discussed how e-logs may allow better collection of gear information through the ability to prepopulate fields that do not regularly change, and the need for the fleet to form good reporting habits at the start of the elog transition relating to additional potential fields, specifically, those required by WCPFC logbooks and ROP, fields relevant to collecting data on depredation, and shape of mainline set.	TTRAG 29	CSIRO, AFMA	**ONGOING:** At TTRAG 37 (March meeting 2023), the RAG agreed to keep this as an ongoing action item, due to work being undertaken with CPUE standardisation and noted this agenda item may inform future data priorities.
8.	AFMA to work with Tuna Australia to develop operationally feasible options to capture discard sizes for swordfish. i.e. (E-log comment section, tick box for fish between 10-20kg, head only, small, medium or large).	TTRAG 34	AFMA/Tuna Australia	**ONGOING**: AFMA sought advice from the RAG, the RAG agreed to keep this as an ongoing action item, due to work currently being undertaken with CPUE standardisation and noted this agenda may inform future data priorities.

Australian Government
Australian Fisheries Management Authority

Climate Science Summary – Eastern Tuna and Billfish Fishery

Key messages

- Variability in the ETBF will increase as La niña and El niño events increase in severity and frequency over the next few decades.
- Fishing will continue to have a greater effect on Pacific tuna populations than climate change until at least mid-century.
- Pacific stocks of skipjack and yellowfin are predicted to move eastwards by 2050, southerly movement of albacore may occur.
- Declines in the abundance of yellowfin, southern bluefin tuna and swordfish projected in the ETBF through to 2040.
- Some projections suggest a decline in albacore in the ETBF by 2040, however there is significant uncertainty of the effects of climate change on albacore across the Pacific basin, with some scenarios suggesting population increases are possible.

Climate sensitivity and preliminary projections for ETBF species

The FRDC "Guidance on Adaptation of Commonwealth Fisheries management to climate change" project (Fulton et al, 2021) provided an assessment of climate sensitivity and preliminary projections of change in abundance due to climate change for most Commonwealth fish species. These projections come with varying levels of confidence and additional interpretive comments (e.g. likely geographic shifts) for some species. They are based on quantitative models, however there is some uncertainty in these preliminary projections. While the exact numbers should be treated with caution, the general direction of change is relatively robust.

Preliminary projections of change in abundance due to climate change for key ETBF species:

Species	Preliminary projection to 2040	Comment on projection
Albacore	▼ 20-25% (Medium confidence)	Fairly uniform, move on shelf at southern extent
Bigeye tuna	Steady (Medium confidence)	Food web interactions could cause a drop
Broadbill swordfish	▼ 5-60% (Medium confidence)	Larger drops in some areas due to food web changes; strongest decline at the northern extent.
Skipjack tuna	▲up to 20%	Spatially uniform
Southern bluefin tuna	▼ 30-40%	Decline more in north, overlap more with tropical tunas
Striped marlin	▼ up to 5% (Medium confidence)	
Yellowfin tuna	▼ 5-15% (Medium confidence)	Decline spatially uniform

Other climate science resources for the ETBF

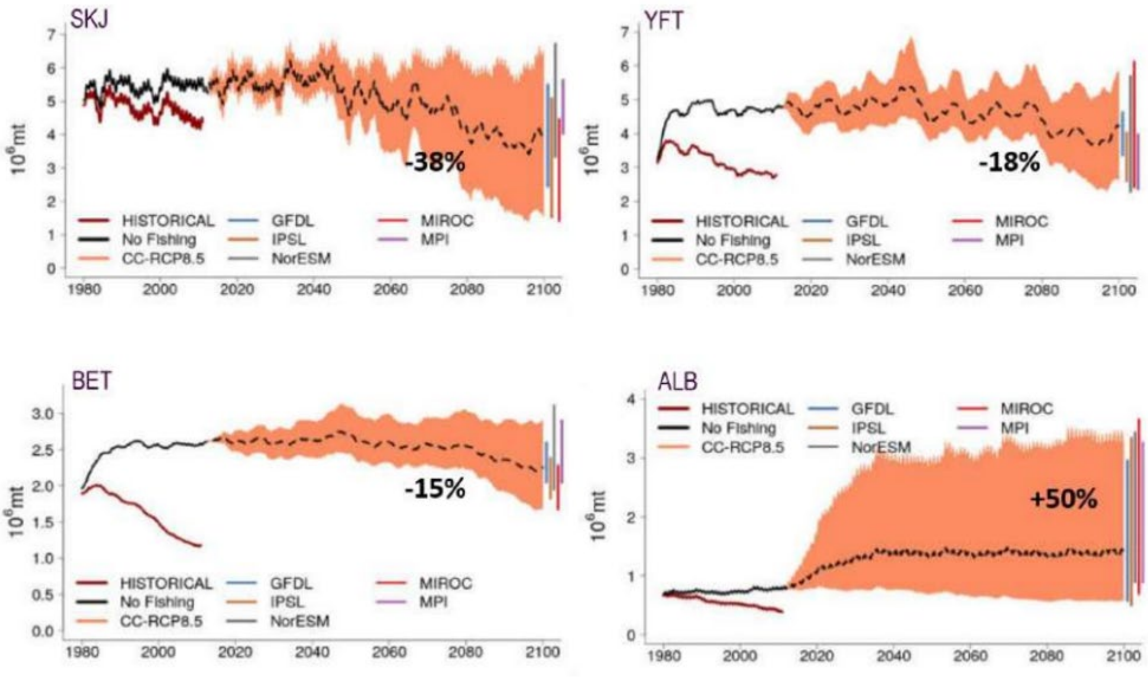
Title: Decadal scale projection of changes in Australian fisheries stocks under climate change
Year: 2017 **Link:** [2016-139-DLD.pdf (frdc.com.au)]
Key relevant points:

- Biomass of YFT and BET predicted to decline under constant fishing and even more so under high emissions climate change scenario.
- Distributional shift predicted for SBT away from environments that are marginal for SBT
- Southward shifts predicted for skipjack tuna and seabirds
- Pelagic species were found to have a lower sensitivity to climate change than other taxonomic groups

Title: Impact of climate change on tropical Pacific tuna and their fisheries in Pacific Islands waters and high seas areas
Year: 2018 **Link:** https://meetings.wcpfc.int/node/10666

Key relevant points:

- Fishing pressure is expected to be the dominant driver of tuna population statis until at least mid-century
- Projections show an eastern shift in biomass of SKJ and YFT over time
- Biomass of tropical tuna across the WCPO is relatively stable until 2050 then start to decline. Total biomass of SKJ is expected to decline. YFT is projected to be stable across the WCPO and BET is expected to decrease slightly.
- Some projections for ALB predict a rapid increase, however they are associated with much uncertainty. Other projections indicate biomass will remain stable
- Larger proportions of the stocks are expected in international waters



Title: Investigate oceanographic and environmental factors impacting on the Eastern Tuna and Billfish Fishery
Year: 2023 **Link:** [TBC]

Key relevant points:

- Sub-surface ocean state variables are important in influencing the spatial and temporal variability in ETBF species. However, these variables are limited in their ability to be explain catch rates.
- The project provided an analysis ready dataset for us in ongoing scientific investigation and can be used to inform management. It has also provisioned for two real time forecasts of ocean state - seasonal forecasts of ocean state (http://poama.bom.gov.au/project/etbf/index.html, Box 1), and case studies of habitat model forecasts and project outputs (http://www.cmar.csiro.au/etbf-oceanographic-influences/index.html)

References and additional resources:

Climate change and Pacific tuna fisheries. SPC. OFMP2 Factsheet.

Fulton EA, Hobday AJ, Pethybridge H, Blanchard J, Bulman C, Butler I, Cheung W, Gorton B, Hutton T, LozanoMontes H, Matear R, Pecl G, Villanueva C, Zhang X (2017) Decadal scale projection of changes in Australian fisheries stocks under climate change.

Fulton, E.A., van Putten, E.I, Dutra, L.X.C., Melbourne-Thomas, J., Ogier, E., Thomas, L. Rayns, N., Murphy, R., Butler, I., Ghebrezgabhier, D., Hobday, A.J. (2021) Guidance on Adaptation of Commonwealth Fisheries management to climate change. CSIRO Report for FRDC. Hobart. https://www.frdc.com.au/project/2016-059

Senina I, Lehoday P, Calmettes B, Dessert M, Hampton J, Smith N, Gorgues T, Aumont O, Lengaigne M, Menkes C, Nicol S Gehlen M (2018) Impact of climate change on tropical Pacific tuna and their fisheries in pacific islands waters and high seas areas. 14th Scientific Committee of the Western and Central Pacific Fisheries Commission, Busan, Korea. WCPFC-SC14-2018/EB-WP-01 https://meetings.wcpfc.int/node/10666

SPC-OFP (2022) Ecosystem and climate indicators. 18th Scientific Committee of the Western and Central Pacific Fisheries Commission, online. WCPFC-SC18-2022/EB-WP-01. https://meetings.wcpfc.int/node/16313

Climate & Ecosystem Status Report

Eastern Tuna and Billfish Fishery

June 2023

Attachment 3b

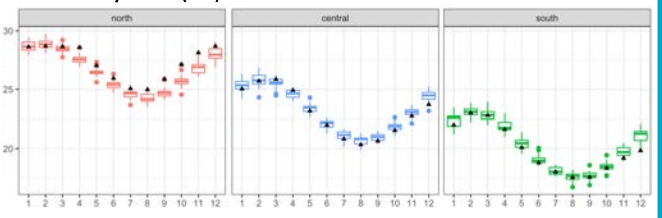
Historical Period

Climate Drivers

Monthly Southern Oscillation Index[1] (link).

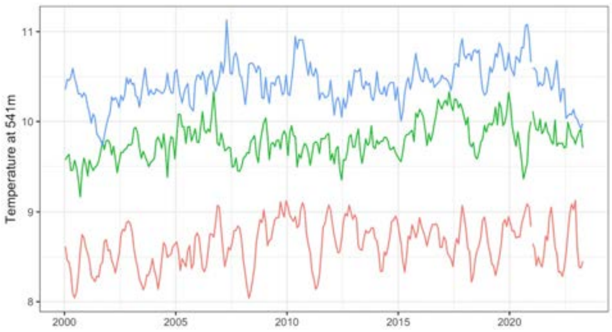
Sea Surface Temperature

Monthly SST (°C) from 2000-2022:



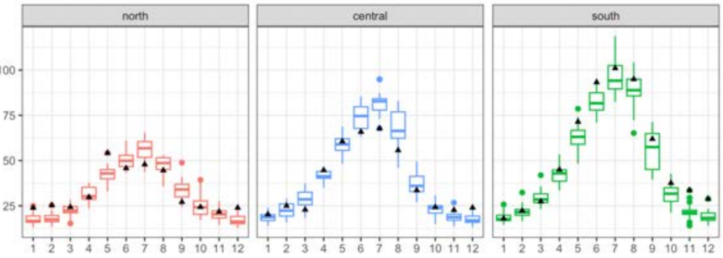
Seasonal SST dynamics for each region, with black triangles show the most recent monthly SST (July 2022-June 2023). SST last year was warmer than average in the North, but cooler than average in Central and South regions. This may support higher recruitment.

Subsurface Temperature



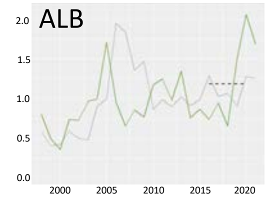
Temperature at 500 m indicates sub-surface ocean structure. All regions have warmed over time, but more so in the Central and South regions[3].

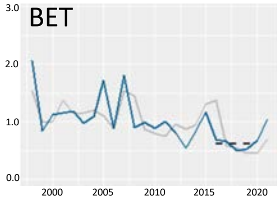
Monthly Mixed Layer Depth (MLD; m) from 2000-2022:

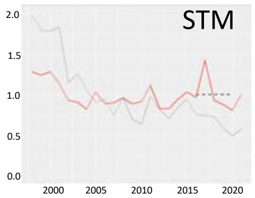


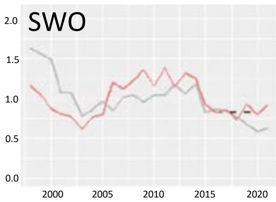
MLD indicates the depth of surface mixing and can impact the distribution of top predators. MLD can be deeper in the South & Central regions but varies seasonally. Black triangles show the most recent monthly MLD (Jun 2022-May2023).

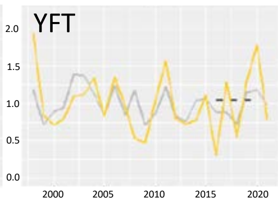
Ecosystem and Fishery











Standardised (coloured line) and nominal (grey line) CPUE for ETBF (all sizes). Dashed line is 5-year mean.[4]

Observations

- Catches higher during El Niño.
- Recreational fishing sector noted a recruitment event is occurring due to juvenile species being caught.
- Bigeye is usually fished at different depths especially before El Niño.
- High sea temperatures during La Niña thought to be good conditions for spawning.

Sources: BOM[1] NOAA[2] CMEMS[3] CSIRO[4] AFMA[5]

Climate & Ecosystem Status Report

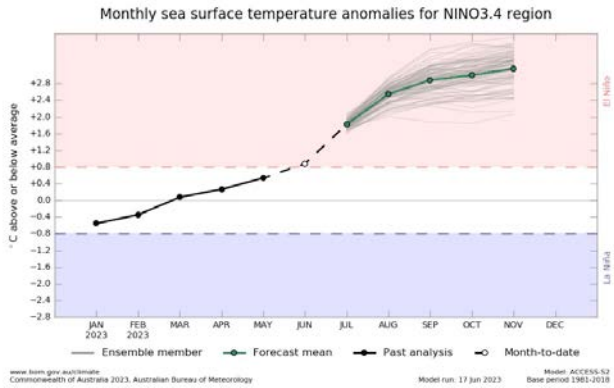
Eastern Tuna and Billfish Fishery

June 2023

Future Outlook for 2023

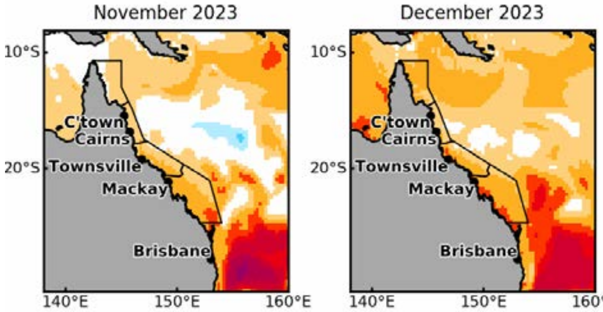
Climate Drivers

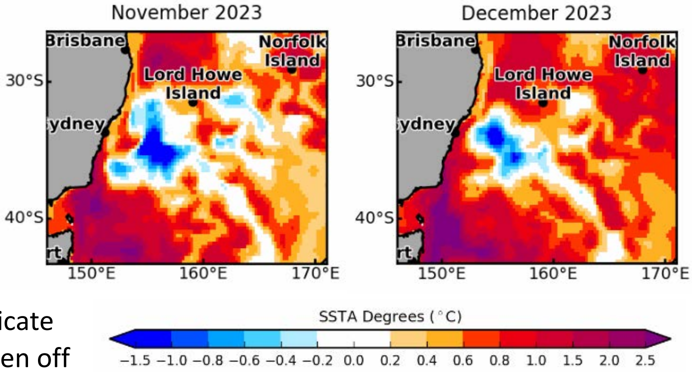
Currently transitioning to El Niño[1] (link)



El Niño is predicted[1] (link). These conditions can favour higher catches for YFT, BET, ALB, & STM in the Western Central Pacific[4]

Temperature for the region

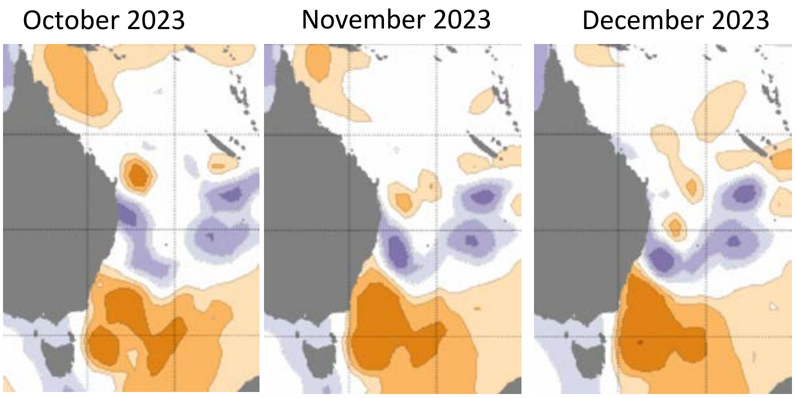




Forecasts of SST anomalies for July and August indicate warmer conditions off QLD and cooler conditions seen off NSW[1] (link).

Base period 1981-2018

Sea Surface Height Forecasts



Forecasts of sea surface height show how regional ocean dynamics may change over the next 3 months[1]. Sea surface Height anomalies can indicate the location of eddies.

Sources: BOM[1] NOAA[2] CMEMS[3] CSIRO[4] AFMA[5]

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Attachment 4.2

Oceans & Atmosphere
www.csiro.au

Summary of the size distributions for tuna and billfish in the Eastern Tuna and Billfish Fishery–1998 to 2022

Laura Tremblay-Boyer and Ashley Williams

6 July 2022

CSIRO Oceans & Atmosphere
Battery Point, Hobart 7004, Tasmania, Australia.

Citation

Tremblay-Boyer, L. and Williams, A. (2023). Summary of the size distributions for tuna and billfish in the Eastern Tuna and Billfish Fishery–1998 to 2022. Working Paper presented to the the 38th meeting of the Tropical Tuna Resource Assessment Group held 11–13 July 2023, Mooloolaba.

Acknowledgement

We would like to thank Robert Campbell and James Dell for their support in the development and interpretation of these updated analyses as well as their insights on tuna and billfish longline fisheries in Australia. Many thanks to Scott Cooper (CSIRO) for his assistance in processing the weight sampling data. Funding for this project was provided by AFMA and CSIRO.

Copyright and disclaimer

Important disclaimer

Meeting participants are reminded that the data, and all documents provided for discussion, are **commercial-in-confidence** and must not be distributed outside of the meeting.

1 Introduction

In the Eastern Tuna and Billfish Fishery (ETBF), weight data is collected by processors along the east coast of Australia and collated by Tuna Australia (since 2020). The data is made available to CSIRO researchers for analysis. Temporal and spatial trends in the distribution of target fish size data are useful to examine as an indicator of stock condition, for instance if larger fish become less prevalent or if there is an increase in the number of small fish caught (indicating a strong recruitment cohort).

This paper summarises the weight sampling data for the ETBF for the 1998–2022 period with a focus on 2022. Graphical summaries of the distribution of the sampled weights are presented, following on previous work by Campbell et al. (2020), Hillary et al. (2021) and Tremblay-Boyer and Williams (2021). While there are weight data available for some by-product species such as rudderfish and mahi mahi, the focus here is on key tuna and billfish target species, namely albacore tuna (*Thunnus alalunga*), bigeye tuna (*Thunnus obesus*), yellowfin tuna (*Thunnus albacares*), broadbill swordfish (*Xiphias gladius*) and striped marlin (*Kajikia audax*).

2 Methods

Weight data are collected by 16 different processors and markets along locations on the east coast, with some additional samples coming from Tasmania. Individual measurements are recorded for most individuals, with bulk measurements also taken for albacore tuna and some by-product species. For bulk measurements the corresponding number of fish is usually included, but not always.

The data are compiled on a financial year basis (from 1 July to June 30), with the data received by CSIRO in two batches covering the January-June and the July-December periods.

When missing from bulk records, the fish count is imputed from the average fish weight for that year and species, unless an average fish weight was also included in the record.

Weights are reported in the aggregated summaries as dressed weights using the processed state most common for the species, namely whole weight for albacore tuna, gilled and gutted for bigeye and yellowfin tuna, and headed and gutted for broadbill swordfish and striped marlin. When processed state is missing (most records prior to 2020), it is assumed to be the most common state for that species.

Summaries are included at the resolution of the calendar year. Quantile distributions are computed from individual fish measurements only (i.e. bulk samples are excluded). Standard errors for the mean weights are provided, but precision is likely over-estimated given pseudoreplication in the samples.

3 Results

Overall sample sizes by species for 1998 to 2022 are shown by region in Table 1, with a breakdown by quarter for 2022 in Table 2. Most samples come from Mooloolaba (about 61.5%), followed by Cairns and Brisbane. Mean weights varied by quarter in 2022 (Table 3), with highest mean weights in the fourth quarter for yellowfin tuna, bigeye tuna, and broadbill swordfish, second quarter for albacore tuna and third quarter for striped marlin.

Table 1: Number of size samples collected by region and species from 1998 to 2022. Bulk samples are only included for albacore tuna.

Region	Bigeye tuna	Yellowfin tuna	Broadbill swordfish	Striped marlin	Albacore tuna	Albacore tuna (bulk)	Total
Cairns	78027	177774	12628	355	45459	487	314730
Mooloolaba	217225	424655	342129	48059	144793	784738	1961599
Brisbane	39497	114814	49165	9328	66260	48324	327388
Queensland	1791	6994	7676	525	474	624	18084
QLD South Coast	383	3384	229	141	14536	18134	36807
NSW North Coast	30892	106829	36416	6844	3439	100269	284689
Sydney	3243	13522	2107	408	337	318	19935
NSW South Coast	20724	95042	17606	8890	8371	46980	197613
NSW General	1344	20722	3477	1065	49	0	26657
Tasmania	3	3	42	0	9	1311	1368
Total	393129	963739	471475	75615	283727	1001185	3188870

Table 2: Number of individual samples collected in 2022 by species and quarter

Species	1	2	3	4
Albacore tuna	319	721	979	423
Bigeye tuna	1466	3081	2633	1139
Yellowfin tuna	5044	7884	11917	8661
Broadbill swordfish	2760	3272	3440	3207
Striped marlin	264	669	590	1248

Table 3: Mean weight in kg (standard error) by species and quarter of individual samples in 2022

Species	1	2	3	4
Albacore tuna	16.6 (0.31)	17.9 (0.34)	15.2 (0.17)	17.3 (0.46)
Bigeye tuna	32.9 (0.35)	35.4 (0.26)	34.3 (0.24)	36.7 (0.48)
Yellowfin tuna	33.1 (0.21)	32.2 (0.16)	30.7 (0.09)	36.1 (0.13)
Broadbill swordfish	39.8 (0.54)	39.7 (0.52)	41.8 (0.57)	44.9 (0.61)
Striped marlin	55.2 (0.64)	61.3 (0.54)	65.6 (0.78)	61.8 (0.50)

3.1 Albacore tuna

The mean size by quarter for albacore tuna is shown in Figure 1 for 1998 to 2022. There appears to be a slight increase in mean weight over time, with some variability. The annual size distribution (Figure 2) shows an increase in the median value over time and bimodality for some years, including 2021 and 2022. Most of the samples come from southern Queensland with some variability in median weight over time but a slight increase in recent years, but noting lower sample sizes for that period. (Figure 3).

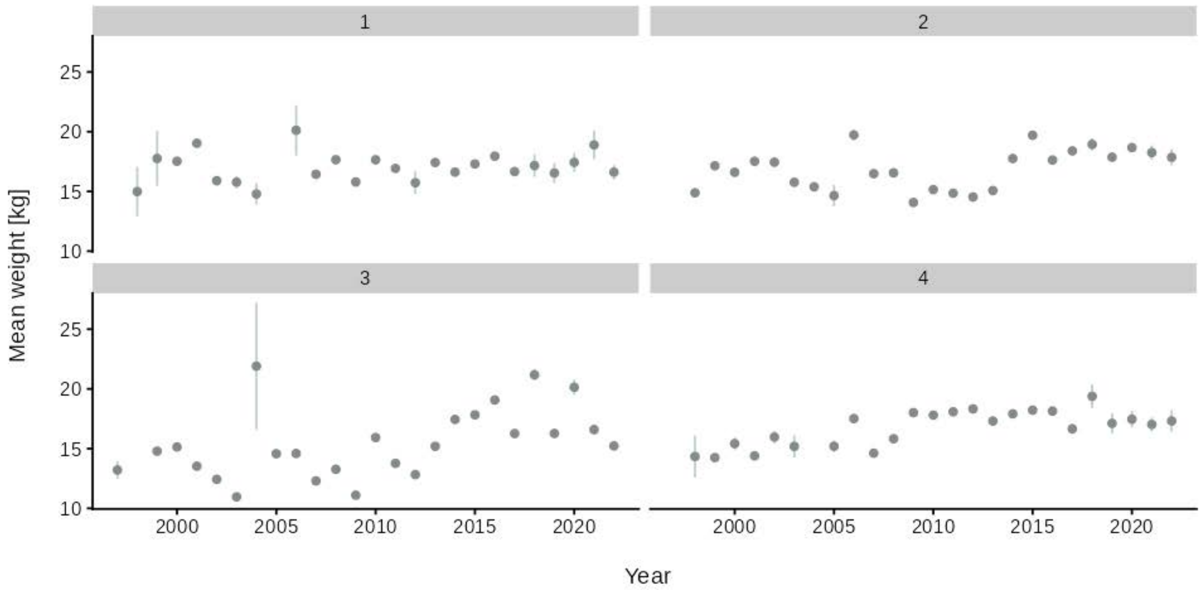

Figure 1: Mean weight (kg) of albacore tuna by quarter from 1998 to 2022. The whiskers show the approximate 95% confidence interval.

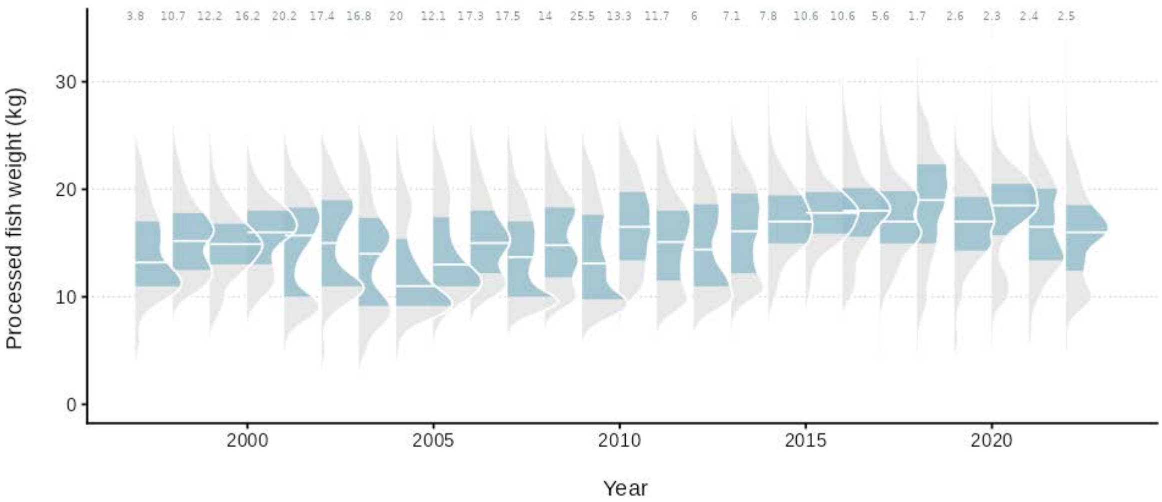

Figure 2: Shape of the size distribution of albacore tuna samples from 1998 to 2022. The 25th–75th interquartile band is highlighted in blue and the median is shown as a white line. Annual sample sizes (in thousands) are included above the corresponding size distribution.

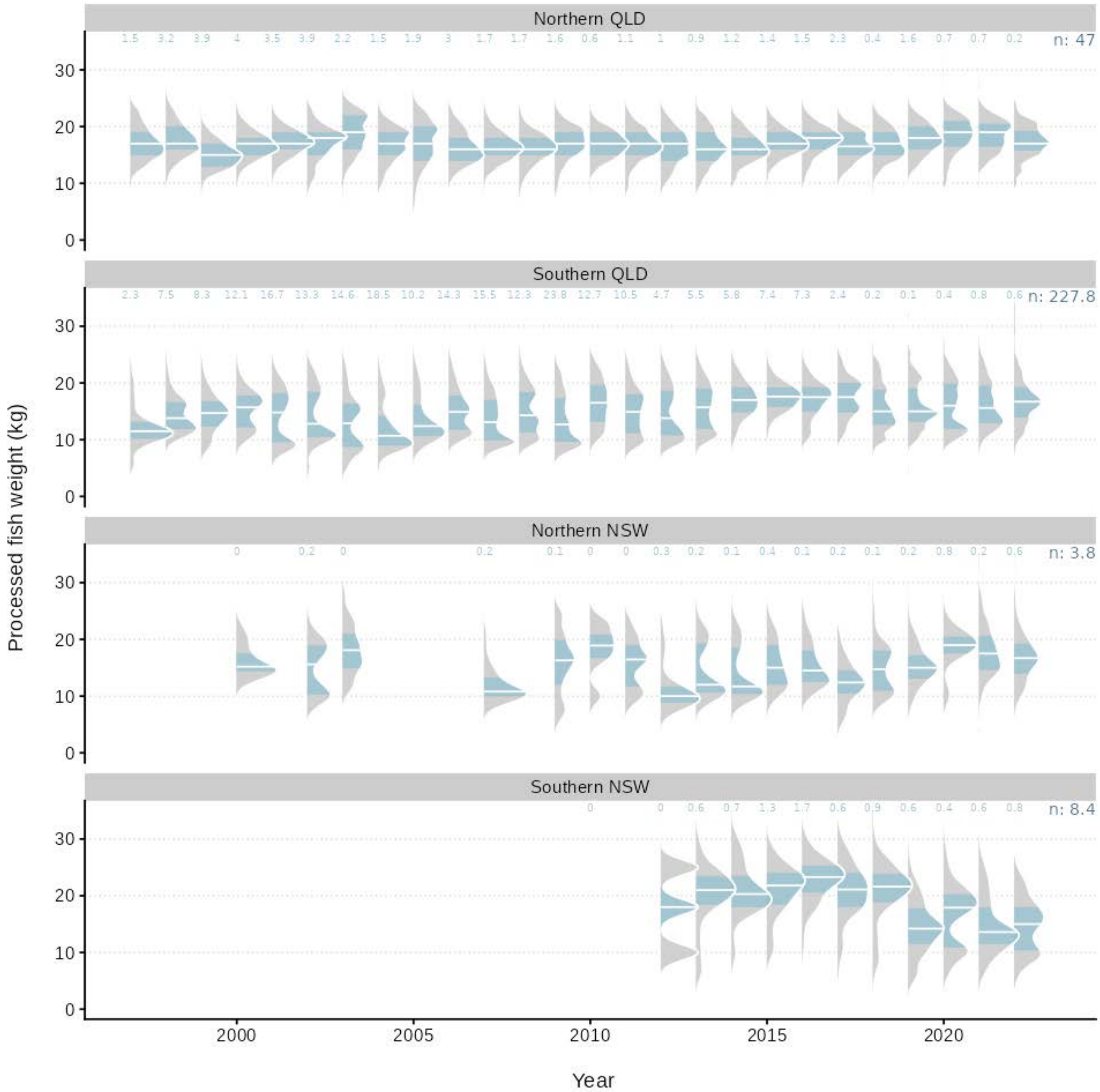

Figure 3: Shape of the size distribution of albacore tuna samples by key regions from 1998 to 2022. The 25th–75th interquartile band is highlighted in blue and the median is shown as a white line. Annual sample sizes (in thousands) are included above the corresponding size distribution, with total samples in the region (in thousands) shown in the top right of each panel.

3.2 Bigeye tuna

The mean size by quarter for bigeye tuna is shown in Figure 4 for 1998 to 2022. There is no clear signal in mean weights over time, except for quarters 3 and 4 where mean weight has increased in recent years. The annual size distribution (Figure 5) shows variability in the median value across years with frequent bimodality, seen in 2021 but not in 2022. Trends in size distribution vary across regions with most samples coming from southern Queensland where median weight shows no clear trends over time (Figure 6). Individuals sizes are generally smaller in northern and southern Queensland. There also appears to be a 3 to 4 years size cohort signal in both northern and southern New South Wales, although sample sizes in those regions are lower. Most samples were from the 'Prime' size class in 2022 and there is no clear trend in the distribution of size classes over time (Figure 7).

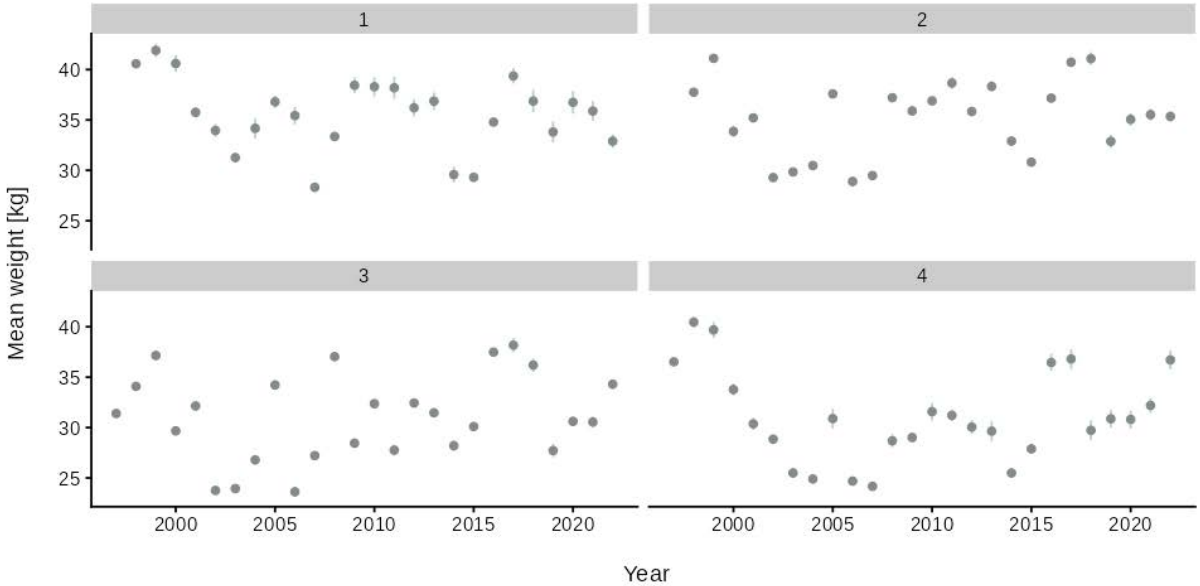

Figure 4: Mean weight (kg) of bigeye tuna by quarter from 1998 to 2022. The whiskers show the approximate 95% confidence interval.

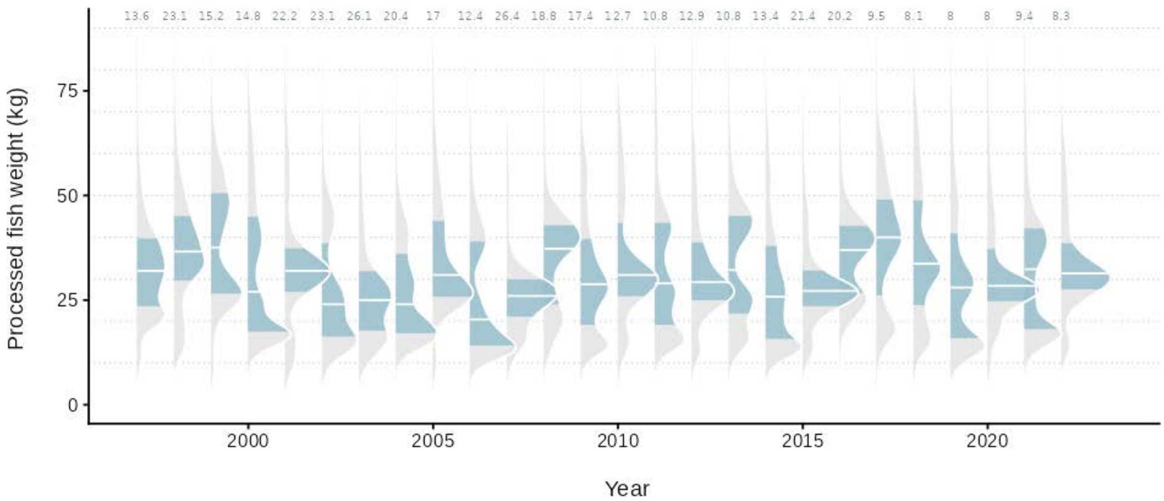

Figure 5: Shape of the size distribution of bigeye tuna samples from 1998 to 2022. The 25th–75th interquartile band is highlighted in blue and the median is shown as a white line. Annual sample sizes (in thousands) are included above the corresponding size distribution.

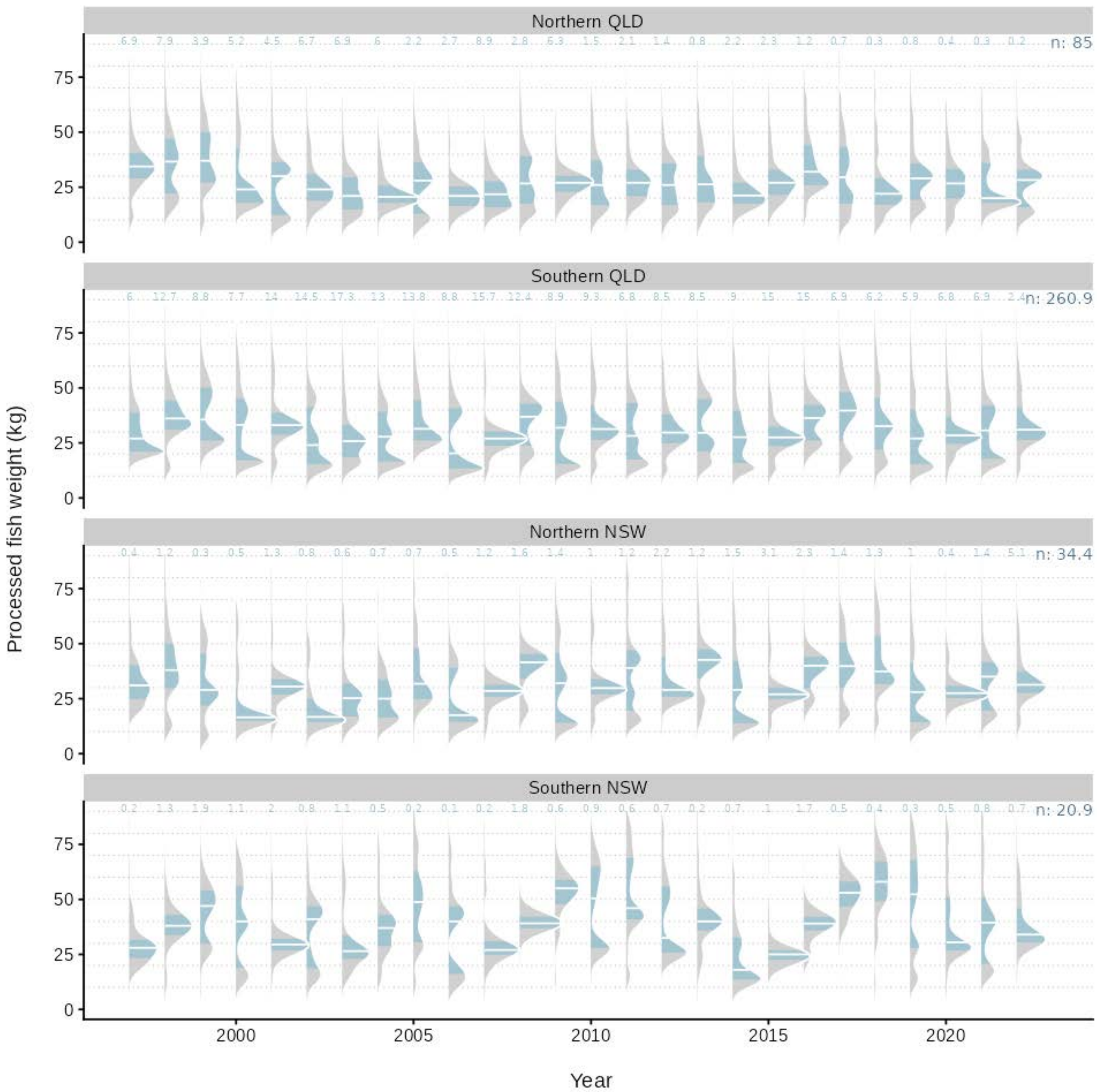

Figure 6: Shape of the size distribution of bigeye tuna samples by key regions from 1998 to 2022. The 25th–75th interquartile band is highlighted in blue and the median is shown as a white line. Annual sample sizes (in thousands) are included above the corresponding size distribution, with total samples in the region (in thousands) shown in the top right of each panel.

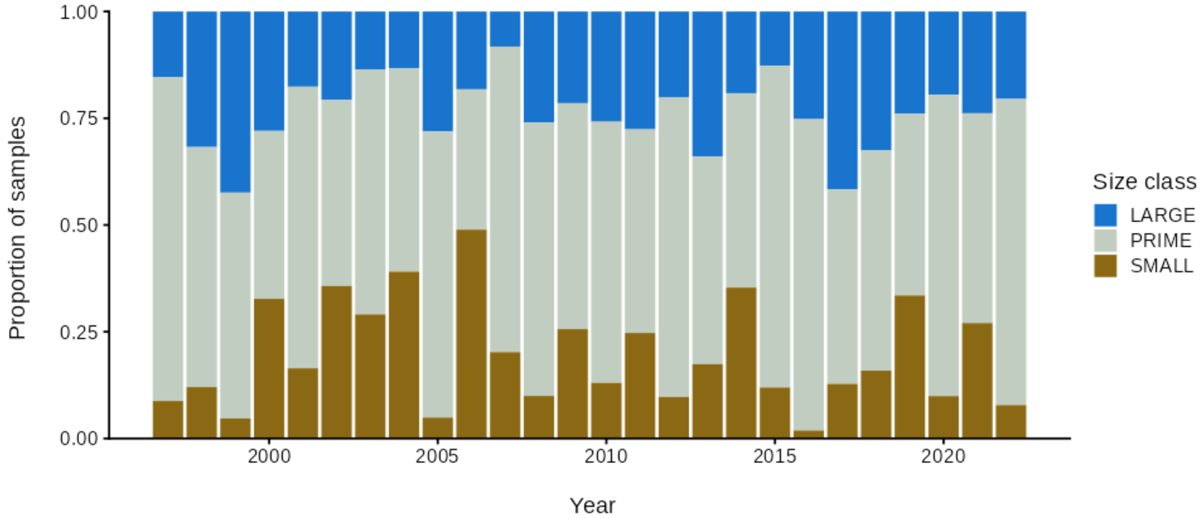

Figure 7: Distribution of size classes in bigeye tuna samples over 1998 to 2022.

3.3 Yellowfin tuna

The mean size by quarter for yellowfin tuna is shown in Figure 8 for 1998 to 2022. There is no clear signal in mean weights over time, although recent observations appear on average to be higher than in the earlier time period. The annual size distribution (Figure 9) shows some variability in the median value across years with no clear trends in recent years and bimodality in 2022. Most samples come from southern Queensland and there are no clear trends in size distribution between regions (Figure 10). The frequency of smaller individuals (recruits) over time in the size samples has been variable over time, with most samples from 2022 coming from the ‘Small’ category in contrast to 2021 when most samples came from the ‘Prime’ category (Figure 11).

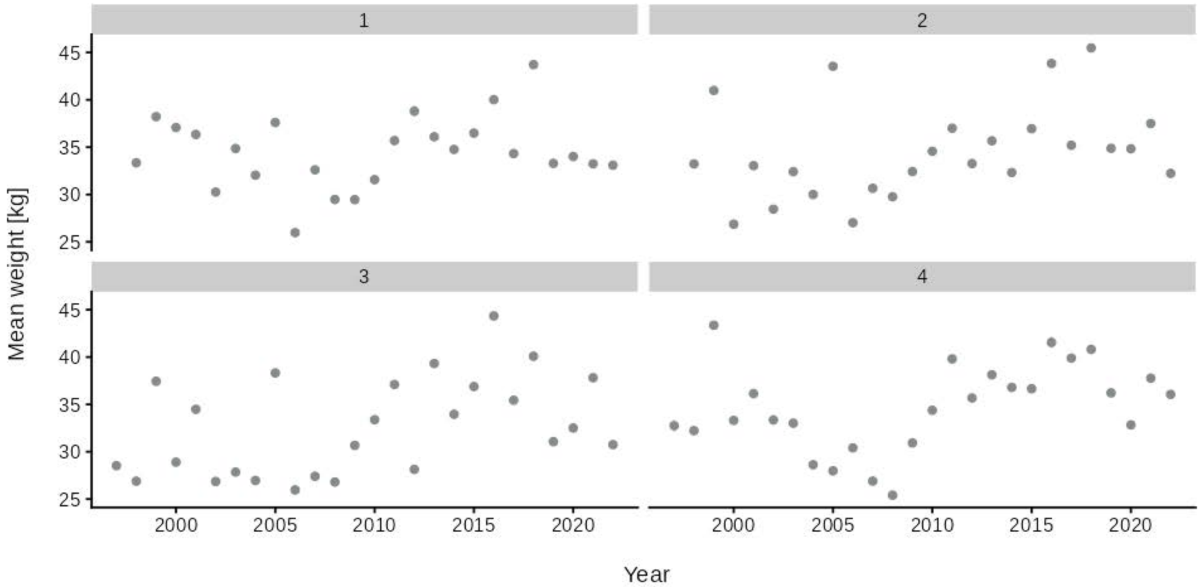

Figure 8: Mean weight (kg) of yellowfin tuna by quarter from 1998 to 2022. The whiskers show the approximate 95% confidence interval.

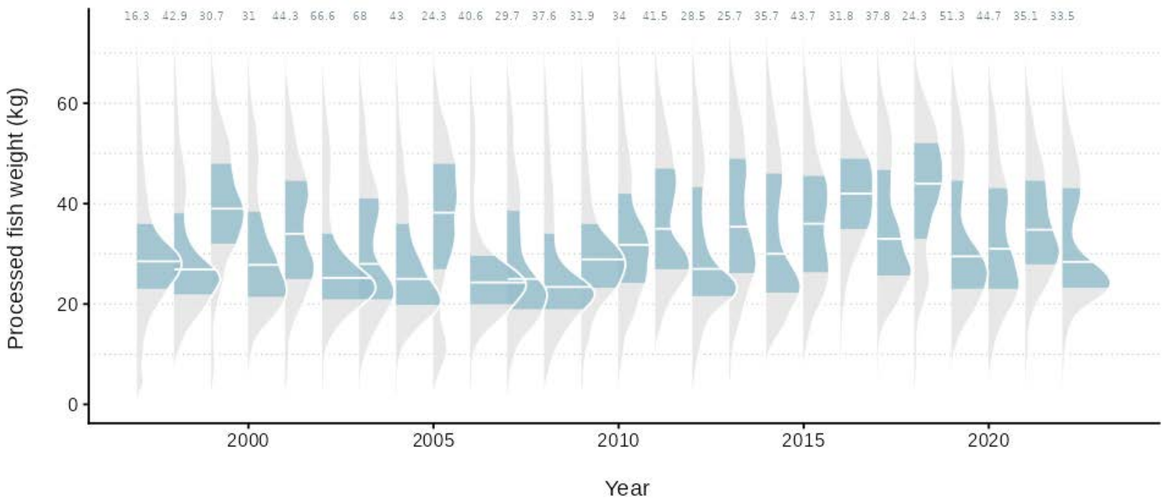

Figure 9: Shape of the size distribution of yellowfin tuna samples from 1998 to 2022. The 25th–75th interquartile band is highlighted in blue and the median is shown as a white line. Annual sample sizes (in thousands) are included above the corresponding size distribution.

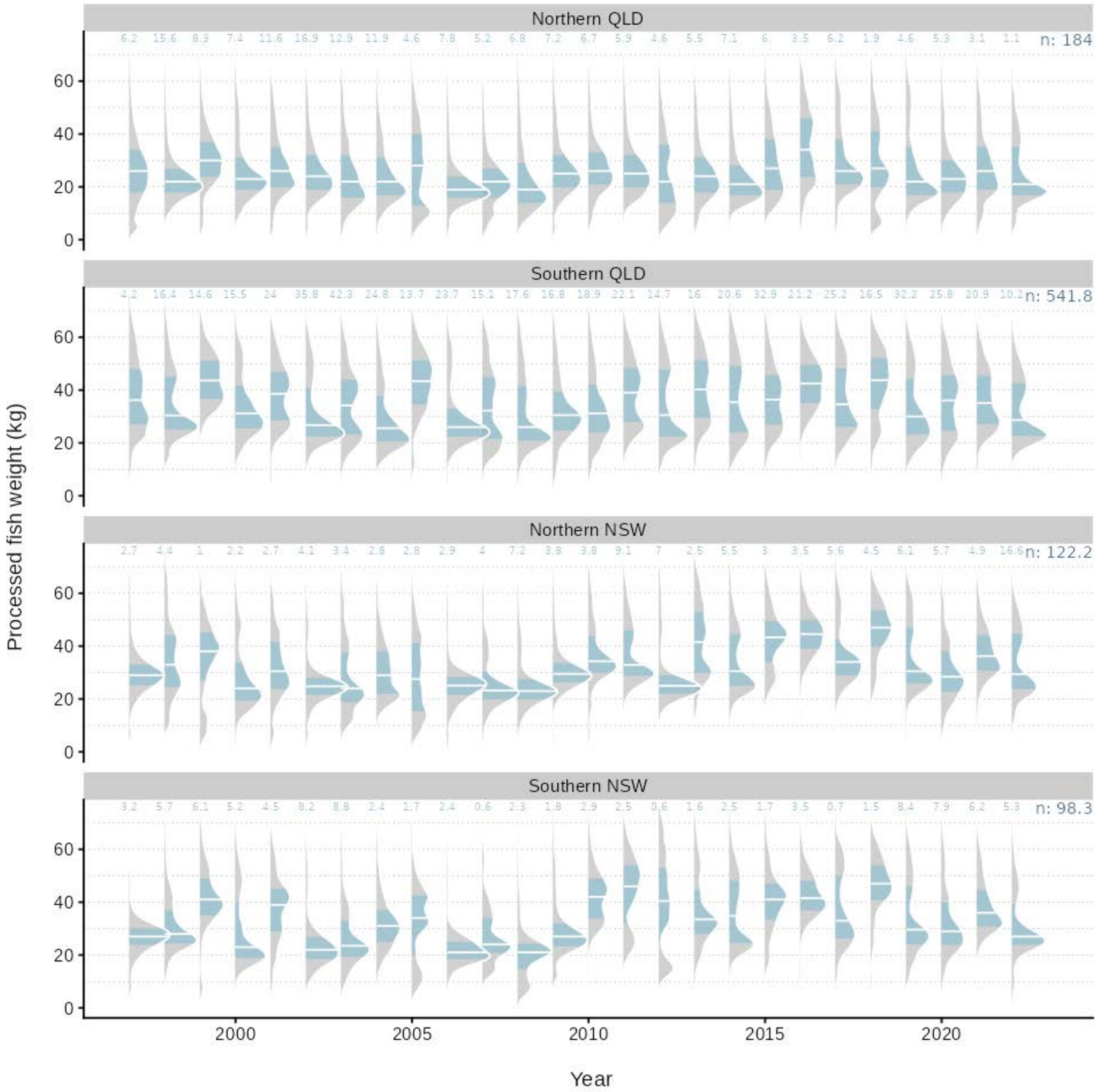

Figure 10: Shape of the size distribution of yellowfin tuna samples by key regions from 1998 to 2022. The 25th–75th interquartile band is highlighted in blue and the median is shown as a white line. Annual sample sizes (in thousands) are included above the corresponding size distribution, with total samples in the region (in thousands) shown in the top right of each panel.

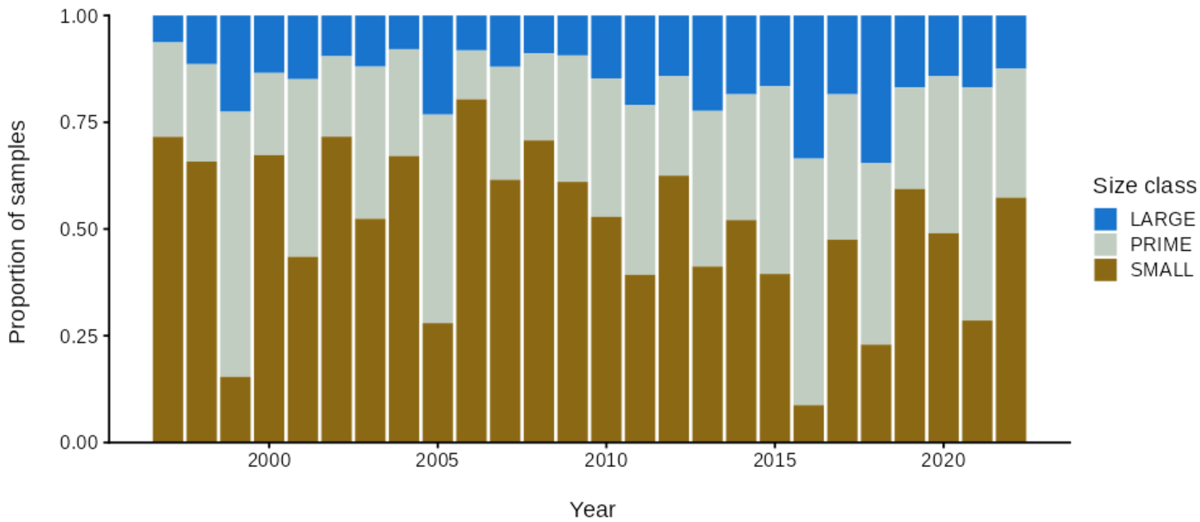

Figure 11: Distribution of size classes in yellowfin tuna samples over 1998 to 2022.

3.4 Broadbill swordfish

The mean size by quarter for broadbill swordfish is shown in Figure 12 for 1998 to 2022. Mean weight appears to have declined in the last 5-7 years with a slight uptick in quarters 1, 2 and 4, but there is no clear temporal signal on the long-term. The annual size distribution (Figure 13) shows a clear mode of smaller individuals and a median much higher than the mode across all years, reflecting a wide span of weights in the catch samples. The mode is less pronounced in 2022 compared to recent years, with a slightly higher median. Most samples came from southern Queensland except in 2022 where most samples came from northern New South Wales. Individuals sampled in New South Wales appear smaller than those sampled in northern and southern Queensland, with some year-to-year variability in sample sizes (Figure 14). Median size has increased in 2022 in all four regions. There has been a recent increase in the prevalence of smaller individuals (recruits) with a concurrent decrease in the large size classes (Figure 15). Most 2022 samples came from the 'Small' and 'Prime' size categories.

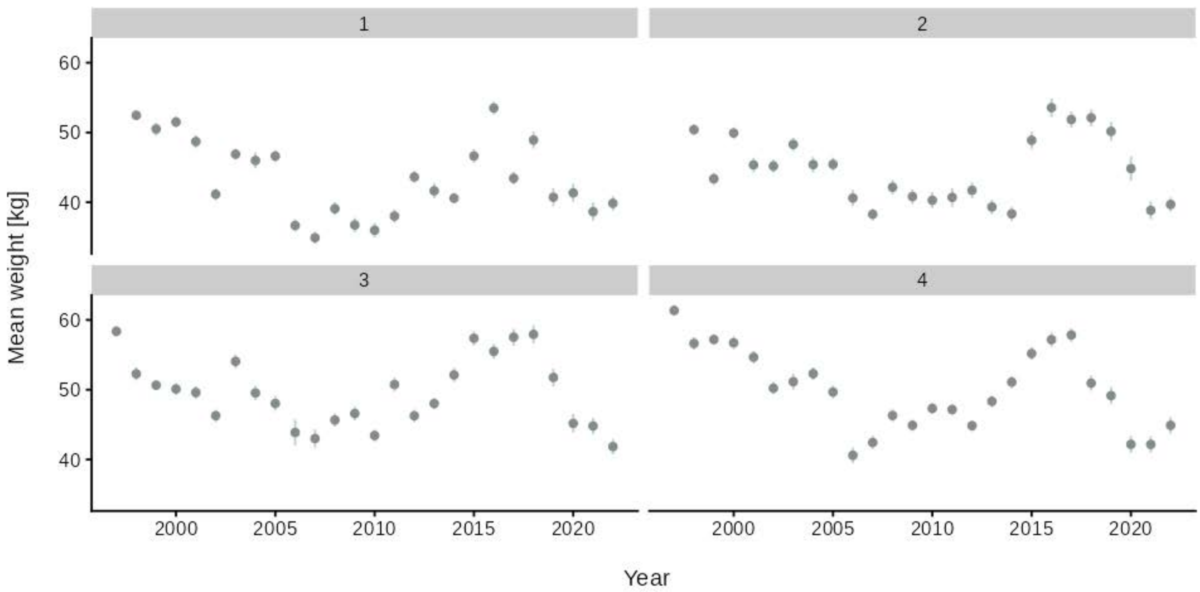

Figure 12: Mean weight (kg) of broadbill swordfish by quarter from 1998 to 2022. The whiskers show the approximate 95% confidence interval.

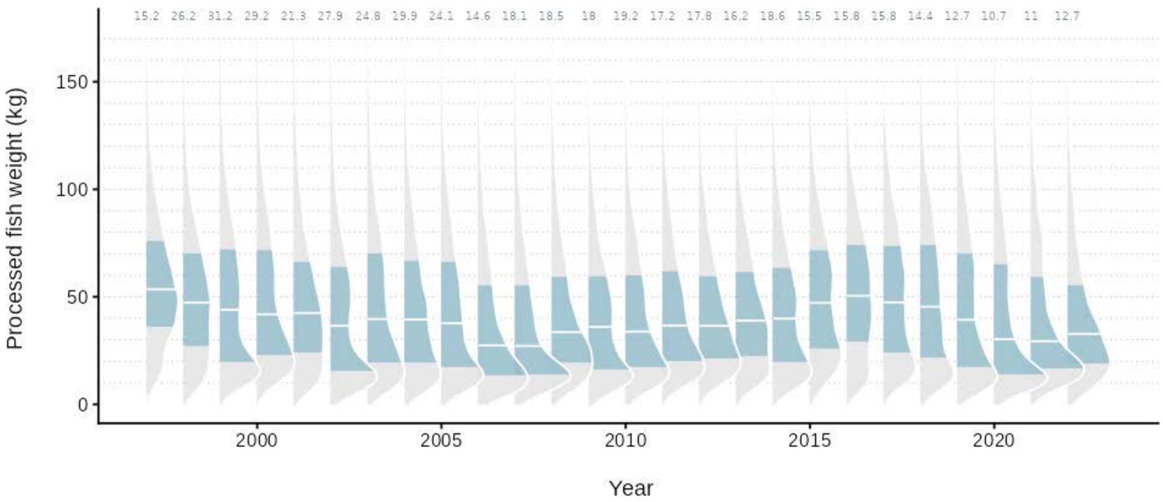

Figure 13: Shape of the size distribution of broadbill swordfish samples from 1998 to 2022. The 25th–75th interquartile band is highlighted in blue and the median is shown as a white line. Annual sample sizes (in thousands) are included above the corresponding size distribution.

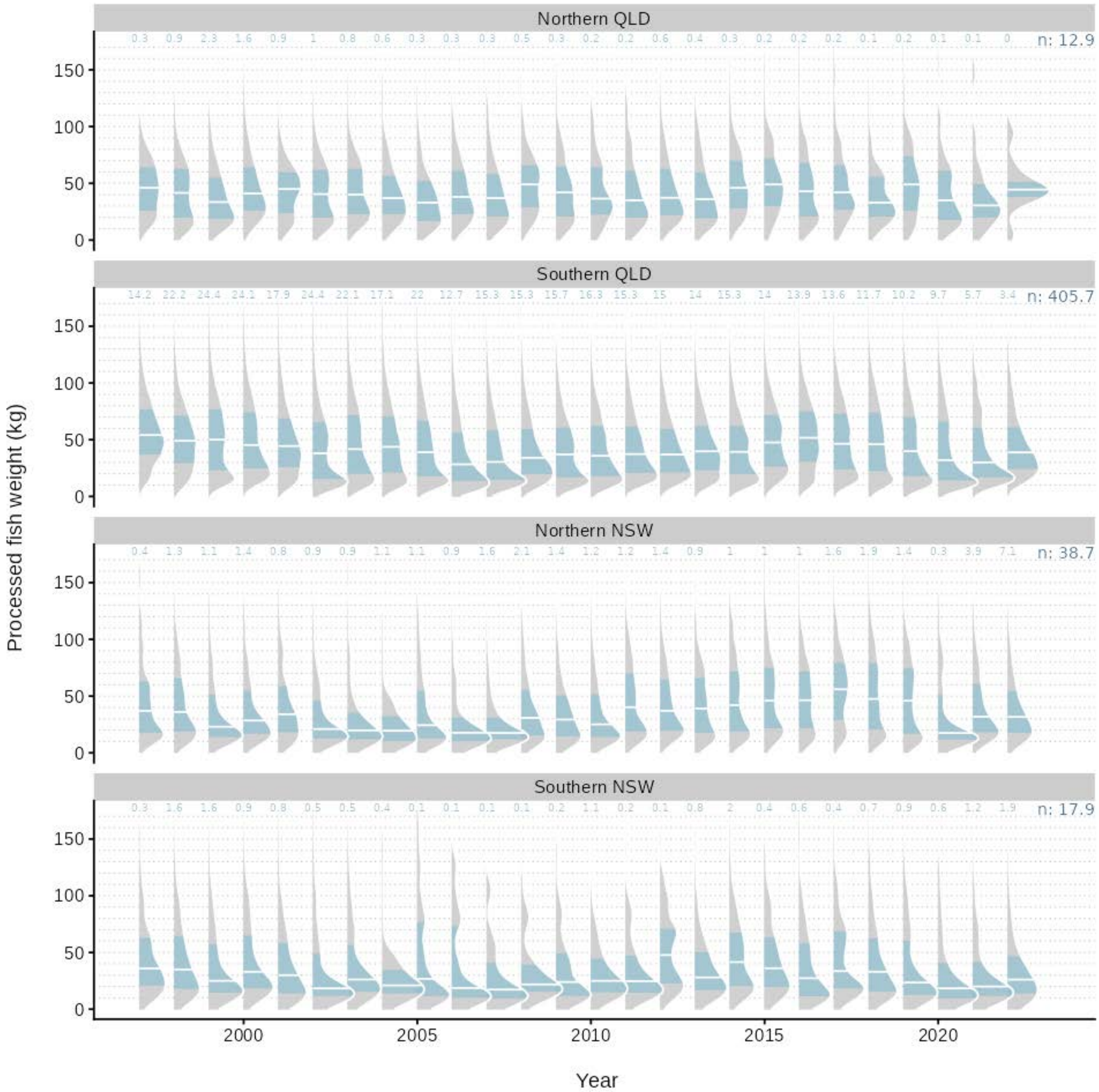

Figure 14: Shape of the size distribution of broadbill swordfish samples by key regions from 1998 to 2022. The 25th–75th interquartile band is highlighted in blue and the median is shown as a white line. Annual sample sizes (in thousands) are included above the corresponding size distribution, with total samples in the region (in thousands) shown in the top right of each panel.

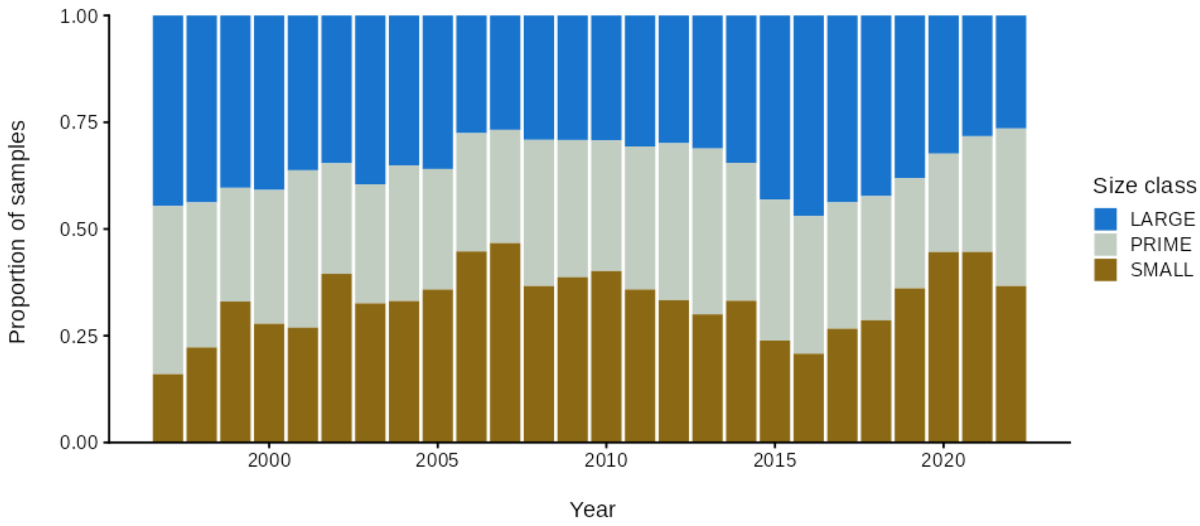

Figure 15: Distribution of size classes in broadbill swordfish samples over 1998 to 2022.

3.5 Striped marlin

The mean size by quarter for striped marlin is shown in Figure 16 for 1998 to 2022. There appears to have been a slight decline in mean weight since 2010 across all quarters, with an uptick in 2022. The annual size distribution (Figure 17) shows a clear mode throughout with a decline in median size over time but a slight increase from 2021 to 2022. There is no clear trend in size distribution across regions with most samples coming from southern Queensland (Figure 18). Most of the catch consists of individuals of 'Prime' size-class and there has been a recent decrease in the prevalence of large individuals in the sampled catch (Figure 19).

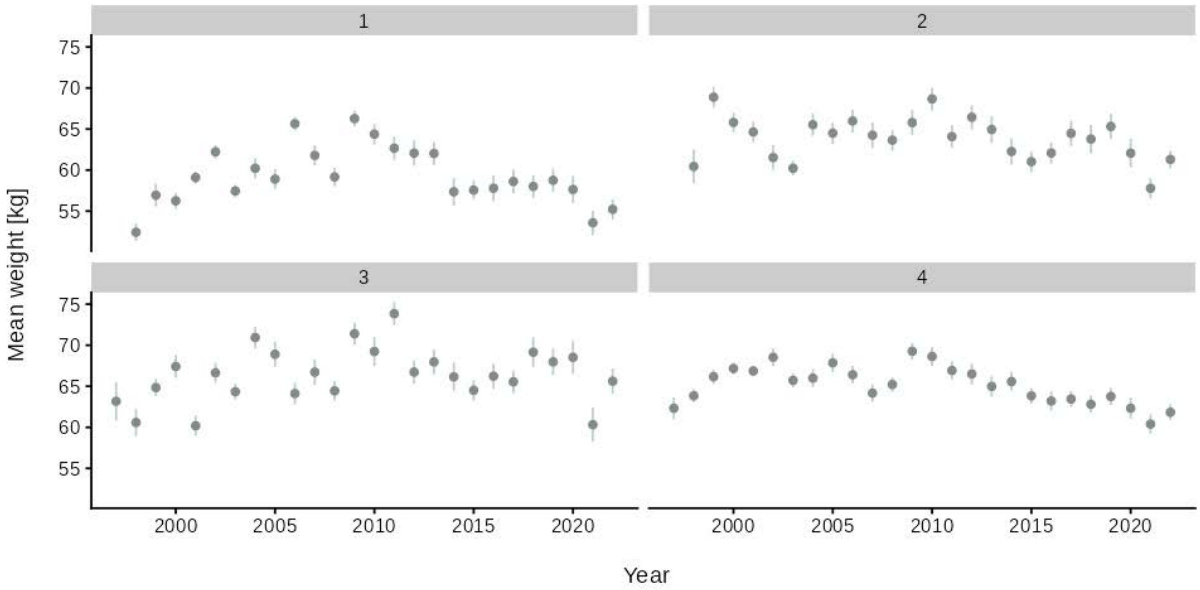

Figure 16: Mean weight (kg) of striped marlin by quarter from 1998 to 2022. The whiskers show the approximate 95% confidence interval.

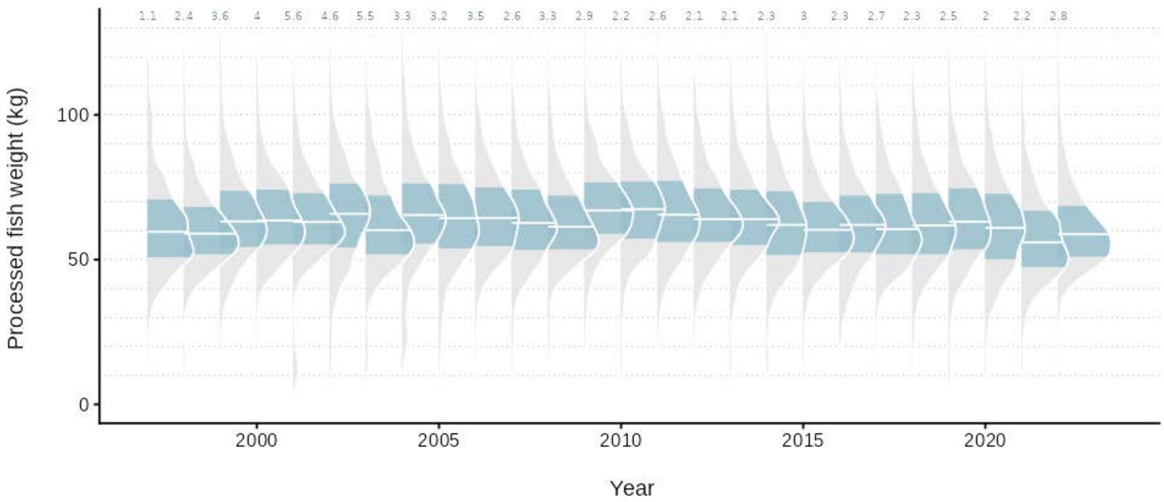

Figure 17: Shape of the size distribution of striped marlin samples from 1998 to 2022. The 25th–75th interquartile band is highlighted in blue and the median is shown as a white line. Annual sample sizes (in thousands) are included above the corresponding size distribution.

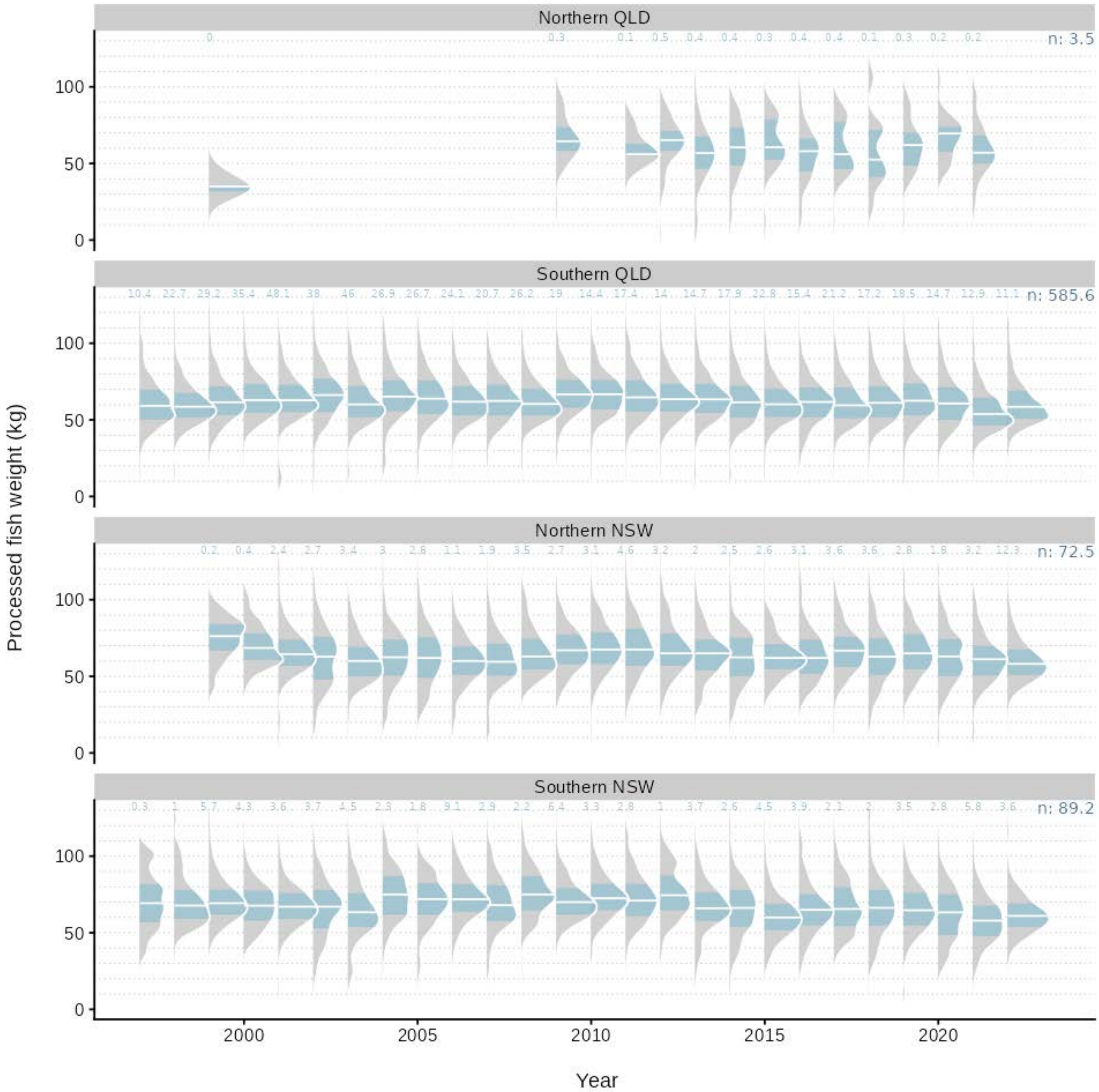

Figure 18: Shape of the size distribution of striped marlin samples by key regions from 1998 to 2022. The 25th–75th interquartile band is highlighted in blue and the median is shown as a white line. Annual sample sizes (in hundreds) are included above the corresponding size distribution, with total samples in the region (in hundreds) shown in the top right of each panel.

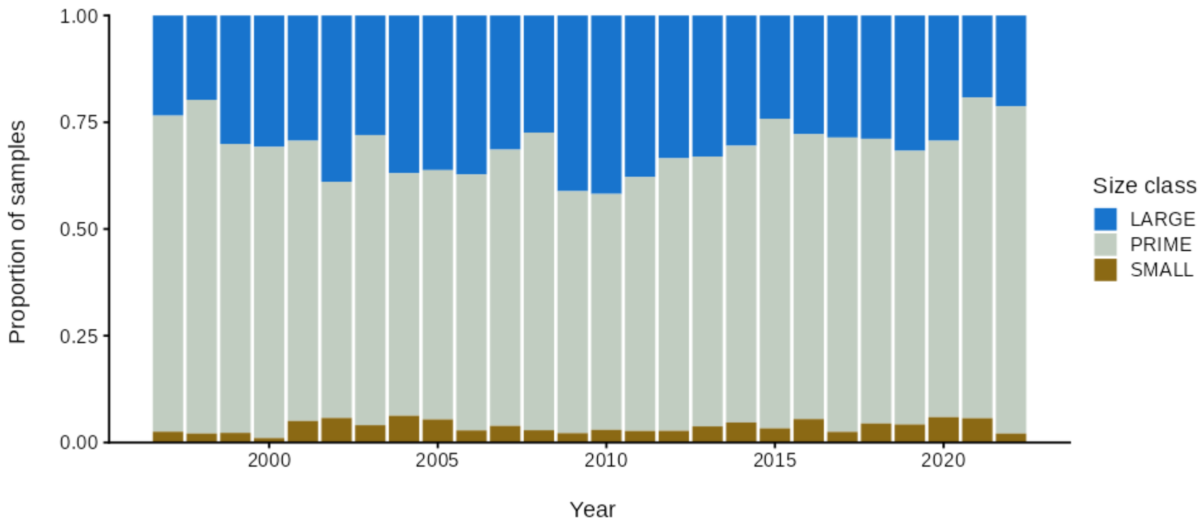

Figure 19: Distribution of size classes in striped marlin samples over 1998 to 2022.

4 Summary

This report summarised weight sampling data for the ETBF up to 2022. Updated graphical outputs were included to improve the characterisation of size distributions overall and across regions.

The data are broadly consistent with previous summaries by Campbell et al. (2020), Hillary et al. (2021) and Tremblay-Boyer and Williams (2021).

Key points include:

- Mean albacore weight appears stable across most quarters
- Weight statistics for bigeye and yellowfin tuna are highly variable, with bimodality in size distributions for both species reducing the usefulness of summary statistics
- Mean weight for bigeye tuna has increased or been stable in 2022 for most quarters
- Overall temporal trends in size for billfish show much less inter-annual variability than those for tuna species
- Mean weight for broadbill swordish is still low compared to earlier years but showed a slight increase in 2022 across most quarters
- Striped marlin mean weight has increased slightly across all quarters but is still low compared to previous years

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Hillary, R., Dell, J., and Williams, A. (2021). Summary of 2020 ETBF weight frequency data. Working Paper to the 32nd meeting of Tropical Tuna Resource Assessment Group held, 27-29 July 2021.

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Standardised CPUE indices for the target species in the Eastern Tuna and Billfish fishery–1998 to 2022

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8 July 2023

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Important disclaimer

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1 Introduction

Standardised catch-per-unit-effort (CPUE) is commonly used as an index of stock abundance to inform fisheries management. It is derived by first estimating the effect of key operational (e.g. hooks-between-float, bait) and environmental (e.g., season, sea surface temperature) variables on the ratio of catch to effort for a given species by fishing set (i.e. nominal CPUE). The effect of influential variables are then removed from model prediction of annual CPUE to obtain an index of stock abundance independent from the effect of fishing practices.

In the Eastern Tuna and Billfish Longline Fishery (ETBF), standardised CPUE indices are derived for albacore tuna (*Thunnus alalunga*, ALB), bigeye tuna (*Thunnus obesus*, BET), yellowfin tuna (*Thunnus albacares*, YFT), southern bluefin tuna (*Thunnus maccoyii*, SBT), broadbill swordfish (*Xiphias gladius*, BBL), and striped marlin (*Kajikia audax*, STM). These indices underpin the management advice provided by the Tropical Tuna Resource Assesment Group (TTRAG). For broadbill swordfish, the sub-adult('prime') index further informs the harvest strategies within a Management Strategy Evaluation framework, resulting in an annual update of the Total Allowable Catch.

CPUE indices are derived for the ETBF at the level of the local stock for all tuna and billfish species. For yellowfin tuna, bigeye tuna and broadbill swordfish, indices are also developed for specific size-classes, namely adults and recruits for bigeye and yellowfin tuna, and adults, sub-adults and recruits for broadbill swordfish. These size categories were previously agreed by the TTRAG (see also Campbell 2020 for further background).

This document updates the standardised CPUE indices for key target species in the ETBF over the period 1998 to 2022. It builds on previous work by Tremblay-Boyer et al. (2022a), Dell et al. (2021), Campbell (2020). Key updates in this year's indices include the trial of a new approach to identify changing fishing strategies over time and the exploration of the effects of various eddy characteristics on catch rates.

2 Methods

2 Data

The CPUE standardisation models use logbook data collected and managed by the Australian Fisheries Management Authority (AFMA) for the ETBF. The logbook data consist of an entry for each fishing set which records catch by species (retained and discarded) and effort information (hooks) as well as other variables describing operational practices for the set, such as the number of floats (or bubbles), the bait type used, the length of the mainline, etc. The logbook data used to train the CPUE model are groomed to remove entries with missing operational covariates (e.g. bait) or records that appear unlikely (e.g. hooks-between-floats greater than 40). In some instances, records are imputed if they are null or likely erroneous. When the effort (in number of hooks) on the logbook is left blank or recorded as less than 50 hooks, the number of hooks for that operation is set equal to the average number of hooks deployed across all longline operations for the relevant year. Where a catch weight is recorded but not the corresponding number of fish, the average weight of fish for that species caught in that year is used to estimate the number of fish (and vice-versa). Logbook records are assigned to different fishing areas defined by focal species following Campbell (2018) (Figure 1). The species-specific areas are used as a covariate in the standardisation models as well as a scaler when computing annual indices.

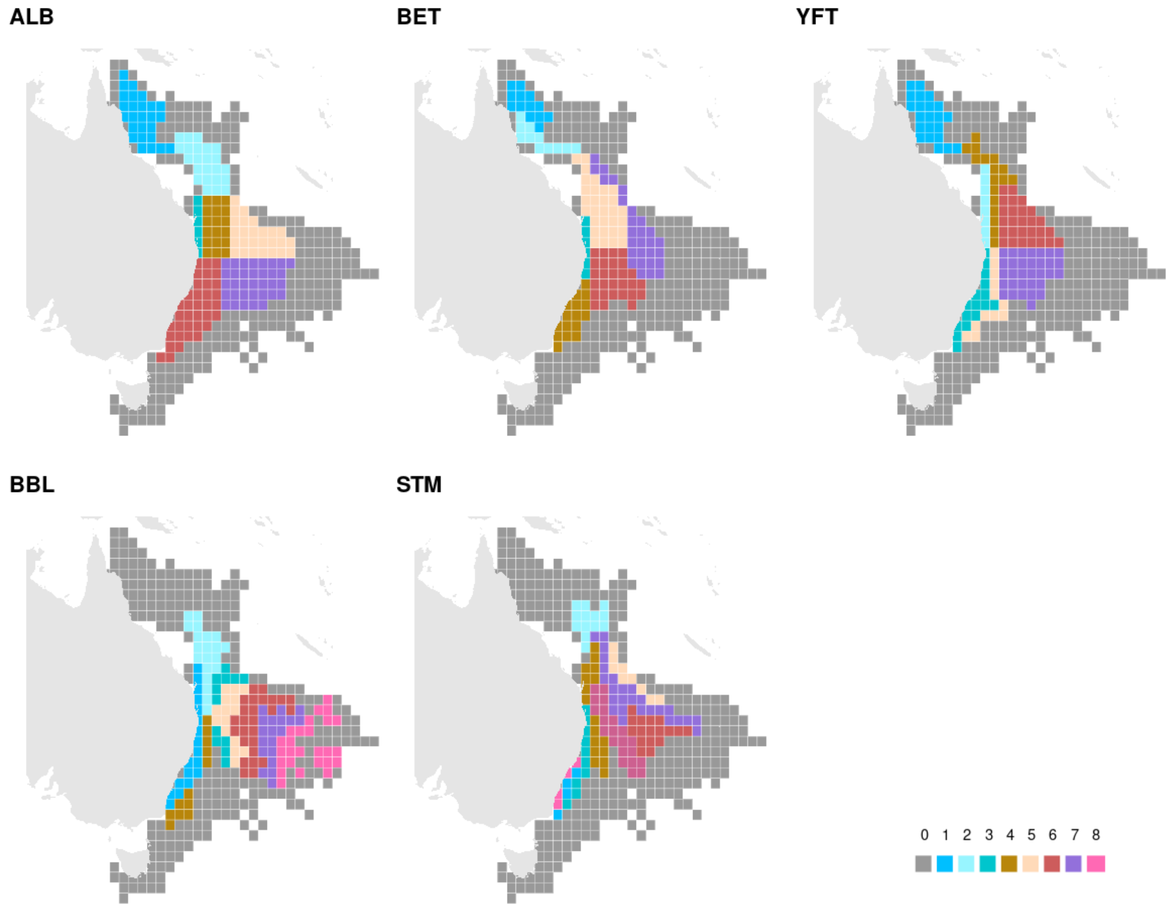

Figure 1: Map of the areas used as covariates in the CPUE standardisation for each species.

Species catch is apportioned by size class based on separate size sampling data collected by processors. Individuals are assigned to size-classes based on their weight, using the cut-offs defined in Table 1 (see also Campbell, 2020).

Oceanographic covariates from the ACCESS S2 database (Australian Community Climate and Earth-System Simulator-Seasonal; Hudson et al. 2017) are appended to the logbook data based on the location and date of the fishing set. All oceanographic covariates are aggregated at the monthly resolution. Bathymetry data are obtained from the National Center for Atmospheric Research at the 1/12° resolution. The Southern Oscillation Index (a metric used to quantify the strength of the El Niño Southern Oscillation) is obtained from the National Centers for Environmental Information at the monthly resolution.

2 Species targeting

Species targeting behaviour by vessel crew can span diverse aspects of fishing operations and have a strong impact on realised catch rates for the target species on a given fishing set. It can also be hard to infer from the logbook data alone. A common approach is to use an unsupervised classification algorithm (e.g., k-means or hierarchical clustering) to assign fishing sets to

Table 1: Weight cut-offs (kilograms) used to apportion individuals to age categories

Species	Size-category	Quarter 1	2	3	4
Bigeye tuna	Recruit–Adults	14.63	17.99	19.45	21.51
Yellowfin tuna	Recruits–Adults	22.66	29.95	32.85	35.96
Broadbill swordfish	Recruits–Sub-adults	20.47	22.62	27.53	30.36
	Sub-adults–Adults	47.96	49.57	57.09	59.84

'targeting strategies' based on the proportion of each species of interest in the total set catch (see He et al. 1997). This implicitly assumes that the species that is most prevalent in the fishing set is being targeted, which might be appropriate for some target species.

A targeting effect has been included in recent ETBF CPUE standardisations following this approach, but at the level of fishing trips instead of sets (Campbell, 2020). Species composition at the level of the fishing set is likely to be more variable due to the randomness of chance encounters between fishing gear and schools of fish. Aggregating the data at the level of the fishing trip should reduce the variability in species composition due to randomness, and result in a more robust allocation of fishing sets to fishing strategies. However, discussions at recent TTRAGs have also highlighted that fishing strategy can change during a fishing trip based on a variety of factors including weather conditions, market demand and success of previous fishing sets in the same fishing trip.

In addition, there are some concerns with the identification of fishing strategy based on species composition in the catch alone. For instance, species composition could also be confounded with a signal of abundance driven by habitat, season or natural variability, such as species 'pulses' that are often observed in the ETBF. Also, different types of set configurations are used to target the same species in the ETBF (e.g., deep-setting for albacore tuna); identifying strategy based on species composition alone would not allow to differentiate amongst these. Finally, fishing strategies in the ETBF have changed over time, driven in part by management and market factors. Ideally, the approach to identify fishing strategies would be flexible enough to account for the dynamic nature of fishing strategies in the ETBF. In its current format, the species composition-based approach does not account for time period when allocating fishing sets to a fishing strategy.

A new approach was developed this year to attempt to address these concerns. It expands on previous work by Parsa et al. (2020) and was initially presented to TTRAG 36. Under this approach (referred to here as the 'metiers' approach), sets are allocated to fishing strategies based on a suite of operational covariates in addition to species composition. The rationale is that the inclusion of fishing set characteristics should provide additional information to distinguish an actual fishing strategy enacted by the fishing crew from a local signal of abundance. To account for inter-annual changes in fishing strategies, fishing strategies are first identified at the annual level instead of the whole time-series. This allows to capture more diversity in the fishing strategies that are used in different time periods of the fishery, and also to identify fishing strategies that persist through time. The method to apply both approaches are outlined below.

2.1 Identification of overall fishing strategies from species composition

The previous approach to identify fishing strategies was updated with the logbook data for the 1998 to 2022 period. Only the main target species were retained when computing species composition, namely albacore tuna, bigeye tuna, yellowfin tuna, southern bluefin tuna, broadbill swordfish and striped marlin. Logbook records were only retained if the associated total trip catch was of at least one individual across these species. The species composition for each fishing trip was then the proportion of each species to the total catch of the fishing trip. Data were arcsine-square-root transformed prior to classification to normalise their distribution. A cluster analysis was applied on the normalised proportions using the 'clara' algorithm implemented in the 'cluster' package (Maechler et al., 2021) to identify 7 fishing strategies. The number of fishing strategies was specified as 7 based on earlier work by Parsa et al. (2020). Each fishing set was then assigned the fishing strategy of its fishing trip.

2.2 Identification of 'metiers' from fishing set characteristics

The new 'metiers' approach is implemented in two steps. In the first step, records from the logbook data are split based on the calendar year where the fishing set occurred, and an unsupervised classification algorithm ('Partitioning Around Medoids', PAM; Maechler et al., 2021) is applied, for each year subset, to a user-specified matrix of operational and species proportion covariates. The algorithm identifies a user-specified number of most representative fishing sets ('medoids') in the dataset, and each fishing set can then be assigned to a medoid cluster based on how similar they are to the cluster's medoid (i.e., median characteristics).

The algorithm requires the user to specify how many medoids should be identified from the dataset as well as a distance metric. Also, a silhouette metric (Rousseeuw, 1987) can be computed for each cluster and is a measure of cluster differentiation, with a higher value indicating more dissimilarity between that cluster and others identified by the classification algorithm. Based on data exploration and further examination of the silhouette metric under different medoid numbers, a number of six medoids was chosen as the default value for the PAM algorithm. The Gower dissimilarity (Gower, 1971) was used as a distance metric as it allows the inclusion of non-numeric fields (e.g., bait species) in the classification algorithm and is well suited to input variables of different types and scales.

A number of candidate covariates lists were trialled based on Parsa et al. (2020) and further discussions at TTRAG 36. The distribution of the silhouette metric across clusters and years was used to identify the list of covariates that generated on average the most unique clusters across time. The final list of covariates consisted of the following set characteristics: longitude, latitude, number of hooks, hooks-between-floats, mainline length, cosine of the fishing date, the proportion of the moon that was illuminated, the lights-to-hook ratio, the distance of the set from the shelf, the bait species and the life-status of the bait. Species proportions for albacore tuna, bigeye tuna, yellowfin tuna, southern bluefin tuna, broadbill swordfish, striped marlin and mahi mahi in the fishing set were also included.

The second step of the metiers approach used expert TTRAG opinion to inform the right grouping for the fishing strategies (clusters) identified at the annual level. Once the final set of annual clusters had been determined using the chosen model, the average value of the input covariates by annual cluster was computed from each cluster's allocated fishing sets. The resulting average values by cluster were mapped using a force-directed-graph dimension-reduction technique (Epskamp et al., 2012) to visualise trends in the annual clusters over the 1998 to 2022 time period. Metiers (fishing strategies) were identified by grouping annual clusters based on their operational and species composition attributes, with further support provided by TTRAG members as to what groupings might be more representative of actual fishing strategies.

Based on this consultation, seven metiers were identified in the ETBF through time: yellowfin tuna targeting in the Coral Sea area, mixed tuna targeting along the East Australian current, deep-setting for albacore, mixed tuna targeting using fresh (often scat) bait, mixed tuna and swordfish targeting, intensive swordfish targeting prior to the implementation of fishing quotas, and southern bluefin tuna targeting. Annual clusters (and fishing sets therein) were assigned to each of these metiers based on their location on the force-directed-graph.

The metiers variable was included as a categorical variable in the CPUE standardisation. An alternative metier configuration grouping the mixed tuna targeting, mixed tuna and swordfish targeting and intensive swordfish targeting metiers was also trialled (i.e., 5 metiers instead of 7). Key results from the metiers analysis are included in Appendix A. Note that the final indices did not include the metiers covariates as there were unresolved concerns in the increased variability they generated in the standardised indices. As such, this year's indices are based on the species composition approach to identify fishing strategy.

2 CPUE standardisation models

CPUE models were trained independently for each species and size-class based on the groomed logbook data. Nominal CPUE by fishing set (shot) was predicted as a function of a given list of covariates using a two-step hurdle approach:

First, the probability of catching a fish of a given species (and size class, for size-specific models) was estimated by assuming a binomial process for the probability of a positive catch ($p(C > 0)$) and the probability of zero catch ($p(C = 0)$). The response (observed) variable for this binomial model was whether at least one of the species [size class] had been caught in the fishing set. A logit link function was used to relate the binomial response variable to the linear predictor.

Second, the expected value of the catch (when positive) for a given species [size class] was estimated, assuming a Gamma error distribution and a log-scale link function. For this 'positive' model, only the subset of logbook data with sets where at least one individual of the given species [size-class] was caught were retained. The response variable for the positive model was the total catch in numbers (retained R and discarded D) in the fishing set for the focal species. For size-class specific indices, the response variable for each fishing set i was:

$$C_i = R_i \times P_{S,f(i)} + D_i \times P_{D,S},$$

where $P_{S,f}$ is the estimated proportion of the size-class S in fishing trip f and P_D is a fixed proportion of the discards assumed to consist of the size-class (Table 2).

An area-quarter weighted sum using the binomial (probability of catching an individual of a given species [size class], p) and the positive (catch rate when there is a catch event, μ) model is then used to derive the annual CPUE indices for the species [size class] I_Y as:

$$I_{Y,Q,A} = p_{Y,Q,A} \cdot \mu_{Y,Q,A}$$
$$I_Y = \frac{1}{N_Q} \sum_{Q=1}^{N_Q} \sum_{A=1}^{N_A} E_A \cdot I_{Y,Q,A},$$

Table 2: Proportion of discards allocated to each size-class by species

Species	Recruits	Sub-adults	Adults
Bigeye tuna	0.838	—	0.162
Yellowfin tuna	0.841	—	0.159
Broadbill swordfish	0.91	0.053	0.037

where E_A is the total number of 1° cells that were fished at least once in area A. The final index is then mean-standardised.

2.1 Model developments in 2023

General Additive Models (GAMs; Wood 2017) were used for the standardisation as detailed in (Tremblay-Boyer et al., 2022a). GAMs were chosen as a modelling platform as they allow for flexible, non-linear relationships between the response variable and continuous covariates. GAMs can handle saturating relationships, e.g., when catch rates increase linearly with a certain variable but then plateau with further increase of that variable (e.g., with light-to-hook ratio for some species), or peak then decrease beyond certain values (e.g. the effect of sea surface temperature on catch rates for many species). In this year's models, continuous covariates were allowed to have some form of non-linear relationship with the response variable via the use of a low flexibility (k=4) thin plate regression splines to constrain spline wiggliness. Categorical variables such as bait, area or target species, were treated as fixed effects, as in previous implementations.

One constraint of linear models such as GLMs and GAMs is that they cannot handle records with missing values for any of the covariates. As such, the inclusion of an additional covariate might result in some of the observations being discarded if the new covariate has missing values for some records. At times, the inclusion of a covariate might influence the index not because of the covariate itself but because of records being discarded as a result of including this covariate (due to missing values). As such, the proportion of missing entries for each covariate was examined to ensure that covariates with missing entries were not included if they resulted in a high number of records being discarded. This only impacted oceanographic covariates, namely, wind speed, current speed and its derived variables, as well as mixed layer depth. In addition, the set time covariate was removed from the standardisation given issues with 2021 values in the AFMA database. The exclusion of this covariate allowed the inclusion of early records in the analysis which had previously been excluded due to anomalous entries for the set time field. The grooming procedure to allow fishing sets in the standardisation was also revised to allow additional fishing sets if they met criteria in the value of the hooks, hook-between-floats, mainline length and set time fields (Tremblay-Boyer et al., 2022b).

A new class of environmental covariates was included in this year's analysis to capture the potential effects of eddies on catch rates. A database predicting eddy characteristics in the ETBF (including location, polarity, age and radius) was obtained from AVISO [1]. Fishing sets locations were compared to daily eddy outlines predictions from 1998 to 2022 to ascertain whether they occurred within an eddy. New eddy-related fields were appended to the logbook data to describe (1) whether sets were in a cyclonic eddy, an anti-cyclonic eddy or outside of an eddy, (2) the age

[1] https://www.aviso.altimetry.fr/en/data/products/value-added-products/global-mesoscale-eddy-trajectory-product.html

of the eddy for sets that occurred in an eddy and (3) the radius of the eddy. Sets outside of eddies were assigned a value of zero for both these fields. Results from standardisation models including these new eddy covariates are shown in Appendix E but the new eddy covariates were not retained in the final standardisation due to limited influence on final indices.

Table 3 lists the covariates used in the standardisation model, divided into three categories: time or area, operational, and environmental.

Table 3: Summary of covariates used in standardisation models

Covariate	Description	Type	2023 models
year	Calendar year	Categorical	Fixed effect
qtr	Quarter	Categorical	Fixed effect
area_SP	Area	Categorical	Fixed effect
tripclustercat_trip	Targeting cluster	Categorical	Fixed effect
per_lights	Light-to-hook ratio on set	Continuous	Spline
bait	Bait type	Categorical	Fixed effect
STIME_HOUR_UTC	Time of setting	Continuous	Circular spline
HPB	Hooks-between-floats	Continuous	Spline
MAINL	Mainline length (km)	Continuous	Spline
hpkm	Hooks per kilometer of line	Continuous	Spline
bubblen	Number of floats	Continuous	Spline
bathy_updated	Bathymety	Continuous	Spline
SOI_updated	SOI	Continuous	Spline
SST_access	Sea surface temperature	Continuous	Spline
phase	Moon phase	Continuous	Circular spline
daynvess	Number of vessels fishing on the same day in the 1° cell	Continuous	Spline
monnvess	Number of vessels fishing on the same month in the 1° cell	Continuous	Spline
shelfdist (new)	Distance from fishing set to the shelf (km)	Continuous	Spline
metiers (new)	Fishing strategy from main metiers grouping	Categorical	Fixed effect
metiers2 (new)	Fishing strategy from alternative metiers grouping	Categorical	Fixed effect
eddy_category (new)	Polarity of eddy where present	Categorical	Fixed effect
eddy_age (new)	Age of eddy (days) where present	Continuous	Spline
eddy_radius (new)	Radius of eddy (km) where present	Continuous	Spline

2.2 Stepwise model runs

The covariate structure for the standardisation models was updated in a stepwise fashion in order to examine the impact of each successive change on the resulting standardised indices. Model structure was kept the same across all species and size-classes. The following model steps were used:

- Base 2022 [basemod]: A rerun of the accepted 1998–2021 model structure on the new dataset extract with the 2022 year removed
- 2023 data update [base2022_gamcphase_nospeed_selectedfilter]: A rerun of the accepted 1998–2021 model structure on the new dataset extract including 2022, using the same grooming rules as in Tremblay-Boyer et al. (2022a)

- 2023 data update full dataset [base2022_gamcphase_nospeed]: A rerun of the accepted 1998-2021 models on the new dataset extract including 2022
- 2023 no set time [base2022_gamcphase_nospeed_notime]: The updated model with the set time covariate removed
- Final model: 2023 data update with distance to shelf [base2022_gamcphase_nospeed_shelfdist]: Previous step with addition of a non-linear relationship for the distance of fishing sets to the shelf

3 Results

3 Albacore tuna

Standardised CPUE indices for albacore tuna were developed for all sizes aggregated only (Figure 2). Both nominal and standardised indices are highly variable over time and show no clear trends from the mid-2000s onwards. The final 2023 model is slightly less variable over time than the 1998–2021 index.

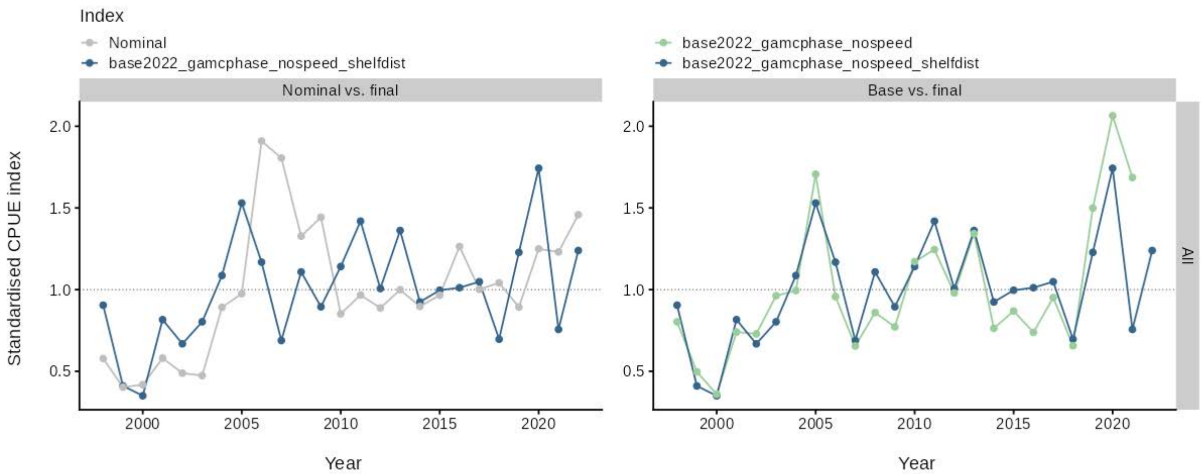

Figure 2: Comparison of the final standardised CPUE index (blue line) for 1998 to 2022 for albacore tuna (All) with the nominal CPUE index (grey line; left panel) and with the accepted 1998–2021 model (green line; right panel).

3 Bigeye tuna

Standardised CPUE indices for bigeye tuna were developed for all sizes aggregated (Figure 3), adults (Figure 4),and recruits (Figure 5).Both the nominal and standardised aggregated indices show a steady decline over time, with some variability and a recent increase to long-term series average. Series for all three size groups show a high value around 2006-2007 driven by the year-quarter interaction (Appendix C) and not accounted for by the operational covariates used in the CPUE standardisation. The final models are similar to the 1998–2021 models, with slightly less variability at the start of the time-series especially. Overall trends are similar for all size groups, with the recruit index showing the most variability (Figure 5). The standarised indices decreased or were stable fo all size groups.

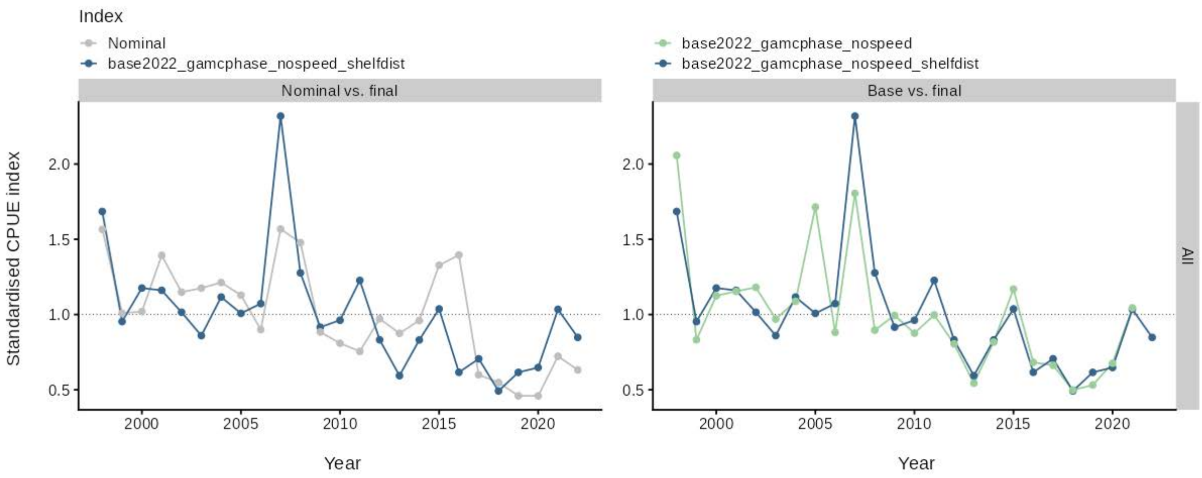

Figure 3: Comparison of the final standardised CPUE index (blue line) for 1998 to 2022 for bigeye tuna (All) with the nominal CPUE index (grey line; left panel) and with the accepted 1998–2021 model (green line; right panel).

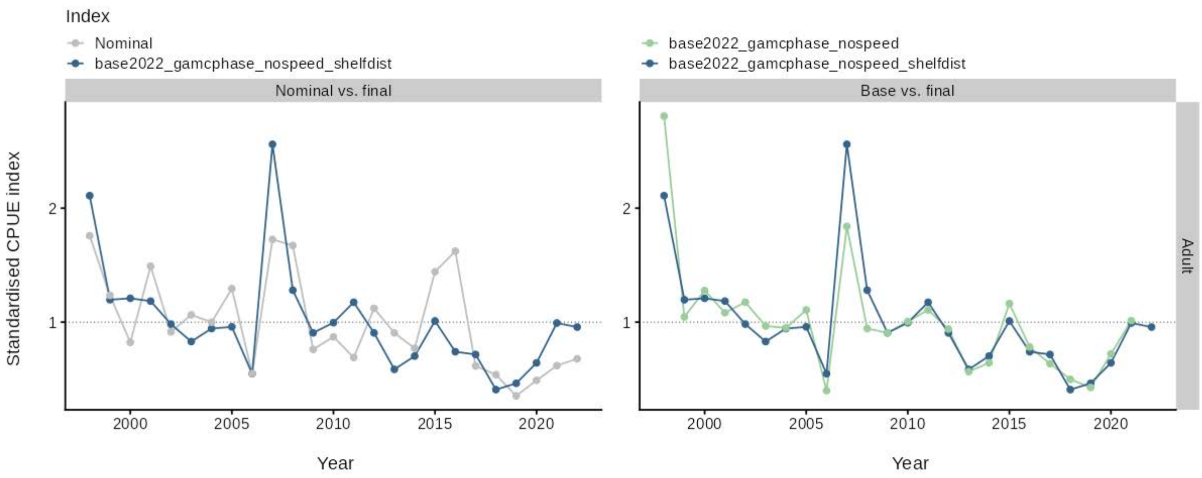

Figure 4: Comparison of the final standardised CPUE index (blue line) for 1998 to 2022 for bigeye tuna (Adult) with the nominal CPUE index (grey line; left panel) and with the accepted 1998–2021 model (green line; right panel).

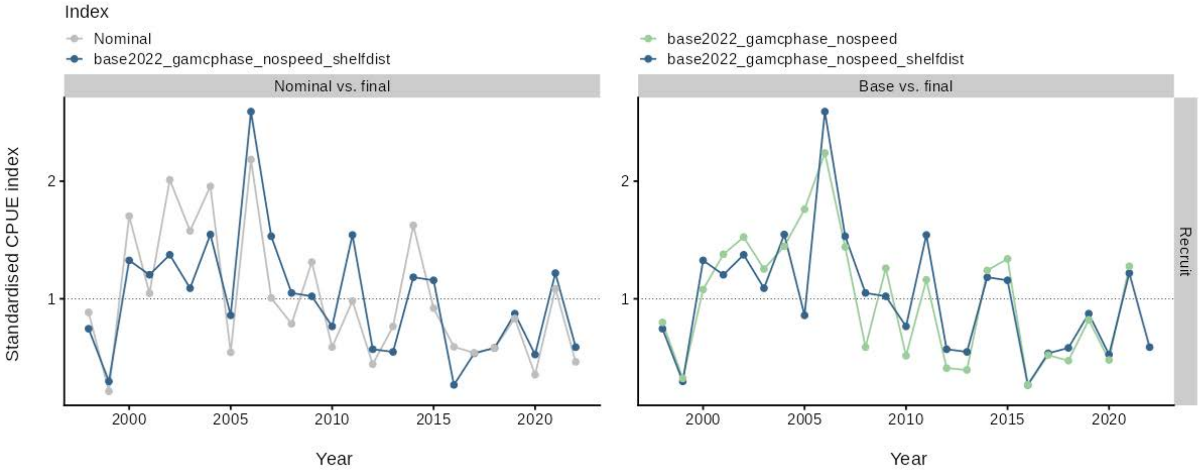

Figure 5: Comparison of the final standardised CPUE index (blue line) for 1998 to 2022 for bigeye tuna (Recruit) with the nominal CPUE index (grey line; left panel) and with the accepted 1998–2021 model (green line; right panel).

3 Yellowfin tuna

Standardised CPUE indices for yellowfin tuna were developed for all sizes aggregated (Figure 6), adults (Figure 7), and recruits (Figure 8).Both the nominal and standardised aggregated indices are stable for all size groups but highly variable over time. The final models are similar to the 1998–2021 models but slightly less variable. The standardised indices increased from 2021 to 2022 for all size groups.

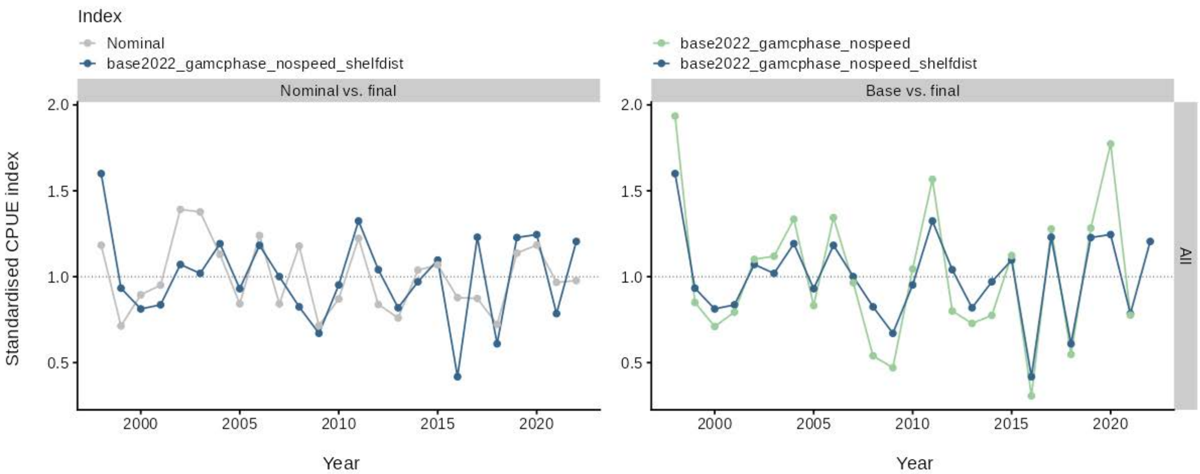

Figure 6: Comparison of the final standardised CPUE index (blue line) for 1998 to 2022 for yellowfin tuna (All) with the nominal CPUE index (grey line; left panel) and with the accepted 1998–2021 model (green line; right panel).

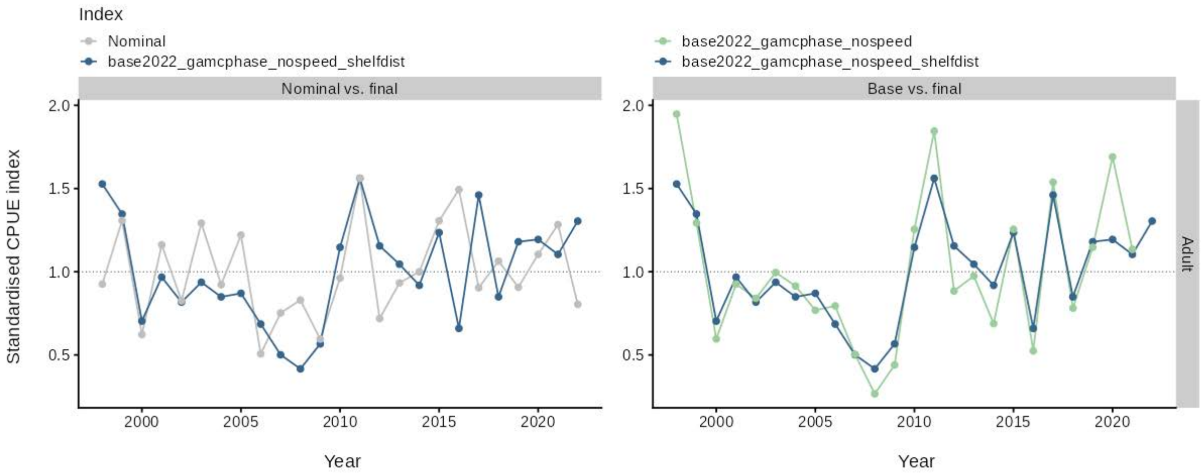

Figure 7: Comparison of the final standardised CPUE index (blue line) for 1998 to 2022 for yellowfin tuna (Adult) with the nominal CPUE index (grey line; left panel) and with the accepted 1998–2021 model (green line; right panel).

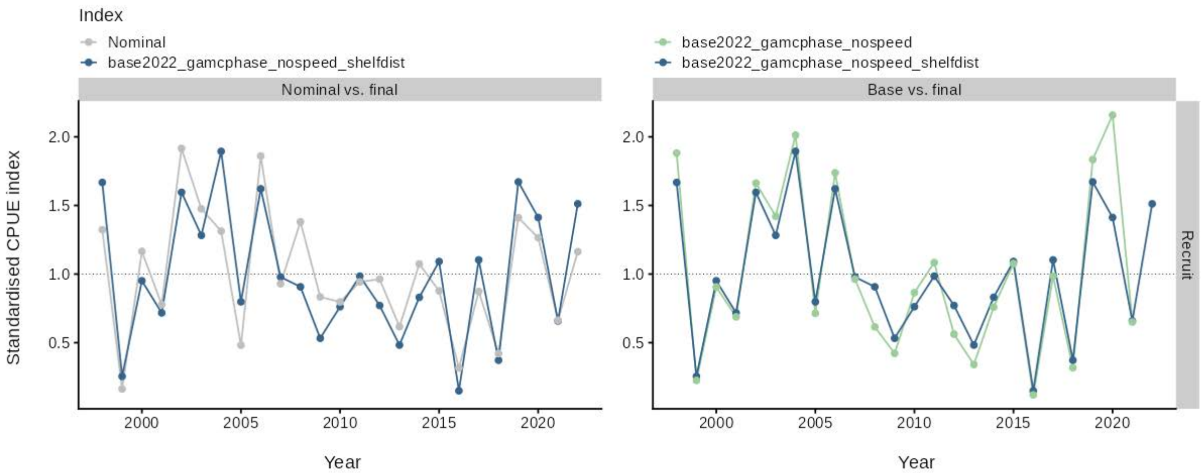

Figure 8: Comparison of the final standardised CPUE index (blue line) for 1998 to 2022 for yellowfin tuna (Recruit) with the nominal CPUE index (grey line; left panel) and with the accepted 1998–2021 model (green line; right panel).

3 Broadbill swordfish

Standardised CPUE indices for broadbill swordfish were developed for all sizes aggregated (Figure 9), adults (Figure 10), sub-adults (Figure 11) and recruits (Figure 12). For all size groups but the recruits, the nominal index declines over time from an initial high with a recent recovery, while the standardised index appears to vary cyclically with a low period from 2016. The final models are similar to the 1998–2021 models but slightly less variable. There is an increase in indices from 2021 to 2022 for all size groups, except recruits where the index stays stable (Figure 12). The sub-adults group shows the steepest increase in 2022 (Figure 11).

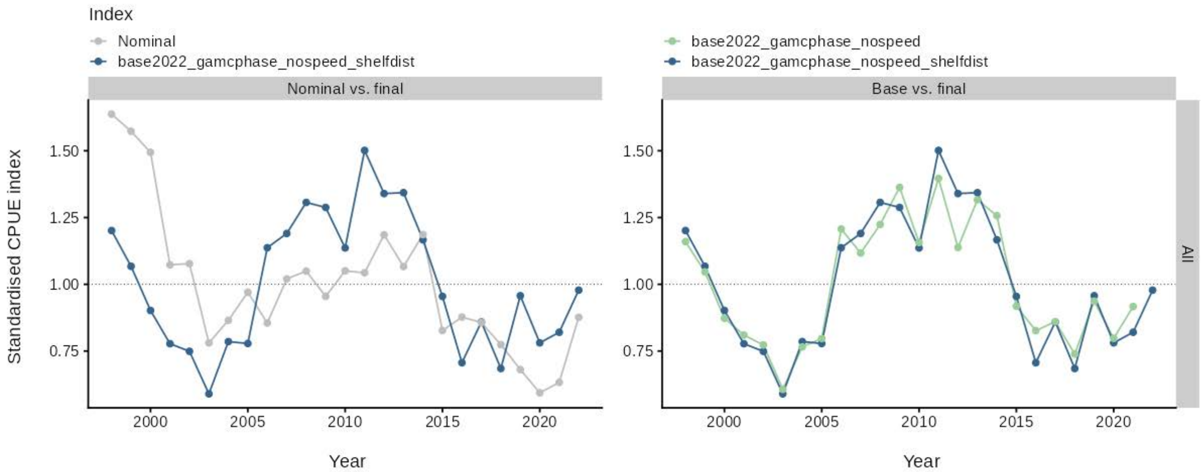

Figure 9: Comparison of the final standardised CPUE index (blue line) for 1998 to 2022 for broadbill swordfish (All) with the nominal CPUE index (grey line; left panel) and with the accepted 1998–2021 model (green line; right panel).

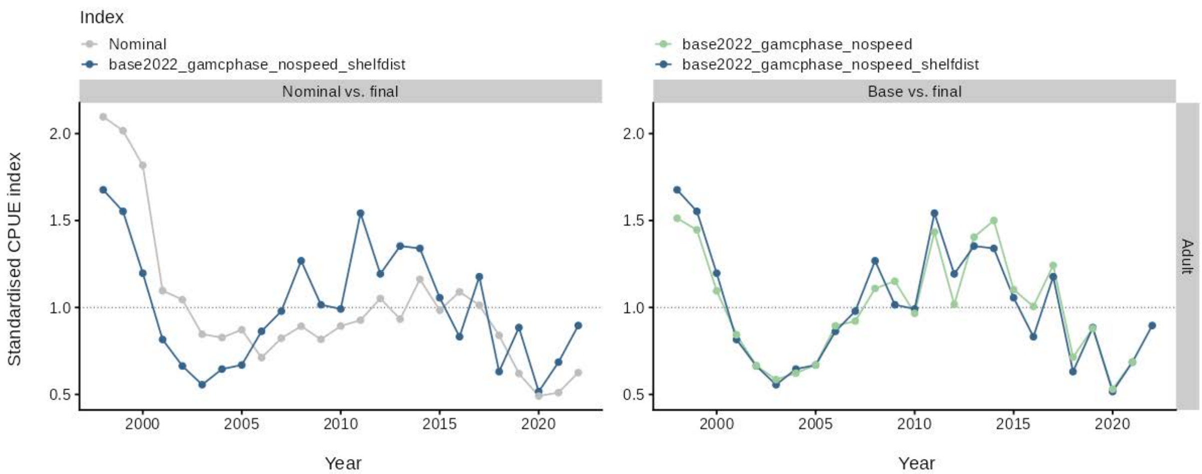

Figure 10: Comparison of the final standardised CPUE index (blue line) for 1998 to 2022 for broadbill swordfish (Adult) with the nominal CPUE index (grey line; left panel) and with the accepted 1998–2021 model (green line; right panel).

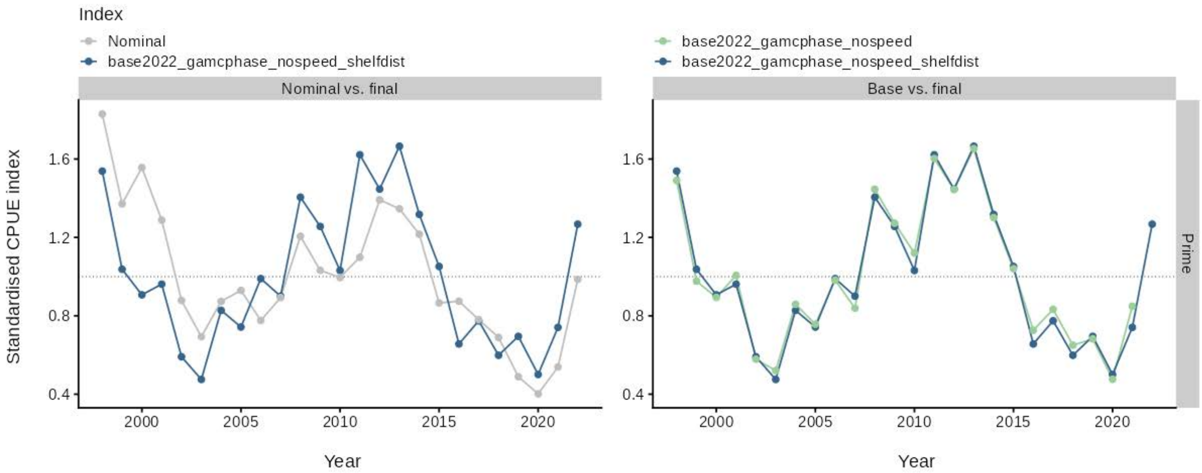

Figure 11: Comparison of the final standardised CPUE index (blue line) for 1998 to 2022 for broadbill swordfish (Sub-adult) with the nominal CPUE index (grey line; left panel) and with the accepted 1998–2021 model (green line; right panel).

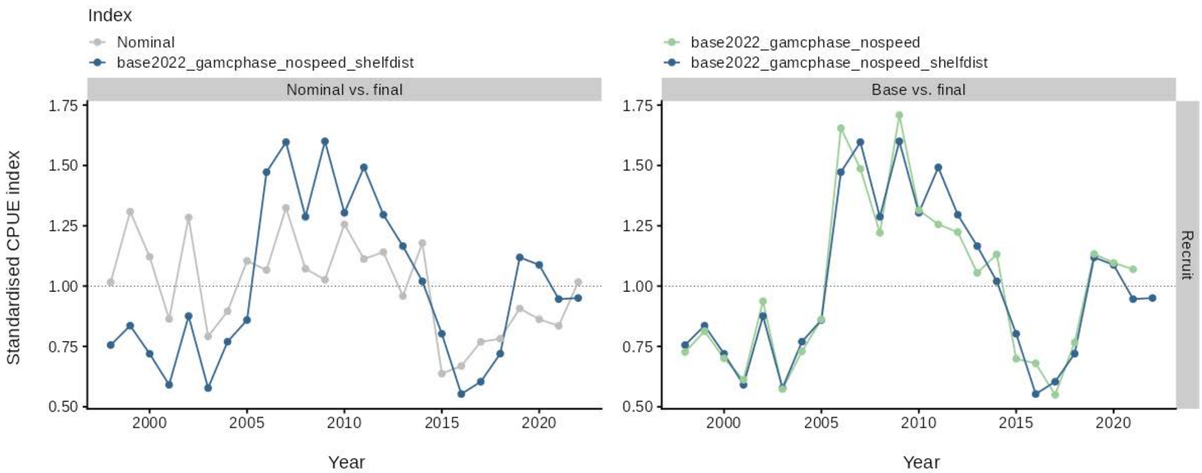

Figure 12: Comparison of the final standardised CPUE index (blue line) for 1998 to 2022 for broadbill swordfish (Recruit) with the nominal CPUE index (grey line; left panel) and with the accepted 1998–2021 model (green line; right panel).

3 Striped marlin

Standardised CPUE indices for striped marlin were developed for all sizes aggregated only (Figure 13).The nominal index shows a steady decline over time from an initial high in 1998 while the standardised index is mostly stable since the mid-2000s, with a strong standardisation effect at the start of the time-series and some variability in recent years. The trend in the final model is similar to the 1998–2021 index but the final index shows less variability over time. There was an increase in the standardised index from 2021 to 2022.

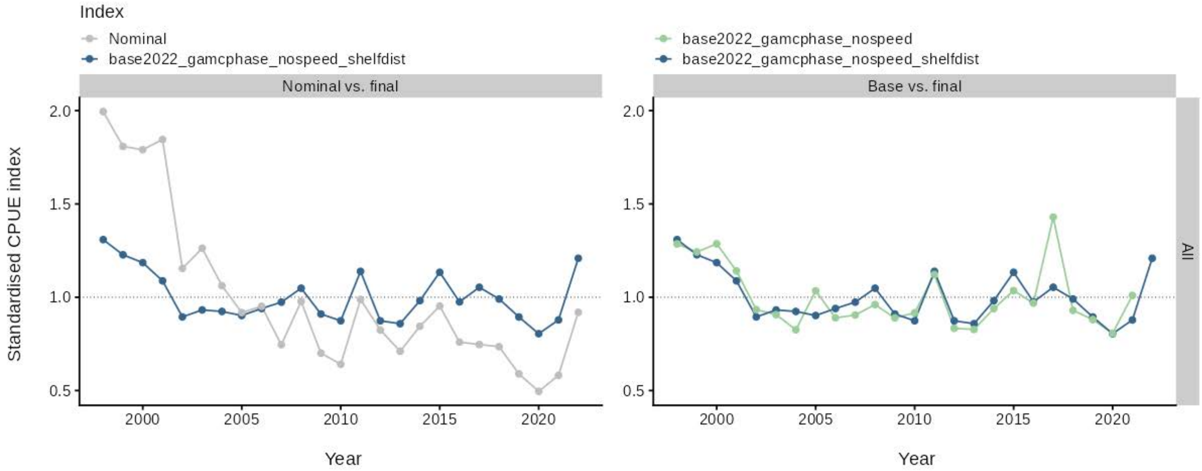

Figure 13: Comparison of the final standardised CPUE index (blue line) for 1998 to 2022 for striped marlin (All) with the nominal CPUE index (grey line; left panel) and with the accepted 1998–2021 model (green line; right panel).

4 Discussion

This year's update of standardised indices for the Eastern Tuna and Billfish fishery further expanded on the approach developped in 2022 where General Additive Models were used as a modelling framework for CPUE standardisation (Tremblay-Boyer et al., 2022a). Based on updated indices, relative abundance appeared to havee increased in 2022 for albacore tuna, yellowfin tuna, broadbill swordfish and striped marlin, and decreased for bigeye tuna (noting many of the indices remain quite variable).

Two key areas of model development were explored for this year's indices. First, a new approach was explored to refine the identification of fishing strategies in the ETBF, with the aim to replace the current targeting covariate based on species composition with an updated metier approach that also considers the operational characteristics of fishing sets. Second, covariates describing the interaction of fishing sets with eddies were developed based on a database of daily eddy location in the ETBF.

Both the metiers and eddy-based covariates were tested in this year's updated CPUE standardisation but ultimately not retained. The replacement of the species composition-based targeting covariate with the metiers-derived one induced a high amount of additional variability in some of the indices. As such, it was considered more prudent to retain the old targeting approach until the source of this additional variability was understood, noting that the refinement of the treatment of fishing strategy remains a high priority. One starting point for further exploration is that some of the covariates used to inform the metiers are also used as covariates in the standardisation itself, which might lead to some model instability if the metiers levels are confounded with some of the numerical covariates.

The development of the eddy covariates provided useful insights into the dynamic nature of the fishery but had little impact on the standardised indices when included as part of the model. This might be due to the fact that fishing set deployment strategies around eddies varies across operators, and that there are no clear trends in eddy occurrence through time. Future exploration of the effects of eddies will attempt to account for possible interactions with the target species and operators.

Concerns were raised at previous TTRAGs as to whether the index was correctly standardising for changes in fishing strategies that occurred during the COVID period, especially in 2020 when opportunities for fresh exports by plane were curtailed. There are some features in the standardised index that appear to match the 2020 COVID period (e.g., the 2020 decline in swordfish subadult abundance and the 2020 increase in albacore abundance). Work presented at TTRAG 36 highlighted that changes in fishing operations during 2020 could be captured by the distribution of key operational fields in the logbook. As such, ongoing work will further refine the treatment of operational covariates to ensure that proxy covariates such as the Area and Area-Qtr effects are not preventing the model from fitting realistic functional relationships between catch rates and operational covariates.

Another research priority for improving ETBF indices is the treatment of evolving effort patterns over the fishing areas over the time-period for which the indices are developed. This is currently handled by the use of pre-defined species-specific areas that are used as covariates in the index, as drivers of implicit model weights for fishing sets used to train the model and as scalers in the computation of the final annual indices. An ideal approach would not rely on pre-defined areas to generate the index given dynamic spatial patterns of both effort and abundance in the ETBF. Improving the treatment of spatio-temporal effects should thus remain an active area of investigation for this fishery. The first step is to derive the index based on a prediction of abundance in the spatial domain area for the model which allows to clearly separate covariates thought to impact abundance vs. catchability. The current approach assumes that only year, quarter and pre-defined area affect abundance but other covariates included in the model, e.g., SOI, bathymetry and SST, relate to habitat and should also index abundance. Ongoing work to improve index computation is underway but was not completed in time for TTRAG 38.

Finally, from the data collection perspective, the use of a fixed constant to apportion discards to size-classes for the 1998 to 2022 period remains problematic, especially as discard practices can change over time. These proportions were originally obtained based on observer sampling. While observer data are no longer collected since the implementation of electronic monitoring, alternatives to quantify the size distribution of discards should be considered by the TTRAG. This issue should be prioritised for discussion at future TTRAGs.

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A Appendix: Metiers-approach to identifying fishing strategies

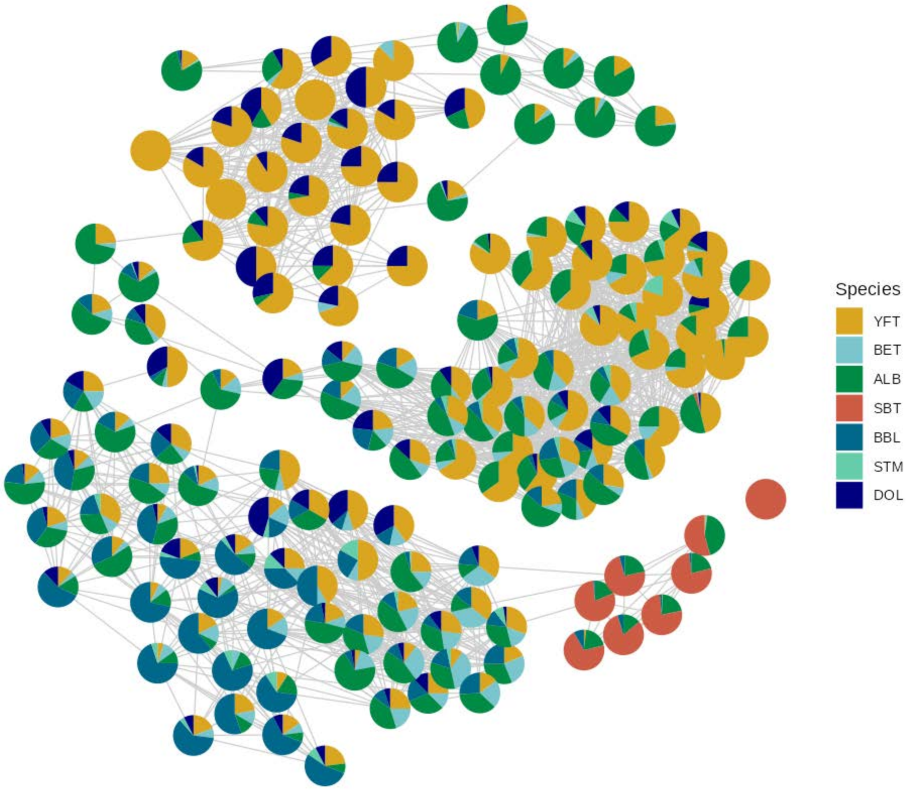

Figure A-1: Force-directed-graph for the selected final model of annual clusters from 1998 to 2022. Each point (pie) shows one of the six clusters identified for a given year; points closer together are more similar in terms of the operational and species composition characterics of their fishing sets. Pies show the proportion of each species in the total catch of each annual cluster.

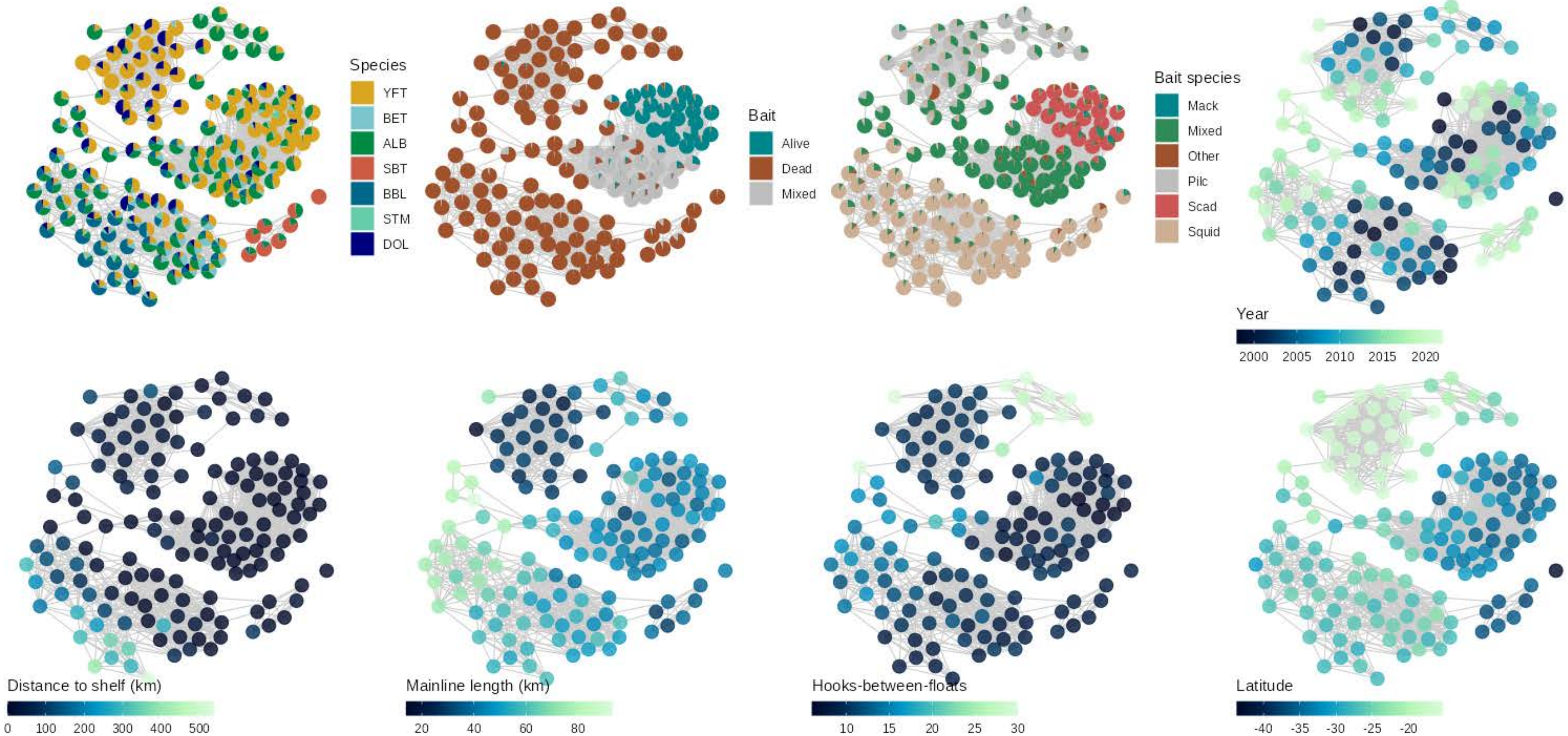

Figure A-2: Force-directed-graph for the selected final model of annual clusters from 1998 to 2022. Each point (pie) shows one of the six clusters identified for a given year; points closer together are more similar in terms of the operational and species composition characterics of their fishing sets. Points are coloured to show the mean value for the fishing sets in each cluster of key operational characteristics (panels).

B Appendix: Effects of changes in model structure

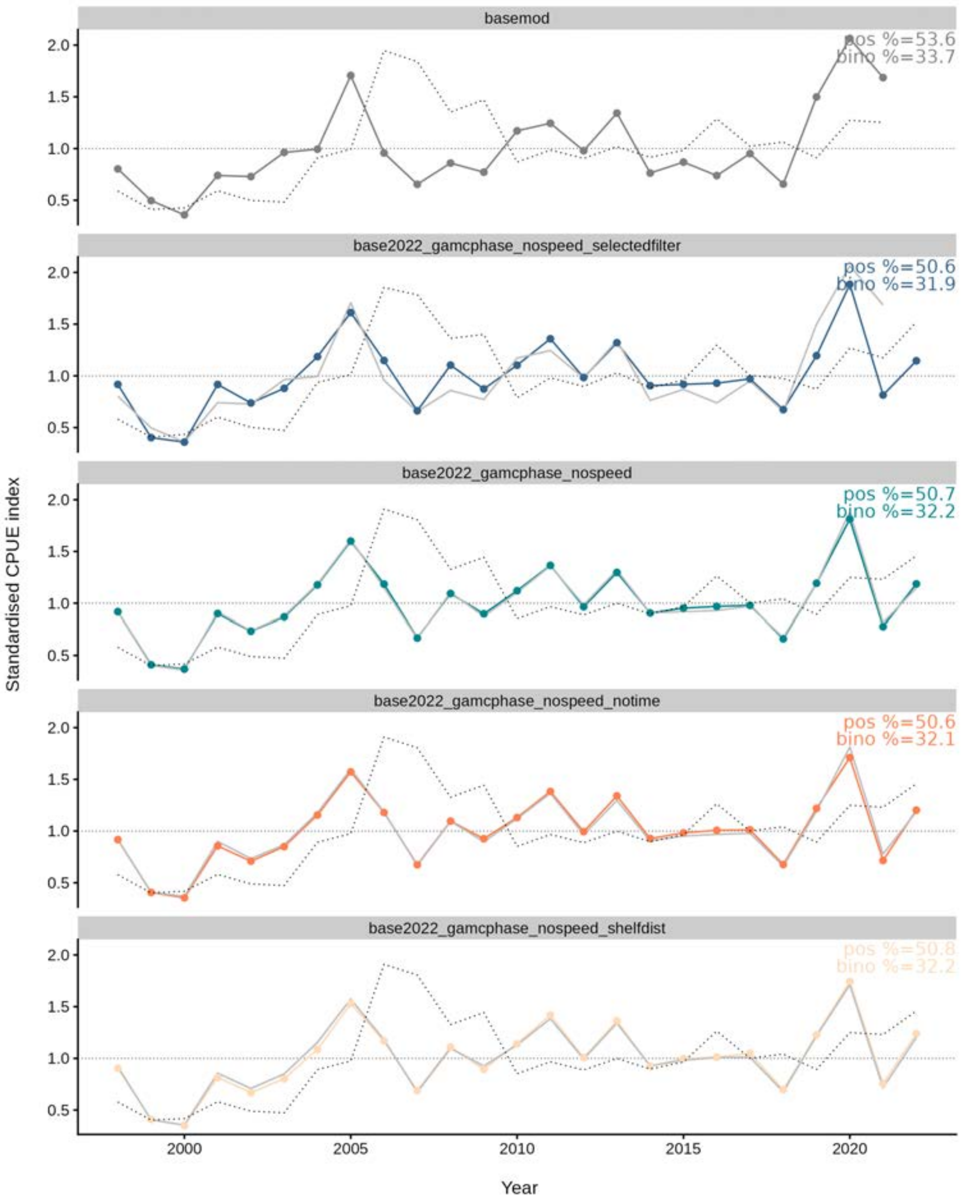

Figure B-1: Stepwise comparison of the progression from the accepted 1998–2021 model to the final standardised CPUE index for 1998 to 2022 for albacore tuna (All). The grey line shows the index from the preceding step and the dotted line shows the nominal index. The proportion of the deviance explained by each model component is in the top-right corner.

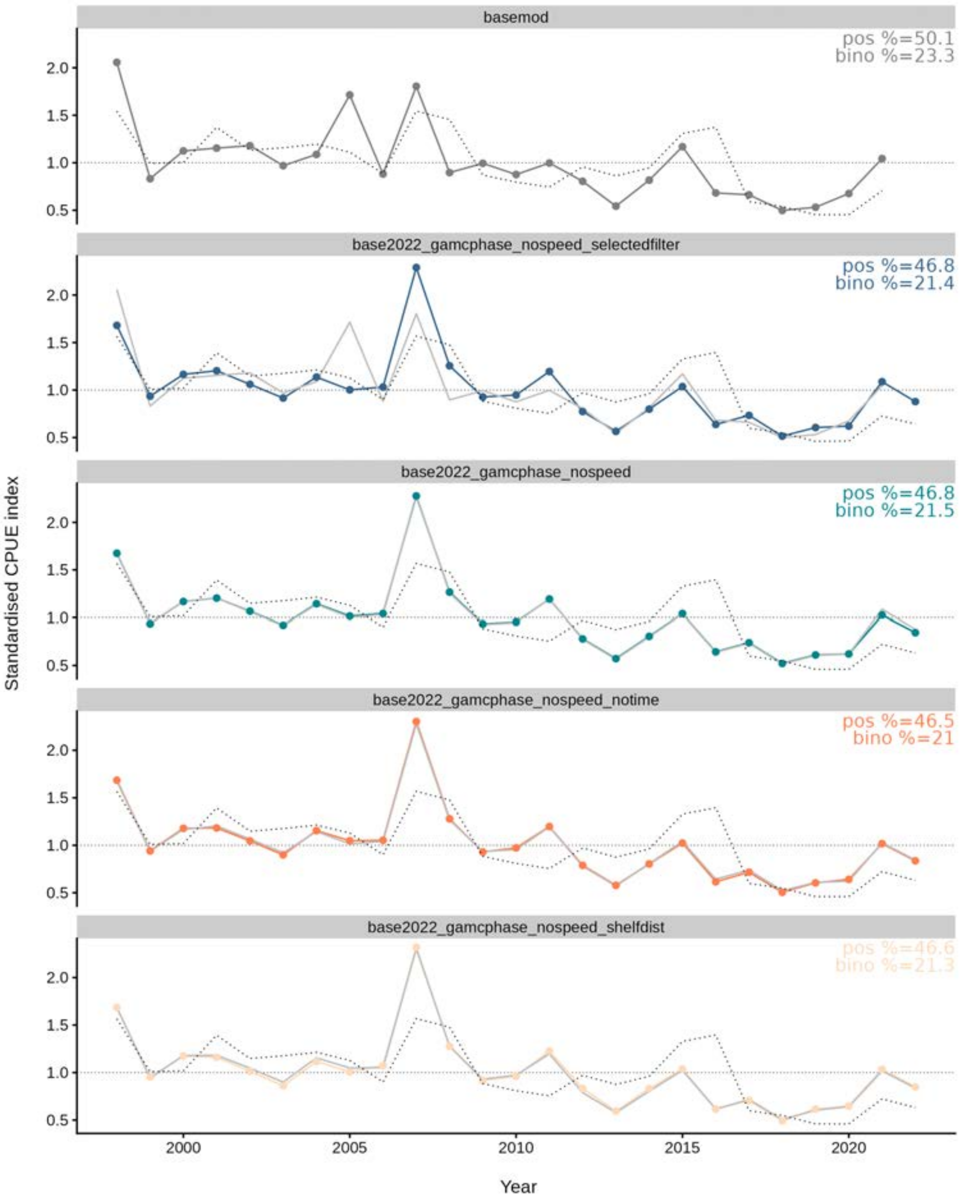

Figure B-2: Stepwise comparison of the progression from the accepted 1998–2021 model to the final standardised CPUE index for 1998 to 2022 for bigeye tuna (All). The grey line shows the index from the preceding step and the dotted line shows the nominal index. The proportion of the deviance explained by each model component is in the top-right corner.

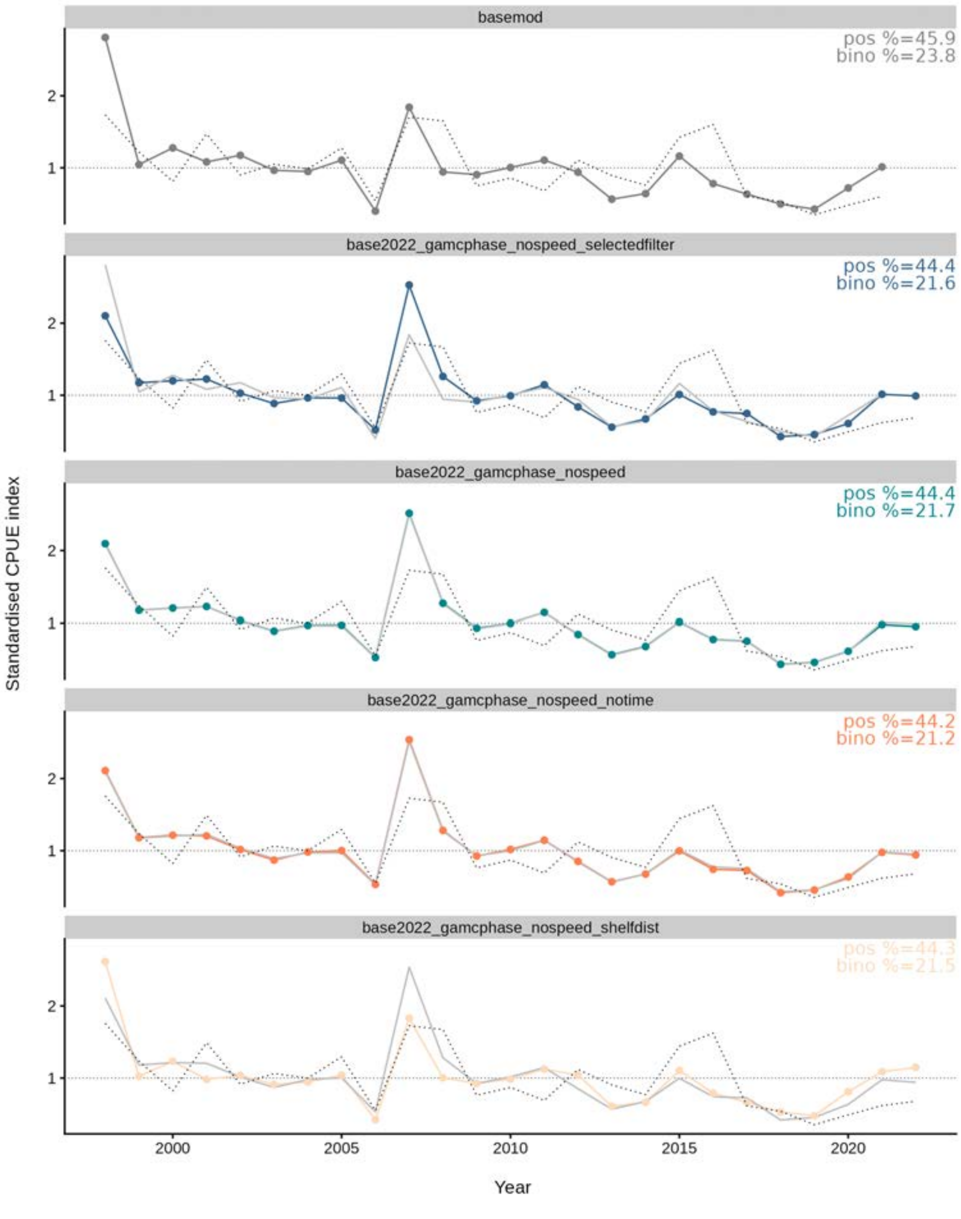

Figure B-3: Stepwise comparison of the progression from the accepted 1998–2021 model to the final standardised CPUE index for 1998 to 2022 for bigeye tuna (Adult). The grey line shows the index from the preceding step and the dotted line shows the nominal index. The proportion of the deviance explained by each model component is in the top-right corner.

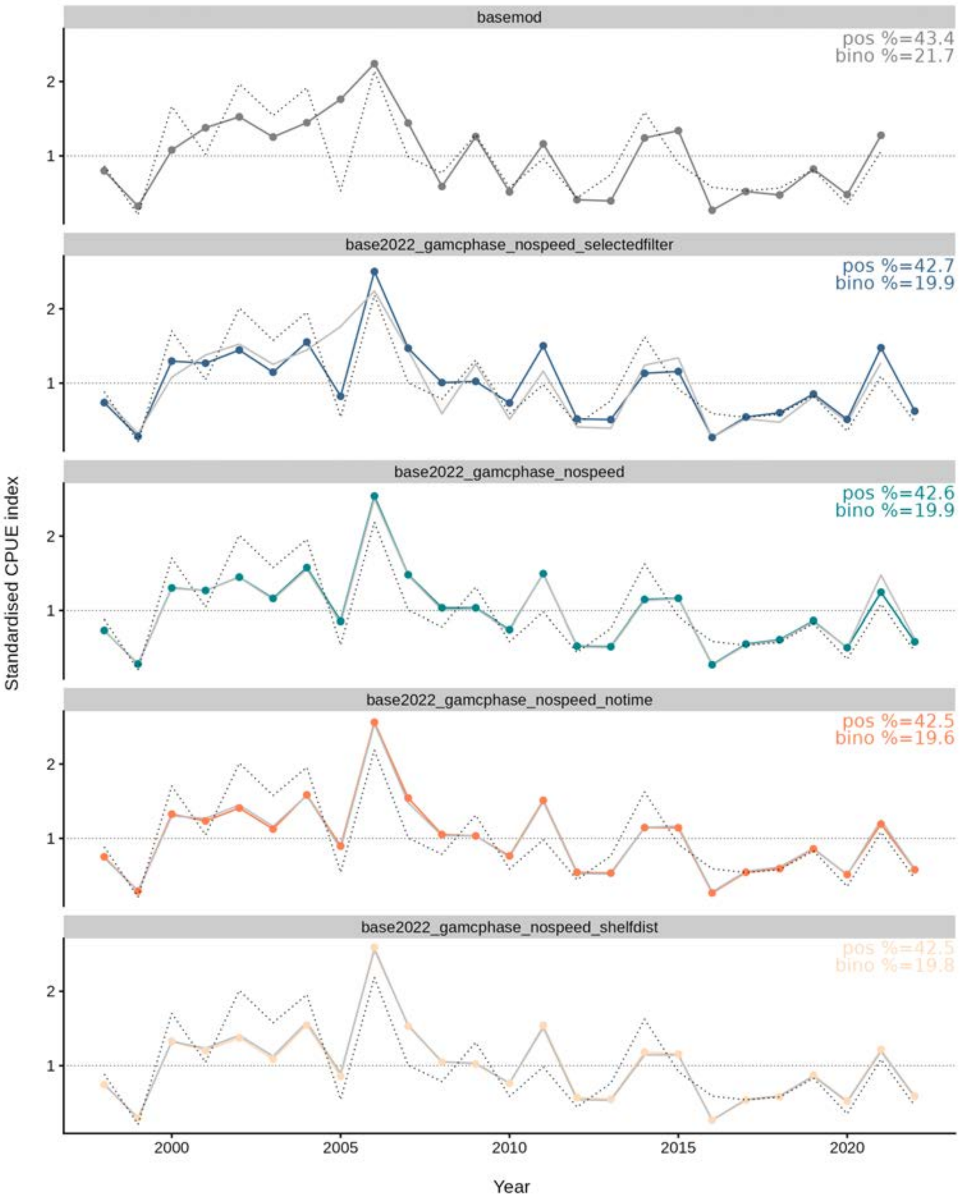

Figure B-4: Stepwise comparison of the progression from the accepted 1998–2021 model to the final standardised CPUE index for 1998 to 2022 for bigeye tuna (Recruit). The grey line shows the index from the preceding step and the dotted line shows the nominal index. The proportion of the deviance explained by each model component is in the top-right corner.

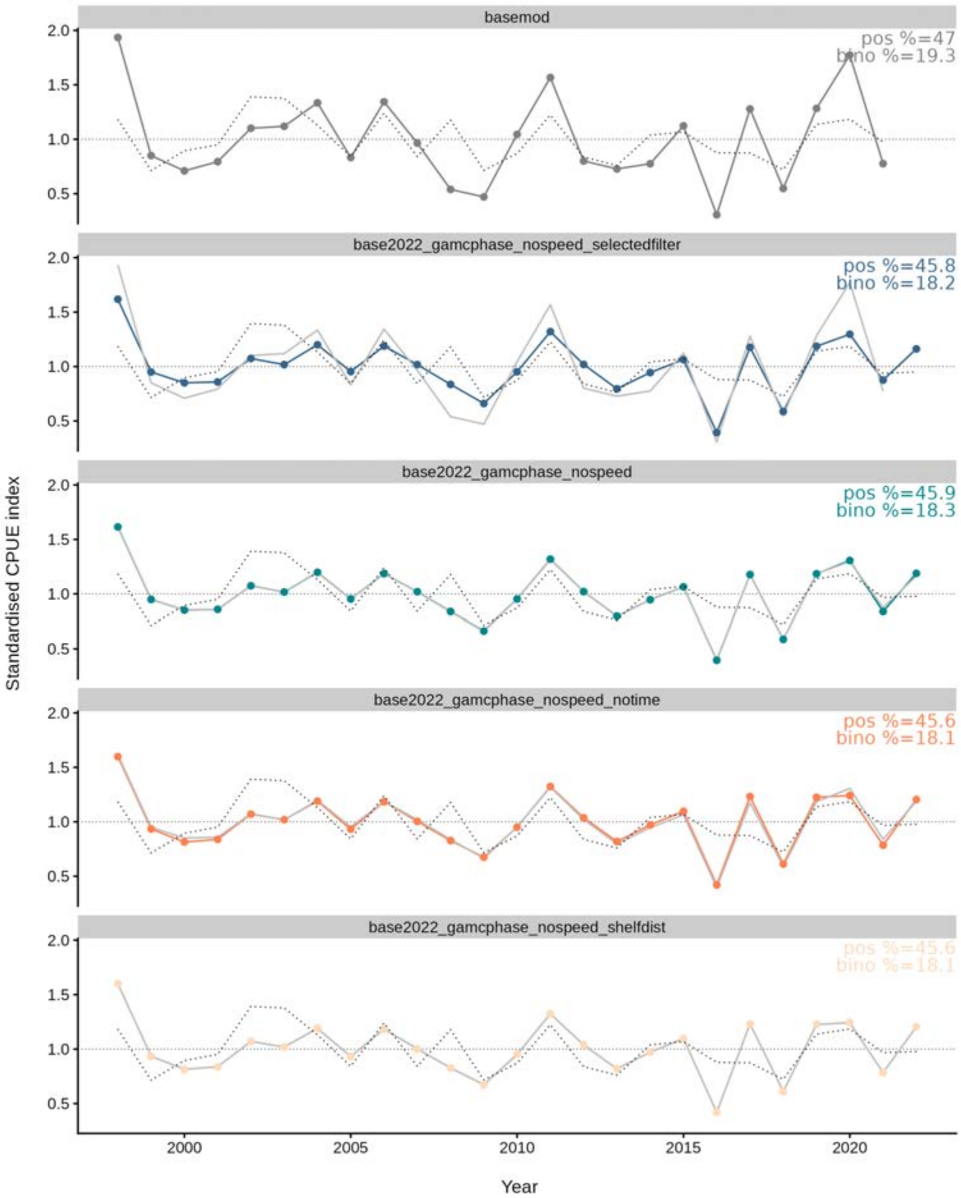

Figure B-5: Stepwise comparison of the progression from the accepted 1998–2021 model to the final standardised CPUE index for 1998 to 2022 for yellowfin tuna (All). The grey line shows the index from the preceding step and the dotted line shows the nominal index. The proportion of the deviance explained by each model component is in the top-right corner.

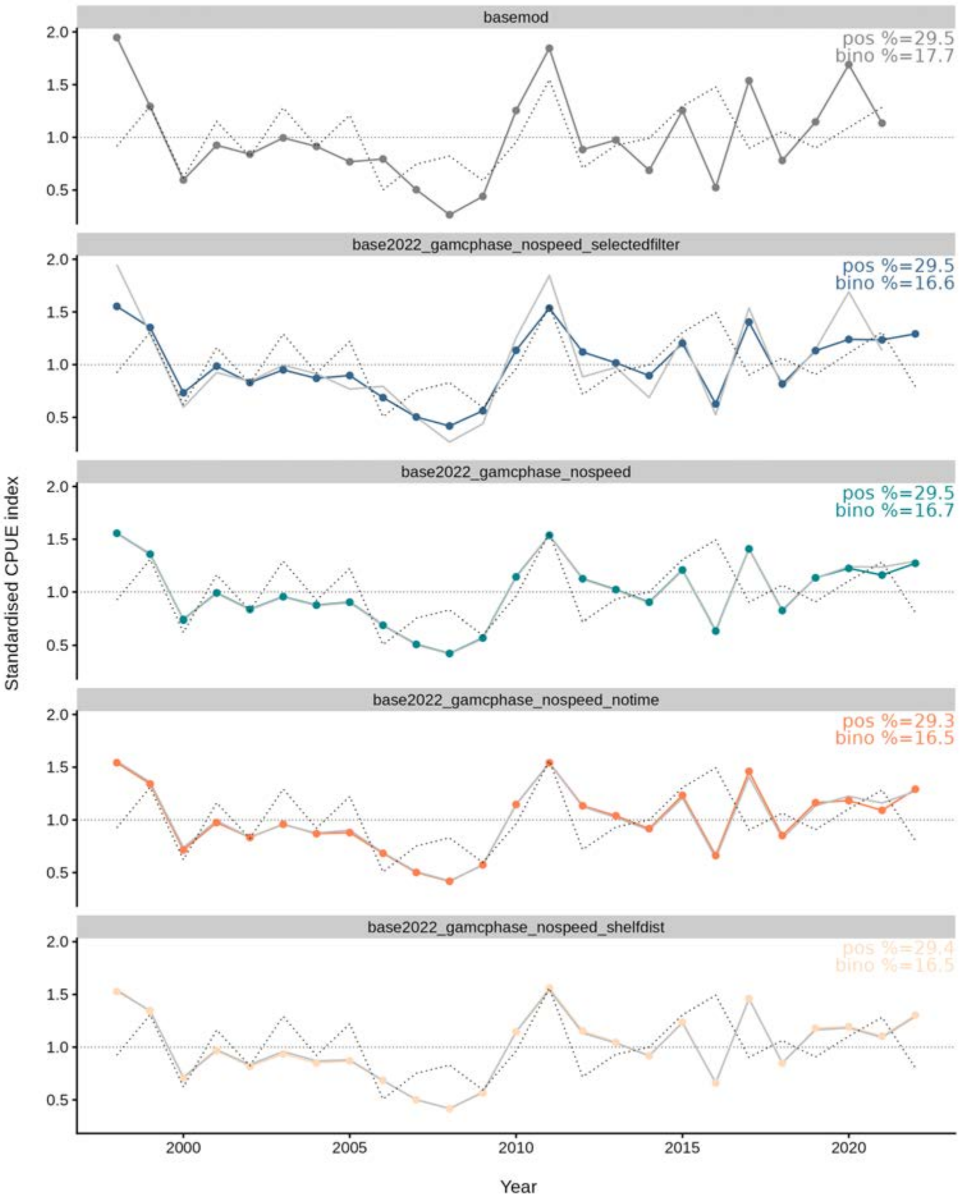

Figure B-6: Stepwise comparison of the progression from the accepted 1998–2021 model to the final standardised CPUE index for 1998 to 2022 for yellowfin tuna (Adult). The grey line shows the index from the preceding step and the dotted line shows the nominal index. The proportion of the deviance explained by each model component is in the top-right corner.

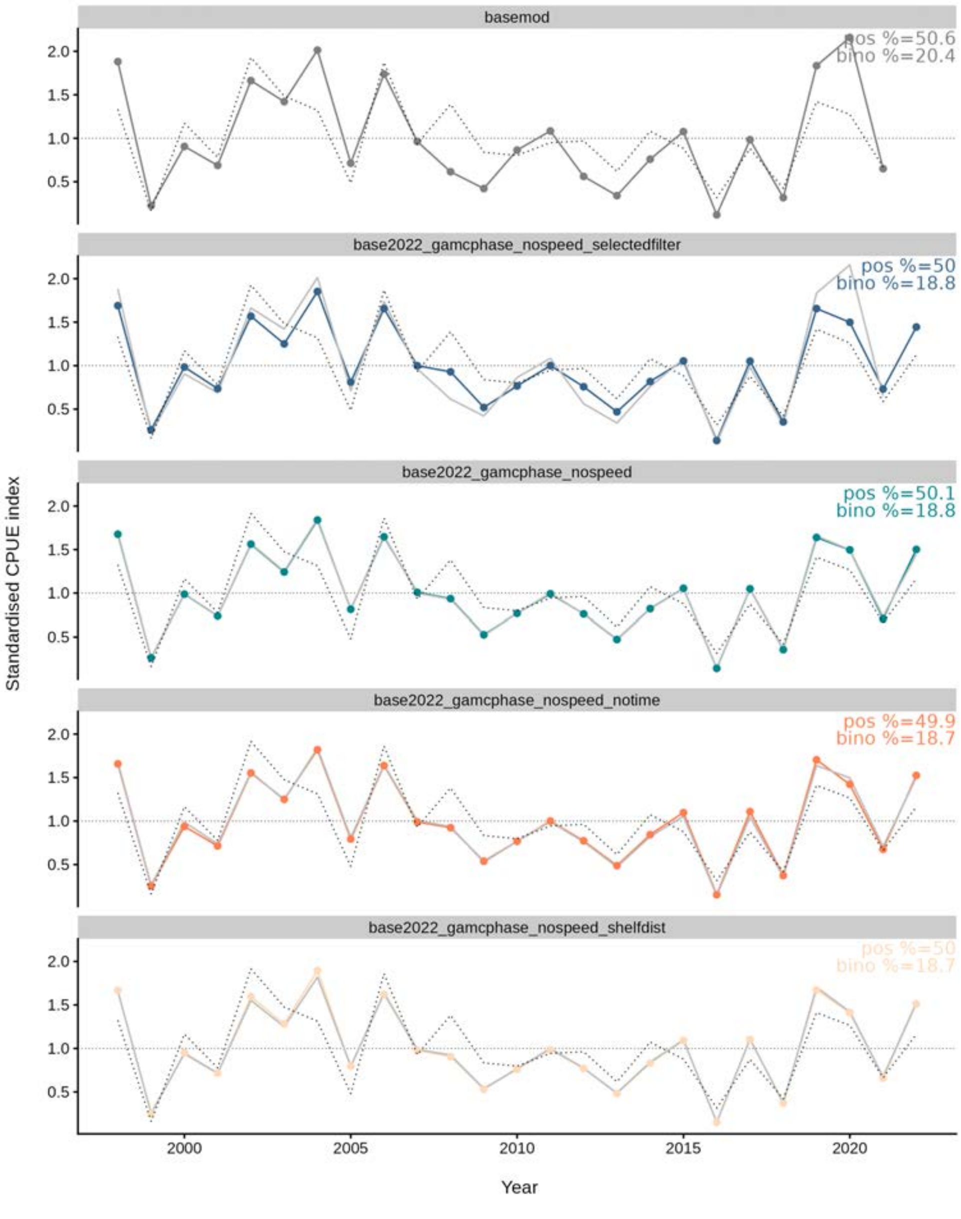

Figure B-7: Stepwise comparison of the progression from the accepted 1998–2021 model to the final standardised CPUE index for 1998 to 2022 for yellowfin tuna (Recruit). The grey line shows the index from the preceding step and the dotted line shows the nominal index. The proportion of the deviance explained by each model component is in the top-right corner.

Figure B-8: Stepwise comparison of the progression from the accepted 1998–2021 model to the final standardised CPUE index for 1998 to 2022 for broadbill swordfish (All). The grey line shows the index from the preceding step and the dotted line shows the nominal index. The proportion of the deviance explained by each model component is in the top-right corner.

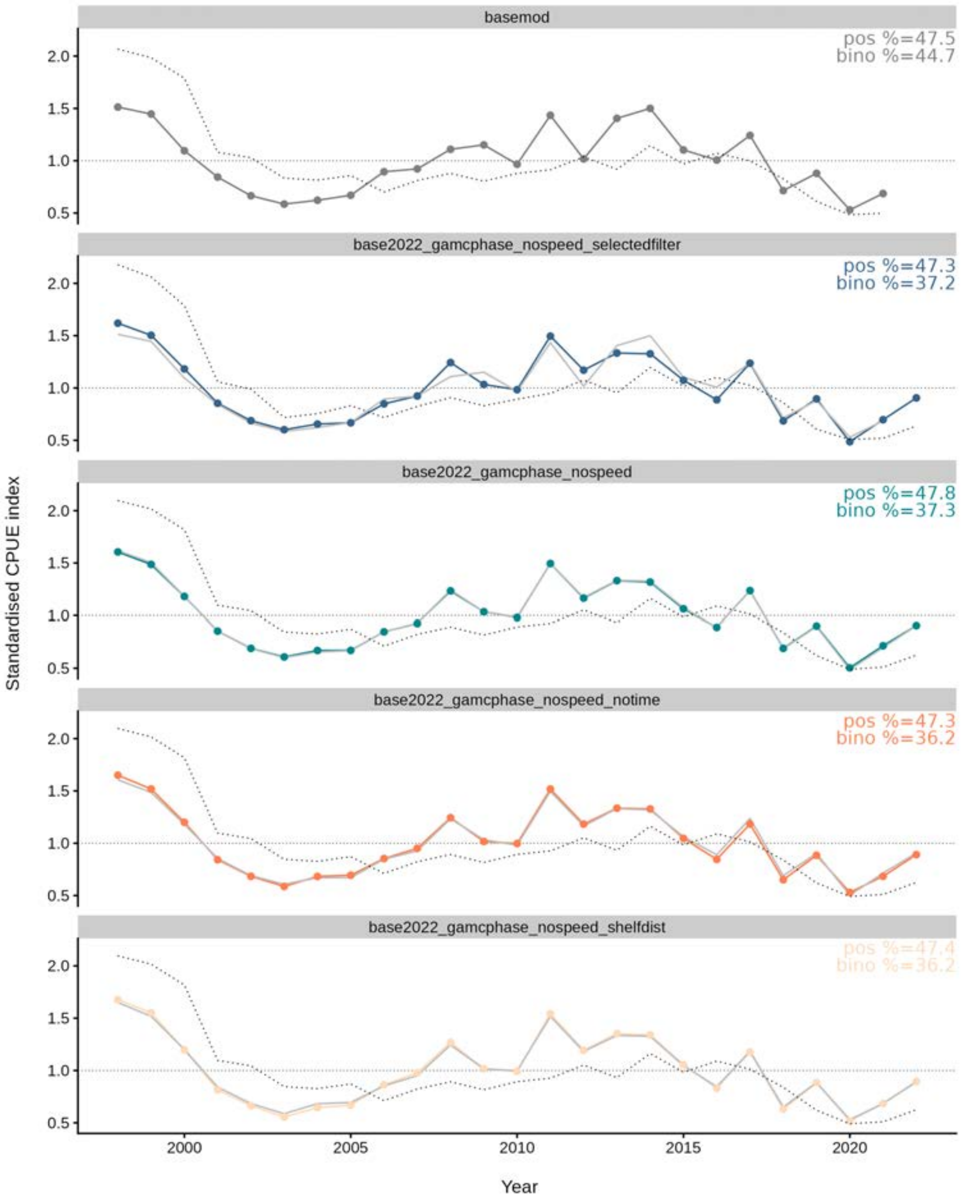

Figure B-9: Stepwise comparison of the progression from the accepted 1998–2021 model to the final standardised CPUE index for 1998 to 2022 for broadbill swordfish (Adult). The grey line shows the index from the preceding step and the dotted line shows the nominal index. The proportion of the deviance explained by each model component is in the top-right corner.

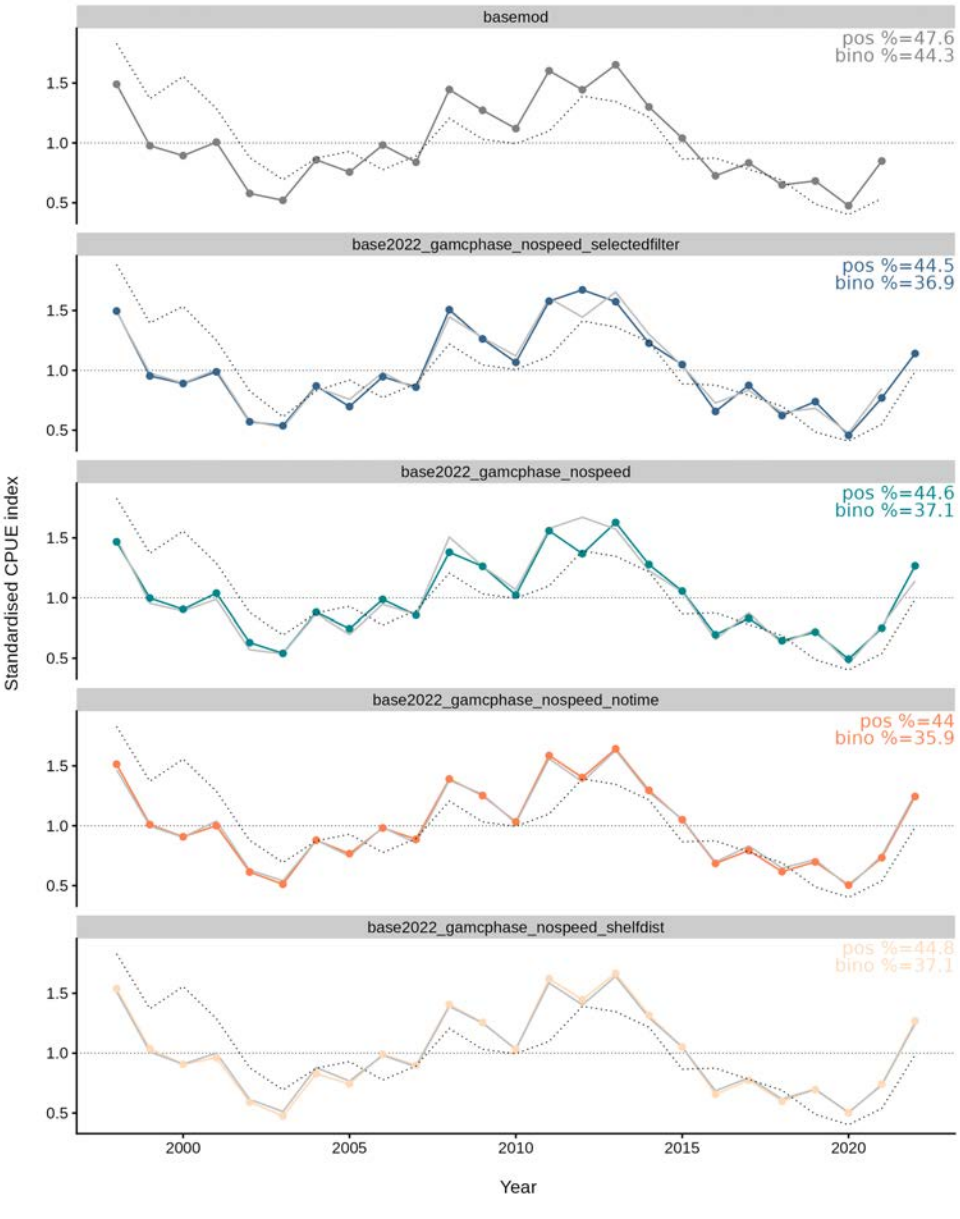

Figure B-10: Stepwise comparison of the progression from the accepted 1998–2021 model to the final standardised CPUE index for 1998 to 2022 for broadbill swordfish (Sub-adult). The grey line shows the index from the preceding step and the dotted line shows the nominal index. The proportion of the deviance explained by each model component is in the top-right corner.

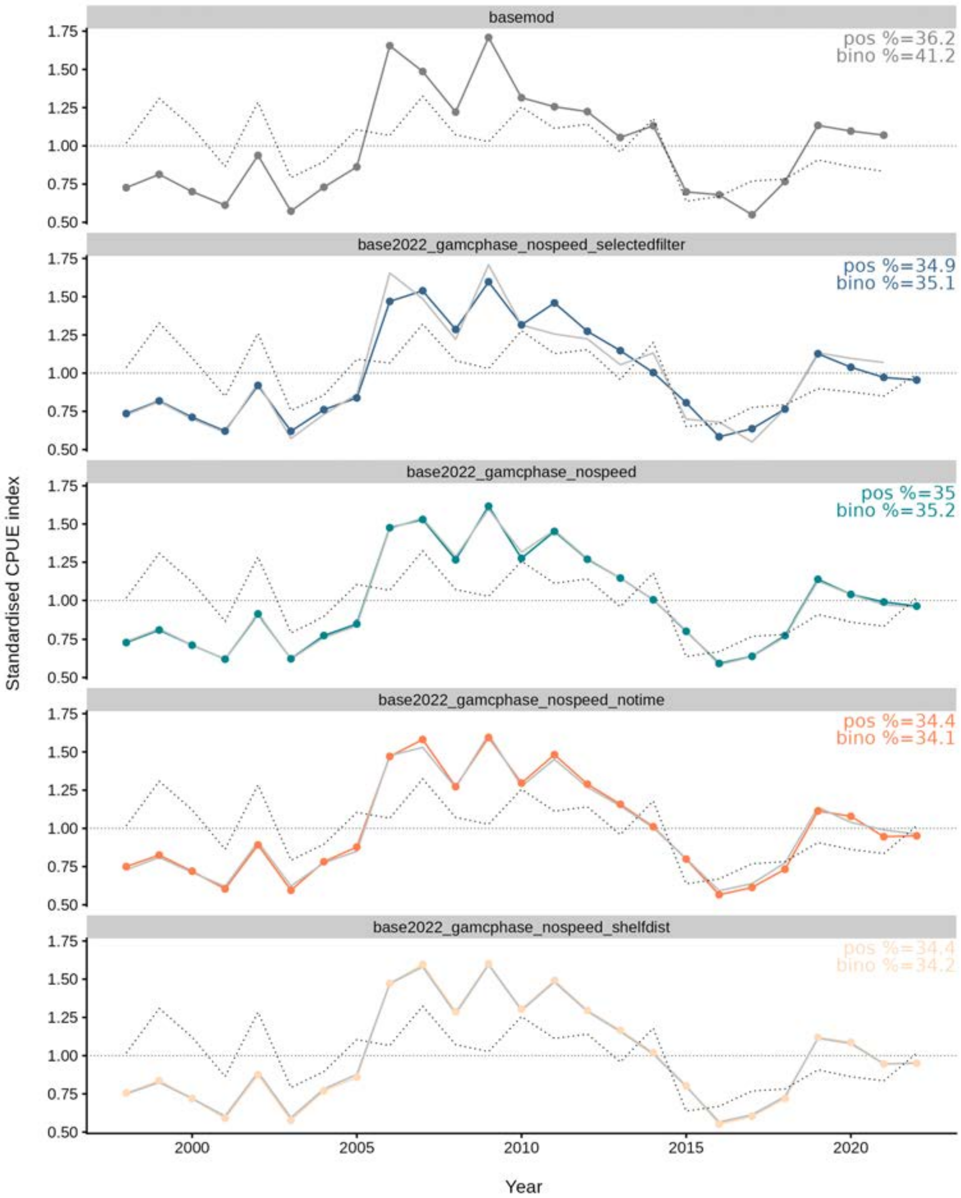

Figure B-11: Stepwise comparison of the progression from the accepted 1998–2021 model to the final standardised CPUE index for 1998 to 2022 for broadbill swordfish (Recruit). The grey line shows the index from the preceding step and the dotted line shows the nominal index. The proportion of the deviance explained by each model component is in the top-right corner.

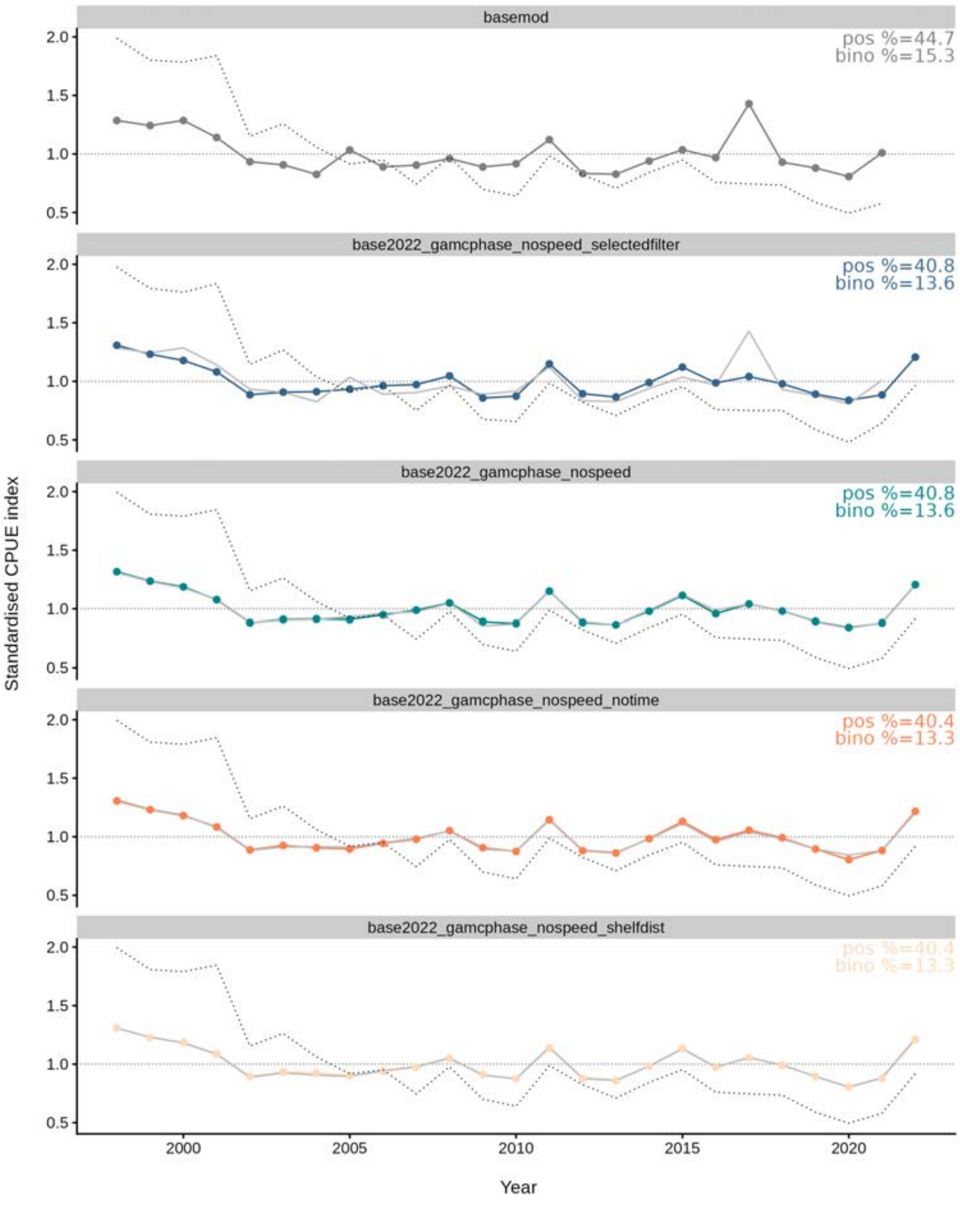

Figure B-12: Stepwise comparison of the progression from the accepted 1998–2021 model to the final standardised CPUE index for 1998 to 2022 for striped marlin (All). The grey line shows the index from the preceding step and the dotted line shows the nominal index. The proportion of the deviance explained by each model component is in the top-right corner.

C Appendix: Stepwise effect of covariates on final standardised index

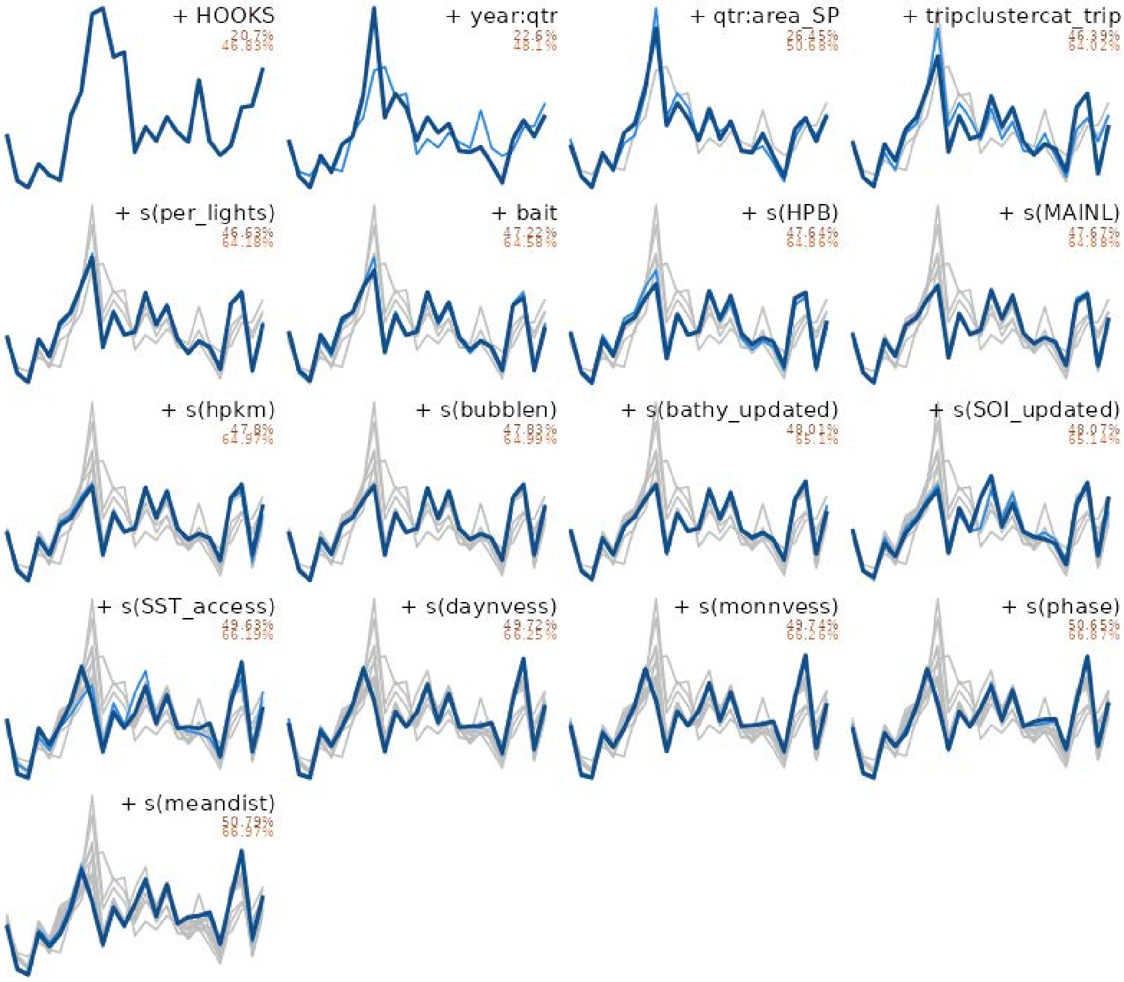

Figure C-1: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for albacore tuna (All). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

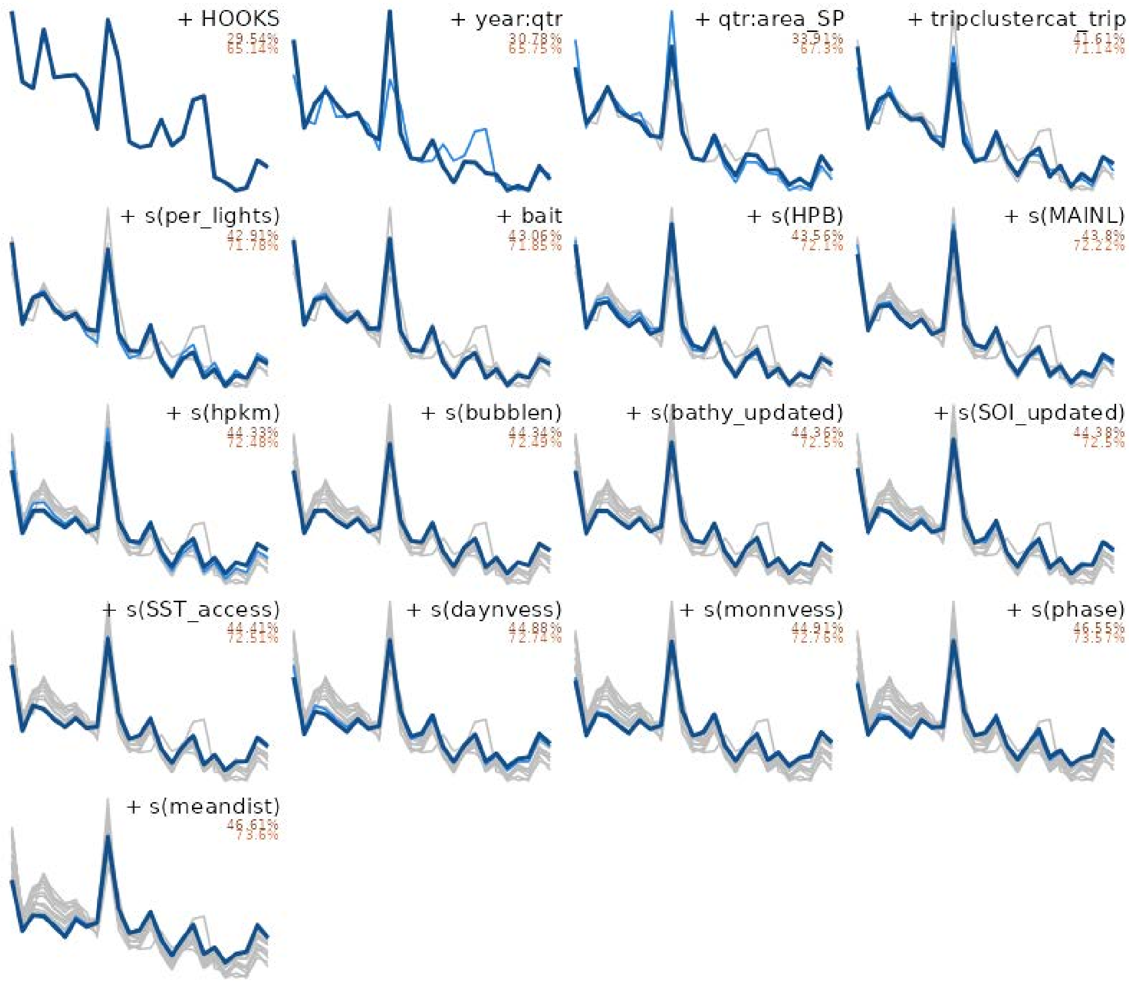

Figure C-2: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for bigeye tuna (All). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

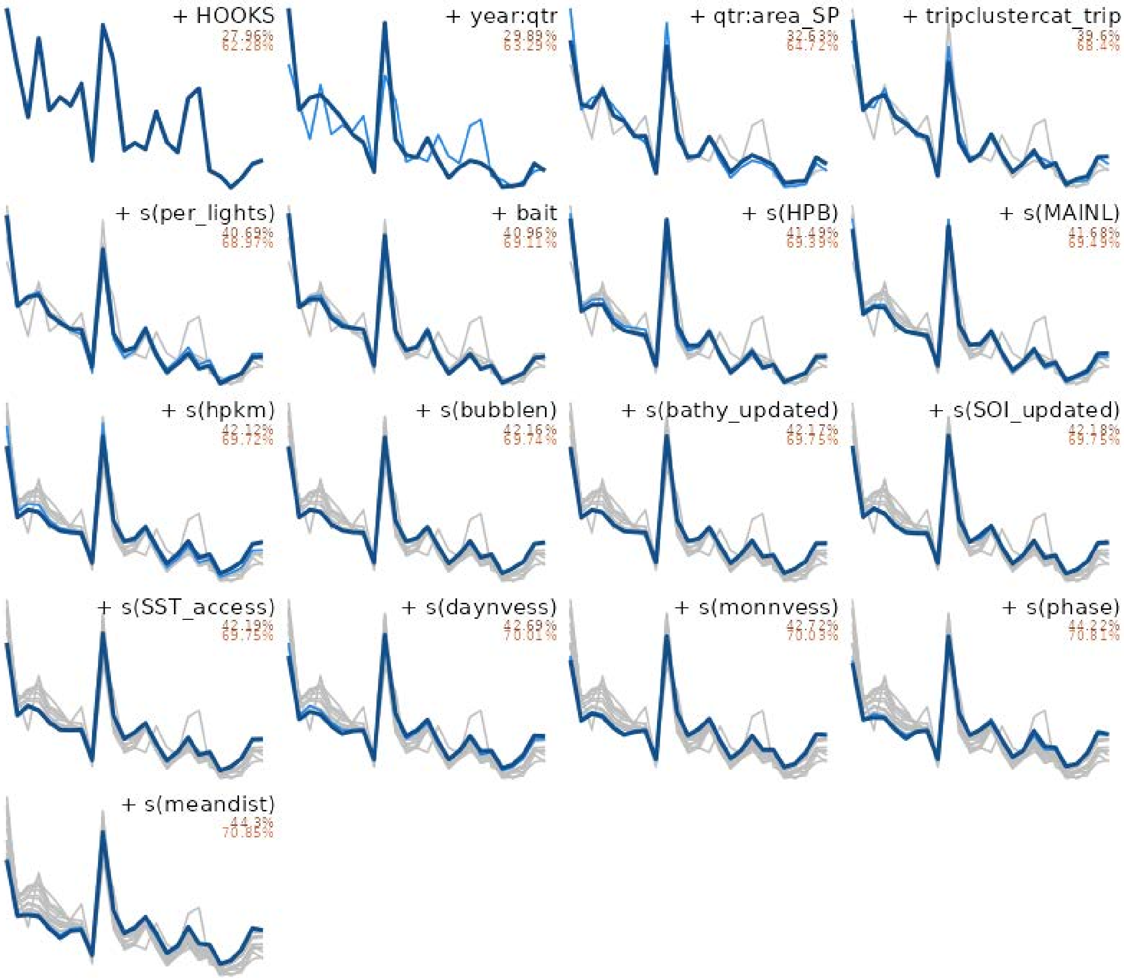

Figure C-3: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for bigeye tuna (Adult). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

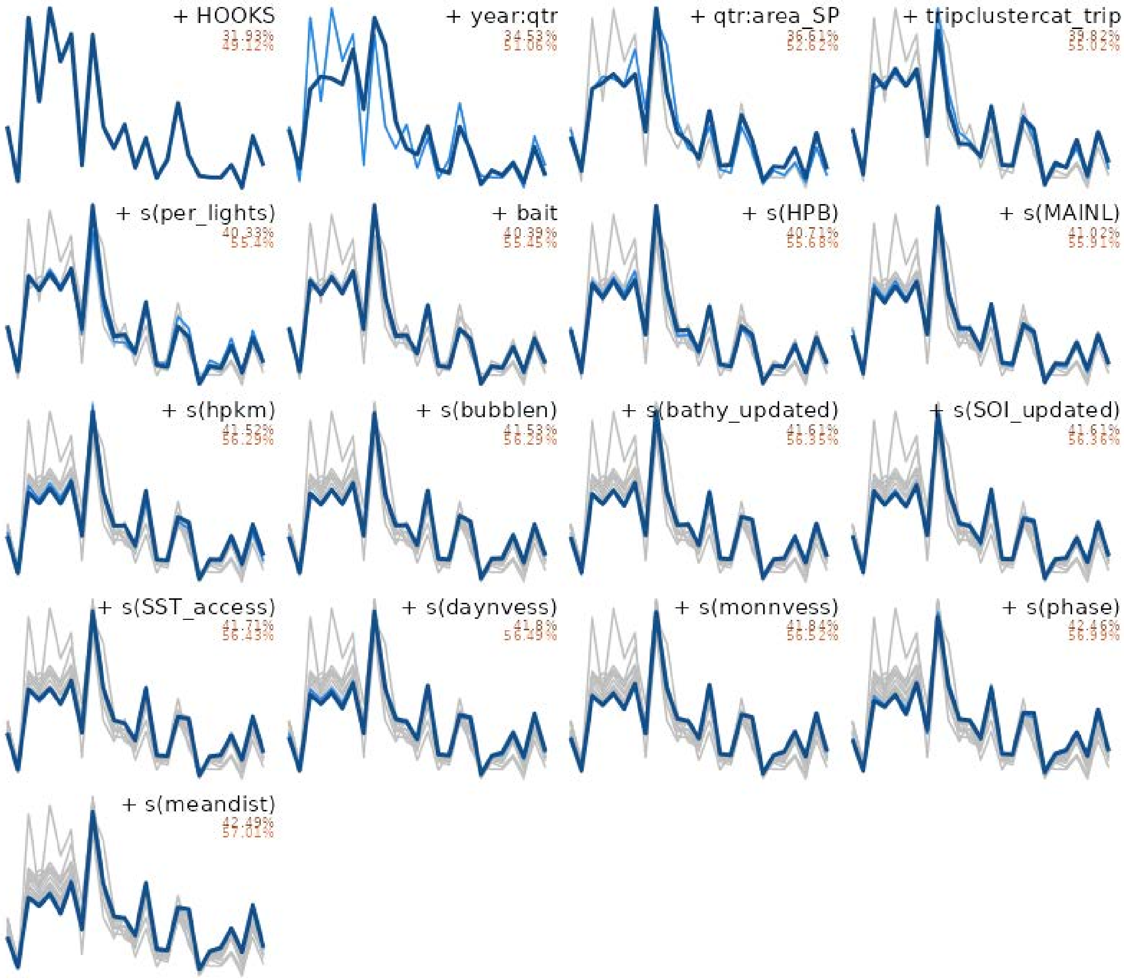

Figure C-4: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for bigeye tuna (Recruit). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

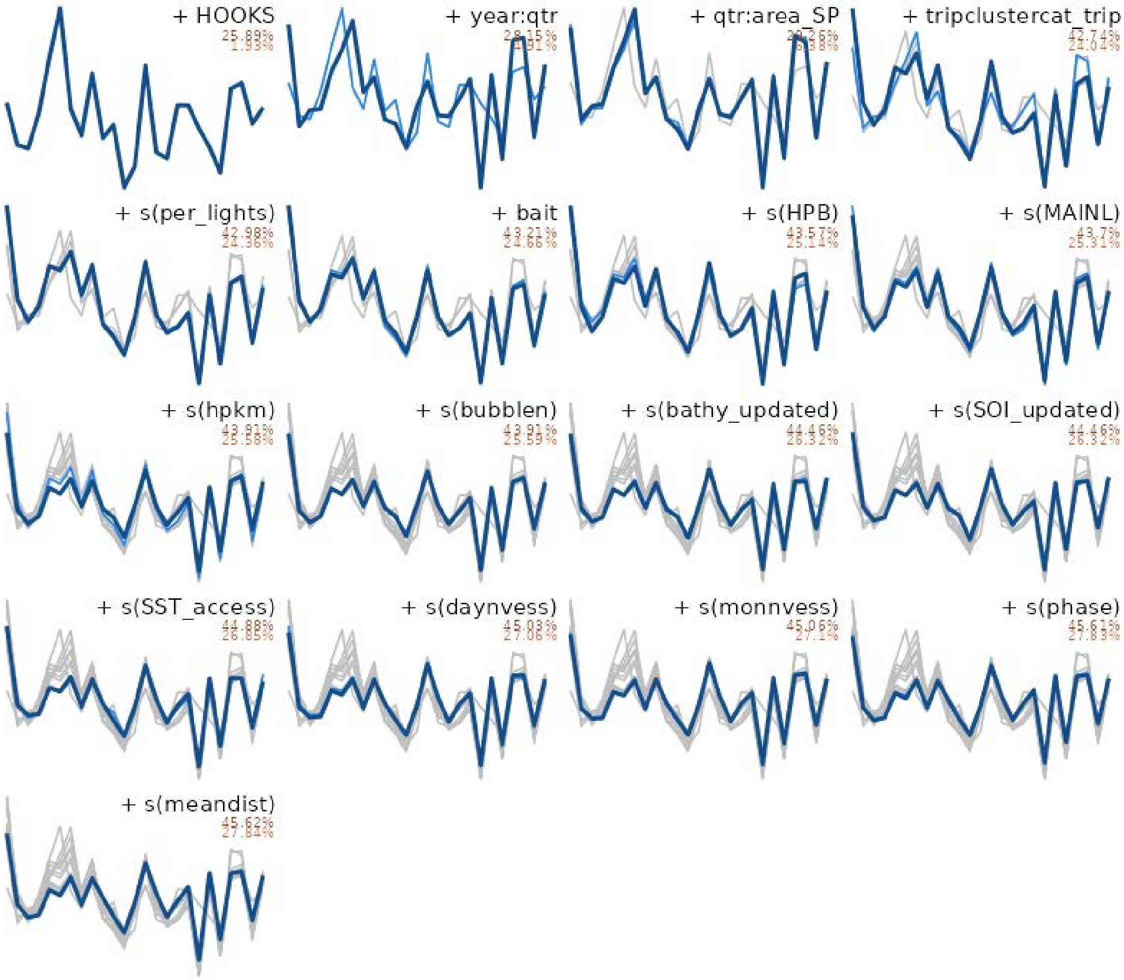

Figure C-5: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for yellowfin tuna (All). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

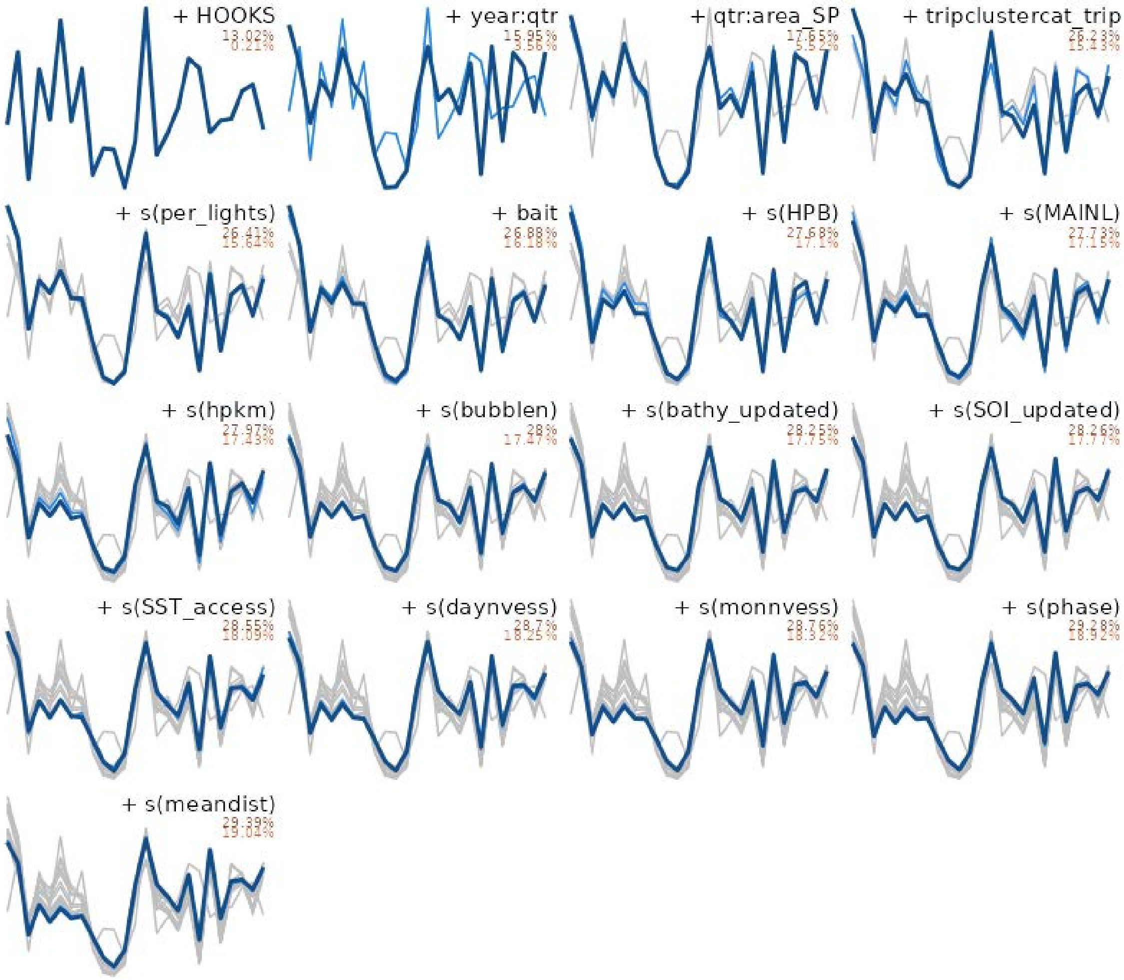

Figure C-6: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for yellowfin tuna (Adult). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

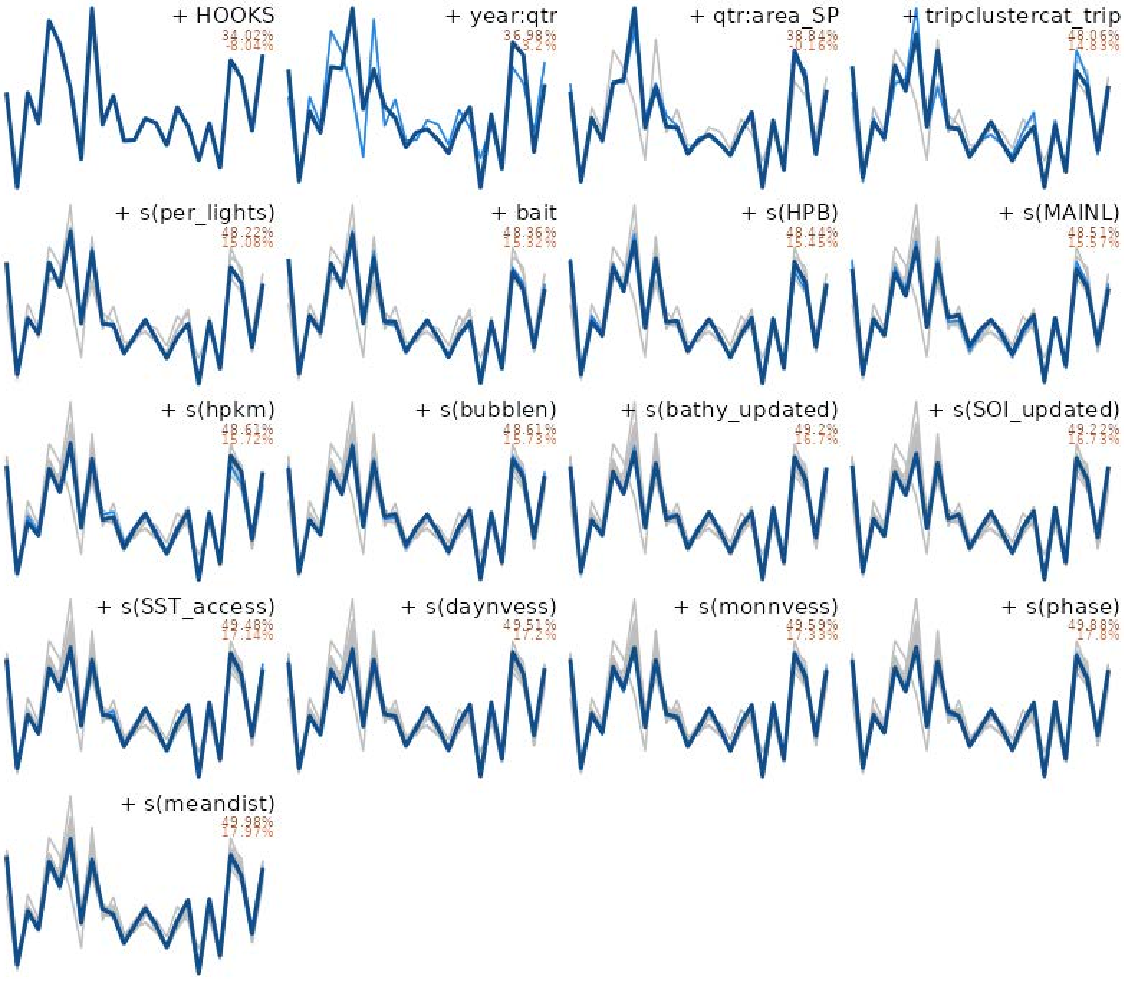

Figure C-7: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for yellowfin tuna (Recruit). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

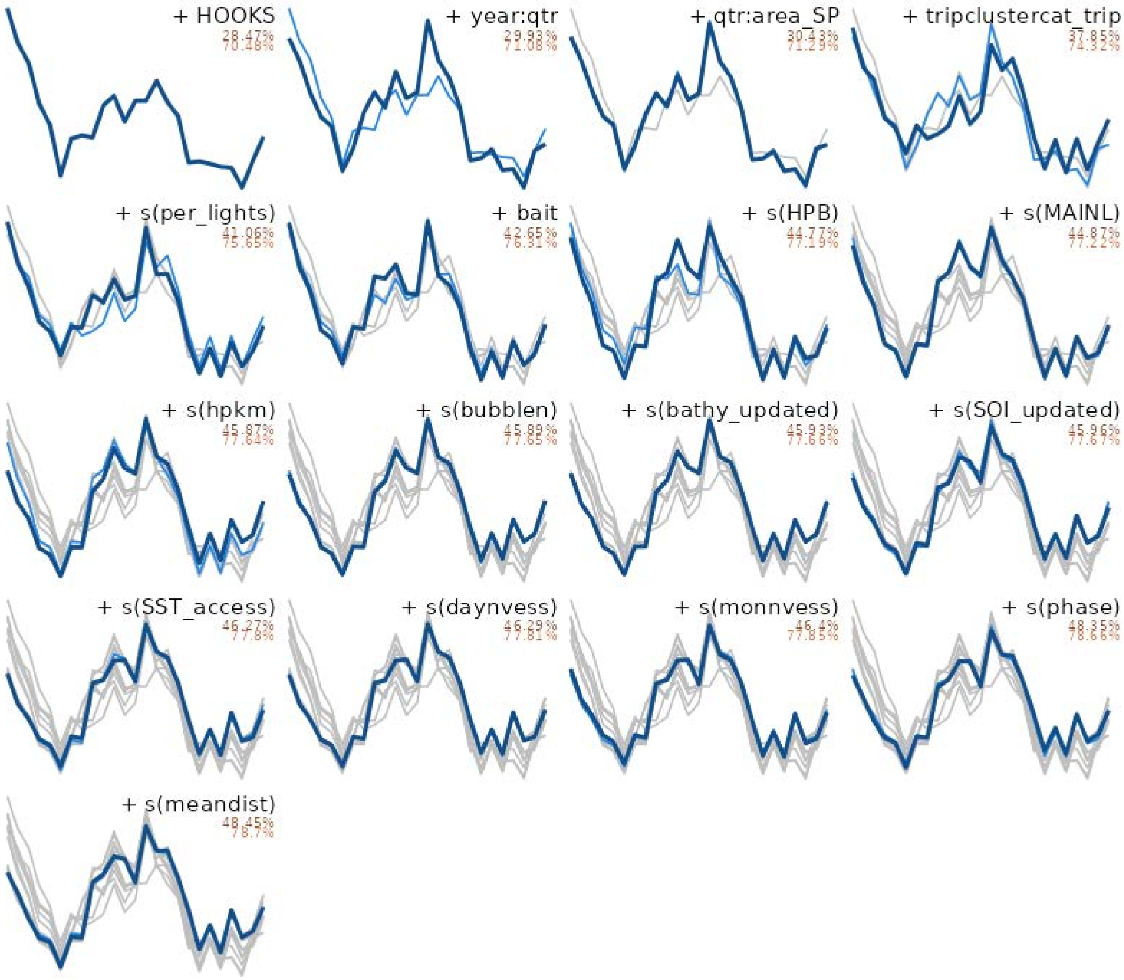

Figure C-8: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for broadbill swordfish (All). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

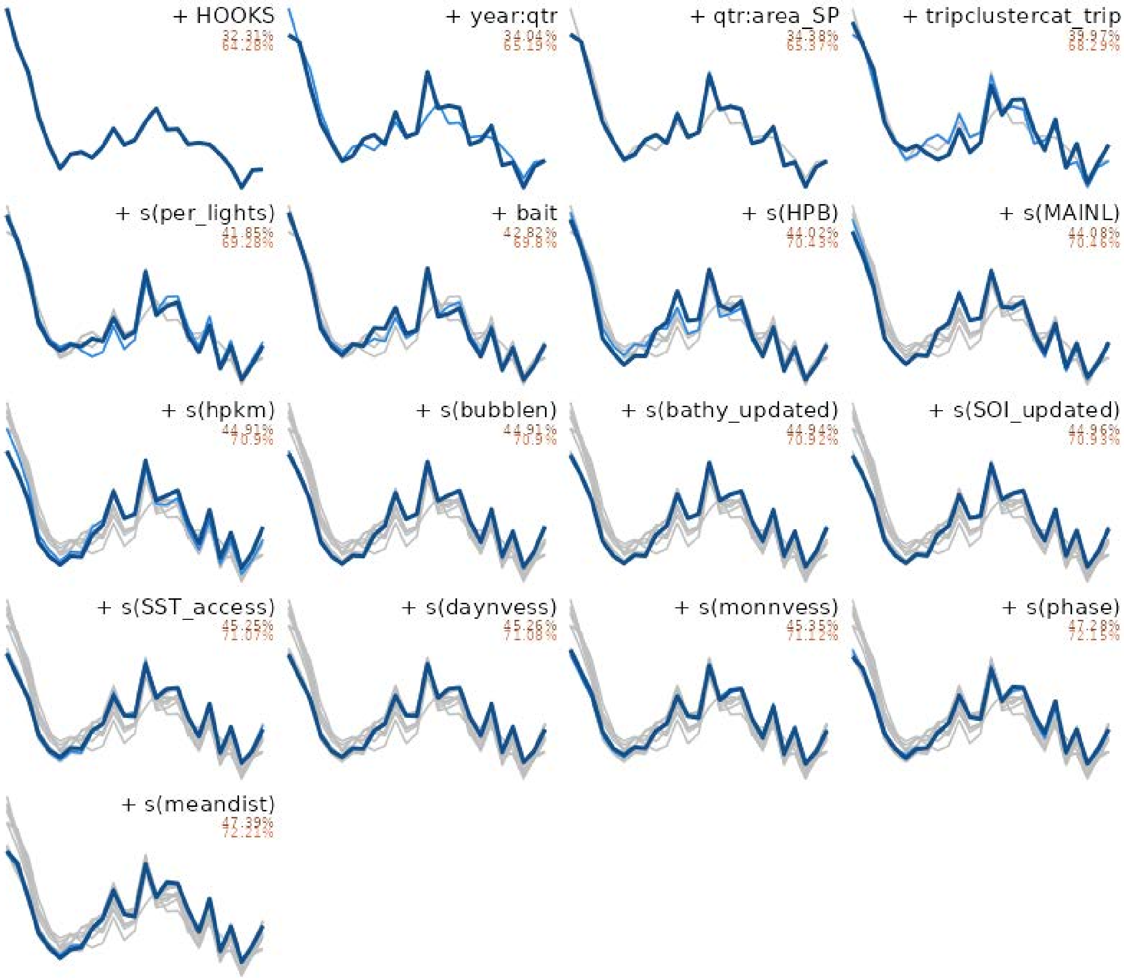

Figure C-9: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for broadbill swordfish (Adult). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

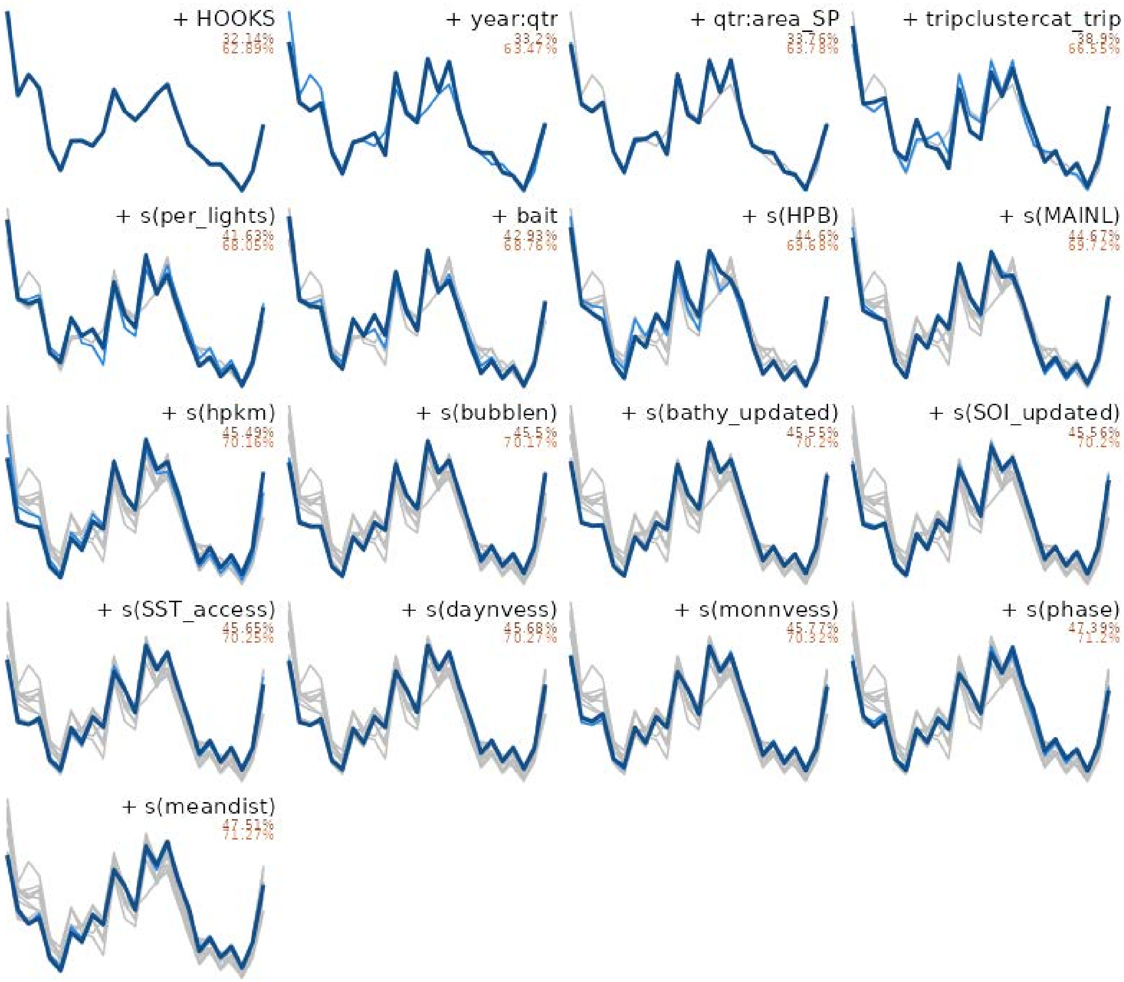

Figure C-10: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for broadbill swordfish (Sub-adult). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

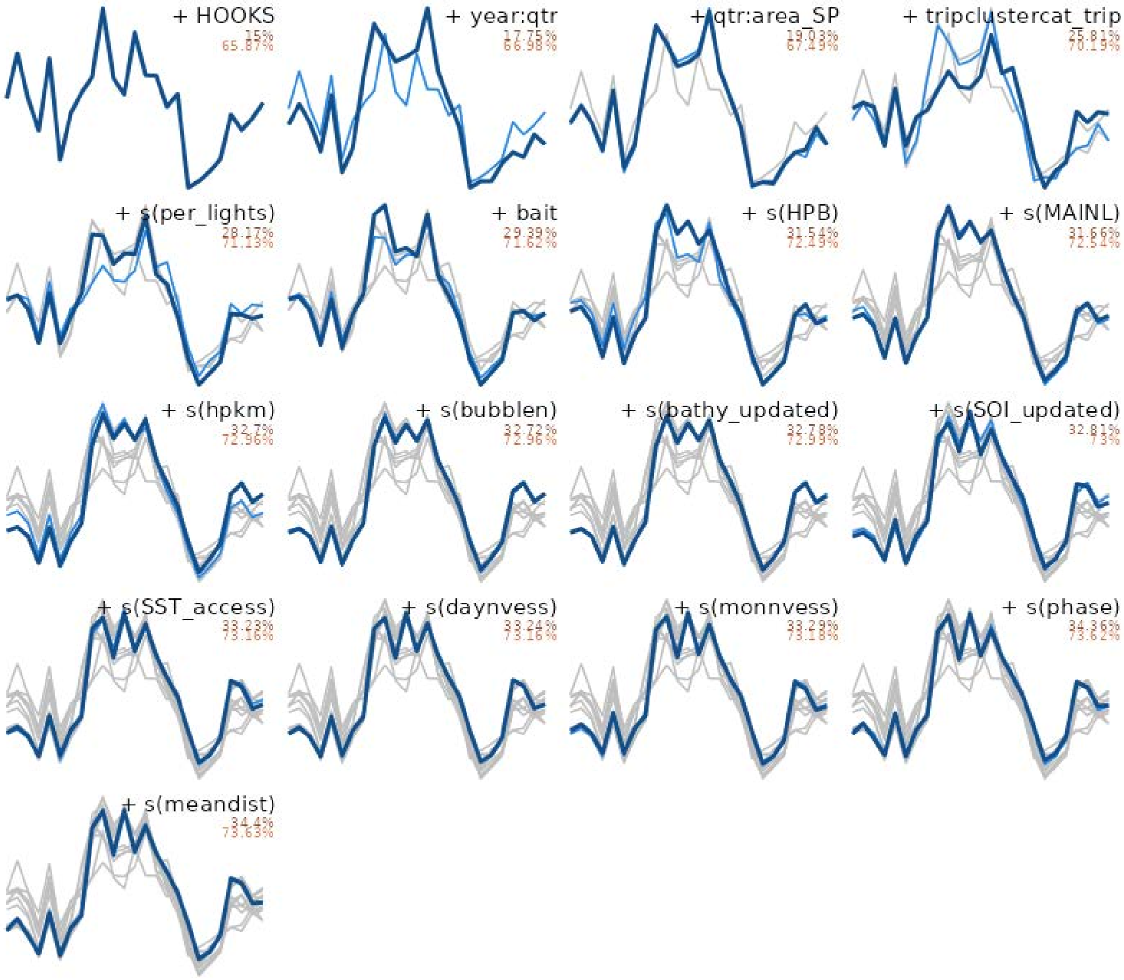

Figure C-11: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for broadbill swordfish (Recruit). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

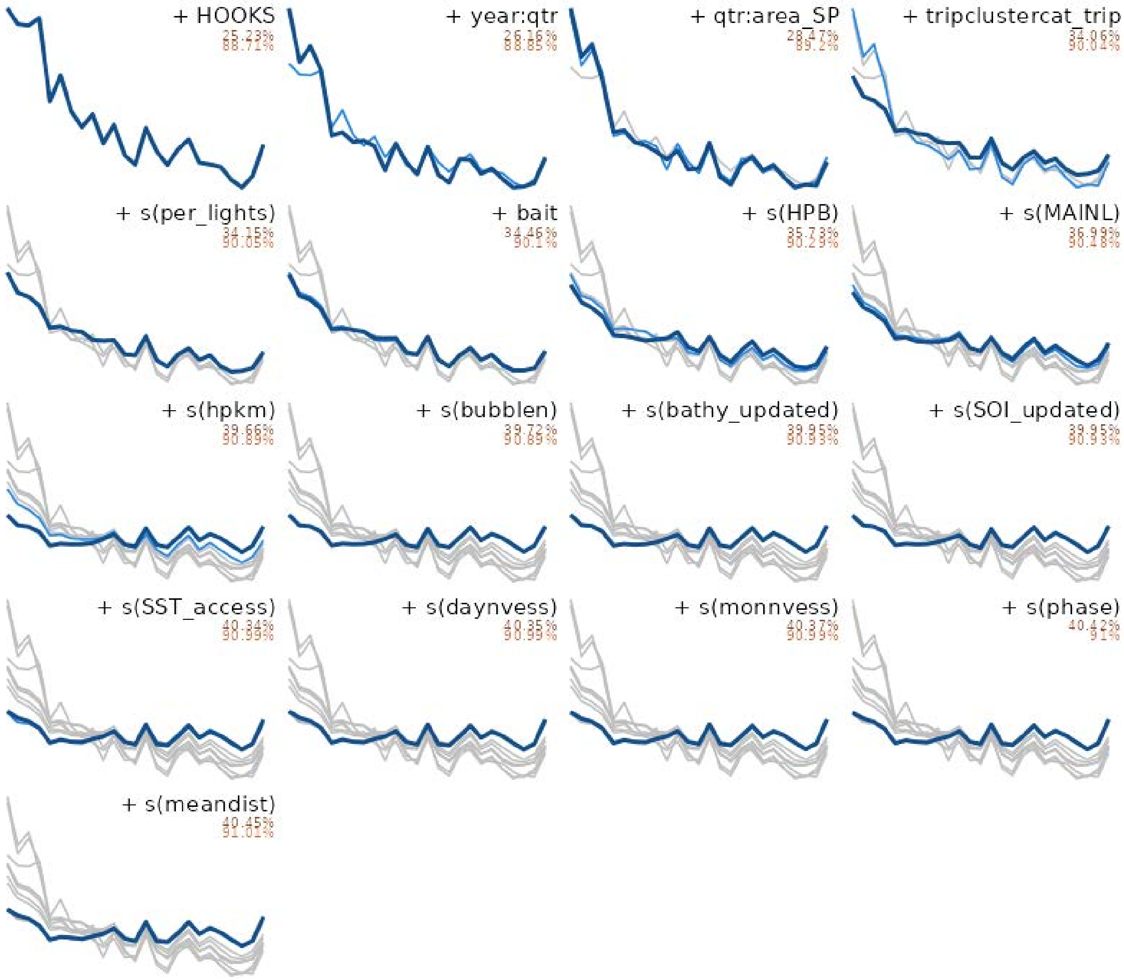

Figure C-12: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for striped marlin (All). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

D Appendix: Effect of inclusion of metiers covariate on standardised index

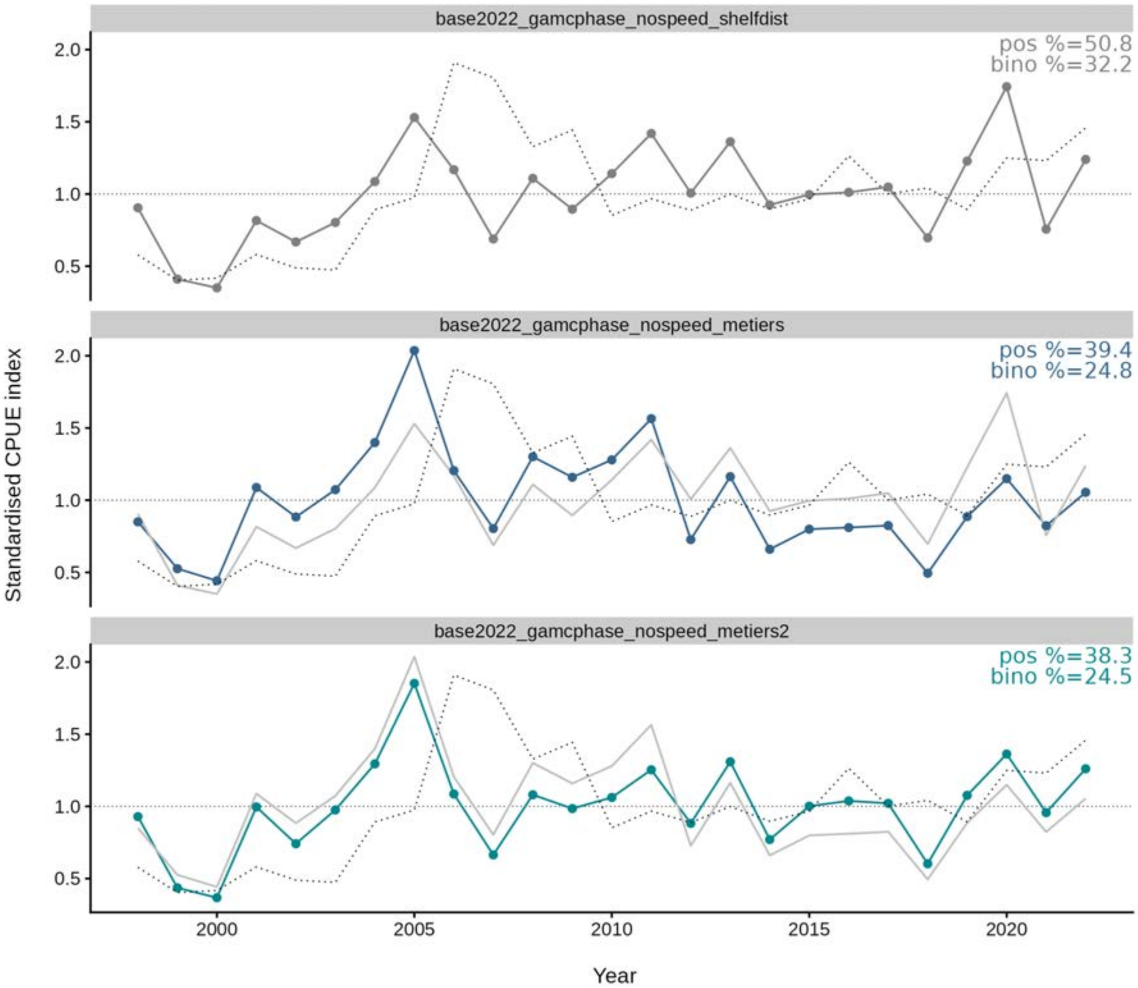

Figure D-1: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for albacore tuna (All). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

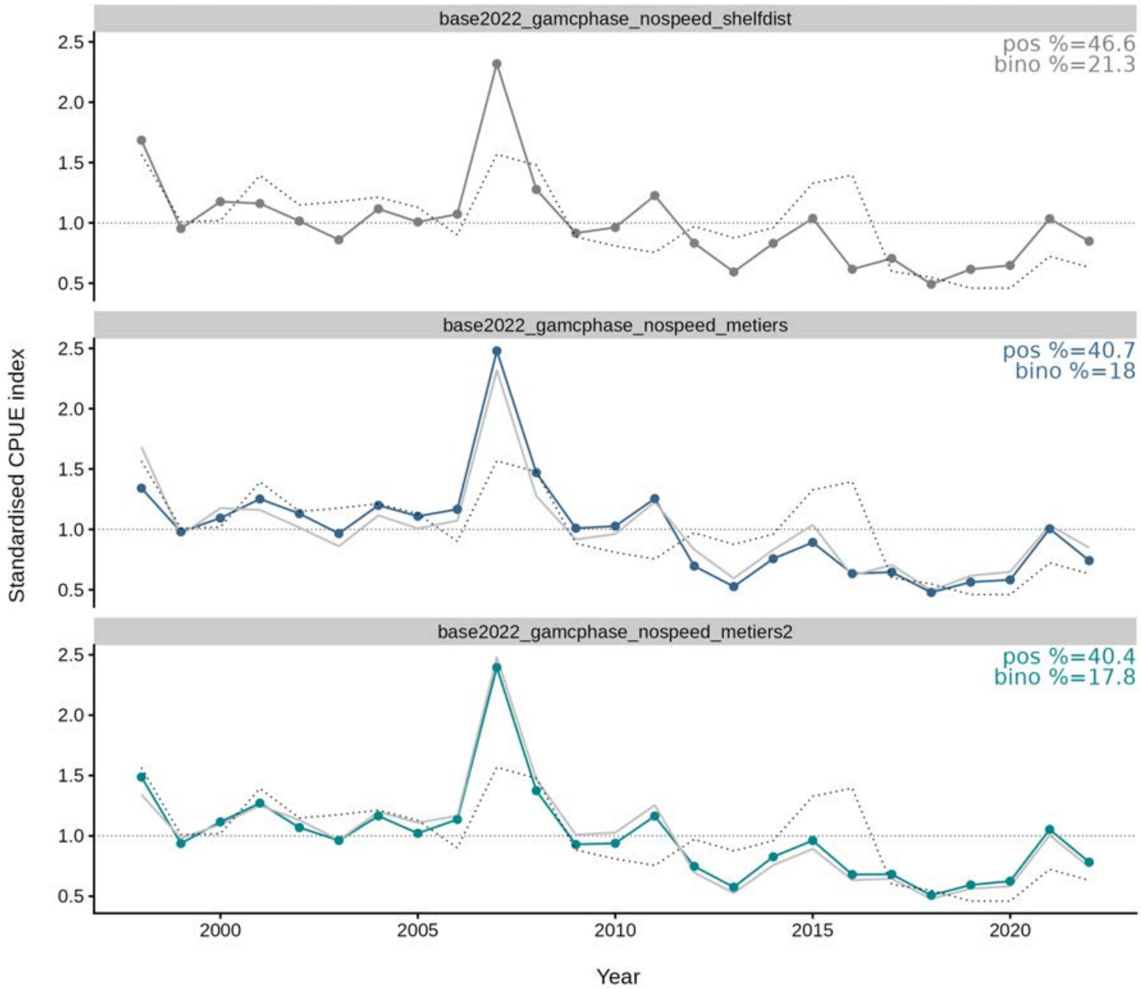

Figure D-2: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for bigeye tuna (All). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

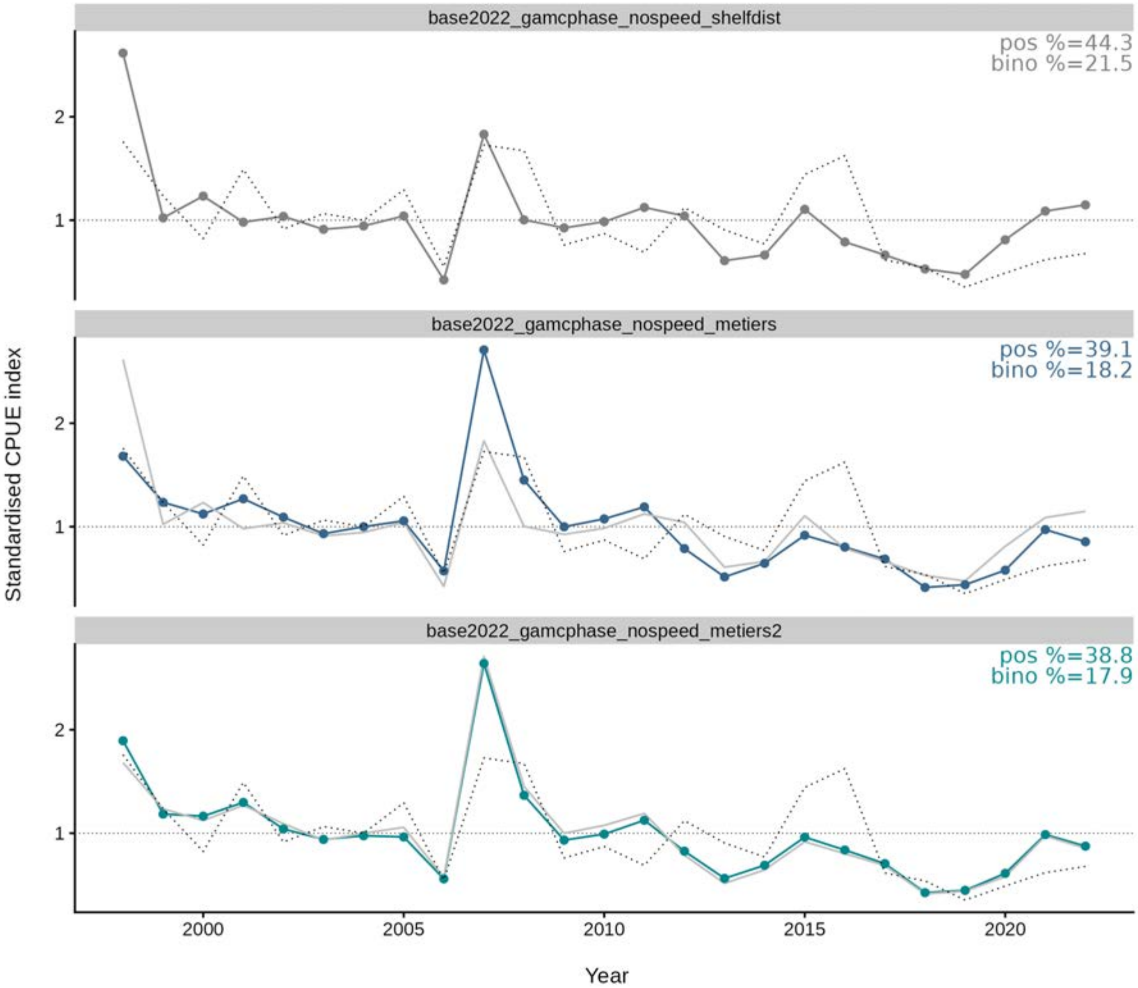

Figure D-3: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for bigeye tuna (Adult). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

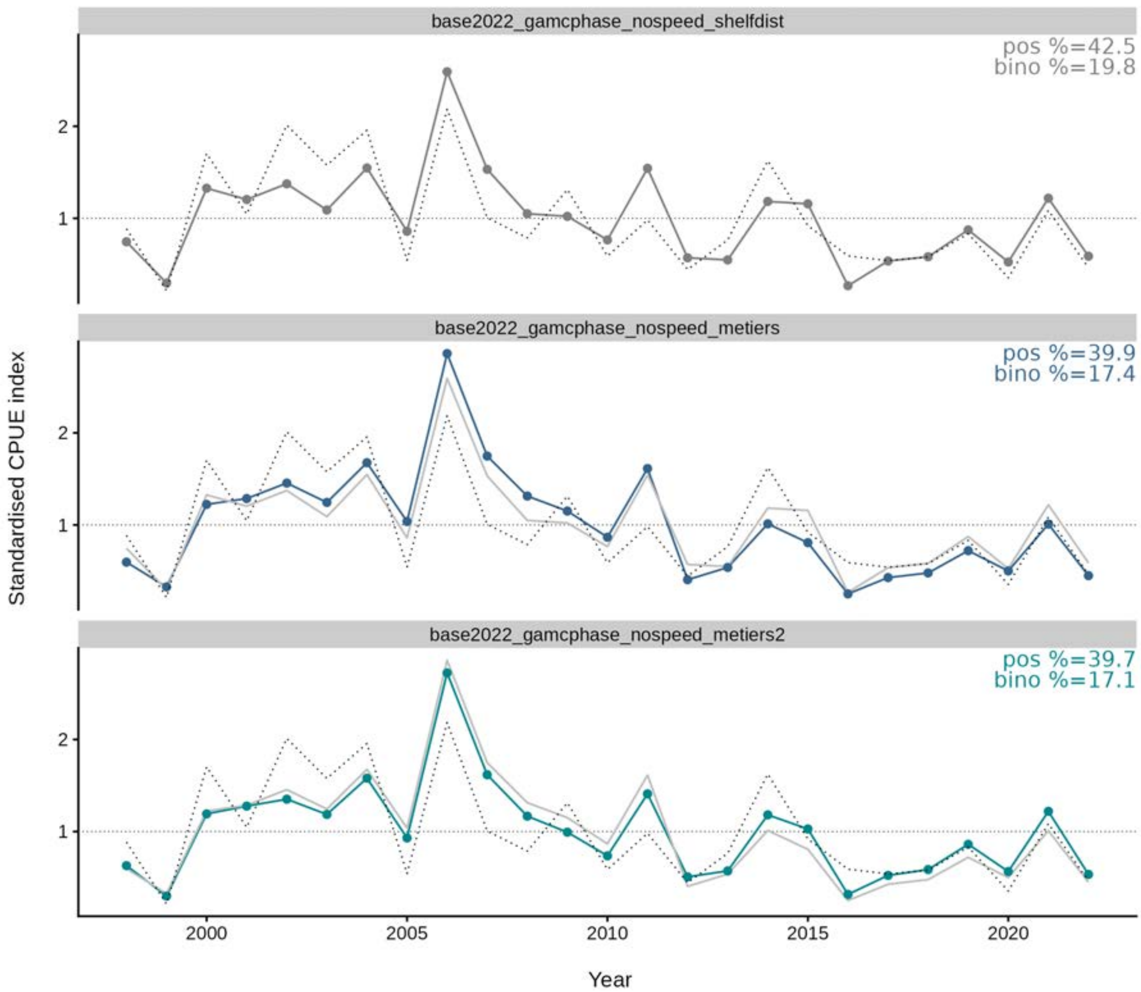

Figure D-4: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for bigeye tuna (Recruit). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

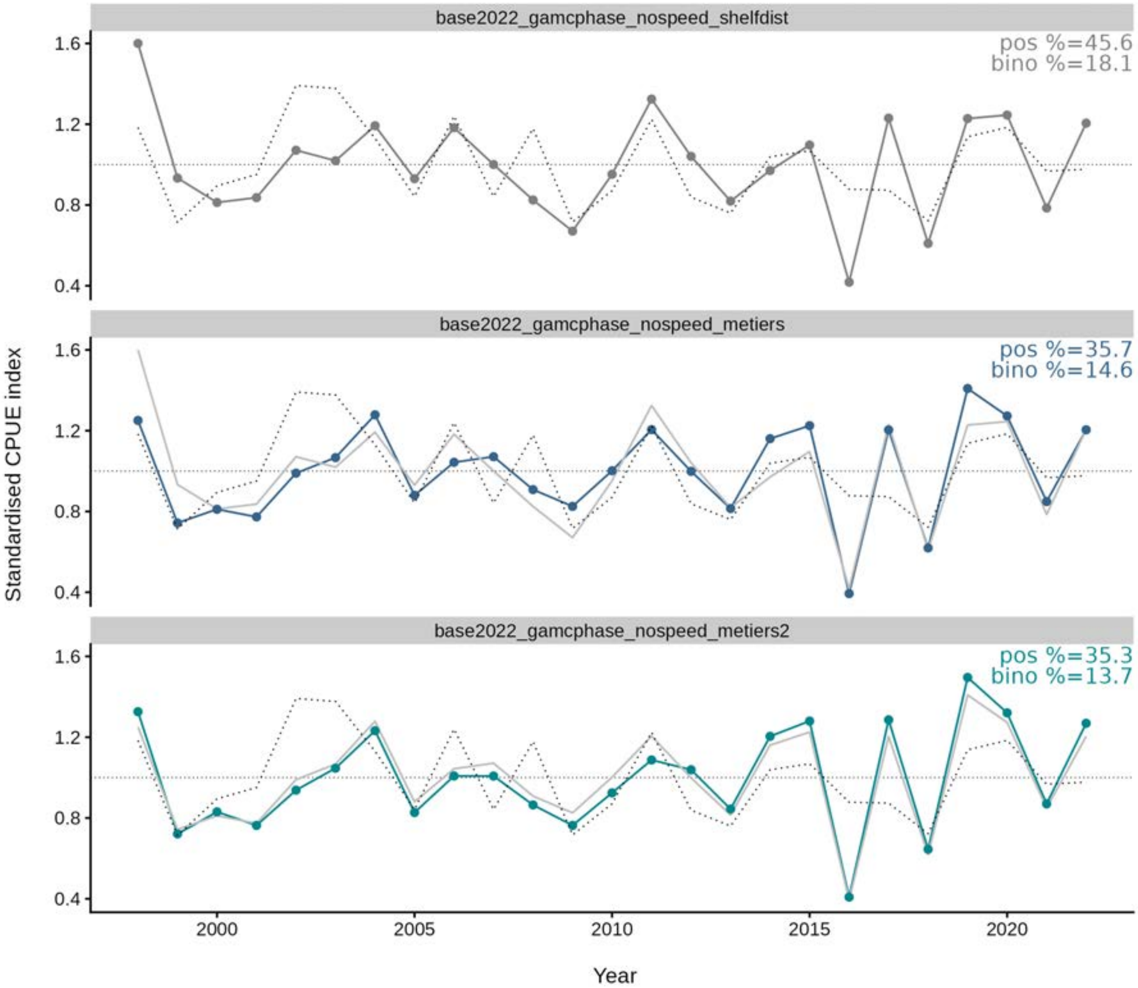

Figure D-5: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for yellowfin tuna (All). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

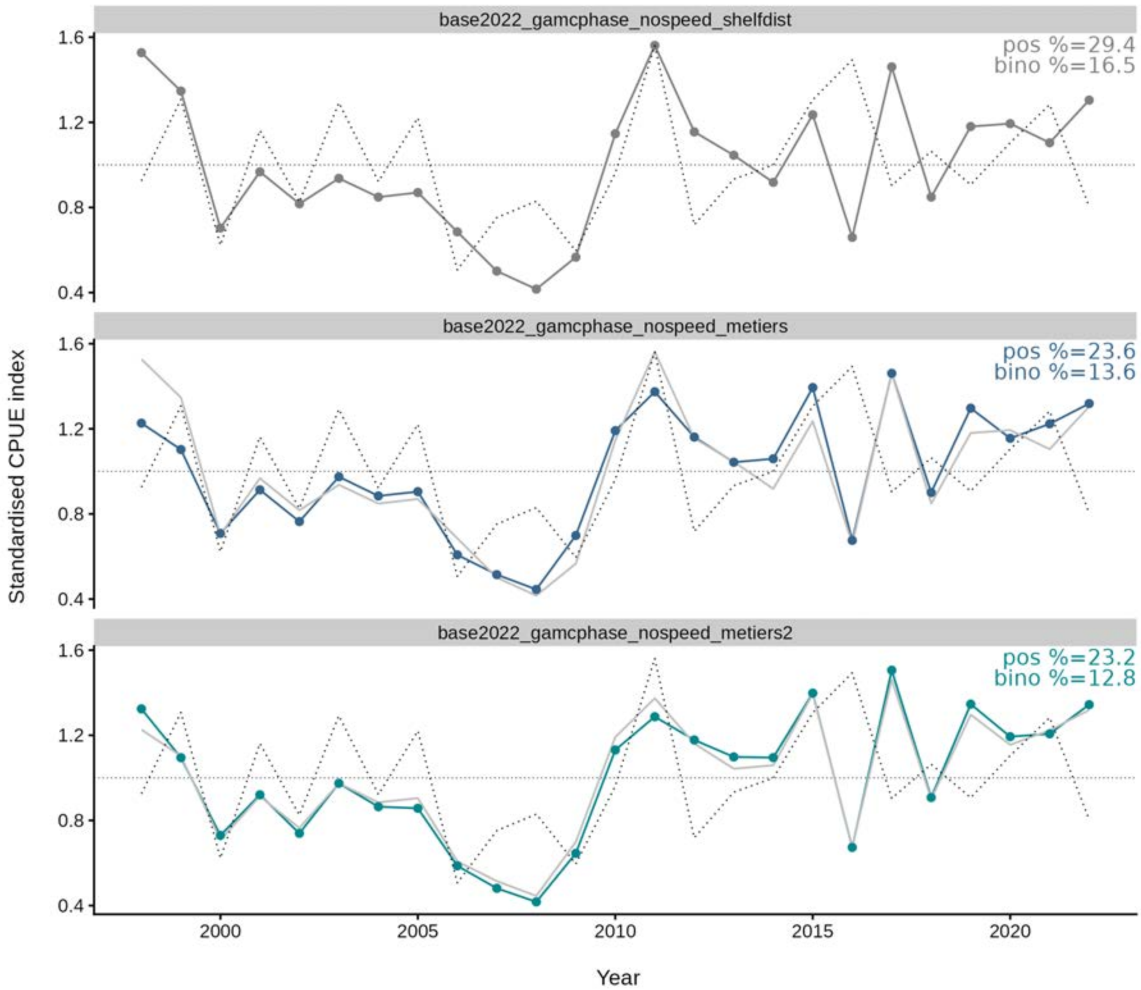

Figure D-6: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for yellowfin tuna (Adult). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

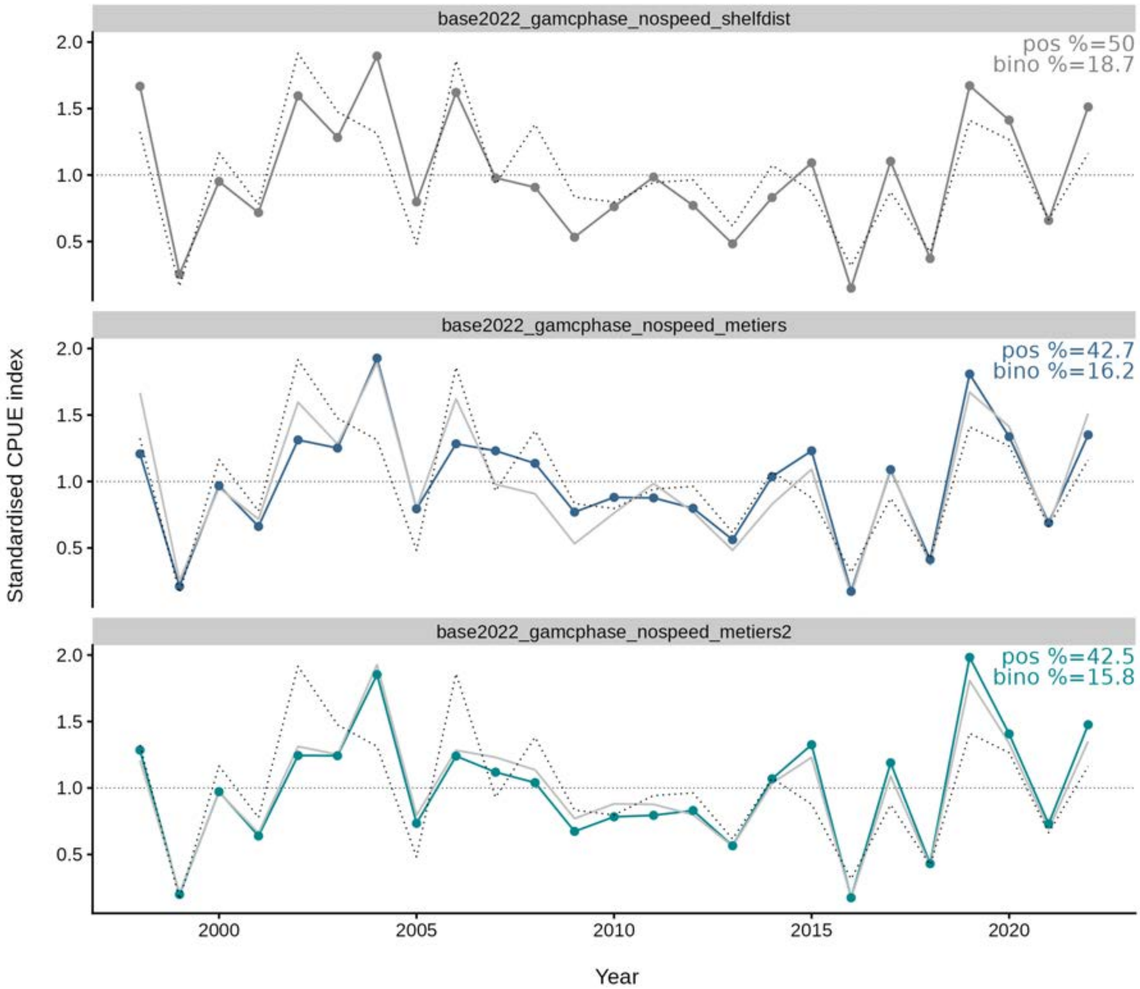

Figure D-7: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for yellowfin tuna (Recruit). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

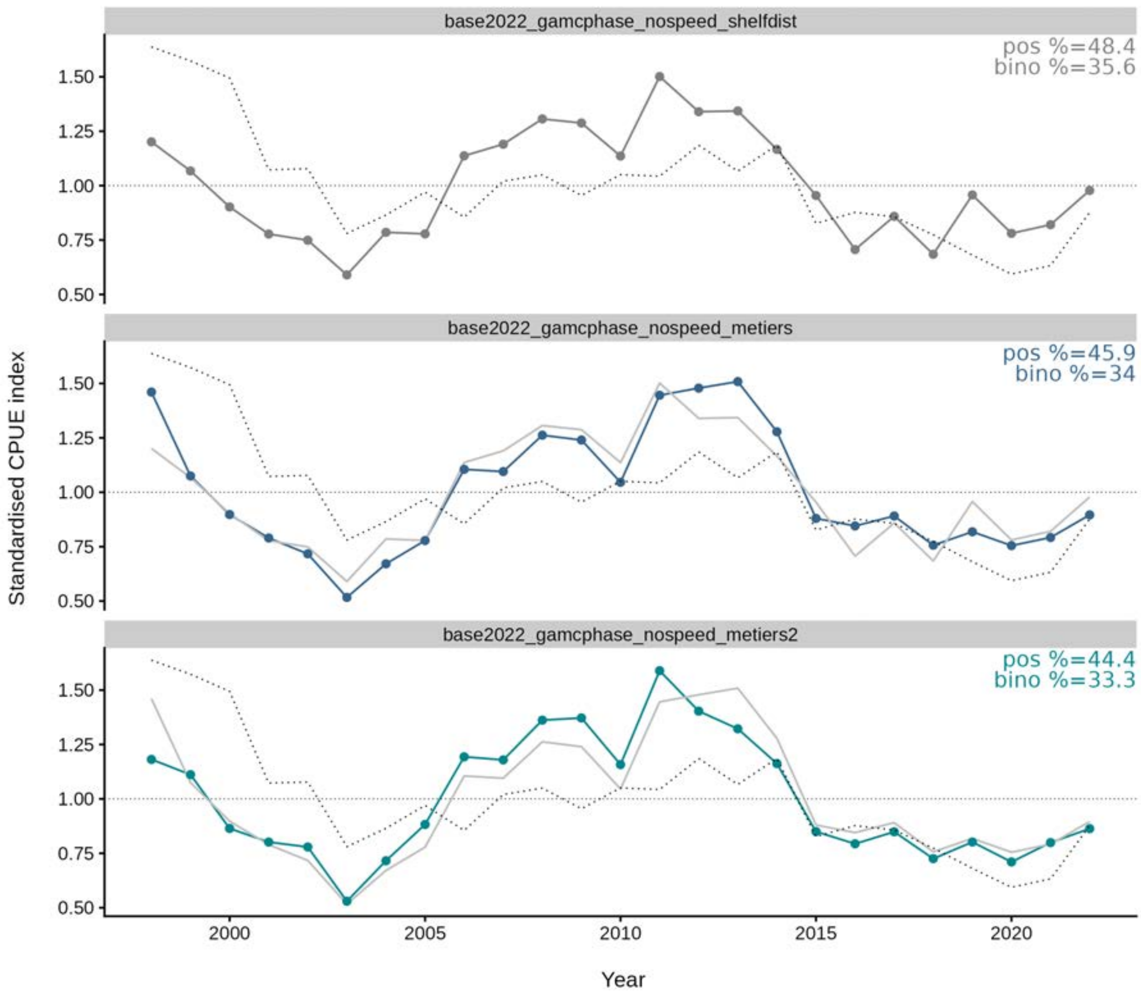

Figure D-8: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for broadbill swordfish (All). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

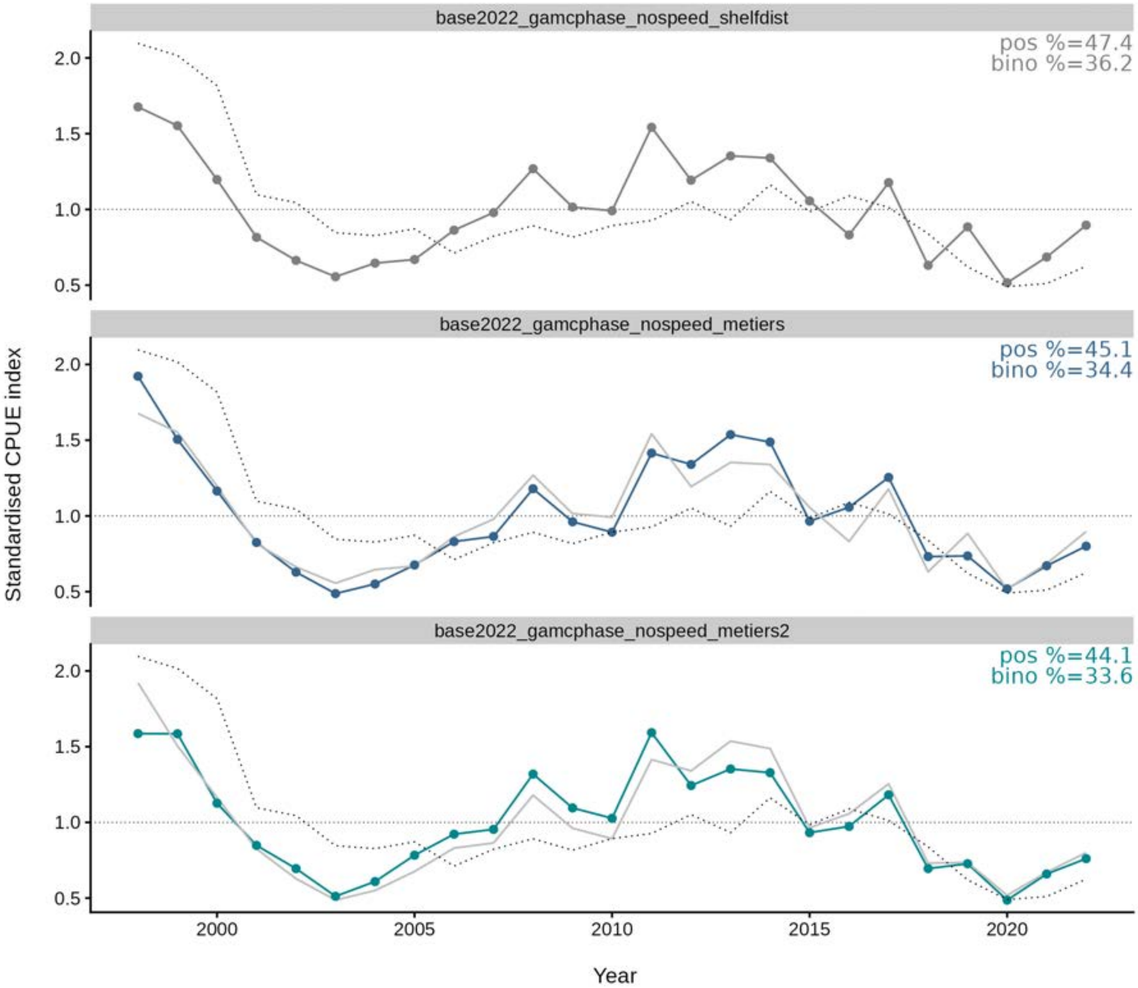

Figure D-9: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for broadbill swordfish (Adult). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

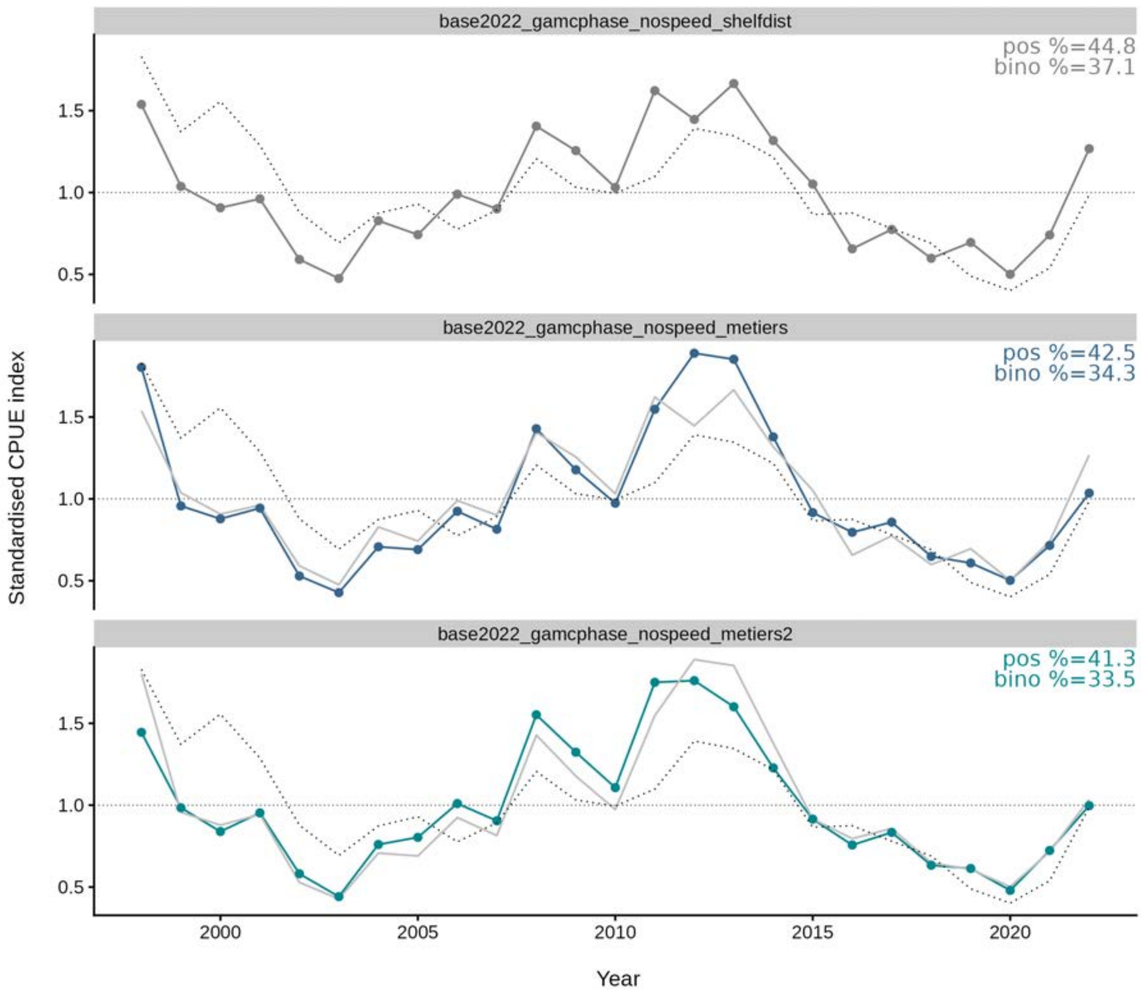

Figure D-10: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for broadbill swordfish (Sub-adult). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

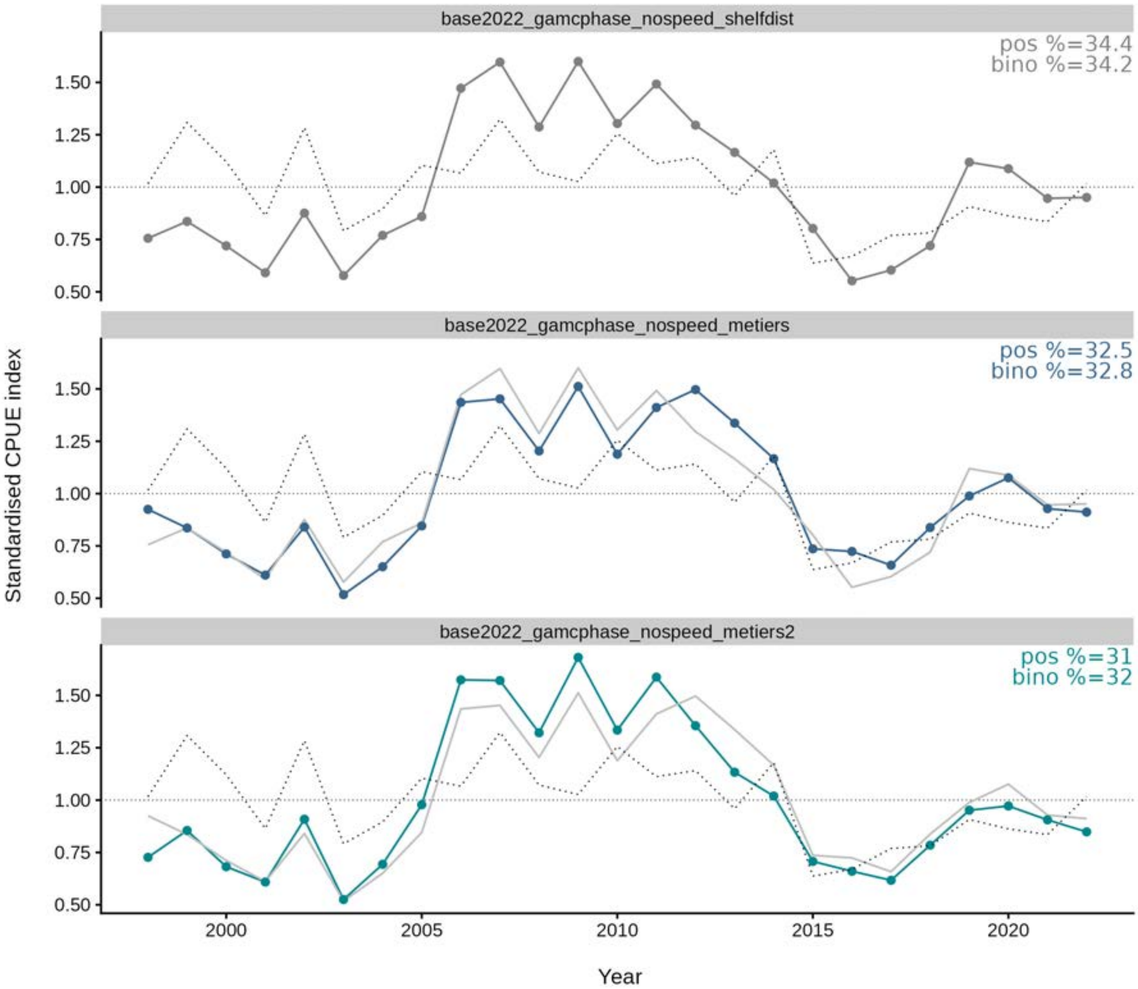

Figure D-11: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for broadbill swordfish (Recruit). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

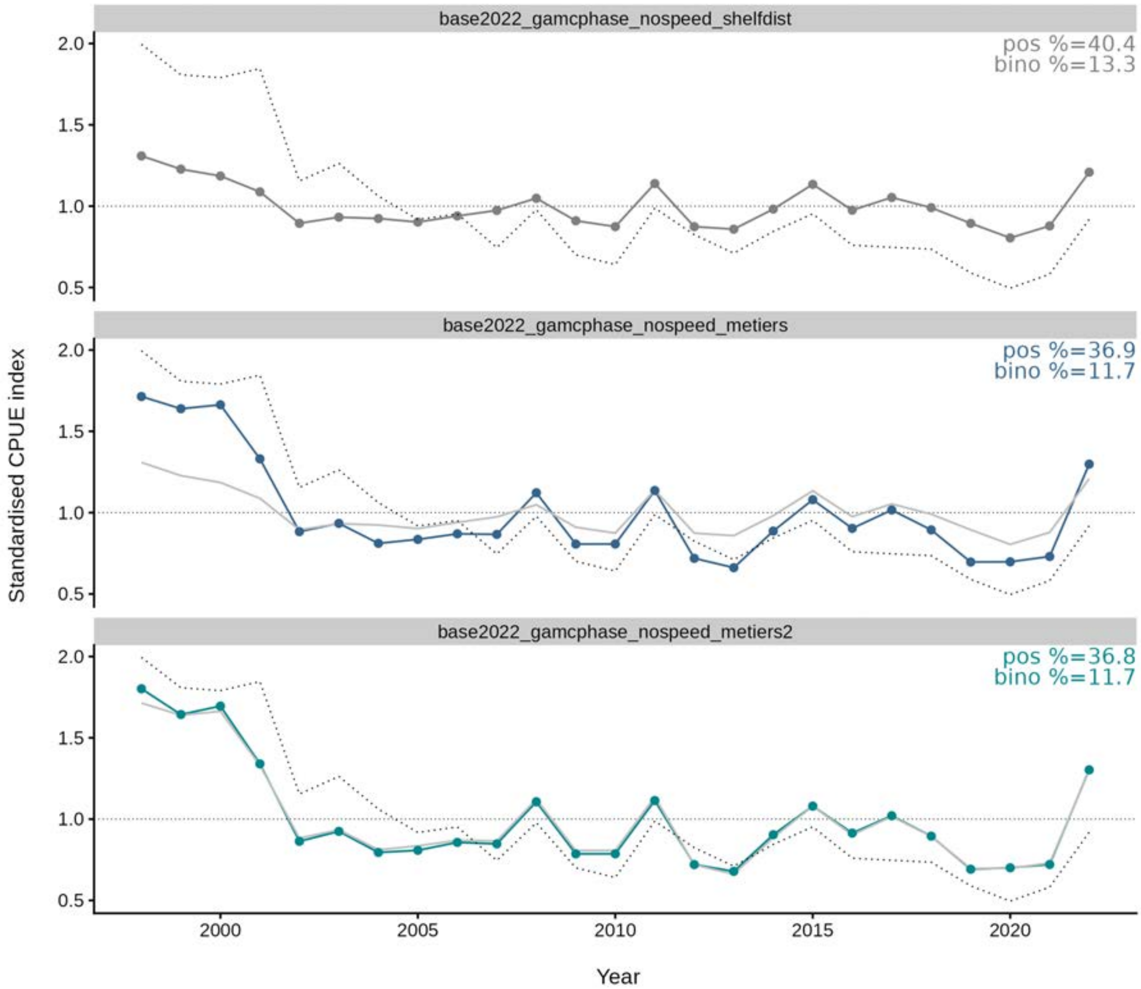

Figure D-12: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for striped marlin (All). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

E Appendix: Effect of inclusion of eddy covariates on standardised index

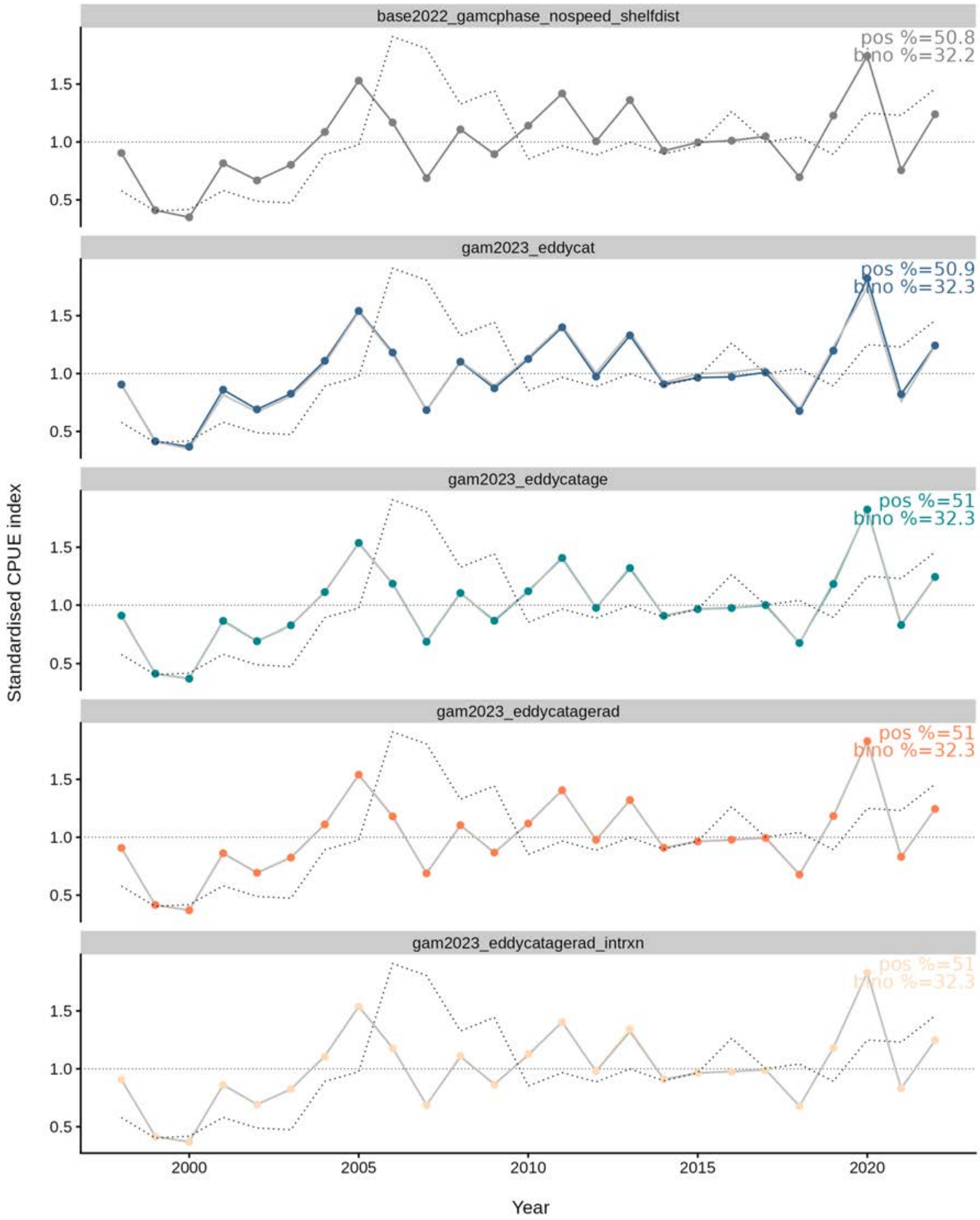

Figure E-1: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for albacore tuna (All). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

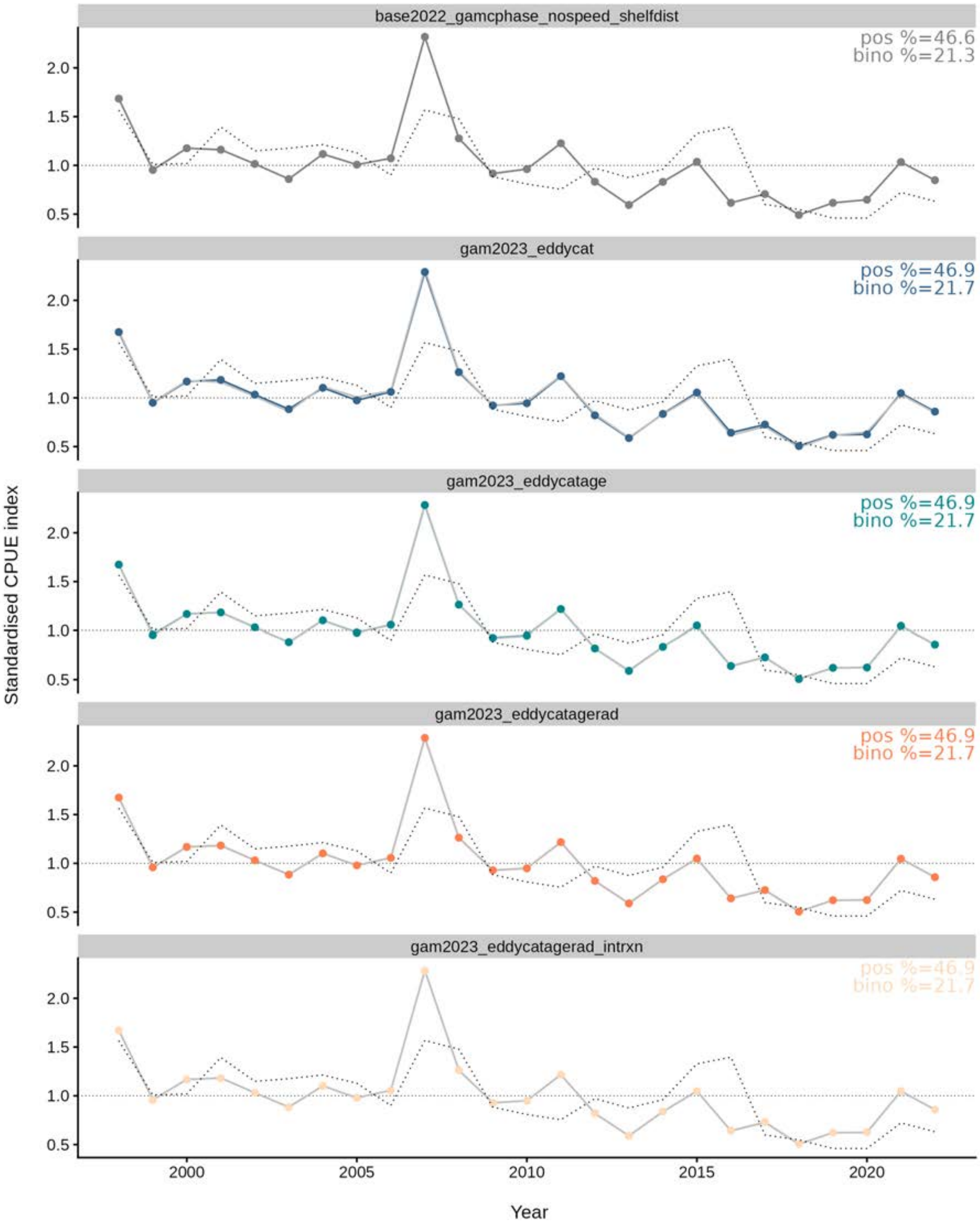

Figure E-2: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for bigeye tuna (All). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

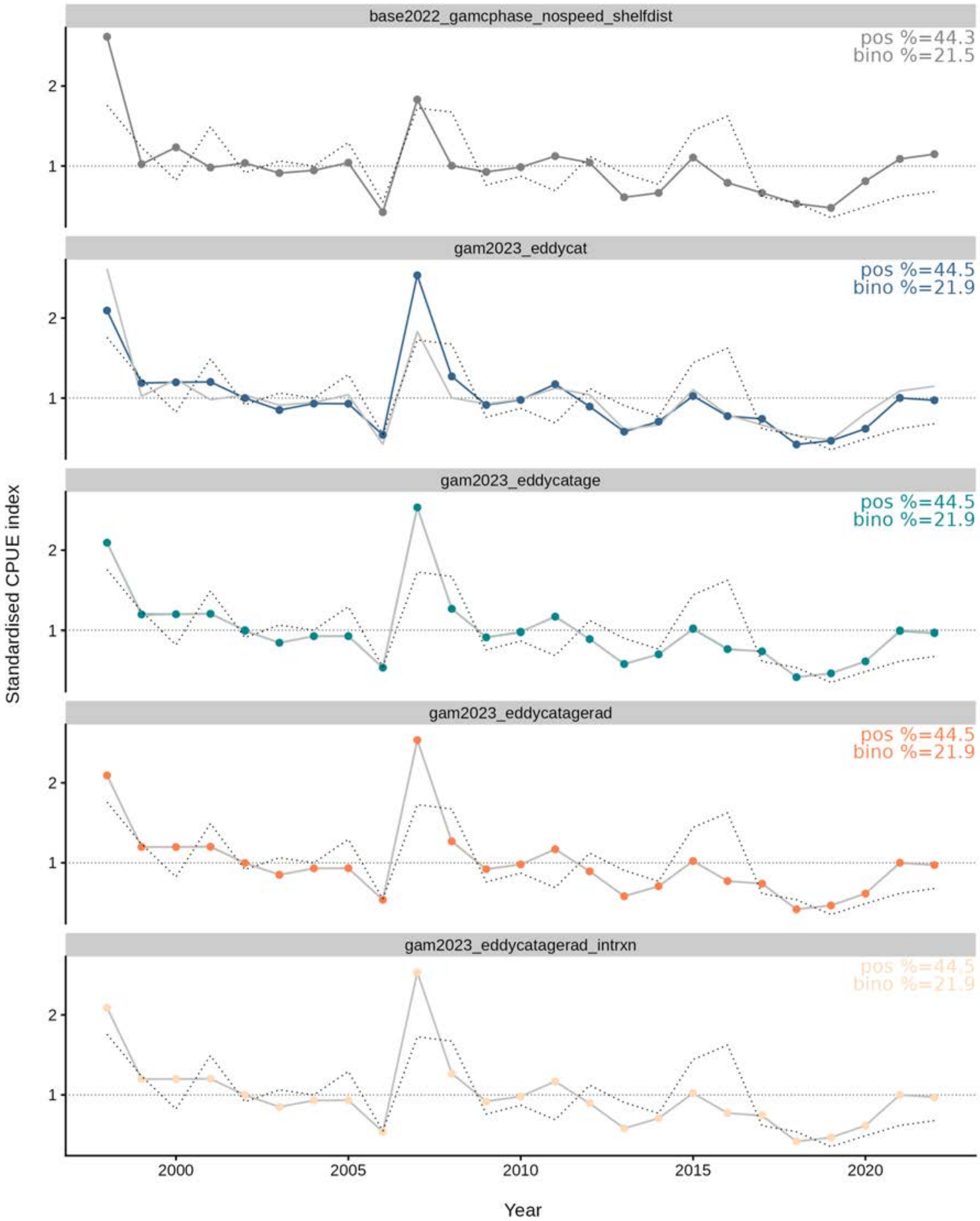

Figure E-3: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for bigeye tuna (Adult). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

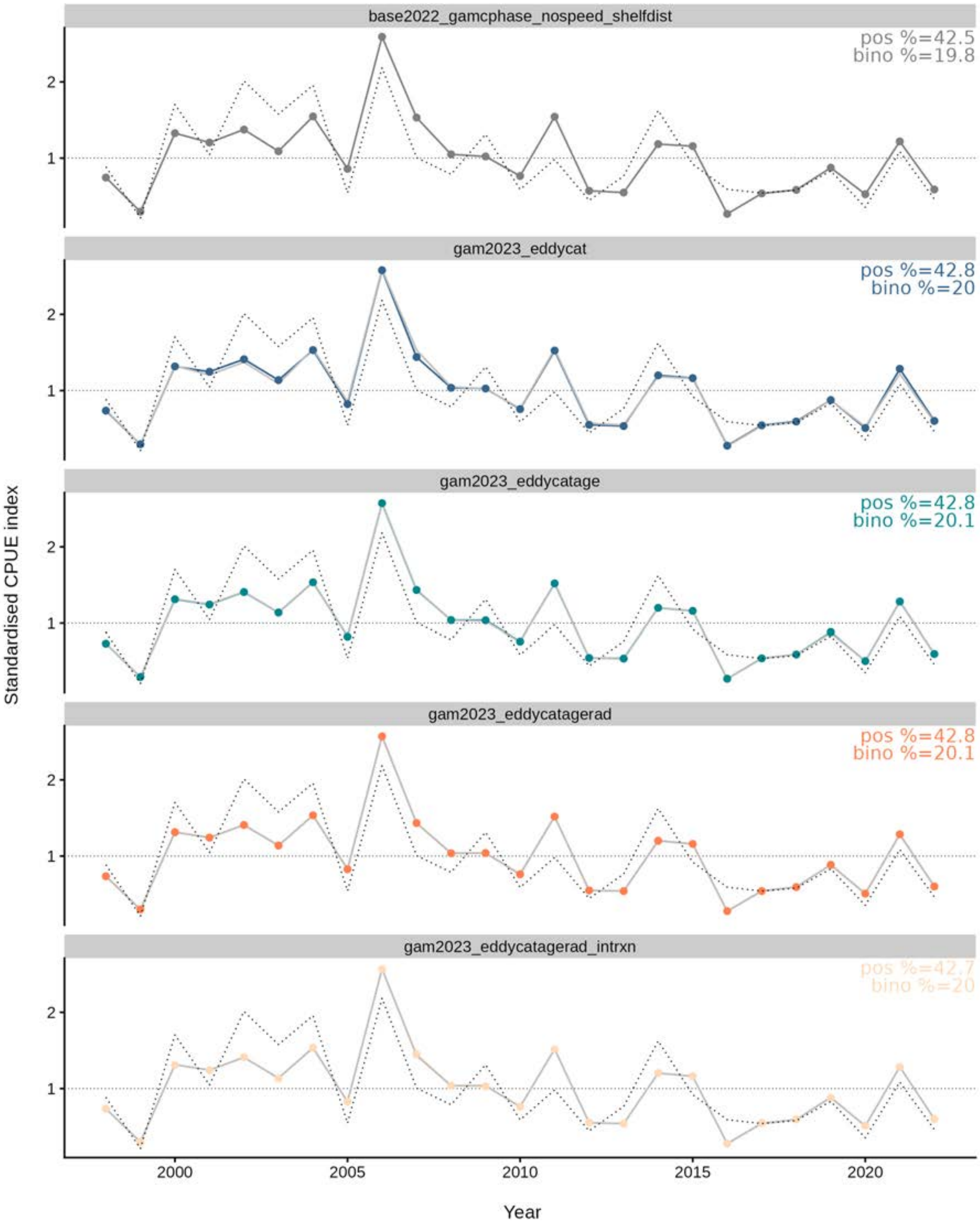

Figure E-4: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for bigeye tuna (Recruit). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

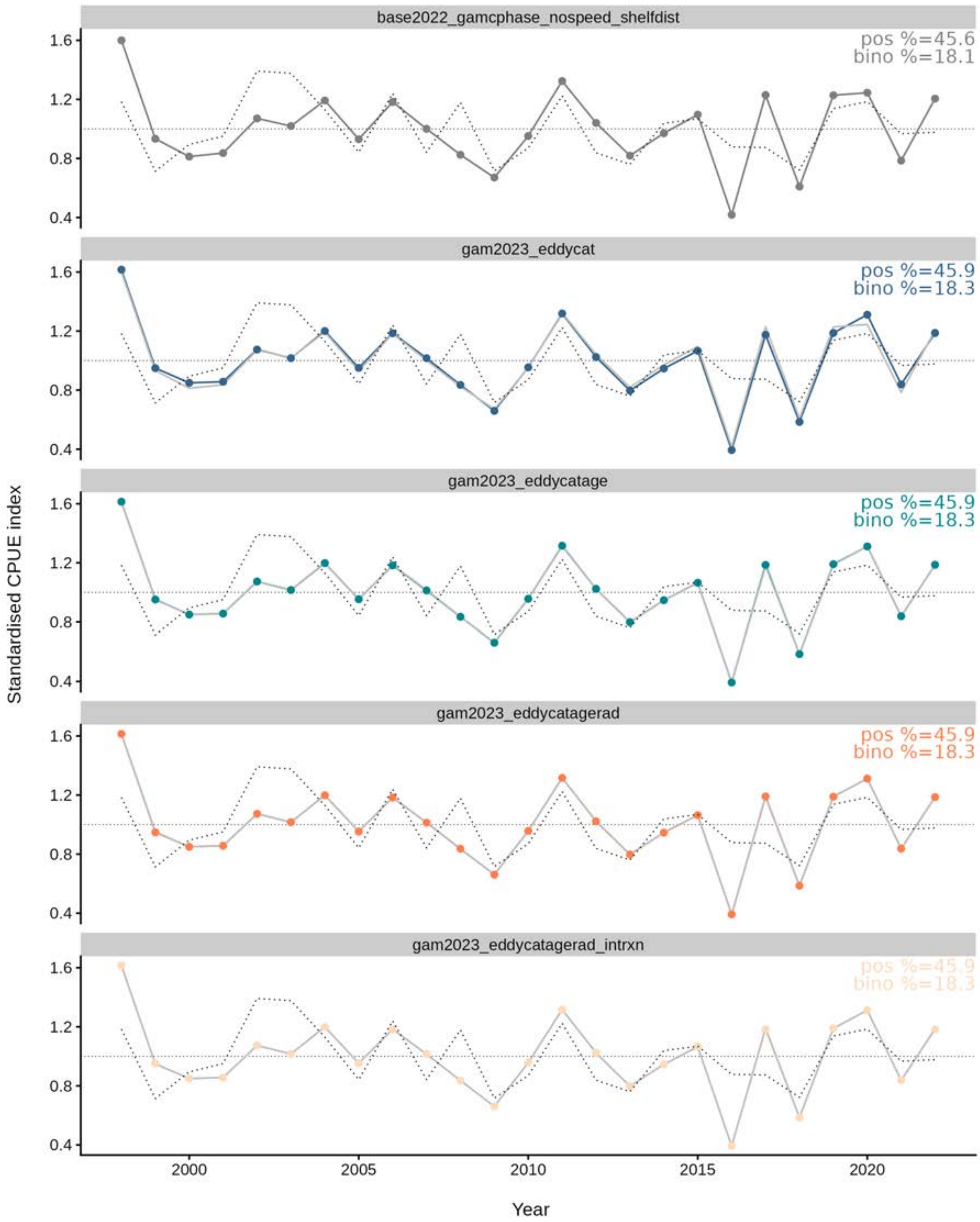

Figure E-5: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for yellowfin tuna (All). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

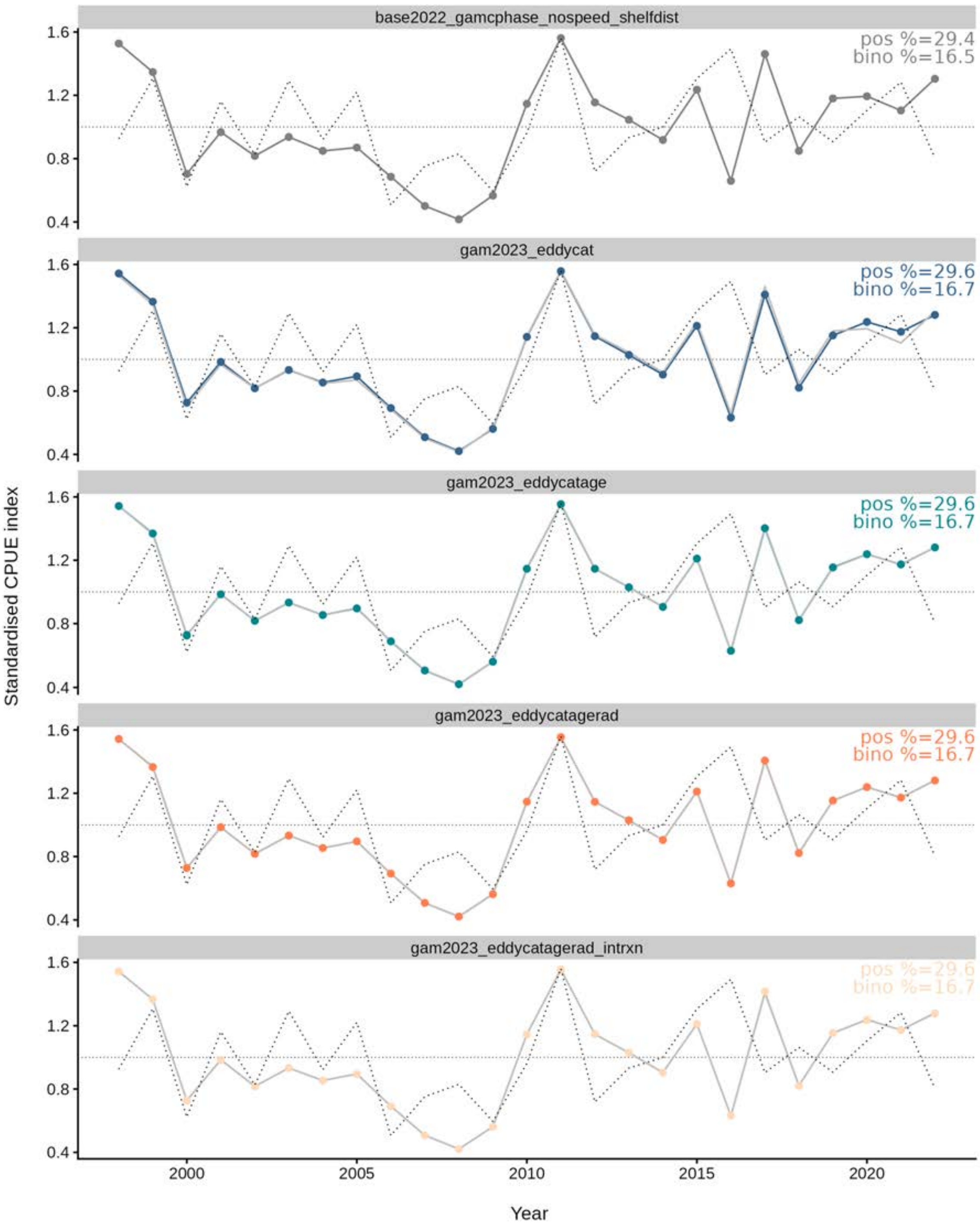

Figure E-6: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for yellowfin tuna (Adult). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

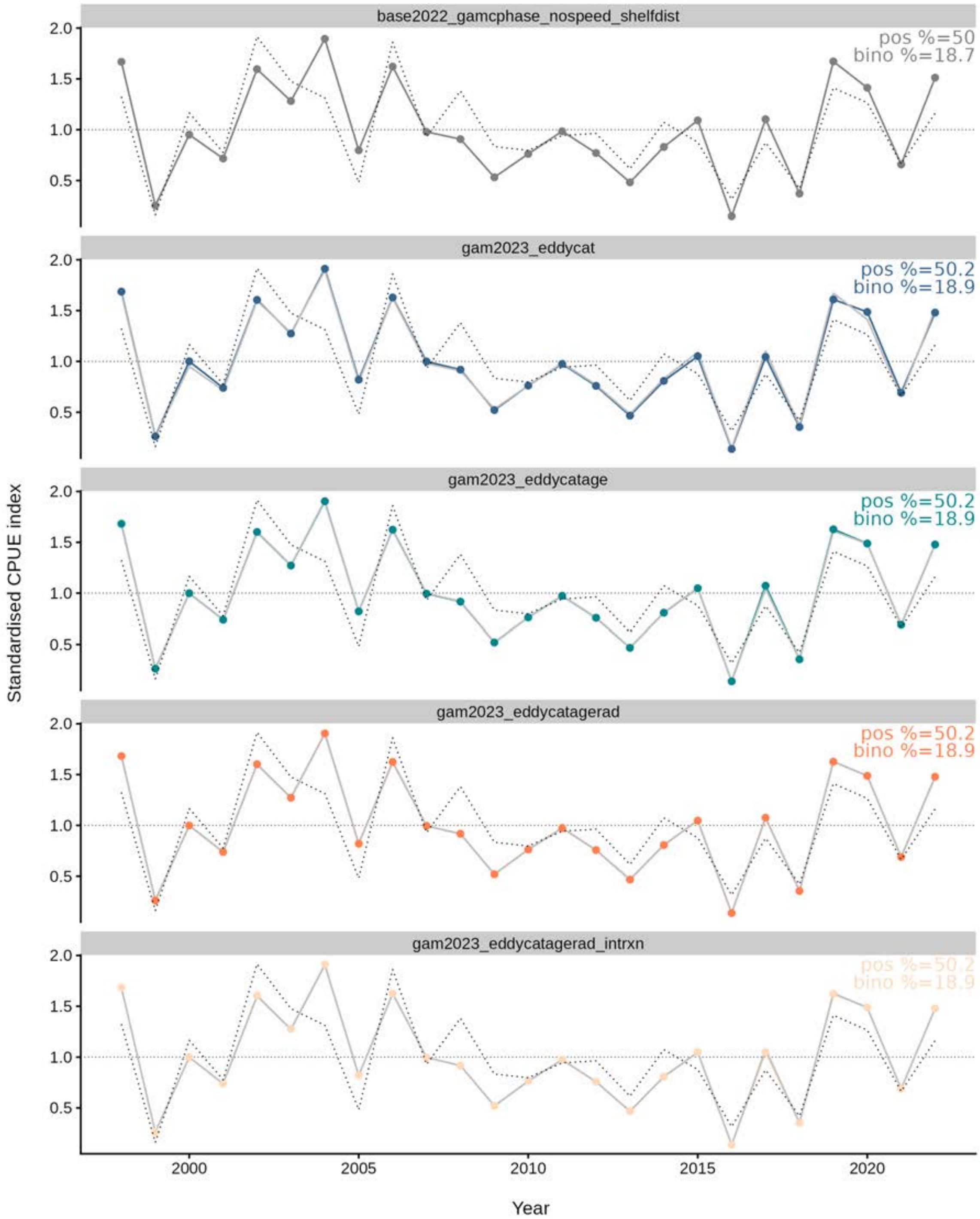

Figure E-7: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for yellowfin tuna (Recruit). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

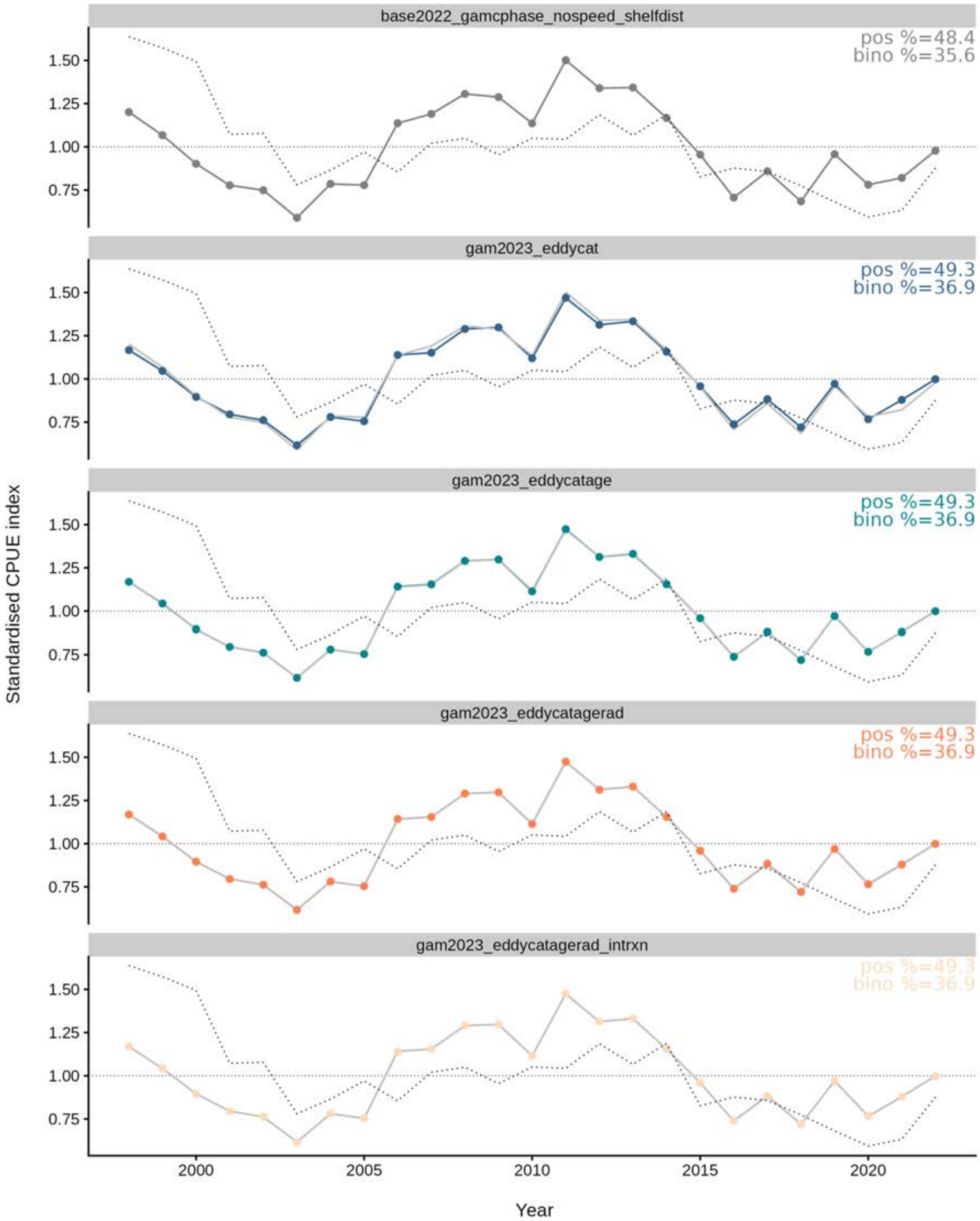

Figure E-8: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for broadbill swordfish (All). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

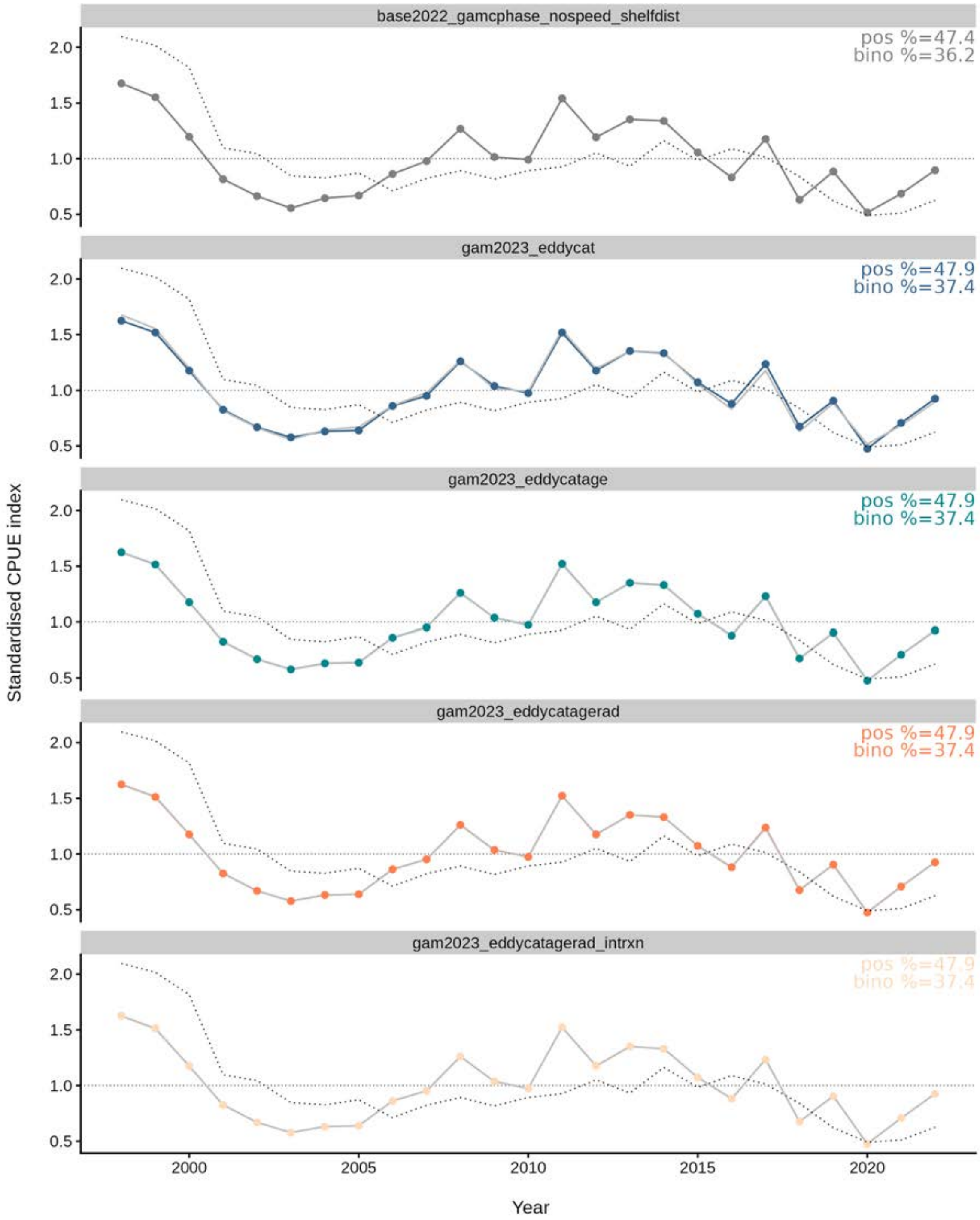

Figure E-9: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for broadbill swordfish (Adult). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

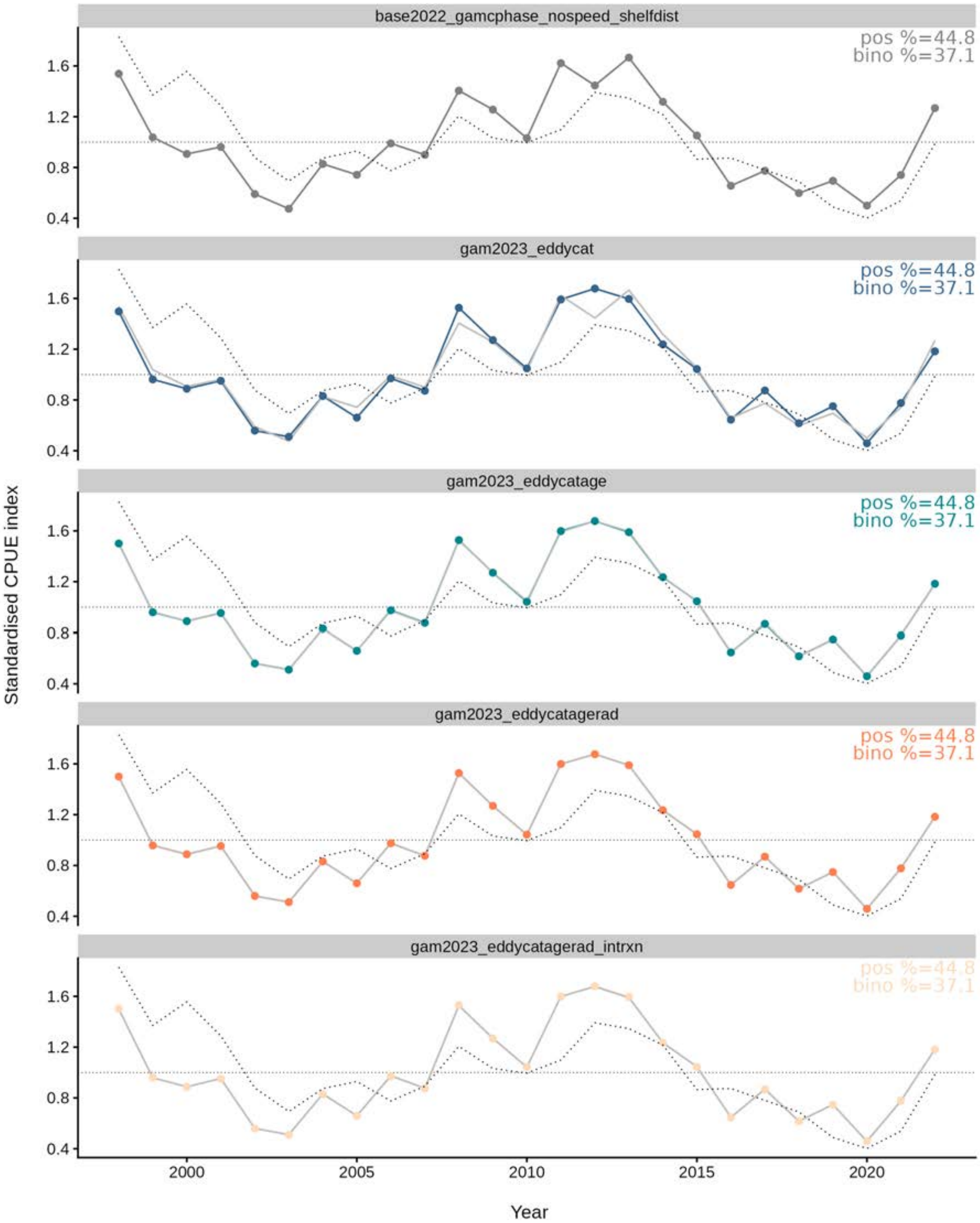

Figure E-10: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for broadbill swordfish (Sub-adult). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

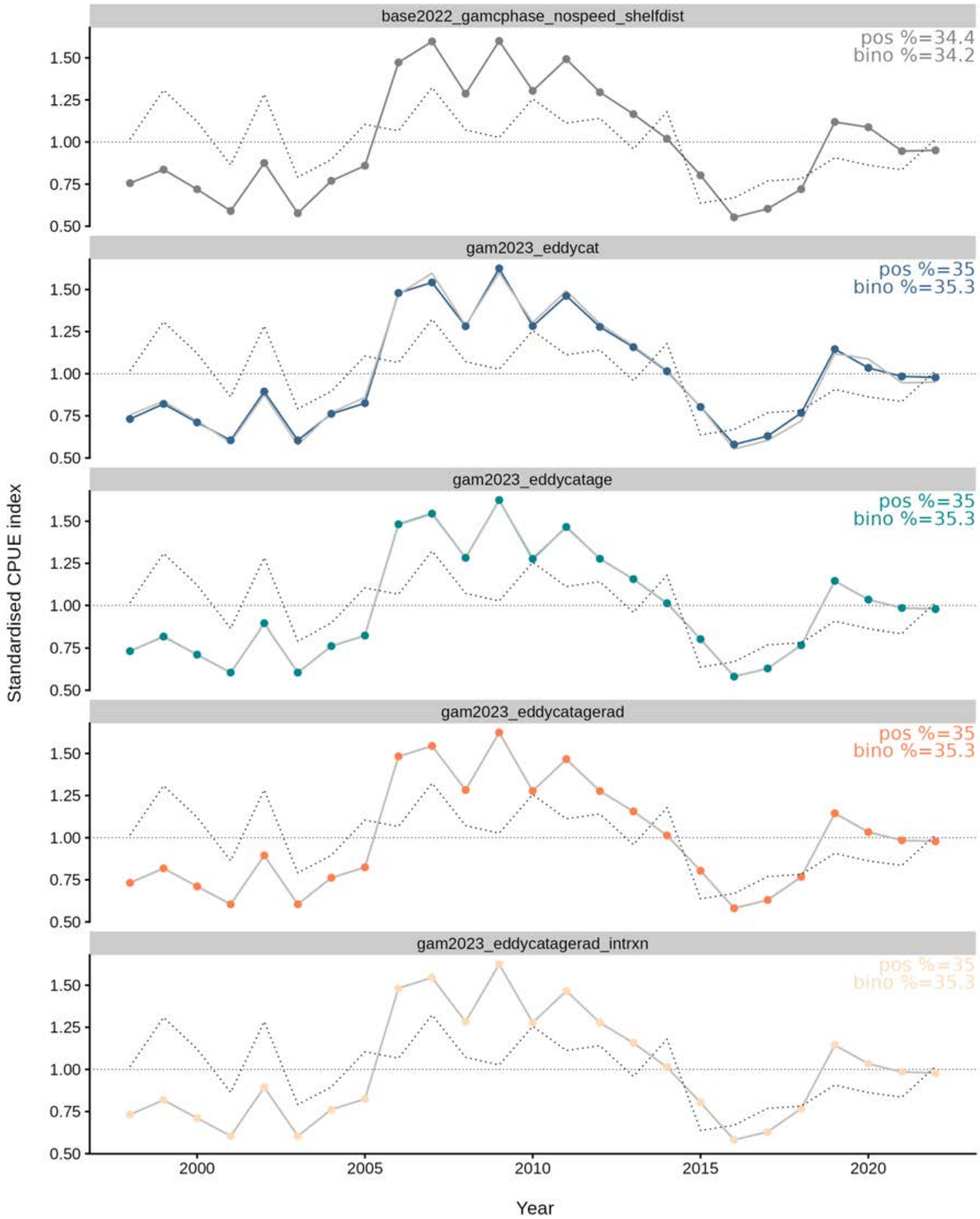

Figure E-11: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for broadbill swordfish (Recruit). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

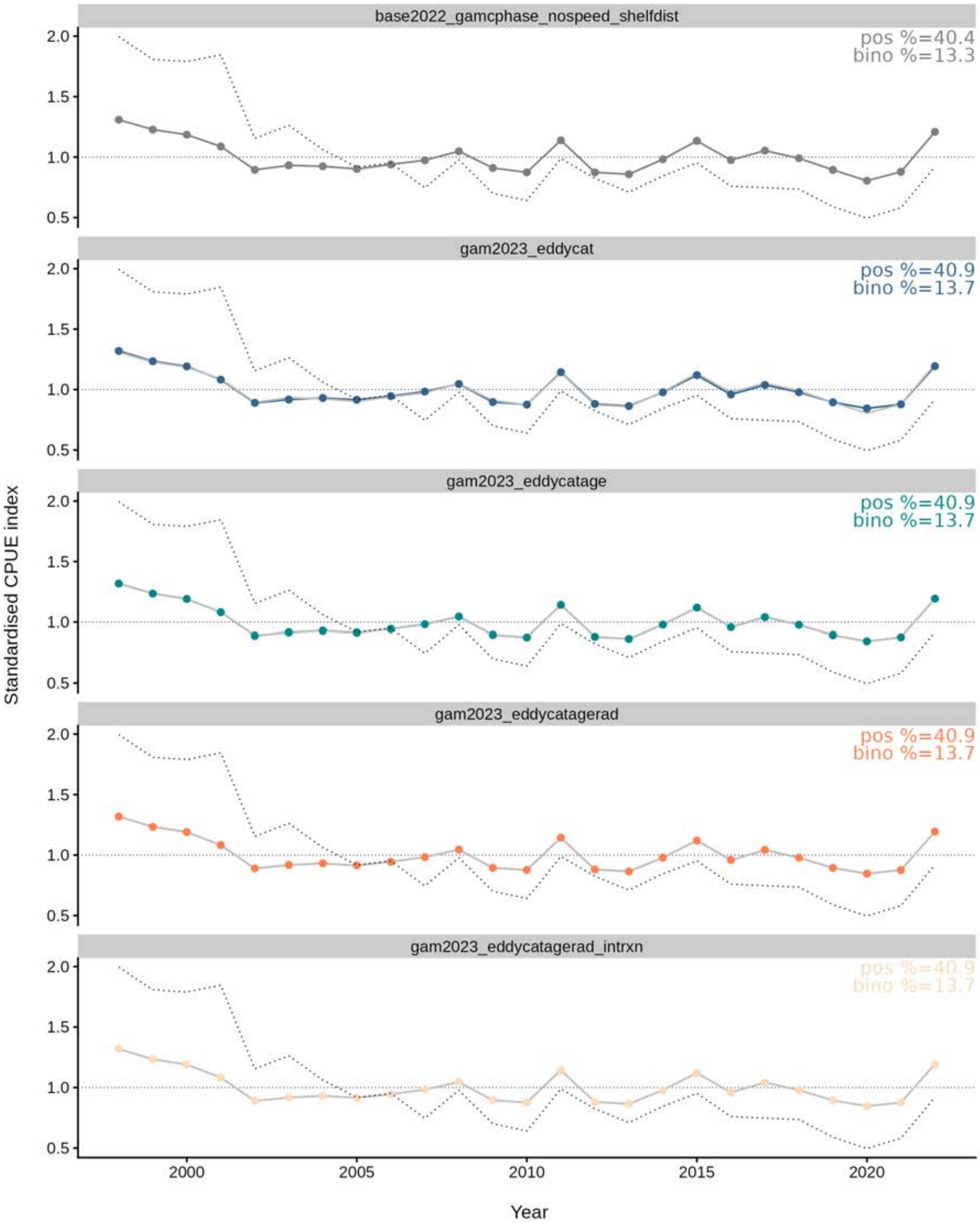

Figure E-12: Stepwise comparison of the relative influence of the addition of each successive covariate on the final standardised CPUE index for striped marlin (All). The dark blue line shows the standardised index at that step, the light blue line shows the index from the preceding step, and the grey lines show indices from all steps prior. The percentage of the deviance explained for the binomial component is shown in the top-corner in red, and for the positive component in orange.

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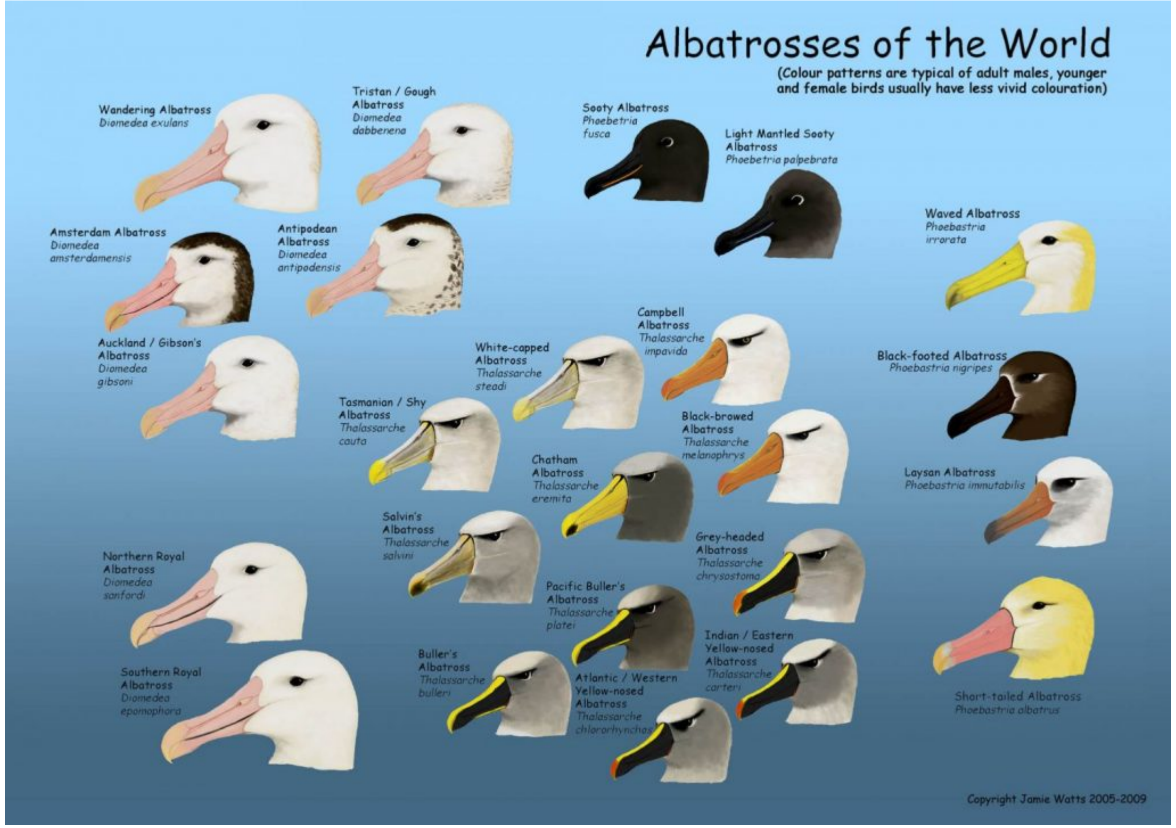
Development of DNA markers to identify seabird bycatch using feathers

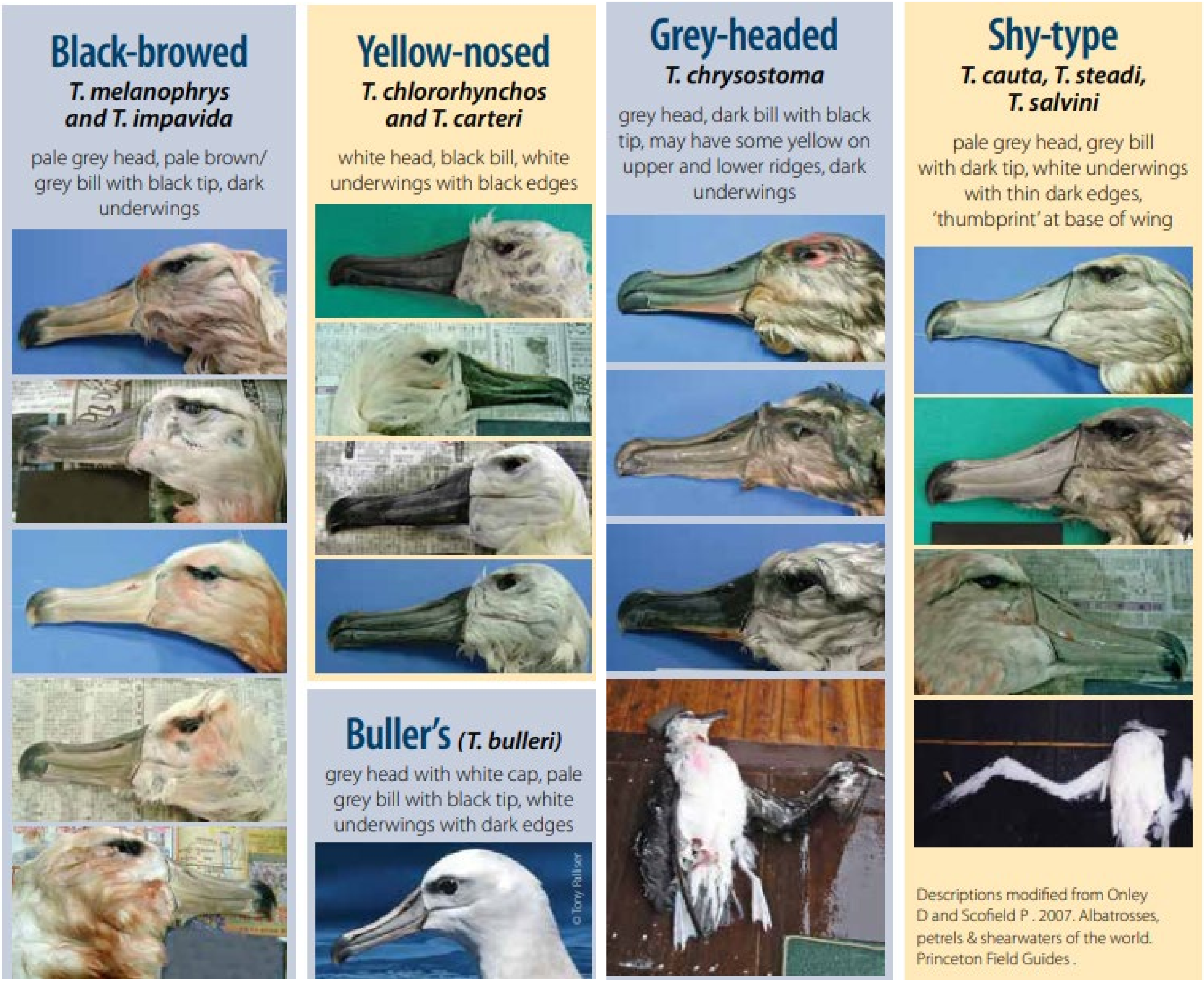
Attachment 6.1

Photo: Graham Robertson

Why we need to determine seabird species



- Environmental laws require prompt reporting of bycaught seabirds.
- Accurate reporting is essential for species conservation.
- Implementation of recovery plans and threat abatement plans depends on the best available information about which species has been bycaught.
- Australia's international obligations include reporting of all seabird bycatch to the highest resolution possible.



The development of genetic markers for species identification was driven in recognition of how difficult it is to identify many seabird species.

- It is hard to identify degraded specimens.

Shy Albatross

White Capped Albatross

The development of genetic markers for species identification was driven in recognition of how difficult it is to identify many seabird species.

- It is hard to identify degraded specimens.
- Visual similarities of closely related species.

Juvenile Wandering Albatross

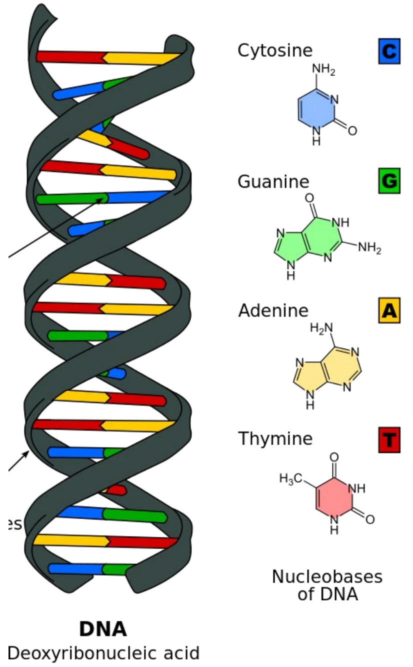
Adult Wandering Albatross

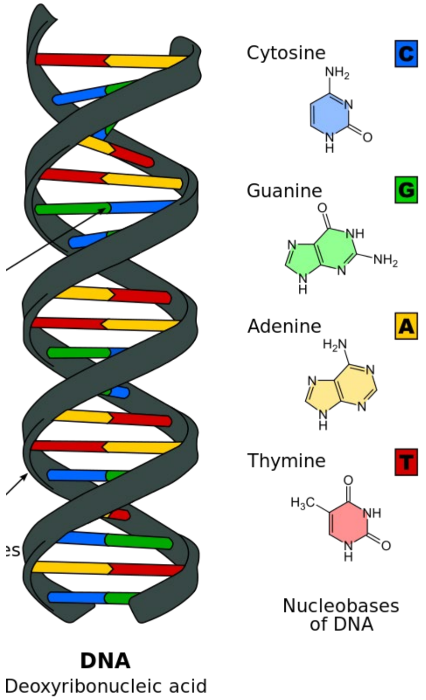
The development of genetic markers for species identification was driven in recognition of how difficult it is to identify many seabird species.

- It is hard to identify degraded specimens.
- Visual similarities of closely related species.
- During plumage changes from juvenile stages to adulthood, identification of Albatrosses can be difficult, and birds may be confused with other large albatrosses with similar colourings.

Background

- Sequencing DNA means determining the order of the four nucleotides or "bases" - that make up the DNA molecule -A,T,C and G
- The specific sequence of A, T, C, and G nucleotides within an organism's DNA is unique to that individual
- These nucleotides are the chemical building blocks of DNA. The order, or sequence, of these blocks tells your cells how to behave.
- The sequence of this DNA is then compared to a reference library which contains information of many species linked to their sequence.
- GenBank is an example of a genetic sequence database, a collection of all publicly available DNA sequences.





Species

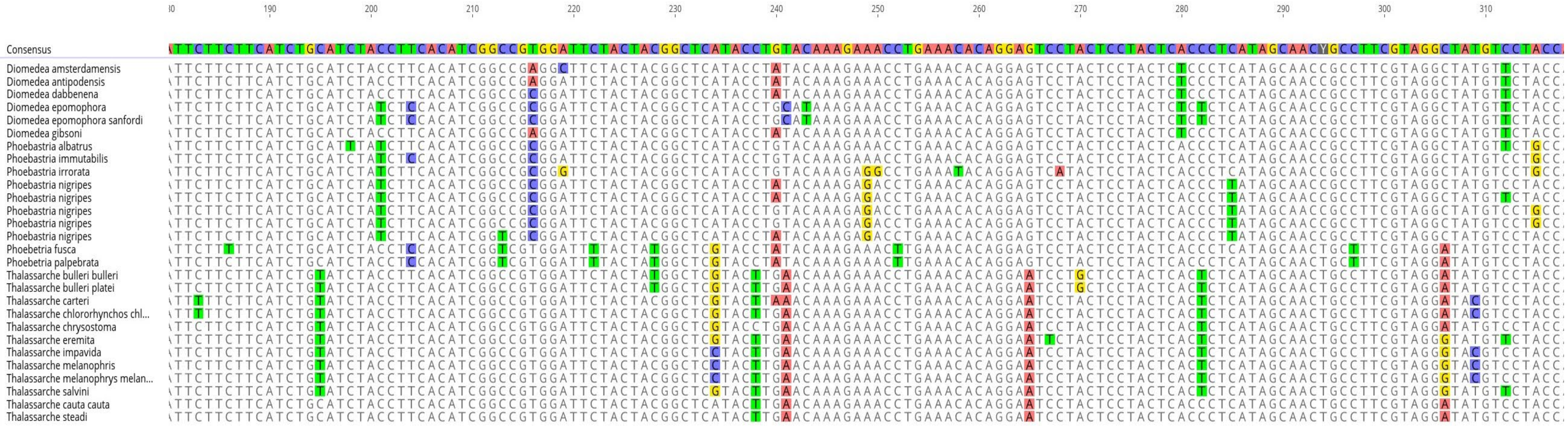
https://birds.fandom.com/

- This list of seabirds in this study include species which are frequently seen in Australian waters and are therefore subject to interactions in oceanic longline fisheries
- 36 key species were identified from the recovery and threat abatement plans
- All of the birds belong to the order Procellariiformes

❑22 Albatross

❑Six Shearwaters

❑Eight Petrels


190
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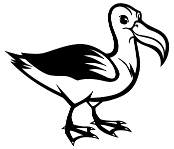
310
Consensus
Diomedea amsterdamensis
Diomedea antipodensis
Diomedea dabbenena
Diomedea epomophora
Diomedea epomophora sanfordi
Diomedea gibsoni
Phoebastria albatrus
Phoebastria immutabilis
Phoebastria irrorata
Phoebastria nigripes
Phoebastria nigripes
Phoebastria nigripes
Phoebastria nigripes
Phoebastria nigripes
Phoebetria fusca
Phoebetria palpebrata
Thalassarche bulleri bulleri
Thalassarche bulleri platei
Thalassarche carteri
Thalassarche chlororhynchos chl...
Thalassarche chrysostoma
Thalassarche eremita
Thalassarche impavida
Thalassarche melanophris
Thalassarche melanophrys melan...
Thalassarche salvini
Thalassarche cauta cauta
Thalassarche steadi

Primer Design

We used 2 markers in this study – Cytochrome b and the Control Region

Forward Primer

Reverse Primer



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AGTCATCGATCGTACGTAGCTAGCCATTTCTAAGGCTAACTATCTACGATCGTGATAAGCCT

AGTCATCGATCGTACGTACCTAGCTATAGCTTAAGCTAGCGGTCTACGACCGTGATAAGCCT

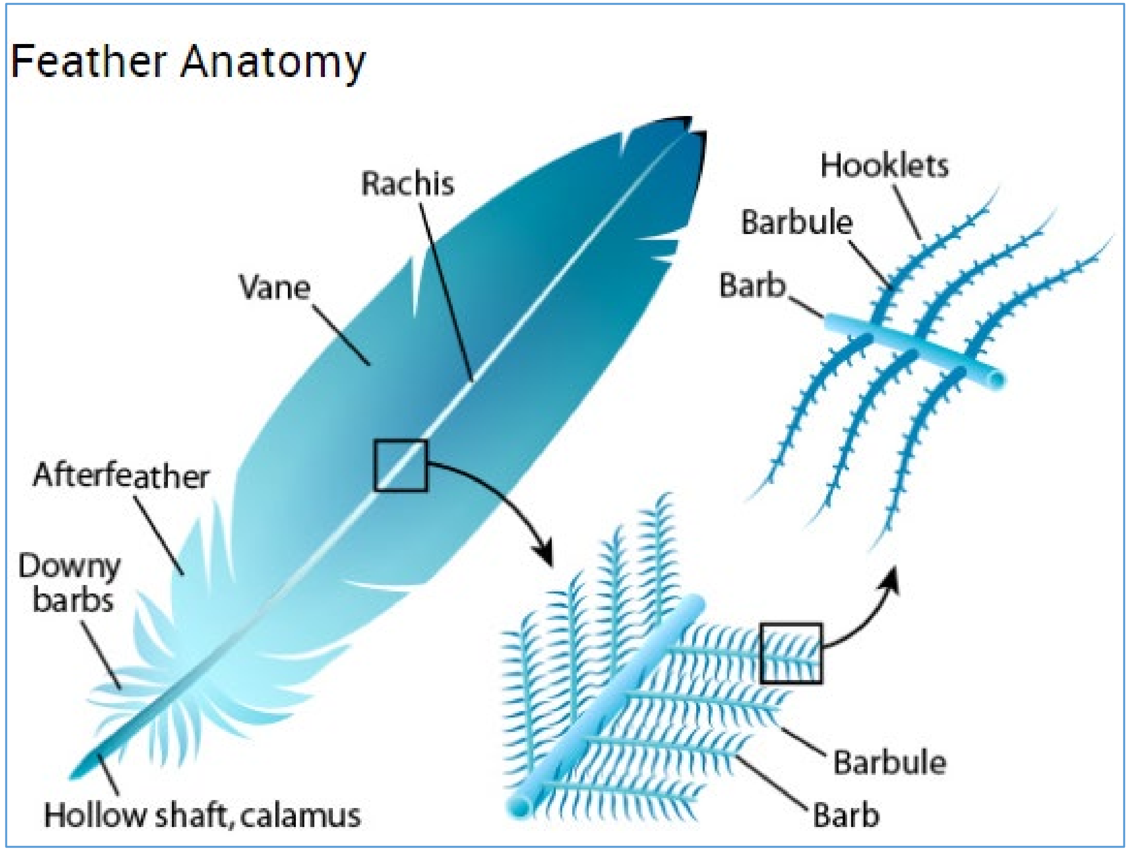
Feathers

At the base of the feather is the calamus or quill. The DNA is within the quill.

It is important to pluck the feathers as the DNA is on the ends of the feathers.

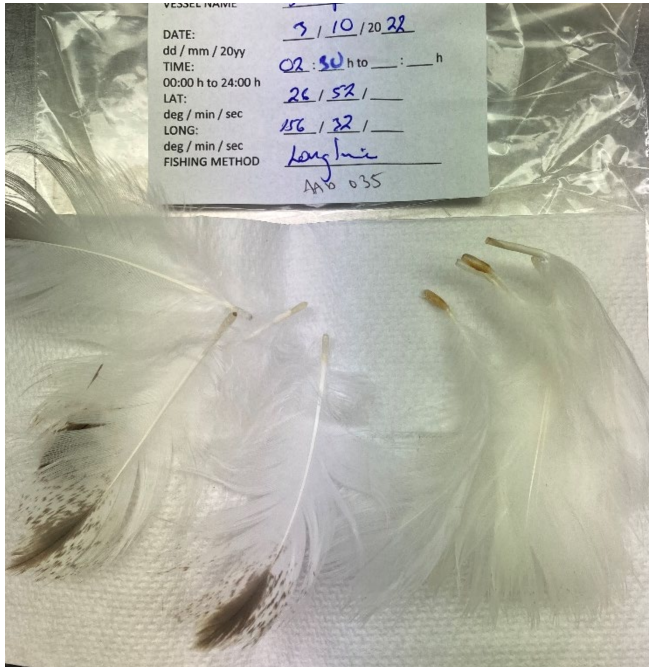
Advantages of collecting feathers:

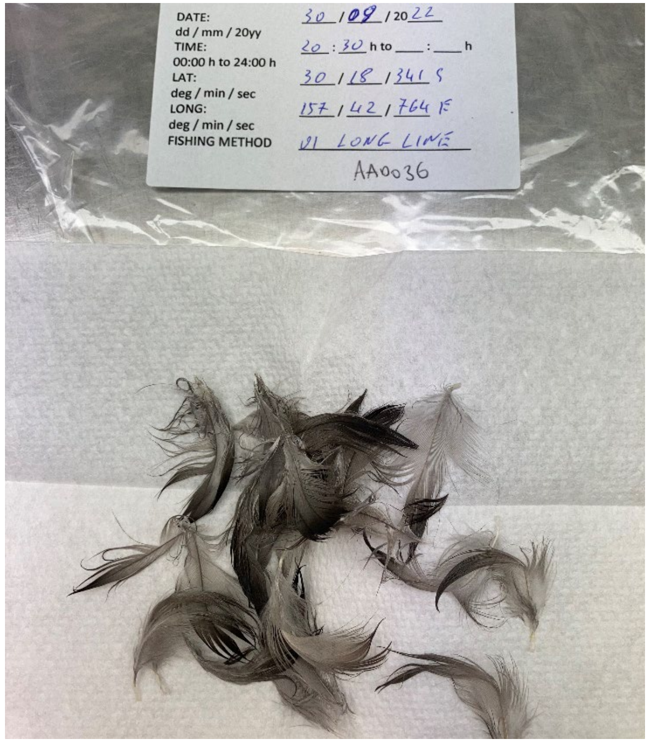
- Relatively easy to collect
- Very little training is required
- No specific storage requirements



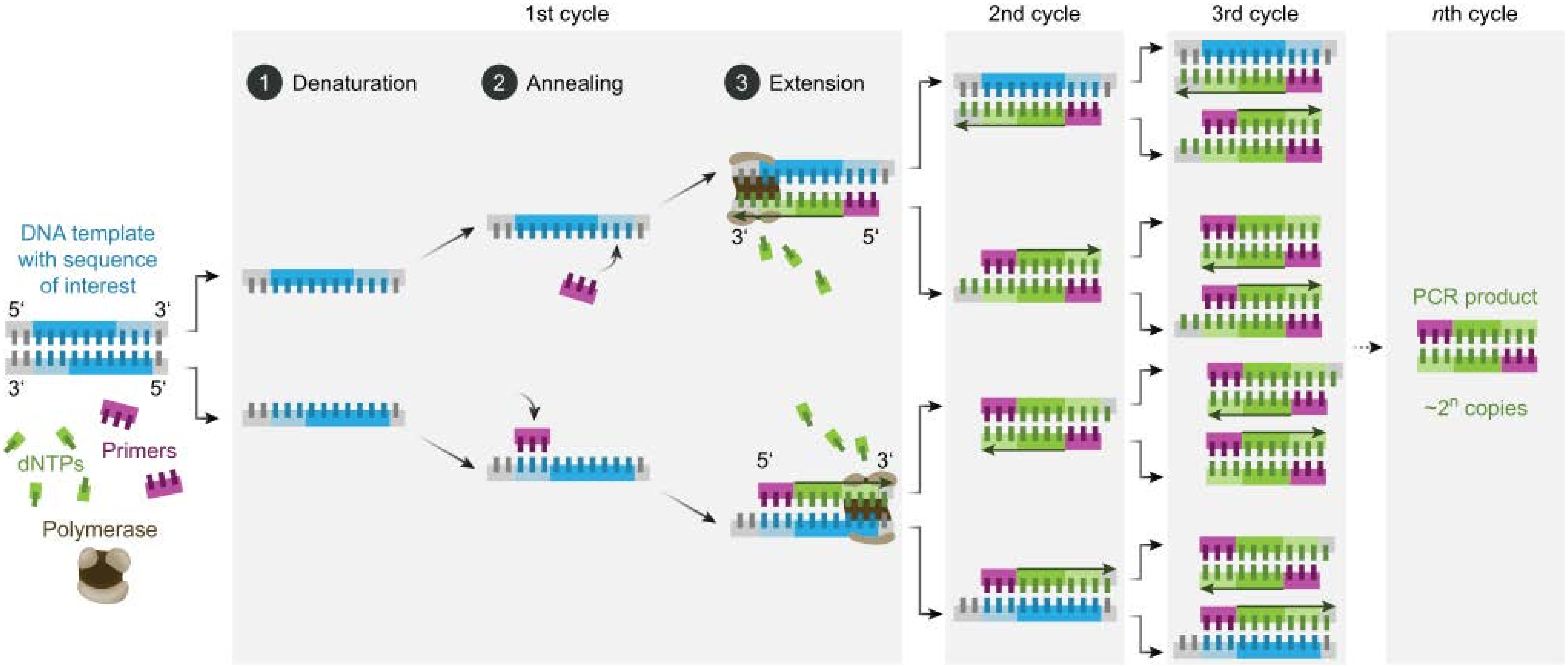
Feather DNA

- 2-3 quills are cut off the base of the feather
- They are placed in a lysis buffer which helps break open the cells and release the DNA.
- The DNA selectively binds to the membrane and proteins and other cellular debris pass through.
- It is then washed several times and resuspended in a buffer.

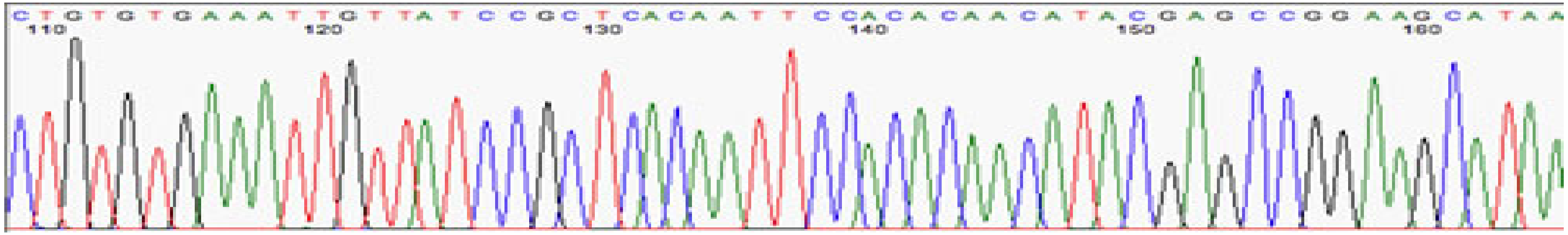




Polymerase Chain Reaction (PCR)



- DNA Sequence



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ATATACATAGCCACGTAAACGGGCATACCCTTTTTATCCCCTCACGAACCCCCAGAGGACAA

GTACTTCAATAGTCCCTACTACATAACACTCAAACGGATTAAACCCATAACCTTCAAGTTCTG
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ATAACATGCAATCCCTTCTCGTAGGACCGGTAGCTGTCGGACCAGGTTATCTATTAATCGTTC
TTCTCA

>BycatchFeather_AAD017_Cytochromeb

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CATACAAGCCCTTCACGCGGATTATCTCTCTCTTATCCCCGGCCGGAACACAAGCGCCCTTA

AGCCCAATAGTCCCTAGTACCATATACTATCTCCCCTCGTGCTGAAAACTACCTACCTTCTTAC
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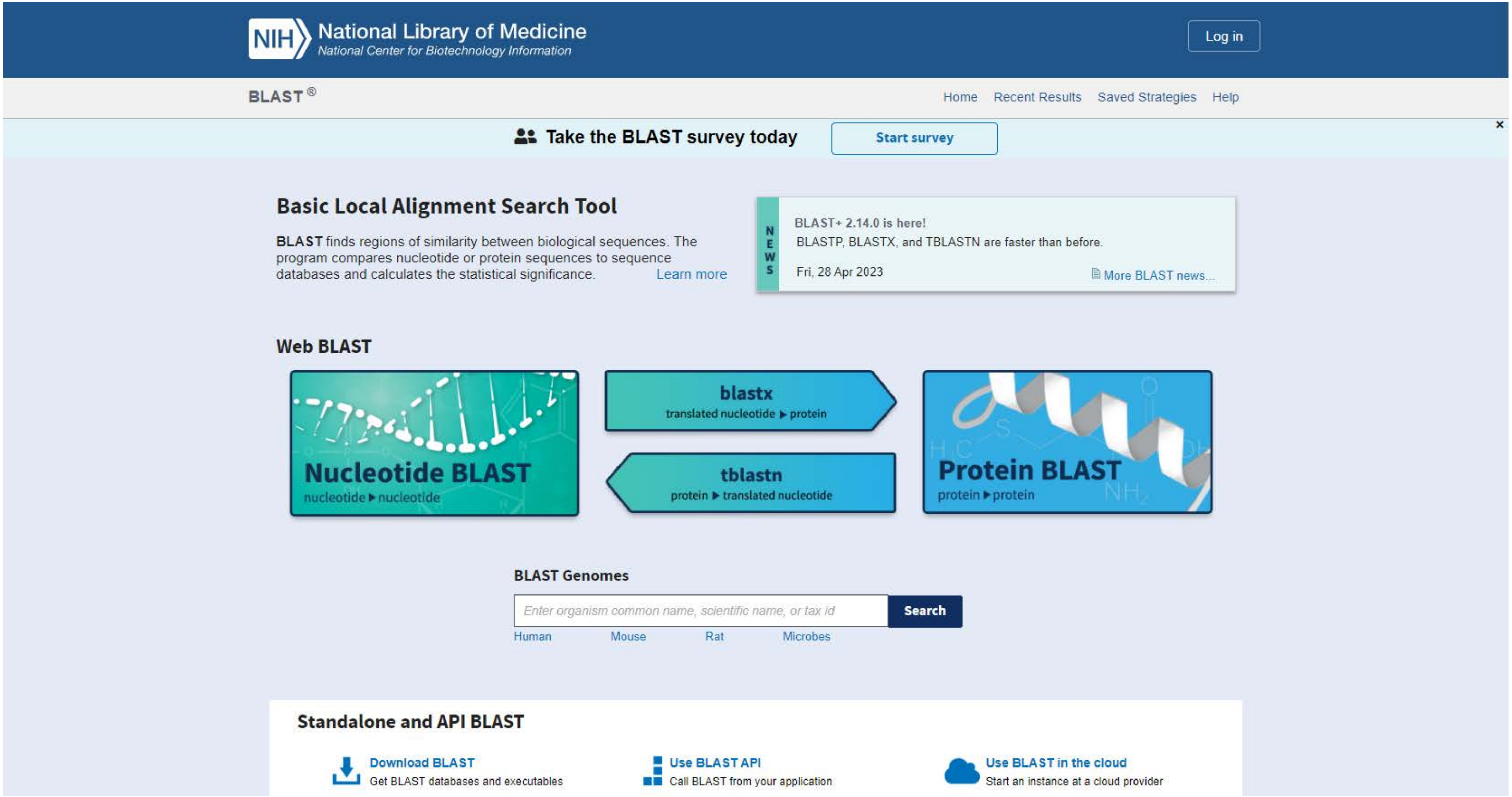
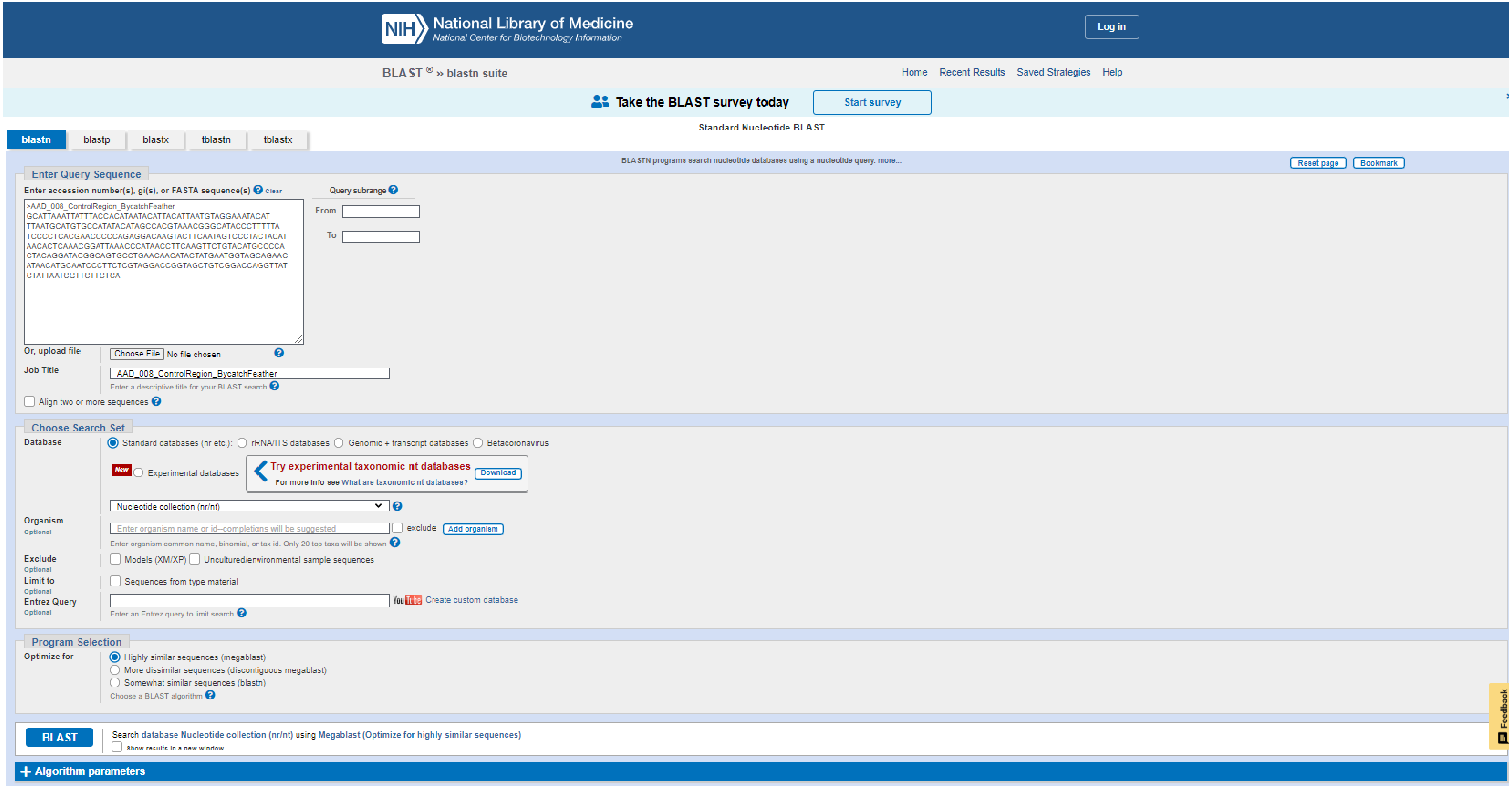
GACAAAACCCTTCAATCATCTCTCGCCGGACCGGTCTCTCGAGCTGGGTTATTTATTAATCG
TTCTTCT

BLAST (Basic Local Alignment Search Tool)





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Saved Strategies
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Take the BLAST survey today
Start survey
Standard Nucleotide BLAST
blastn
blastp
blastx
tblastn
tblastx
BLASTN programs search nucleotide databases using a nucleotide query. more...
Reset page
Bookmark
Enter Query Sequence
Enter accession number(s), gi(s), or FASTA sequence(s) Clear
>AAD_008_ControlRegion_BycatchFeather
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ATAACATGCAATCCCTTCTCGTAGGACCGGTAGCTGTCGGACCAGGTTAT
CTATTAATCGTTCTTCTCA
Query subrange
From
To
Or, upload file
Choose File No file chosen
Job Title
AAD_008_ControlRegion_BycatchFeather
Enter a descriptive title for your BLAST search
Align two or more sequences
Choose Search Set
Database
Standard databases (nr etc.):
rRNA/ITS databases
Genomic + transcript databases
Betacoronavirus
New
Experimental databases
Try experimental taxonomic nt databases
For more info see What are taxonomic nt databases?
Download
Nucleotide collection (nr/nt)
Organism
Optional
Enter organism name or id--completions will be suggested
exclude
Add organism
Enter organism common name, binomial, or tax id. Only 20 top taxa will be shown
Exclude
Optional
Models (XM/XP)
Uncultured/environmental sample sequences
Limit to
Optional
Sequences from type material
Entrez Query
Optional
YouTube
Create custom database
Enter an Entrez query to limit search
Program Selection
Optimize for
Highly similar sequences (megablast)
More dissimilar sequences (discontiguous megablast)
Somewhat similar sequences (blastn)
Choose a BLAST algorithm
BLAST
Search database Nucleotide collection (nr/nt) using Megablast (Optimize for highly similar sequences)
Show results in a new window
Feedback
+ Algorithm parameters

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Molecule type	dna
Query Length	319
Other reports	Distance tree of results MSA viewer

+ Add organism

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Filter Reset

Descriptions | Graphic Summary | Alignments | Taxonomy

Sequences producing significant alignments

Download Select columns Show 100

select all *100 sequences selected*

GenBank Graphics Distance tree of results MSA Viewer

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Thalassarche bulleri haplotype BulF1 control region, partial sequence; mitochondrial	Thalassarche bulleri	492	492	96%	2e-134	95.45%	327	DQ029001.1
Thalassarche eremita haplotype EreF2 control region, partial sequence; mitochondrial	Thalassarche eremita	436	436	96%	1e-117	92.21%	327	DQ029006.1
Thalassarche salvini haplotype SalF2 control region, partial sequence; mitochondrial	Thalassarche salvini	431	431	96%	5e-116	91.88%	327	DQ029008.1
Thalassarche steadi haplotype sD16 D-loop, partial sequence; mitochondrial	Thalassarche steadi	425	425	93%	2e-114	92.33%	299	FJ617167.1
Thalassarche bulleri isolate MG29 control region, partial sequence; mitochondrial	Thalassarche bulleri	411	411	69%	6e-110	100.00%	222	MH271540.1
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Thalassarche bulleri isolate BB09 control region, partial sequence; mitochondrial	Thalassarche bulleri	411	411	69%	6e-110	100.00%	222	MH271452.1
Thalassarche bulleri isolate BB01 control region, partial sequence; mitochondrial	Thalassarche bulleri	411	411	69%	6e-110	100.00%	222	MH271445.1
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Thalassarche bulleri isolate BB44 control region, partial sequence; mitochondrial	Thalassarche bulleri	405	405	69%	3e-108	99.55%	222	MH271486.1
Thalassarche bulleri isolate BB40 control region, partial sequence; mitochondrial	Thalassarche bulleri	405	405	69%	3e-108	99.55%	222	MH271482.1
Thalassarche bulleri isolate BB31 control region, partial sequence; mitochondrial	Thalassarche bulleri	405	405	69%	3e-108	99.55%	222	MH271473.1
Thalassarche bulleri isolate BB24 control region, partial sequence; mitochondrial	Thalassarche bulleri	405	405	69%	3e-108	99.55%	222	MH271466.1

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Other reports	Distance tree of results	MSA viewer

+ Add organism

Percent Identity [ ] to [ ]   E value [ ] to [ ]   Query Coverage [ ] to [ ]

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Descriptions | Graphic Summary | Alignments | Taxonomy

Sequences producing significant alignments   Download   Select columns   Show 100

select all   *100 sequences selected*   GenBank   Graphics   Distance tree of results   MSA Viewer

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Thalassarche eremita haplotype EreF2 control region, partial sequence; mitochondrial	Thalassarche eremita	436	436	96%	1e-117	92.21%	327	DQ029006.1
Thalassarche salvini haplotype SalF2 control region, partial sequence; mitochondrial	Thalassarche salvini	431	431	96%	5e-116	91.88%	327	DQ029008.1
Thalassarche steadi haplotype sD16 D-loop, partial sequence; mitochondrial	Thalassarche steadi	425	425	93%	2e-114	92.33%	299	FJ617167.1
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Description	None
Molecule type	dna
Query Length	319
Other reports	Distance tree of results MSA viewer

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Percent Identity ___ to ___ E value ___ to ___ Query Coverage ___ to ___

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Sequences producing significant alignments Download Select columns Show 100

select all *100 sequences selected* GenBank Graphics Distance tree of results MSA Viewer

Description	Scientific Name	Max Score	Total Score	Query Cover	E value	Per. Ident	Acc. Len	Accession
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Thalassarche bulleri haplotype BulF1 control region, partial sequence; mitochondrial	Thalassarche bulleri	492	492	96%	2e-134	95.45%	327	DQ029001.1
Thalassarche eremita haplotype EreF2 control region, partial sequence; mitochondrial	Thalassarche eremita	436	436	96%	1e-117	92.21%	327	DQ029006.1
Thalassarche salvini haplotype SalF2 control region, partial sequence; mitochondrial	Thalassarche salvini	431	431	96%	5e-116	91.88%	327	DQ029008.1
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Thalassarche bulleri isolate BB24 control region, partial sequence; mitochondrial	Thalassarche bulleri	405	405	69%	3e-108	99.55%	222	MH271466.1

Download GenBank Graphics

Thalassarche bulleri haplotype BulF2 control region, partial sequence; mit

Sequence ID: DQ029002.1 **Length:** 327 **Number of Matches:** 1

Range 1: 20 to 327 GenBank Graphics ▼ Next Match

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Thalassarche bulleri haplotype BulF2 control region, partial mitochondrial

GenBank: DQ029002.1

FASTA Graphics PopSet

Go to:

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DEFINITION  Thalassarche bulleri haplotype BulF2 control region, partial
            sequence; mitochondrial.
ACCESSION   DQ029002
VERSION     DQ029002.1
KEYWORDS    .
SOURCE      mitochondrion Thalassarche bulleri (Buller's albatross)
  ORGANISM  Thalassarche bulleri
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            Archelosauria; Archosauria; Dinosauria; Saurischia; Theropoda;
            Coelurosauria; Aves; Neognathae; Procellariiformes; Diomedeidae;
            Thalassarche.
REFERENCE   1  (bases 1 to 327)
  AUTHORS   Abbott,C.L., Double,M.C., Trueman,J.W., Robinson,A. and Cockburn,A.
  TITLE     An unusual source of apparent mitochondrial heteroplasmy: duplicate
            mitochondrial control regions in Thalassarche albatrosses
  JOURNAL   Mol. Ecol. 14 (11), 3605-3613 (2005)
   PUBMED   16156827
REFERENCE   2  (bases 1 to 327)
  AUTHORS   Abbott,C.L., Double,M.C., Trueman,J.W.H., Robinson,A. and
            Cockburn,A.
  TITLE     Direct Submission
  JOURNAL   Submitted (05-MAY-2005) School of Botany and Zoology, The
            Australian National University, Daley Rd, Canberra, ACT 0200,
            Australia
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ORIGIN
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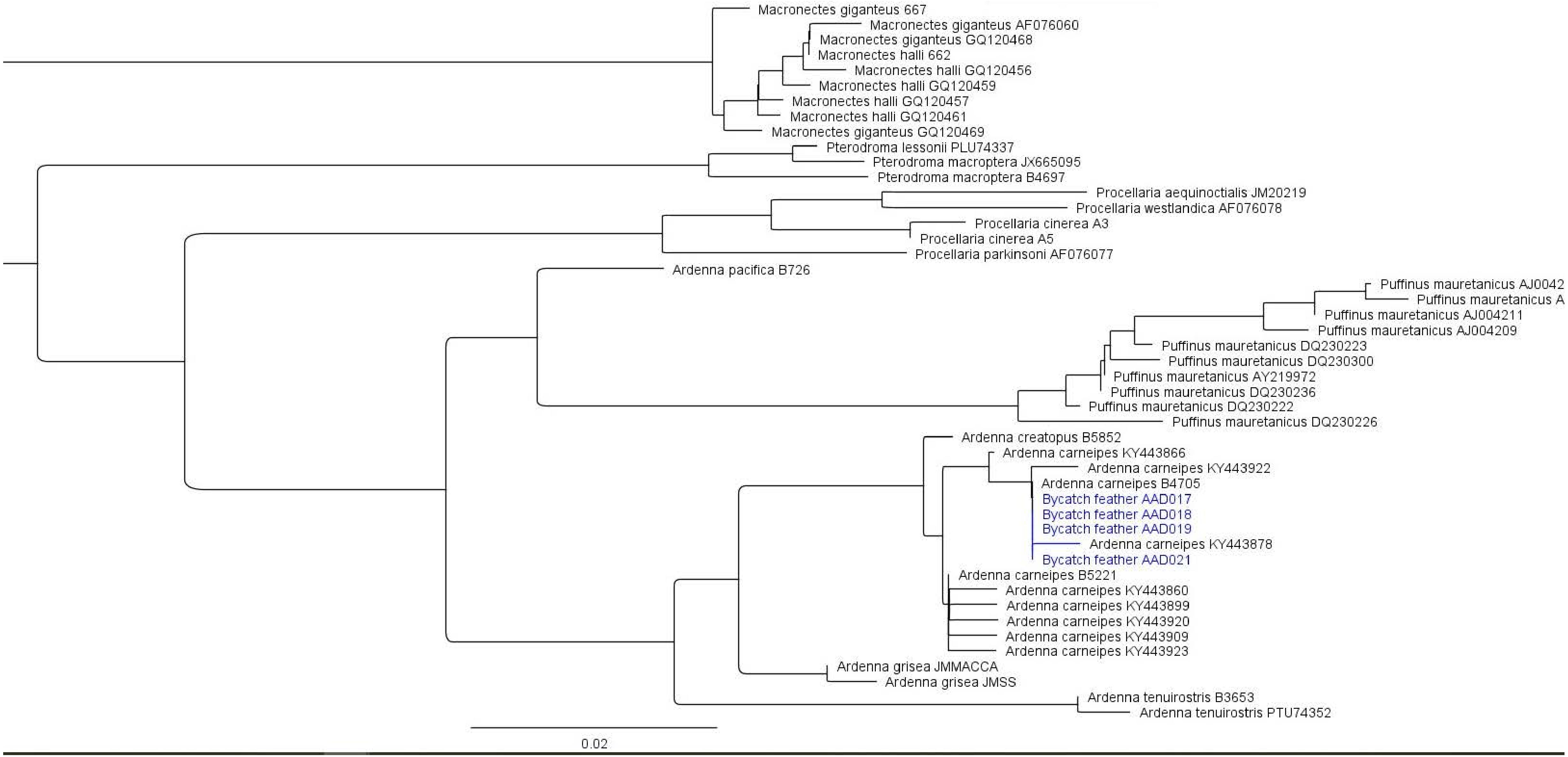
Phylogenetic Tree for Petrels using Cytb



Reference Database

- What happens if there isn’t a sequence on GenBank for an unknown sample?
- We have also been working on building a reference database.
- We have sourced 80 samples of known provenance that have a reliable taxonomic identification.
- These were obtained from museum collections and archived DNA samples at the Australian Antarctic Division.
- The sequences will help build DNA reference databases

Results from ETBF feathers

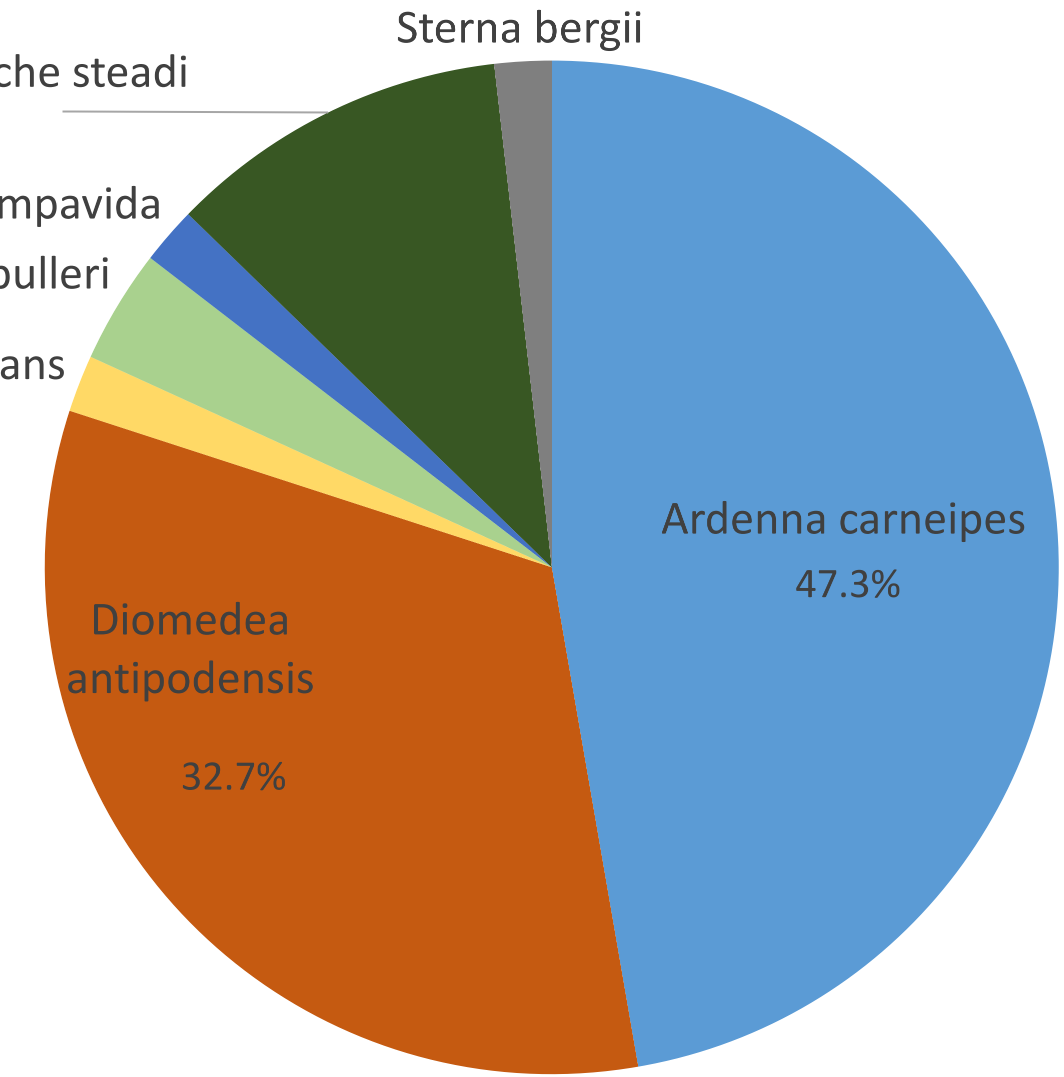
The results are not intended to be critical of the crew ID skills but rather to improve confidence in our knowledge of the species caught.

Species genetic identification from feathers 2019- 2022

Species	Common Name	2019	2020	2021	2022	Total
Ardenna carneipes	Flesh-footed Shearwater	2		4	20	26
Diomedea antipodensis	Antipodean Albatross	5			13	18
Diomedea exulans	Wandering Albatross				1	1
Thalassarche bulleri	Buller's Albatross	1		1		2
Thalassarche impavida	Campbell's Albatross			1		1
Thalassarche steadi	White-capped Albatross	3	2		1	6
Sterna bergii	Crested Tern		1			1
	Feathers sent to AAD	**11**	**3**	**6**	**35***	**55**
	(% of total bycaught seabirds recorded)	**14%**	**9%**	**14%**	**(61%)**	**26%**
	Dead seabird interactions ETBF (TEP reports)	**78**	**33**	**42**	**57**	**210**

*We are waiting on the results from four feathers from 2022 (have only processed 35 in total)

Species genetic identification from feathers 2019- 2022



e-log and Genetic ID data 2019-2022

Identification of bycatch specimen(s)				Resolution of identification		Agreement between elog and genetic ID		
Date of Interaction (mm/yyyy)	Number of bycatch samples	elog record (AFMA)	Genetics (this study)	elog	Genetics	Family level	Genus level	Species level
02/2019	1	Ardenna spp. - undifferentiated	Thalassarche steadi* (White-capped Albatross)	Genus	Species	Y	Y	N
04/2019	1	Diomedeidae - undifferentiated	Thalassarche steadi* (White-capped Albatross)	Family	Species*	Y	N	N
05/2019	1	Diomedea exulans (Wandering Albatross)	Thalassarche steadi* (White-capped Albatross)	Species	Species*	Y	N	N
09/2019	1	Diomedeidae - undifferentiated	Thalassarche bulleri (Bullers Albatross)	Family	Species	Y	N	N
10/2019	5	Diomedeidae - undifferentiated	Thalassarche steadi* (White-capped Albatross)	Family	Species	Y	N	N
10/2019	1	Ardenna tenuirostris (Short-tailed Shearwater)	Ardenna carneipes (Flesh-footed Shearwater)	Species	Species	Y	Y	N
11/2019	1	Diomedeidae - undifferentiated	Thalassarche steadi* (White-capped Albatross)	Family	Species*	Y	N	N
03/2020	1	Thalassarche melanophris (Black-browed Albatross)	Thalassarche steadi* (White-capped Albatross)	Species	Species*	Y	Y	N
06/2020	1	Thalassarche cauta (Shy Albatross)	Thalassarche steadi* (White-capped Albatross)	Species	Species*	Y	Y	N*
10/2020	1	Laridae (tern)	Sterna bergii (Crested Tern)	Family	Species	Y	N	N
06/2021	1	Diomedeidae - undifferentiated	Thalassarche impavida (Campbell Albatross)	Family	Species	Y	N	N
09/2021	3	no e-log record	Ardenna carneipes (Flesh-footed Shearwater)	n/a	Species	n/a	n/a	n/a
09/2021	1	Diomedeidae - undifferentiated	Ardenna carneipes (Flesh-footed Shearwater)	Family	Species	N	N	N
10/2021	1	Diomedeidae - undifferentiated	Thalassarche bulleri (Bullers Albatross)	Family	Species	Y	N	N
10/2022	1	NO DATA provided	Diomedea exulans Wandering Albatross)	n/a	Species	n/a	n/a	n/a
10/2022	1	NO DATA provided	Thalassarche steadi* (White-capped Albatross)	n/a	Species	n/a	n/a	n/a
10/2022	13	NO DATA provided	Thalassarche steadi* (White-capped Albatross)	n/a	Species	n/a	n/a	n/a
10/2022	20	NO DATA provided	Ardenna carneipes (Flesh-footed Shearwater)	n/a	Species	n/a	n/a	n/a

* Discrimination between *Thalassarche cauta* and *T. steadi* based on genetic methods has 97% accuracy (Abbott et al, 2006).

We have genetic data for 55 feathers

3 feathers from 2021 had no e-log record.

35 Feathers from 2022 have no e-log data provided to AAD

e-log and Genetic ID data 2019-2022

Identification of bycatch specimen(s)				Resolution of identification		Agreement between elog and genetic ID		
Date of Interaction (mm/yyyy)	Number of bycatch samples	elog record (AFMA)	Genetics (this study)	elog	Genetics	Family level	Genus level	Species level
02/2019	1	Ardenna spp. - undifferentiated	Thalassarche steadi* (White-capped Albatross)	Genus	Species	Y	Y#	N
04/2019	1	Diomedeidae - undifferentiated	Thalassarche steadi* (White-capped Albatross)	Family	Species*	Y	N	N
05/2019	1	Diomedea exulans (Wandering Albatross)	Thalassarche steadi* (White-capped Albatross)	Species	Species*	Y	N	N
09/2019	1	Diomedeidae - undifferentiated	Thalassarche bulleri (Bullers Albatross)	Family	Species	Y	N	N
10/2019	5	Diomedeidae - undifferentiated	Thalassarche steadi* (White-capped Albatross)	Family	Species	Y	N	N
10/2019	1	Ardenna tenuirostris (Short-tailed Shearwater)	Ardenna carneipes (Flesh-footed Shearwater)	Species	Species	Y	Y	N
11/2019	1	Diomedeidae - undifferentiated	Thalassarche steadi* (White-capped Albatross)	Family	Species*	Y	N	N
03/2020	1	Thalassarche melanophris (Black-browed Albatross)	Thalassarche steadi* (White-capped Albatross)	Species	Species*	Y	Y	N
06/2020	1	Thalassarche cauta (Shy Albatross)	Thalassarche steadi* (White-capped Albatross)	Species	Species*	Y	Y	N*
10/2020	1	Laridae (tern)	Sterna bergii (Crested Tern)	Family	Species	Y	N	N
06/2021	1	Diomedeidae - undifferentiated	Thalassarche impavida (Campbell Albatross)	Family	Species	Y	N	N
09/2021	3	no e-log record	Ardenna carneipes (Flesh-footed Shearwater)	n/a	Species	n/a	n/a	n/a
09/2021	1	Diomedeidae - undifferentiated	Ardenna carneipes (Flesh-footed Shearwater)	Family	Species	N	N	N
10/2021	1	Diomedeidae - undifferentiated	Thalassarche bulleri (Bullers Albatross)	Family	Species	Y	N	N

*One sample has conflicting data:

elog: Diomedeidae = Albatross at family level

genetics: Flesh-footed Shearwater

lwl comment: from e-log mutton bird

Animal Type	Scientific Name	Lwl-comment
BIRD	Diomedeidae	mutton bird

* Discrimination between *Thalassarche cauta* and *T. steadi* based on genetic methods has 97% accuracy (Abbott et al, 2006).

e-log and Genetic ID data 2019-2022

Identification of bycatch specimen(s)				Resolution of identification		Agreement between elog and genetic ID		
Date of Interaction (mm/yyyy)	Number of bycatch samples	elog record (AFMA)	Genetics (this study)	elog	Genetics	Family level	Genus level	Species level
02/2019	1	Ardenna spp. - undifferentiated	Thalassarche steadi* (White-capped Albatross)	Genus	Species	Y	Y	N
04/2019	1	Diomedeidae - undifferentiated	Thalassarche steadi* (White-capped Albatross)	Family	Species*	Y	N	N
05/2019	1	Diomedea exulans (Wandering Albatross)	Thalassarche steadi* (White-capped Albatross)	Species	Species*	Y	N	N
09/2019	1	Diomedeidae - undifferentiated	Thalassarche bulleri (Bullers Albatross)	Family	Species	Y	N	N
10/2019	5	Diomedeidae - undifferentiated	Thalassarche steadi* (White-capped Albatross)	Family	Species	Y	N	N
10/2019	1	Ardenna tenuirostris (Short-tailed Shearwater)	Ardenna carneipes (Flesh-footed Shearwater)	Species	Species	Y	Y	N
11/2019	1	Diomedeidae - undifferentiated	Thalassarche steadi* (White-capped Albatross)	Family	Species*	Y	N	N
03/2020	1	Thalassarche melanophris (Black-browed Albatross)	Thalassarche steadi* (White-capped Albatross)	Species	Species*	Y	Y	N
06/2020	1	Thalassarche cauta (Shy Albatross)	Thalassarche steadi* (White-capped Albatross)	Species	Species*	Y	Y	N*
10/2020	1	Laridae (tern)	Sterna bergii (Crested Tern)	Family	Species	Y	N	N
06/2021	1	Diomedeidae - undifferentiated	Thalassarche impavida (Campbell Albatross)	Family	Species	Y	N	N
09/2021	3	no e-log record	Ardenna carneipes (Flesh-footed Shearwater)	n/a	Species	n/a	n/a	n/a
09/2021	1	Diomedeidae - undifferentiated	Ardenna carneipes (Flesh-footed Shearwater)	Family	Species	N	N	N
10/2021	1	Diomedeidae - undifferentiated	Thalassarche bulleri (Bullers Albatross)	Family	Species	Y	N	N
10/2022	1	NO DATA provided	Diomedea exulans Wandering Albatross)	n/a	Species	n/a	n/a	n/a
10/2022	1	NO DATA provided	Thalassarche steadi* (White-capped Albatross)	n/a	Species	n/a	n/a	n/a
10/2022	13	NO DATA provided	Thalassarche steadi* (White-capped Albatross)	n/a	Species	n/a	n/a	n/a
10/2022	20	NO DATA provided	Ardenna carneipes (Flesh-footed Shearwater)	n/a	Species	n/a	n/a	n/a

Of the remaining 16 feathers:

At **FAMILY** level 16/16 match (e.g. Diomedeidae)

* Discrimination between *Thalassarche cauta* and *T. steadi* based on genetic methods has 97% accuracy (Abbott et al, 2006).

e-log and Genetic ID data 2019-2022

		Identification of bycatch specimen(s)		**Resolution of identification**		**Agreement between elog and genetic ID**		
Date of Interaction(mm/yyyy)	Number of bycatch samples	elog record (AFMA)	Genetics (this study)	elog	Genetics	Family level	Genus level	Species level
02/2019	1	Ardenna spp. - undifferentiated	Ardenna carneipes	Genus	Species	Y	Y	N
04/2019	1	Diomedeidae - undifferentiated	Thalassarche steadi*	Family	Species*	Y	N	N
05/2019	1	Diomedea exulans	Thalassarche steadi*	Species	Species*	Y	N	N
09/2019	1	Diomedeidae - undifferentiated	Thalassarche bulleri	Family	Species	Y	N	N
10/2019	5	Diomedeidae - undifferentiated	Diomedea antipodensis	Family	Species	Y	N	N
10/2019	1	Ardenna tenuirostris	Ardenna carneipes	Species	Species	Y	Y	N
11/2019	1	Diomedeidae - undifferentiated	Thalassarche steadi*	Family	Species*	Y	N	N
03/2020	1	Thalassarche melanophris	Thalassarche steadi*	Species	Species*	Y	Y	N
06/2020	1	Thalassarche cauta	Thalassarche steadi*	Species	Species*	Y	Y	N*
10/2020	1	Laridae (tern)	Sterna bergii	Family	Species	Y	N	N
06/2021	1	Diomedeidae - undifferentiated	Thalassarche impavida	Family	Species	Y	N	N
09/2021	3	no e-log record	Ardenna carneipes	n/a	Species	n/a	n/a	n/a
09/2021	1	Diomedeidae - undifferentiated	Ardenna carneipes	Family	Species	N	N	N
10/2021	1	Diomedeidae - undifferentiated	Thalassarche bulleri	Family	Species	Y	N	N
10/2022	1	NO DATA provided	Diomedea exulans	n/a	Species	n/a	n/a	n/a
10/2022	1	NO DATA provided	Thalassarche steadi*	n/a	Species	n/a	n/a	n/a
10/2022	13	NO DATA provided	Diomedea antipodensis	n/a	Species	n/a	n/a	n/a
10/2022	20	NO DATA provided	Ardenna carneipes	n/a	Species	n/a	n/a	n/a

* Discrimination between *Thalassarche cauta* and *T. steadi* based on genetic methods has 97% accuracy (Abbott et al, 2006).

Of the remaining 16 feathers:

At **GENUS** level 4/16 match (NB the genus *Puffinus* is now *Ardenna*

e-log and Genetic ID data 2019-2022

Identification of bycatch specimen(s)				Resolution of identification		Agreement between elog and genetic ID		
Date of Interaction (mm/yyyy)	Number of bycatch samples	elog record (AFMA)	Genetics (this study)	elog	Genetics	Family level	Genus level	Species level
02/2019	1	Ardenna spp. - undifferentiated	Thalassarche steadi* (White-capped Albatross)	Genus	Species	Y	Y	N
04/2019	1	Diomedeidae - undifferentiated	Thalassarche steadi* (White-capped Albatross)	Family	Species*	Y	N	N
05/2019	1	Diomedea exulans (Wandering Albatross)	Thalassarche steadi* (White-capped Albatross)	Species	Species*	Y	N	N
09/2019	1	Diomedeidae - undifferentiated	Thalassarche bulleri (Bullers Albatross)	Family	Species	Y	N	N
10/2019	5	Diomedeidae - undifferentiated	Thalassarche steadi* (White-capped Albatross)	Family	Species	Y	N	N
10/2019	1	Ardenna tenuirostris (Short-tailed Shearwater)	Ardenna carneipes (Flesh-footed Shearwater)	Species	Species	Y	Y	N
11/2019	1	Diomedeidae - undifferentiated	Thalassarche steadi* (White-capped Albatross)	Family	Species*	Y	N	N
03/2020	1	Thalassarche melanophris (Black-browed Albatross)	Thalassarche steadi* (White-capped Albatross)	Species	Species*	Y	Y	N
06/2020	1	Thalassarche cauta (Shy Albatross)	Thalassarche steadi* (White-capped Albatross)	Species	Species*	Y	Y	N*

4 birds were identified to species

At **SPECIES** level 0/16 match

Shy and White-capped Albatross are very hard to tell apart visually

- A single base substitution (A or G), within the control region, can discriminate between Shy and White-capped Albatross with 97% accuracy.
- These two species can be identified using other molecular methods however this was outside the scope for this study

* Discrimination between *Thalassarche cauta* and *T. steadi* based on genetic methods has 97% accuracy (Abbott et al, 2006).

Conclusions

- The combined use of the Cytb and CR markers provides an easily-applied, simple and effective genetic diagnostic tool to identify seabird species using genetic samples extracted from feathers.
- The discrepancies between genetic and e-log records highlights the need for ongoing refinement of monitoring methods.
- This study has highlighted the prevalence of TEP species, such as flesh-footed shearwaters, Antipodean albatrosses and white-capped albatrosses, bycaught in Australian waters. These three species made up 91% (n=50/55) of the total feather samples collected from 2019-2022.

Importance of developing DNA markers

- This research is the first practical demonstration of the effectiveness of taking feather samples from dead seabirds for DNA analyses.
- The Commonwealth fisheries Bycatch Policy and TAP require species resolution data on bycatch.
- This research improves confidence in bycatch reporting by providing species level identification of bycatch.
- We hope AFMA support the ongoing implementation of this method in identifying seabird bycatch to species level.

A huge thank you to all the fishers from the ETBF that have provided feathers.

e-log and Genetic ID data 2019-2022

Identification of bycatch specimen(s)				Resolution of identification		Agreement between elog and genetic ID		
Date of Interaction (mm/yyyy)	Number of bycatch samples	elog record (AFMA)	Genetics (this study)	elog	Genetics	Family level	Genus level	Species level
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04/2019	1	Diomedeidae - undifferentiated	Thalassarche steadi* (White-capped Albatross)	Family	Species*	Y	N	N
05/2019	1	Diomedea exulans (Wandering Albatross)	Thalassarche steadi* (White-capped Albatross)	Species	Species*	Y	N	N
09/2019	1	Diomedeidae - undifferentiated	Thalassarche bulleri (Bullers Albatross)	Family	Species	Y	N	N
10/2019	5	Diomedeidae - undifferentiated	Thalassarche steadi* (White-capped Albatross)	Family	Species	Y	N	N
10/2019	1	Ardenna tenuirostris (Short-tailed Shearwater)	Ardenna carneipes (Flesh-footed Shearwater)	Species	Species	Y	Y	N
11/2019	1	Diomedeidae - undifferentiated	Thalassarche steadi* (White-capped Albatross)	Family	Species*	Y	N	N
03/2020	1	Thalassarche melanophris (Black-browed Albatross)	Thalassarche steadi* (White-capped Albatross)	Species	Species*	Y	Y	N
06/2020	1	Thalassarche cauta (Shy Albatross)	Thalassarche steadi* (White-capped Albatross)	Species	Species*	Y	Y	N*
10/2020	1	Laridae (tern)	Sterna bergii (Crested Tern)	Family	Species	Y	N	N
06/2021	1	Diomedeidae - undifferentiated	Thalassarche impavida (Campbell Albatross)	Family	Species	Y	N	N
09/2021	3	no e-log record	Ardenna carneipes (Flesh-footed Shearwater)	n/a	Species	n/a	n/a	n/a
09/2021	1	Diomedeidae - undifferentiated	Ardenna carneipes (Flesh-footed Shearwater)	Family	Species	N	N	N
10/2021	1	Diomedeidae - undifferentiated	Thalassarche bulleri (Bullers Albatross)	Family	Species	Y	N	N
10/2022	1	NO DATA provided	Diomedea exulans Wandering Albatross)	n/a	Species	n/a	n/a	n/a
10/2022	1	NO DATA provided	Thalassarche steadi* (White-capped Albatross)	n/a	Species	n/a	n/a	n/a
10/2022	13	NO DATA provided	Thalassarche steadi* (White-capped Albatross)	n/a	Species	n/a	n/a	n/a
10/2022	20	NO DATA provided	Ardenna carneipes (Flesh-footed Shearwater)	n/a	Species	n/a	n/a	n/a

* Discrimination between *Thalassarche cauta* and *T. steadi* based on genetic methods has 97% accuracy (Abbott et al, 2006).

Does AFMA accept the release of this data in this form?

Questions?

ICES Journal of
Marine Science

ICES CIEM International Council for the Exploration of the Sea Conseil International pour l'Exploration de la Mer

ICES Journal of Marine Science (2020), 77(3), 921–929. doi:10.1093/icesjms/fsaa020

Original Article

An empirical Bayesian approach for estimating fleet- and vessel-level bycatch rates in fisheries with effort heterogeneity and limited data: a prospective tool for measuring bycatch mitigation performance

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[2]*Institute for Applied Ecology, University of Canberra, Bruce, Australian Capital Territory 2617, Australia*
[3]*Oceanic Fisheries Programme, Pacific Community, BPD5 Noumea 98848, New Caledonia*

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Parsa, M., Emery, T. J., Williams, A. J., and Nicol, S. An empirical Bayesian approach for estimating fleet- and vessel-level bycatch rates in fisheries with effort heterogeneity and limited data: a prospective tool for measuring bycatch mitigation performance. – ICES Journal of Marine Science, 77: 921–929.

Received 23 October 2019; revised 15 January 2020; accepted 27 January 2020; advance access publication 27 February 2020.

Minimizing fishing-induced mortality on bycatch and endangered, threatened or protected species is a necessity for fisheries managers. Estimating individual vessel bycatch rates by dividing the amount of bycatch by effort (nominal rate) can be biased, as it does not consider effort heterogeneity within the fleet and ignores prior knowledge of fleet bycatch rates. We develop an empirical Bayesian approach for estimating individual vessel and fleet bycatch rates that: (i) considers effort heterogeneity among vessels and; (ii) pools data from similar vessels for more accurate estimation. The proposed standardized bycatch rate of a vessel is, therefore, the weighted average of the pool rate and nominal rate of the vessel; where the weights are functions of the vessel's fishing effort and a constant estimated from the model. We apply this inference method to the estimation of seabird bycatch rates in the component of the Australian Eastern Tuna and Billfish Fishery targeting yellowfin tuna. We illustrate the capability of the method for providing fishery managers with insights on fleet-wide bycatch mitigation performance and the identification of outperforming and underperforming vessels. This method can also be used by fishery managers to develop fleet-wide performance measures or quantitative evaluation standards.

Keywords: bycatch, catch rates, Eastern Tuna and Billfish Fishery, Poisson–gamma, protected species, seabirds, threat abatement plan

Introduction

Global fisheries bycatch in wild-capture fisheries is an issue of growing concern (Diamond, 2004; Gilman *et al.*, 2008). Species that have little or no economic value to fishers (e.g. due to their small size); prohibited species (e.g. those managed in other fisheries); regulatory discards (e.g. species below or above the size limit); or endangered, threatened or protected (ETP) species (e.g. marine turtles, seabirds) are all examples of bycatch species (Diamond, 2004). For this article, we refer hereafter to bycatch species as those species that are caught and subsequently discarded at sea, or in the case of ETP species, interacted with at sea.

While the 1982 United Nations Convention of the Law of the Sea under Article 61 requires signatories to determine the biological and ecological impacts of fishing on non-target (bycatch) species, this can be difficult for most commercial fisheries that lack fishery-dependent data. As reported by Tuck (2011), bycatch data are often limited due to inadequate and incomplete information on vessel characteristics, fishing effort, and species composition. Many species are under- or over-reported, non-reported, or misreported in fishery logbooks (Walsh *et al.*, 2002; Walsh *et al.*, 2005; Sampson, 2011; Mangi *et al.*, 2016; Macbeth *et al.*, 2018). For example, in an examination of catch rates for blue shark

(*Prionace glauca*), Walsh *et al.* (2002) found that underreported catches in fishery logbooks were due to fishers being too busy to report incidental catches. In a similar study examining the catch rates for blue marlin (*Makaira nigricans*), Walsh *et al.* (2005) observed that fishers tended to over-report catches due to misidentifying striped marlin (*Tetrapturus audax*) and shortbill spearfish (*Tetrapturus angustirostris*) as blue marlin. The inadequacies of fishery logbook data have often led decision-makers to use at-sea observer data as an alternative to quantify bycatch taken by commercial fisheries. However, at-sea observer data have its own suite of biases (Benoît and Allard, 2009; Faunce and Barbeaux, 2011; Wakefield *et al.*, 2018) and any extrapolations of at-sea observer data at low levels of coverage are likely to produce imprecise and inaccurate results when capture of a species is a rare occurrence (Wakefield *et al.*, 2018).

Despite the issues associated with logbook data, it often remains the principal source of information on fishery catch and effort due to many management authorities requiring vessels to fill out their logbook as a condition of their licence or permit (Sampson, 2011). Access to fishery logbook data allows the nominal discard rate for bycatch species to be calculated at an individual vessel or fleet level. This is often done by dividing the amount of bycatch by the total effort for a given vessel. This is termed the "nominal" estimate. This vessel-level estimation could be unbiased if there are sufficient observations (i.e. adequate sample size), and fishers have not changed their fishing practices over the time period assessed. However, this is often not the case, as different vessels enter and exit the fishery through time and change their fishing practices, influencing catchability (Tuck, 2011). Furthermore, consider two longline vessels with the same standard seabird bycatch rate of zero (0.0 bycatch per 1000 hooks), where vessel 1 expended a significantly greater amount of effort compared with vessel 2. Calculation of the nominal estimate would suggest that both vessels are performing identically; however, from the perspective of a fishery manager, vessel 1 is outperforming vessel 2 since there has been no bycatch recorded with a substantially greater exposure to risk (i.e. effort). Moreover, a fishery manager is more confident in the bycatch rate of vessel 1, simply due to the greater level of effort expended compared with vessel 2, whose zero-bycatch rate could simply be due to chance through limited exposure. The nominal estimate also only uses each vessel's information for estimating the rate and ignores other available information (e.g. effort data) from "similar" vessels in each fleet or fishery. Given these limitations, we propose a "standardized" estimate using an empirical Bayesian approach that considers effort heterogeneity among the fleet and pools data from "similar" vessels for rate estimation. Similar vessels are defined as those that share comparable fishing behaviour patterns [e.g. "fishing styles" after Boonstra and Hentati-Sundberg (2016) or "fishing tactics" after Pelletier and Ferraris (2000)] and can be pre-determined using variable quantitative or semi-quantitative methods based on the data from the commercial fishery or expert judgement, respectively.

Vessel-, fleet- and fishery-level estimations of bycatch rates are sources of information that assist fisheries managers with monitoring the performance of bycatch mitigation measures. Vessel-level estimation may provide insight (through a targeted investigation) on why a vessel is underperforming (higher bycatch rate) or outperforming (lower bycatch rate) the fleet average (e.g. due to fishing in an area with the high abundance of protected species or appropriately deploying mitigation devices, respectively). Comparing the vessel-level estimated bycatch rates to the fleet-level estimate ensures that individual vessels are accountable for their actions and allows managers to set quantifiable bycatch thresholds for the fishery. Quantifiable measures, standards or reference points that guide expected levels of performance can create incentives for industry to reduce their bycatch rates through, for example altering fishing behaviour or adopting alternative bycatch mitigation technology (Diamond, 2004; Grafton *et al.*, 2007; Kirby and Ward, 2014; Lent and Squires, 2017). When these performance standards create market-based incentives or disincentives (carrots and sticks) for industry, they have the potential to further improve fleet bycatch performance and reduce regulatory costs (Gjertsen *et al.*, 2010; Pascoe *et al.*, 2010). For example, in Australia, there is a Threat Abatement Plan (TAP) for seabirds, which sets a maximum permissible bycatch rate of 0.01 or 0.05 birds per 1000 hooks in various Australian Commonwealth fisheries (Commonwealth of Australia, 2018). Attached to this performance measure are criteria developed to guide the management response when the bycatch rate is exceeded, which may target individual vessels or the fleet and may have immediate economic costs (Commonwealth of Australia, 2018).

In this article, we outline an inference method for calculating a model-estimated (standardized) bycatch rate for each vessel, which is the weighted average of the pool (fleet) rate and the nominal estimation rate of the individual vessel. Using an empirical Bayesian approach for the analysis of rare-event data is not new (Myers *et al.*, 2002; Quigley *et al.*, 2011) and has been shown to produce less biased and more consistent estimates of the probabilities of rare events compared with conventional statistical methods (Khakzad *et al.*, 2014). We apply this method to a case study of seabird bycatch rates in the yellowfin tuna component of the Australian Eastern Tuna and Billfish Fishery (ETBF). We use the Australian ETBF as an example because we are confident that the fishery logbook data are the accurate representation of catch composition and bycatch of protected species in the years subsequent to the introduction of electronic monitoring technologies (Emery *et al.*, 2019a). The results of the analysis are discussed in the context of (i) developing quantitative performance standards for bycatch species; (ii) reducing the transaction costs of management decision-making through a risk-based approach; and (iii) making fishers individually accountabile for their bycatch rates.

Methodology

Poisson–gamma model to estimate bycatch rates

In our model, we assume that the amount of bycatch is approximately proportional to the total units of effort. This assumption is valid and is supported by the existing literature (Hatch, 2018) and the results of our study (see below). To estimate the standardized (seabird bycatch) rate of individual vessels, we develop a Poisson–gamma (Carlin and Louis, 2009) model considering two sources of uncertainties: (i) the uncertainties that arise from the lack of knowledge (e.g. the actual bycatch rate is not known), termed epistemic uncertainty, and (ii) uncertainty associated with natural variations in the sample (e.g. same amount of effort leads to a different amount of bycatch), termed aleatory uncertainties. Consequently, we use a gamma prior distribution to capture epistemic uncertainties within the pool of data to allow us to model the variation in true bycatch (actual seabird bycatch) rates, which are currently unknown. That is, we assume that the true bycatch rate of vessel i is a random variable with the gamma distribution of shape parameter α and scale parameter β. We denote it by $\lambda_i \sim \text{gamma}(\alpha, \beta)$, and the gamma probability density function can be expressed as the following equation. The mean of a gamma distribution is $\frac{\alpha}{\beta}$, and here, we refer it as the pool rate.

$$\pi(\lambda_i) = \frac{\beta^\alpha {\lambda_i}^{\alpha-1} e^{-\beta\lambda_i}}{\Gamma(\alpha)}, \alpha > 0, \beta > 0, \lambda_i > 0. \quad (1)$$

We later update the prior for each vessel to estimate the standardized bycatch rate. The updating process can be done quickly as the posterior of the gamma distribution remains in the gamma family, and we only need to update the shape and scale parameters. If we assume that n_0 bycatch species were observed for E_0 units of effort, Bayes' theorem implies that the posterior distribution is of the form of the following equation:

$$\pi(\lambda n_0, E_0) = \frac{(\beta + E_0)^\alpha \lambda^{\alpha+n_0-1} e^{-(\beta+E_0)\lambda}}{\Gamma(\alpha + n_0)}, \alpha, \ \beta, \lambda, \ \ E_0 > 0, n_0 = 0, 1, 2, 3, \ldots. \quad (2)$$

Assuming that the true bycatch rate $\Lambda_i = \lambda_i$ for vessel i is constant for given E_i units of effort, we can then model the aleatory uncertainty in the bycatch rate through a Poisson probability distribution expressed in the following equation:

$$P(N_i = n_i \Lambda_i = \lambda_i) = \frac{(\lambda_i E)^{n_i} e^{-\lambda_i E_i}}{n!}, E_i > 0, \lambda_i > 0, n_i = 0, 1, 2, \ldots. \quad (3)$$

Since we do not know the true bycatch rate Λ_i for vessel i, we average the Poisson distributions, weighted against the prior distribution in the following equation:

$$P(N_i = n_i) = \int_0^\infty \frac{(\lambda_i E_i)^{n_i} e^{-\lambda_i E_i}}{n_i!} \frac{\beta^\alpha {\lambda_i}^{\alpha-1} e^{-\beta\lambda_i}}{\Gamma(\alpha)} d\lambda, \alpha > 0, \ \beta > 0, \ n_i = 0, 1, 2, \ldots. \quad (4)$$

Greenwood and Yule (1920) proved that the distribution of N_i is Negative Binomial as shown in the following equation:

$$P(N_i = n_i) = \frac{\Gamma(n_i + \alpha)}{\Gamma(\alpha) n_i!} \left(\frac{\beta}{\beta + E_i}\right)^\alpha \left(\frac{E_i}{\beta + E_i}\right)^{n_i}, \alpha > 0, \ \beta > 0, \ n_i = 0, 1, 2, \ldots. \quad (5)$$

To estimate the parameters of the prior distribution, α, β, we use a genetic algorithm optimization method (implemented in MATLAB Global Optimization Toolbox) to maximize the natural logarithm of the marginal likelihood (LML) functions assuming that (pooled) data are generated from the Negative Binomial distribution of (5). Our choice of algorithm was informed by as follows: (i) there being no closed-form solution for finding maximum values of LML functions and (ii) the LML functions being highly nonlinear and nonconvex.

Several methods have been proposed to construct a joint confidence region to address the uncertainty associated with the estimated prior parameters, such as the bootstrap method (Carlin and Gelfand, 1991), and using likelihood theory by assuming the negative of two times the natural logarithm of the relative marginal likelihood function has a chi-square distribution with two degrees of freedom (Basu and Rigdon, 1986). In this study, we used the second approach to construct a joint confidence interval for the maximum likelihood estimates and consequently the posterior mean (standardized) bycatch rate of each vessel.

We let $\hat{\alpha}$ and $\hat{\beta}$ are the estimated values of prior parameters and let vessel i interacts with n_i bycatch species when E_i units of effort have been deployed. We estimate the standardized bycatch rate of vessel i, which is the posterior mean of λ_i as follows:

$$E(\lambda_i | N_i = n_i) = \int_0^\infty \lambda_i \pi\left(\lambda_i | N_i = n_i, \hat{\alpha}, \hat{\beta}\right) d\lambda_i = \frac{\hat{\alpha} + n_i}{\hat{\beta} + E_i}$$

$$= \frac{\hat{\alpha}}{\hat{\beta}}(1 - z) + \frac{n_i}{E_i} z, \quad (6)$$

where $z = \frac{E_i}{\hat{\beta} + E_i}$.

The standardized bycatch rate can be interpreted as a weighted average of the pool (i.e. fleet) mean bycatch rate $(\hat{\alpha}/\hat{\beta})$ and the nominal bycatch rate of the vessel (n_i/E_i) where the weight is the function of a vessel's fishing effort and a scale parameter of the posterior gamma distribution. Equation (6) also implies that when we have more experience (i.e. fishing effort) with a vessel (higher E), more weight will be allocated to the nominal rate, while for a vessel with less experience, more weight will be allocated to the pool rate.

Application of the Poisson–gamma model to the Australian yellowfin tuna sub-fishery

We apply this method to vessels in the yellowfin tuna sub-fishery of the Australian ETBF to illustrate how the method can provide fishery managers with insights on fleet-wide bycatch mitigation performance and identify non-performing vessels for targeted intervention. The ETBF is a pelagic longline fishery that operates within the Australian Exclusive Economic Zone and adjacent high sea waters targeting yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus obesus*), albacore tuna (*Thunnus alulunga*), broadbill swordfish (*Xiphias gladius*), and striped marlin (*T. audax*). The ETBF operates from Cape York, east and south to the Victorian–South Australian border, including waters around Tasmania and the high seas of the Pacific Ocean (Figure 1a). In 2018, there were a total of 40 longline vessels active in the ETBF (Patterson *et al.*, 2018). In the ETBF, vessels that have fished >30 days in the previous or current fishing season must have operational electronic monitoring technology installed.

The yellowfin tuna sub-fishery of the Australian ETBF was differentiated from other sub-fisheries using a non-hierarchical clustering method, partitioning around medoids as similarly employed by Duarte *et al.* (2009) that identified structures within the data to quantitatively categorize individual fishing events to a particular métier (for more information on métier analysis, see Pelletier and Ferraris, 2000; Holley and Marchal, 2004). While the primary target species of the yellowfin tuna sub-fishery is yellowfin tuna, there is also a high proportion of oilfish (*Ruvettus pretiosus*) and striped marlin caught as by-products. The yellowfin tuna sub-fishery is a year-round fishery with most sets occurring between 7 and 9 a.m. off the New South Wales and Victorian State coastlines (Figure 1b). Typical gear characteristics include shallow setting with limited light stick use. In undertaking this analysis, we limit our study to the years 2016–2018 when electronic monitoring technologies were installed on all full-time ETBF vessels.

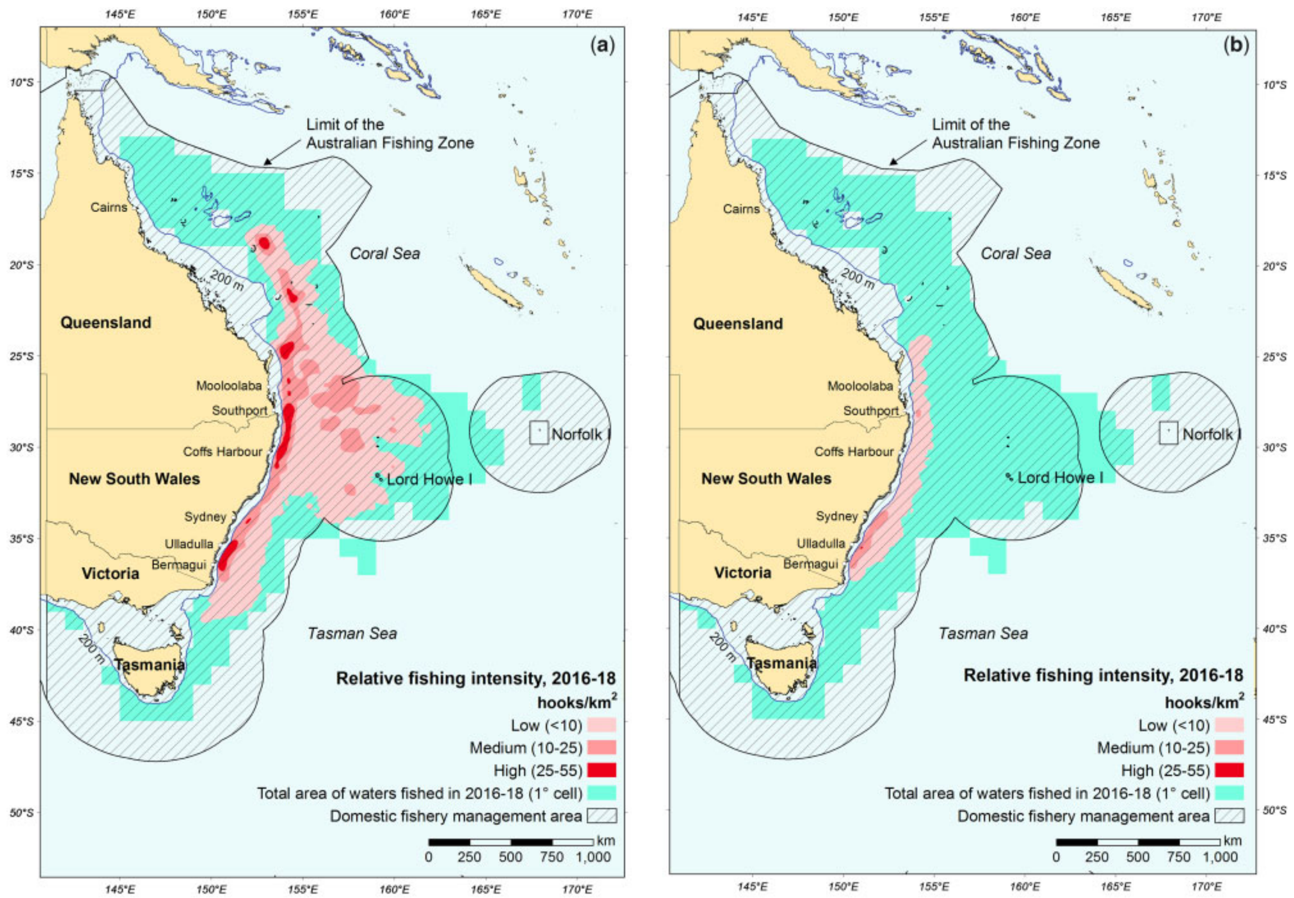

Figure 1. Area and relative fishing intensity in the (a) eastern tuna and billfish fishery and (b) yellowfin tuna component of the eastern tuna and billfish fishery in 2016–2018 calendar years.

This decision was based on recently published studies indicating that fishers have improved their logbook reporting of bycatch and protected species in these years, and there is high congruence between logbook and electronic monitoring analyst-reported seabird bycatch rates (Larcombe *et al.*, 2016; Emery *et al.*, 2019a, b). In 2016–2018, there were a total of 23, 29 and 26 longline vessels active, respectively, in this sub-fishery.

Results

Fishing effort in the yellowfin tuna sub-fishery

There was high heterogeneity in the effort data for the 34 ETBF vessels operating in the yellowfin tuna sub-fishery during 2016–2018, with *vessel_id 15* setting 216 000 hooks and *vessel_id 6* and *21* just 1000 hooks, for example (Figure 2a). Furthermore, the amount of seabird bycatch varied among vessels with similar effort levels (Figure 2b). For example, *vessel_id 16* and *vessel_id 28* expended a similar amount of effort (160–180 000 hooks) in the yellowfin tuna sub-fishery between 2016 and 2018, but the number of recorded seabirds was different (six and one, respectively) (Figure 2b). Nevertheless, there was a positive linear correlation (Pearson's $r = 0.59$, $p = 0.00028$) between the number of seabirds and the effort for each vessel. This result supports the assumption of proportionality between the amount of seabird bycatch and the amount of effort in the yellowfin tuna sub-fishery of the ETBF.

Assessing seabird bycatch rates in the yellowfin tuna sub-fishery

The mean seabird bycatch rate was 0.019 for the yellowfin tuna sub-fishery (i.e. average pool rate) based on (5), which was used in association with the nominal bycatch rate of the vessel in (6) to generate the standardized bycatch rate for each vessel. The standardized bycatch rate of a vessel with low levels of fishing effort was closer to the average pool rate, while the standardized bycatch rate of a vessel with high levels of fishing effort was closer to their nominal bycatch rate (Figure 3).

The fit of the estimated predictive distribution model to the empirical data was robust (Figure 4). There was a good fit to the data in both the centre and right-hand tails of the distribution, while there was a slight overestimation and underestimation of the zero and one occurrences, respectively, on the left-hand tail of the distribution (Figure 4). The good fit to the upper right-hand tail of the distribution is very important since this has greater consequences for seabird populations if the true bycatch rate of a vessel is relatively high.

It is evident that between 2016 and 2018 the average pool rate (red line in Figure 5) in the yellowfin tuna sub-fishery was below the maximum permissible bycatch rate of 0.05 seabird per 1000 hooks (blue line) recommended in the Australian Seabird TAP (Commonwealth of Australia, 2018) (Figure 5). However, there was a large variation among the 34 individual vessels, with some vessels having high standardized bycatch rates above the TAP

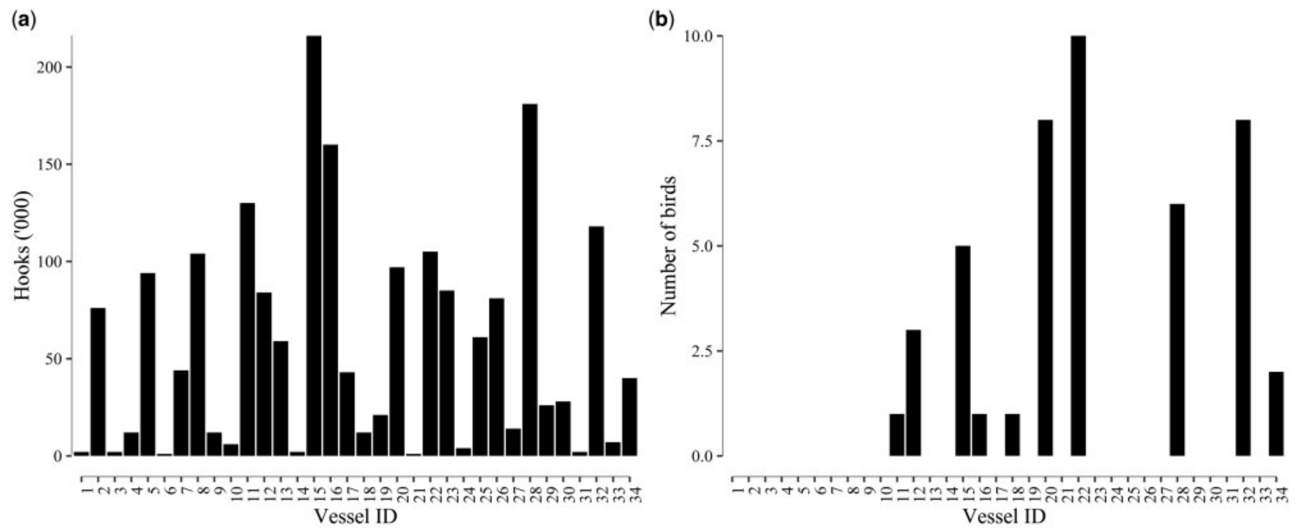

Figure 2. Total fishing effort (a) and amount of seabird bycatch (b) for a total of 34 vessels operating in the yellowfin tuna sub-fishery for the years 2016–2018.

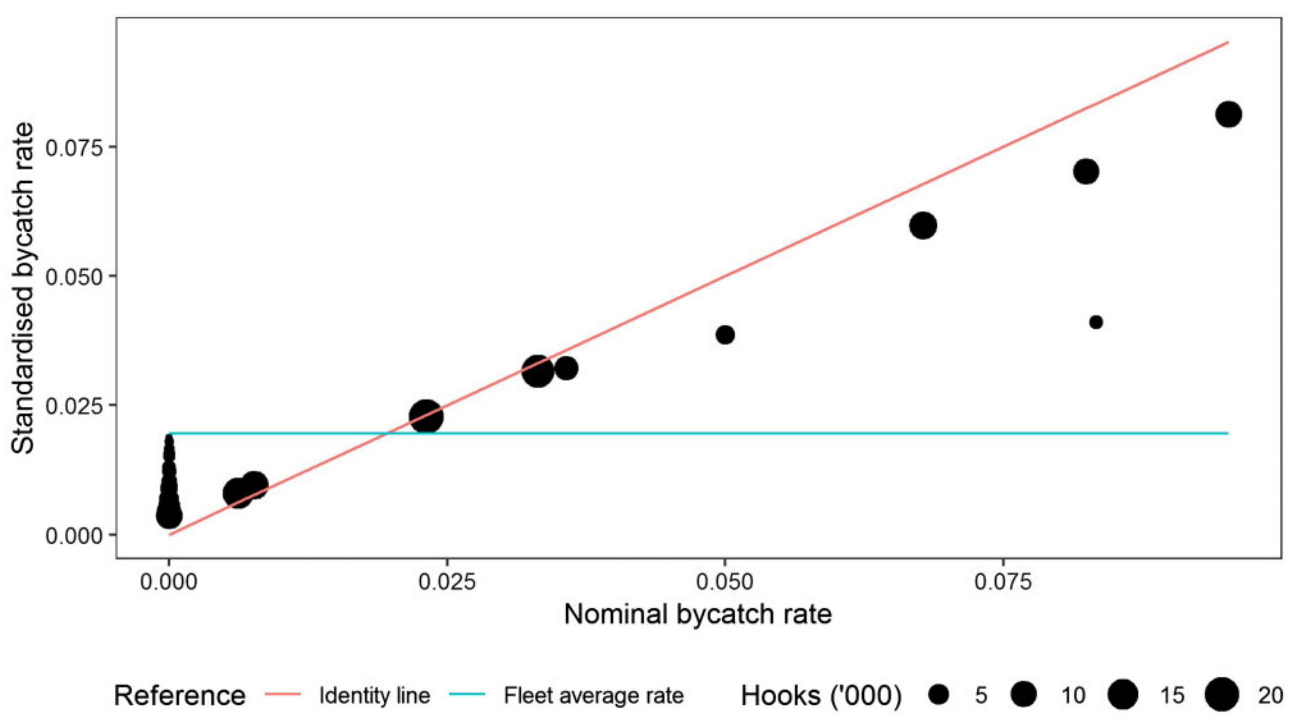

Figure 3. Standardized seabird bycatch rates for all 34 vessels in the yellowfin tuna sub-fishery for the years 2016–2018 plotted against their nominal bycatch rate. The size of each point represents the total effort of each vessel in '000s hooks. The red line is the identity line (1:1), and the blue line is the mean estimated bycatch rate for the fleet (i.e. average pool rate).

(e.g. *vessel_id 20*, *22*, and *32*) and others having lower standardized bycatch rates (e.g. *vessel_id 2, 5* and *8*). The level of uncertainty in the estimated bycatch rates also varied substantially at the individual vessel level (Figure 5).

Discussion

Attaining robust estimates of bycatch rates in fisheries is a significant challenge due to their low (often rare in the case of ETP species) frequency of occurrence, leading to uncertainty in rate estimation, which can be a significant barrier to the development of effective mitigation strategies (Komoroske and Lewison, 2015; Martin *et al*., 2015; Suuronen and Gilman, 2019). Despite these challenges, fisheries managers are often required to make inferences about bycatch rates to inform their decision-making. This can lead to biased, imprecise estimates when using nominal estimation (dividing the total amount of bycatch by total effort) to determine the rate (Martin *et al*., 2015). By considering effort heterogeneity among vessels and pooling the data from homogenous vessels (vessels that share comparable fishing behavioural patterns), our model-estimated (standardized) bycatch rate overcomes some of the shortcomings of nominal estimation (Bishop *et al.*, 2008). It also requires minimal data: only the total effort and amount of bycatch for each homogenous vessel within the timeframe of interest. This makes it more accessible to use in data-limited fisheries and easier for decision-makers to update

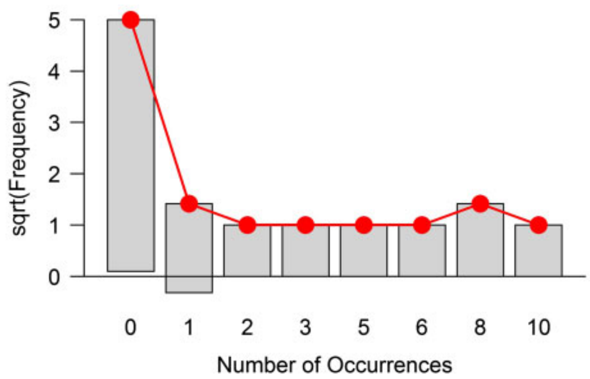

Figure 4. Hanging rootogram of the Poisson–gamma model fitted to seabird bycatch data for all 34 vessels in the yellowfin tuna sub-fishery for the years 2016–2018. The red line shows the expected amount of seabird bycatch estimated by the model, while the observed amount of seabird bycatch is shown as bars hanging from the red lines. The *x*-axis shows bins representing the nominal amount of seabird bycatch, while the *y*-axis shows the square root of the expected or observed amount of seabird bycatch. When the bar does not touch the *x*-axis (e.g. zero occurrences), it means that the amount of bycatch predicted by the model is higher than in the empirical data, while when the bar does touch the *y*-axis (e.g. one occurrence), it means that the amount of bycatch predicted by the model is lower than in the empirical data.

and review regularly. Furthermore, by using Bayesian methods, which are well suited to the analysis of rare-event bycatch data, we can more fully integrate uncertainty, produce less volatile bycatch rate estimates, and enable evaluation of these estimates relative to existing performance measures (Gardner *et al.*, 2008; Martin *et al.*, 2015). We should emphasize that while other factors contribute to the bycatch rate, such as climate, location, food availability, and seasonality (Martin *et al.*, 2015; Cortés *et al.*, 2017), they were not considered in our model to ensure simplicity but could be incorporated as covariates in future modifications of this approach. Moreover, while we used a machine-learning clustering method to pre-determine homogenous vessels within the yellowfin tuna sub-fishery of the ETBF, expert opinion can likewise be used to identify vessels that share comparable fishing behavioural patterns.

There are several important applications that will benefit from the empirical inference method we have developed. For instance, there is a need to evaluate the performance of individual fishing vessels and fleets against quantifiable targets such as bycatch performance measures or reference points, to inform management decision-making (Grafton *et al.*, 2007; Gjertsen *et al.*, 2010; Kirby and Ward, 2014). Our standardized bycatch rate can be used as a key indicator to measure the performance of an individual vessel/fleet relative to quantifiable targets (while also accounting for uncertainty) to identify outperforming and underperforming vessels for further investigation or corrective action. In our case study, it has allowed fishery managers to compare seabird bycatch rates of individual vessels and the fleet relative to the Australian TAP maximum permissible bycatch rate of 0.05 birds per 1000 hooks and quantitatively measure how individual vessels are performing relative to the fleet average. This can also be updated regularly to ensure responsiveness to changes in the status of bycatch species or reference points.

Our inference method also allows a hierarchy of the homogenous fleet to be developed in a risk management context to

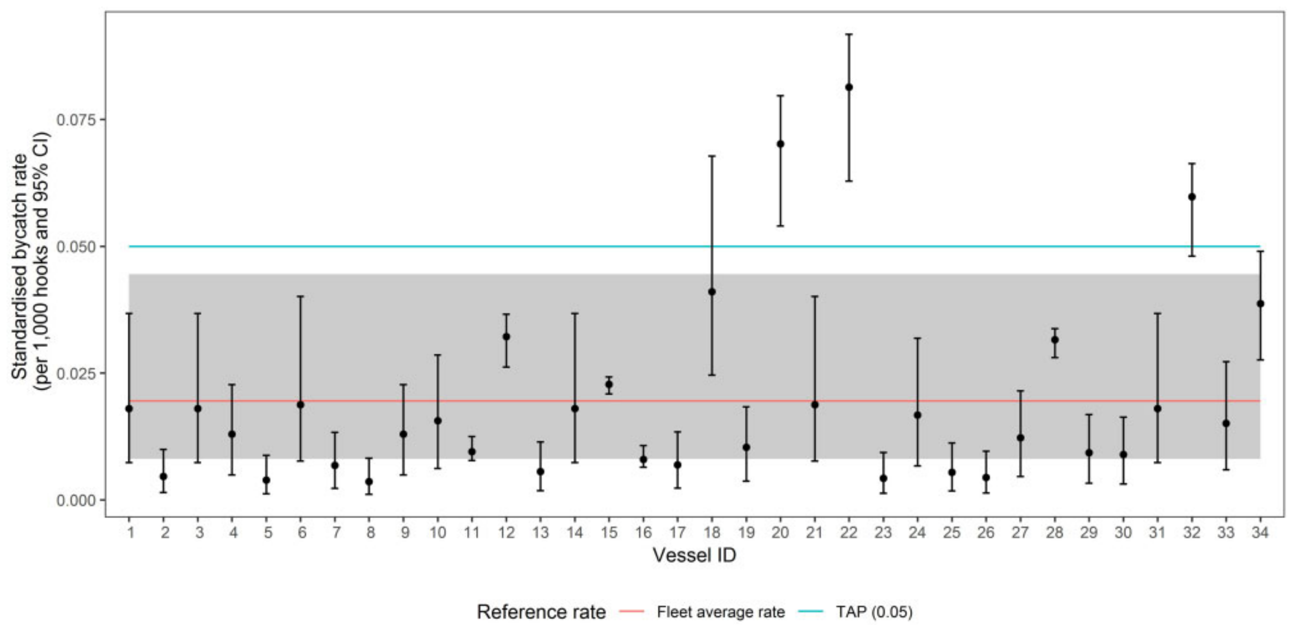

Figure 5. Standardized seabird bycatch rates for the 34 vessels in the yellowfin tuna sub-fishery for the years 2016–2018. The blue line represents the TAP recommended reference point (0.05 seabirds per 1000 hooks), and the red line represents the average pool rate. The grey shaded area represents the confidence interval for the estimated average pool rate.

prioritize resourcing and inform management decision-making. Decision rules can then be formulated based on each level of the hierarchy if considered prudent. We define three hierarchical levels based on the standardized bycatch rates (i.e. risk to seabirds), uncertainty and pre-existing management objectives (e.g. TAP: 0.05 seabirds per 1000 hooks). The "low-risk element" (i.e. those vessels with standardized bycatch rates and confidence intervals below the pre-existing limit reference point) would be considered best practice in the fishery and outperforming vessels, from which further information could be sought to determine their success in deploying mitigation measures and reducing bycatch. The "high-risk element" (i.e. those vessels with standardized bycatch rates and confidence intervals above the pre-existing limit reference point) would be considered poor-performing and prioritized for the investigation to determine what corrective action or mitigation measures are required to improve performance. The "uncertain risk element" (i.e. those vessels standardized bycatch rates above or below the pre-existing limit reference point but with confidence intervals that encompass the pre-existing limit reference point) is prioritized for further analysis to identify if their fishing operations share practices that reflect vessels in the "high-risk element". If similar practices are identified, corrective actions can be implemented. If the analysis remains inconclusive, these vessels may be prioritized for more intensive monitoring to rapidly acquire informative data before any decision could be made about their performance.

In the absence of a pre-defined bycatch performance measure, the standardized bycatch rate of the fleet could contribute to the formation of an appropriate performance measure (e.g. limit reference point) for an individual bycatch species. Conventionally, a limit reference point is defined as the level at which the risk of recruitment impairment is regarded as unacceptably high, or the minimum acceptable level of bycatch at which the measures being adopted are likely to be having the desired conservation effect (Tuck, 2011; Moore *et al.*, 2013; DAWR, 2018). When set as a performance measure (e.g. the Australian TAP for seabirds), it provides guidance on expected levels of performance for industry and provides the means for decision-makers to evaluate and improve bycatch mitigation (Grafton *et al.*, 2007). It also represents a uniform control limit for vessels that will drive adaptation and facilitate the robust assessment of mitigation technologies (Komoroske and Lewison, 2015). In the absence of information to determine population abundance using conventional assessments, this type of analysis can allow different stakeholders or interest groups to discuss appropriate limit reference points, which could be readily adjusted upon application or if new information on population abundance becomes available. Moreover, it can be applied in the context of "continuous improvement" until a limit reference point is defined with the objective of continually lowering the standardized bycatch rate of the fleet.

The ability to use a standardized bycatch rate to measure annually the individual and fleet performance against the limit reference point can create incentives for industry to be more individually accountable of their bycatch. This can be achieved by decision-makers introducing penalties (and/or rewards) for vessels that exceed (or maintain their bycatch below) the limit reference point (Diamond, 2004; Pascoe *et al.*, 2010). These market-based incentives could be in the form of restricting access to certain fishing areas, temporary loss of right of access and/or fines, creating a cost for sub-standard performance that would induce fishers to make choices that reduce bycatch (Diamond, 2004; Pascoe *et al.*, 2010). This is not too dissimilar from the system of dolphin mortality limits established to manage dolphin bycatch in the purse-seine tuna fisheries of the eastern Pacific Ocean managed under the *Agreement on the International Dolphin Conservation Programme* (Anon, 1999; Gjertsen *et al.*, 2010). Under this programme, a total annual limit of 5000 dolphins is set for the fishery in the Agreement Area and an equal share of this limit assigned to each applicable vessel (Anon, 1999). If at any time a vessel exceeds their dolphin mortality limit, they must cease fishing for tuna in association with dolphins, creating an incentive for improved bycatch mitigation. There is also a similar programme for the management of New Zealand sea lion (*Phocarctos hookeri*) mortalities in the New Zealand squid fishery, with a fishing-related mortality limit derived from a Bayesian model (Breen *et al.*, 2003) set annually (Chilvers, 2008). Once the limit is reached within a season, the fishery is then closed, creating an incentive for fishers to reduce their bycatch (Robertson and Chilvers, 2011).

While our standardized bycatch rate cannot be used to measure current population status (initial or current abundance), it can be used to monitor the performance of individual vessels and the fleet relative to the performance measure for an individual species. Of course, this assumes that decision-makers have access to data at a species taxonomic level that can be trusted. Fisher-reported logbook data have often been found to be inaccurate and inconsistent with at-sea observer data from the same trip, due to fishers either misreporting, under-reporting, over reporting, or non-reporting their bycatch (Sampson, 2011; Mangi *et al.*, 2016; Macbeth *et al.*, 2018). While in this case study we used logbook data that have been verified (using an electronic monitoring programme) (Emery *et al.*, 2019a, b), our model is not constrained to fisheries with verifiable logbook data. It can easily be applied to fisheries with unverified logbook data or extrapolated at-sea observer data (assuming coverage is sufficient) but noting the issues and caveats with precision remain the same as if an alternative model was run using that data (Wakefield *et al.*, 2018).

We developed a model to estimate standardized individual vessel and fleet bycatch rates that can be widely applied, is simple and accessible for fisheries with limited data, can deal with uncertainty in rate estimation, and can be easily interpreted in a risk context. Risk-based approaches or frameworks are useful for decision-makers to prioritize scarce resources (both in terms of further investigation or corrective action). Our model can also be readily updated to determine whether a vessel's bycatch rate changes over time or following intervention and has the potential to include additional information such as location and seasonality as covariates. Lastly, this approach could be tailored to each bycatch issue or situation and combined with additional risk-based models, such as fisheries compliance risk assessments (e.g. AFMA, 2017), to provide a more comprehensive risk framework for the fishery.

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Attachment 8a

Australian Government
Australian Fisheries Management Authority

Australian Tuna and Billfish Fisheries

Strategic Research Plan
2017 – 2021

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1 Introduction

The Australian Tuna and Billfish Fisheries (ATBF) Strategic Research Plan provides a framework that identifies the key strategic research needs in these fisheries for the five-year period 2017-2021 inclusive.

This document aims to assist the Tropical Tuna Management Advisory Committee (TTMAC) to identify and support research that will help achieve the management goals for the tropical tuna fisheries which include the Eastern Tuna and Billfish Fishery (ETBF), the Western Tuna and Billfish Fishery (WTBF), and the Eastern and Western Skipjack Tuna Fisheries. The Strategic Research Plan also aims to ensure that research projects fit within a comprehensive and strategic research plan for the fisheries.

The annual research priorities detail the specific research topics of focus each financial year that have been identified by TTMAC. These will be updated by TTMAC on an annual basis in consultation with the Tropical Tuna Resource Assessment Group (TTRAG).

2 AFMA Corporate goals and strategies

Research activities funded by AFMA must focus on attaining AFMA's primary management objectives, which are:

i. to ensure the ecological sustainability of the fishery; and
ii. to maximise the economic efficiency of the fishery.

AFMA has developed three research goals to assist in achieving these management objectives, which are outlined in Attachment A.

These research goals should act as a guide for TTMAC in developing ATBF research plans, identifying research priorities for the annual call for research and assessing research proposals.

3 Identifying research needs

Research activities must be consistent with AFMA's corporate goals and strategies, although the drivers of research can be considered to fall into five categories:

3.1 Biological

Biological fisheries information is essential to adequately assess the stocks and estimate the size of sustainable harvests from those stocks.

3.2 Ecological

Information about the impact of fisheries on the marine ecosystem is essential to assist AFMA achieve our objective of ensuring Commonwealth fisheries are ecologically sustainable. Ecological risk assessments (ERAs) are a central component of the Ecological Risk Management (ERM) framework and are conducted on all Commonwealth fisheries. The results of ERAs assist in identifying and prioritising research needs regarding fishery impacts on the marine ecosystem, and in guiding research investment, data collection, monitoring, and future management decisions.

3.3 Economic

Many factors influence the overall economic performance of the fishery. AFMA require an understanding of the effects of economic changes in the tropical tuna fisheries to manage these fisheries to maximise economic efficiency.

3.4 Social

Research into the social aspects of the fishery is important to maximise the social benefits of the fishery to the community. Social research aspects may include investigating access to the resource and resource allocation issues.

The success of fisheries management in the ATBF should be monitored and measured through appropriate performance indicators. These performance indicators, together with appropriate reference points, must relate to the management objectives and have identified actions associated with them.

4 Research Priority Areas and Needs

The following research areas have been identified as high priority needs for the next five years by TTRAG and TTMAC. These are consistent with AFMA's strategic goals and priorities and are not listed in order of priority.

4.1 Provision of Data

- Provision of biological data to support relevant projects (Stock assessments)
- Provision of economic data to support relevant projects
- Provision of environmental data to support relevant projects
- Provision of recreational catch data to support relevant projects

4.2 Biological Research Priorities

- *Stock assessments*
  - Ensure stock assessments are conducted on target species in Australia's Tropical Tuna and Billfish Fisheries.
  - Ensure appropriate assessments are conducted for other species caught in Australia's Tropical Tuna and Billfish Fisheries.
  - Improve understanding of biological characteristics of species caught in Australia's Tropical Tuna and Billfish Fisheries.
  - Develop harvest strategies for target and byproduct species as needed.

- Evaluate the effectiveness of the harvest strategies for Australia's Tropical Tuna and Billfish Fisheries.

- *Connectivity*
  - Improve understanding of stock structure of primary species in Australia's Tropical Tuna and Billfish Fisheries.
  - Investigate the levels of mixing between Australian fish resources and fish resources in the broader Indian and Western and Central Pacific Oceans.
  - Investigate the cross fishery interactions between Australia's Tropical Tuna and Billfish Fisheries and other fisheries.

4.3 Ecological Research Priorities

- *Bycatch and Byproduct*
  - Investigate measures to improve bycatch mitigation in fishing operations.
  - Investigate the effects of fishing in Australia's Tropical Tuna and Billfish Fisheries on non-target species.
- *Climate impacts*
  - Measure the effects of climate change on key species and ecosystems in Australia's Tropical Tuna and Billfish Fisheries.
  - Investigate oceanographic and environmental factors impacting Australia's Tropical Tuna and Billfish Fisheries.

- *Ecological Risk Assessment*
  - Review the Ecological Risk Assessment for the Australia's Tropical Tuna and Billfish Fisheries.
  - Evaluate the relevance of certain species rated as high risk.

4.4 Economic and Social Research Priorities

- *Spatial Management measures*
  - Investigate the economic and ecological impacts of Marine Protected Areas and closures.
  - Investigate the need for resource sharing between the Commonwealth and other jurisdictions or sectors.

- *Economic viability*
  - Determine trends in the economic performance of Australia's Tropical Tuna and Billfish Fisheries.
  - Cost / Benefit Analysis of management costs (levies) versus the fishery outputs in Australia's Tropical Tuna and Billfish Fisheries.

Conclusion

This research plan provides a framework for identifying the key research priorities in the ATBF for 2017-2021 that will help achieve the management goals for Australia's Tropical Tuna and Billfish Fisheries, and ensure that endorsed research projects fit within a strategic framework.

TTRAG should identify the research needs for management of the stocks consistent with the research priorities of the ATBF strategic research plan.

Attachment A

Corporate Plan 2014–2017 goals and strategies	
Goal	**Strategy**
1. Manage key commercial species at levels that support maximum economic yield.	• Manage fisheries in line with the Commonwealth Fisheries Harvest Strategy Policy and Guidelines and AFMA Harvest Strategy Framework. • Implement measures to recover remaining overfished stocks.
2. Improve the net economic returns of Commonwealth fisheries.	• Facilitate the development of underutilised fisheries resources. • Support the Department of Agriculture and fishery stakeholders in the revision of the Commonwealth Fisheries Harvest Strategy Policy and Guidelines. • Develop and implement approaches to further reduce the amount of discarded fish.
3. Prevent unacceptable impacts of Commonwealth fisheries on marine ecosystems and organisms.	• Regularly review fishery risks and management measures under AFMA's Ecological Risk Management Framework. • Continue to manage fisheries in line with the Commonwealth Policy on Fisheries Bycatch (Bycatch Policy).
4. Implement management arrangements and frameworks that are both cost effective and encourage compliance.	• Make fisheries management arrangements more uniform, understandable and enforceable with appropriate penalties. • Continue to improve business processes, information flows and financial arrangements to reduce costs. • Continue to improve the effectiveness of quota management for Commonwealth Fisheries through the Quota Administration Policy and related instruments. • Apply individual accountability in appropriate fisheries.
5. Effectively deter illegal fishing in Commonwealth fisheries, the Australian Fishing Zone and adjacent regions.	• Conduct and enable compliance programs that target identified high risks. • Conduct capacity building programs with neighbouring countries to enhance fisheries management and governance frameworks and compliance programs. • Promote and advocate deterrence, prevention and cooperation at regional fisheries forums to deter illegal fishing.
6. Streamline regulations and approvals and reduce costs of compliance and fisheries management.	• Further adapt business processes and technologies that match the core needs of AFMA and its stakeholders. • Continue to reduce regulatory burden and cost to industry through reduction of red tape and unnecessary regulatory requirements, including establishment investment in electronic monitoring and data transfer technologies, and upgrading of fishery—management specific software. • Explore opportunities to streamline fisheries assessments under the Environment Protection and Biodiversity Conservation Act 1999.
7. Facilitate co—management [1] in Commonwealth fisheries.	• For fisheries under the *Fisheries Management Act 1991*, apply lessons from co—management trials and assist the development of new arrangements.
8. Transparent and effective engagement with the community and other stakeholders.	• Improve communications in a style usable by stakeholders through appropriate media channels. • Ensure the effective operation of management advisory committees and resource assessment groups, as the principal source of advice to the AFMA Commission. • Increase public accessibility and availability of scientific and other fishery management information. • Continue to work with the Department of Agriculture in servicing regional fisheries management organisations and other international fishery bodies