SCIENTIFIC COMMITTEE
EIGHTEENTH REGULAR SESSION

Online meeting
10 – 18 August 2022

PROJECT 60: PROGRESS TOWARDS ACHIEVING SC17 RECOMMENDATIONS

WCPFC-SC18-2022/ST-IP-03 rev1

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Revision 1

- Table 3 have been updated to correct errors in right column for recent years.

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Introduction

The objective of Project 60 is to improve the accuracy and precision of species composition data for tuna (skipjack, yellowfin and bigeye) caught by purse-seine fisheries in the WCPO, in order to improve species-specific catch histories and size compositions that are used in the stock assessments of these key target species in the WCPO. The project history is provided in Appendix A of this report.

The achievements from July 2021 to June 2022 are summarised in Table 1, and reported in further detail in Appendix B. In addition, corrected species composition estimates for purse seine catches have been updated to include 2021 (see Figure 1 and Figure 2) using the agreed estimation procedure (see Peatman et al., 2020). Effect plots for the updated species composition models are provided in Appendix C. Observer data for 2021 had not been fully submitted to SPC and loaded into the master observer database at the time of preparing this report, and so the catch estimates for 2021 should be considered preliminary.

A proposed workplan for 2022-23 is provided in Table 2, and the Scientific Committee is invited to review the workplan and prioritise the associated activities for 2022-23.

Issues arising

Observer coverage rates in 2020 and 2021 were lower than pre COVID-19 levels. A sub-sampling exercise was undertaken to explore the precision of grab-sample based composition estimates with realised observer coverage rates from 2020 and 2021 (see Appendix B). The sub-sampling analysis was restricted to region 6 of the eight region structure used in the 2022 skipjack assessment (Figure 3), given the low rates of observer coverage elsewhere. Increases in the coefficients of variation of species proportions were in the region of 80 to 250% at an MFCL fishery resolution, depending on the species and set type, resulting from the reduced observer coverage rates in 2020 and 2021. The precision of bigeye proportions was the most heavily impacted by the reduction in observer coverage rates. The reductions in accuracy of estimated purse seine catch compositions has implications on the reliability of tropical tuna stock assessments, particularly for bigeye.

Observer coverage rates in regions 7 and 8 have been particularly low since the third quarter of 2020 (< 10% - Figure 4). Species composition estimates in these regions for 2020 and 2021 will have been primarily informed by the species composition models, rather than generated directly from grab samples. As such, the impact of reduced observer coverage rates on the accuracy of estimated compositions in regions 7 and 8 is speculative. Concerns regarding the reliability of estimates for regions 7 and 8 will only be resolved through increased levels of observer coverage into the future.

Cannery data has the potential to inform, or be used to verify, estimates of purse seine catch compositions. This is particularly relevant given the low coverage of grab-sample based estimates in since the onset of the Covid-19 pandemic. However, coverage rates of cannery data are currently relatively low. In this context, we have proposed consideration of a WCPFC project to improve the coverage and utility of cannery data, in order to maximise it’s value with respect to purse seine catch compositions (see Potential uses of cannery data, Appendix B).

We note the decision to return to 100% purse seine observer coverage at the beginning of 2023, as soon as it is safe and logistically feasible. We recommend future assessments consider accounting for greater uncertainty of purse seine catch estimates for 2020 and 2021 (and potentially 2022), to mitigate the impact of errors in catch estimates on management.

Recommendations

We invite the Scientific Committee to:

1. Note the progress towards the Project 60 workplan agreed at SC17.
2. Note the results of the sub-sampling exercise, which suggests a substantial reduction in the precision of estimates of purse seine species compositions for 2020 and 2021 as result of reduced observer coverage rates due to Covid-19.
3. Review the proposed activities and their priority for Project 60 in the year ahead with reporting to SC19 (Table 2).
4. Recognising the importance of processor data for the validation of tuna species composition, consider a future WCPFC project to cover, *inter alia*, the following areas:
   (i) The SSP or WCPFC Contractor to work with relevant CCM port and flag states to obtain purse seine processor data not yet provided, using the guidelines to ensure data confidentiality.
   (ii) The SSP or WCPFC Contractor to work with relevant CCMs to review the protocols for collecting purse seine processor data at each source, including species identification.
   (iii) The SSP to continue the management and data quality of purse seine processor data submission, including the identification of gaps, resolving duplicate processor data (e.g. when Final Outturn [FOT] data are provide from a different source).

Table 1 Progress towards addressing SC17 recommendations (continued on following page).

Recommendation	Progress
Paired grab-spill trips (target: 4 to 6): • Targeting fleets with likely availability of comprehensive Final Outturn data (to be provided on a voluntary basis). • Additional data should allow for improved estimates of bias correction factors, and provide a more powerful dataset for testing for species and/or school association specific correction factors *Due to the continuing impacts of COVID-19, the 2020 Budget allocated for this activity (~USD40,000) to be used in 2022–2023*	Postponed due to COVID-related travel restrictions.
Simulation model of observer sampling: • Exploration of potential bias from between-brail variability in size • Inform need for set-type and/or species-specific correction factors	Available spill sampling data were reviewed to assess their potential to inform the structure of the simulation model, particularly brail-variability in size. There are relatively few sets with spill samples from multiple brails in SPC's data holdings. The construction of simulation model should be postponed until additional paired grab/spill sampling data are available, noting that the current spill sampling protocol should result in more frequent spill sampling of multiple brails. Bayesian models of grab sample bias were used to assess support for set-type and species-specific correction factors. There was no clear support for either set-type or species specific correction factors. This analysis was primarily intended to support development of the simulation model, and is reported in more detail in Appendix B.
Continue to explore opportunities for collaboration with members to support the Project 60 workplan, including comparisons of observer samples, and potentially model-based, species composition estimates, with accurate unloadings / landings / cannery data	No collaborative analyses were undertaken in 2021-22. Opportunities for collaboration will continue to be sought to support the proposed workplan for 2022-23, with consideration of activity priority.

Recommendation	Progress
Investigation of video-based sampling for estimation of species and size compositions	Trials of Electronic Monitoring (EM) on purse seine vessels in the WCPO have shown this technology can be used for estimating species and size composition. EM service providers have made progress in developing automated analysis tools (using Artificial Intelligence and Machine Learning) where proprietary and publicly available databases of annotated images are used to run these tools. However, differences between vessels' setup and operations means there is a need for developing vessel specific databases to ensure efficient analysis. Paired EM and observer trips are also needed to measure accuracy of species and size composition data provided through EM. Further trials are expected in 2022 or later, once travel to PICTs resumes and the necessary logistics can be arranged.
Cost-benefit analysis of alternative sampling approaches for long-term estimation of species compositions (i.e. at-sea sampling vs port sampling)	Scheduled for consideration in 2023-24.

Table 2 Proposed activities for Project 60 for 2022-23 and their priority.

Activity	Priority
Paired grab-spill trips (target: 4 to 6): • Targeting fleets with likely availability of comprehensive Final Outturn data (to be provided on a voluntary basis). • Additional data should allow for improved estimates of bias correction factors, and provide a more powerful dataset for testing for species and/or school association specific correction factors *Due to the continuing impacts of COVID-19, the 2020 Budget allocated for this activity (~USD40,000) to be used in 2022–2023*	High
Continue to explore opportunities for collaboration with members to support the Project 60 workplan, including comparisons of observer samples, and potentially model-based, species composition estimates, with accurate unloadings / landings / cannery data	Medium
Investigation of video-based sampling for estimation of species and size compositions	Medium

Acknowledgements

T. Peatman's contribution was supported by the WCPFC and the European Union's "Pacific-European Union Marine Partnership Programme".

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Figures

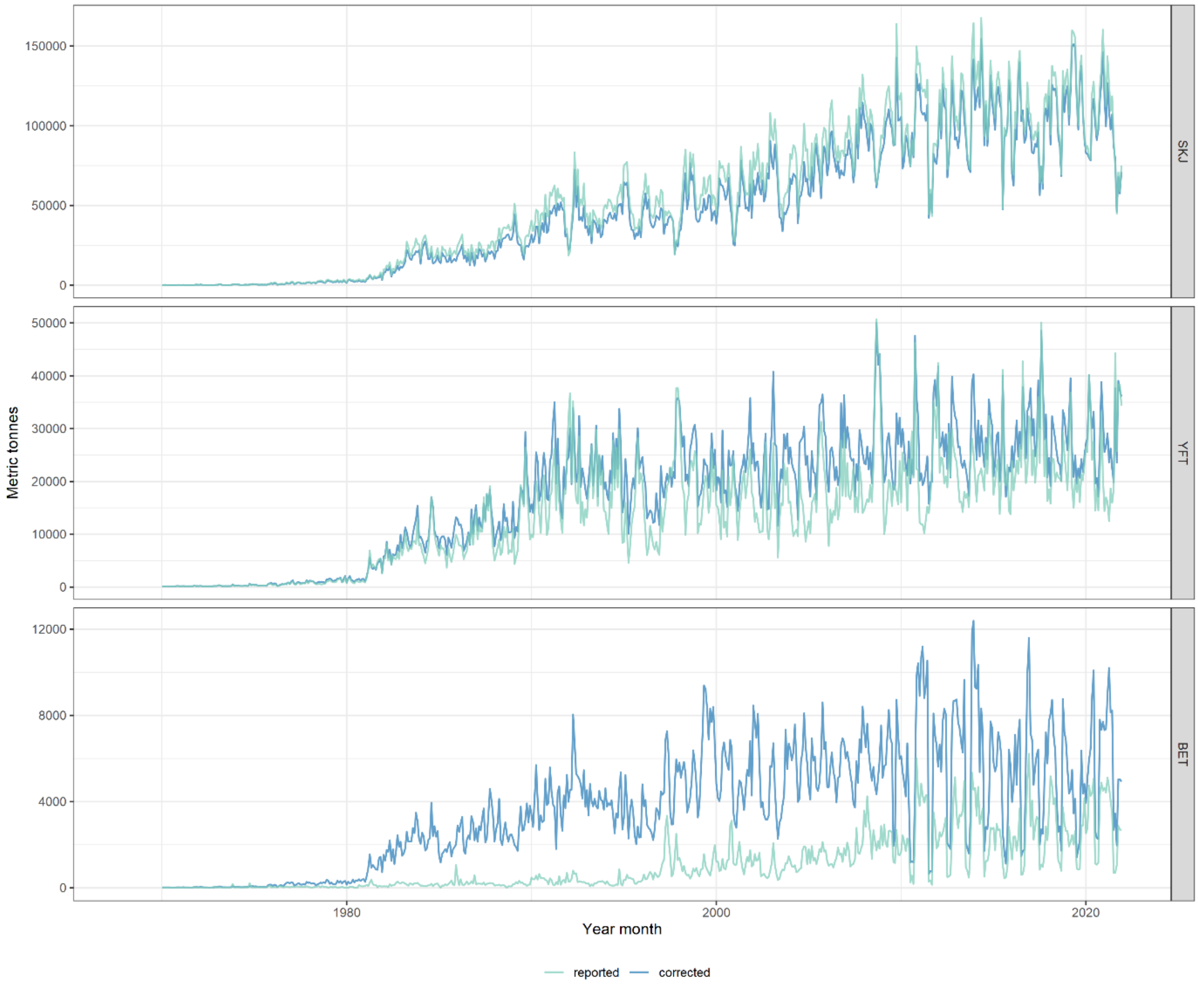

Figure 1 Corrected (blue) and reported (turquoise) purse seine catch by year and month for skipjack (top), yellowfin (middle) and bigeye (bottom panel).

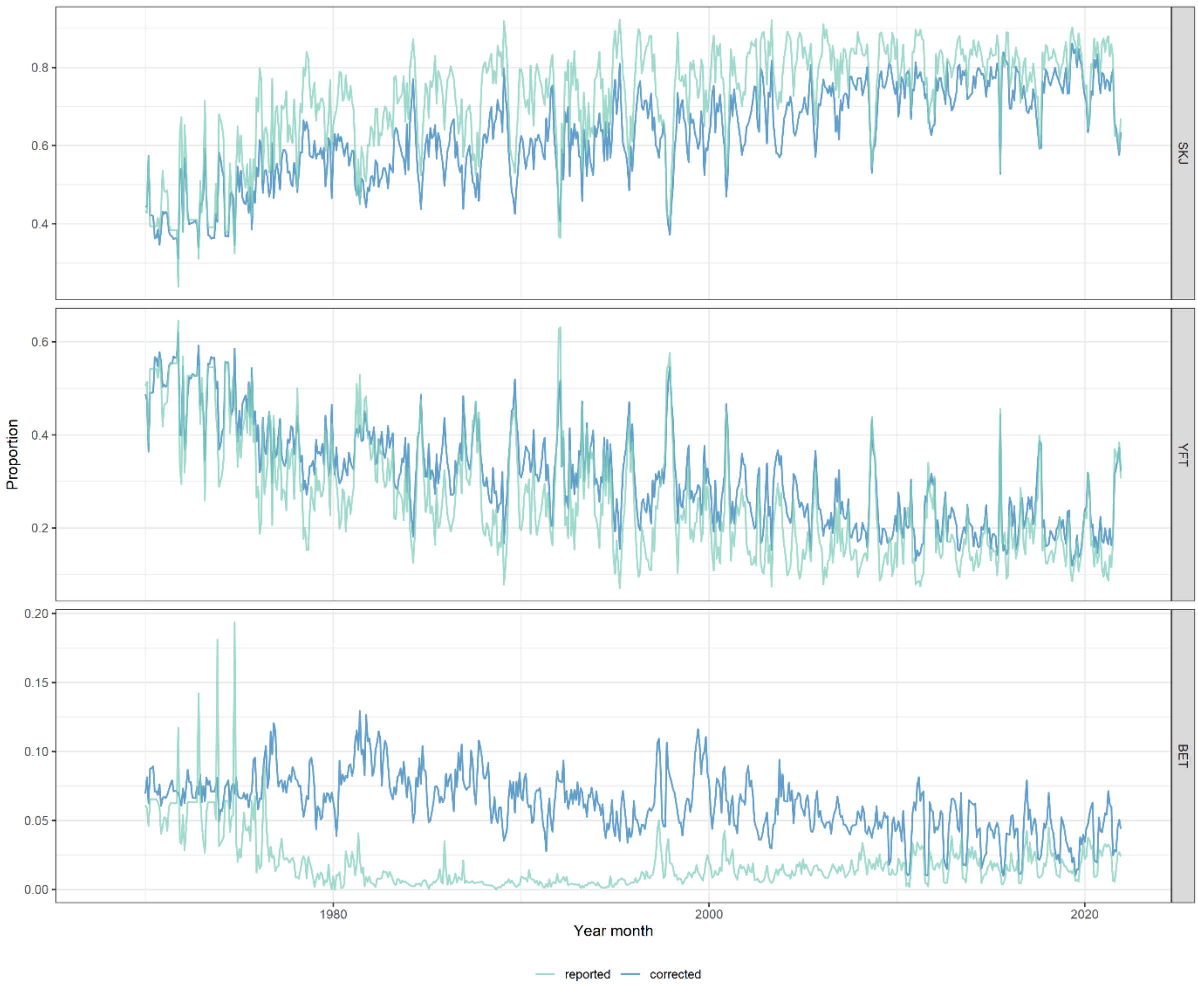

Figure 2 Corrected (blue) and reported (turquoise) purse seine catch proportions by year and month for skipjack (top), yellowfin (middle) and bigeye (bottom panel).

Appendix A

Project history

Project 60 and work on the collection and evaluation of purse seine species composition data through paired sampling and unloading data comparisons began in April 2009. The initial duration of the project was from April 2009 to the end of January 2010. The project was extended in April 2010 through January 2011, and then from February 2011 to 31 January 2012.

Following discussion of the "Plan for the improvement of the availability and use of purse-seine composition data" (SPC-OFP 2012), the Scientific Committee made the following recommendation (Anon., 2012a) at para 89, section d: *"Project 60 be continued through 2013. The study has a target of 50 trips to be sampled, of which 35 trips will be completed by the end of 2012".*

The Commission (Anon., 2012b) supported the SC8 recommendation and approved the project with funding to cover the cost of the remaining 15 trips for further analysis. In 2014 further research for project 60 was supported under the SC9 unobligated budget, with additional funding from PNG.

SC11 noted that future work should include finalisation of analyses of existing data, the collection of further paired sampling data where these results can be compared to accurate estimates of landed weights by species, and simulation modelling to assess alternative sampling protocols (Anon., 2015a). The Scientific Committee made the following recommendation (Anon., 2015a) at para 107:

a) The WCPFC science/data service provider produce an update to Table 1 in ST-WP-02 annually (until an agreement on methodology can be reached) as it provides a very useful summary of the purse-seine catch estimates derived using the four different methods to ascertain catch composition.

b) In regards to the implementation of observer spill sampling in the tropical purse seine fishery,

> *i. The WCPFC Secretariat and the WCPFC scientific services provider investigate operational aspects including alternatives for spill sampling on purse seine vessels where the current spill sampling protocol is difficult to implement and report back to SC12.*
>
> *ii. The WCPFC scientific services provider will undertake additional data collection and analyses to evaluate the benefits of spill sampling compared to corrected grab sampling.*

To implement the 2015 Scientific Committee recommendations, and after approval from the Commission (Anon., 2015b), the WCPFC Secretariat contracted the Scientific Services Provider to continue Project 60. In 2016, the Scientific Service Provider proposed a work plan for the continuation of Project 60 (Smith and Peatman, 2016) which was subsequently endorsed by the 2016 Scientific Committee (Anon., 2016). In 2017, the Scientific Service Provider presented work undertaken between SC12and SC13, along with a proposed work plan (Peatman et al., 2017b). The 2017 Scientific Committee recommended that future work proposed by the Scientific Service provider continue over the coming year, with reporting to SC14, and agreed that the work should continue in the medium term subject to annual review (Anon., 2017). Since 2017, the Scientific Service Provider has reported annually to the Scientific Committee progress against the agreed Project 60 workplan, and a proposed work plan for Project 60 moving forward.

Appendix B

Analyses conducted in 2021-22

Construction of a simulation model for observer sampling

There has been interest in developing a simulation model of observer sampling to both explore potential mechanisms for bias in grab samples, as well as to assess the performance of different sampling approaches for the estimation of purse seine catch compositions (e.g. see Peatman et al., 2018). Between-brail variability, and within-brail variability, in species and sizes both have the potential to introduce bias into observer sampling. Spill samples provide the best source of information to assess between-brail variability, given the relatively high numbers of sampled fish per brail relative to grab samples. However, this comes at the expense of fewer sampled brails per set.

Available spill sampling data were explored to assess the extent to which the dataset may inform levels of between-brail variability in species and size compositions, including data from both paired grab/spill trips as well as spill sampling data collected by the Philippines observer programme (PHOB). There were comparatively few sets where spill samples were collected from multiple brails from paired grab/spill trips, and no clear instances were identified in the PHOB dataset. At this stage, we recommend that construction of the simulation model be postponed until additional paired grab/spill data are available. We note that the updates to the spill sampling protocol in 2018 (Peatman et al., 2018) are expected to lead to more frequent spill sampling of multiple brails for a given set.

Bayesian estimation of grab sample bias

Currently, grab sample bias is assumed to be invariant across species and set-type when correcting purse seine species compositions (e.g. see Peatman et al., 2018). However, there have been some indications that grab sample bias may vary between species (McCardle, 2013). Bayesian models of grab sample bias were developed to test for between species and/or set-type differences in grab sample bias, fitted to observations from the paired grab/spill dataset.

The models had a multinomial likelihood function, and were constructed using the RStan package (Stan Development Team, 2021). Let q_{ij} represent the proportions of spill sampled fish in length class i from set j. In the simplest case, with grab sample bias invariant across species and set-type, the number of grab samples in length class i in set j, denoted Y_{ij}, was modelled as

$$E\left(Y_{ij}\right) = n_j p_{ij}$$

$$\mathrm{Var}\left(Y_{ij}\right) = n_j p_{ij}\left(1 - p_{ij}\right)$$

$$p_{ij} = \frac{q_{ij}\, f\left(\overline{FL}_{ij}\right)}{\sum_i q_{ij}\, f\left(\overline{FL}_{ij}\right)}$$

where n_j is the total number of grab samples in set j, p_{ij} is the probability that a grab sample from set j is in length class i, $\overline{FL}_{ij}$ is the mean fork length of fish in length class i from set j (calculated from spill samples), and $f(\quad)$ is a cubic spline representing grab sample bias. Models with species-specific grab sample bias had an equivalent structure, but with a spline of grab sample bias specific to skipjack, and another spline for yellowfin and bigeye. Here, i represents a combination of length class and species. Models with set-type specific bias were also constructed, with cubic splines for grab sample bias specific to free school sets and associated sets.

The denominator of the expression for p_{ij} is required to force p_{ij} to sum to one for a given set. However, this leads to issues with identifiability of the scale of the spline coefficients, i.e. rescaling the spline coefficients results in the same effective bias smooth. To counter this, the spline coefficients were represented in the model as a simplex, with uniform beta priors. This enforces an arbitrary scale on the coefficients (they must sum to one), without constraining the shape of the spline. Length classes were defined as < 40cm, 40-44cm, 45-49cm, 50-54cm, 55-59cm, 60-69cm and ≥70cm.

Models were fitted using four chains with 2,000 iterations per chain, including a burn-in period of 1,000 iterations. Diagnostics used to assess model fit were primarily based on posterior predictive checks, and convergence was assessed using $\hat{R}$ diagnostics. Support for the inclusion of species and set-type specific splines was assessed using leave one out estimates of expected log pointwise predictive density (ELPD LOO – Vehtari et al., 2017). We also fitted exploratory models with bias represented on the logit-scale. However, posterior predictive checks indicated relatively poor fits, and these models were not considered further.

Comparisons of ELPD LOO did not provide clear support for set-type specific grab sample bias. The inclusion of set-type specific bias smooths increased ELPD LOO (ΔELPD LOO = 76.3), though the increase was modest in relation to the standard error (SE of ΔELPD LOO = 41.3). The inclusion of species-specific bias smooths also increased ELPD LOO, though again the increase was modest in relation to the standard errors (ΔELPD LOO = 76.3; SE of ΔELPD LOO = 47.3).

Estimated grab sample bias, invariant across species and set-type, is provided in Figure 5. The estimated relationship between bias and fork length is similar to that for the correction factors currently used to correct for grab sample bias (e.g. see Peatman et al., 2018). However, the estimates of bias presented here demonstrate a decreasing trend with increasing fork lengths greater than 60cm, whereas the correction factors suggest a weak increase in bias from the 60-69cm size class to the ≥70cm size class. This difference may in part reflect the use of length-bin specific correction factors, which ignores variation in lengths within length bins between sets.

Testing for differences in grab sample bias between species and set-types should be re-examined as and when additional data are available from paired grab / spill trips. At this stage, we recommend that the ‘correction factors’ continue to be used to correct grab sample bias.

Sub-sampling analysis to assess precision of species composition estimates in 2020 and 2021

Purse seine observer coverage rates have been impacted by COVID-19. A sub-sampling exercise was undertaken in 2021 to explore the impacts of reduced observer coverage rates on the precision of species composition estimates (Peatman et al., 2021). Samples were drawn at random from available observer data for 2018 and 2019 to achieve assumed reductions in observer coverage, and estimates of species compositions generated. Here, we extend the sub-sampling analysis to estimate the precision in estimated species compositions with realised observer rates in 2020 and 2021.

Available observer trips from 2016 to 2019 were resampled to achieve realised observer coverage rates in 2020 and 2021, and the average observer coverage rate across 2018 and 2019 (i.e. pre Covid-19), at a resolution of year, quarter, region and flag. One thousand random draws were taken without replacement for each coverage rate. Grab-sample based species composition estimates were then estimated in the usual way for each random draw, by:

- Summing estimated species catches across 'observed' sets, stratified by year, quarter, 5° cell, flag and association (free school vs. associated sets).
- Converting from species-specific catch to species-specific proportions for each strata.
- Then applying these stratified estimates of species-specific proportions to strata-specific total reported catches to get species-specific catch.

For strata with no observer coverage in the subsampled dataset, species proportions were calculated from the subsampled dataset at a coarser resolution of year, quarter and set type (free school vs. associated sets). These coarser resolution estimates of species proportions were applied to total reported catch for the strata in question. The coefficients of variation in overall species proportions were then calculated at the resolution of catch data in the skipjack stock assessment, i.e. year-quarter, region (see Figure 3) and set type (free school vs. associated sets).

Observer coverage rates in regions 7 and 8 in 2020 and 2021 were insufficient to support their inclusion in the sub-sampling analysis, noting that species compositions are only generated directly from grab samples for strata where observer coverage rates exceed 20%. As such, the sub-analysis was restricted to region 6.

Coefficients of variation (CVs) of estimated species proportions are provided in Figure 6 with pre Covid-19 levels of observer coverage, as well as realised coverage rates in 2020 and 2021. The mean CVs of skipjack proportions were c. 0.05 for both set-types with observer coverage rates from 2020 and 2021, compared with a mean CV of c. 0.02 with coverage rates from 2018 and 2019. Mean CVs of yellowfin proportions were c. 0.07 for associated and free-school sets with observer coverage rates from 2020 and 2021, compared with a mean CV of 0.032 with coverage rates from 2018 and 2019. Mean CVs of bigeye proportions were c. 0.37 with observer coverage rates from 2020 and 2021, compared with a mean CV of 0.12 with coverage rates from 2018 and 2019.

The sub-sampling analysis suggests that the reduction in observer coverage rates in 2020 and 2021 has significantly reduced the precision in estimated species proportions, with increases in CVs in the region of 90 to 250% depending on the species and set type.

Potential uses of cannery data

Purse seine processor (cannery) data have been identified as a potentially important source of data for verifying the estimates of purse seine tuna species catch determined from observer data. While there is a requirement for 100% coverage of observers on purse seine vessels in the tropical WCPO purse seine fishery, species composition sampling is only currently possible to undertake on less than 0.2% of the catch to avoid disruptions to the fishing operation. The COVID-19 pandemic has resulted in a reduction in observer coverage in recent years (~50% in 2020 and ~10% in 2021), and therefore another important reason for considering the use of cannery data in estimation of purse seine tuna species composition.

The WCPFC Scientific Service Provider (SSP) could potentially use these data in the process for verifying the estimates of purse seine tuna species composition obtained from the observer data, but the coverage of cannery data submitted to date is unfortunately too low (see Table 3). There are also certain data gaps (for example, the canneries submitting data only receive part of the trip catch) and data quality issues (for example, duplicate data from two different sources) in the cannery data that require resolution.

The Guidelines for the Voluntary Submission of Purse seine Processor data by CCMs to the Commission provide a mechanism for improving the coverage of cannery data for potential use, and we propose the consideration of a future WCPFC project to cover, *inter alia*, the following areas:

- The SSP or WCPFC Contractor to work with relevant CCM port and flag states to obtain purse seine processor data not yet provided, using the guidelines to ensure data confidentiality.
- The SSP or WCPFC Contractor to work with relevant CCMs to review the protocols for collecting purse seine processor data at each source, including species identification.
- The SSP to continue the management, and data quality management, of purse seine processor data submission, including the identification of gaps, resolving duplicate processor data (e.g. when valuable Final Outturn [FOT] data are provide from a different source).

Tables

Table 3 Coverage of matched logsheet/observer/cannery trip data for the WCPFC tropical purse seine fishery (excludes Indonesia, Philippines and Vietnam domestic fisheries).

YEAR	Total Purse seine Tuna catch (MT)				
	WCPFC Estimates	Processor data	%	Matched Log / Obs / Cannery	%
2013	1,570,125	498,424	31.7%	373,440	23.8%
2014	1,737,573	509,689	29.3%	380,278	21.9%
2015	1,523,436	436,504	28.7%	336,345	22.1%
2016	1,524,193	467,132	30.6%	353,175	23.2%
2017	1,434,200	473,818	33.0%	382,596	26.7%
2018	1,636,334	529,670	32.4%	474,088	29.0%
2019	1,774,620	531,431	29.9%	478,519	27.0%
2020	1,564,860	671,823	42.9%	210,388	13.4%
2021	1,443,979	584,879	40.5%	34,084	2.4%

Figures

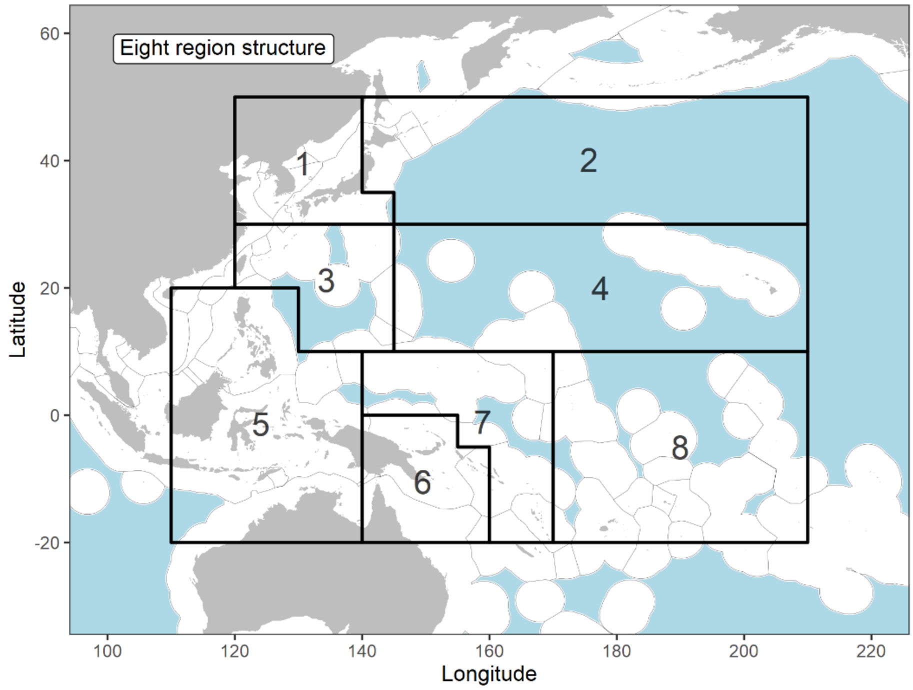

Figure 3 The eight region structure from the 2022 skipjack assessment.

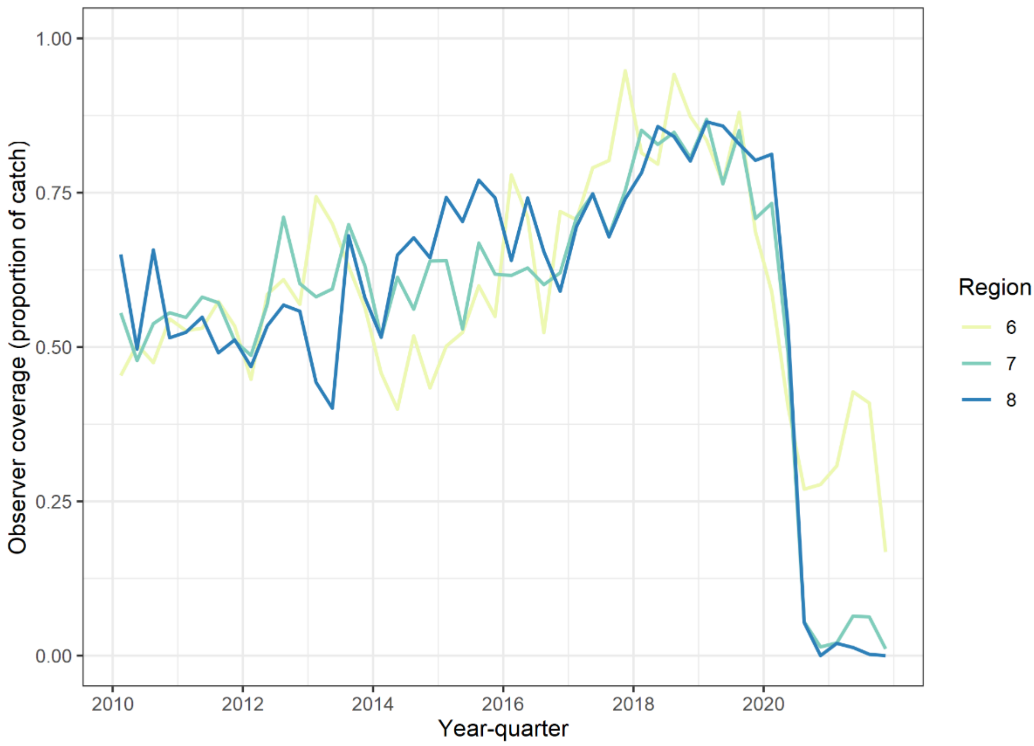

Figure 4 Observer coverage rates by assessment model region (6, 7 and 8) from 2010 to 2021.

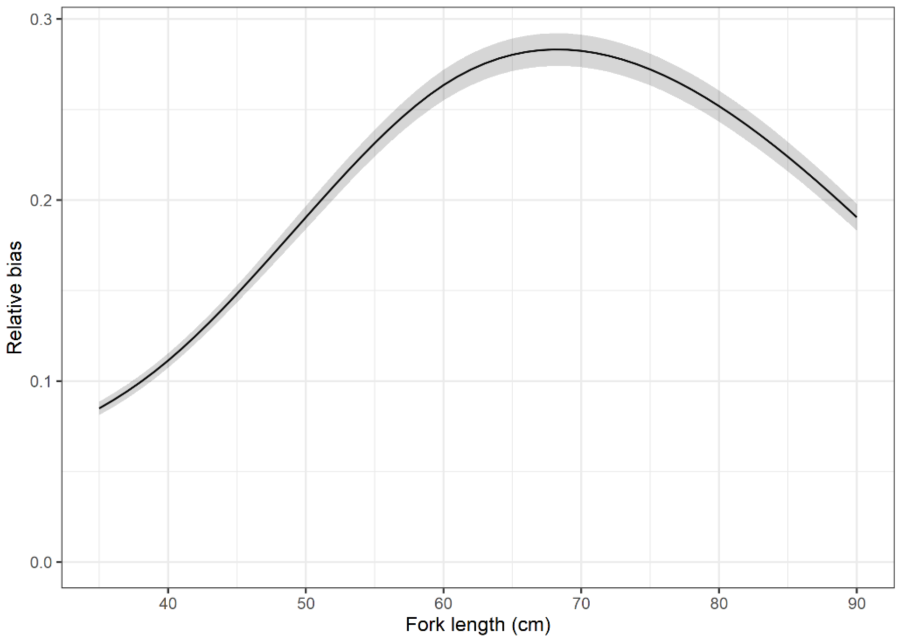

Figure 5 Relative grab sample bias against fork length, from the model with species and set-type invariant bias.

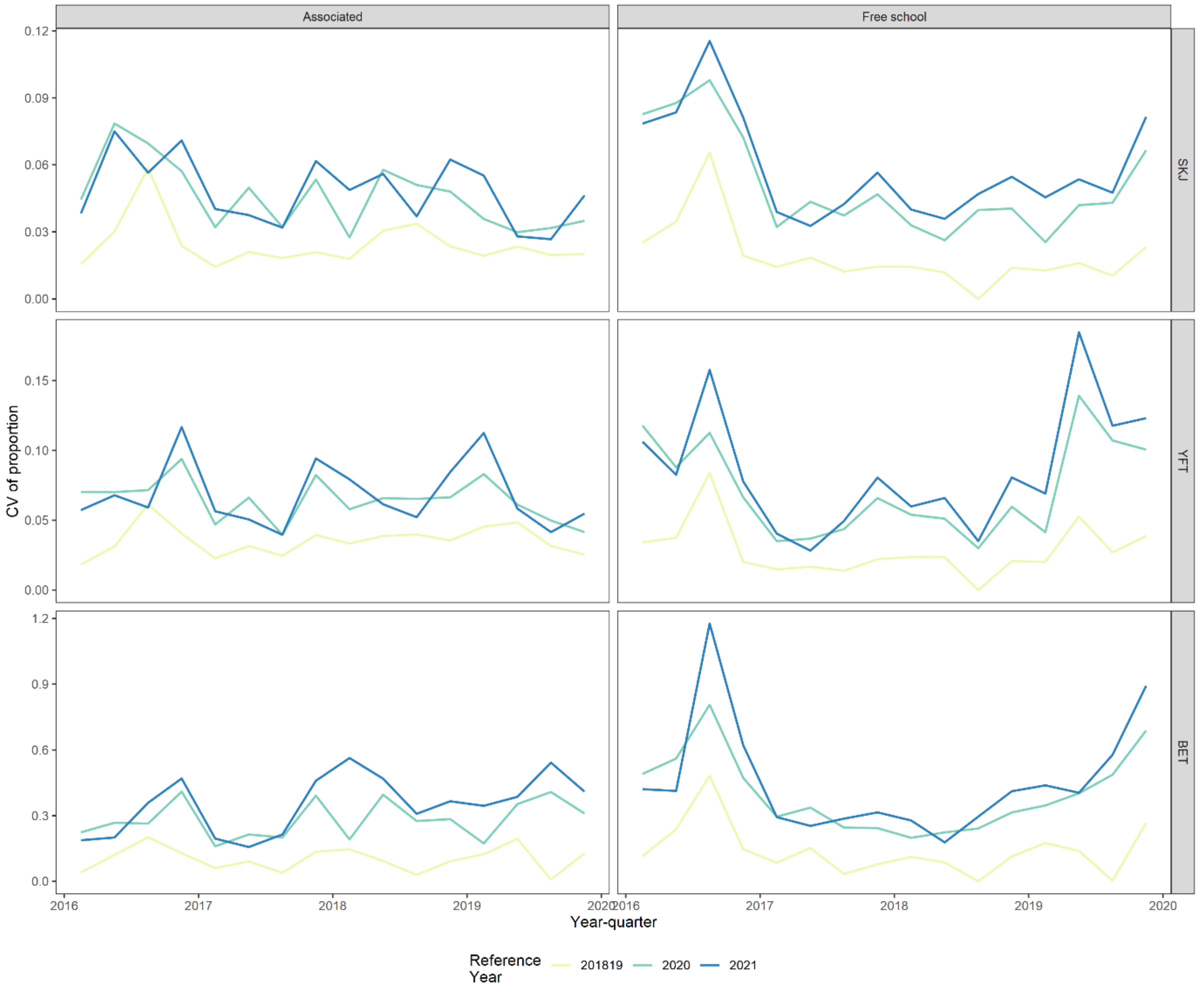

Figure 6 Coefficients of variation of species proportions by year-quarter, species and set type (free-school vs associated) with pre Covid-19 observer coverage rates (reference year = '201819'), as well as coverage rates in 2020 and 2021.

Appendix C

Effect plots for revised species composition models

Skipjack – free school

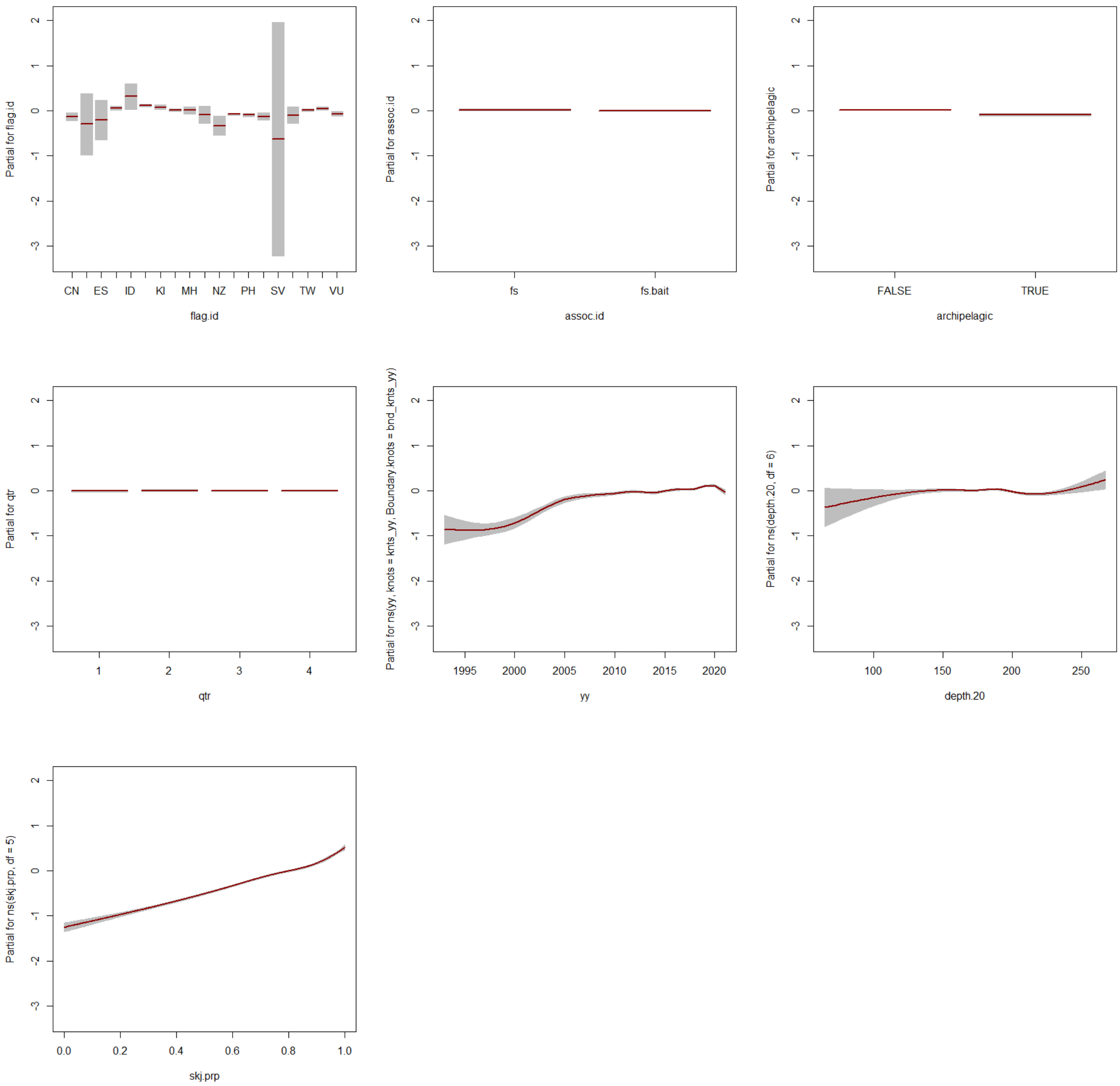

Figure 7 Effect plots for the mean of the beta-component of the skipjack free-school model. Top row, left to right: flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters. Middle row, left to right: quarter; year; isotherm depth. Bottom row: uncorrected skipjack proportion from vessel logbooks.

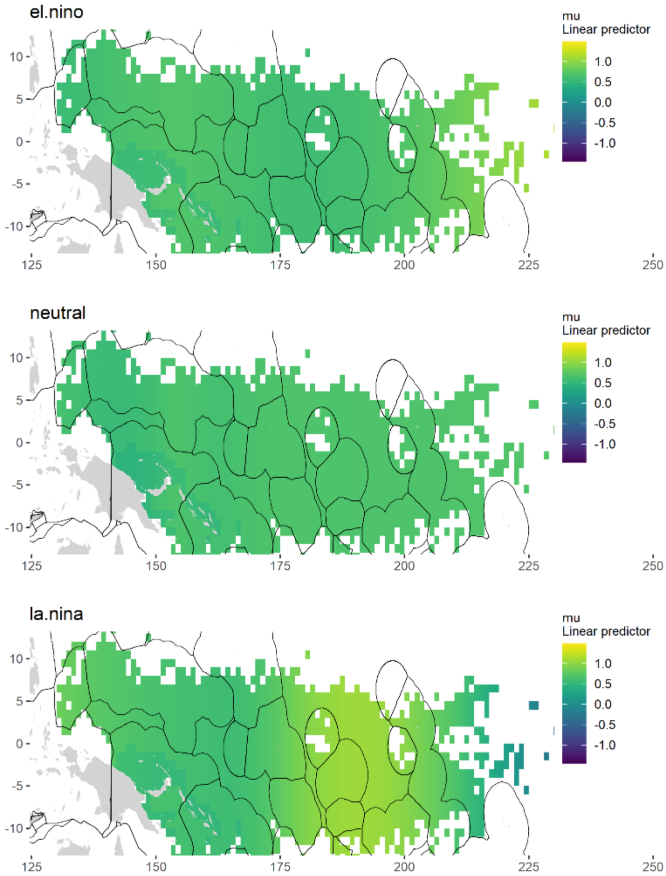

Figure 8 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the skipjack free-school model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

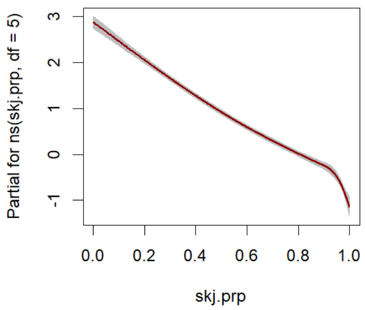

Figure 9 Effect plot for the zero-inflation component of the skipjack free-school model: uncorrected skipjack proportion from vessel logbooks.

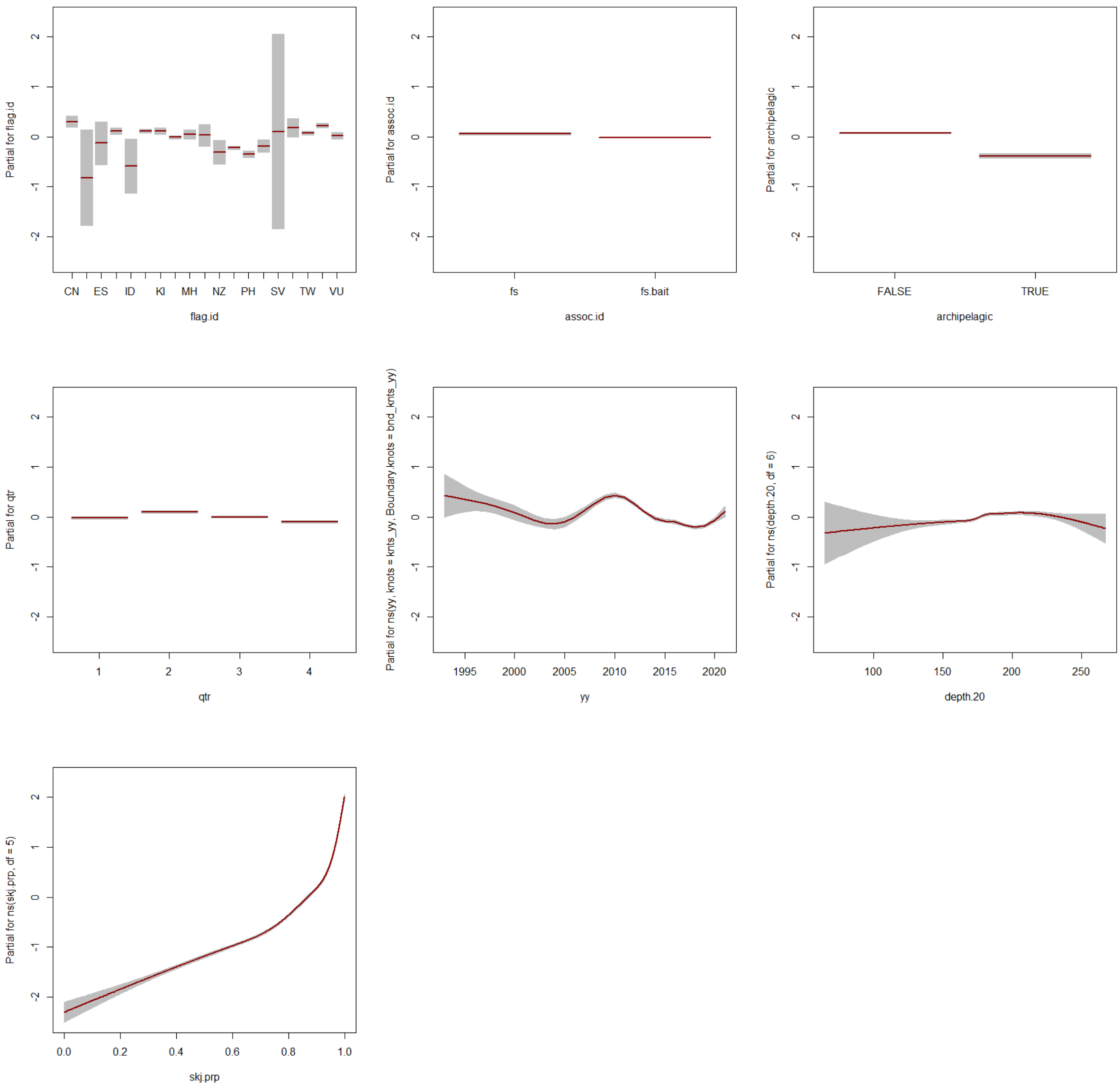

Figure 10 Effect plots for the one-inflation component of the skipjack free-school model. Top row, left to right: flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters. Middle row, left to right: quarter; year; isotherm depth. Bottom row: uncorrected skipjack proportion from vessel logbooks.

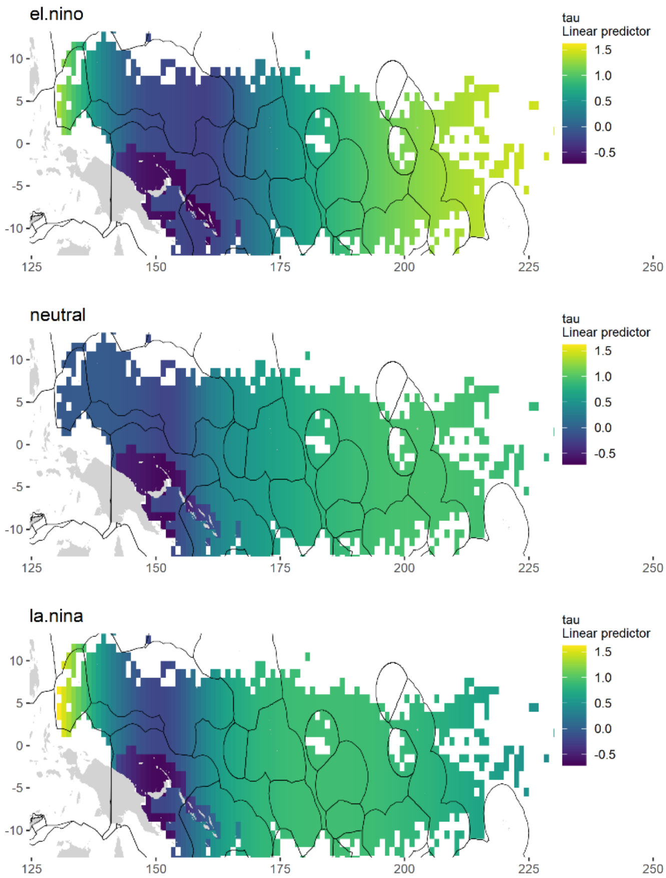

Figure 11 The combined effect of the archipelagic term and the longitude:ONI interaction on the one-inflation component of the skipjack free-school model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

Yellowfin – free school

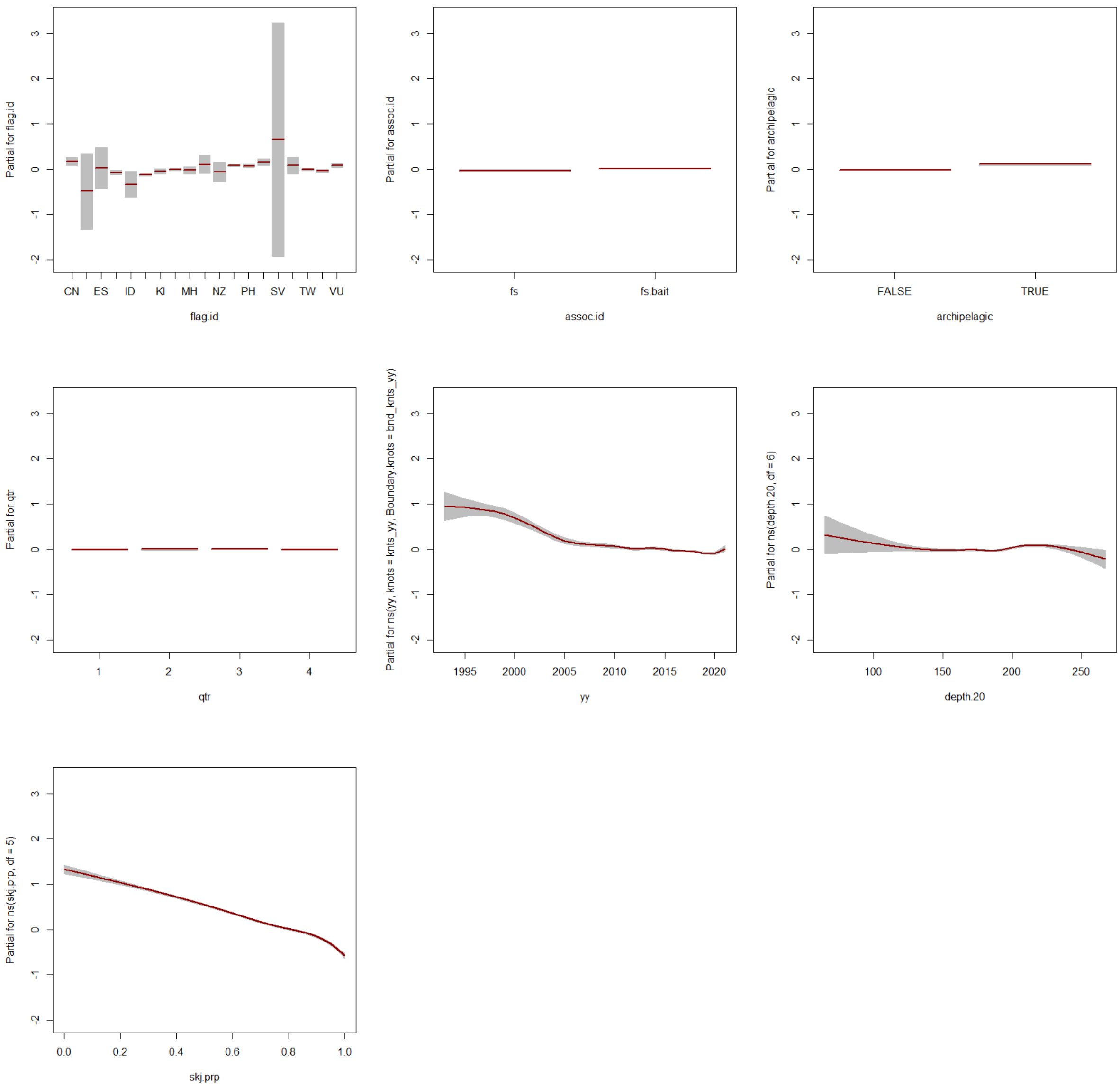

Figure 12 Effect plots for the mean of the beta-component of the yellowfin free-school model. Top row, left to right: flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters. Middle row, left to right: quarter; year; isotherm depth. Bottom row: uncorrected skipjack proportion from vessel logbooks.

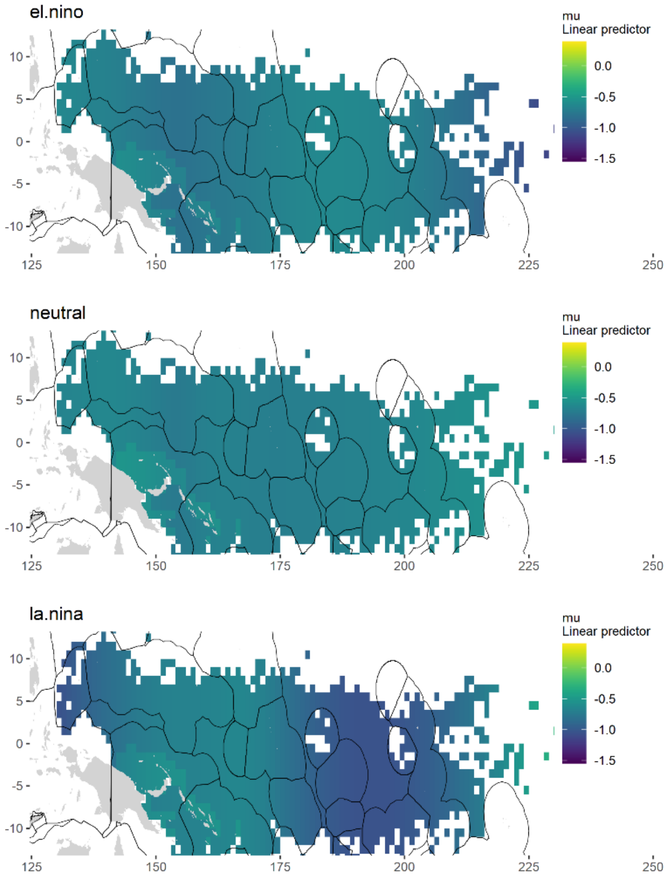

Figure 13 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the yellowfin free-school model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

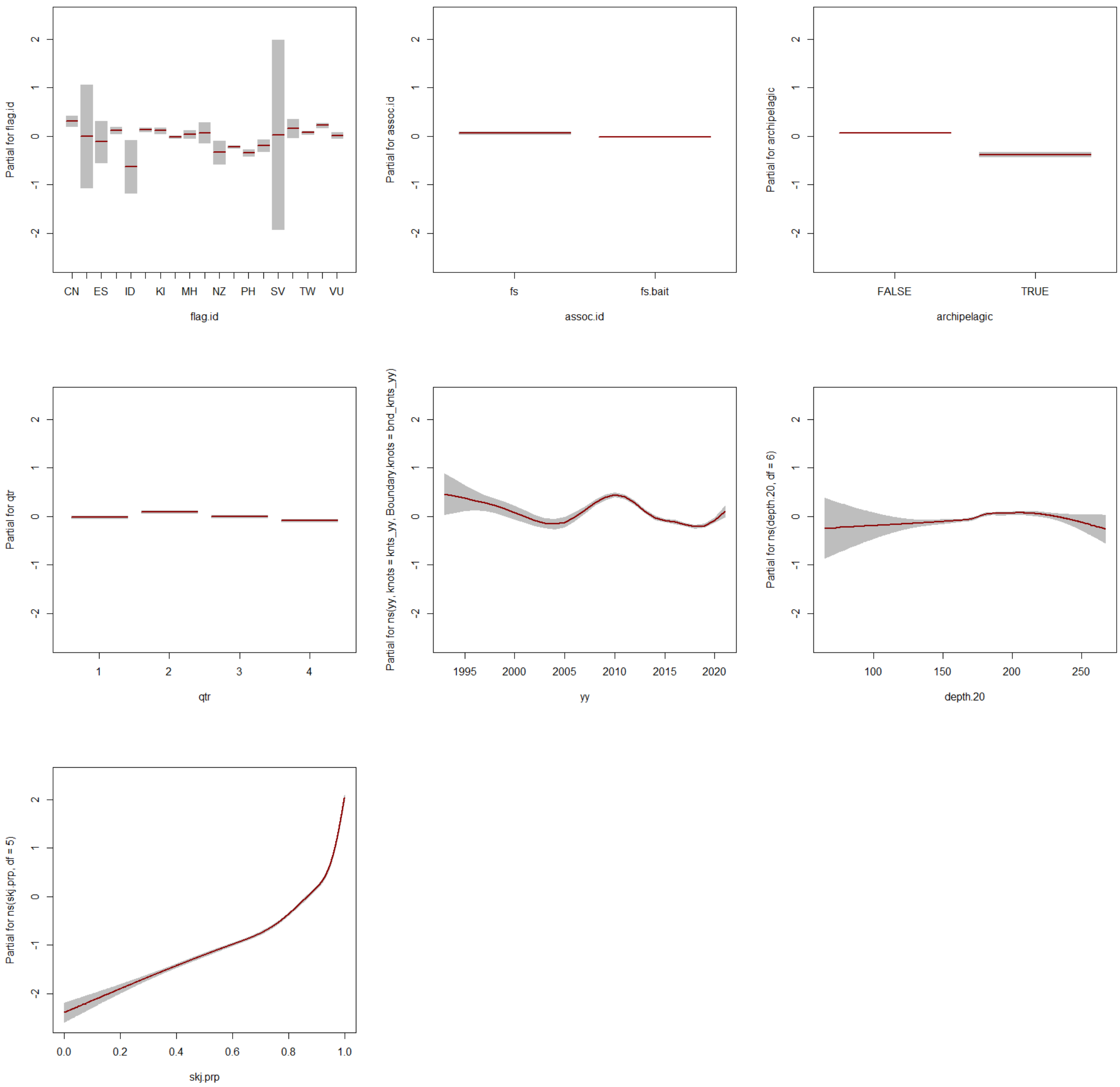

Figure 14 Effect plots for the zero-inflation component of the yellowfin free-school model. Top row, left to right: flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters. Middle row, left to right: quarter; year; isotherm depth. Bottom row: uncorrected skipjack proportion from vessel logbooks.

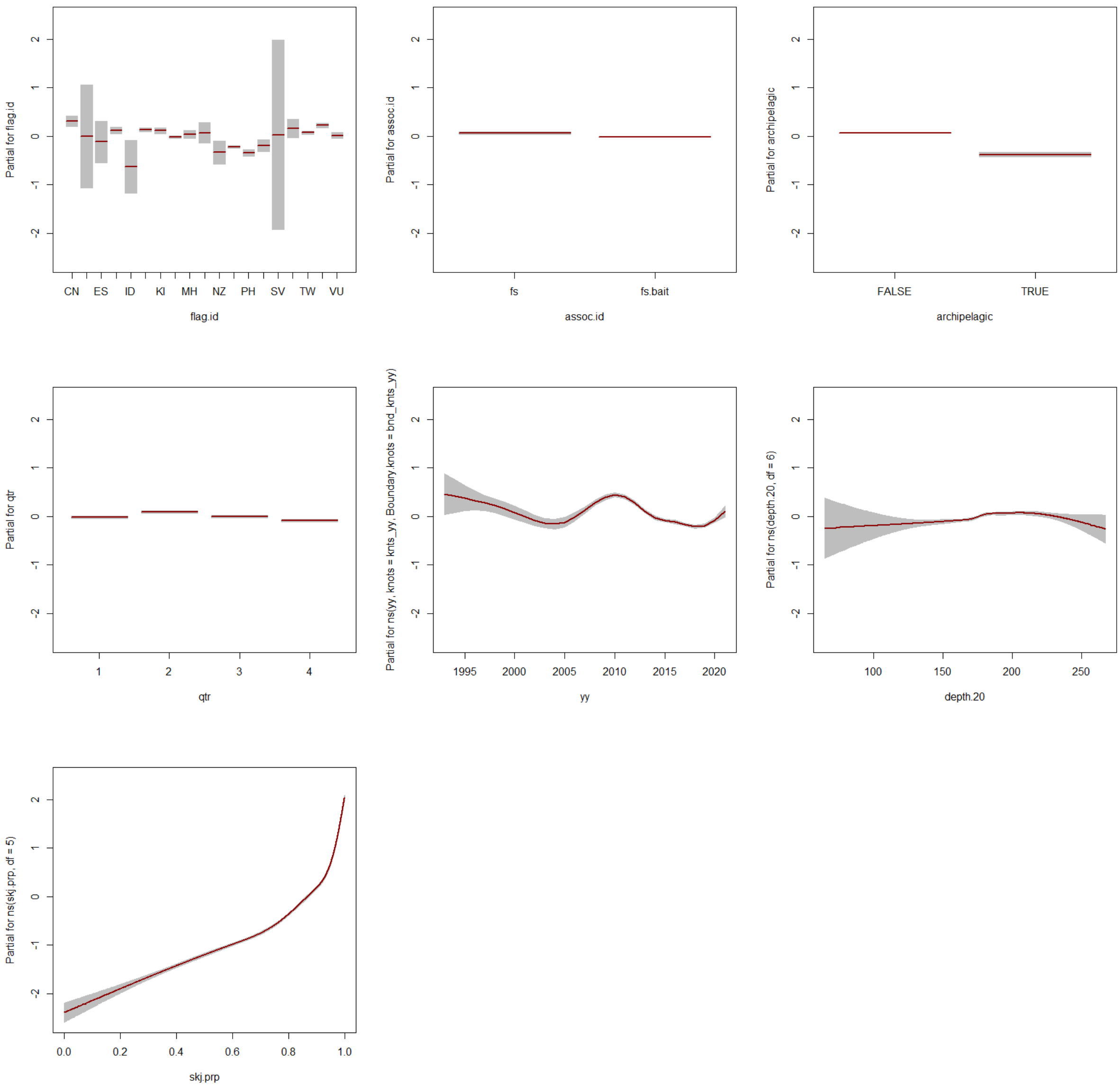

Figure 15 The combined effect of the archipelagic term and the longitude:ONI interaction on the zero-inflation component of the yellowfin free-school model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

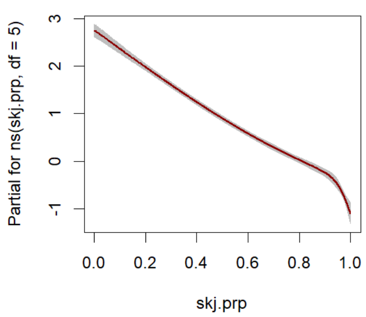

Figure 16 Effect plots for the one-inflation component of the yellowfin free-school model: uncorrected skipjack proportion from vessel logbooks (right).

Bigeye – free school

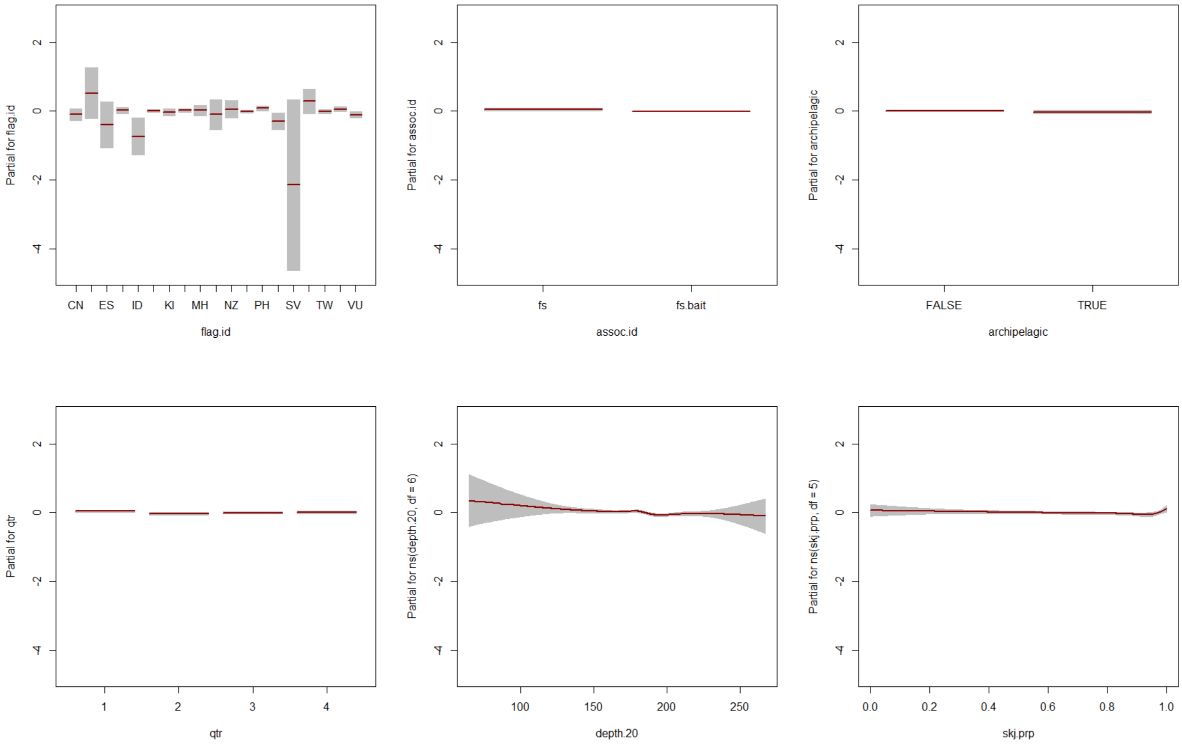

Figure 17 Effect plots for the mean of the beta-component of the bigeye free-school model. Top row, left to right: flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters. Bottom row, left to right: quarter; isotherm depth; and, uncorrected skipjack proportion from vessel logbooks.

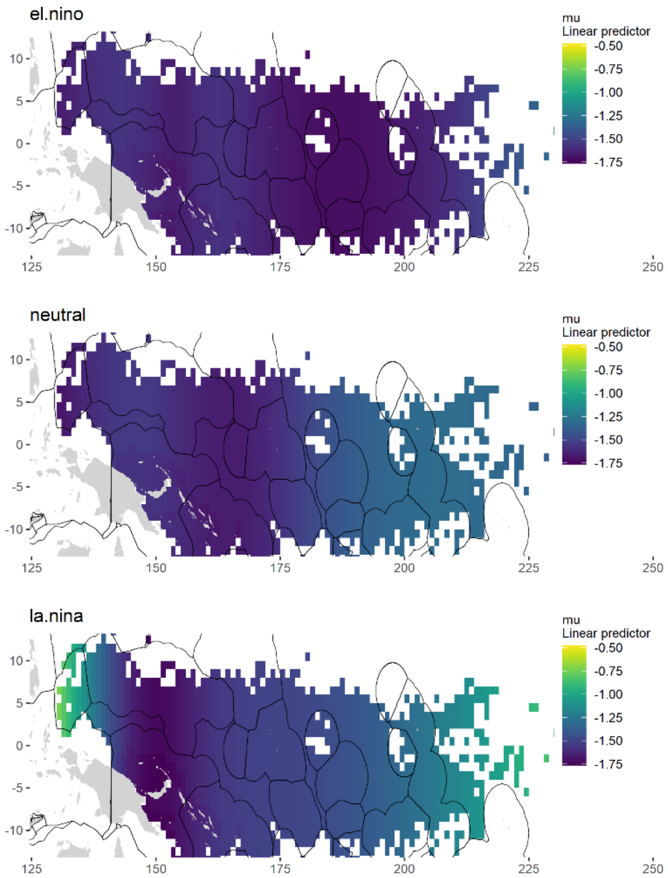

Figure 18 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the bigeye free-school model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

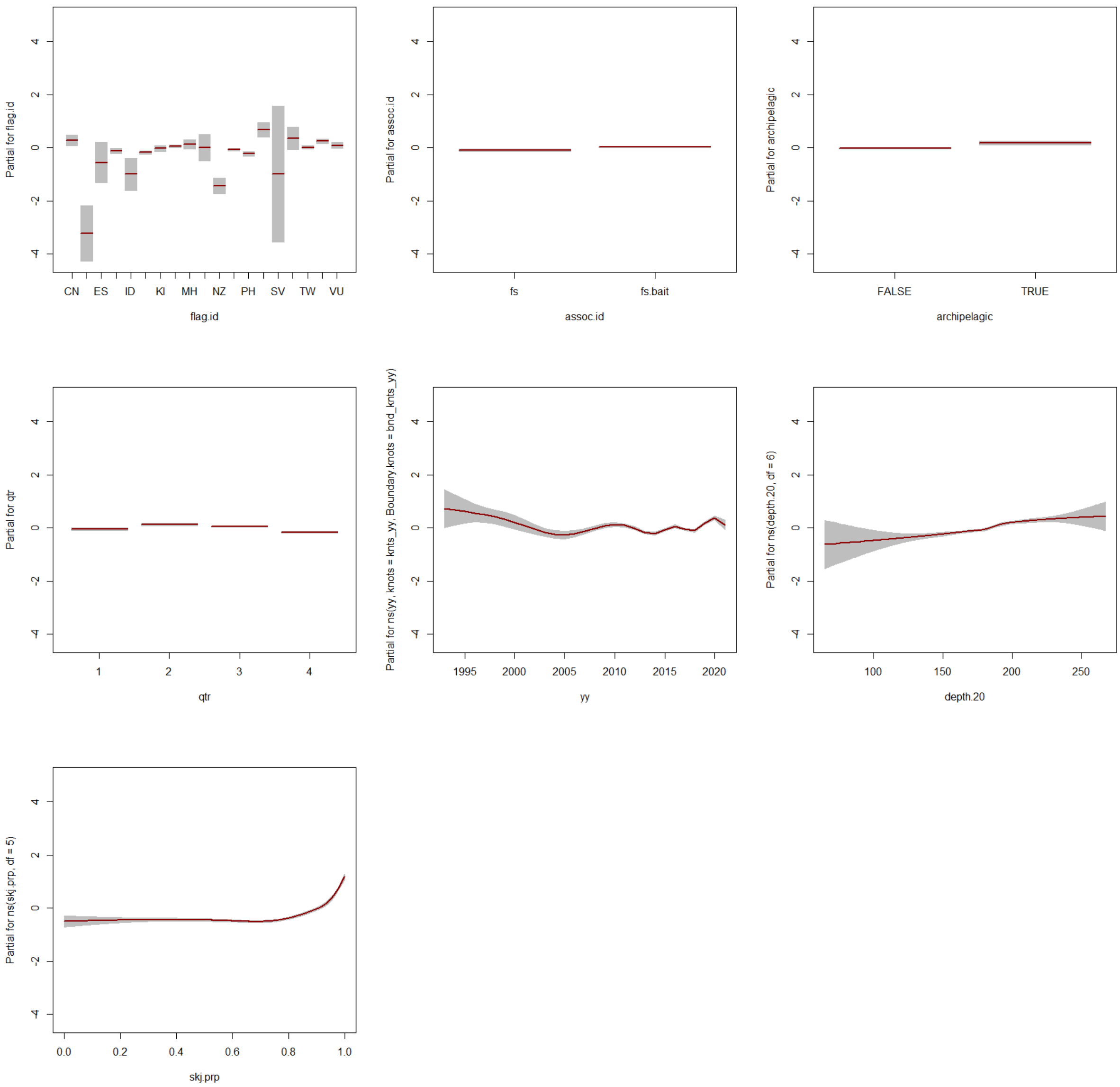

Figure 19 Effect plots for the zero-inflation component of the bigeye free-school model. Top row, left to right: flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters. Middle row, left to right: quarter; year; isotherm depth. Bottom row: uncorrected skipjack proportion from vessel logbooks.

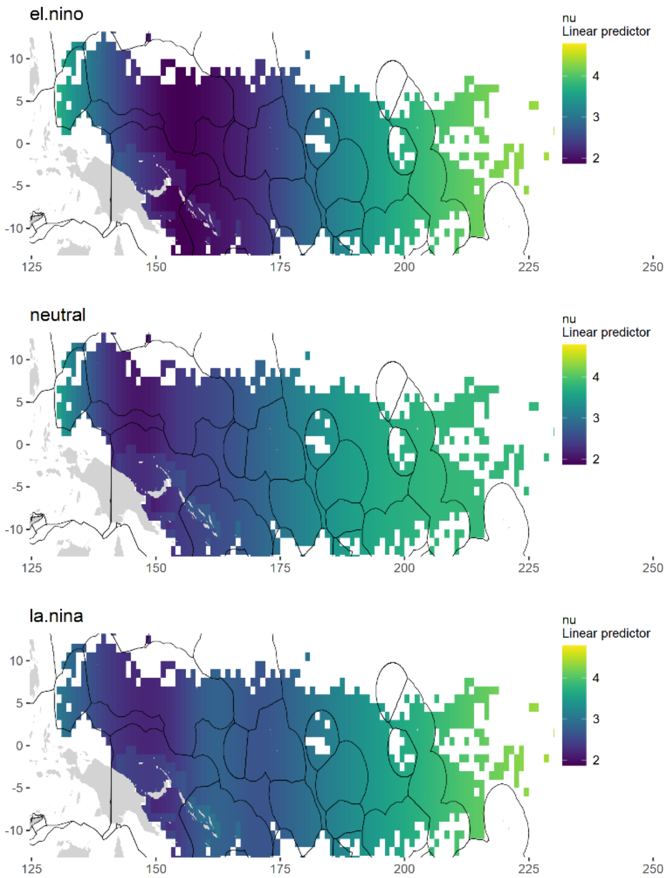

Figure 20 The combined effect of the archipelagic term and the longitude:ONI interaction on the zero-inflation component of the bigeye free-school model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

Skipjack – associated

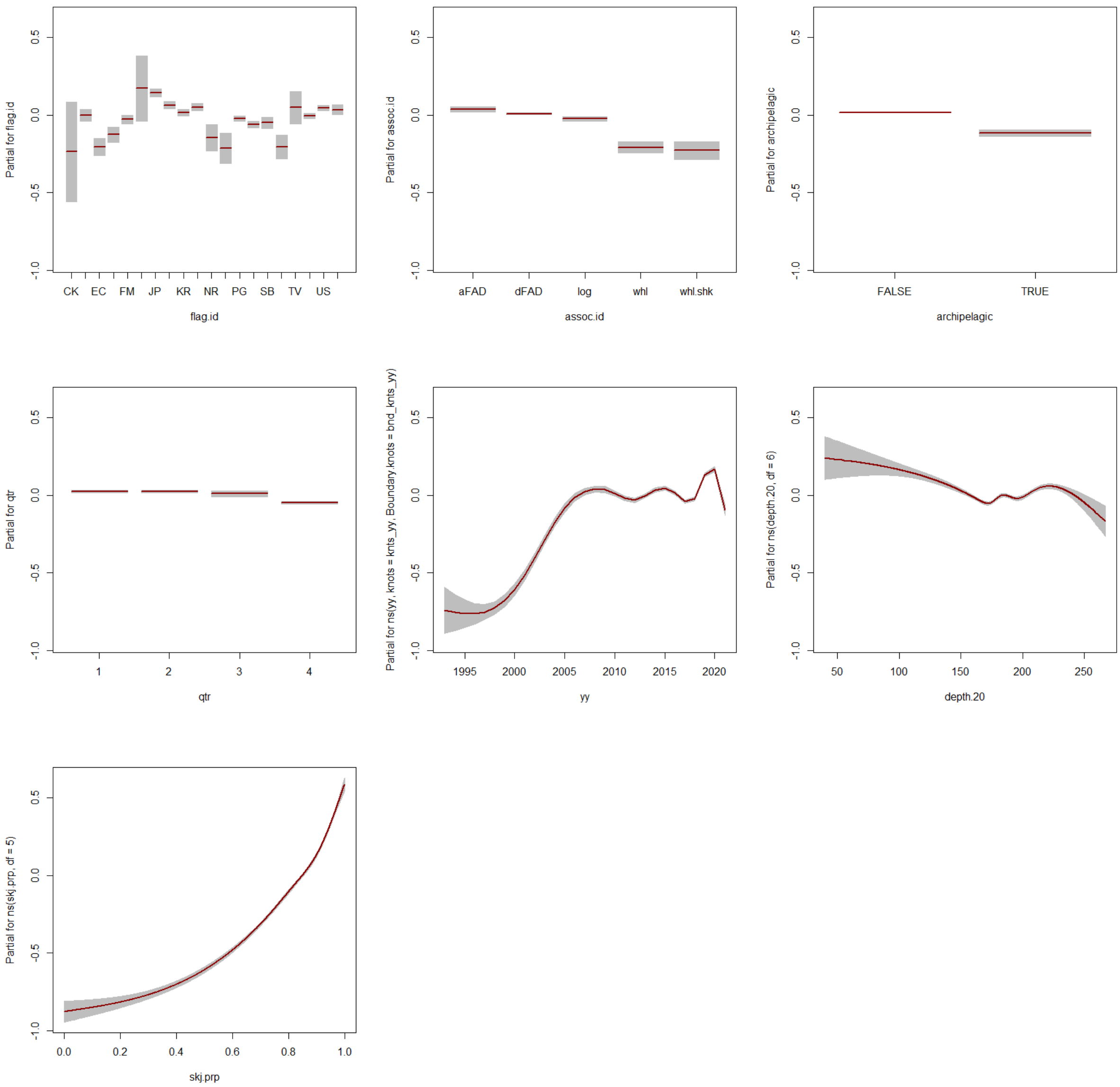

Figure 21 Effect plots for the mean of the beta-component of the skipjack associated model. Top row, left to right: flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters. Middle row, left to right: quarter; year; isotherm depth. Bottom row: uncorrected skipjack proportion from vessel logbooks.

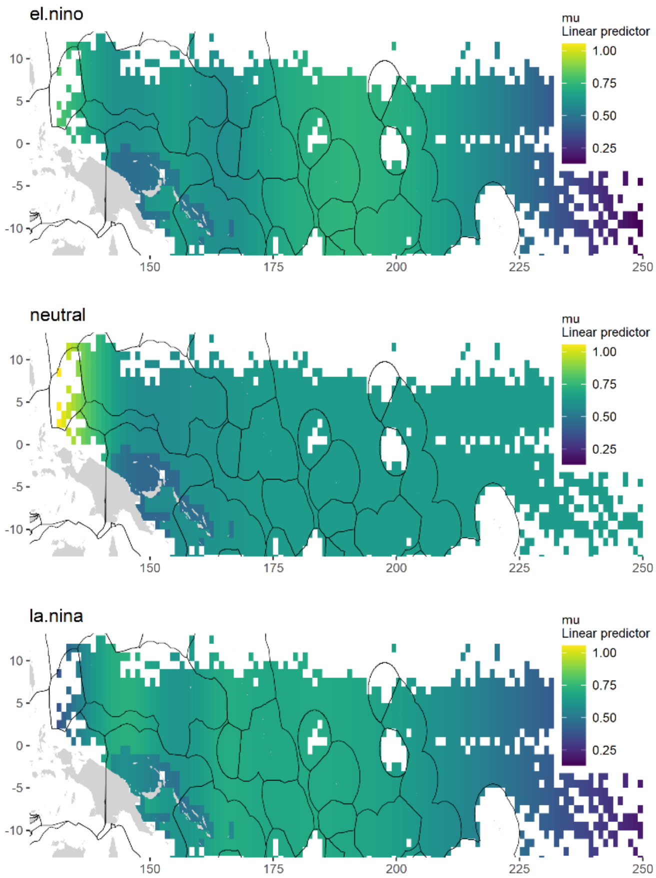

Figure 22 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the skipjack associated model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

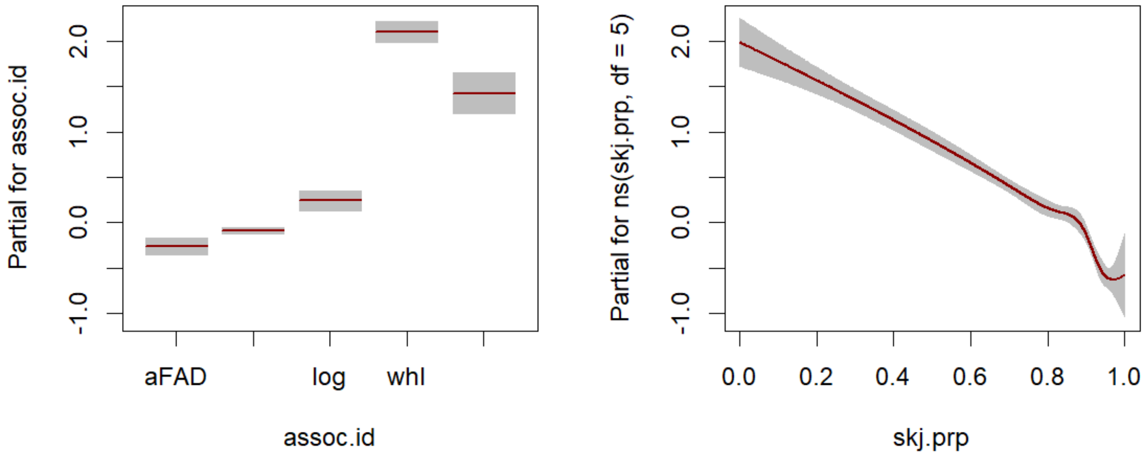

Figure 23 Effect plots for the zero-inflation component of the skipjack associated model: association type (left panel, anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk) and, uncorrected skipjack proportion from vessel logbooks (right panel).

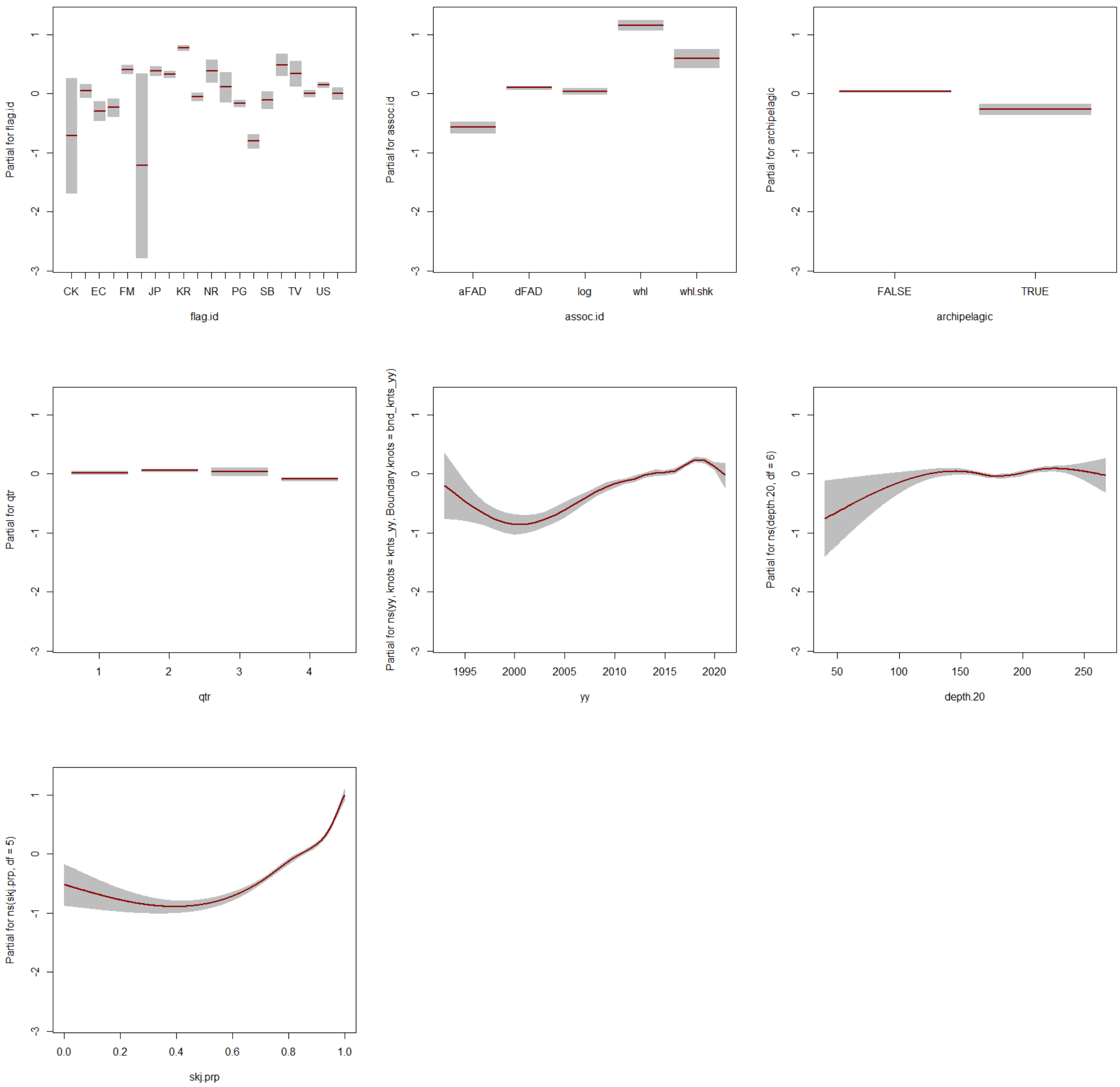

Figure 24 Effect plots for the one-inflation component of the skipjack associated model. Top row, left to right: flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters. Middle row, left to right: quarter; year; isotherm depth. Bottom row: uncorrected skipjack proportion from vessel logbooks.

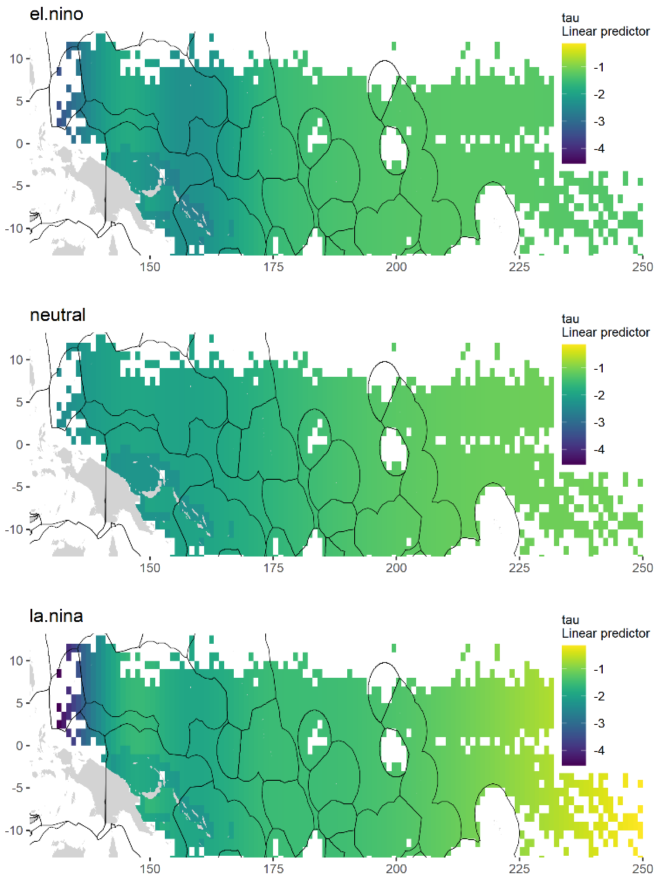

Figure 25 The combined effect of the archipelagic term and the longitude:ONI interaction on the one-inflation component of the skipjack associated model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

Yellowfin – associated

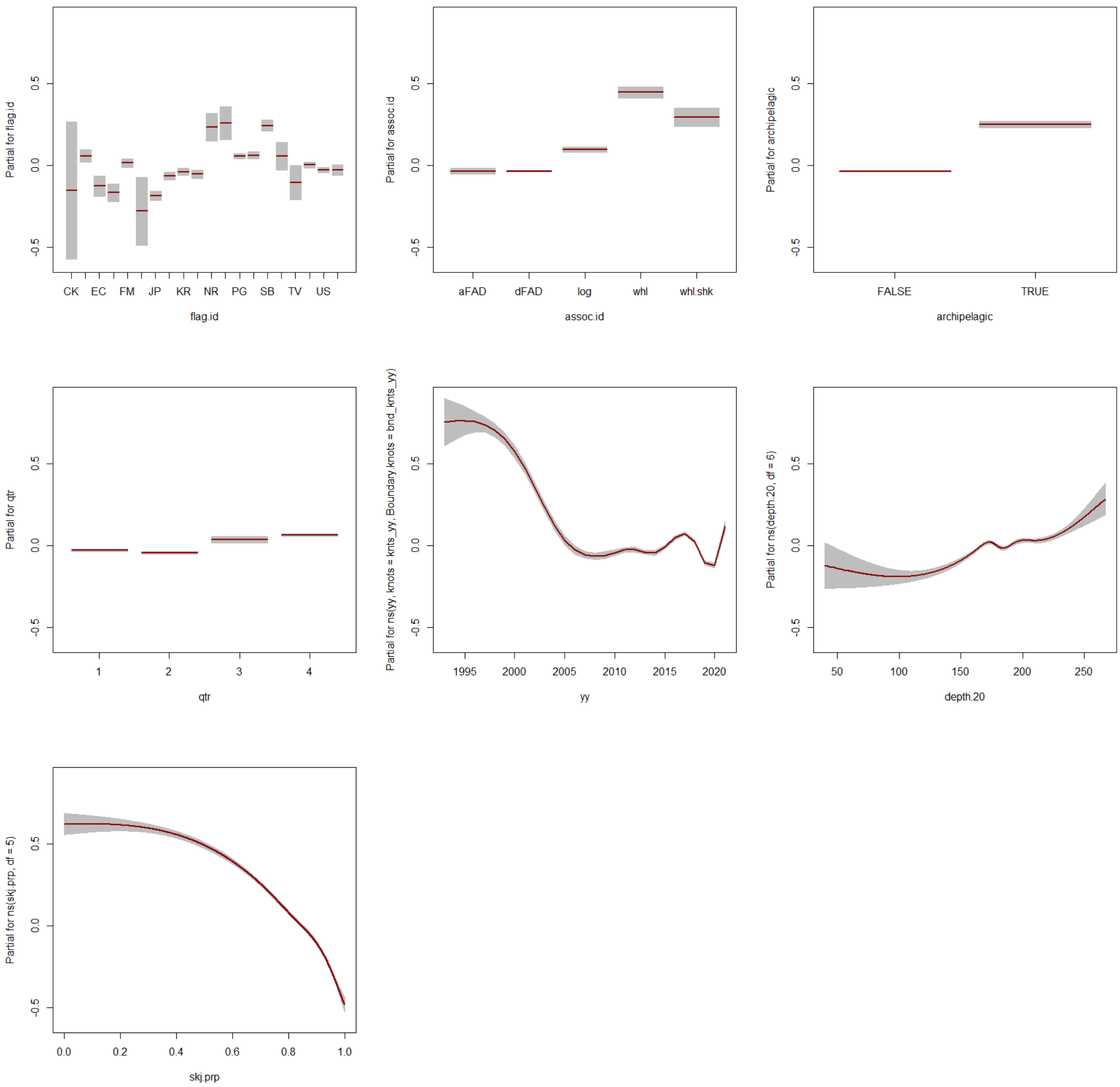

Figure 26 Model effects for the mean of the beta-component of the yellowfin associated model. Top row, left to right: flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters. Middle row, left to right: quarter; year; isotherm depth. Bottom row: uncorrected skipjack proportion from vessel logbooks.

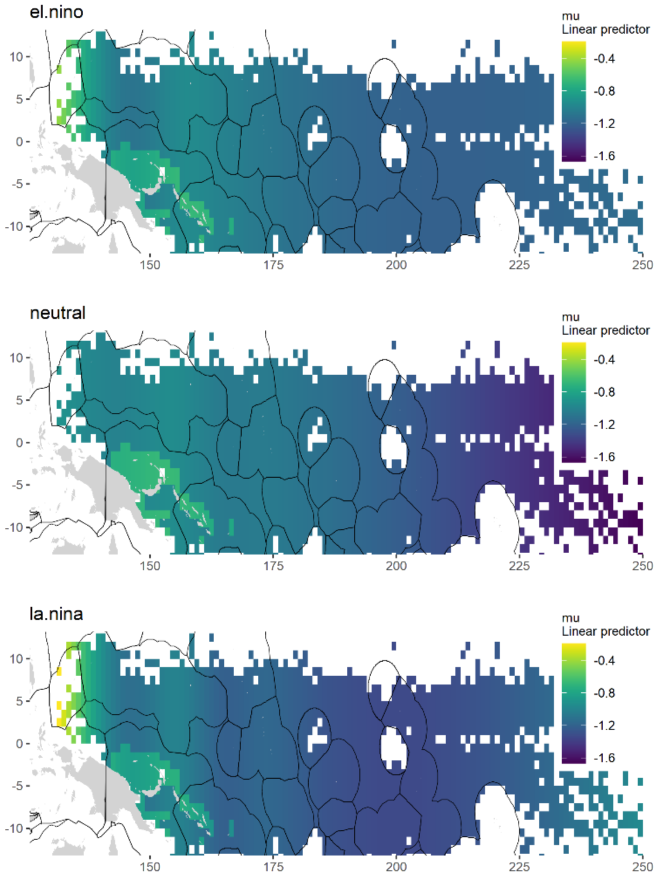

Figure 27 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the yellowfin associated model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

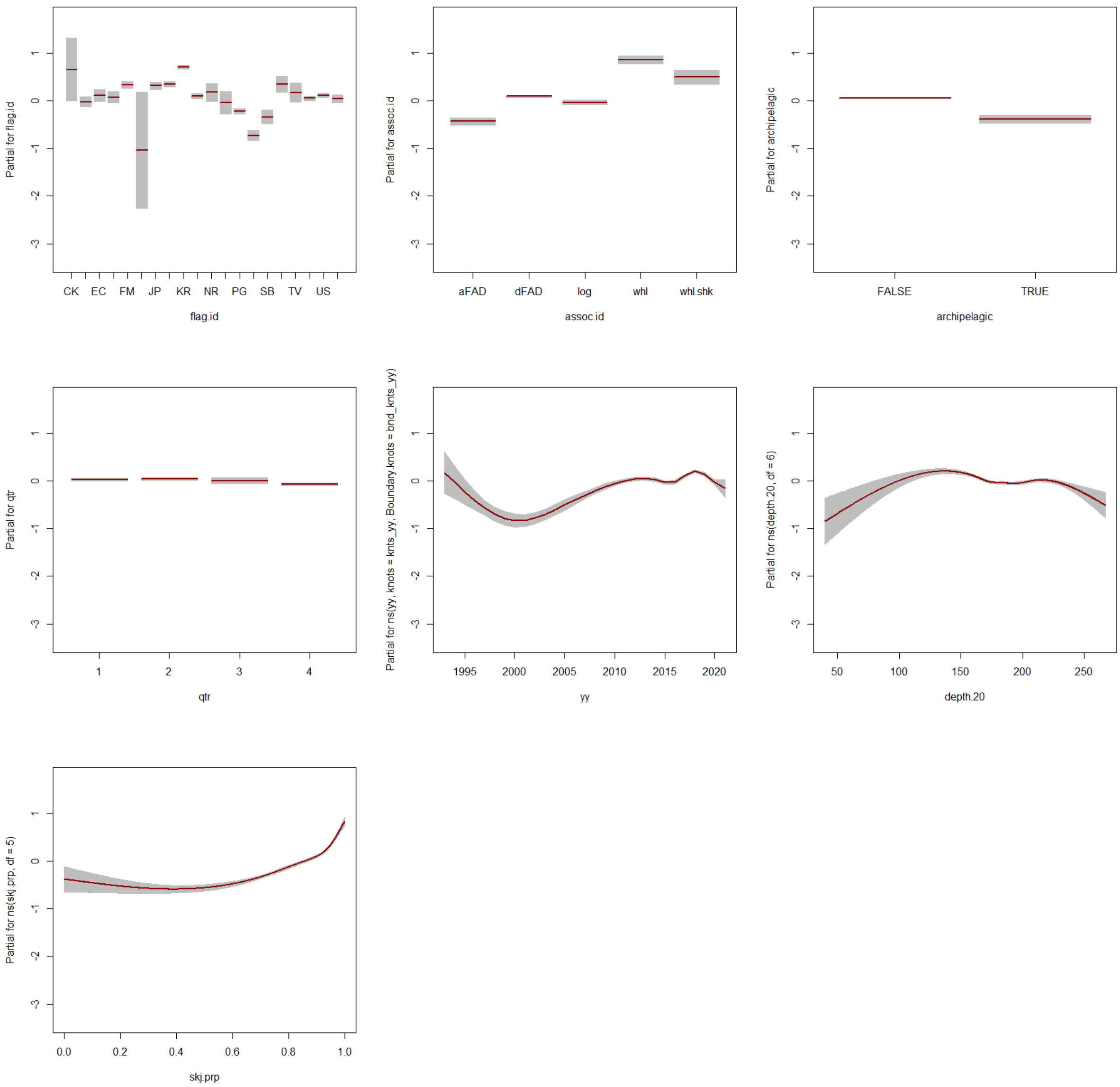

Figure 28 Model effects for the zero-inflation component of the yellowfin associated model. Top row, left to right: flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters. Middle row, left to right: quarter; year; isotherm depth. Bottom row: uncorrected skipjack proportion from vessel logbooks.

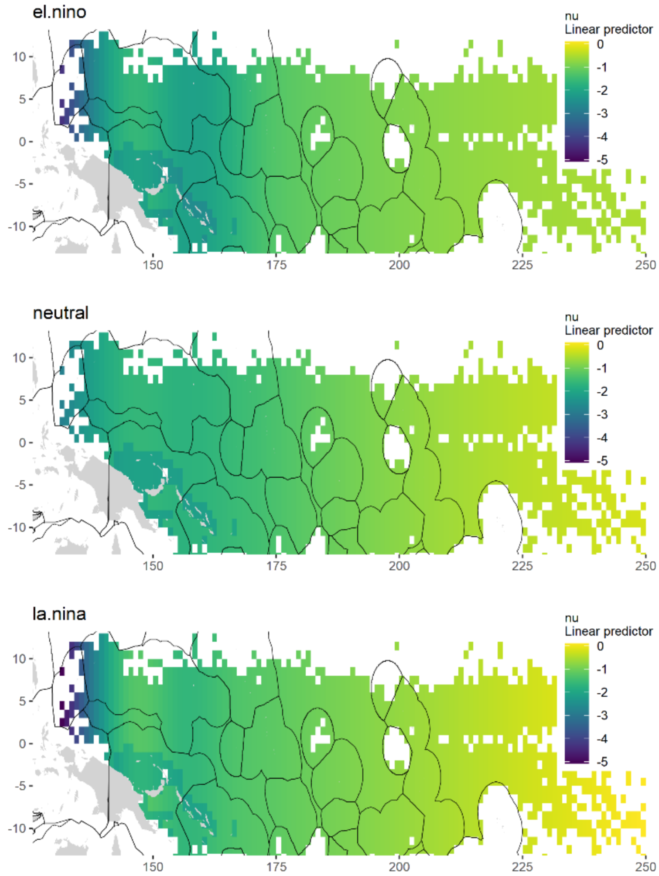

Figure 29 The combined effect of the archipelagic term and the longitude:ONI interaction on the zero-inflation component of the yellowfin associated model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

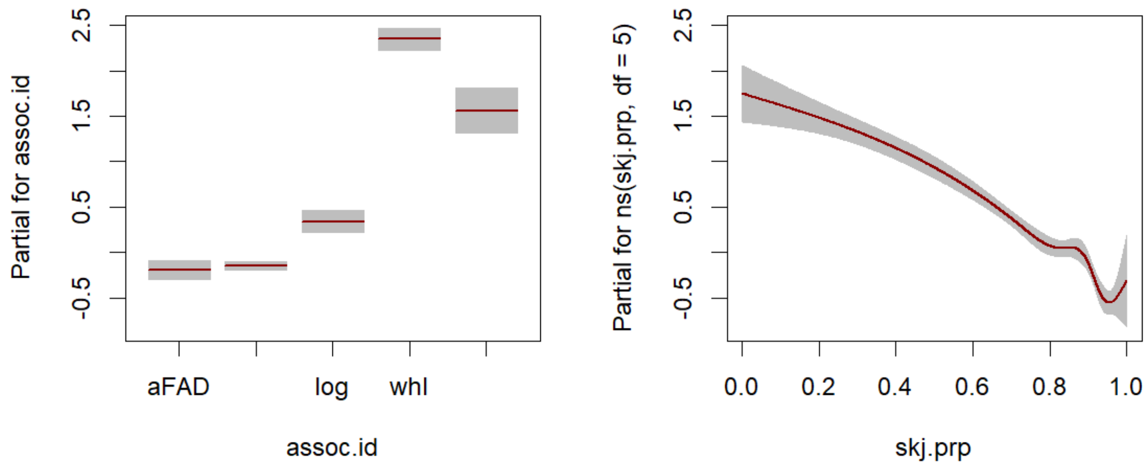

Figure 30 Effect plots for the one-inflation component of the yellowfin associated model: association type (left panel- anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk) and, uncorrected skipjack proportion from vessel logbooks (right panel).

Bigeye – associated

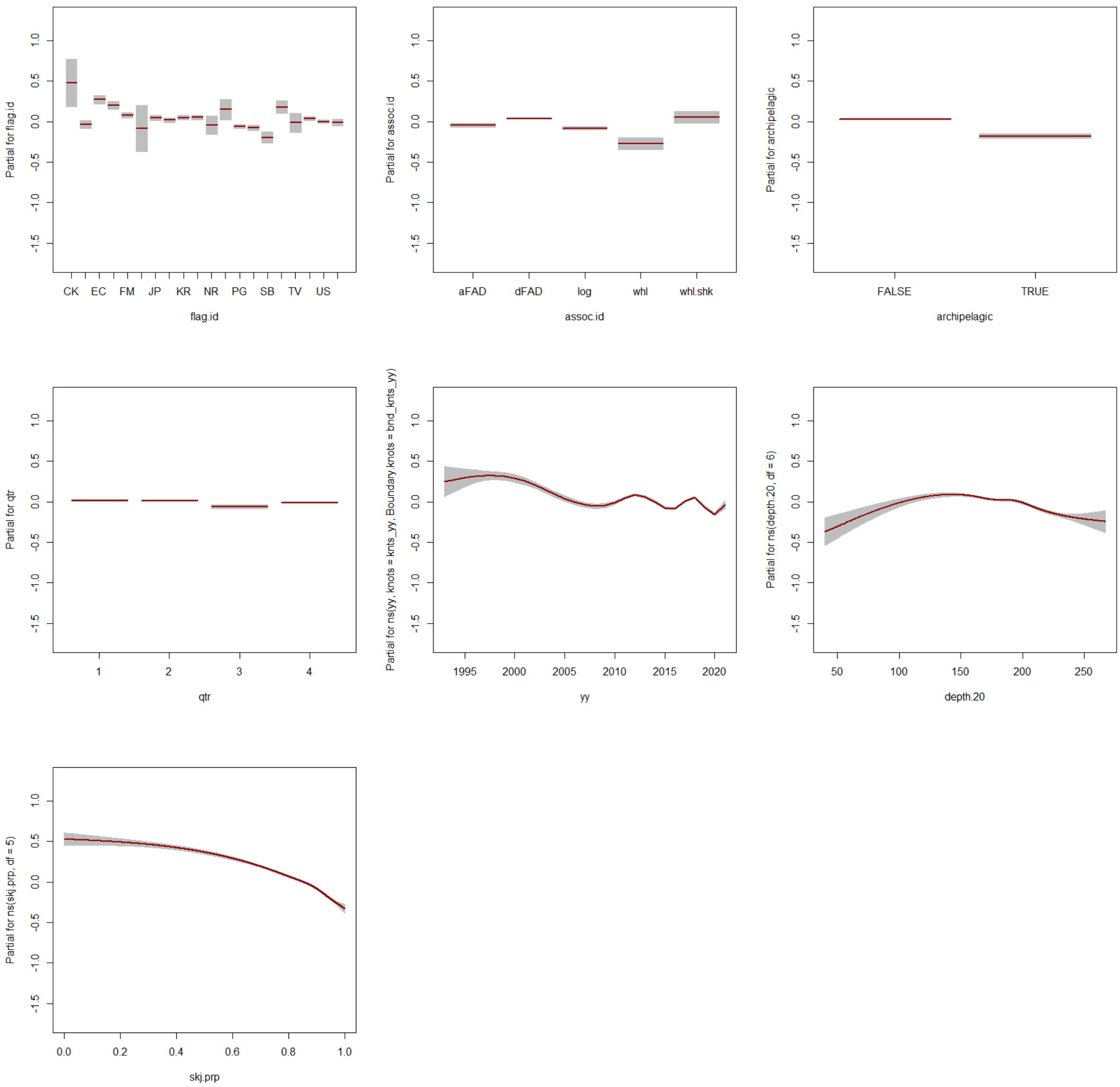

Figure 31 Effect plots for the mean of the beta-component of the bigeye associated model. Top row, left to right: flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters. Middle row: left to right: quarter; year; isotherm depth. Bottom row: uncorrected skipjack proportion from vessel logbooks.

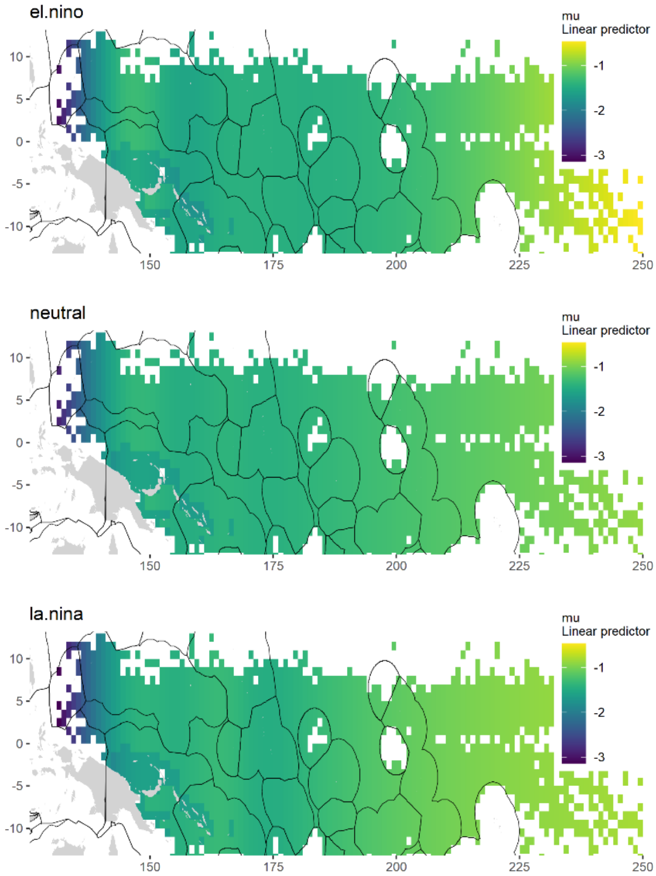

Figure 32 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the bigeye associated model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

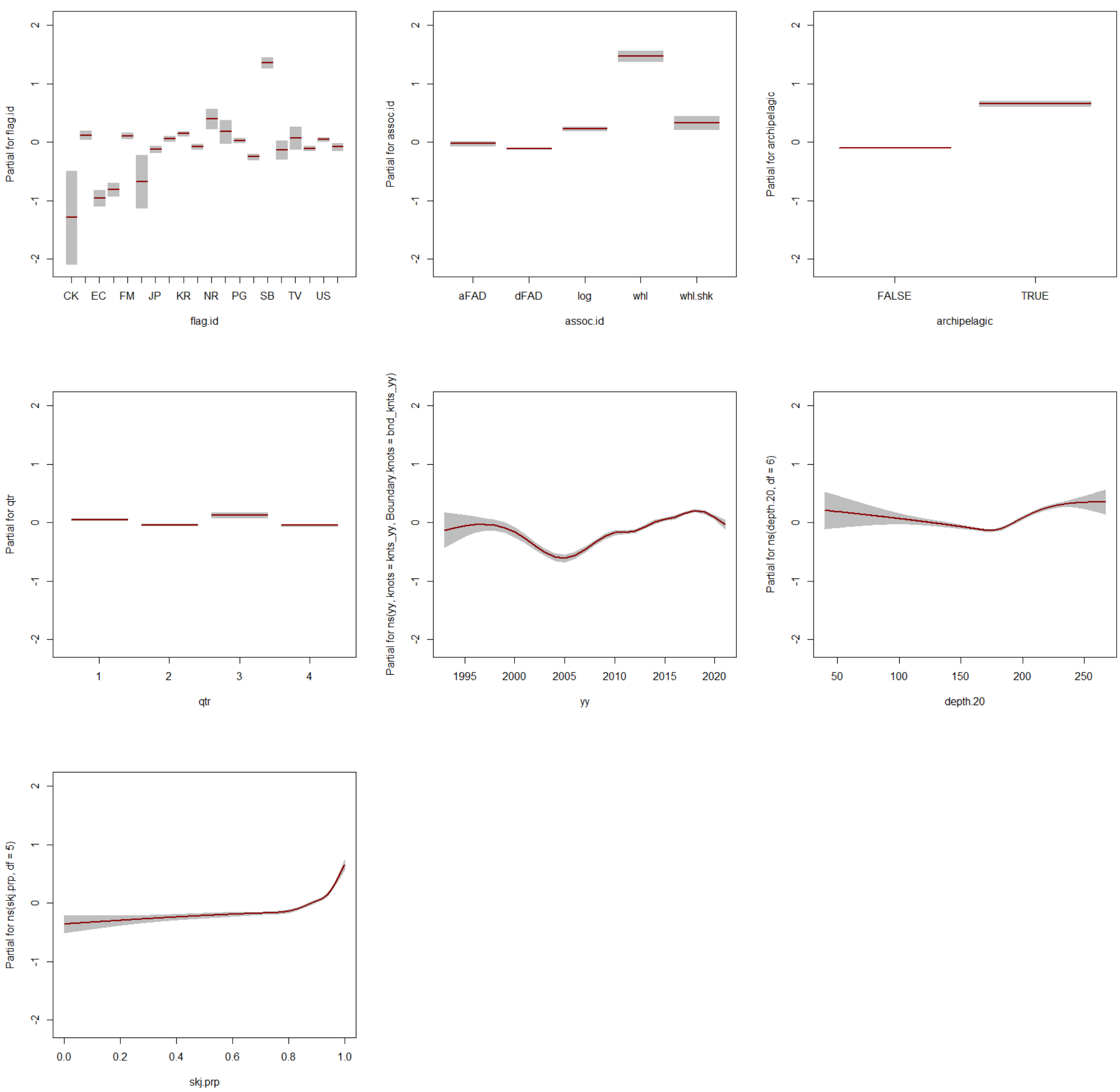

Figure 33 Effect plots for the zero-inflation component of the bigeye associated model. Top row, left to right: flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters. Middle row, left to right: quarter; year; isotherm depth. Bottom row: uncorrected skipjack proportion from vessel logbooks.

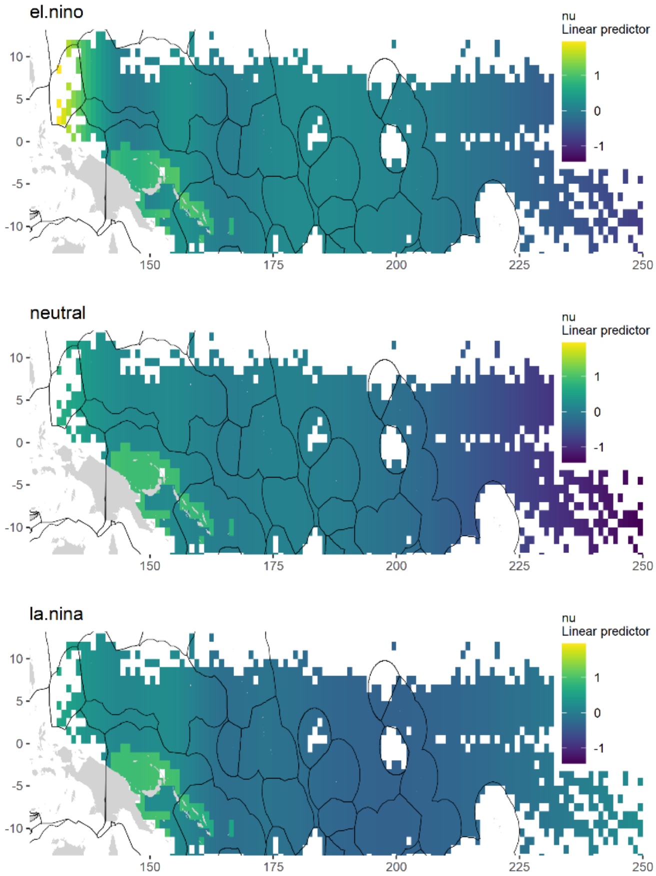

Figure 34 The combined effect of the archipelagic term and the longitude:ONI interaction on the zero-inflation component of the bigeye associated model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

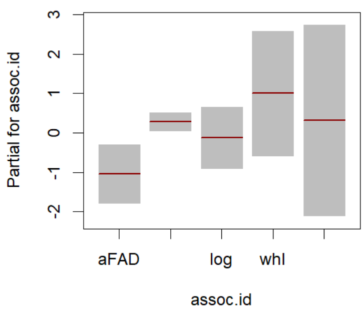

Figure 35 Effect plot for the one-inflation component of the bigeye associated model: association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk).