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PROJECT 60: PROGRESS TOWARDS ACHIEVING SC16 RECOMMENDATIONS

WCPFC-SC17-2021/ST-IP-04

Paper prepared by

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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 2020 to June 2021 are summarised in Table 1, and reported in Appendix B. In addition, corrected species composition estimates have been updated to include 2020 (see Figure 1 and Figure 2) using the agreed estimation procedure (e.g. see Peatman et al., 2020) in combination with the revised species composition models (Appendix C of this report). Observer data for 2020 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 2020 should be considered preliminary.

A proposed workplan for 2021-22 is provided in Table 2, and the Scientific Committee is invited to review the workplan and prioritise the associated activities for 2021-22.

Issues arising

As described in Appendix B, structure in random vessel intercepts was identified whilst investigating potential bias in model-based species compositions. Comparisons of models with and without random vessel intercepts were undertaken to determine whether random vessel intercepts should be included in the model (see Appendix B). Comparisons of marginal predictions at a range of resolutions suggested that the random vessel effects could be removed without materially impacting model predictions. We recommend that the random vessel intercepts be removed from the models.

Observer coverage rates in 2020 are expected to be lower than in recent years due to difficulties placing observers due to COVID-19. A sub-sampling exercise was undertaken to explore the precision of grab-sample based composition estimates with reduced observer coverage rates using data from 2018 to 2019, to explore the likely impact of reduced coverage rates on estimates for 2020. The sub-sampling analysis is reported in Appendix B. Estimates of catches of bigeye, and to a lesser extent yellowfin, were the most sensitive to reductions in observer coverage rate. The sub-sampling exercise suggests that estimates of total species-specific catch in 2020 would be relatively accurate with expected levels of observer coverage, but the accuracy of estimates would be appreciably lower at finer resolutions, i.e. resolutions approaching those currently used for purse seine fisheries in assessment models. For example, 95% intervals for quarterly estimates of bigeye catch in associated sets covered ~ 20 - 40 % with expected levels of observer coverage for 2020. However, species composition estimates for 2020 should be more accurate than those for the period pre-2010, by virtue of the higher observer coverage rates. Observer coverage rates for 2021 are expected to be substantially lower than 2020, and so it is reasonable to expect that resulting estimates of species compositions for 2021 will also be less accurate than those for recent years. Less accurate estimates of purse seine catch compositions has implications on the reliability of tropical tuna stock assessments, particularly for bigeye.

We therefore recommend a return to 100% purse seine observer coverage as soon as it is safe and logistically feasible, and future assessments to consider accounting for greater uncertainty of purse seine catch estimates for 2020 and 2021, 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 SC16.
2. Note the results of the sub-sampling exercise, which suggests less accurate estimates of purse seine species compositions for 2020 and 2021 as result of reduced observer coverage rates due to Covid-19, and consider recommendations for:
   (i) a return to 100% purse seine observer coverage as soon as it is safe and logistically feasible, and
   (ii) future assessments to consider accounting for greater uncertainty of purse seine catch estimates for 2020 and 2021, to mitigate the impact of errors in catch estimates on management.
3. Review the recommended simplification of the catch composition models, i.e. removal of random vessel intercepts.
4. Review the proposed activities and their priority for Project 60 in the year ahead with reporting to SC18 (Table 2).

Table 1 Progress towards addressing SC16 recommendations (continued on following page).

Recommendation	Progress
Paired grab-spill trips (target: 4 to 6): • Targeting fleets with likely availability of comprehensive landings slips 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	Postponed due to COVID-related travel restrictions.
Continue to explore opportunities for collaboration with members, specifically undertaking comparisons of observer samples, and potentially model-based, species composition estimates, with accurate unloadings / landings / cannery data	No collaborative analyses were undertaken in 2020-21. Opportunities for collaboration will continue to be to support the proposed workplan for 2021-22, with consideration of activity priority.
Simulation model: • Exploration of potential bias from between-brail variability in size • Inform need for set and/or species-specific correction factors	Scheduled for 2021-22
Comparisons of grab-sample and model-based estimates of species of compositions (i.e. observations vs model predictions) at a trip-level.	Comparisons of grab-sample and model-based estimates at a trip-level did not reveal systematic bias in model predictions, though there was a tendency at a trip-level to “fit down the middle”, particularly for bigeye. The analyses are reported in more detail in Appendix B.

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 once travel to PICTs resumes.
Cost-benefit analysis of alternative sampling approaches for long-term estimation of species compositions (i.e. at-sea sampling vs port sampling)	Postponed to 2021/22

Table 2 Proposed activities for Project 60 for 2021-22 and their priority.

Activity	Priority
Paired grab-spill trips (target: 4 to 6): • Targeting fleets with likely availability of comprehensive landings slips 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 2021–2022*	High
Simulation model: • Exploration of potential bias from between-brail variability in size • Inform need for set and/or species-specific correction factors	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
Cost-benefit analysis of alternative sampling approaches for long-term estimation of species compositions (i.e. at-sea sampling vs port sampling)	Low

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Figures

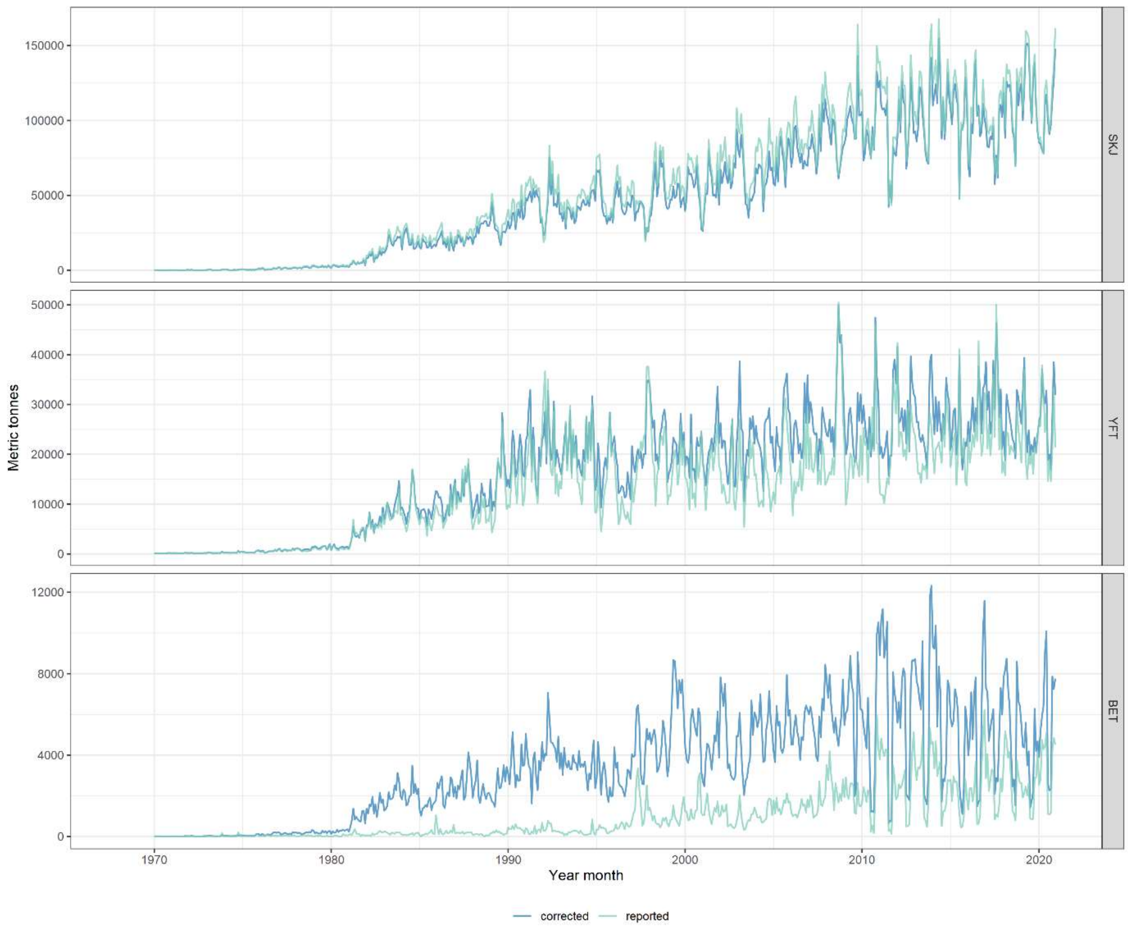


Figure 1 Corrected (blue) and reported (turquoise) purse seine catch by year and month for skipjack (top), yellowfin (middle) and bigeye (bottom panel).

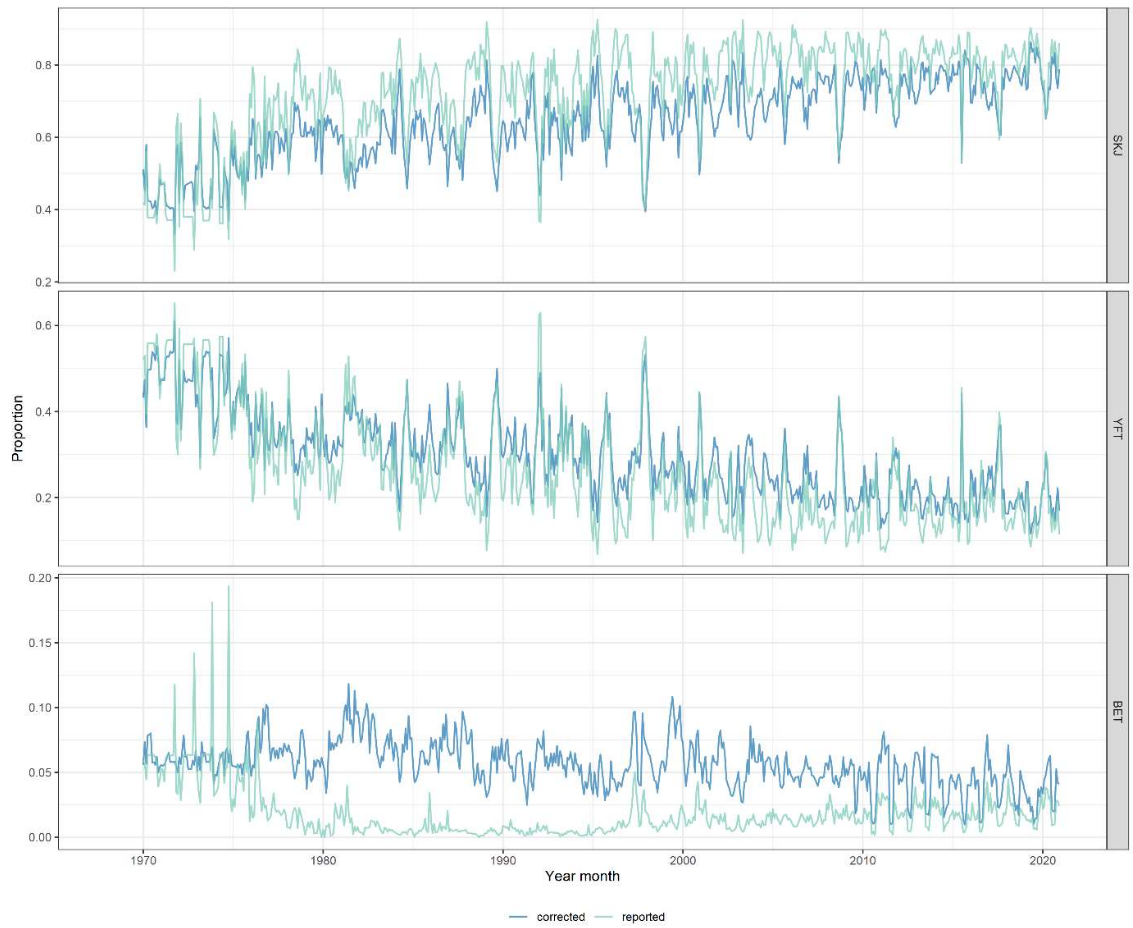


Figure 2 Corrected (blue) and reported (turquoise) purse seine catch proportions by year and month for skipjack (top), yellowfin (middle) and bigeye (bottom panel).

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 2020-21

Comparisons of sample-based and model-based composition estimates

Comparisons of grab-sample and model-based estimates of species compositions for the US purse seine fleet identified discrepancies between the two sets of estimates (Peatman, 2020). As a result, comprehensive trip-level comparisons of observer-sample and model-based estimates was included in the Project 60 workplan for 2020-21 to assess potential bias in model-based estimates (Peatman et al., 2020). Predicted species compositions were generated from the fitted models and compared against the sample-based estimates of species compositions (i.e. the modelled dataset) at a trip level, as well as at coarser resolutions. For models with random vessel intercepts, marginal predictions were generated by setting the vessel effect to 0.

Updating species composition model specifications

As part of the investigation into potential bias in model-based estimates, structure was identified in random vessel intercepts. Random vessel intercepts were included to account for between vessel-variation in catch compositions, and in doing so reduce serial auto-correlation in residuals. However, structure in random vessel intercepts could result in biased marginal predictions. As such, the species composition models were fitted with and without random vessel intercepts. Model fits and predictions were then compared to determine whether inclusion of random vessel intercepts was warranted.

Sub-sampling analysis to assess precision of species composition estimates with reduced observer coverage

Observer coverage is expected to be somewhat lower in 2020 than in recent years due to COVID-19. At the time of preparing this report, the coverage rate for 2020 was expected to be at best 45 to 50% of sets once all data have been loaded, based on observer placement information. This represents an approximate 40% reduction in observer coverage rates relative to those for 2018 and 2019 when coverage rates of processed data were in the region of 80% of sets.

A sub-sampling exercise was undertaken to assess the precision in grab-sample based estimates of species compositions in 2018 and 2019 with reduced rates of observer coverage. Available observer trips for 2018 and 2019 were resampled to achieve reduced numbers of observer trips in 10 % increments, with 1,000 random draws 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.

As the observer coverage rates were reduced, there was an increasing number of strata for which observer data were no longer available. For these strata, the available observer data were used to calculate species proportions at a resolution of year and association (free school vs. associated sets), and these coarser resolution estimates were then applied to total reported catch.

Results and discussion

Comparisons of sample-based and model-based composition estimates, and updating species composition model specifications

Model-based estimates of species compositions were relatively insensitive to the removal of random vessel intercepts, both at a set-level (Figure 3) and at coarser resolutions (Figure 4). Comparisons of model-based and sample-based estimates of species compositions did not suggest bias in model-based estimates relative to the modelled dataset, either for the models with random vessel intercepts, or for models without random vessel intercepts (e.g. Figure 5 to Figure 7). However, the models for bigeye in particular displayed a tendency to 'fit down the middle' regardless of whether random vessel intercepts were included, i.e. the models were not able to explain some of the between-trip variability in bigeye proportions (e.g.Figure 6). The apparent noise in model-estimates of species compositions at a trip level is to be expected given that the 'observations' in the modelled dataset are themselves estimates based on grab samples, and as such are imprecise at fine resolutions (e.g. Peatman et al., 2017a).

Comparisons of models with and without random vessel intercepts did not support the inclusion of the random vessel intercepts. Estimates of species compositions were insensitive to the inclusion of random vessel intercepts, with no evidence of an improvement in predictive accuracy with their inclusion. The inclusion of random vessel intercepts resulted in weak reductions in serial auto-correlation in residuals. There was no indication that the inclusion of random vessel intercepts had resulted in bias in species composition estimates. However, the structure in the vessel effects is a concern. As such we recommend that the random vessel intercepts are removed from the species composition models, noting the impact on estimated species compositions is limited (Figure 8). The specification of the revised species composition models is provided in Appendix C. Future revisions to the model specifications should reconsider random effects, and correlated residual structures, as a means of addressing the autocorrelation in residuals. This will be particularly important if uncertainty in model-based estimates is required.

Sub-sampling analysis to assess precision of species composition estimates with reduced observer coverage

The metric of comparison for the sub-sampling exercise was the estimated species-specific catch (mt) from the sub-sampled dataset, expressed as the proportion of the estimated species-specific catch from the full observer dataset. The 95% intervals of proportions were widest for bigeye, and narrowest for yellowfin (Figure 9). 95% intervals were broader for associated sets in the third quarter of both 2018 and 2019 for all species, reflecting the lower levels of effort due to FAD closures (Figure 10). Annual estimates of species compositions for 2018 and 2019 with a reduction in observer coverage of 40% (i.e. a relative observer coverage rate of 60%) had 95% intervals spanning ~ 1.5% for skipjack, 6% for yellowfin and 12% for bigeye (Figure 9). The 95% intervals were broader when undertaking comparisons at a finer resolution. E.g. at a year, quarter and free school vs associated set resolution, the 95% intervals for skipjack and yellowfin were 3 - 7% and 12 - 24% respectively. (Figure 10). The corresponding 95% intervals for bigeye were particularly broad for free school sets at 37 - 77%, which have low proportions of bigeye, and 20-42% for associated sets (Figure 10). The sub-sampling exercise also suggested systematic and increasing bias in species compositions as observer coverage rate decreased (Figure 9). This bias may be caused by using coarse resolution estimates for strata with no observer coverage in the sub-sampling exercise, noting that these would ordinarily be based on model-based species compositions. Future work in this area should consider a more detailed consideration of reduced observer coverage. For example, it may be that the reductions in observer coverage may be particularly pronounced for specific fleets, regions, and/or parts of the year.

Figures

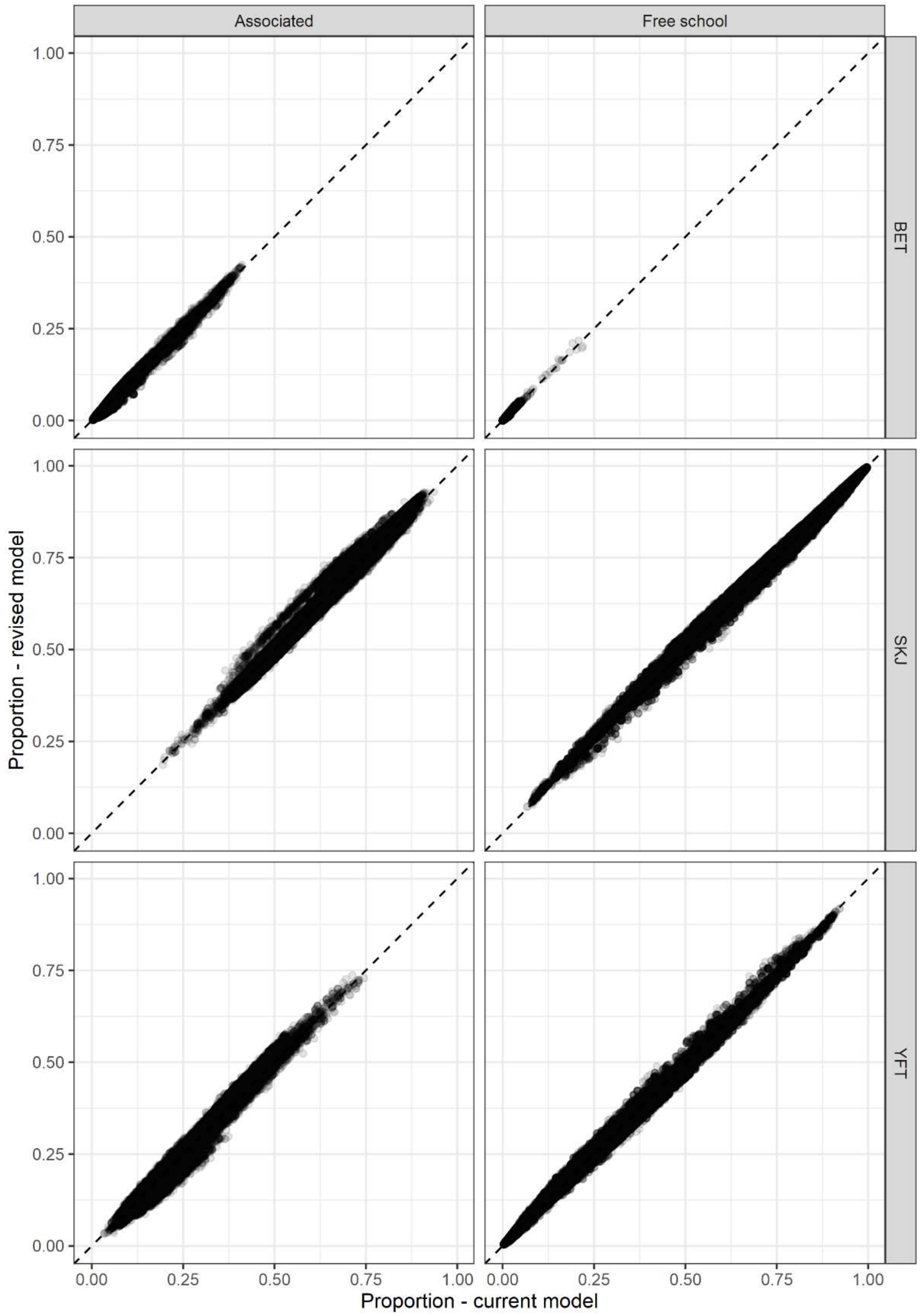


Figure 3 Set-level model-based species proportions with (x-axis) and without (y-axis) random vessel intercepts for associated sets (left column) and free school sets (right column). Estimates for the current model (with random intercepts) are marginal predictions, with the vessel effect set to 0.

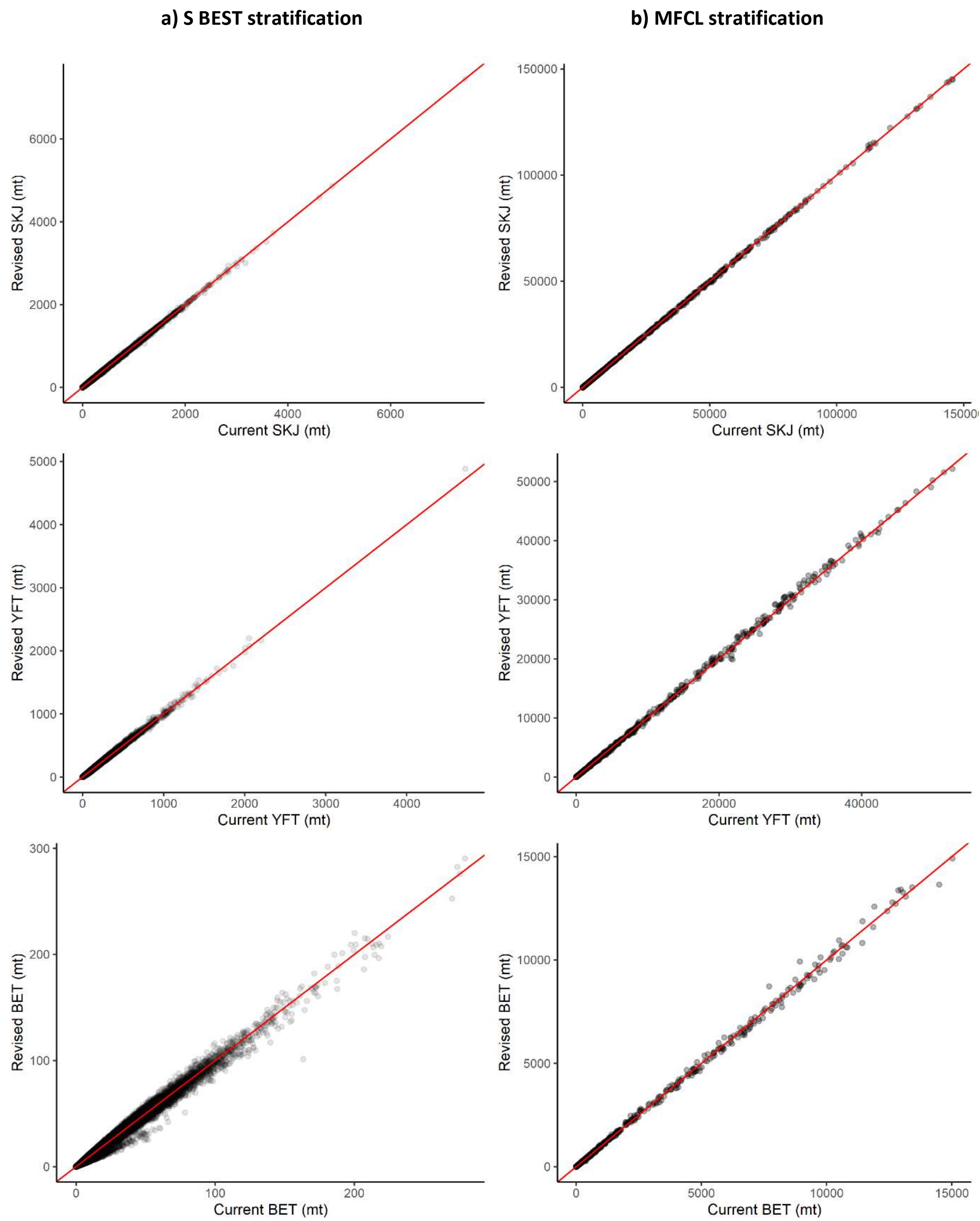


Figure 4 Model-based composition estimates with ('current' - x-axis) and without ('revised' - y-axis) random vessel intercepts, at an S BEST stratification (left column) and at the resolution of current MFCL assessment models (right column).

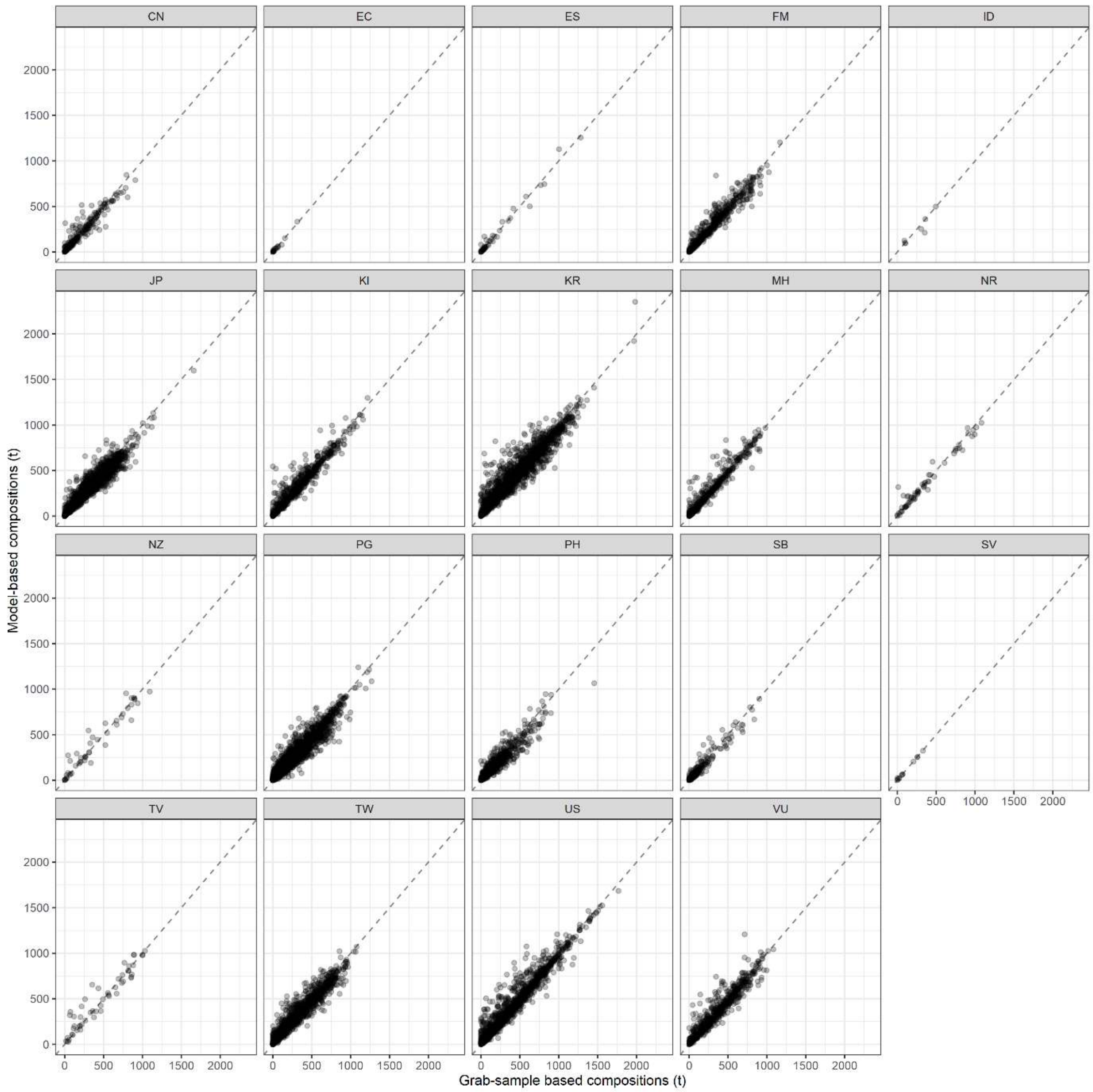


Figure 5 Trip-by-trip comparisons of model-based (y-axis) and grab-sample based (x-axis) estimates of skipjack (mt) in free school sets, for the revised model without random vessel intercepts. Each panel is a separate flag.

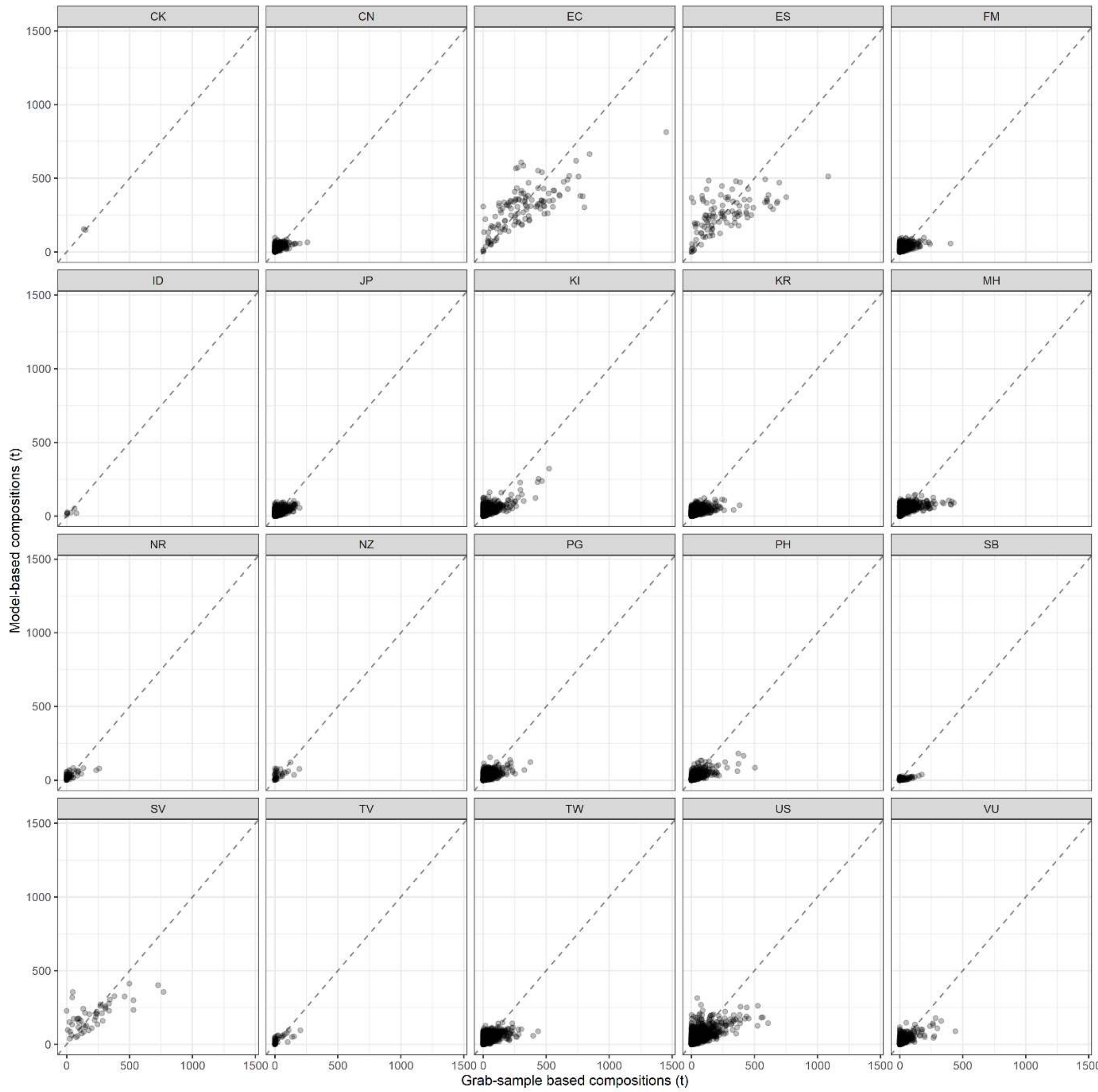
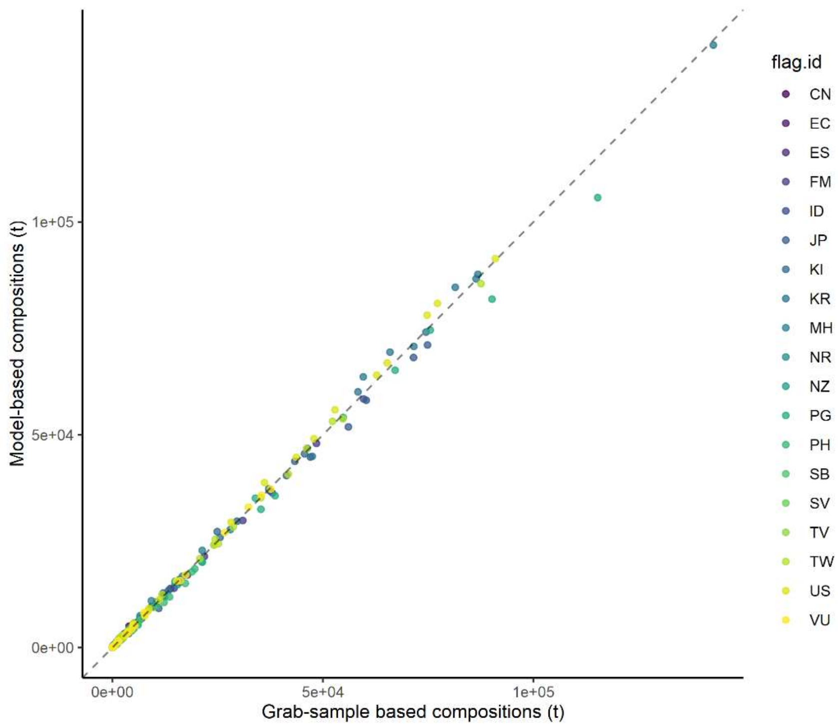


Figure 6 Trip-by-trip comparisons of model-based (y-axis) and grab-sample based (x-axis) estimates of bigeye (mt) in associated sets, for the revised model without random vessel intercepts. Each panel is a separate flag.

a) SKJ– free school sets



b) BET – associated sets

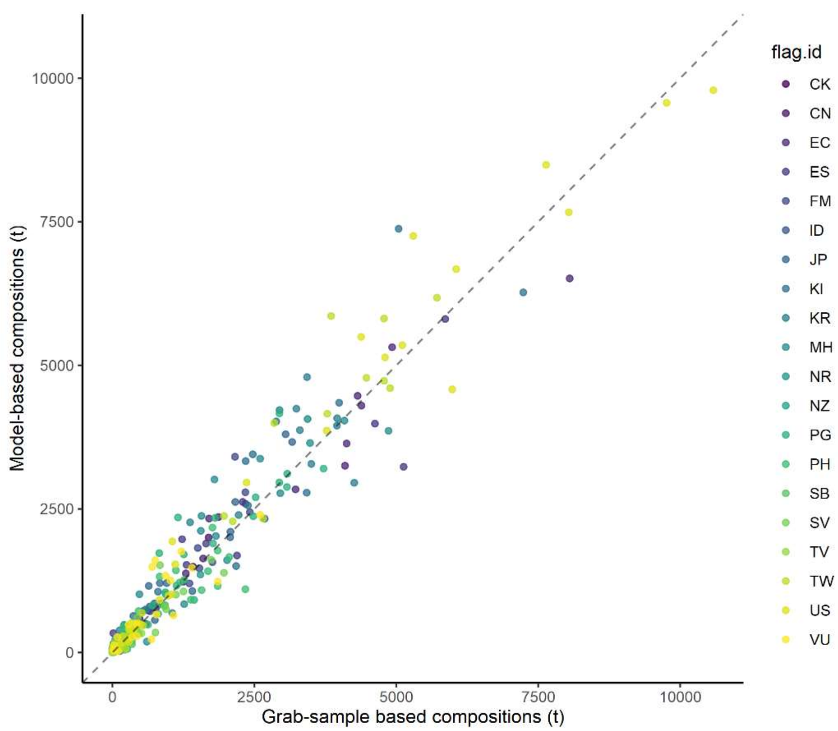


Figure 7 Comparisons of model-based (y-axis) and grab-sample based (x-axis) estimates (mt) of a) skipjack in free-school sets, and b) bigeye in associated sets, for the revised model without random vessel intercepts. Each point represents a flag and year combination, with points coloured by flag.

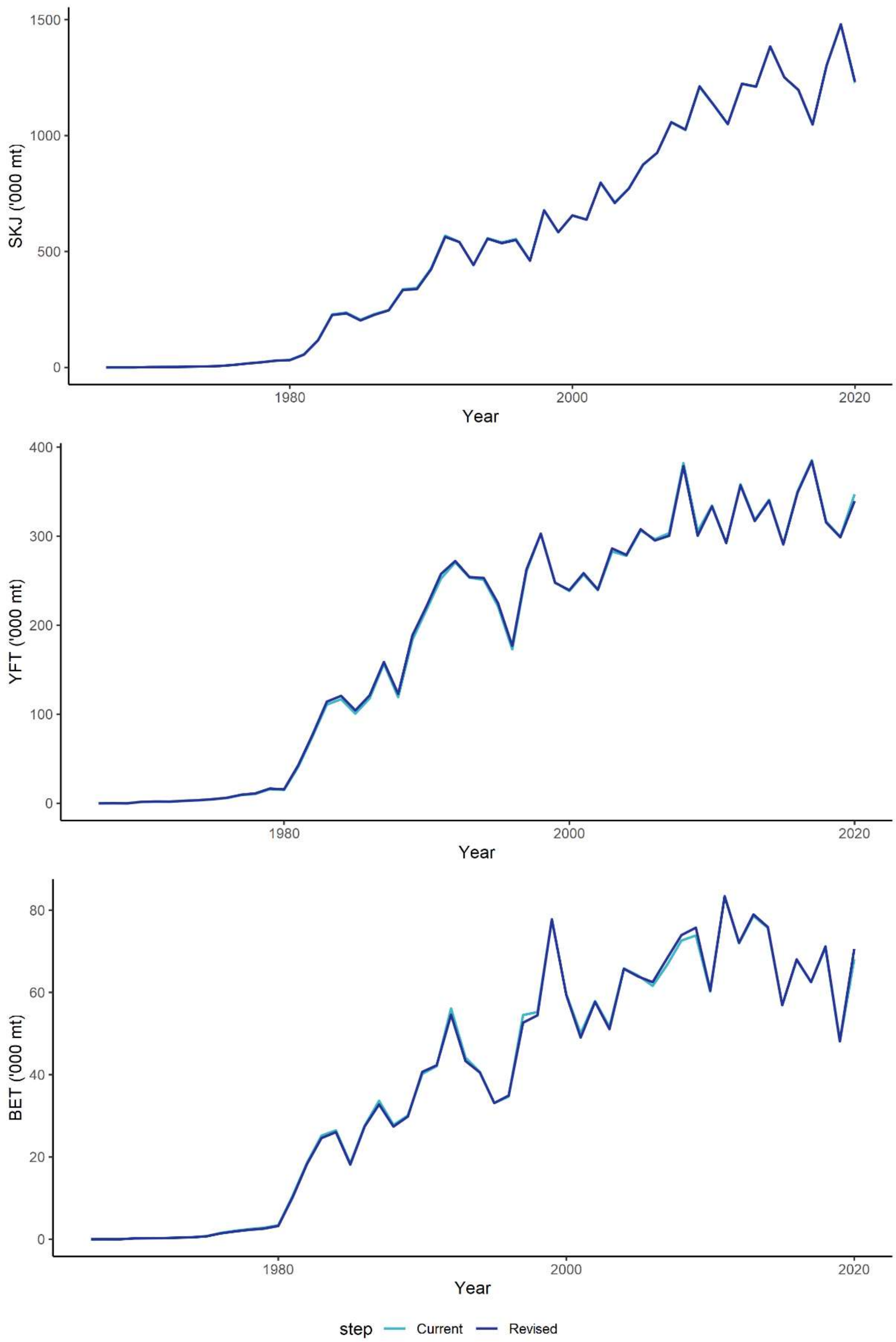


Figure 8 Comparison of annual species compositions when using the current model specification (with random vessel intercepts, turquoise) and the revised model specification (without vessel intercepts, dark blue).

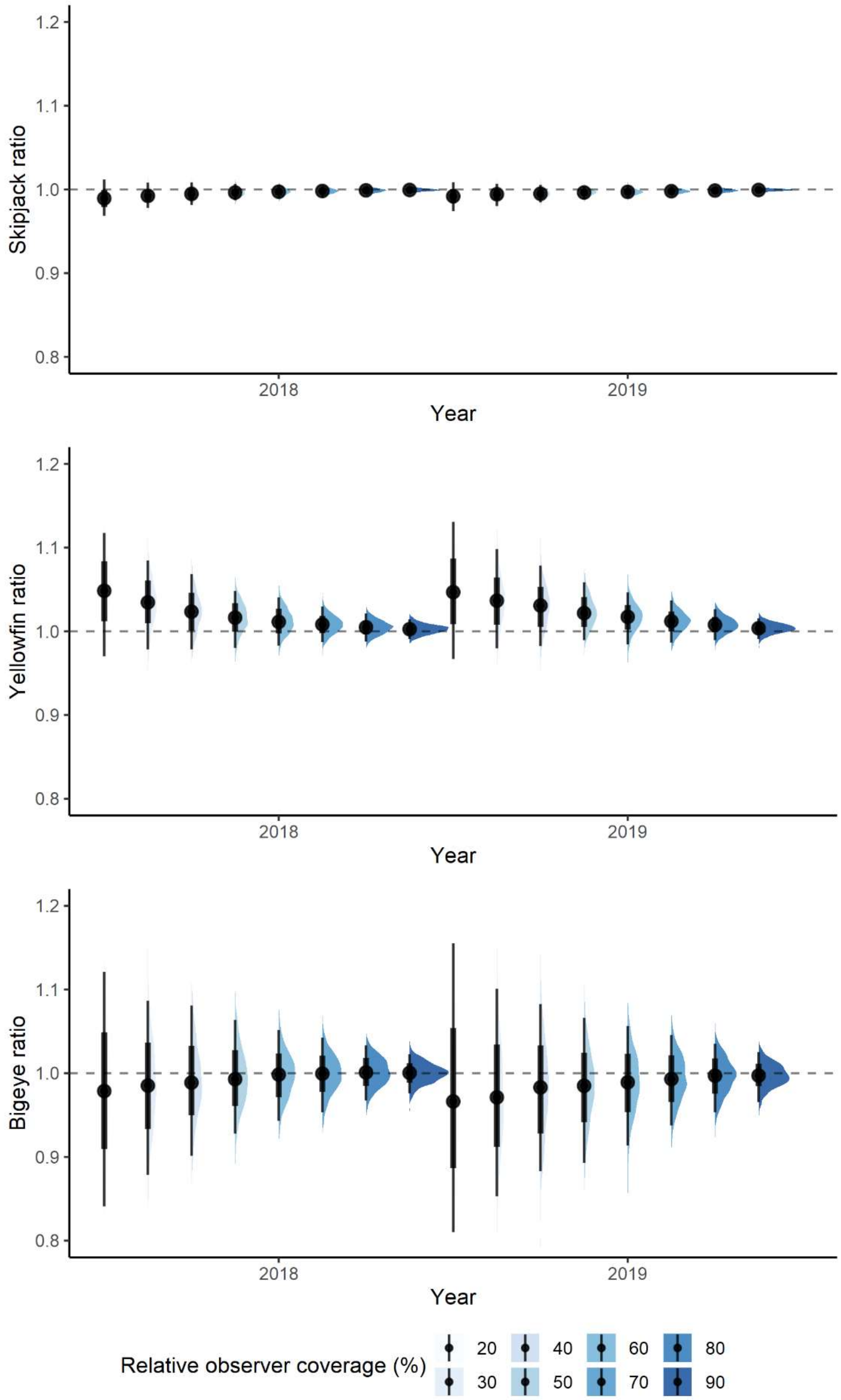


Figure 9 Interval plots summarising the accuracy and precision of annual species-specific catch estimates (mt) at different sub-sampling rates. The density plots are coloured by the observer coverage rate relative to the actual observer coverage of the year in question, i.e. a 90% relative observer coverage rate in 2019 equates to a 10% reduction from the actual observer coverage rate in 2019. The thin and thick lines provide the 95% and 66% intervals respectively, and the circle provides the median.

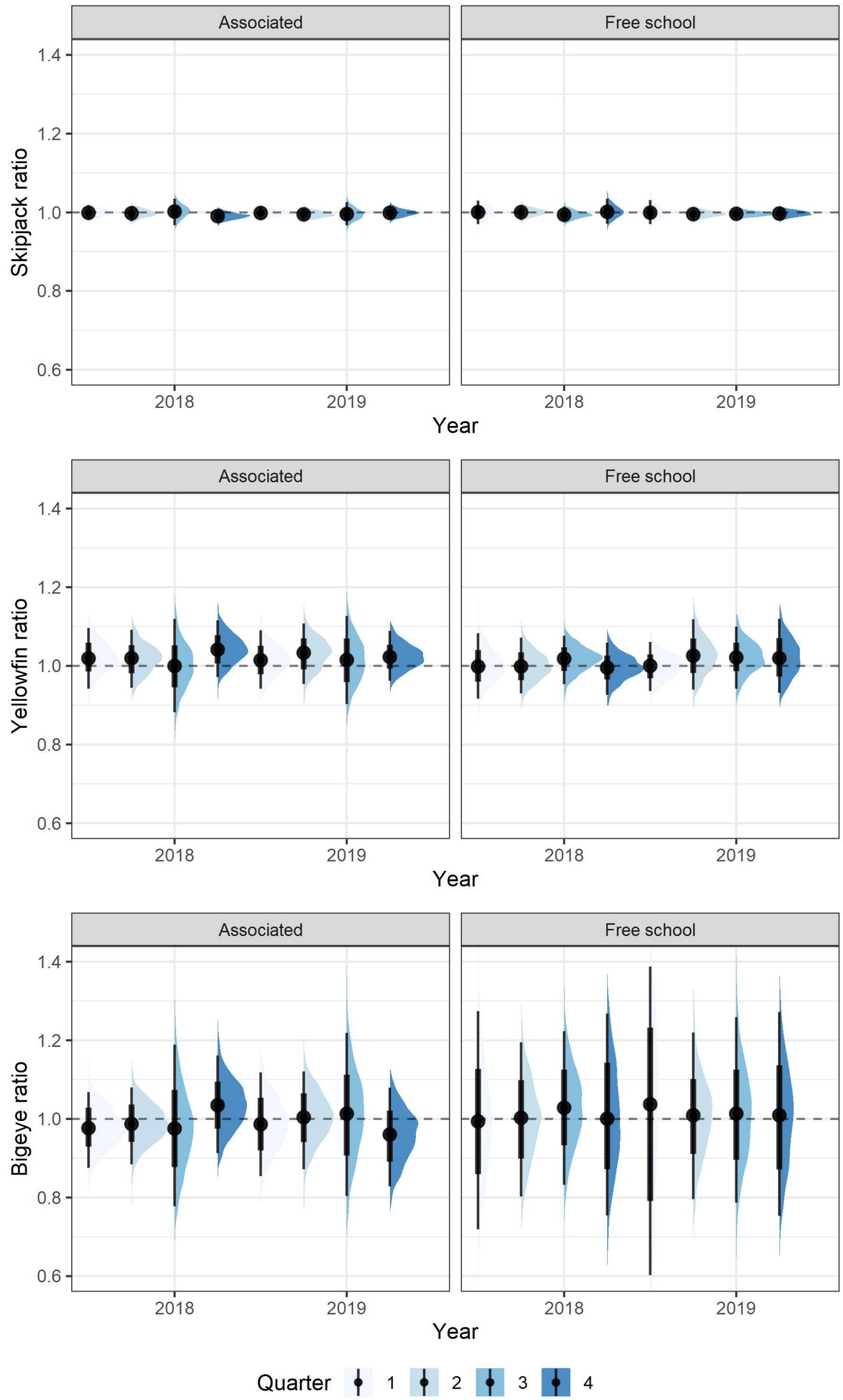


Figure 10 Interval plots summarising the accuracy and precision of species-specific catch estimates (mt) at a resolution of year, quarter and free school vs associated sets, with a relative observer coverage rate of 60% (i.e. a 40% decrease in coverage). The density plots are coloured by quarter. The thin and thick lines provide the 95% and 66% intervals respectively, and the circle provides the median.

Appendix C

Specification of revised species composition models

The revised model for skipjack proportions on associated sets was specified as:

$$E[SKJ_{ij}] = \frac{\tau_{ij} + \mu_{ij}}{1 + \upsilon_{ij} + \tau_{ij}}$$

where the mean of the beta distribution, μ_{ij}, the zero inflation component, υ_{ij}, the one inflation component, τ_{ij}, and the variance parameter, σ_{ij}, were parameterised:

$$\ln\left(\frac{\mu_{ij}}{1-\mu_{ij}}\right) = \beta_0 + flag_{ij} + assoc_{ij} + archipelagic_{ij} + qtr_{ij} + f(yy_{ij}) + f(isotherm_{ij}) + f(prop_{SKJ}) + ONI_{ij} * f(lon_{ij})$$

$$\ln(\upsilon_{ij}) = \beta_0 + assoc_{ij} + f(prop_{SKJ})$$

$$\ln(\tau_{ij}) = \beta_0 + flag_{ij} + assoc_{ij} + archipelagic_{ij} + qtr_{ij} + f(yy_{ij}) + f(isotherm_{ij}) + f(prop_{SKJ}) + ONI_{ij} * f(lon_{ij})$$

$$\ln\left(\frac{\sigma_{ij}}{1-\sigma_{ij}}\right) = \beta_0$$

where subscripts i and j refer to set and vessel, $flag_{ij}$ is a categorical variable for the flag of the vessel, $assoc_{ij}$ is a categorical variable for the school association, $archipelagic_{ij}$ is a categorical variable for set locations inside/outside archipelagic waters, qtr_{ij} is a categorical variable for quarter, yy_{ij} is year, $isotherm_{ij}$ is the depth of the 20°C isotherm, $prop_{SKJ}$ is the uncorrected proportion of skipjack from aggregate catch and effort data, ONI_{ij} is a categorical variable for the Oceanic Nino Index (grouped to El Nino, neutral and La Nina), lon_{ij} is the longitude of the set and $f(\quad)$ are cubic regression splines. The association types for unassociated sets were: unassociated schools, “fs”; and, unassociated schools feeding on baitfish, “fs.bait”. The association types for associated sets were: schools associated to anchored FADs (“aFAD”), drifting FADs (“dFAD”), logs (“log”), whales (“whl”) and whale sharks (“whl.shk”).

The zero-inflation parameter, υ_{ij}, does not directly reflect the probability of a zero response, this is given by $\upsilon_{ij}(1 + \upsilon_{ij} + \tau_{ij})^{-1}$. Similarly, the probability of a one response is $\tau_{ij}(1 + \upsilon_{ij} + \tau_{ij})^{-1}$.

The revised model for yellowfin proportions on associated sets was specified as:

$$E[YFT_{ij}] = \frac{\tau_{ij} + \mu_{ij}}{1 + \upsilon_{ij} + \tau_{ij}}$$

where the mean of the beta distribution, μ_{ij}, the zero inflation component, υ_{ij}, the one inflation component, τ_{ij}, and the variance parameter, σ_{ij}, were parameterised:

$$\ln\left(\frac{\mu_{ij}}{1-\mu_{ij}}\right) = \beta_0 + flag_{ij} + assoc_{ij} + archipelagic_{ij} + qtr_{ij} + f(yy_{ij}) + f(isotherm_{ij}) + f(prop_{SKJ}) + ONI_{ij} * f(lon_{ij})$$

$$\ln(\upsilon_{ij}) = \beta_0 + flag_{ij} + assoc_{ij} + archipelagic_{ij} + qtr_{ij} + f(yy_{ij}) + f(isotherm_{ij}) + f(prop_{SKJ}) + ONI_{ij} * f(lon_{ij})$$

$$\ln(\tau_{ij}) = \beta_0 + assoc_{ij} + f(prop_{SKJ})$$

$$\ln\left(\frac{\sigma_{ij}}{1-\sigma_{ij}}\right) = \beta_0$$

The final model for bigeye proportions on associated sets was specified as:

$$E[BET_{ij}] = \frac{\tau_{ij} + \mu_{ij}}{1 + \upsilon_{ij} + \tau_{ij}}$$

where the mean of the beta distribution, μ_{ij}, the zero inflation component, υ_{ij}, the one inflation component, τ_{ij}, and the variance parameter, σ_{ij}, were parameterised:

$$\ln\left(\frac{\mu_{ij}}{1-\mu_{ij}}\right) = \beta_0 + flag_{ij} + assoc_{ij} + archipelagic_{ij} + qtr_{ij} + f(yy_{ij}) + f(isotherm_{ij}) + f(prop_{SKJ}) + ONI_{ij} * f(lon_{ij})$$

$$\ln(\upsilon_{ij}) = \beta_0 + flag_{ij} + assoc_{ij} + archipelagic_{ij} + qtr_{ij} + f(yy_{ij}) + f(isotherm_{ij}) + f(prop_{SKJ}) + ONI_{ij} * f(lon_{ij})$$

$$\ln(\tau_{ij}) = \beta_0 + assoc_{ij}$$

$$\ln\left(\frac{\sigma_{ij}}{1-\sigma_{ij}}\right) = \beta_0$$

The revised model for skipjack proportions on unassociated sets was specified as:

$$E[SKJ_{ij}] = \frac{\tau_{ij} + \mu_{ij}}{1 + \upsilon_{ij} + \tau_{ij}}$$

where the mean of the beta distribution, μ_{ij}, the zero inflation component, υ_{ij}, the one inflation component, τ_{ij}, and the variance parameter, σ_{ij}, were parameterised:

$$\ln\left(\frac{\mu_{ij}}{1-\mu_{ij}}\right) = \beta_0 + flag_{ij} + assoc_{ij} + archipelagic_{ij} + qtr_{ij} + f(yy_{ij}) + f(isotherm_{ij}) + f(prop_{SKJ}) + ONI_{ij} * f(lon_{ij})$$

$$\ln(\upsilon_{ij}) = \beta_0 + f(prop_{SKJ})$$

$$\ln(\tau_{ij}) = \beta_0 + flag_{ij} + assoc_{ij} + archipelagic_{ij} + qtr_{ij} + f(yy_{ij}) + f(isotherm_{ij}) + f(prop_{SKJ}) + ONI_{ij} * f(lon_{ij})$$

$$\ln\left(\frac{\sigma_{ij}}{1-\sigma_{ij}}\right) = \beta_0$$

The revised model for yellowfin proportions on unassociated sets was specified as:

$$E[YFT_{ij}] = \frac{\tau_{ij} + \mu_{ij}}{1 + \upsilon_{ij} + \tau_{ij}}$$

where the mean of the beta distribution, μ_{ij}, the zero inflation component, υ_{ij}, the one inflation component, τ_{ij}, and the variance parameter, σ_{ij}, were parameterised:

$$\ln\left(\frac{\mu_{ij}}{1-\mu_{ij}}\right) = \beta_0 + flag_{ij} + assoc_{ij} + archipelagic_{ij} + qtr_{ij} + f(yy_{ij}) + f(isotherm_{ij}) + f(prop_{SKJ}) + ONI_{ij} * f(lon_{ij})$$

$$\ln(\upsilon_{ij}) = \beta_0 + flag_{ij} + assoc_{ij} + archipelagic_{ij} + qtr_{ij} + f(yy_{ij}) + f(isotherm_{ij}) + f(prop_{SKJ}) + ONI_{ij} * f(lon_{ij})$$

$$\ln(\tau_{ij}) = \beta_0 + f(prop_{SKJ})$$

$$\ln\left(\frac{\sigma_{ij}}{1-\sigma_{ij}}\right) = \beta_0$$

The revised model for bigeye proportions on unassociated sets was specified as:

$$E[BET_{ij}] = \frac{\tau_{ij} + \mu_{ij}}{1 + \upsilon_{ij} + \tau_{ij}}$$

where the mean of the beta distribution, μ_{ij}, the zero inflation component, υ_{ij}, the one inflation component, τ_{ij}, and the variance parameter, σ_{ij}, were parameterised:

$$\ln\left(\frac{\mu_{ij}}{1-\mu_{ij}}\right) = \beta_0 + flag_{ij} + assoc_{ij} + archipelagic_{ij} + qtr_{ij} + f(isotherm_{ij}) + f(prop_{SKJ}) + ONI_{ij} * f(lon_{ij})$$

$$\ln(\upsilon_{ij}) = \beta_0 + flag_{ij} + assoc_{ij} + archipelagic_{ij} + qtr_{ij} + f(yy_{ij}) + f(isotherm_{ij}) + f(prop_{SKJ}) + ONI_{ij} * f(lon_{ij}) + b_j$$

$$\ln(\tau_{ij}) = \beta_0$$

$$\ln\left(\frac{\sigma_{ij}}{1-\sigma_{ij}}\right) = \beta_0$$

Effect plots for revised species composition models

Skipjack – free school

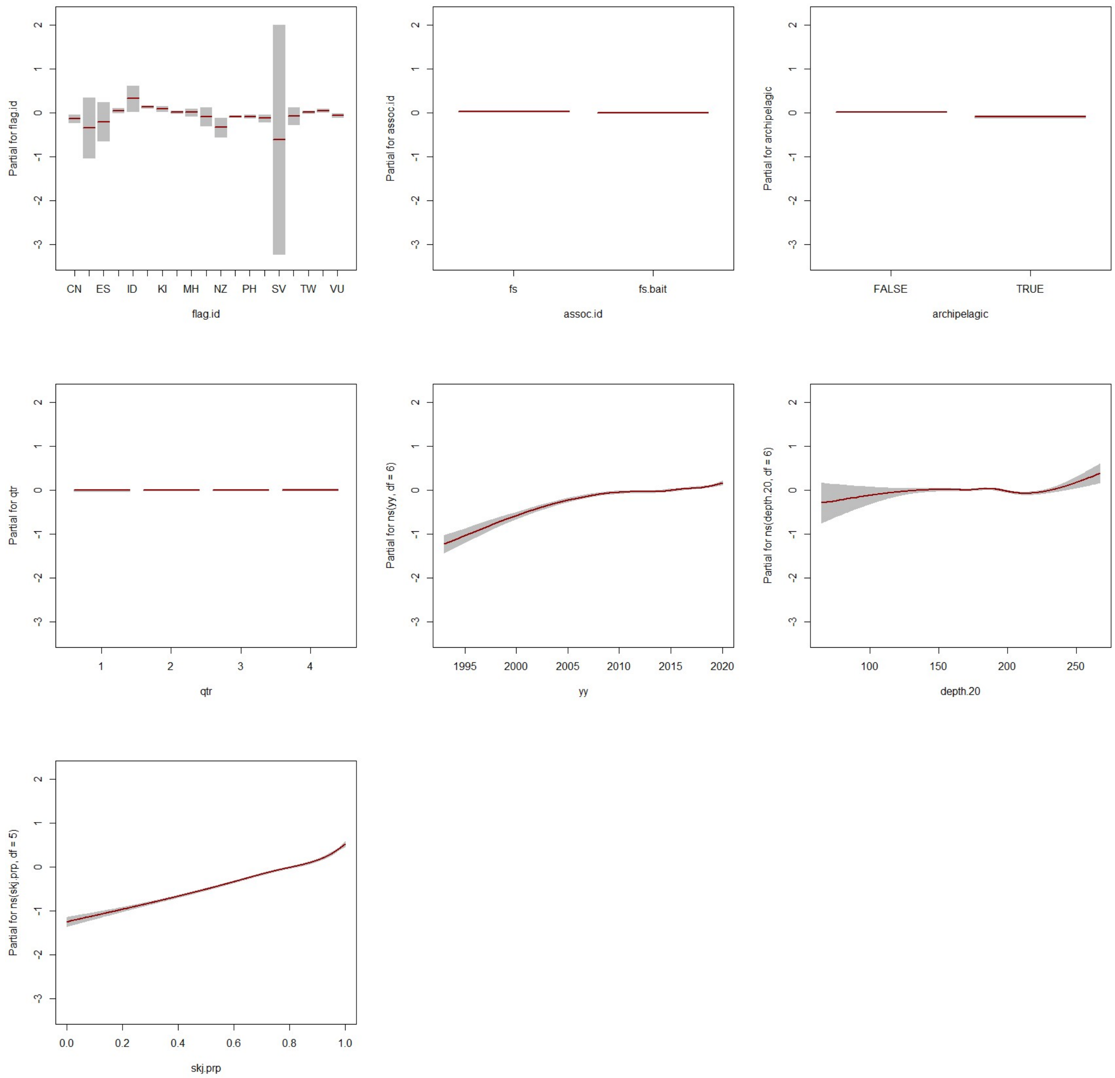


Figure 11 Effect plots for the mean of the beta-component of the skipjack free-school model. Top row, left to right: flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters. Middle row, left to right: quarter; year; isotherm depth. Bottom row: uncorrected skipjack proportion from vessel logbooks.

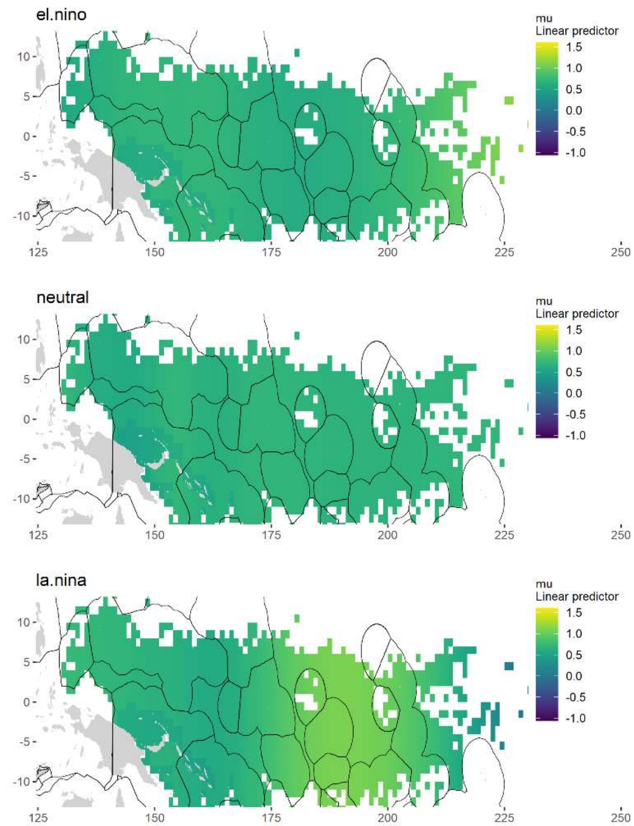


Figure 12 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the skipjack free-school model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

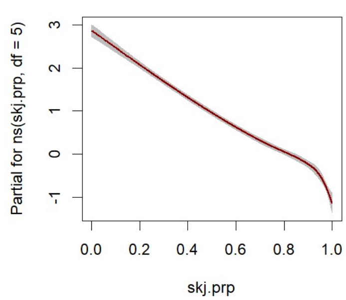


Figure 13 Effect plot for the zero-inflation component of the skipjack free-school model: uncorrected skipjack proportion from vessel logbooks.

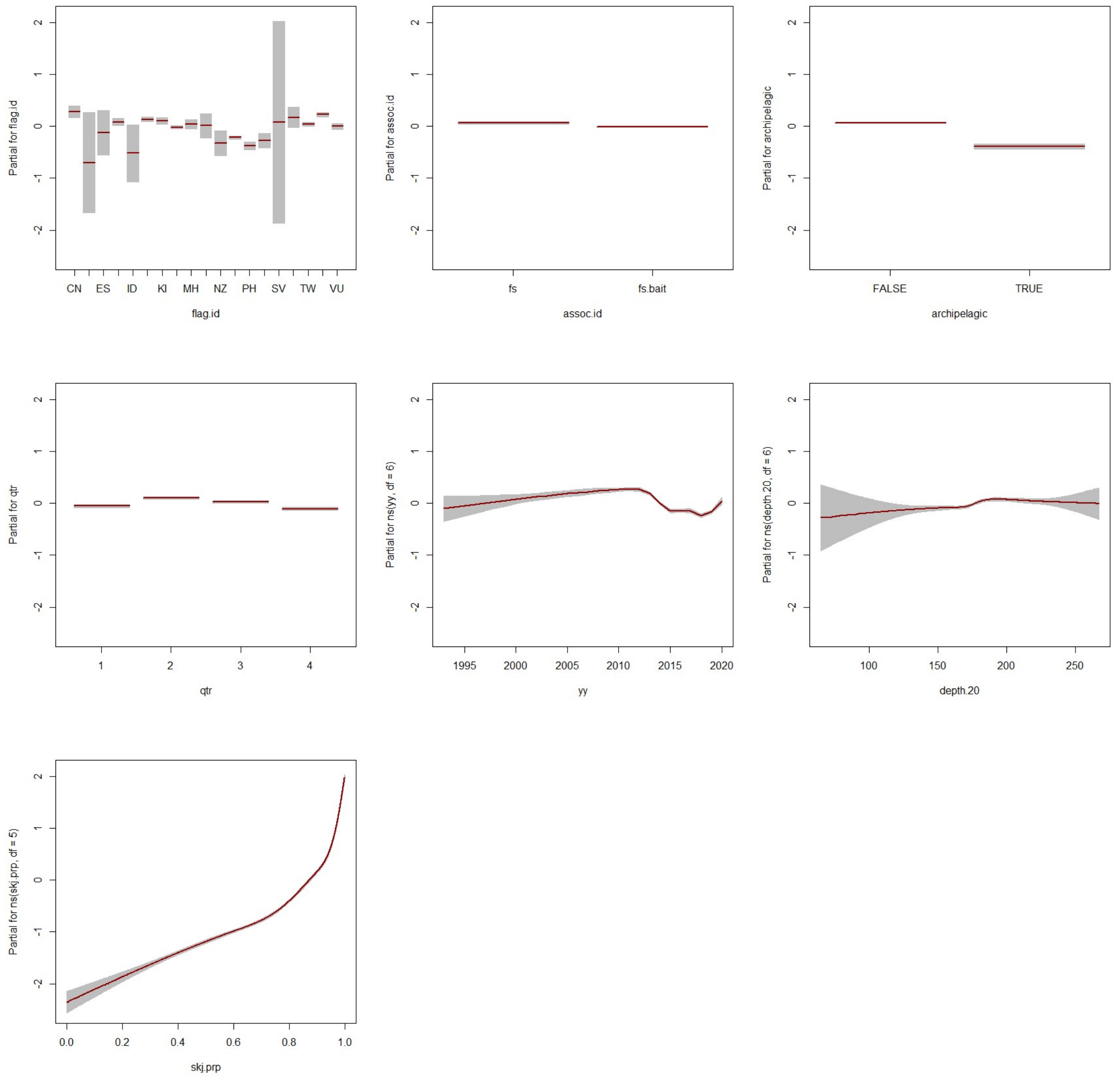


Figure 14 Effect plots for the one-inflation component of the skipjack free-school model. Top row, left to right: flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters. Middle row, left to right: quarter; year; isotherm depth. Bottom row: uncorrected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

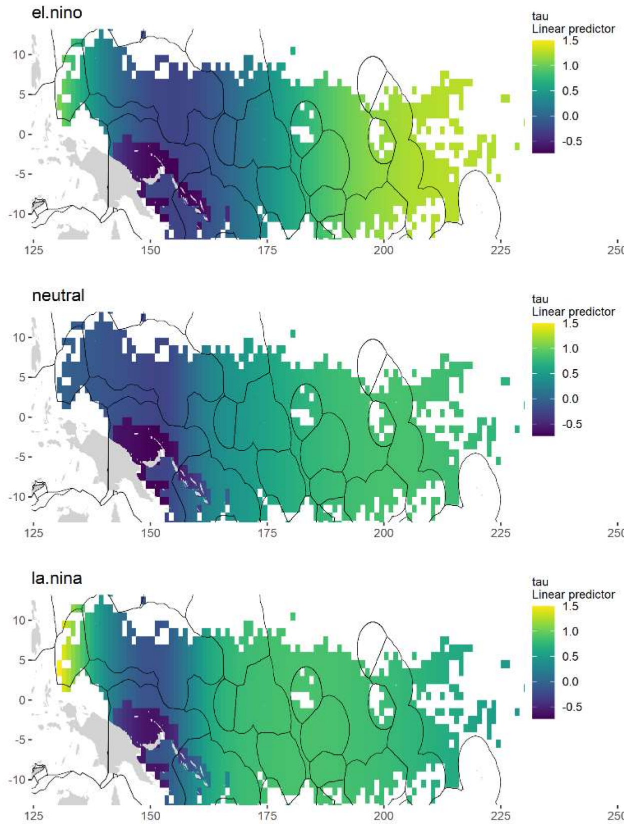


Figure 15 The combined effect of the archipelagic term and the longitude:ONI interaction on the one-inflation component of the skipjack free-school model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

Yellowfin – free school

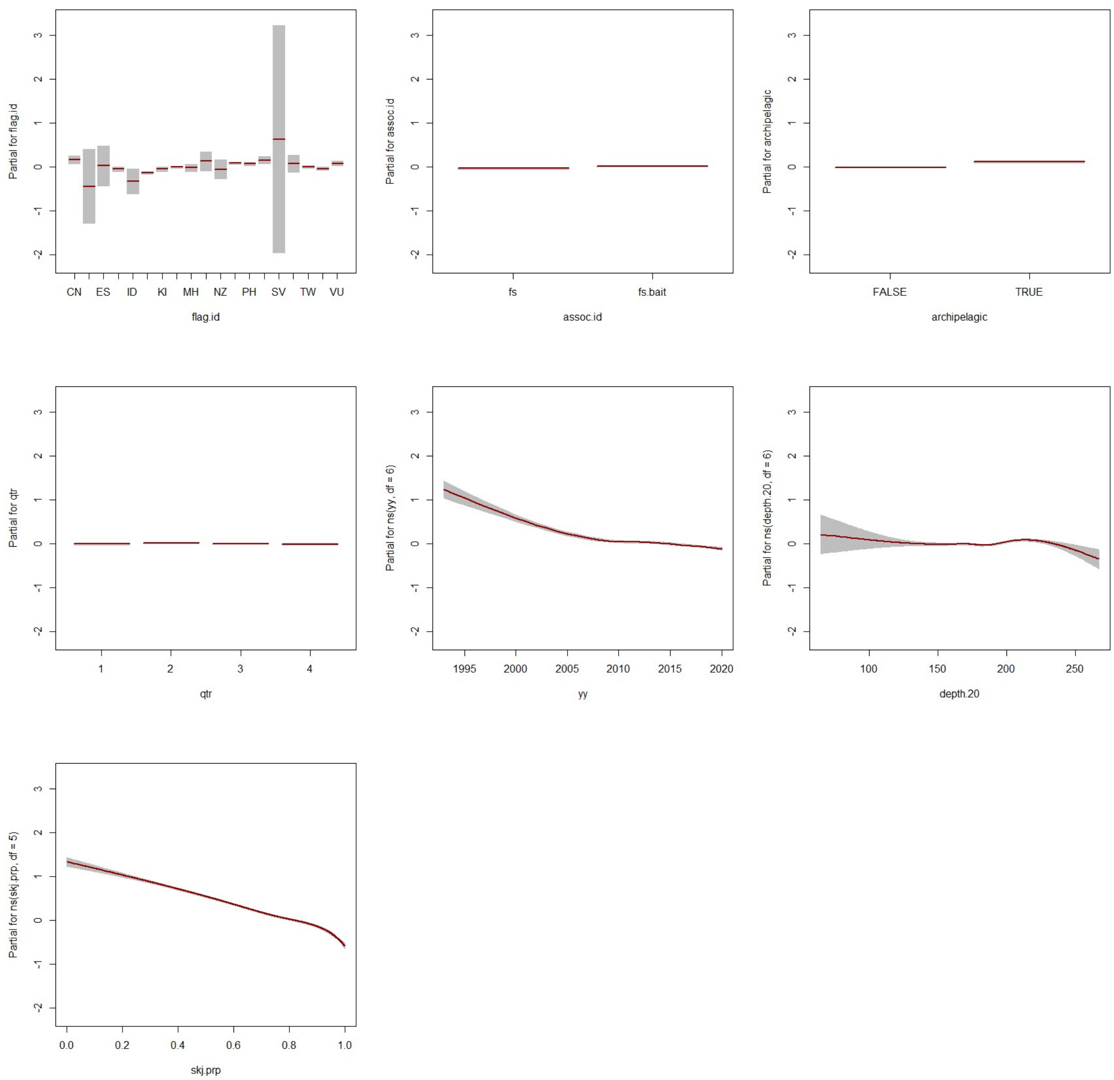


Figure 16 Effect plots for the mean of the beta-component of the yellowfin free-school model. Top row, left to right: flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters. Middle row, left to right: quarter; year; isotherm depth. Bottom row: uncorrected skipjack proportion from vessel logbooks.

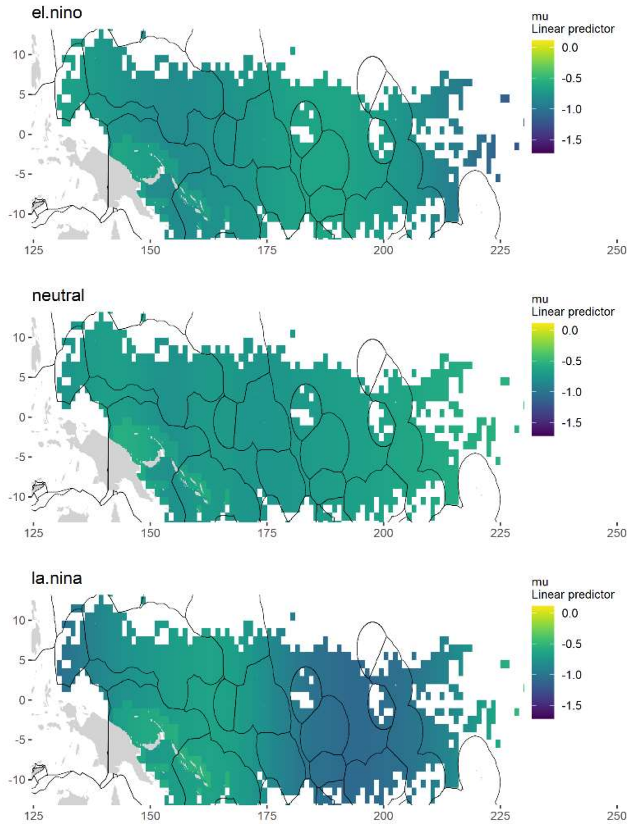


Figure 17 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the yellowfin free-school model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

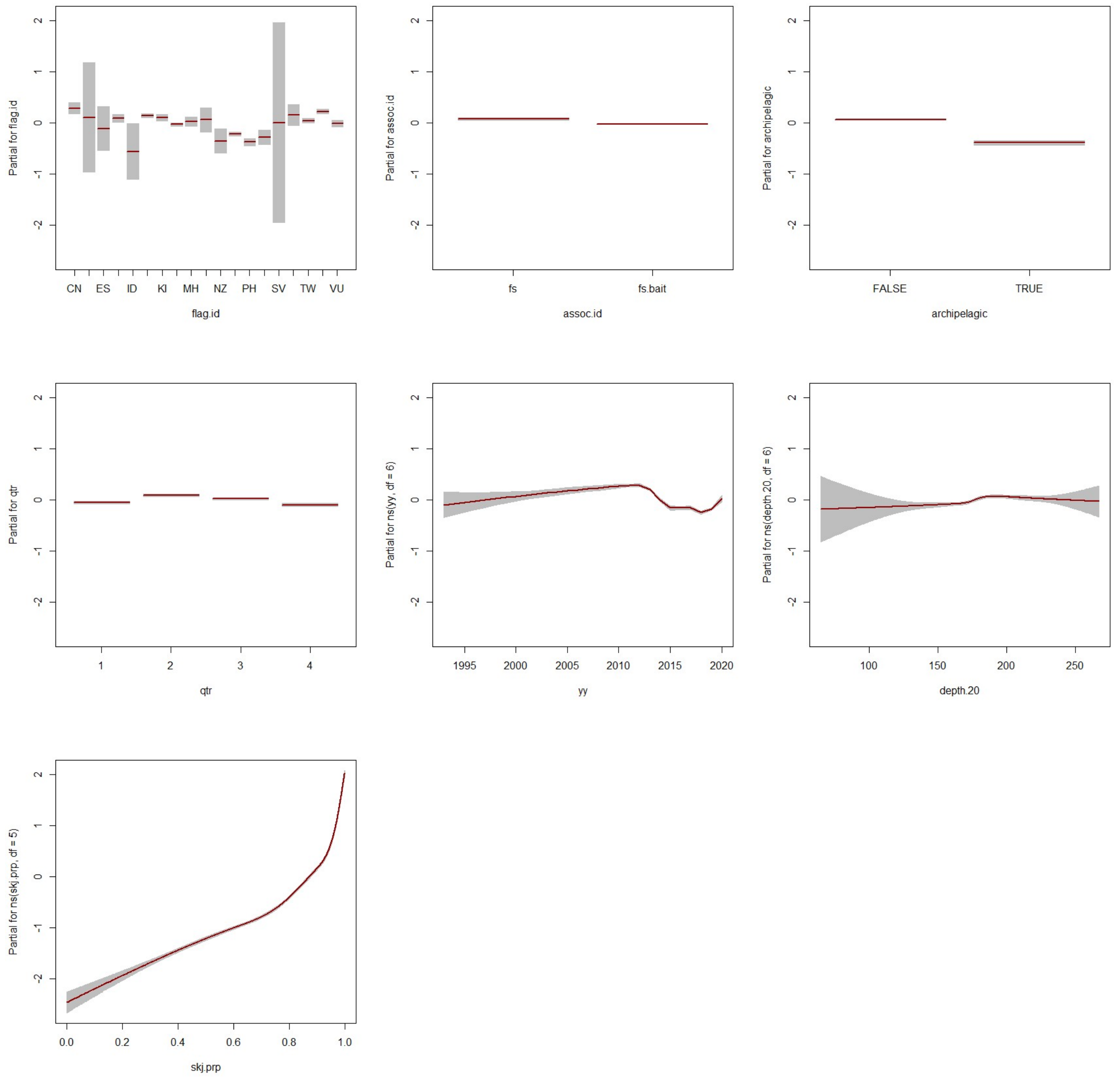


Figure 18 Effect plots for the zero-inflation component of the yellowfin free-school model. Top row, left to right: flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters. Middle row, left to right: quarter; year; isotherm depth. Bottom row: uncorrected skipjack proportion from vessel logbooks.

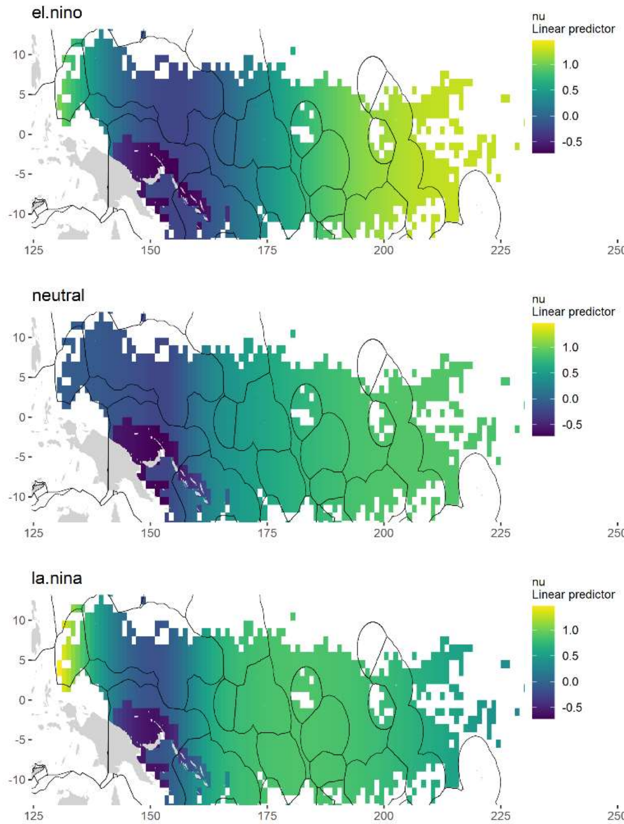


Figure 19 The combined effect of the archipelagic term and the longitude:ONI interaction on the zero-inflation component of the yellowfin free-school model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

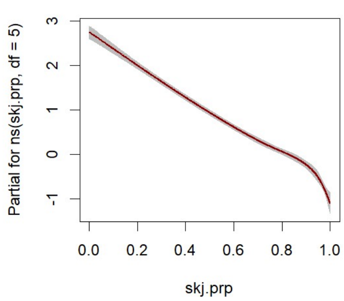


Figure 20 Effect plots for the one-inflation component of the yellowfin free-school model: uncorrected skipjack proportion from vessel logbooks (right).

Bigeye – free school

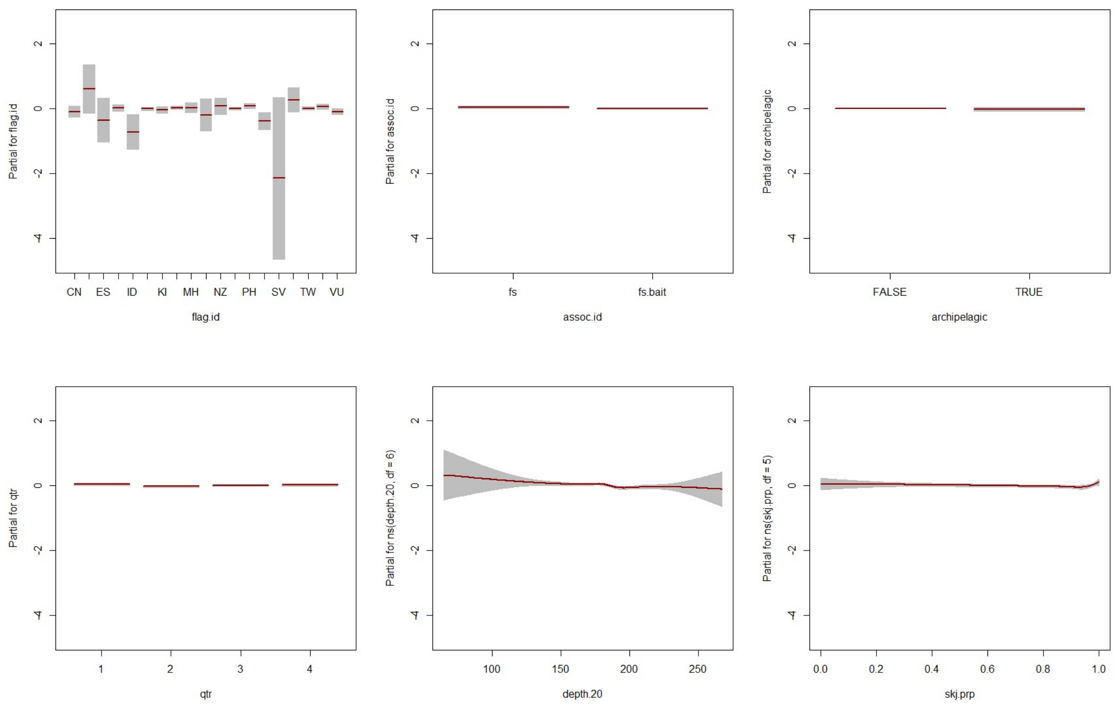


Figure 21 Effect plots for the mean of the beta-component of the bigeye free-school model. Top row, left to right: flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters. Bottom row, left to right: quarter; isotherm depth; and, uncorrected skipjack proportion from vessel logbooks.

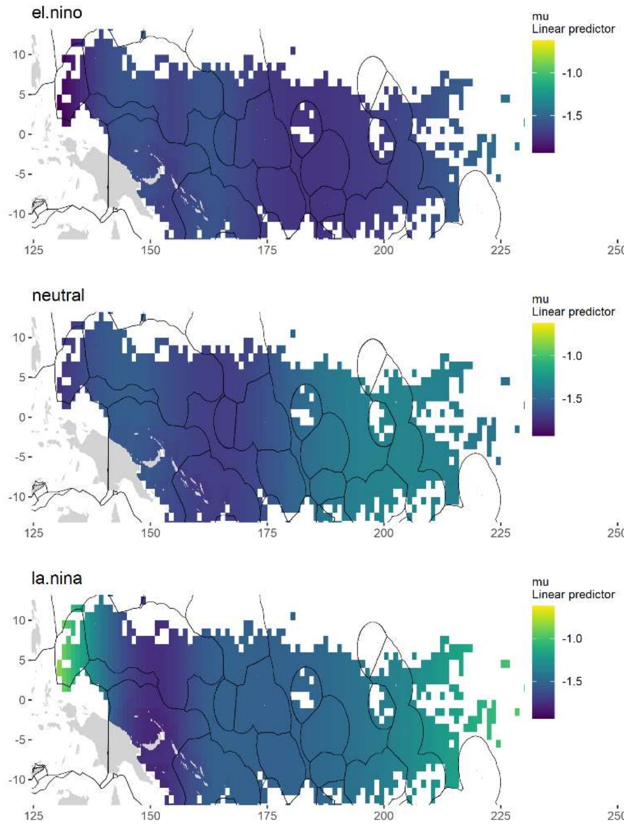


Figure 22 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the bigeye free-school model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

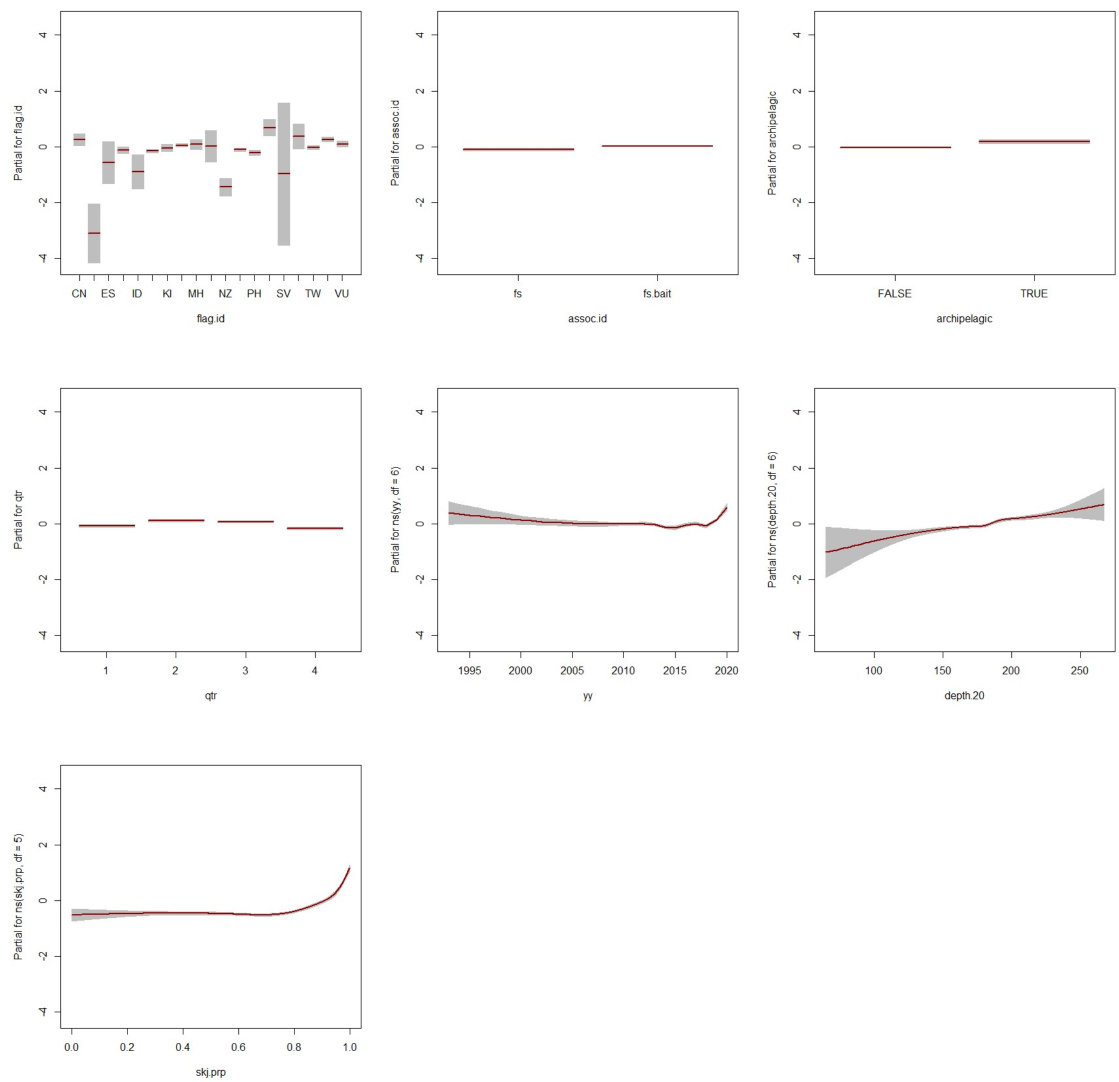


Figure 23 Effect plots for the zero-inflation component of the bigeye free-school model. Top row, left to right: flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters. Middle row, left to right: quarter; year; isotherm depth. Bottom row: uncorrected skipjack proportion from vessel logbooks.

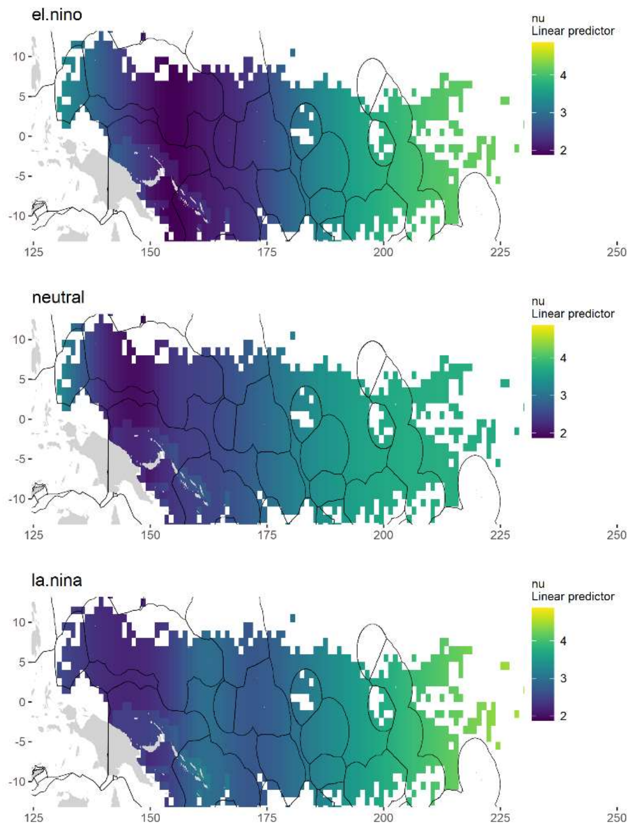


Figure 24 The combined effect of the archipelagic term and the longitude:ONI interaction on the zero-inflation component of the bigeye free-school model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

Skipjack – associated

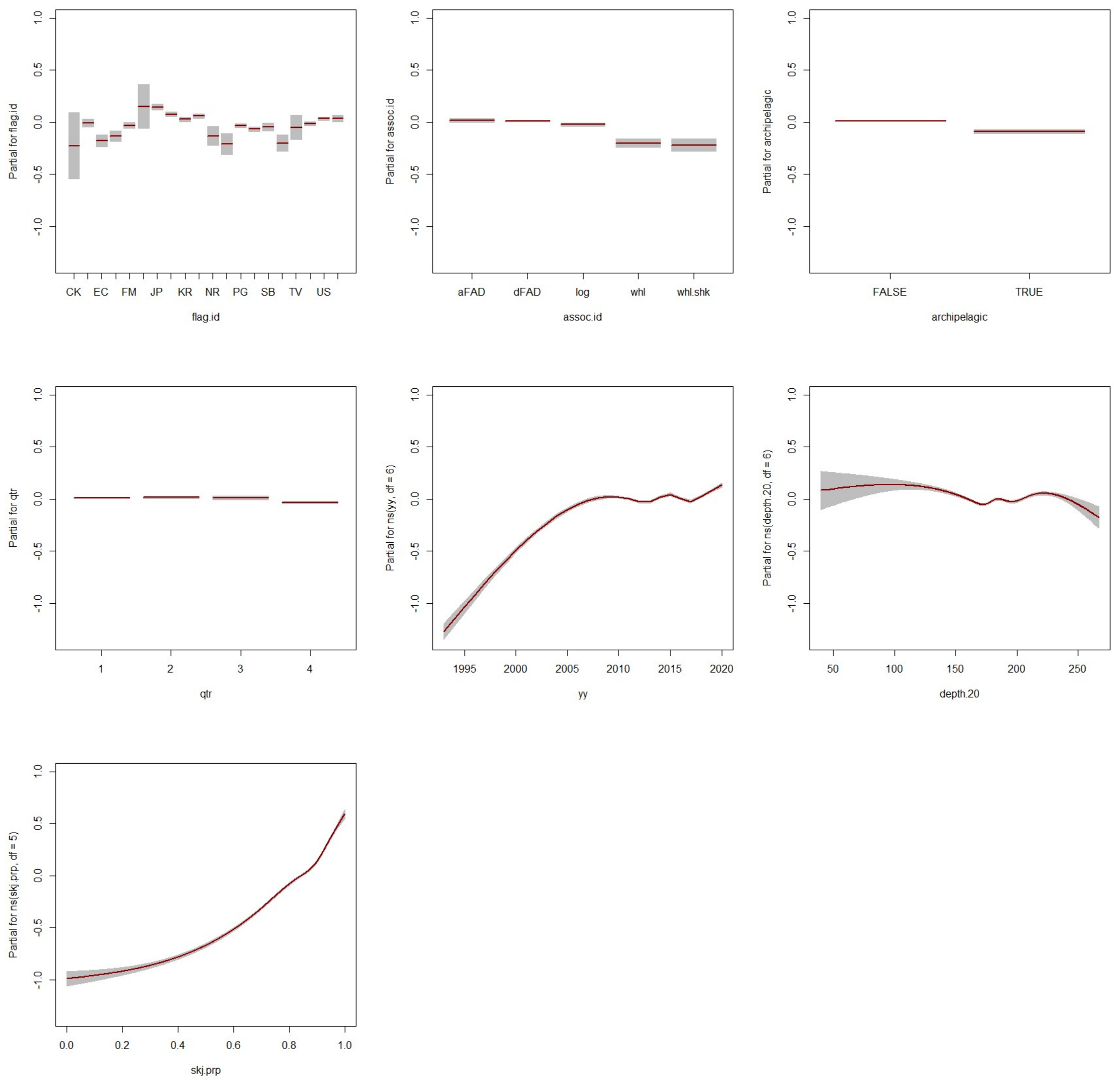


Figure 25 Effect plots for the mean of the beta-component of the skipjack associated model. Top row, left to right: flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters. Middle row, left to right: quarter; year; isotherm depth. Bottom row: uncorrected skipjack proportion from vessel logbooks.

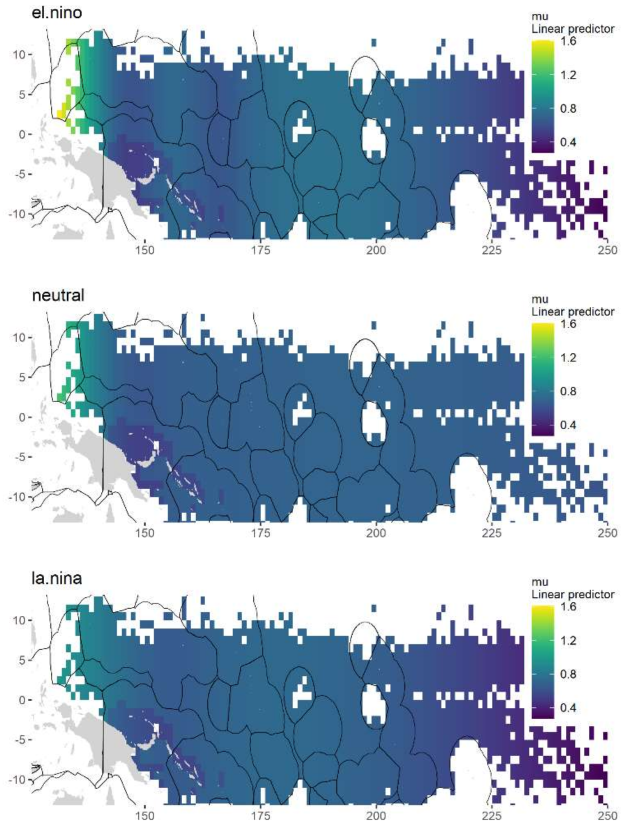


Figure 26 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the skipjack associated model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

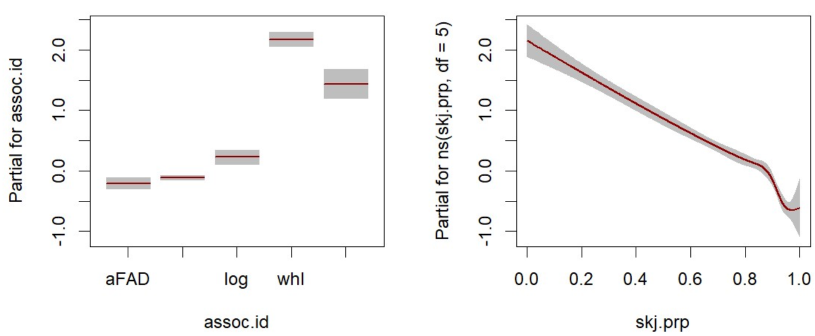


Figure 27 Effect plots for the zero-inflation component of the skipjack associated model: association type (left panel, anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk) and, uncorrected skipjack proportion from vessel logbooks (right panel).

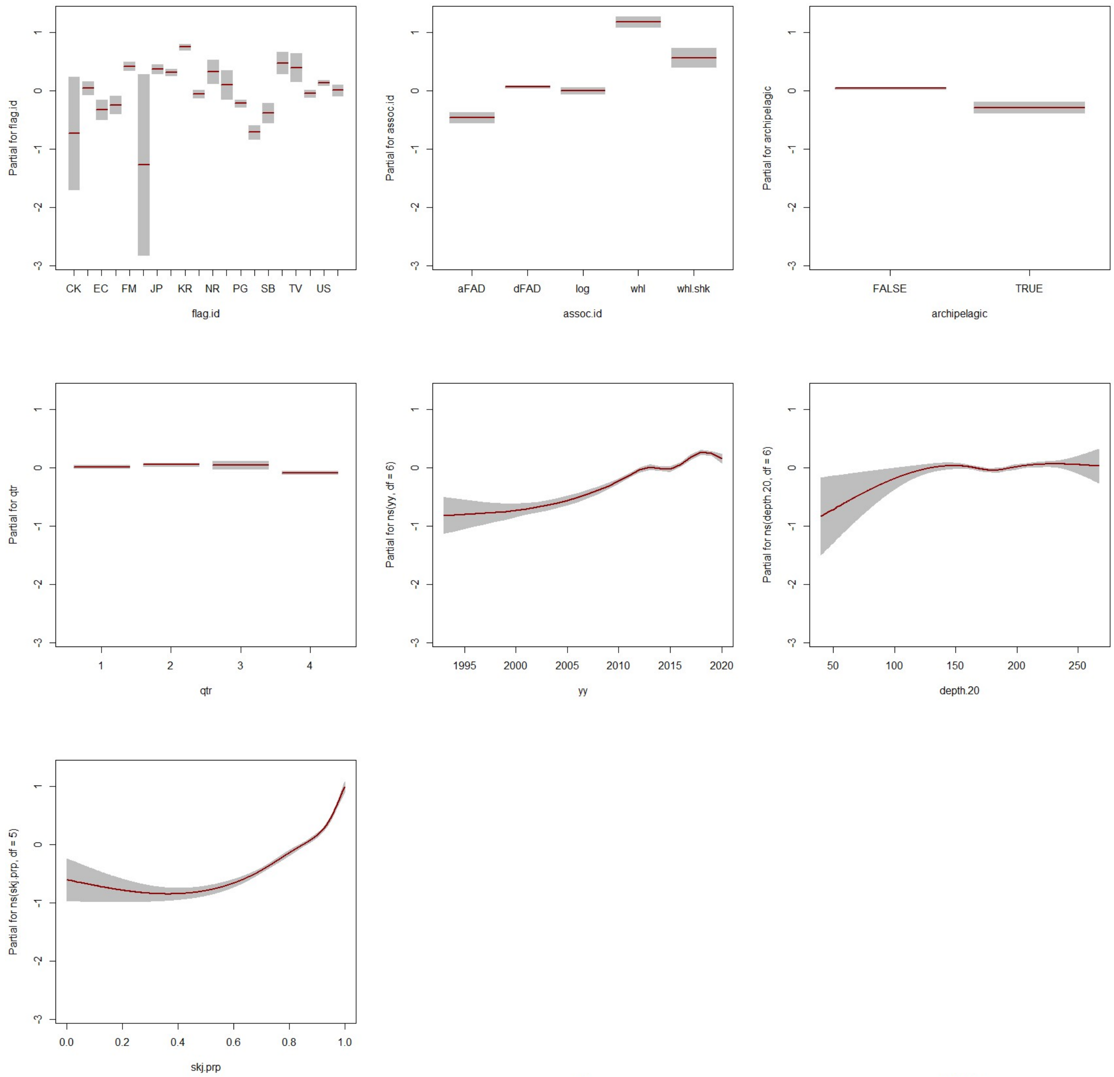


Figure 28 Effect plots for the one-inflation component of the skipjack associated model. Top row, left to right: flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters. Middle row, left to right: quarter;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

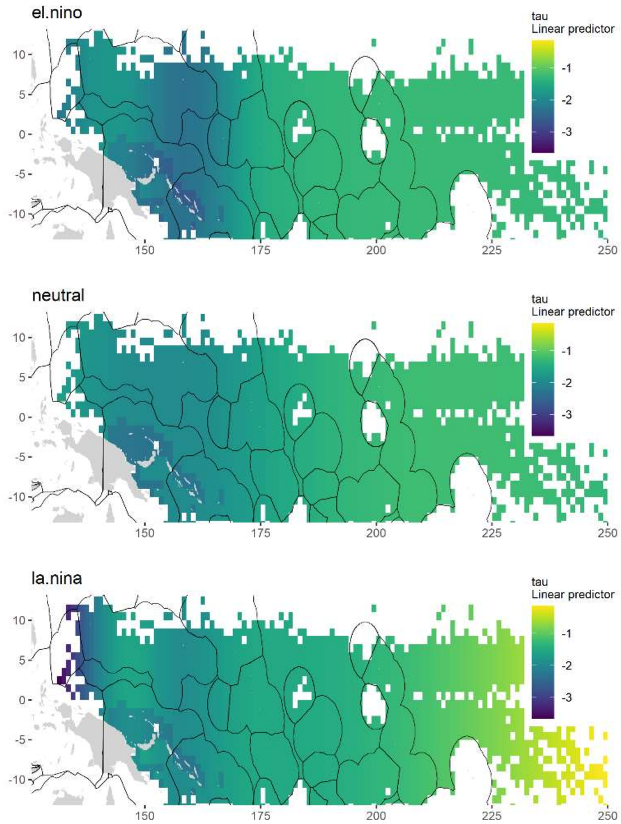


Figure 29 The combined effect of the archipelagic term and the longitude:ONI interaction on the one-inflation component of the skipjack associated model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

Yellowfin – associated

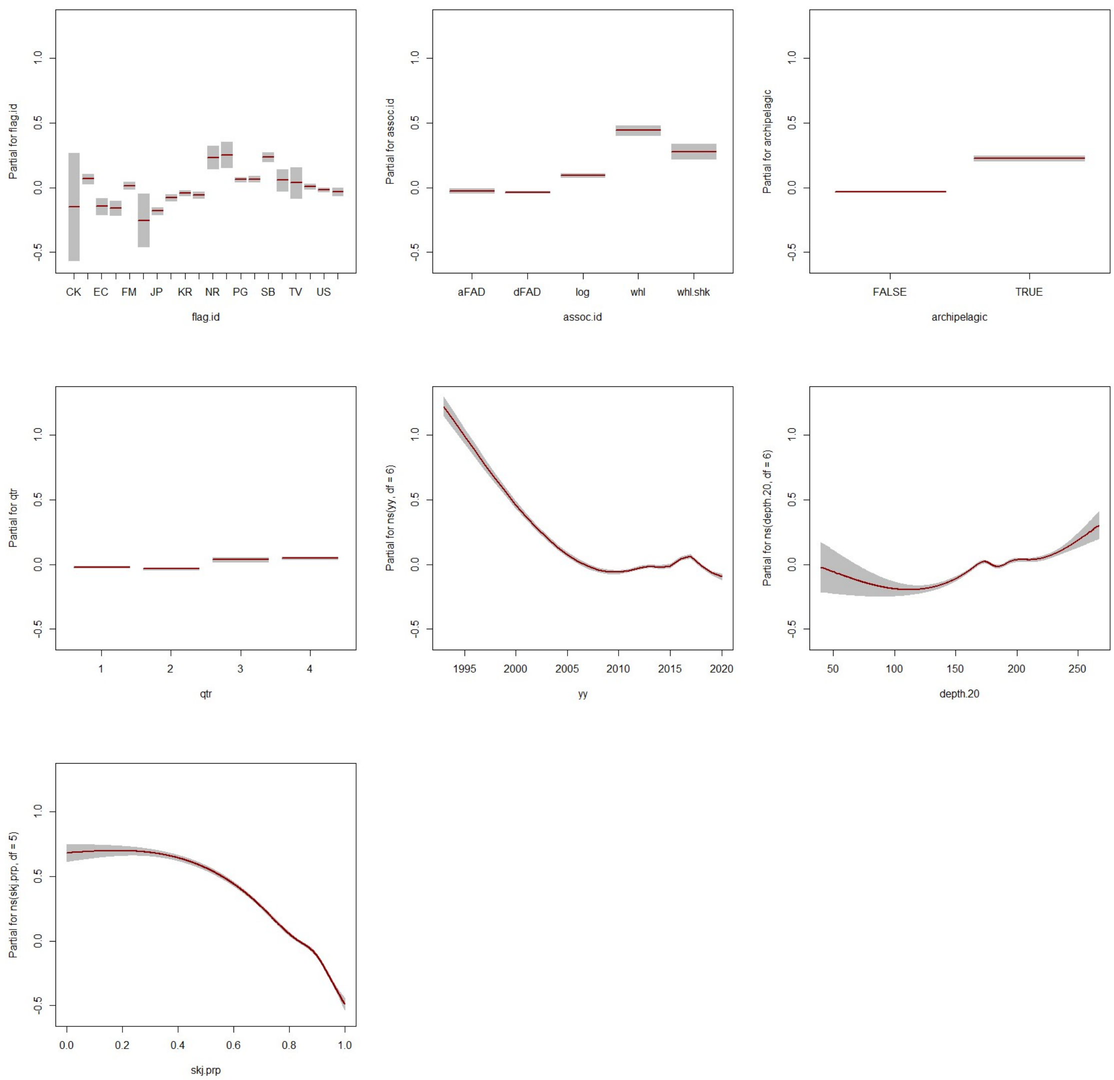


Figure 30 Model effects for the mean of the beta-component of the yellowfin associated model. Top row, left to right: flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters. Middle row, left to right: quarter; year; isotherm depth. Bottom row: uncorrected skipjack proportion from vessel logbooks.

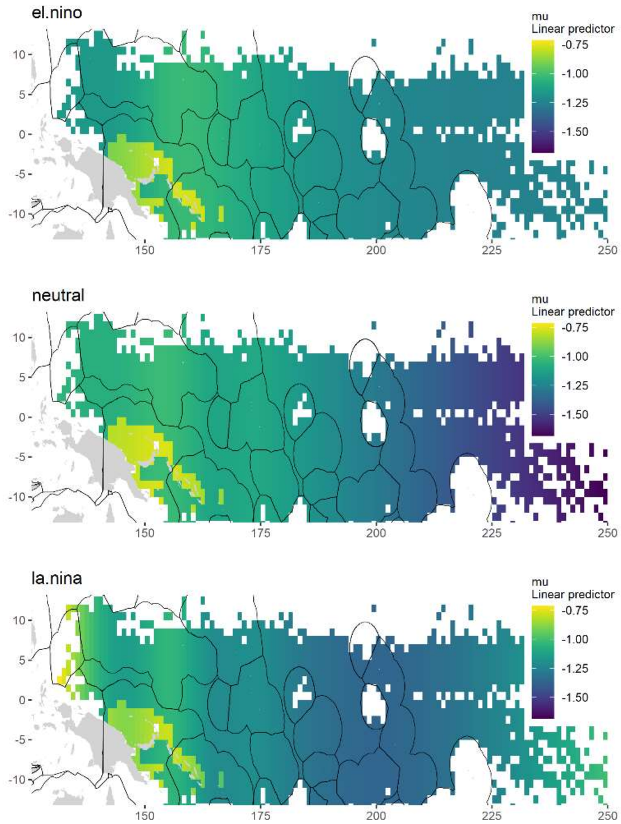


Figure 31 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the yellowfin associated model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

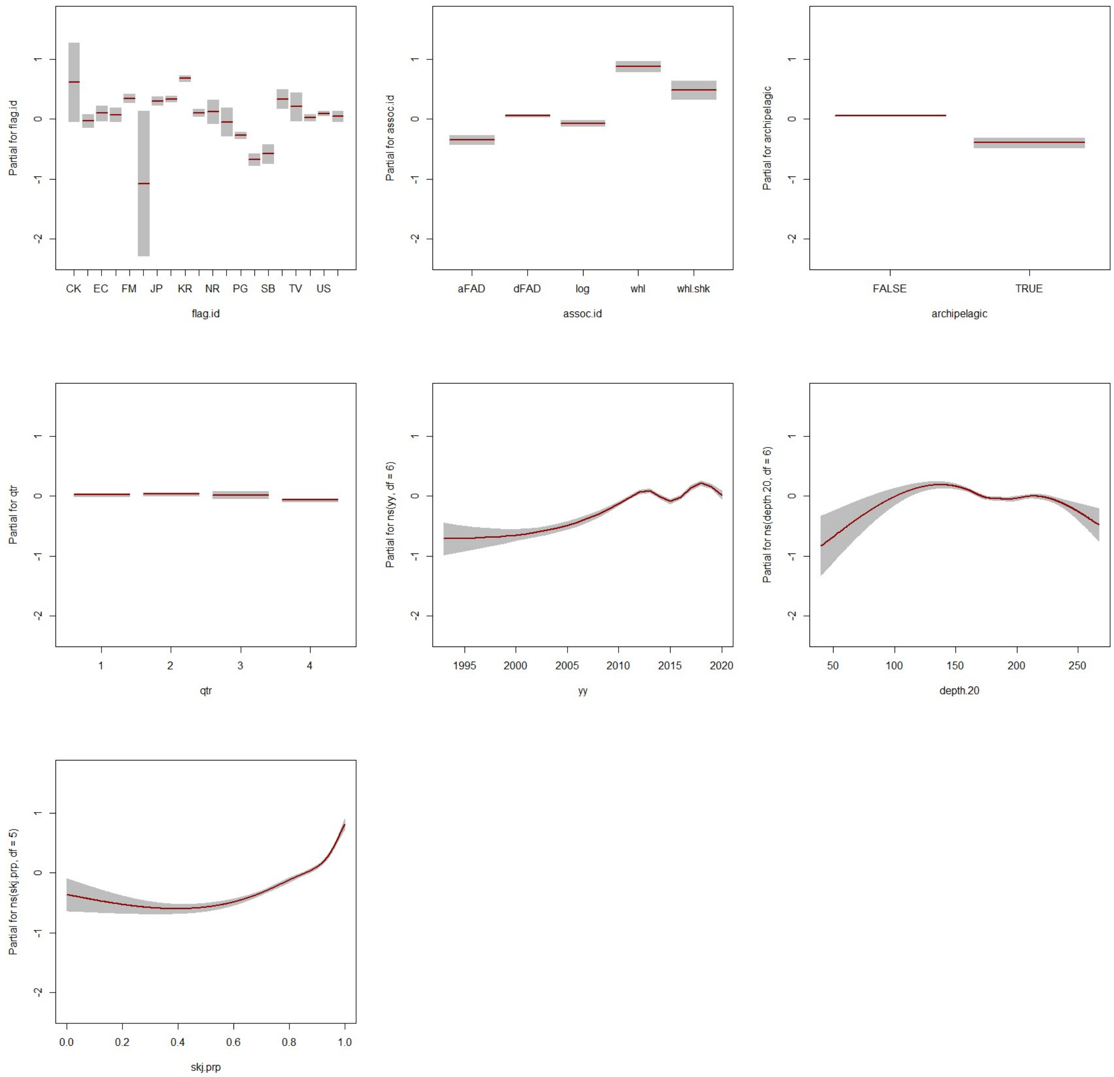


Figure 32 Model effects for the zero-inflation component of the yellowfin associated model. Top row, left to right: flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters. Middle row, left to right: quarter; year; isotherm depth. Bottom row: uncorrected skipjack proportion from vessel logbooks.

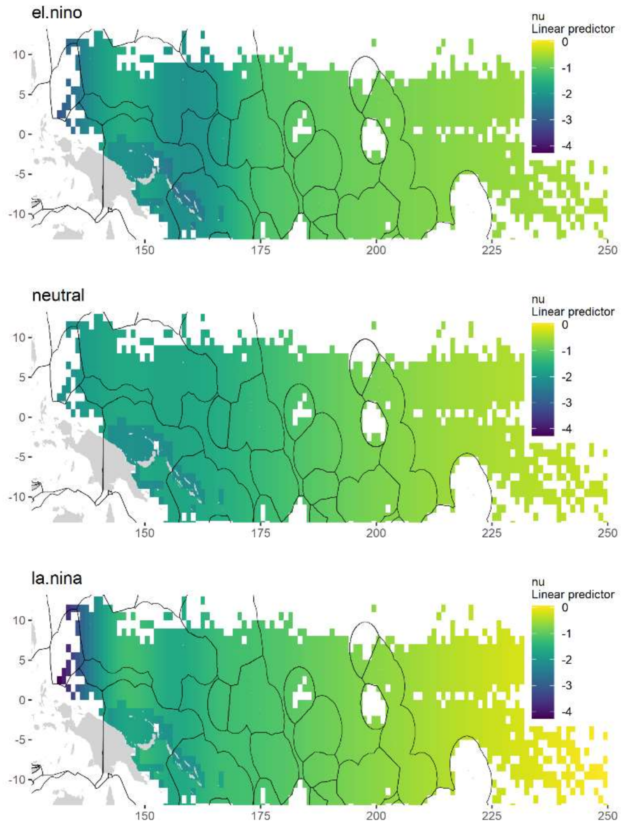


Figure 33 The combined effect of the archipelagic term and the longitude:ONI interaction on the zero-inflation component of the yellowfin associated model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

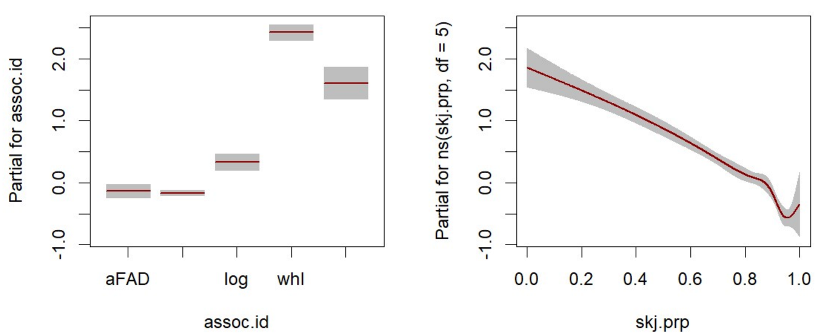


Figure 34 Effect plots for the one-inflation component of the yellowfin associated model: association type (left panel- anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk) and, uncorrected skipjack proportion from vessel logbooks (right panel).

Bigeye – associated

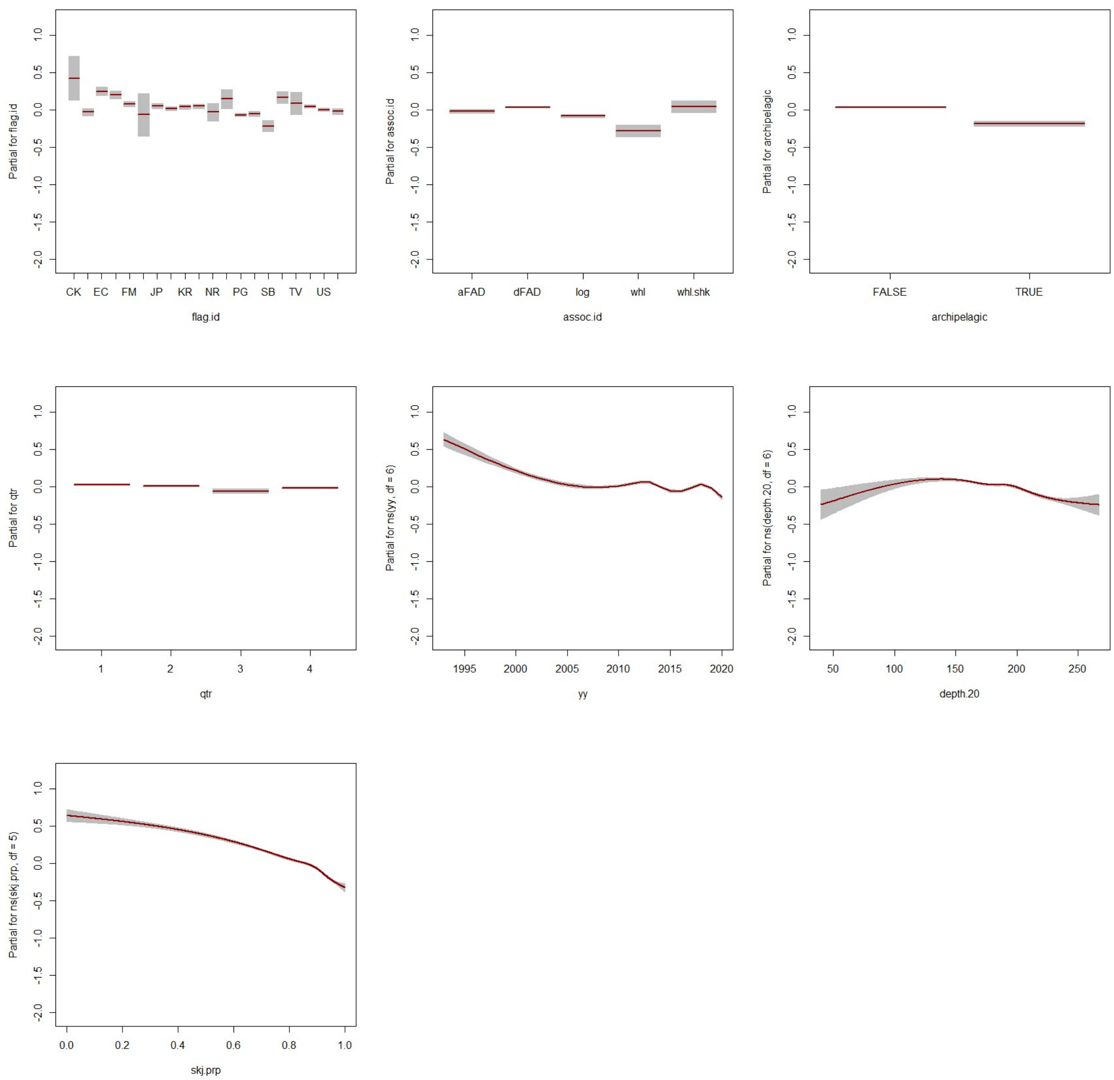


Figure 35 Effect plots for the mean of the beta-component of the bigeye associated model. Top row, left to right: flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters. Middle row: left to right: quarter; year; isotherm depth. Bottom row: uncorrected skipjack proportion from vessel logbooks.

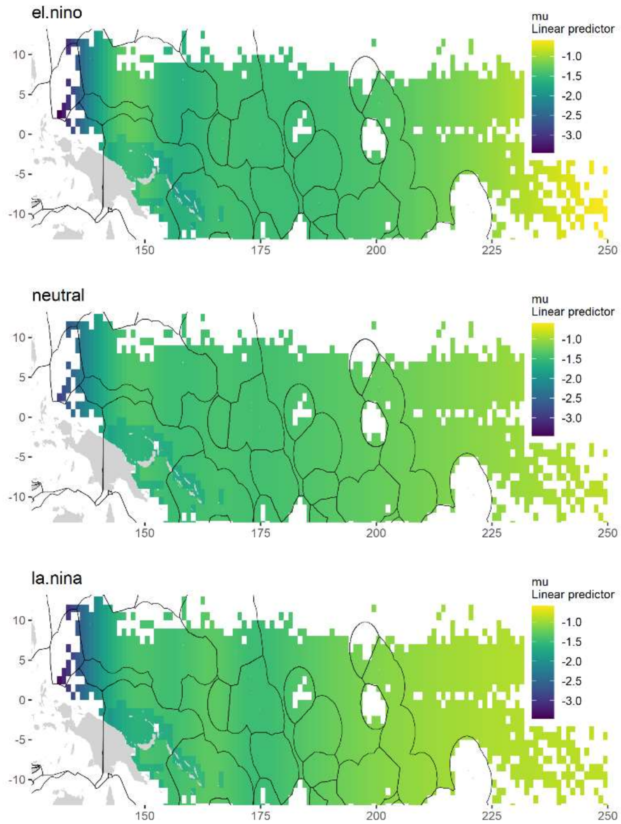


Figure 36 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the bigeye associated model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

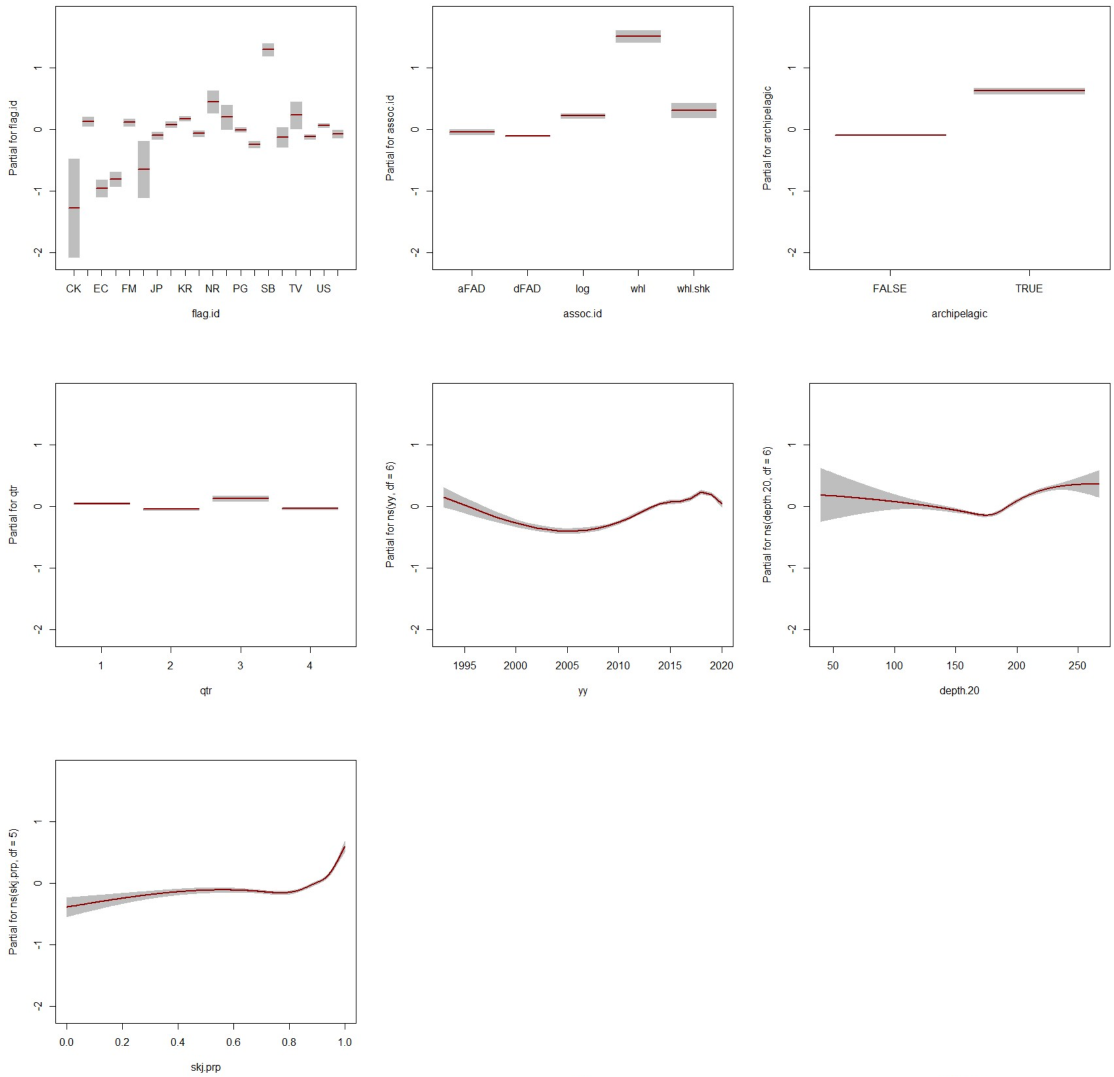


Figure 37 Effect plots for the zero-inflation component of the bigeye associated model. Top row, left to right: flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters. Middle row, left to right: quarter; year; isotherm depth. Bottom row: uncorrected skipjack proportion from vessel logbooks.

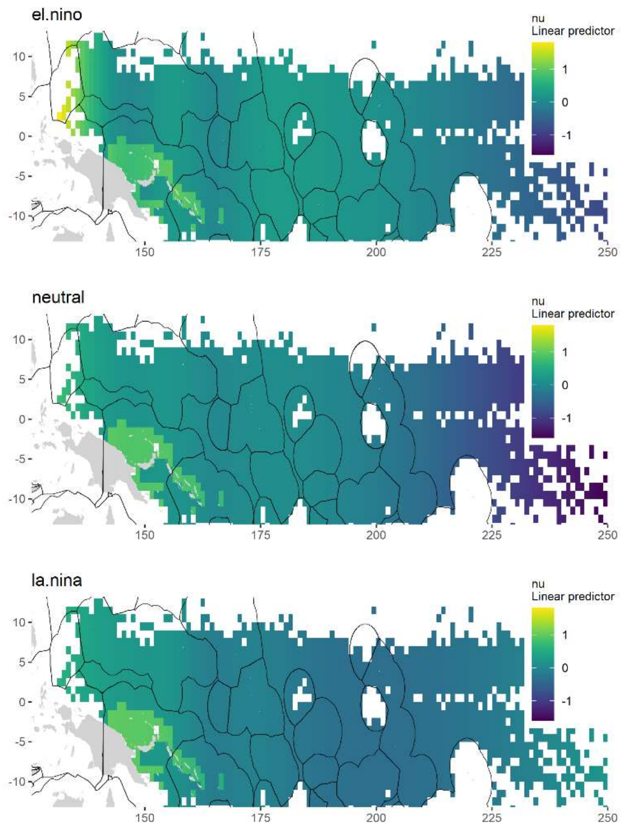


Figure 38 The combined effect of the archipelagic term and the longitude:ONI interaction on the zero-inflation component of the bigeye associated model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

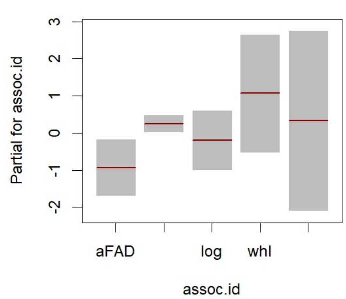


Figure 39 Effect plot for the one-inflation component of the bigeye associated model: association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk).