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Project 60: Progress Towards Achieving SC19 Recommendations

WCPFC-SC20-2024/ST-WP-02

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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 recommendations from WCFPC SC19 for Project 60 are summarised in Table 1, along with a commentary on progress from August 2023 to July 2024. The specifications of the species composition models were also refined, summarised in Appendix B. Effect plots for the updated species composition models are provided in Appendix C. In addition, corrected species composition estimates for purse seine catches have been updated to include 2023 (see Figure 1 and Figure 2) using the agreed estimation procedure (see Peatman et al., 2020). Observer data for 2023 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 and observer coverage rates for 2023 should be considered preliminary.

Issues arising

Observer coverage rates of WCPFC purse seine fisheries were substantially reduced in mid-2020 due to the impacts of COVID-19, particularly for regions 7 and 8 from the 2022 skipjack assessment (Figure 3, Figure 4). The reductions in observer coverage rates varied among flags, e.g., with relatively weak reductions for purse seiners flagged to Papua New Guinea and the Solomon Islands. The reduction in observer coverage since mid-2020 is reflected in the corresponding increase in the proportion of total purse seine catch with model-based estimates of species compositions (Table 2). Observer coverage rates in the first quarter of 2023 increased sharply, with a corresponding reduction in the proportion of catches from strata with model based estimates. However, coverage rates of available observer data then decreased in the last three quarters of 2023. This recent decrease may reflect the delay in the submission and loading of purse seine observer data. Regardless, estimates of species proportions for the period of low observer coverage will have relatively low precision, particularly for bigeye (Peatman et al., 2022), and may also be biased due to the variation in observer coverage between purse seine fleets and areas.

Discussion

In the last year, limited progress was made against SC19's recommendations for the Project 60 workplan. It has been difficult to undertake additional paired grab-spill trips in recent years due to a variety of factors, not least the Covid-19 pandemic and it's impacts on the placement of observers on purse seine vessels. Spill sampling can also disrupt the brailing of catches with potential implications on catch quality, which may act as a disincentive for undertaking paired trips. Additional paired trips have primarily been of interest as this would provide a more informative dataset for the testing of variation in grab sample bias, e.g., among species or set-types. As such, paired trips have consistently been assigned a high-priority in the Project 60 workplan. However at this stage, it appears unlikely that sufficient additional paired grab-spill trips could be undertaken to allow meaningful testing for potential variation in grab sample bias. We also note that comparative analyses of species composition estimates from different data sources have suggested that the existing estimates of grab sample bias can be used to obtain accurate estimates of species compositions (e.g., Peatman et al., 2017b). There is also generally a lack of new information that could inform other activities in the Project 60 workplan, e.g., trials of video based sampling. In this context, we recommend that WCPFC Project 60 be marked as complete, until such a time as new information becomes available to support related activities. However, we note that there are several outstanding issues related to estimation of catch compositions of purse seine vessels in the WCPFC Convention Area (see the following Section).

Outstanding issues

Currently, species composition estimates are based directly on observer samples for strata with a minimum observer coverage rate of 20%. The 20% threshold originated in Lawson (2013), who noted that it was set arbitrarily and suggested testing of alternative thresholds. The 20% threshold may result in imprecise estimates of species compositions for strata with high rates of observer coverage, but limited levels of catches and so relatively few grab samples. Comparisons of model-based and observer sample-based species composition estimates with estimates from independent data sources would provide a means for assessing the performance of, and potentially improving, the 20% threshold used to switch between observer sample-based and model-based estimates. Adjustment of the 20% threshold may not have a substantial impact on catch estimates at an MFCL region, however it is expected to improve catch estimates at finer-scales which are needed for other work of the Scientific Committee. This demonstrates the continued importance of collaborative analyses with Members holding comprehensive and accurate estimates of species compositions that are independent of those derived from grab samples.

There is also the need to assess the relative strengths and weaknesses of differing approaches to estimation of species compositions. The current approach relies on grab samples collected by observers. Observers can only sample a low proportion of total catches, and as such the resulting estimates of catch compositions at fine scales are noisy. Additionally, grab samples have been shown to be biased, with over-representation of larger fish and vice versa. There would also be other benefits to reducing or stopping the collection of grab samples, e.g., collection of biological samples, etc. Video-based monitoring provides a means of collecting samples on species and size compositions. Cannery data also has the potential to inform, or be used to verify, estimates of purse seine catch compositions (SPC-OFP, 2024). This is particularly relevant given the low coverage of grab-sample based estimates since the onset of the COVID-19 pandemic. However, coverage rates of cannery data have also been relatively low, though there have been recent improvements in the matching of cannery and vessel logbook data (e.g., Table 3).

The specification of species composition models will require periodic updating. Future work should consider the use of models that better reflect the compositional nature of the response variables, rather than modelling each species' proportion of catch in isolation. This will also facilitate estimation of uncertainty in catch compositions. Additionally, potential temporal changes in the effects of reported catch compositions could be explored. The accuracy of reported catch compositions may have changed through time, e.g., in response to skipper renumeration structure. There may also be value in moving to spatial-temporal models, or other more flexible modelling approaches (e.g., Duparc et al., 2020).

Recommendations

We invite the Scientific Committee to:

1. Note the progress towards the Project 60 workplan agreed at SC20 (Table 1).

2. Note the improvements to the species composition models used to generate model-based estimates of species compositions for strata with relatively low observer coverage rates.
3. Note the continued potential for comparative analyses of species compositions from different data sources to inform the approach used to estimate catch compositions, e.g., the threshold for observer coverage that determines whether estimates are model based. These comparative analyses rely on independent estimates of catch compositions held by Members.
4. Consider marking Project 60 as complete, noting that work on species compositions of purse seine catches can continue through the provision of scientific advice by the SSP.

Acknowledgements

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Tables

Table 1 Progress towards addressing SC19 recommendations (continued on following page).

Activity	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.	No paired grab-spill trips were undertaken in 2023-24.
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 (i.e. extensions of comparative analyses reported in Peatman et al., 2017a; Peatman, 2022).	No collaborative analyses were undertaken in 2023-24. Future collaboration with members has the potential to contribute to improved estimates of purse seine species compositions.
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. Additional EM trials were not undertaken in 2023-24.
Cost-benefit analysis of alternative sampling approaches for long-term estimation of species compositions (i.e. at-sea sampling vs port sampling)	This activity was not prioritised for 2023-24.

Table 2 The proportion of purse seine catch with model-based species composition estimates by year and quarter from 2000 to 2023 (excludes Indonesia, Philippines and Vietnam domestic fisheries).

Year	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec
2000	0.975	0.958	0.986	0.954
2001	0.952	0.944	0.969	0.993
2002	0.963	0.877	0.903	0.951
2003	0.913	0.987	0.955	0.985
2004	0.967	0.868	0.920	0.942
2005	0.975	0.931	0.875	0.887
2006	0.913	0.875	0.907	0.820
2007	0.821	0.823	0.847	0.812
2008	0.838	0.773	0.834	0.891
2009	0.762	0.831	0.613	0.828
2010	0.199	0.193	0.124	0.164
2011	0.121	0.114	0.133	0.185
2012	0.197	0.130	0.068	0.103
2013	0.207	0.222	0.086	0.132
2014	0.151	0.086	0.051	0.086
2015	0.081	0.111	0.086	0.047
2016	0.064	0.032	0.038	0.040
2017	0.030	0.028	0.054	0.021
2018	0.016	0.019	0.035	0.015
2019	0.009	0.016	0.031	0.025
2020	0.062	0.163	0.828	0.830
2021	0.840	0.903	0.839	0.808
2022	0.854	0.876	0.883	0.806
2023	0.202	0.431	0.610	0.612

Table 3 Coverage of matched logsheet/observer/cannery trip data for the WCPFC tropical purse seine fishery (excludes Indonesia, Philippines and Vietnam domestic fisheries). Source: SPF-OFP (2024).

YEAR	Total Purse seine Tuna catch (MT)						
	WCPFC Estimates	Processor data	%	Matched Log / Cannery	%	Matched Log / Obs / Cannery	%
2013	1,570,125	498,424	31.7%	421,356	26.8%	373,440	23.8%
2014	1,737,573	509,689	29.3%	420,219	24.2%	380,278	21.9%
2015	1,544,180	436,504	28.3%	389,748	25.2%	336,345	21.8%
2016	1,544,386	467,132	30.2%	413,006	26.7%	353,175	22.9%
2017	1,469,031	473,818	32.3%	415,617	28.3%	382,596	26.0%
2018	1,676,092	529,670	31.6%	487,478	29.1%	474,088	28.3%
2019	1,716,606	554,944	32.3%	554,944	32.3%	502,877	29.3%
2020	1,539,338	690,886	44.9%	690,886	44.9%	220,054	14.3%
2021	1,425,829	667,787	46.8%	667,787	46.8%	38,685	2.7%
2022	1,497,386	632,524	42.2%	632,524	42.2%	52,505	3.5%
2023	1,456,398	604,472	41.5%	604,472	41.5%	244,329	16.8%

Figures

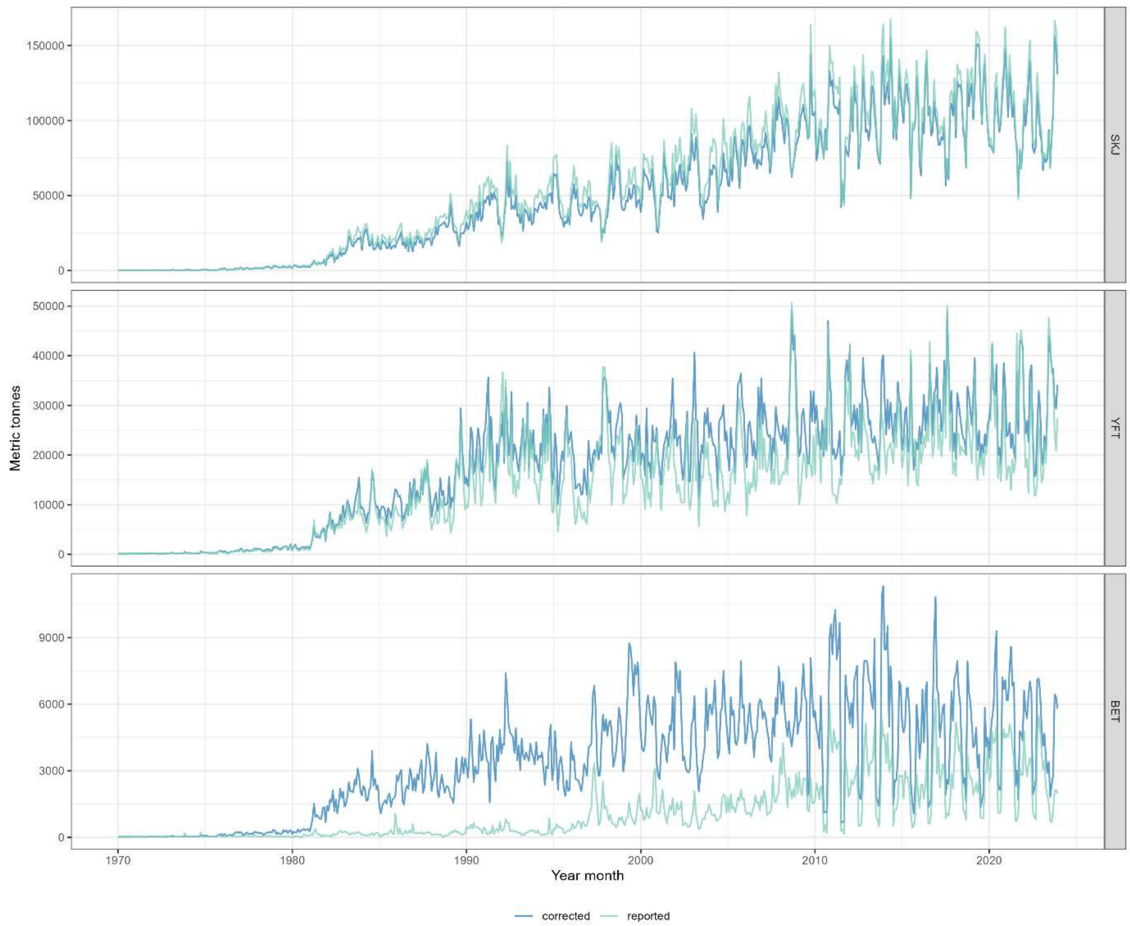

Figure 1 Corrected (blue) and reported (turquoise) purse seine catch by year and month for skipjack (top), yellowfin (middle) and bigeye (bottom panel).

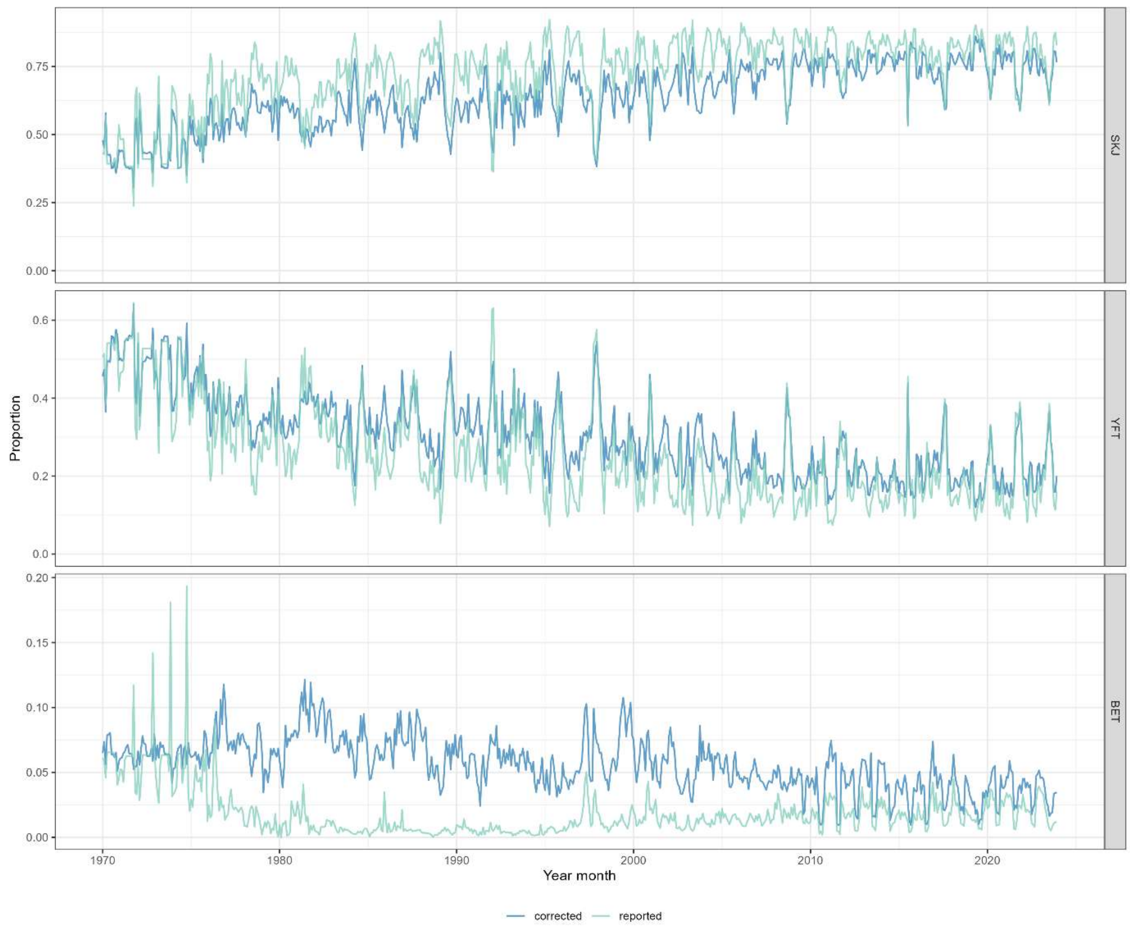

Figure 2 Corrected (blue) and reported (turquoise) purse seine catch proportions by year and month for skipjack (top), yellowfin (middle) and bigeye (bottom panel).

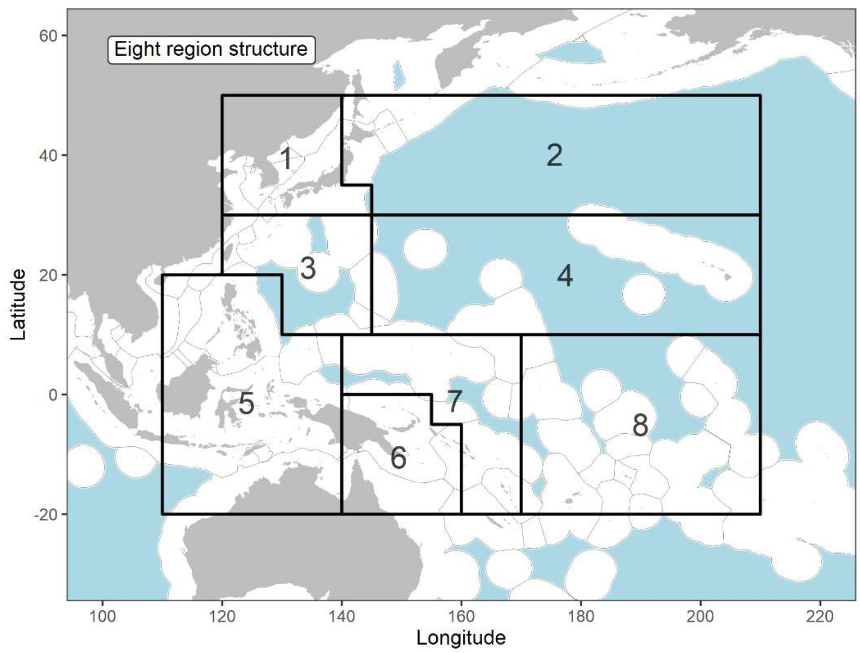

Figure 3 The eight region structure from the 2022 skipjack assessment.

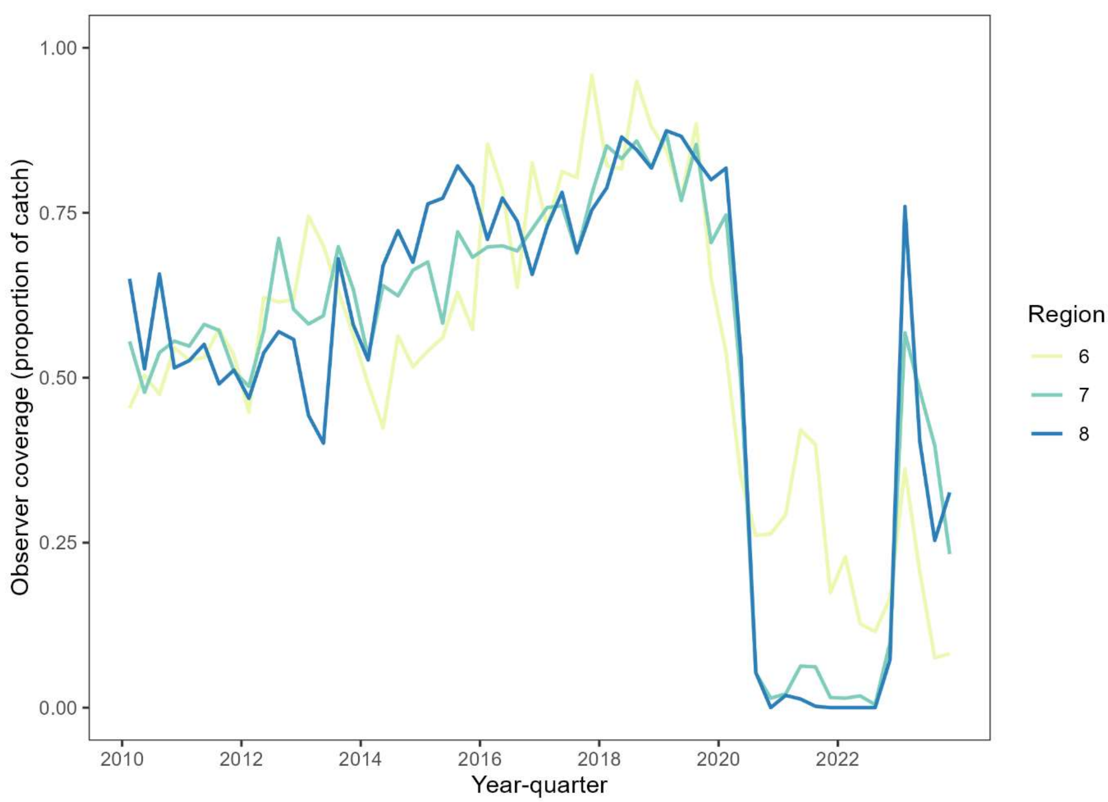

Figure 4 Annual observer coverage rates by region from the 2022 skipjack assessment (6, 7 and 8; Figure 3) from 2010 to 2023.

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 2023-24

Improvements to species compositions models

The specification of the species composition models was revisited, with a specific focus on potential improvements for the Central Pacific region. Purse seine effort in the Central Pacific region is relatively low compared to the western region, but proportions of bigeye in reported and estimated catches can be appreciable.

This analysis used the existing species composition models (described in Peatman et al., 2021) as the starting point. First, we assessed support for alternative knot positions for the longitude effects. In the existing species composition models, five internal knots were used with approximate locations of 150°E, 155°E, 160°E, 170°E and 180°E. The alternative knot locations had a higher number of internal knots in the region east of 180°E, with 7 internal knots located at 140°E, 150°E, 160°E, 170°E, 180°E, 200°E and 220°E. The alternative specification of the longitude knots resulted in substantial improvements to AIC for all six species composition models (Table 1). We then assessed support for the inclusion of (proxy) thermal gradient effects. The inclusion of thermal gradient effects was also supported by AIC. The difference in depth between the 20°C and 18°C isotherms had more support for models of skipjack proportions in free school and associated sets, and models of yellowfin proportions in free school sets. The difference in depth between the 20°C and 15°C isotherms had more support for models of bigeye proportions in free school and associated sets, and models of yellowfin proportions in associated sets.

Table 4 AIC values for alternative model specifications for models of species proportions (FS – free school, ASS – associated sets). Thermal gradient (15°C) and (18°C) refer to the proxies of thermal gradient that were tested, defined as the difference in depth between the 20°C and 15°C isotherms, and the 20°C and 18°C isotherms, respectively.

Model specification	FS-SKJ	FS-YFT	FS-BET	ASS-SKJ	ASS-YFT	ASS-BET
a. Base models (2021)	212,634.2	208,946.4	48,408.0	61,406.1	35,678.7	55,989.1
b. a with alternative lon knots	181,407.3	177,505.8	47,191.5	53,227.0	30,396.1	53,789.2
c. b with thermal gradient (15C)	181,305.2	177,407.1	47,140.7	53,153.8	30,217.6	53,628.0
d. b with thermal gradient (18C)	181,303.6	177,394.7	47,160.8	53,145.7	30,224.9	53,712.4

The increase in coverage of the Central Pacific region with knots for longitude effects and the addition of thermal gradient effects, were both supported by AIC. As such, we recommend that these changes be incorporated into the models used to correct species compositions of purse seine catches in the WCPFC Convention Area (see Appendix C for the model specifications and effects plots).

However, we note that the estimates of species-specific catches at both an annual and S BEST stratification (i.e., year, month, flag-fleet, 1°cell and set-type) were relatively insensitive to the update to the specification of the species composition models (Figure 5 and Figure 6).

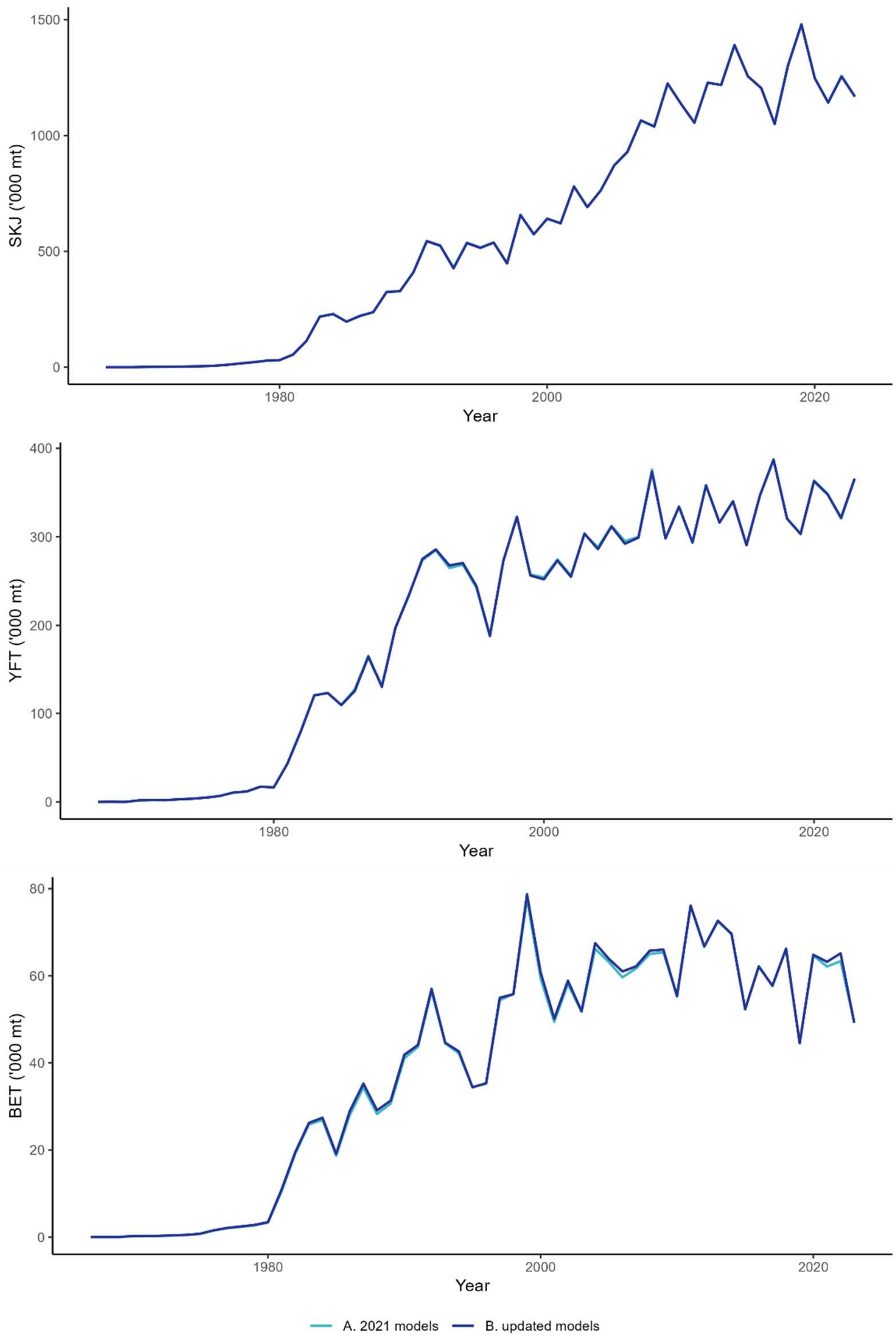

Figure 5 Estimated annual catches (mt) of skipjack (top), yellowfin (middle) and bigeye (bottom) in purse seine catches in the WCPFC Convention Area with a) the 2021 species composition models (light blue), and b) the updated species composition models (dark blue).

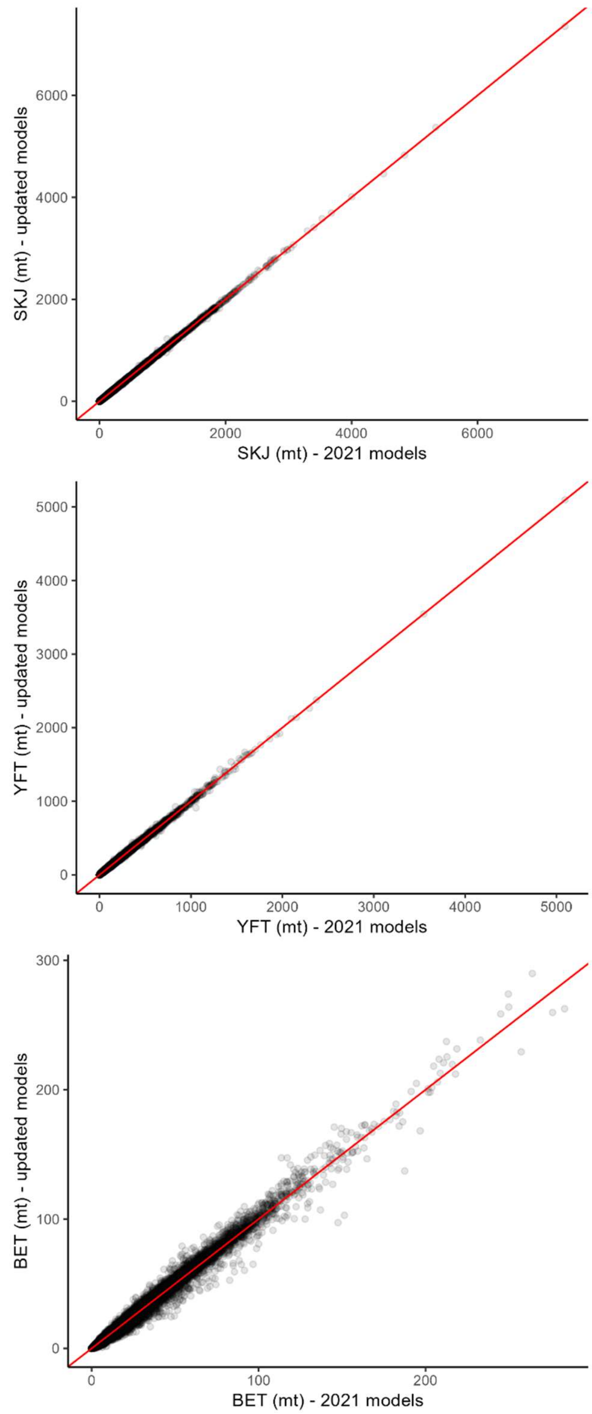

Figure 6 Comparisons of estimated catches of skipjack (top), yellowfin (middle) and bigeye (bottom) at an S BEST resolution in the WCPFC Convention Area with the 2021 species composition models (x-axis) and the updated species composition models (y-axis).

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:

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

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

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

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

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, $gradient_{ij}$ is a proxy for the thermal gradient defined as the difference in depth between the 20°C and 18°C isotherms, $prop_{SKJ}$ 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 $f(\cdot)$ 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:

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

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

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

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

The proxy for thermal gradient ($gradient_{ij}$) was defined as the difference in depth between the 20°C and 15°C isotherms for the model of yellowfin proportions on associated sets.

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:

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

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

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

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

The proxy for thermal gradient ($gradient_{ij}$) was defined as the difference in depth between the 20°C and 15°C isotherms for the model of bigeye proportions on associated sets.

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:

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

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

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

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

The proxy for thermal gradient ($gradient_{ij}$) was defined as the difference in depth between the 20°C and 18°C isotherms for the model of skipjack proportions on unassociated sets.

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:

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

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

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

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

The proxy for thermal gradient ($gradient_{ij}$) was defined as the difference in depth between the 20°C and 18°C isotherms for the model of yellowfin proportions on unassociated sets.

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

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

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:

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

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

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

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

The proxy for thermal gradient ($gradient_{ij}$) was defined as the difference in depth between the 20°C and 15°C isotherms for the model of bigeye proportions on unassociated sets.

Effect plots for revised species composition models

Skipjack – free school

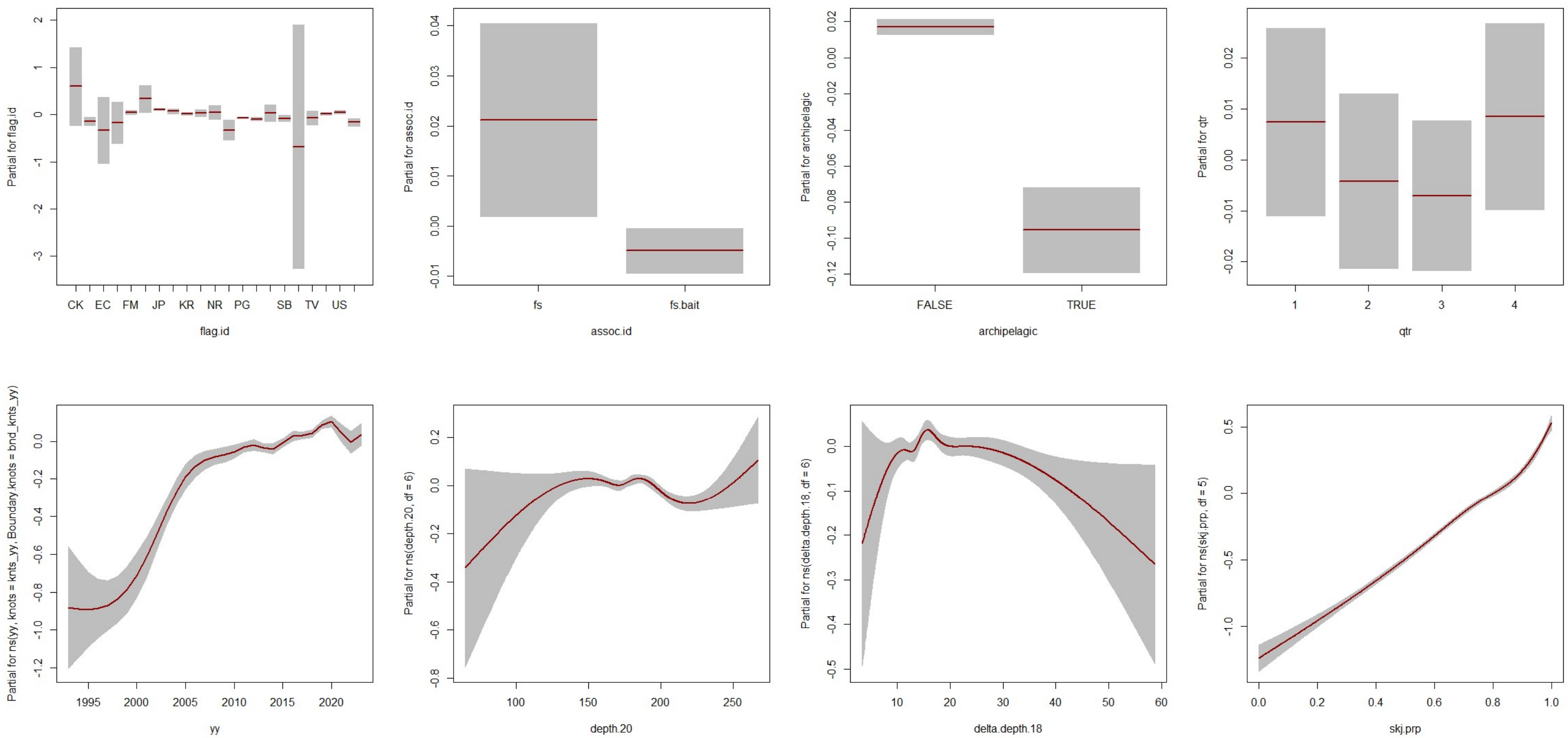

Figure 7 Effect plots for the mean of the beta-component of the skipjack free-school model. Top row, left to right: flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters; quarter. Bottom row, left to right: year; isotherm depth; thermal gradient;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

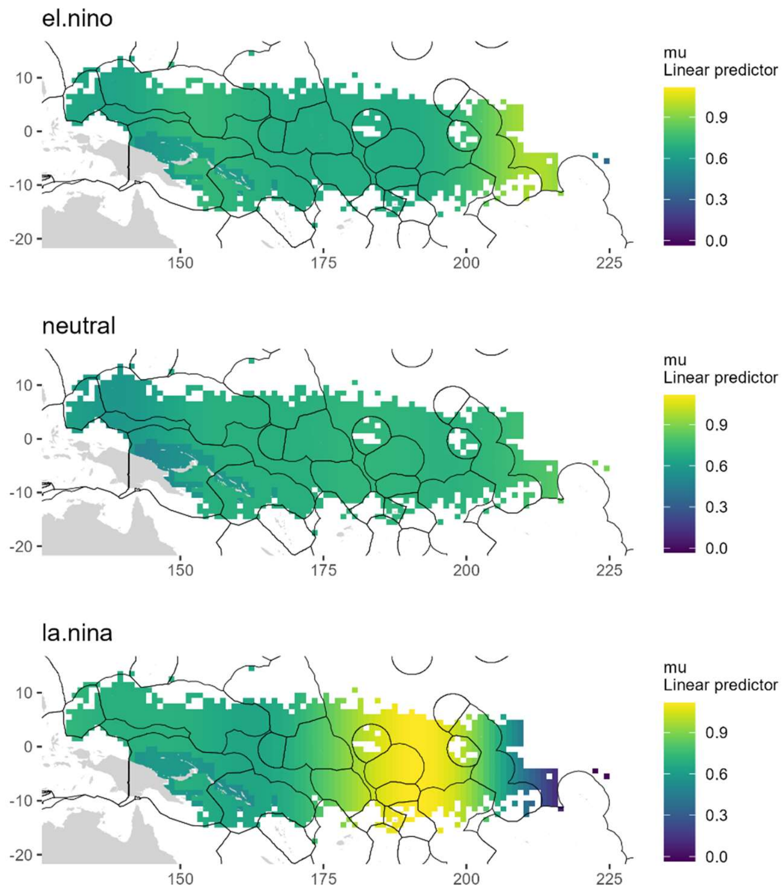

Figure 8 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the skipjack free-school model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

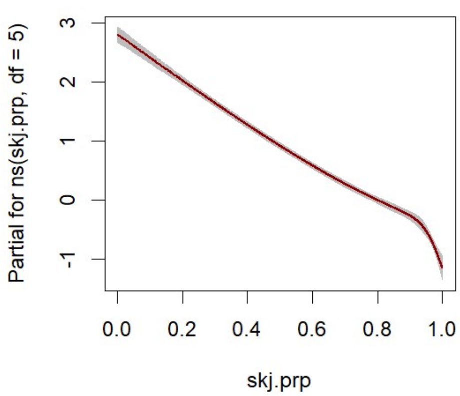

Figure 9 Effect plot for the zero-inflation component of the skipjack free-school model: uncorrected skipjack proportion from vessel logbooks.

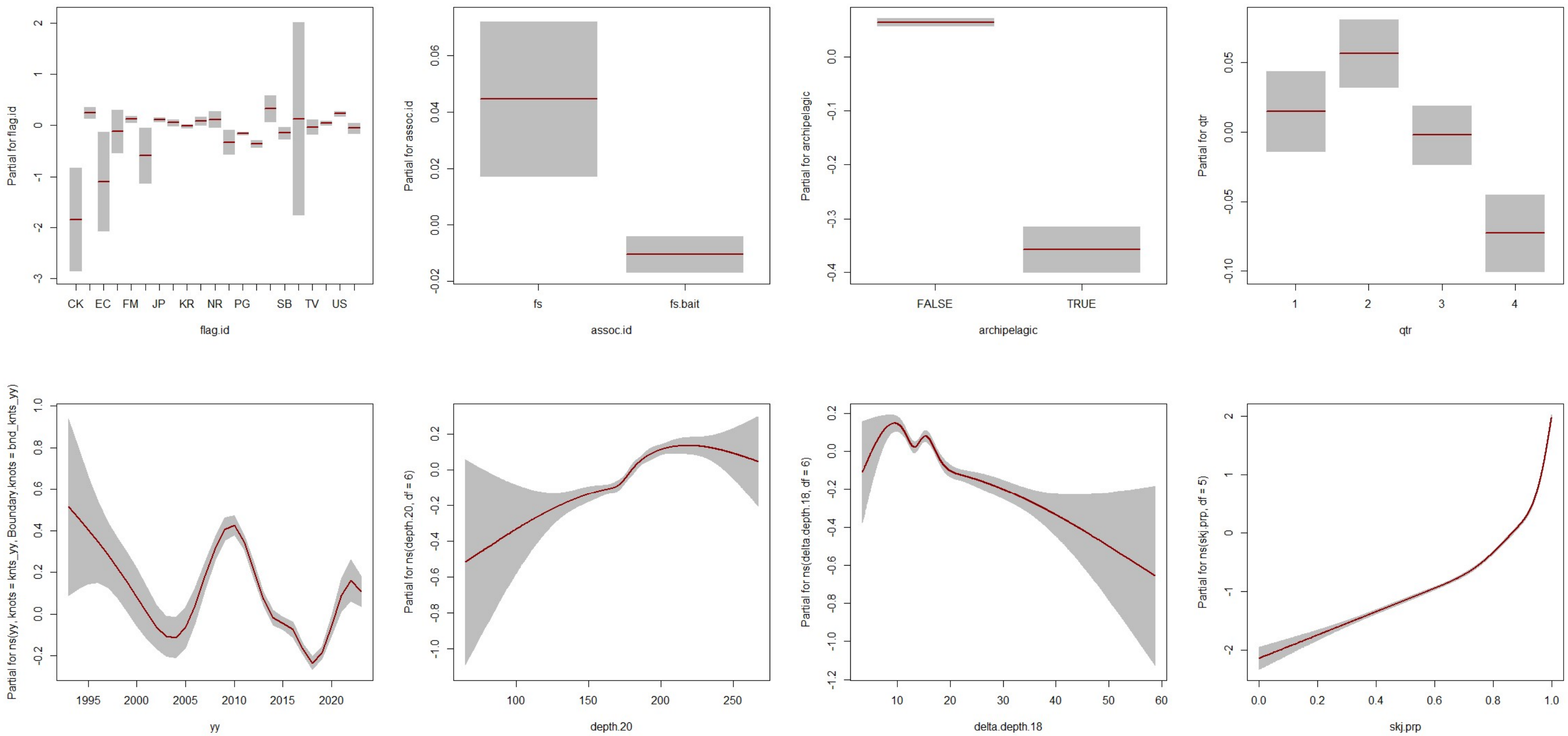

Figure 10 Effect plots for the one-inflation component of the skipjack free-school model. Top row, left to right: flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters; quarter. Bottom row, left to right: year; isotherm depth; thermal gradient;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

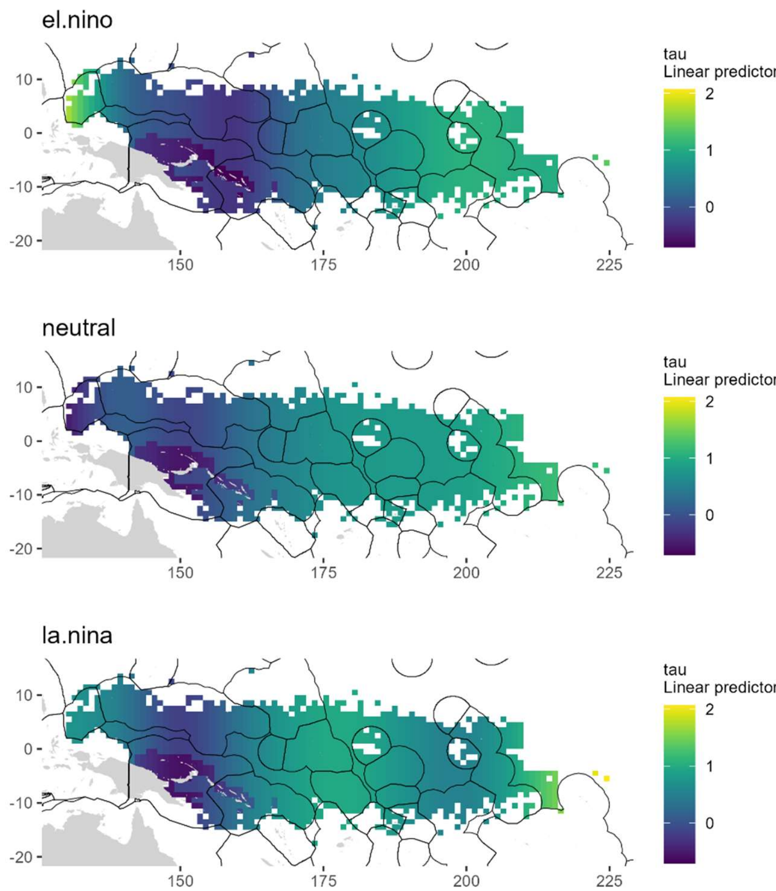

Figure 11 The combined effect of the archipelagic term and the longitude:ONI interaction on the one-inflation component of the skipjack free-school model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

Yellowfin – free school

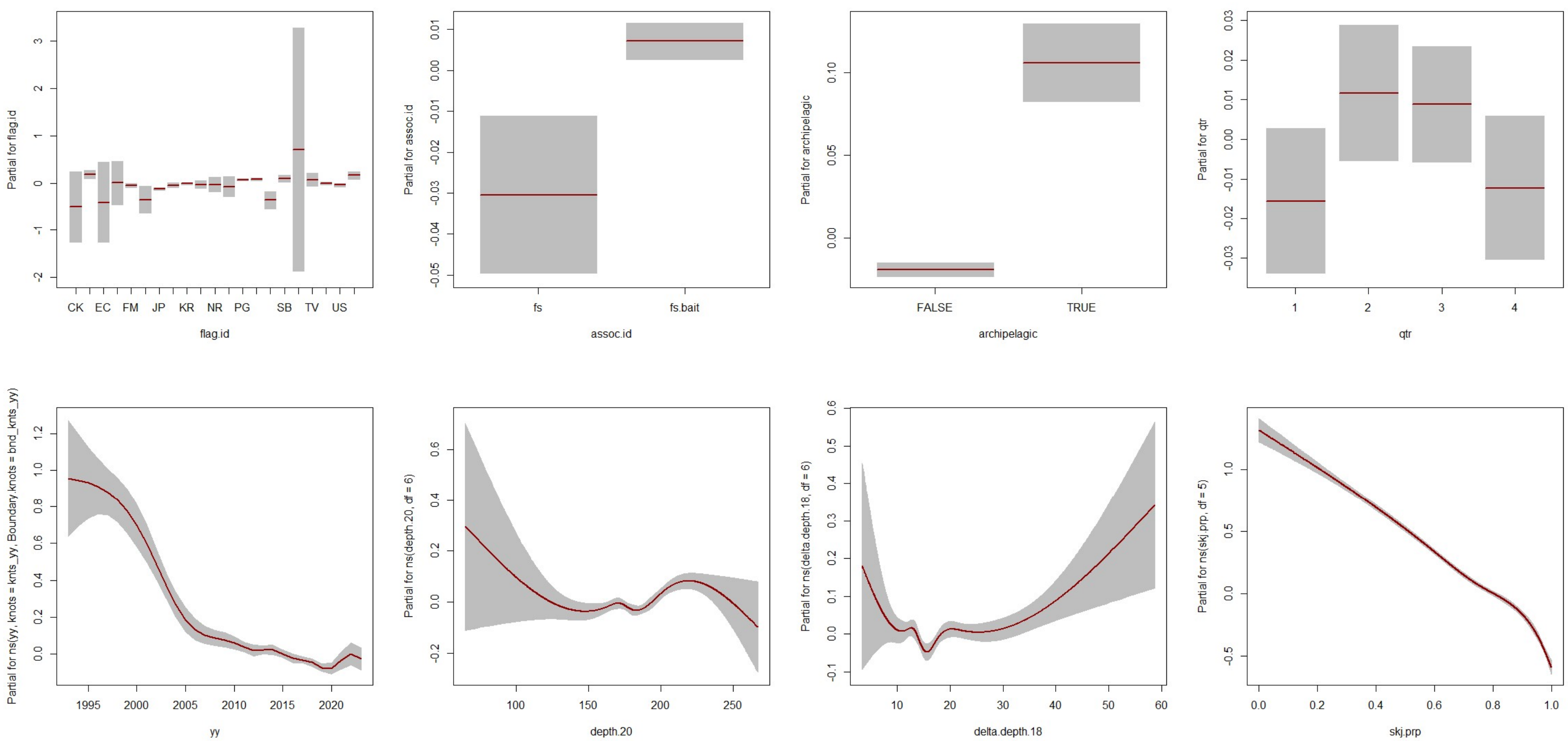

Figure 12 Effect plots for the mean of the beta-component of the yellowfin free-school model. Top row, left to right: flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters; quarter. Bottom row, left to right: year; isotherm depth; thermal gradient;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

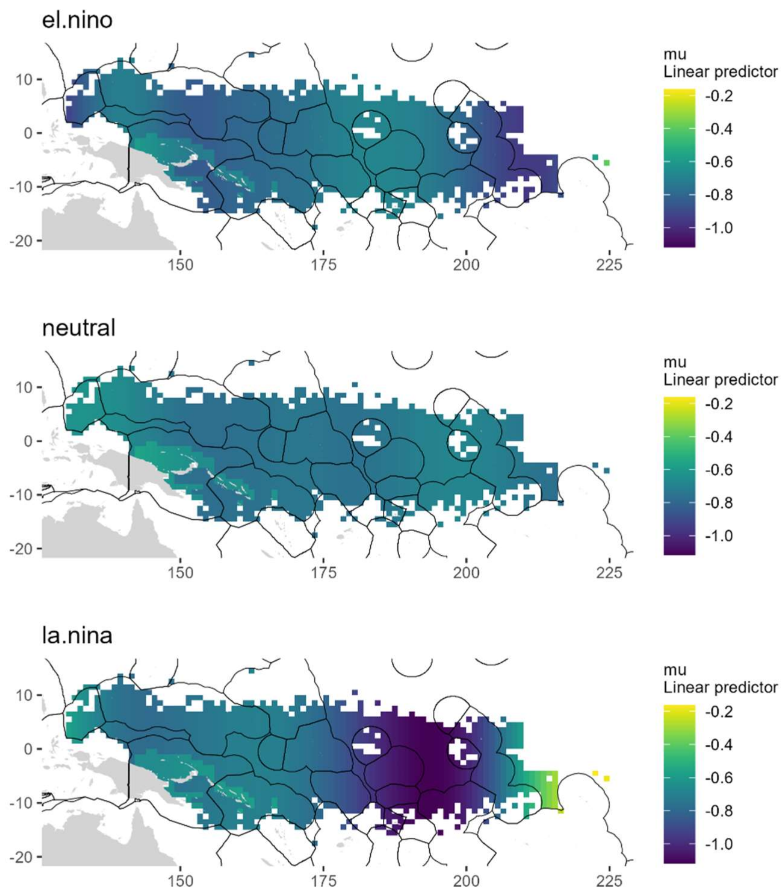

Figure 13 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the yellowfin free-school model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

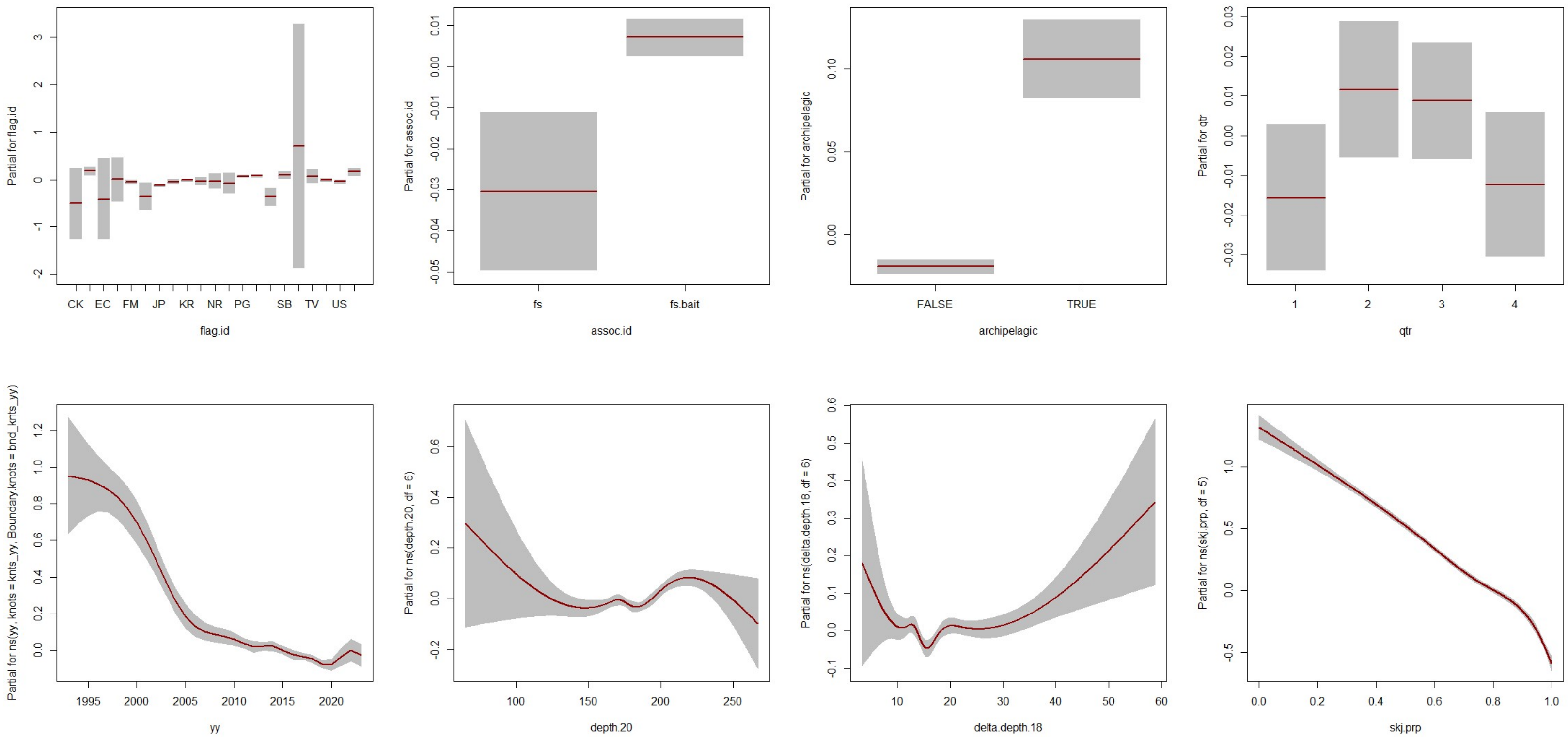

Figure 14 Effect plots for the zero-inflation component of the yellowfin free-school model. Top row, left to right: flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters; quarter. Bottom row, left to right: year; isotherm depth; thermal gradient;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

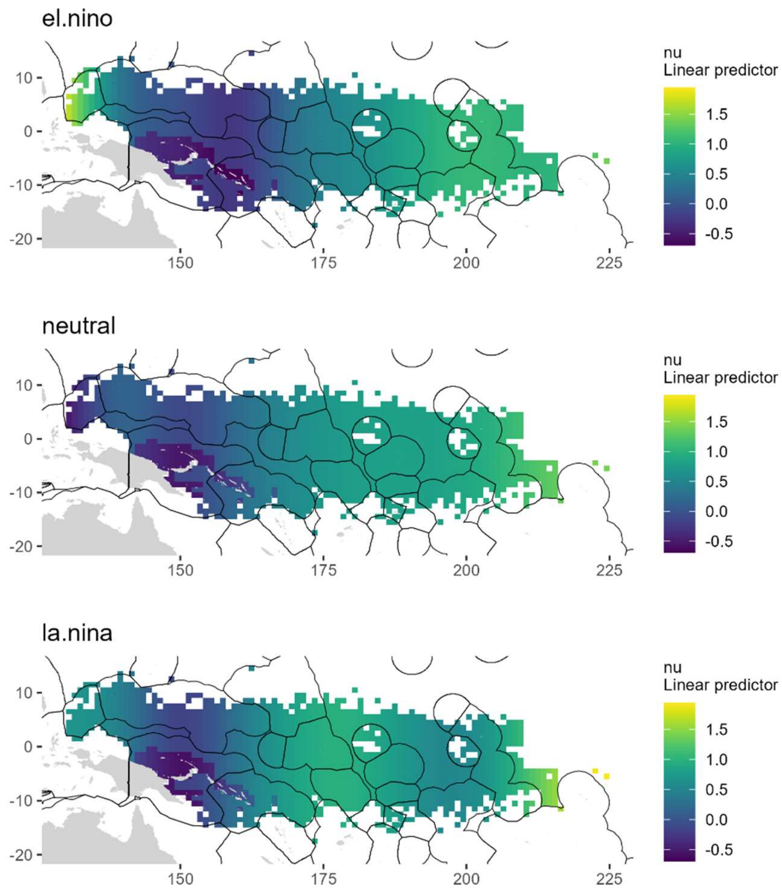

Figure 15 The combined effect of the archipelagic term and the longitude:ONI interaction on the zero-inflation component of the yellowfin free-school model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

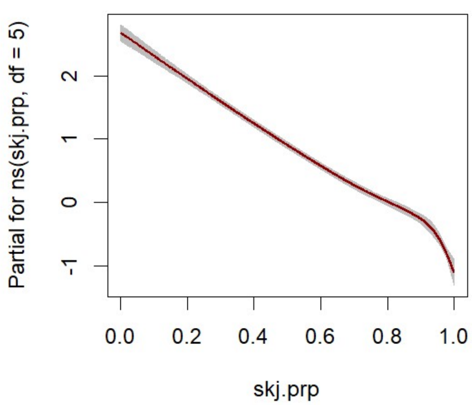

Figure 16 Effect plots for the one-inflation component of the yellowfin free-school model: uncorrected skipjack proportion from vessel logbooks (right).

Bigeye – free school

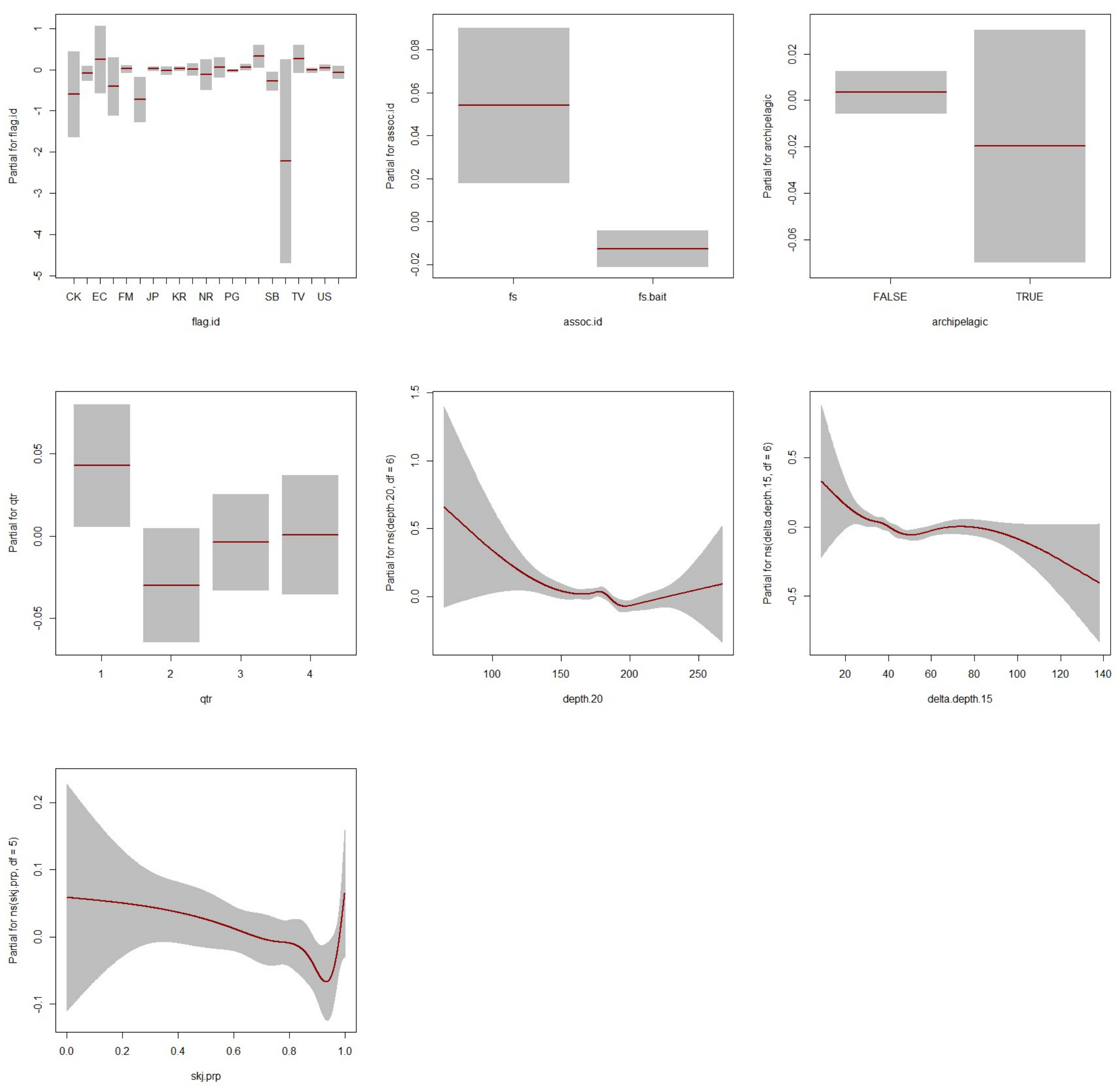

Figure 17 Effect plots for the mean of the beta-component of the bigeye free-school model. Top row, left to right: flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters. Middle row, left to right: quarter; isotherm depth; thermal gradient. Bottom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

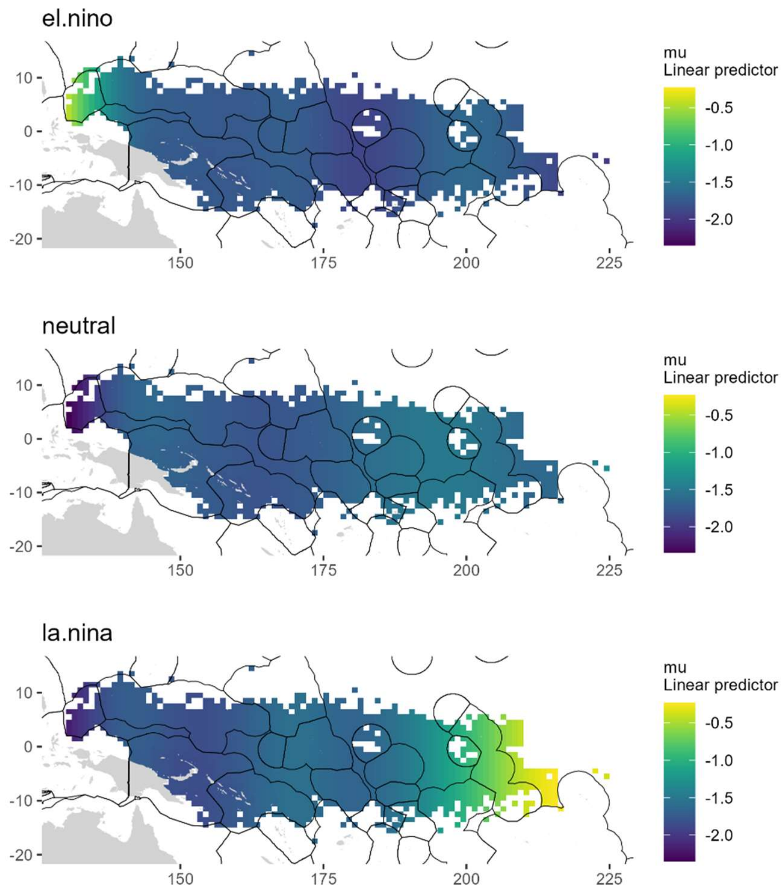

Figure 18 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the bigeye free-school model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

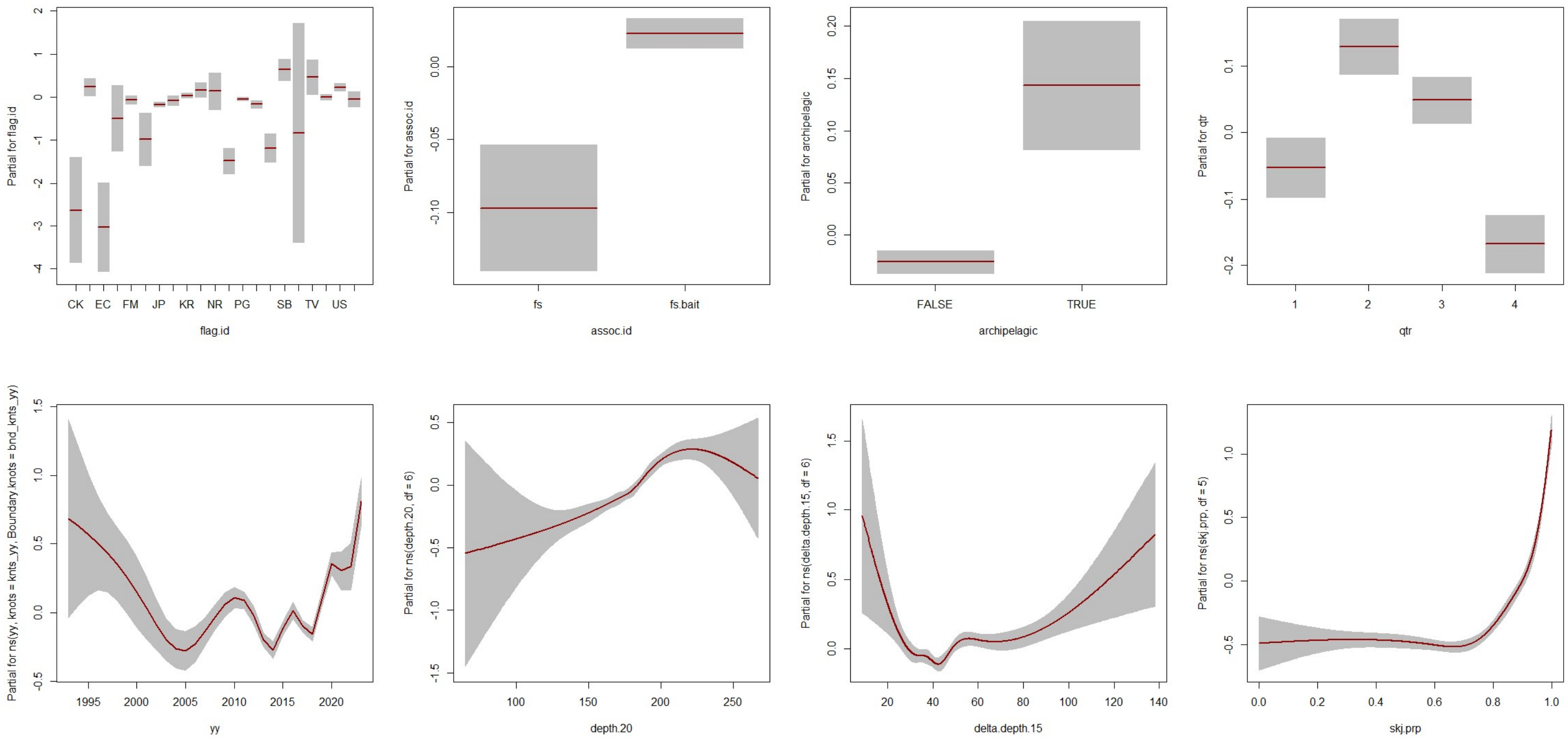

Figure 19 Effect plots for the zero-inflation component of the bigeye free-school model. Top row, left to right: flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters; quarter. Bottom row, left to right: year; isotherm depth; thermal gradient; uncorrected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

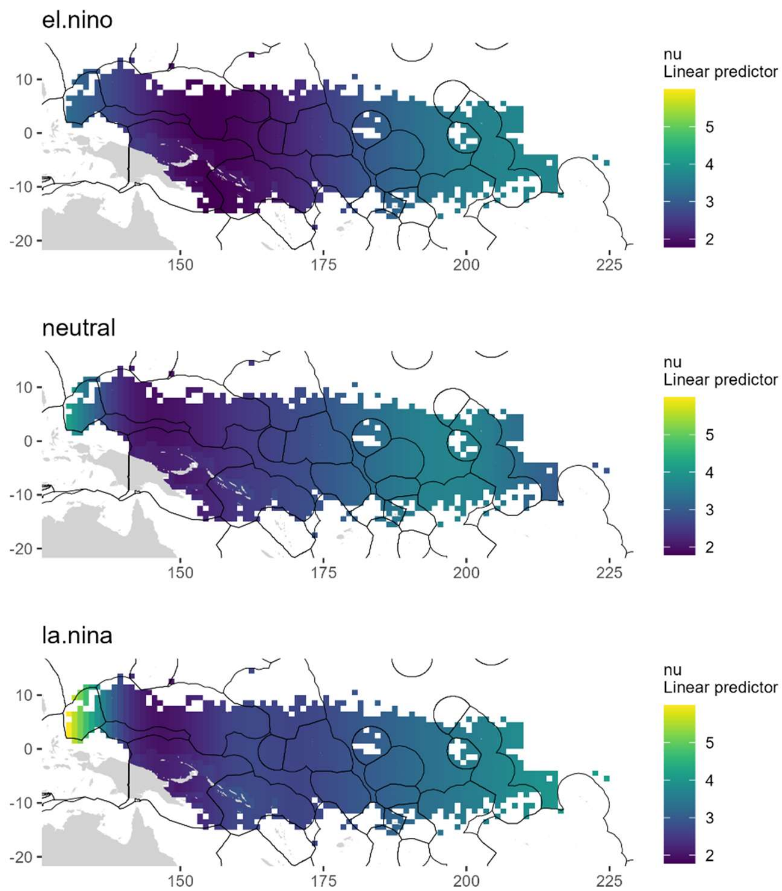

Figure 20 The combined effect of the archipelagic term and the longitude:ONI interaction on the zero-inflation component of the bigeye free-school model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

Skipjack – associated

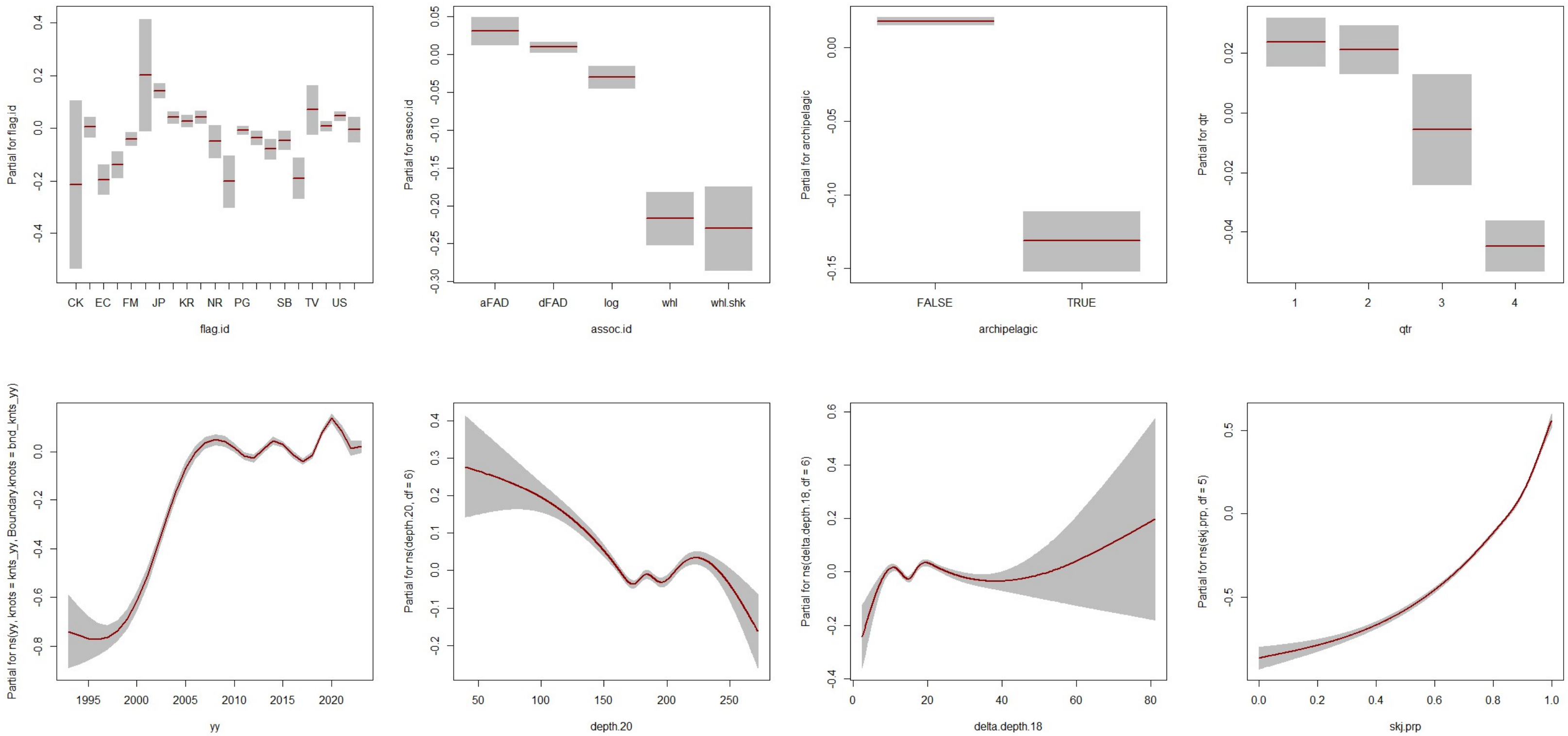

Figure 21 Effect plots for the mean of the beta-component of the skipjack associated model. Top row, left to right: flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters; quarter. Bottom row, left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

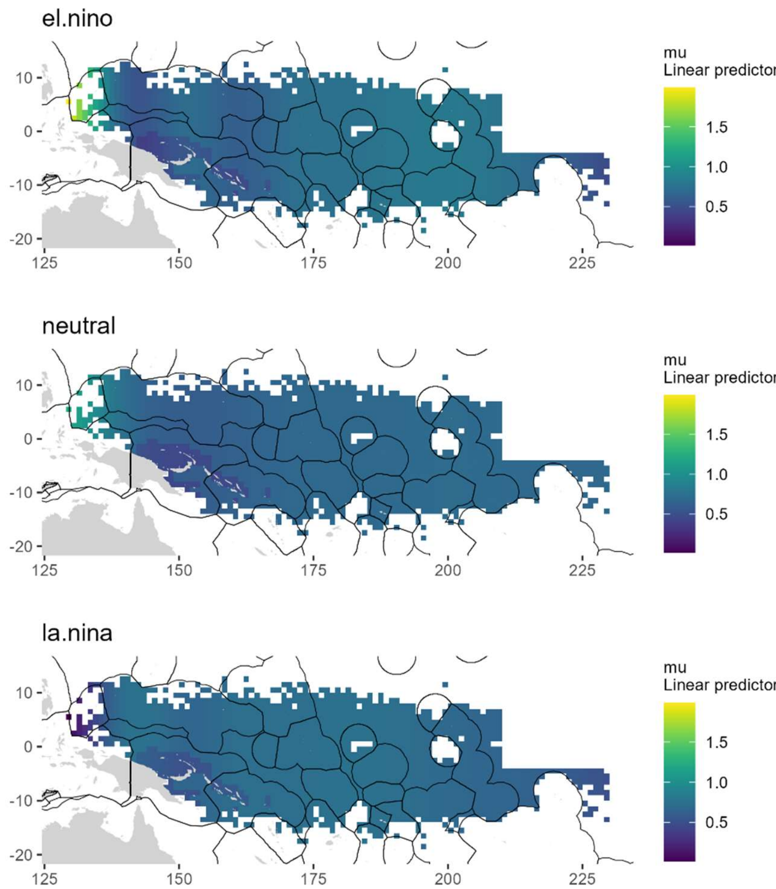

Figure 22 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the skipjack associated model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

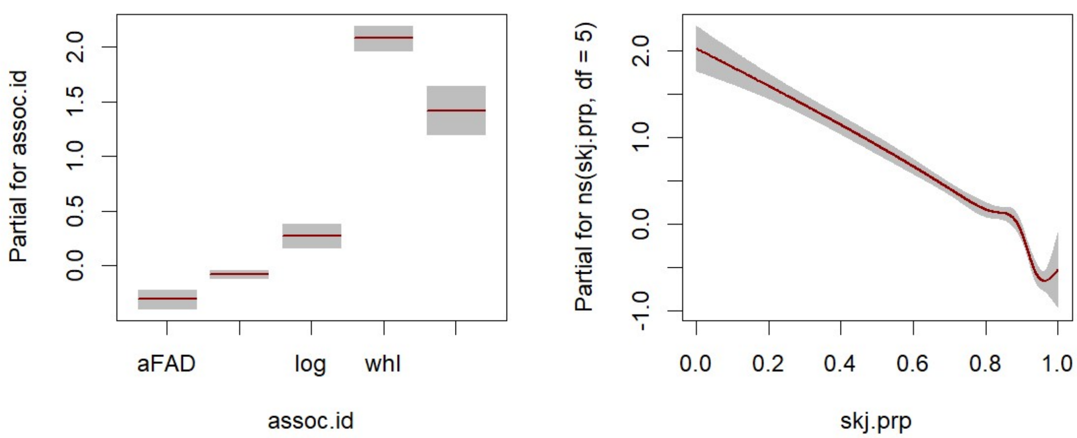

Figure 23 Effect plots for the zero-inflation component of the skipjack associated model: association type (left panel, anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk) and, uncorrected skipjack proportion from vessel logbooks (right panel).

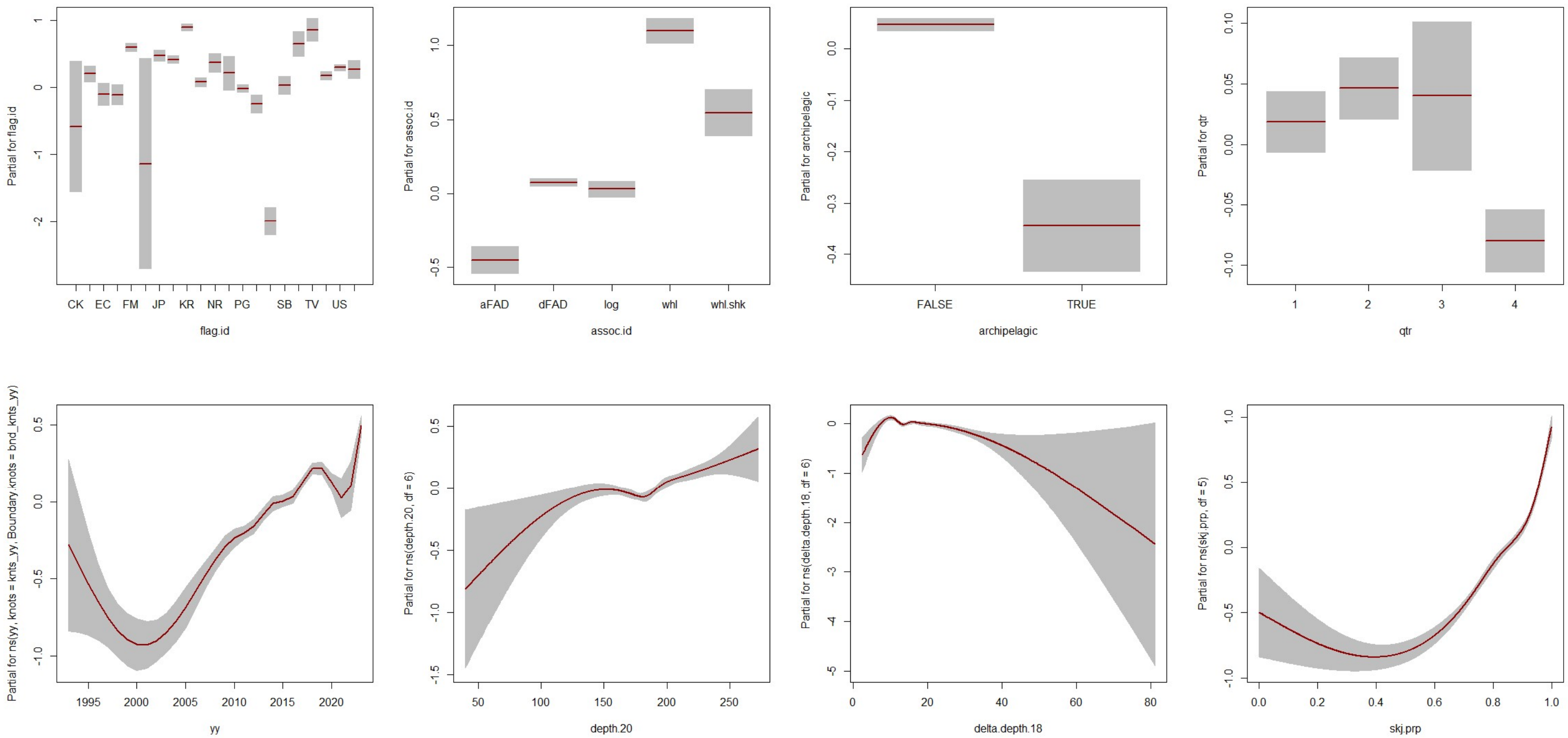

Figure 24 Effect plots for the one-inflation component of the skipjack associated model. Top row, left to right: flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters; quarter. Bottom row, left to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

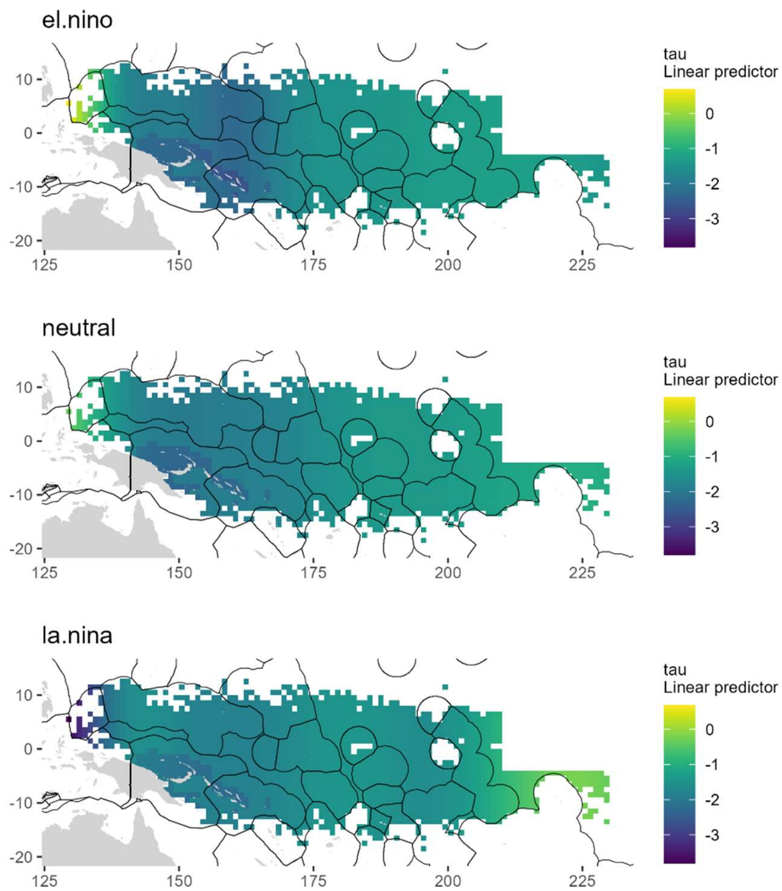

Figure 25 The combined effect of the archipelagic term and the longitude:ONI interaction on the one-inflation component of the skipjack associated model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

Yellowfin – associated

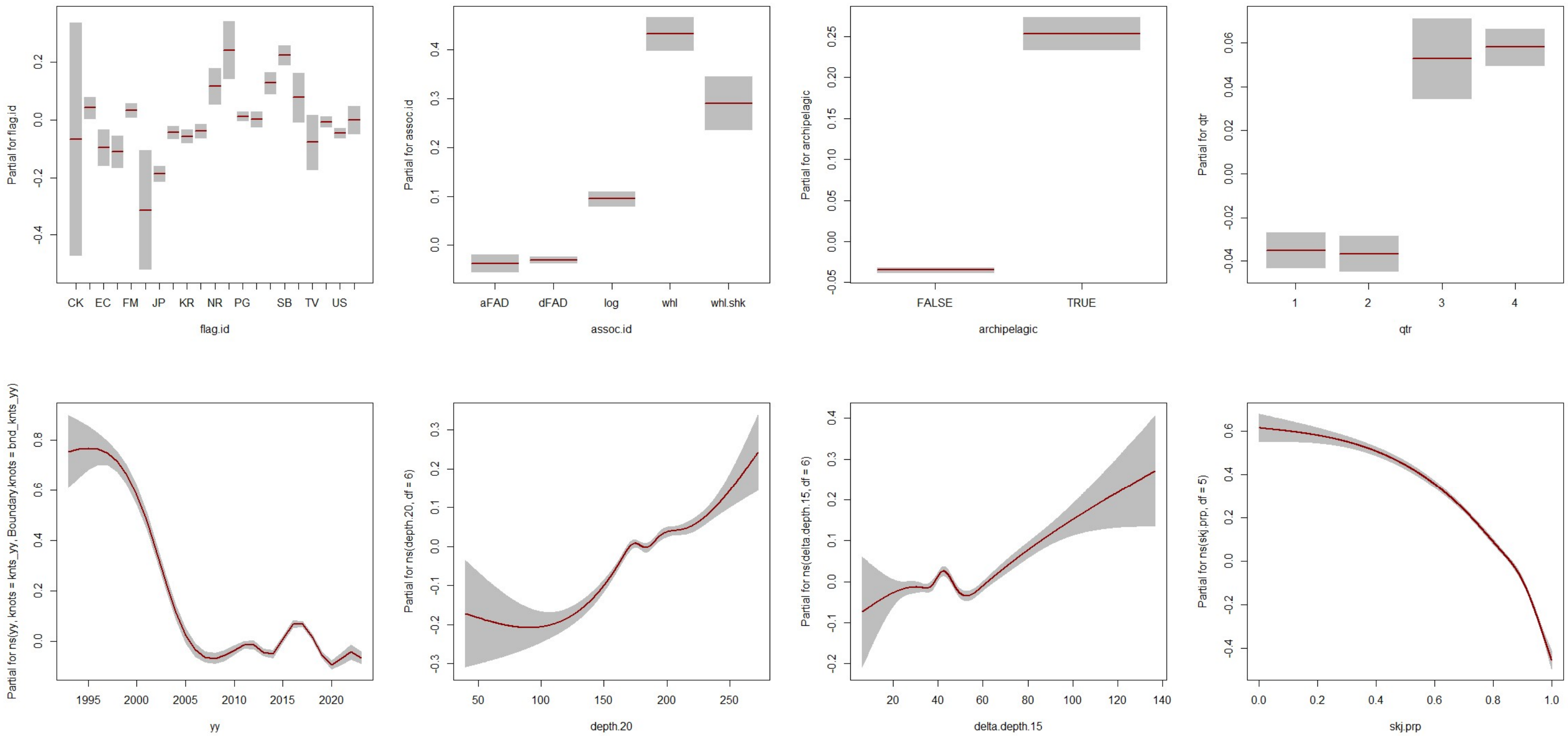

Figure 26 Model effects for the mean of the beta-component of the yellowfin associated model. Top row, left to right: flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters; quarter. Bottom row, left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

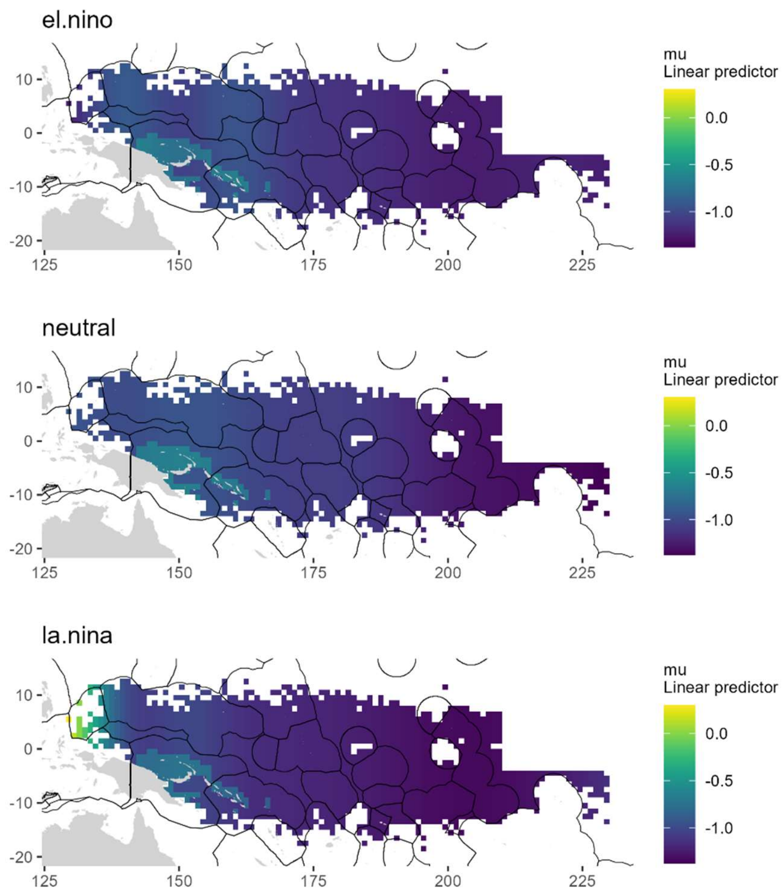

Figure 27 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the yellowfin associated model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

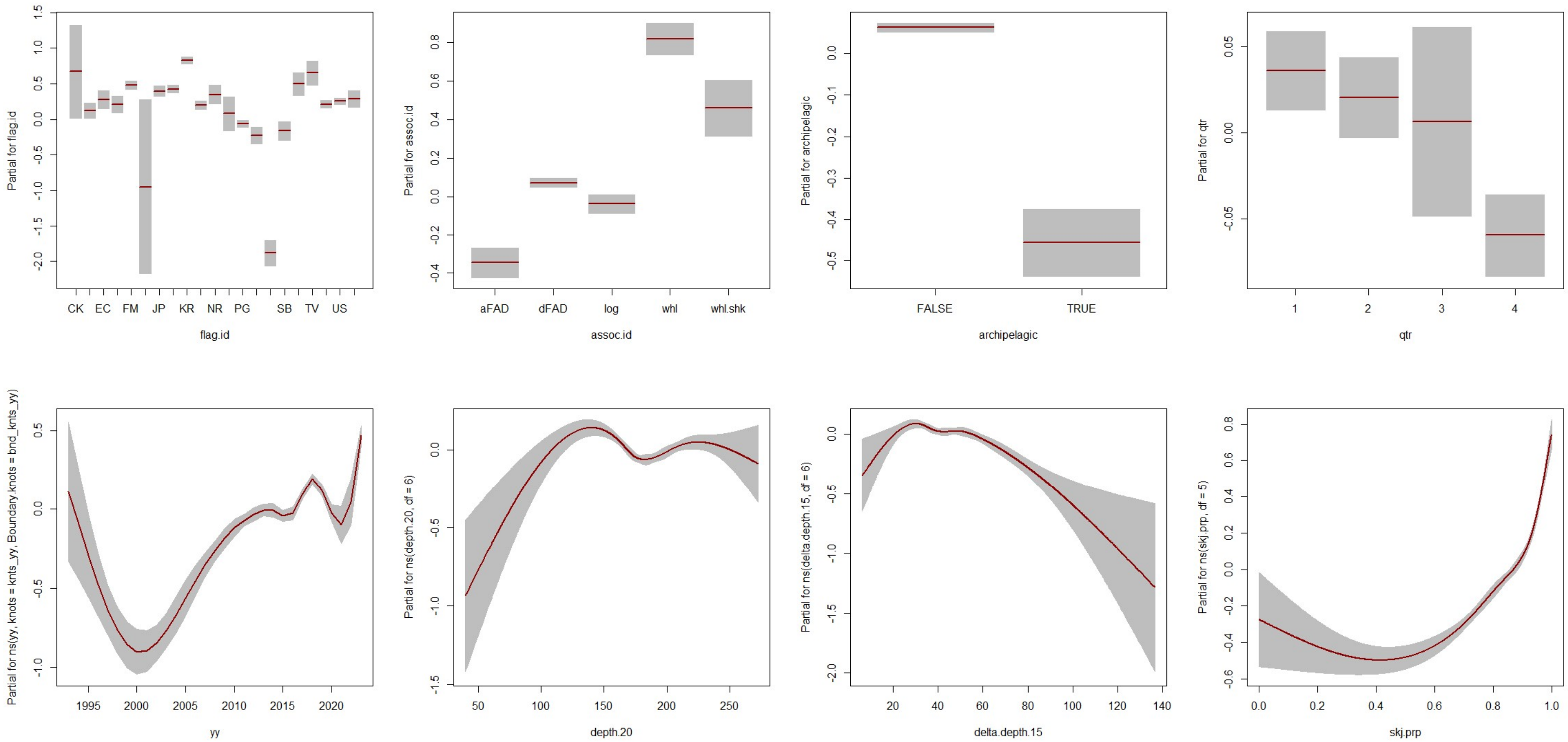

Figure 28 Model effects for the zero-inflation component of the yellowfin associated model. Top row, left to right: flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters; quarter. Bottom row, left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

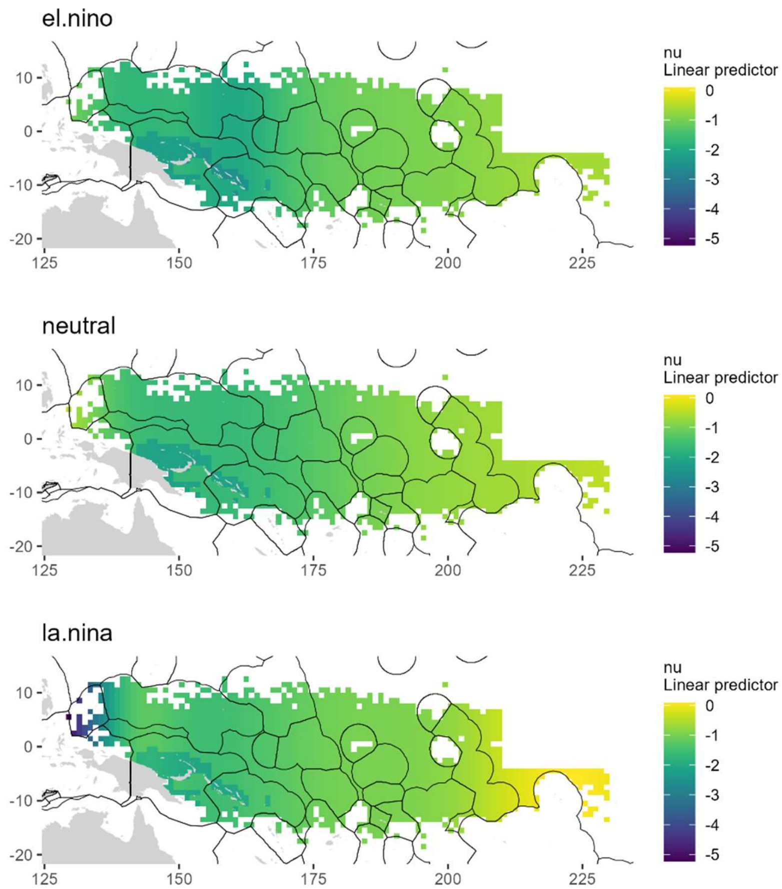

Figure 29 The combined effect of the archipelagic term and the longitude:ONI interaction on the zero-inflation component of the yellowfin associated model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

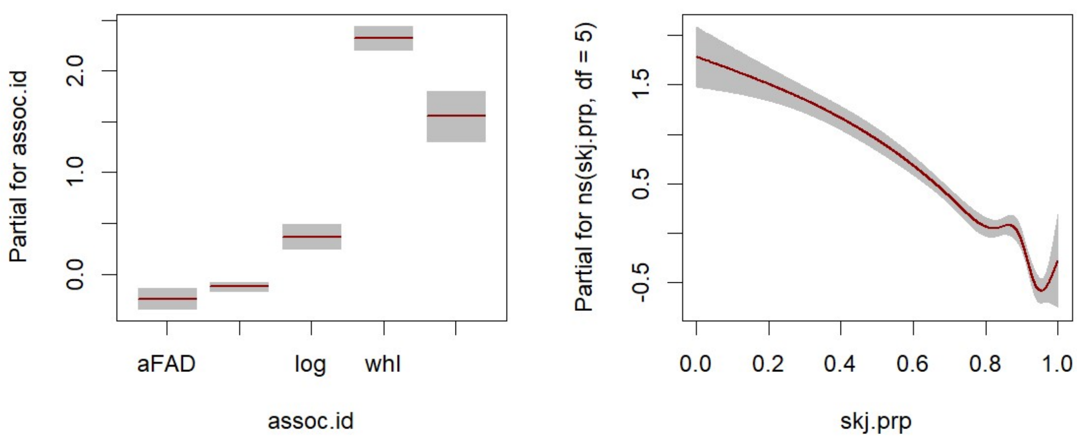

Figure 30 Effect plots for the one-inflation component of the yellowfin associated model: association type (left panel- anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk) and, uncorrected skipjack proportion from vessel logbooks (right panel).

Bigeye – associated

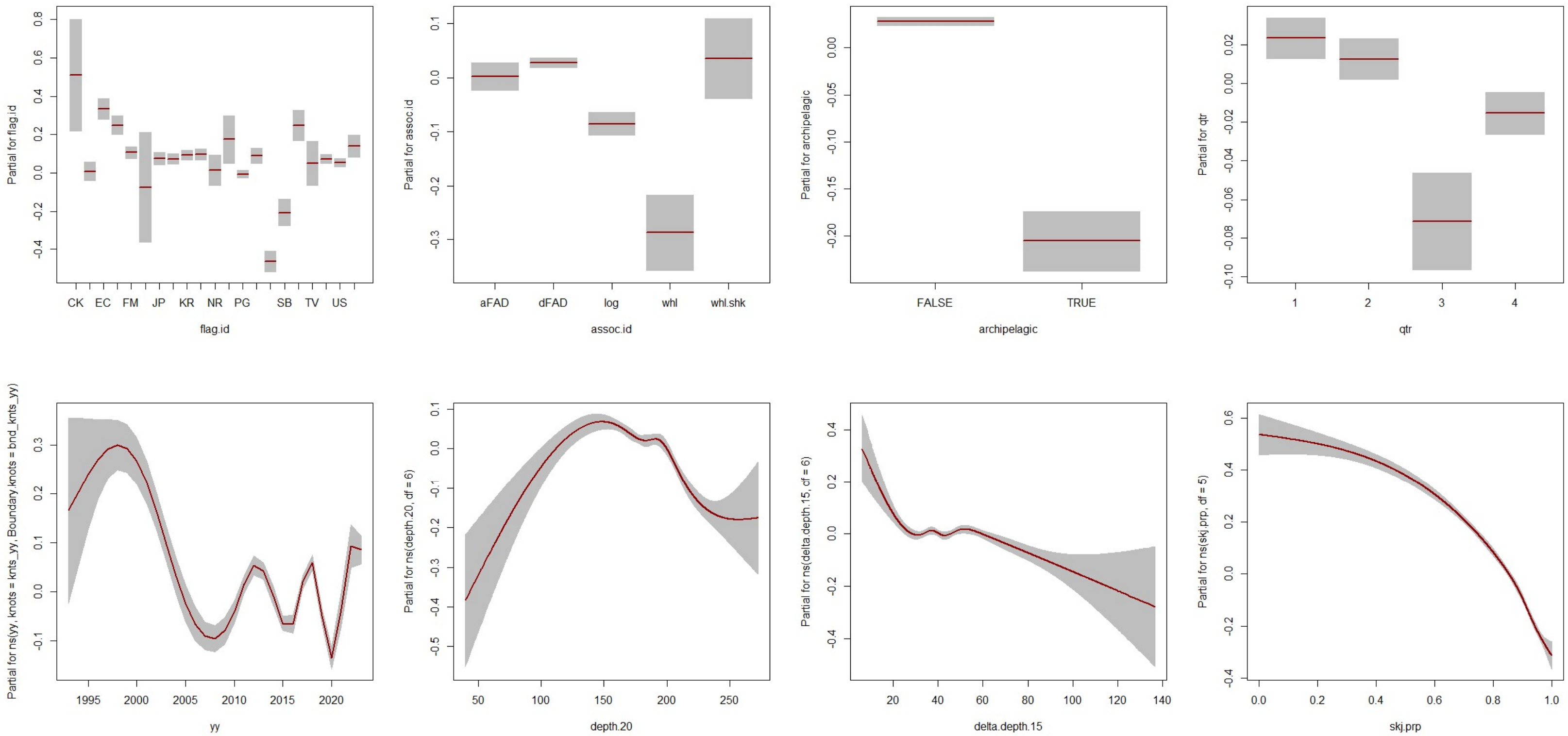

Figure 31 Effect plots for the mean of the beta-component of the bigeye associated model. Top row, left to right: flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters; quarter. Bottom row, left to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

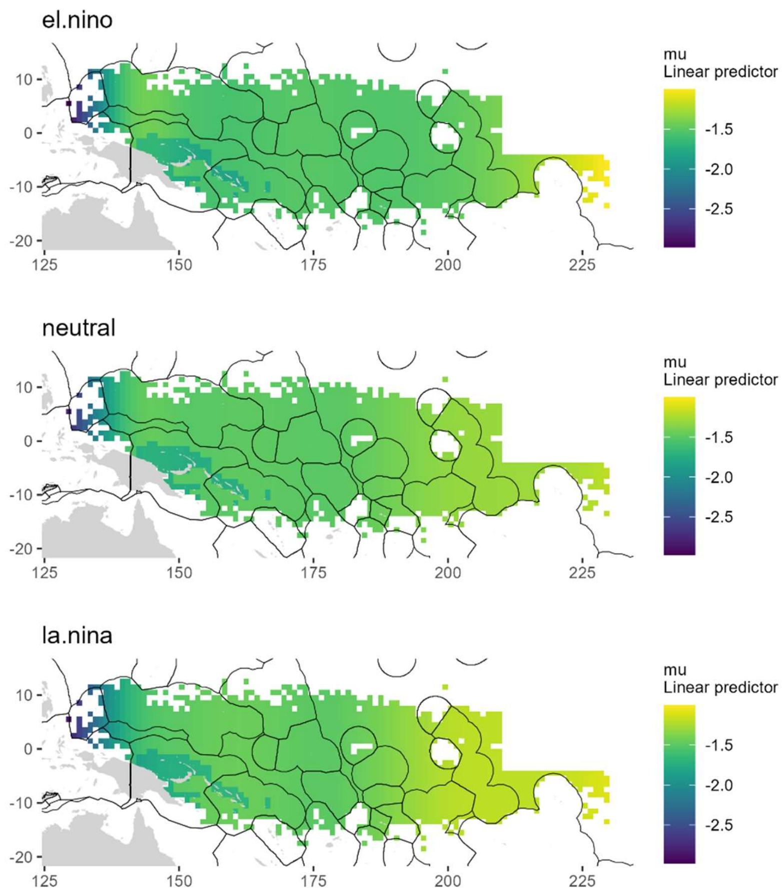

Figure 32 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the bigeye associated model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

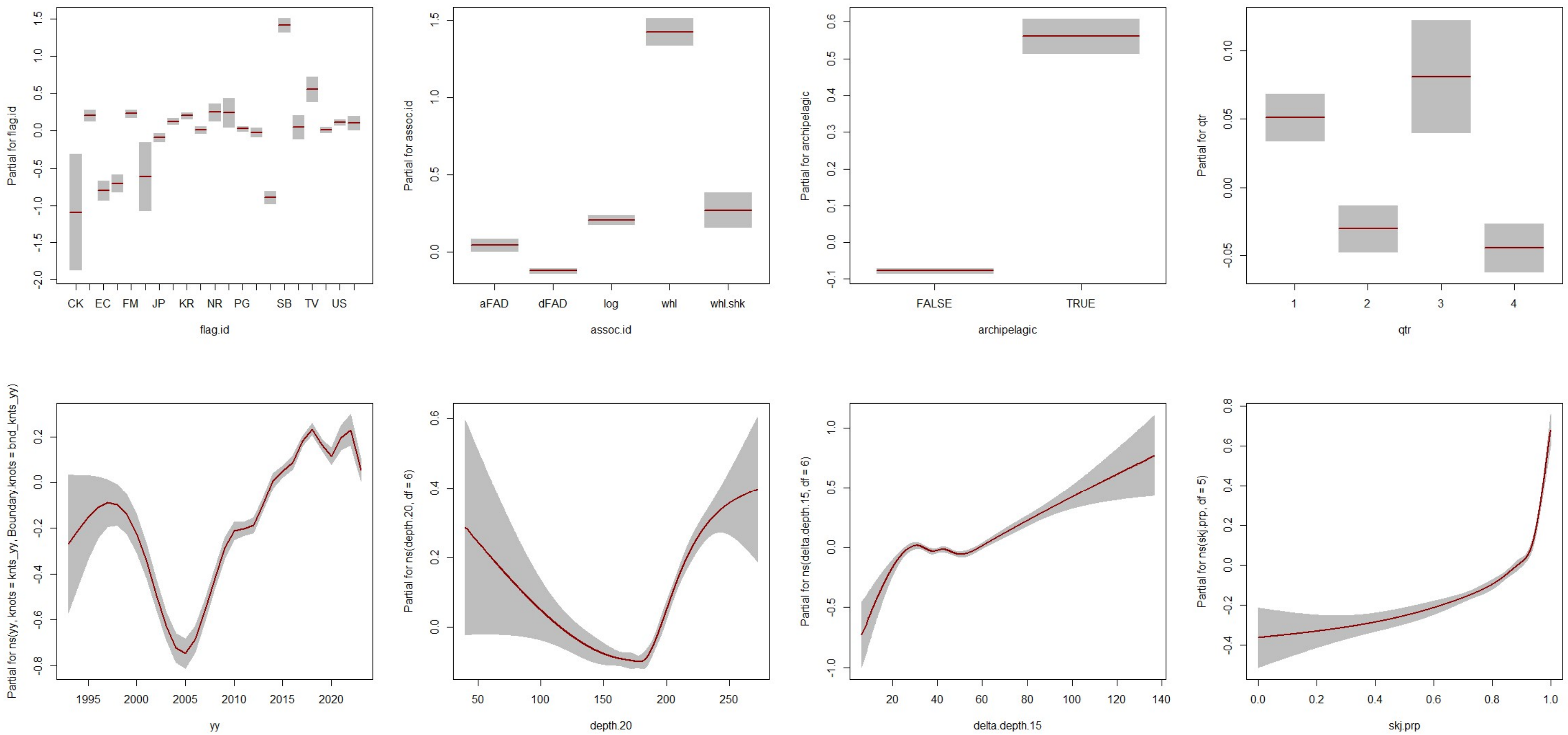

Figure 33 Effect plots for the zero-inflation component of the bigeye associated model. Top row, left to right: flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters; quarter. Bottom row, left to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

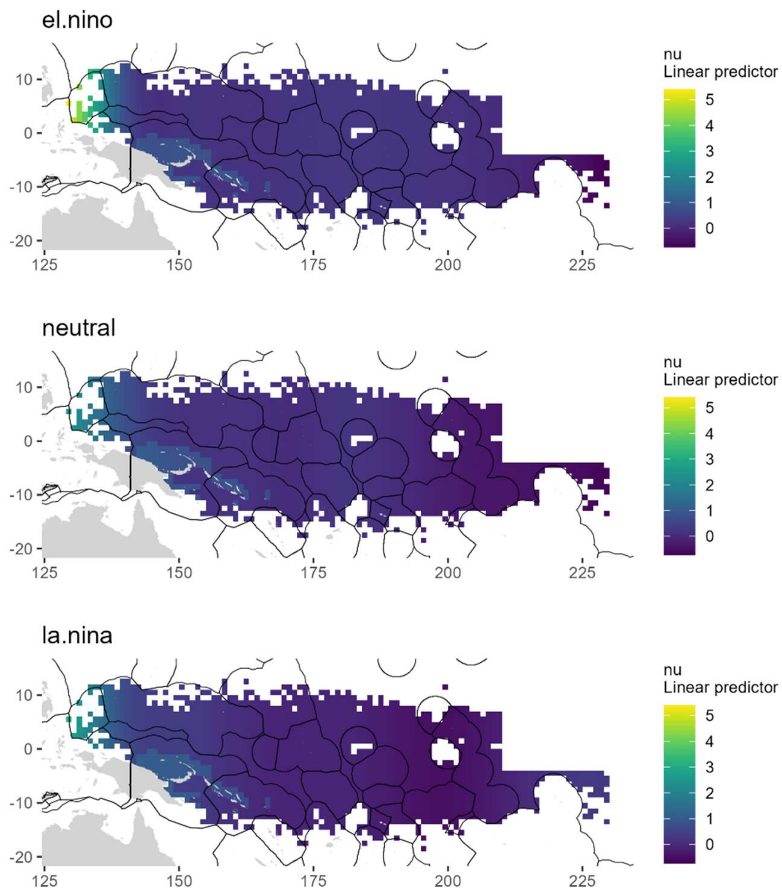

Figure 34 The combined effect of the archipelagic term and the longitude:ONI interaction on the zero-inflation component of the bigeye associated model (top panel – El Nino, middle panel – neutral, bottom panel – La Nina).

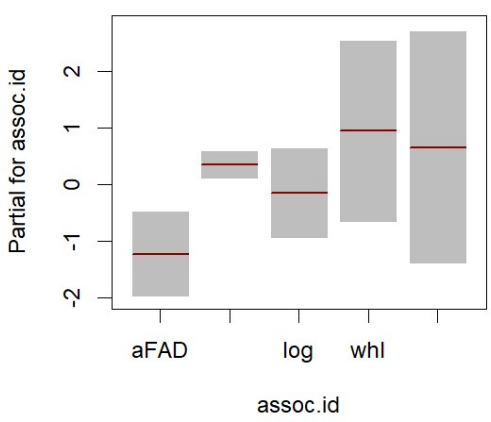

Figure 35 Effect plot for the one-inflation component of the bigeye associated model: association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk).