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Better purse seine catch composition estimates: progress on the Project 60 work plan

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Executive summary

This report summarises progress on the Project 60 work plan as endorsed by the 2018 Scientific Committee. The main activities undertaken since SC14 were: a paired grab/spill trip, conducted on a Solomon Island flagged purse seiner in March 2019; construction of beta response models of species compositions; and, estimation of species-specific catch estimates for purse seiners with a variety of changes to the current methodology.

The generalised additive models currently used to estimate species compositions fit poorly to observations, particularly for bigeye. Zero and one inflated beta models have been developed that achieve better fits and consequently more robust estimates of species compositions. The beta-response models detected between-flag variability in catch compositions. This suggests that the accuracy of observer-sample based species composition estimates would also be improved by additionally stratifying samples by flag.

At SC14, the Scientific Services Provider recommended that grab samples be adjusted to account for grab sample bias using 'correction factors'. On the basis of work presented here, we recommend that: the zero and one inflated beta response models be used for model-based estimates of species compositions; and, that observer samples are stratified by flag when used to directly estimate species compositions. Stepwise changes to species-specific catch estimates were calculated, to identify the sensitivity of catch estimates to the various proposed changes. Species-specific catch estimates were insensitive to the switch to 'correction factor' bias correction, and additional stratification of observer samples by flag. Species-specific catch estimates were most sensitive to the change to beta-response model based estimates. The beta-response models estimated substantially lower yellowfin proportions and higher skipjack proportions for the period from 1997 to 2006, and estimated higher bigeye proportions from 1975 to 1995.

The report concludes with a proposed workplan for 2020, with activities including:

- additional paired grab-spill trips (high priority);
- continuing to explore opportunities for collaboration with members, to undertake comparisons of observer sample and model based estimates of species compositions accurate unloadings, landings or cannery data (high priority);
- investigation of video-based sampling for estimation of species and size compositions (medium);
- construction of a simulation model to explore potential bias from between-brail variability in size and species compositions (medium); and,
- a cost-benefit analysis of alternative sampling approaches for long-term estimation of species and size compositions (low priority).

We recommend that SC consider the activities, and associated priority, proposed for further work under Project 60, along with the specific recommendations regarding species composition estimation:

- Multinomial-model based correction factors be used to correct existing and future grab sample data, rather than the estimates of 'availability';
- The beta-response models be used to generate catch estimates; and,
- Observer samples are stratified by flag when used to directly estimate species compositions.

1 Introduction

1.1 Project Objective

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.

1.2 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 SC12 and SC13, along with a proposed work plan moving forward (Peatman et al., 2017a). 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). The Scientific Service Provider presented a two-year work plan to the 2018 Scientific Committee, reflecting the work undertaken between SC13 and SC14, which was subsequently endorsed (Anon., 2018).

1.3 Project 60 Scope

The scope of Project 60 as outlined in 2016 includes, but is not limited to, the following:

a) Continue to identify key sources of sampling bias in the manner in which species composition data are currently collected from WCPO purse seine fisheries and investigate how such biases can be reduced;
b) Review a broad range of sampling schemes at-sea as well as onshore; develop appropriate sampling designs to obtain unbiased species composition data by evaluating the selected sampling procedures; extend sampling to include fleets, areas and set types where no representative sampling has taken place; verify, where possible, the results of the paired sampling against cannery, unloading and port sampling data;
c) Review current stock assessment input data in relation to purse-seine species composition and investigate any other areas to be improved in species composition data, including the improvements of the accuracy of collected data;
d) Update standard spill sampling methodology if required; and,
e) Analyse additional data collected to evaluate the benefits of spill sampling compared to corrected grab-sampling.

1.4 Addressing SC14 recommendations

The SC recommendations from 2018 were that the Scientific Service Provider should proceed with the two-year work plan proposed in Peatman et al. (2018). The following activities were scheduled to take place before SC15:

a) undertake paired grab-spill sampling trips;
b) construction of a simulation model to explore potential bias from between brail variability;
c) finalise beta-response models of species compositions;
d) explore the need to stratify observer samples by flag when estimating species compositions directly from observer data;
e) report species composition estimates to SC15 with step-wise changes from the existing approach; and,
f) continuing to explore opportunities for collaborative work with members.

This paper sets out work that was undertaken between SC14 and SC15, and proposes a refined workplan for August 2019 onwards. In brief, the following activities have been completed. A paired grab/spill trip was undertaken on a Solomon Island flagged purse seiner in March 2019 (Section 4.1). The estimates of 'availability' and 'correction factors' presented at SC14 have been updated to include data from the additional paired trip. Routines to estimate grab and spill sampling data have been updated to include estimation of uncertainty in catch compositions, by bootstrapping from observations. Beta-response models of species compositions have been developed (Section 2). Significant between-flag variation in catch compositions was detected in the beta-response models, suggesting that stratification of observer samples by flag will improve the accuracy of flag-specific catch compositions when basing species compositions directly on observer data.

On the basis of the above, a number of improvements have been proposed to the methodology currently used to estimate species compositions of purse seine catches in SPC's aggregate catch and effort data holdings. Routines have been developed to generate species compositions with step-wise changes from the current approach. The resulting catch estimates are presented in Section 3. Routines have also been developed to estimate species-specific length frequencies based on available samples, which are presented in Section 4.2. The report finishes with a proposed work plan for 2019/2020.

2 Models of species compositions

Generalised additive models (GAMs) are currently used to estimate species compositions of purse seine catch (Lawson, 2013). Separate models are fitted for each combination of species and school association category (free school vs. associated), and there are three different parameterisations of increasing complexity, i.e. 18 models in total. The models assume normally-distributed errors, and are fitted to observer sample based estimates of species proportions that have been aggregated to a combination of trip and school association (free school vs associated). The models fit relatively poorly to the observations primarily due to the assumed error structure and the bounded nature of the response variable (e.g. Peatman, et al 2018). Model fits are particularly poor for bigeye, which generally represents a low proportion of catches and so frequently have observed proportions close to, or equal to, zero. Beta-response models were proposed as a more statistically robust alternative, with zero and one-inflation to account for observations with an absence of a species in observer samples (normally bigeye) or ones (normally skipjack) (Peatman et al., 2018).

2.1 Method

Here we fit zero and one inflated beta-response models to observer-sample based estimates of species compositions. Spill samples collected by the Philippines observer programme are now available in SPC's master observer database, and were included in the modelled dataset. Species compositions from paired grab-spill trips were based on spill samples where possible. The models were implemented in the R package gamlss (Rigby and Stasinopoulos, 2005). Separate models were constructed for each species and school association (free school v associated) combination, and fitted to set-level observations. The contribution of each observation to the likelihood function was weighted by the square root of the number of samples from the set. Random vessel intercepts were used to account for between-vessel variation in catch compositions. As per Lawson (2012), we included: school association type effects (e.g. drifting FAD, anchored FAD etc), to account for variation in species compositions between different types of associated sets; year and quarter effects, to account for temporal and seasonal variation; flag effects, to account for between-flag variation; and reported skipjack proportions from aggregate catch data, which provides some information on species compositions[2]. We replaced the two-dimensional latitude-longitude surfaces with longitude effects, and introduced an interaction with a categorical variable based on the Oceanic Nino Index (ONI, Huang et al, 2017), as exploratory data analyses suggested that spatial patterns in species compositions might vary between El Nino, La Nina and neutral periods. Months falling in periods with a minimum of 5 consecutive ONI values exceeding 0.5 or less than -0.5 were classified as 'El Nino' and 'La Nina' respectively, and otherwise classified as 'neutral'. Finally, we included the depth of the 20 C isotherm, interpolated from NCEP GODAS monthly mean potential temperatures at depth and regridded to a 1° spatial resolution (Behringer & Xue, 2004[3]). The specifications of the models are provided in Appendix A.

2.2 Results

Effect plots for the final beta-response models are provided in Appendix A, Figure 5 to Figure 33. The y-axis for effects plots of the mean of the beta component are on the logit scale, with a higher value translating to a higher mean proportion. The y-axis for the effect plots of the zero and one-inflation components are on the log scale, with a higher value translating to more prevalent 0s and 1s respectively.

The uncorrected skipjack proportion from aggregate data had the strongest effect on the mean of the beta component of skipjack in free school sets (Appendix A, Figure 5). Free school sets feeding on baitfish, and sets in archipelagic waters, were associated with slightly lower skipjack proportions. A weak increasing trend in skipjack proportions was detected from 2014 onwards, with an apparent increasing trend also detected during the late 1990s and early 2000s. The effect of longitude was strongest during La Nina events, with increased skipjack proportions west of 175E (Appendix A, Figure 6). The effects of model terms on the one-inflation component were generally consistent with the effects of the beta-component of the model, e.g. sets in archipelagic waters were associated with lower rates of pure skipjack catches (Appendix A, Figure 8 and Figure 9). However, there was less variation in longitudinal effects with ONI classification, with sets in the central Pacific associated with higher prevalence of pure skipjack catches. Skipjack proportion had a strong effect on the zero-inflation component of the model, with lower reported skipjack proportions associated with higher prevalence of catches with no skipjack. The term effects of the yellowfin free-school are generally the opposite of the skipjack free-school model (Appendix A, Figure 10 to Figure 14).

Model terms had weak effects on the mean of the beta component of the bigeye free school model (Appendix A, Figure 15). The effect of longitude was strongest in La Nina events, with mean bigeye

[2] The unadjusted proportion of skipjack was determined for the stratum of year – quarter – 2° x 2° grid – school association (associated or unassociated). See Lawson (2013) for more information.
[3] GODAS data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at https://www.esrl.noaa.gov/psd/

proportion increasing in an eastwards direction (Appendix A, Figure 16). Model terms had stronger effects on the zero-inflation component of the bigeye free school model (Appendix A, Figure 17 and Figure 18). Increasing depths of the 20°C isotherm were associated with increased prevalence of bigeye absence in catches. There was also strong between flag-variation. Longitudinal trends demonstrated relatively little variation between ONI classification, with prevalence of catches with no bigeye increasing in an eastwards direction.

Uncorrected skipjack proportion had the strongest effect on the mean of the beta component of the skipjack associated sets model (Appendix A, Figure 19). There was strong between-flag variation. Sets on anchored FADs, drifting FADs and logs were associated with higher skipjack proportions than sets on schools associated with whales and whale sharks. Sets in archipelagic waters were associated with lower skipjack proportions. The effect of year was variable, with higher skipjack proportions in 2010 and 2015. Skipjack proportion and association type both had strong effects on the zero-inflation component of the model (Appendix A, Figure 21). Sets on schools associated with whales and whale sharks were associated with higher prevalence of skipjack absence. Skipjack proportion, flag and school association type all had strong effects on the one-inflation component of the model (Appendix A, Figure 22). Sets on whales and whale sharks were associated with higher prevalence of pure skipjack catch. Sets west of 170E were associated with lower prevalence of pure skipjack catch, particularly during El Nino events (Appendix A, Figure 23). The term effects of the yellowfin associated model are generally the opposite of those for the skipjack associated model (Appendix A, Figure 24 to Figure 28).

Model terms had generally weak effects on the mean of the beta component for bigeye in associated sets (Appendix A, Figure 29). Sets in archipelagic waters were associated with lower bigeye proportions. Deeper 20°C isotherm depths were associated with lower bigeye proportions. Persistent longitudinal trends were detected, with bigeye proportions increasing in an eastward direction (Appendix A, Figure 30). The effects of terms on the zero-inflation component were generally consistent with those from the beta component. Deeper 20°C isotherm depths were associated with higher prevalence of bigeye absence in catches. Sets in archipelagic waters were associated with higher prevalence of bigeye absence.

Spatial / temporal comparisons of predicted and observed species compositions indicated that the models adequately captured broad-scale spatial variations in catch proportions (e.g. Appendix A, Figure 34 to Figure 36). Observed proportions did demonstrate substantially more spatial variability, though this reflects the increased variability in observer sample based catch composition estimates in areas with limited samples.

Auto-correlation of residuals within-trips was identified for all of the beta-response models, and was particularly strong for models of associated set compositions. Replacing random intercepts for vessels with intercepts for vessel-year or vessel-year range combinations reduced, but did not remove, auto-correlation, and introduced issues with violation of distributional assumptions for the random effects. We also note that strong patterns in residuals were detected against set catch volume for models of associated set catch proportions. Skipjack proportions had a tendency to be over-estimated for sets smaller than 20 tonnes and under-estimated for larger sets, with the opposite true for yellowfin (Appendix B, Figure 38). Otherwise, robust model fits were achieved.

2.3 Discussion

The generalised additive models currently used to estimate species compositions fit poorly to observations, particularly when observed proportions are equal, or close, to 0 and 1 (see Section 2.1 and references therein). The fits of the models for bigeye proportions are particularly poor. The zero and one inflated beta response models presented here achieve better fits to catch proportions of all three species, and as such provide a more robust alternative to the existing models of species compositions. We recommend that the beta response models be used to correct reported catches in aggregate catch and effort data, and for the generation of catch estimates for MFCL stock assessments (see Section 3).

Beta-response models detected significant between flag-variation in catch proportions, particularly for associated sets. This suggests that the accuracy of observer-sample based species composition estimates, used for strata where observer coverage exceeds 20 %, would be improved by additionally stratifying samples by flag. This is explored in Section 3.

Within-trip auto-correlation of residuals was detected for all beta-response species composition models, particularly for associated sets. There are a number of potential causes. It is reasonable to expect that the beta-response models are unable to account for fine-scale spatial-temporal variation in catch compositions as a result of the local abundance of tropical tunas. We also note that there is within-trip correlation in set catch volumes, particularly for associated sets. This will likely introduce within-trip correlation in residuals given the detected patterns in residuals against set volume. Regardless, the species composition models are constructed for application to aggregate catch-effort data, and so are not parameterised to account for fine-scale spatial-temporal variation in catch compositions. However, the beta-response models could be used to explore the effect of finer-scale variables on species compositions, for example estimates of FAD density (Escalle et al., 2019).

There are a number of approaches that could be used to model species proportions in catches. As previously noted (e.g. Lawson, 2012), it would be preferable to model species-specific proportions in a single model, e.g. a Dirichlet response model, rather than modelling each species individually. However it would still be necessary to account for zero and ones. The current approach to accounting for spatial variation in proportions could also be improved, including explicitly accounting for latitudinal and longitudinal spatial correlation. We note that the use of longitude effects to account for spatial variation was essentially a compromise, due to difficulties in fitting more complex spatial effects with the inflated beta-response models. The use of appropriate error distributions was considered more important. The R-INLA package (Rue at al., 2009) provides the flexibility to fit complex spatial correlation structures, though currently does not allow for zero and one-inflated beta-responses or Dirichlet response models. There is also the option of constructing bespoke models, fitted using Bayesian inference, that could allow Dirichlet responses and relatively complex spatial correlation structures, though there would likely need to be some trade-off between model complexity and computational time. More broadly, and perhaps more importantly, there is the question as to whether increasingly complex models of species compositions will improve predicted species compositions in years where observer samples are limited, or not available.

3 Step-wise changes in purse seine catch estimates

3.1 Method

Observer samples are currently used to estimate species compositions of aggregate catch for the tropical purse seine fishery (20°S to 20°N) in the WCPFC Convention Area, excluding: the Japanese fleet, which submits corrected catch data; the domestic fisheries of Indonesia and Vietnam; and, effort from the domestic Philippines fleet outside of the high seas pocket. The estimation method depends on the level of observer coverage. The methodology is described in full in Lawson (2012, 2013) with a summary provided in Hampton and Williams (2015). We outline the approach below, to prevent readers from having to refer extensively to previous reports:

- proportions of skipjack, yellowfin and bigeye are estimated directly from pooled observer data (with corrections for grab sample bias using 'availability'), stratified by year, quarter, 5° square and school association (free school v associated), for strata with ≥ 20% observer coverage (of total catch)
- for strata with < 20% observer coverage of catch, generalised additive models (GAMs) are used to predict species proportions, with the models fitted to observer sample based species compositions, again with corrections for grab sample bias using 'availability', and
- the estimates of species proportions are then applied to aggregate catch data at the S_BEST stratification, i.e. year, month, flag and fleet, 1° square and school association type (free school, anchored FAD, drifting FAD etc).

There are a total of 18 GAMs used to estimate species proportions. Separate models were fitted for each species and school association (free school vs associated). And three different model specifications were used: the simplest model specification was used to predict up to and including 1995; a more complex model specification, used to predict for 1996 to 2001; and, the most complex model specification used to predict from 2002 onwards. Full details of these models are provided in Lawson (2013).

'Availability' is defined as the probability of an individual fish being grab sampled from fish of the same length interval, and so should be invariant of individual fish size and species if grab samples are to provide unbiased estimates of size and species compositions (e.g. Lawson, 2013).

The following changes to the above approach have been recommended. Peatman et al (2018) recommended that grab sample bias be corrected using multinomial model-based 'correction factors', initially recommended by Cordue (2013) and implemented by McCardle (2013). In Section 2.3, we propose that the existing models of species compositions be replaced by zero and one-inflated beta-response models. The beta-response models detected between-flag variability in species compositions, and so we also propose that the stratification of observer samples include stratification by flag.

SC14 endorsed the suggestion to provide step-wise changes in catch estimates as a result of proposed changes to the methodology used to estimate species compositions. We therefore provide four time series of purse seine catch estimates generated using the following approaches:

- 1 – the currently used approach (outlined above);
- 2 – approach 1, but with correction of grab sample bias using 'correction factors' rather than 'availability';
- 3 – approach 2, but with zero and one inflated beta-response models used instead of the GAMs;
- 4 – approach 3, but with additional stratification by flag when basing catch compositions directly on observer samples.

The zero and one inflated beta-response models include year effects to account for temporal variation in species compositions. This introduces difficulty when estimating species compositions for years where observer data are either unavailable, i.e. prior to 1993, or limited. Here, we advocate the use of one model specification, with year effects fixed at a specified level when predicting for the earlier part of the time-series. We generated beta-response catch compositions using the 2003 year effect for the period pre-2003, and assess sensitivity of catch estimates to this assumption by also using the 2007 and 2000 year effect for the period pre-2007 and pre-2000 respectively.

3.2 Results

The purse seine catch estimates are most sensitive to the modelling approach (i.e. the transition from approach 2 to approach 3) used to estimate species proportions in strata with low observer coverage (Figure 1 and Figure 2). The GAM models predict substantially higher yellowfin proportions and lower skipjack proportions for the period from 1997 through to 2006 compared to the beta-response models. The GAM models also predict lower bigeye proportions from 1975 through to 1995, and demonstrate more variability from 1996 through to 2010.

The estimates of species-specific purse seine catches and catch proportions are insensitive to whether grab sample bias is corrected with 'availability' or 'correction factors' (Figure 1 and Figure 2). The annual species-specific catch proportions are also insensitive to whether observer samples are stratified by flag. Comparison at a finer resolution, i.e. at a resolution of year, quarter, flag, MFCL region and school association, indicates that stratifying by flag does have some impact on estimated species catches, particularly for bigeye (Figure 3). Species-specific catch estimates are insensitive to stratification by flag at the resolution of current MFCL assessment models, i.e. year, quarter, MFCL region and school association (Figure 4).

3.3 Discussion

The catch estimates are most sensitive to the modelling approach used to estimate species proportions in strata with low observer coverage, particularly for the period 1997 to 2006. The year effects for the GAM models demonstrate strong inter-annual variability for this period, though the year effects have low precision due to the more limited levels of observer coverage at this time (e.g. Appendix B, Figure 39). In particular, the difference between the 1996 and 1997 year effects for models of yellowfin proportions in sets on both free school and associated schools are not significant. As such, the large change in yellowfin, skipjack and bigeye proportions in the late 1990s predicted by the GAMs should be treated with caution. The use of different GAM model parameterisations to estimate species compositions for different time periods also results in strong step changes in species compositions and their variability.

Year effects were fixed at those for 2003 when predicting for years prior to 2003 using the beta response models. This approach has the advantage of avoiding step-changes in species proportions from one year to the next as a result of a changing between parameterisations, whilst still accounting for apparent temporal changes in species compositions pre-2010 when observer coverage was more limited. However this approach ignores any observed temporal variation in species compositions prior to 2003. The cut-off at 2003 was selected due to both the relatively low levels of observer data prior to 2003, contributing approximately 2.5 % to total observed sets for the period 1993 to 2018, and the fact that observer coverage was less representative prior to 2003 in terms of coverage by flag. As such, temporal signals in the observer data may reflect limitations in available observer data rather than underlying changes in species compositions in the fishery.

The estimated species-specific proportions are reasonably sensitive to what year effect is assumed for the early part of the time series (Appendix B, Figure 40 and Figure 41). Assuming the 2000 year effect prior to 2000 increased annual catch of bigeye and yellowfin by an average of 5 and 12 % respectively for the period 1990 to 2000, compared to assuming the 2003 year effect prior to 2003, with a 6 % reduction in skipjack. Conversely, assuming the 2007 year effect prior to 2007 decreased annual bigeye and yellowfin catches by an average of 9 and 10 % respectively, with a 5 % increase in skipjack, over the same time period.

Reported (uncorrected) skipjack catch proportion has a strong effect on the species composition models for skipjack and yellowfin. The inclusion of the term is most influential for catch compositions for years where observer sampling of catches was either limited or lacking. However if reported catch compositions are not independent of observer sampling, then the resulting estimates of species compositions could be biased as the models are predominantly fitted to data for periods of high observer coverage, and predominantly used to predict catch compositions for periods of low observer coverage.

The addition of flag in the stratification of observer samples does result in changes to estimated species compositions at a relatively fine scale. However, it is not possible to determine whether the addition of flag improves the accuracy of estimated species compositions, or whether the changes in catch estimates reflect noise in the observer samples. Catch estimates are insensitive to stratification by flag at the resolution of the MFCL assessment models, so this would have no material impact on inputs to the assessment model input. However, the catch estimates are also used in routine analyses by SPC, and any differences may be important in other applications. Large-scale comparisons of observer-sample based compositions with unloadings data would be informative at exploring the relative accuracy of stratification with and without flag. With the information currently available, and in the context of detected between-flag variation in the species compositions models, we recommend that observer samples be stratified by flag.

4 A summary of other progress

4.1 Paired grab-spill sampling trips

A paired trip was undertaken on a Solomon Island-flagged purse seiner operating from Noro in the western province of the Solomon Islands. The trip was conducted by two SPC staff, using the fleet in Noro owing to the history of cooperation with the fishing company and SPC, the relatively short localised trips, direct unloading by vessels to the cannery and the presence of existing spill sampling bins there. The vessel was a relatively small purse seiner (46m long and less than 719 GRT), hence their trips tend to be short, 2-3 weeks in duration. The vessel and its similar-sized sister ships fish in the archipelagic waters of the Solomon Islands, principally using the company's large array of anchored FADs.

The trip was conducted with two SPC staff doing the spill-sampling and a Solomon Island Observer conducting the grab-sampling. The trip was initiated on 23rd March 2019 and was 13 days in duration. There were 13 sets made (7 free school and 6 FAD sets) for a trip total of 368 mt.

The spill sampling process allowed a greater number of fish to be measured over the trip (4 692 c.f. 943), with a higher proportion of yellowfin sampled by the spill samplers (39% c.f. 35% in grab samples). There was a broad size range of fish with skipjack being measured from 27 to 72 cm fork length and yellowfin 21 to 134 cm fork length. There was only one bigeye measured.

We note that the trip was conducted by two experienced observers from SPC staff, who are also trainers of observer trainers. Considerable information was obtained on how to better conduct future paired spill-grab sampling, gears required and other practical operational considerations. The spill sampling protocol resulted in higher sample sizes, but was also more labour intensive and disruptive to the fishing operation. In this case the two SPC staff were also often assisted by one or two crew in the process. The spill sampling bin was also an obstruction on the relatively small deck and there were safety concerns as the bin had a tendency to slide when hit by the swaying brail.

The species compositions of the two sampling methods were compared with the unloading documentation of the vessel (see Peatman et al., 2017 for the methodology). The unloadings certificate for this trip recorded that skipjack and yellowfin comprised 53 and 47% respectively of the total catch weight. Corrected grab samples overestimated skipjack and underestimated yellowfin, at 58 % (95% confidence interval: 55 to 61 %) and 42 % (95% CI: 39 to 45 %) respectively. Spill samples underestimated skipjack and overestimated yellowfin, at 47 % (95% CI: 46 to 49%) and 53 % (95 % CI: 51 to 54 %). Trip-level estimated length frequencies are provided in Appendix B (Figure 42 and Figure 43).

4.2 A note on length frequencies

The fitted beta-response models have been used to generate length frequencies for MFCL purse seine fisheries at a year and quarter resolution, using the approach outlined in Lawson (2013). We provide some examples in Appendix B (Figure 44 and Figure 45).

5 Overall discussion and implications on future work

At SC14, it was recommended that ‘correction factors’ are used to correct for grab sample bias, rather than estimates of ‘availability’. As discussed in Section 2.3, we further recommend that the zero and one inflated beta response models are used to estimate species-specific proportions, rather than the GAM models, as the beta-response models achieve more robust fits to observations. Finally, we recommend that observer samples be additionally stratified by flag when used directly as the basis for species composition estimates. This work primarily falls under para c) of Project 60’s scope.

The collaborative work with Japan in 2017 (Peatman et al, 2017b) has clearly demonstrated the value in the comparison of observer sample based species and size compositions against comprehensive unloadings data. This approach has a number of advantages. First, the observer-sample-derived estimates of species composition and size composition (aggregated to the commercial categories used in the unloadings data) can be compared against highly accurate trip-level equivalents. The number of trips of data that can be compared is also far higher, e.g. nearly 800 trips in the case of the collaboration with Japan. We suggest that this type of comparative analysis be the immediate focus for 2019, and which would contribute towards para c) of Project 60’s scope. Potential avenues for exploration include:

1. comparison of observer-sample based species and size compositions with unloadings and port sampling data at varying resolutions;
2. comparison of beta-response estimates of species compositions with unloadings data; comparison; and
3. comparison of the relative precision and accuracy of observer-sample and model-based species compositions, to explore whether the currently used > 20 % observer coverage cut-off can be refined, and the extent to which stratification by flag improves accuracy of estimates.

We also note that cannery data provides an additional data source for comparisons with grab sample based estimates of species and size compositions (e.g. Williams, 2018). We anticipate that the cannery data held by WCPFC will become an increasingly valuable data source for comparisons with both observer-sample derived estimates and model-based estimates of species compositions in the medium-term.

Experience from paired grab-spill sampling trips to date suggests that spill sampling gives more accurate and precise estimates of species compositions than corrected grab samples at a trip level, but at more aggregated levels corrected grab samples give similar species compositions (Peatman et al., 2017a; Peatman et al., 2017b). It has been challenging to conduct paired grab-spill trips between SC14 and SC16. Additionally, there were operational difficulties in implementing the revised spill sampling protocol on the paired grab-spill trip in early 2019, partially due to the increased number of brails sampled from each set (Section 4.1). However, the more frequent spill sampling of brails with a lower sampled volume, does provide a practical approach to exploring the degree of between-brail variation in species and size compositions. There are currently insufficient paired trips to robustly estimate association or species-specific correction factors. Additional paired grab-spill data will improve estimates of bias in grab samples, and may allow for more powerful tests of species or school association variation in bias, with resulting improvements to estimates of species composition for the purse seine fishery.

Itano et al. (2019) compared electronic monitoring based sampling to paired grab and spill sampling, and identified potential opportunities for video-based monitoring of catches that could be applicable to the large-scale WPCPFC purse seine fishery. Video-based monitoring provides an opportunity to sample higher proportions of catches than is feasible with the grab sampling protocol. The comparisons of sampling approaches undertaken by Itano et al. (2019) represent a valuable contribution to para b) of Project 60's scope. Continued support to these initiatives, and further investigation of potential approaches for video-based monitoring, would provide additional information to contribute to para b) of Project 60's scope.

The development of a simulation model was proposed to be undertaken between SC14 and SC15. This has not been completed. The simulation model was proposed as a means to both explore the potential link between grab sample bias and between-brail variability in species and size compositions, and the implications on the potential need for species and/or association specific corrections for grab sample bias. We note that additional 'high frequency' spill sampling will be helpful in structuring and parameterising the simulation model, and as such suggest that the other suggested activities are a higher priority for Project 60 work in the short-term.

The proposed activities for Project 60 over the next year reflect a continued shift in emphasis towards large-scale comparisons between unloadings data and observer-sample and model based estimates of species and size compositions, and focussing paired grab-spill sampling efforts towards improving the correction of bias in grab samples.

5.1 Work plan for August 2019 onwards

We propose the following activities for Project 60 from August 2019 onwards, with reporting to SC16:

Activity	**Priority**
1. Paired grab-spill trips (target: 4 to 6): • Targeting fleets with likely availability of comprehensive landings slips data • 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	High
2. Continue to explore opportunities for collaboration with members, specifically undertaking comparisons of observer sample, and potentially model-based, species composition estimates, with accurate unloadings / landings / cannery data	High
3. Investigation of video-based sampling for estimation of species and size compositions	Medium
4. Simulation model • Exploration of potential bias from between-brail variability in size • Inform need for set and/or species specific correction factors	Medium
5. Cost-benefit analysis of alternative sampling approaches for long-term estimation of species compositions (i.e. at-sea sampling vs port sampling)	Low

6 Recommendations

We recommend that SC consider the activities, and associated priority, proposed for further work under Project 60. Specifically, we recommend that:

- Multinomial-model based correction factors be used to correct existing and future grab sample data, rather than the estimates of 'availability';
- The beta-response models be used to generate catch estimates; and,
- Observer samples are stratified by flag when used to directly estimate species compositions.

Acknowledgements

The funding for Project 60 comes from the WCPFC Commission.

We thank the observers, and those supporting the regional observer programme, for the collection and processing of the grab and spill sampling data that we have analysed. Thanks also to Sam McKechnie for his constructive comments and suggestions on an earlier version of this report. Finally, we are grateful to colleagues in Japan, the US and the Solomon Islands for useful discussions.

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Tables

Table 1 Length-weight parameters used in the analyses, taken from the 2019 skipjack assessment (Vincent et al, 2019) and the 2014 yellowfin (Davies et al., 2014) and bigeye (Harley et al., 2014) assessments.

Species	a	b
SKJ	1.144E-05	3.1483
YFT	2.512E-05	2.9396
BET	1.973E-05	3.0247

Figures

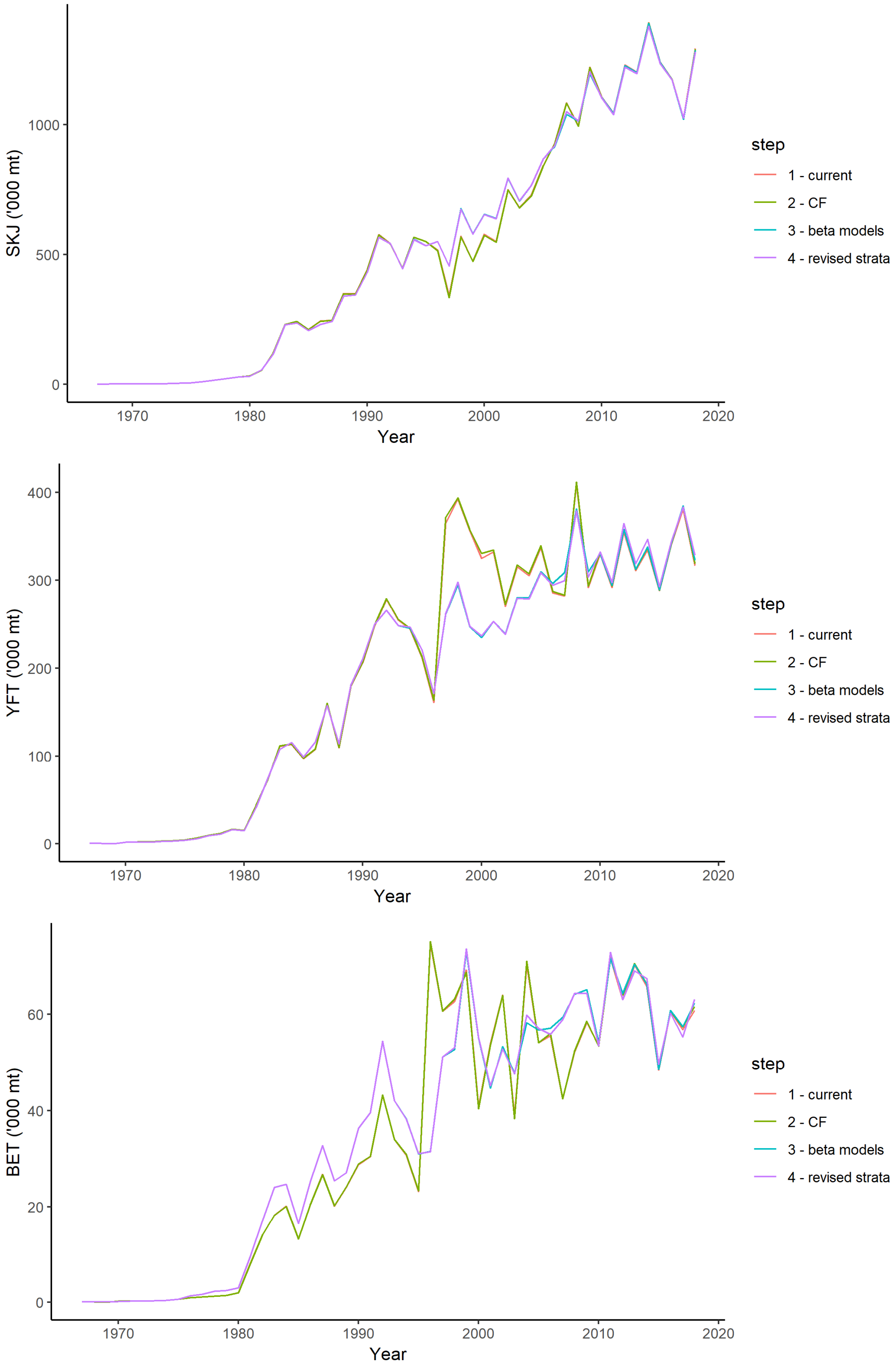

Figure 1 Stepwise changes in purse seine catch estimates from the currently used method (1 – current, red): correction of grab sample bias using correction factors (2 – CF, green); replacing GAMs with zero and one inflated beta-response models (3 – beta models, turquoise); and, the addition of stratification by flag when basing species compositions directly on observer samples.

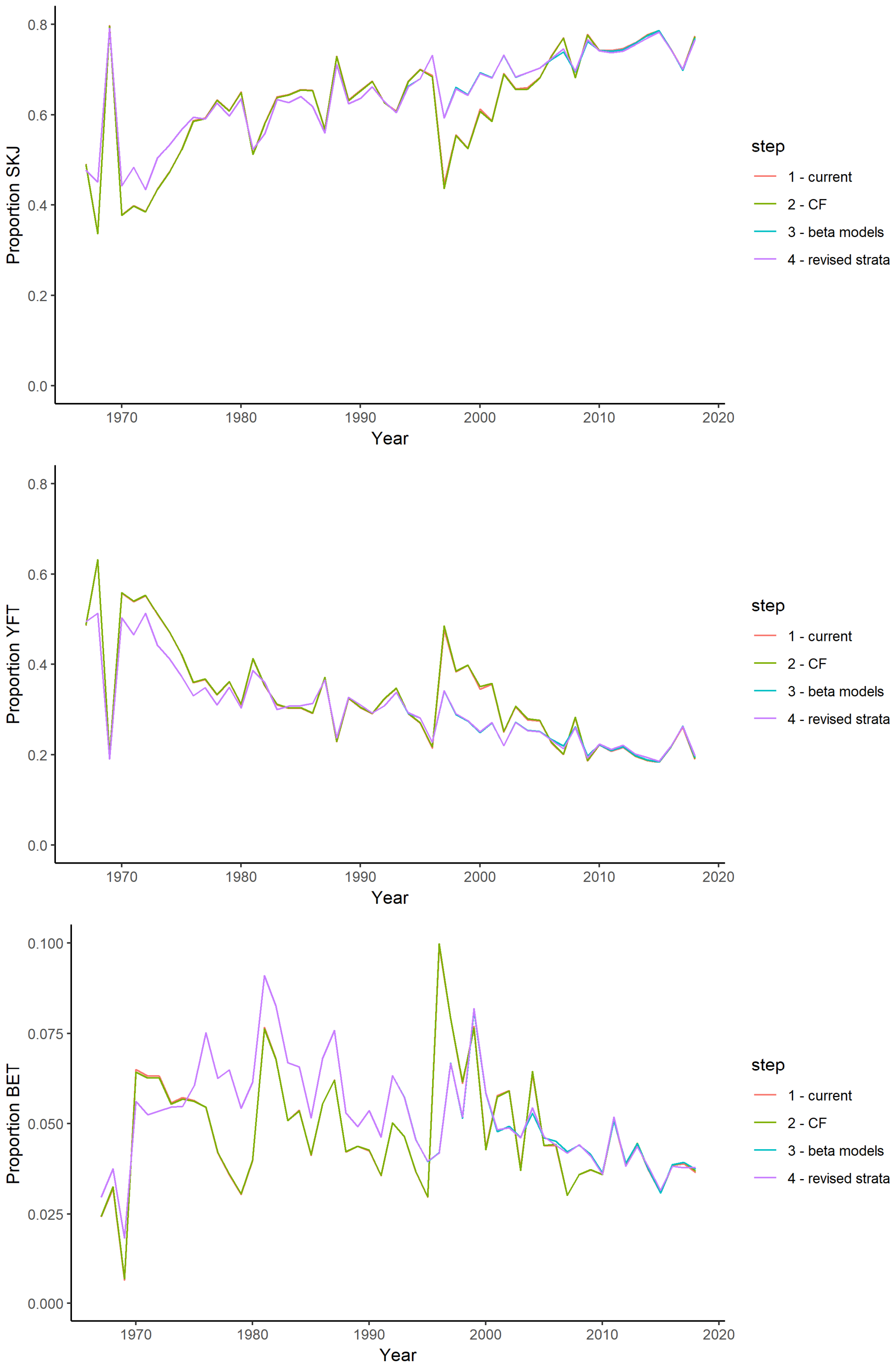

Figure 2 Stepwise changes in purse seine catch proportions from the currently used method (1 – current, red): correction of grab sample bias using correction factors (2 – CF, green); replacing GAMs with zero and one inflated beta-response models (3 – beta models, turquoise); and, the addition of stratification by flag when basing species compositions directly on observer samples.

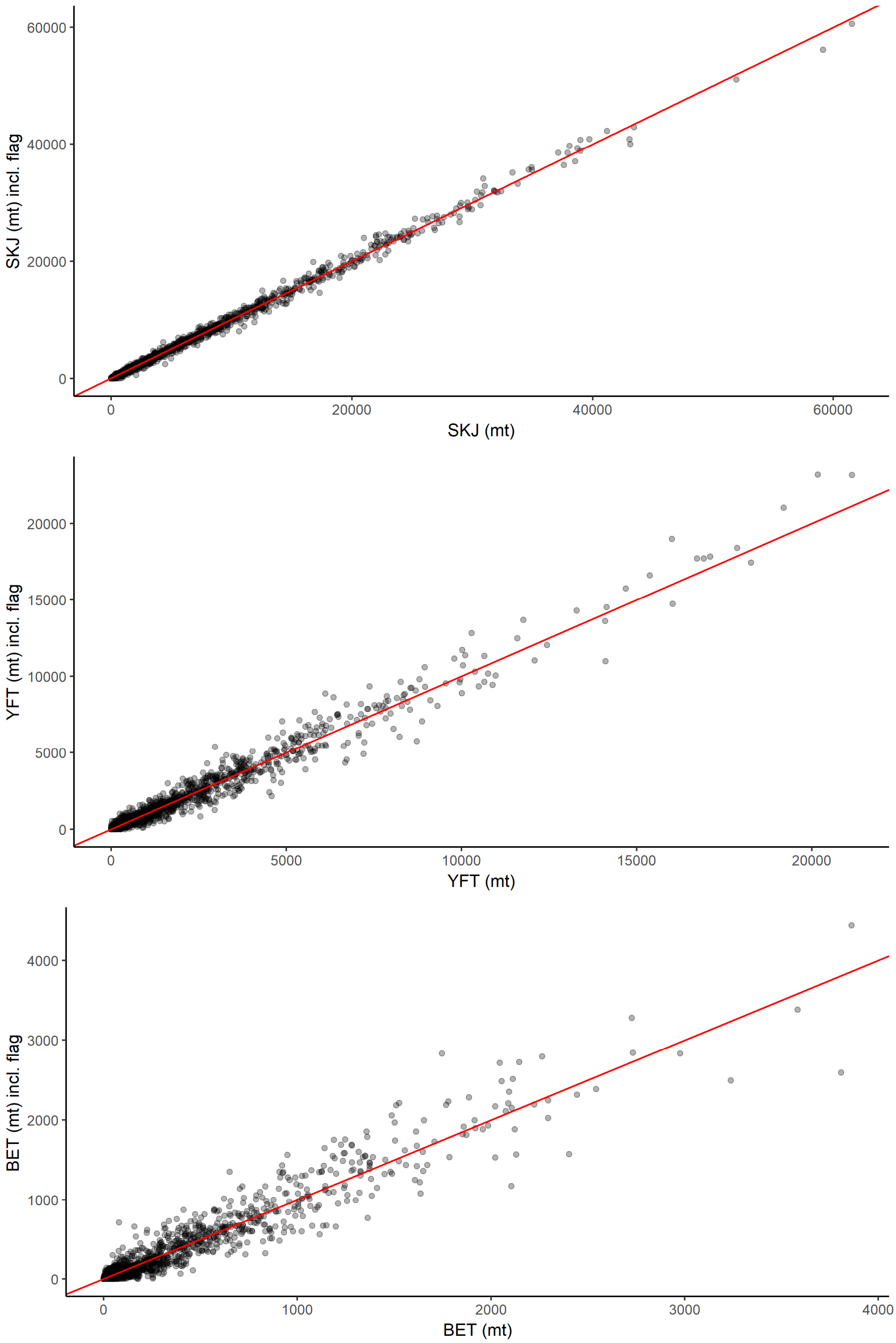

Figure 3 Comparison of skipjack (top), yellowfin (middle) and bigeye (bottom) catch estimates based on observer samples for the currently used stratification (x-axis), and the proposed stratification including flag (y-axis). Each point represents a combination of year, quarter, flag.id, school association (free school vs associated) and MFCL region.

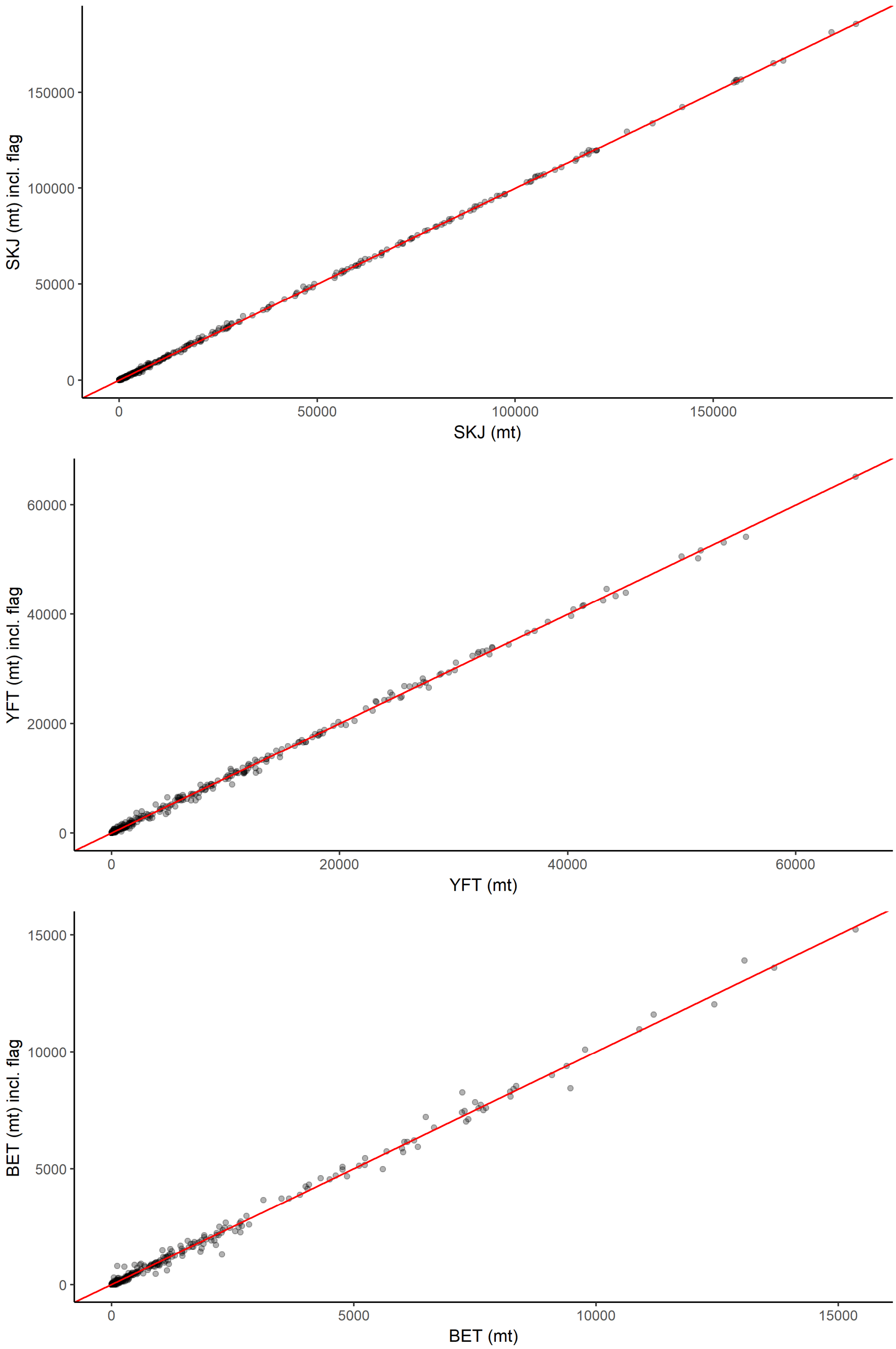

Figure 4 Comparison of skipjack (top), yellowfin (middle) and bigeye (bottom) catch estimates based on observer samples for the currently used stratification (x-axis), and the proposed stratification including flag (y-axis). Each point represents a MFCL assessment model strata, i.e. year, quarter, school association (free school vs associated) and MFCL region.

Appendix A

Specification of inflated-beta response models of species compositions

The final 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:

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

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

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

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

where subscripts i and j refer to set and vessel, $flag_{ij}$ is the flag of the vessel, $assoc_{ij}$ is the type of association (see below for more information), $archipelagic_{ij}$ is an identifier for sets in archipelagic waters, qtr_{ij} is (a categorical) quarter effect, 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 the Oceanic Nino Index (grouped to El Nino, neutral and La Nina), lon_{ij} is the longitude of the set, $f(\ \ )$ are cubic regression splines and b_j are random intercepts for vessel, $b_j \sim N(0, \sigma_b)$. 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 final 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:

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

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

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

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

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:

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

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

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

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

The final 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:

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

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

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

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

The final 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:

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

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

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

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

The final 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:

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

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

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

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

Effect plots for inflated-beta response models of species compositions

Skipjack – free school

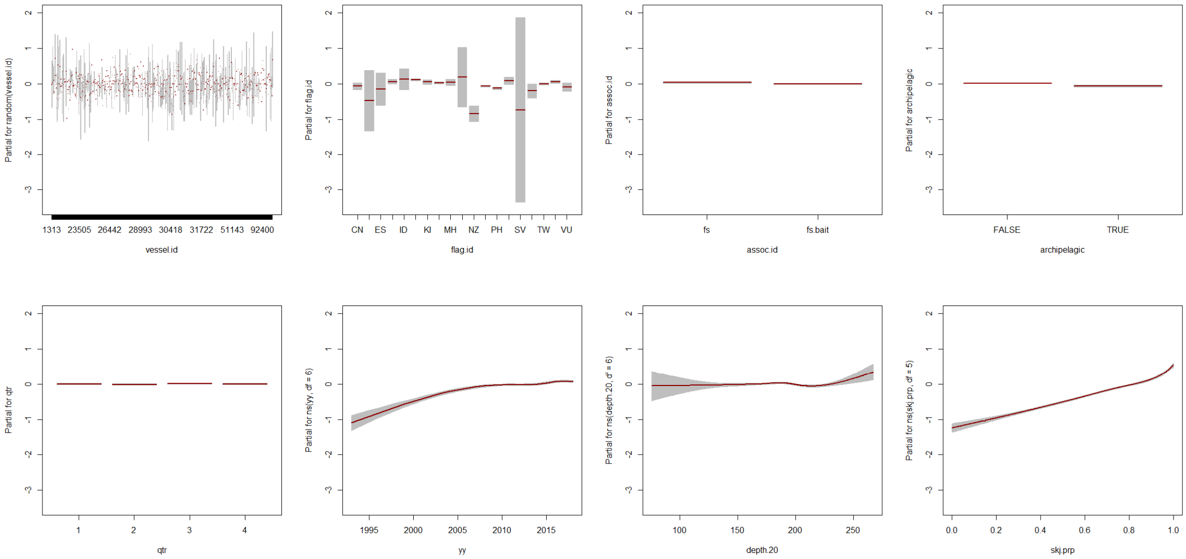

Figure 5 Effects on the mean of the beta-component of the skipjack free-school model. Top row, left to right: random intercept for vessel ID; flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters. Bottom row, left to right: quarter; year; isotherm depth; and, uncorrected skipjack proportion from vessel logbooks.

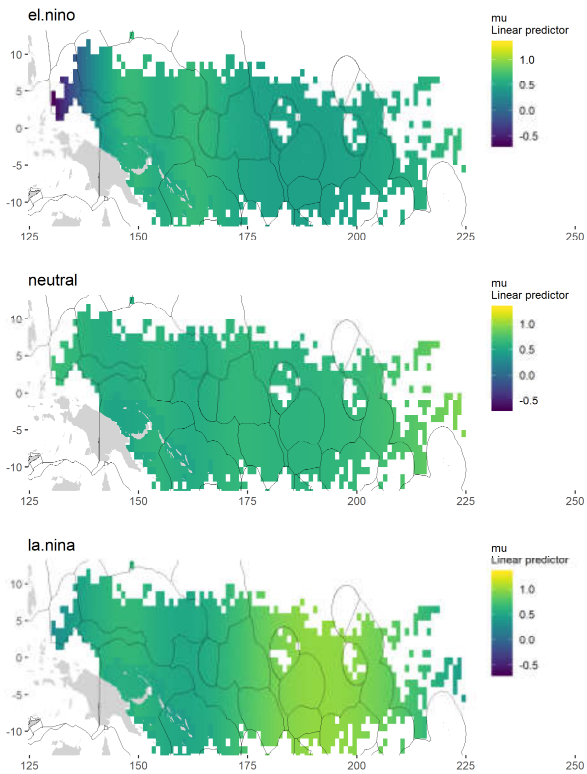

Figure 6 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the skipjack free-school model.

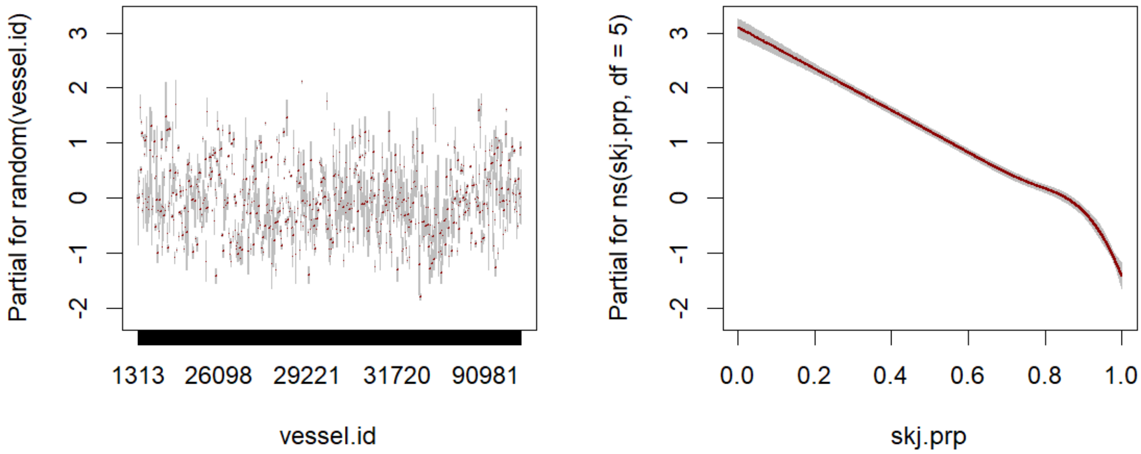

Figure 7 Effects on the zero-inflation component of the skipjack free-school model: random intercept for vessel ID (left); and, uncorrected skipjack proportion from vessel logbooks (right).

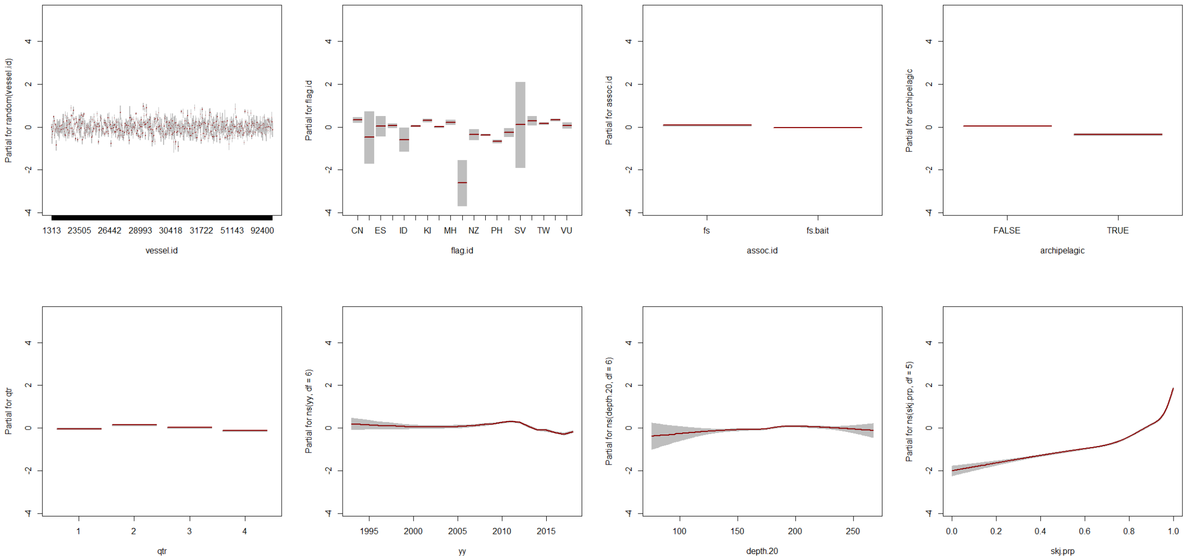

Figure 8 Effects on the one-inflation component of the skipjack free-school model. Top row, left to right: random intercept for vessel ID; flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters. Bottom row, left to right: quarter; year; isotherm depth; and, uncorrected skipjack proportion from vessel logbooks.

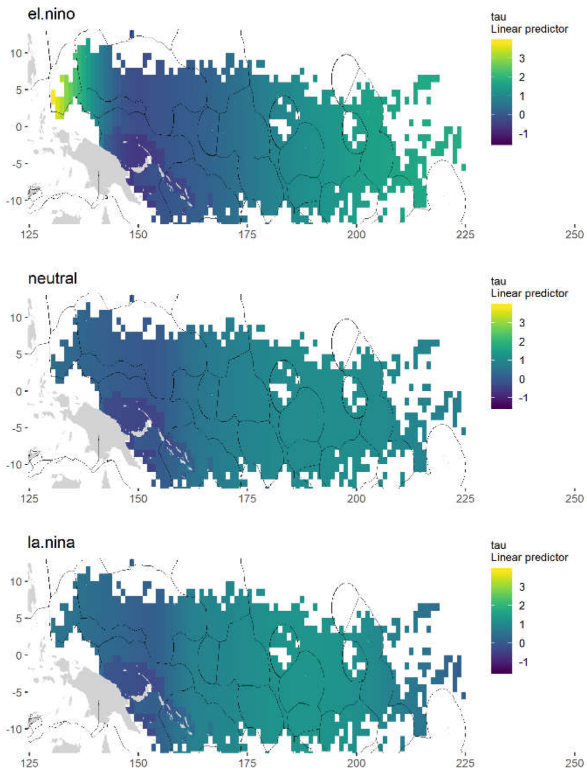

Figure 9 The combined effect of the archipelagic term and the longitude:ONI interaction on the one-inflation component of the skipjack free-school model.

Yellowfin – free school

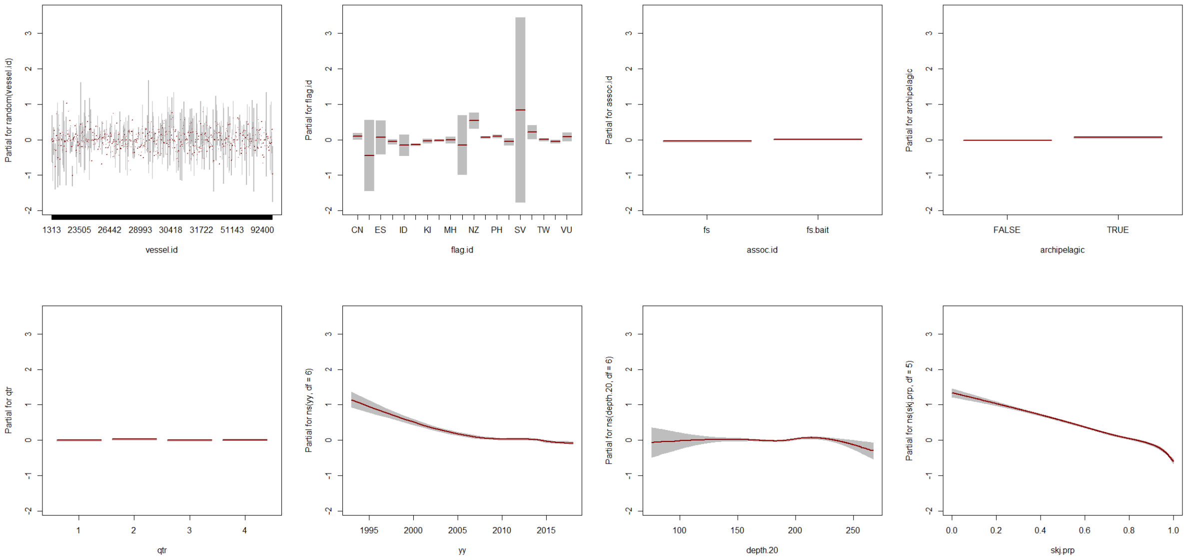

Figure 10 Effects on the mean of the beta-component of the yellowfin free-school model. Top row, left to right: random intercept for vessel ID; flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters. Bottom row, left to right: quarter; year; isotherm depth; and, uncorrected skipjack proportion from vessel logbooks.

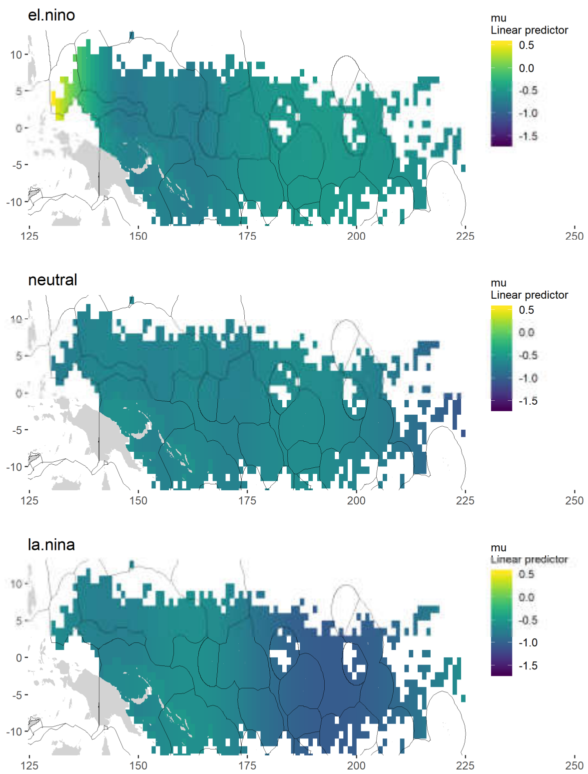

Figure 11 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the yellowfin free-school model.

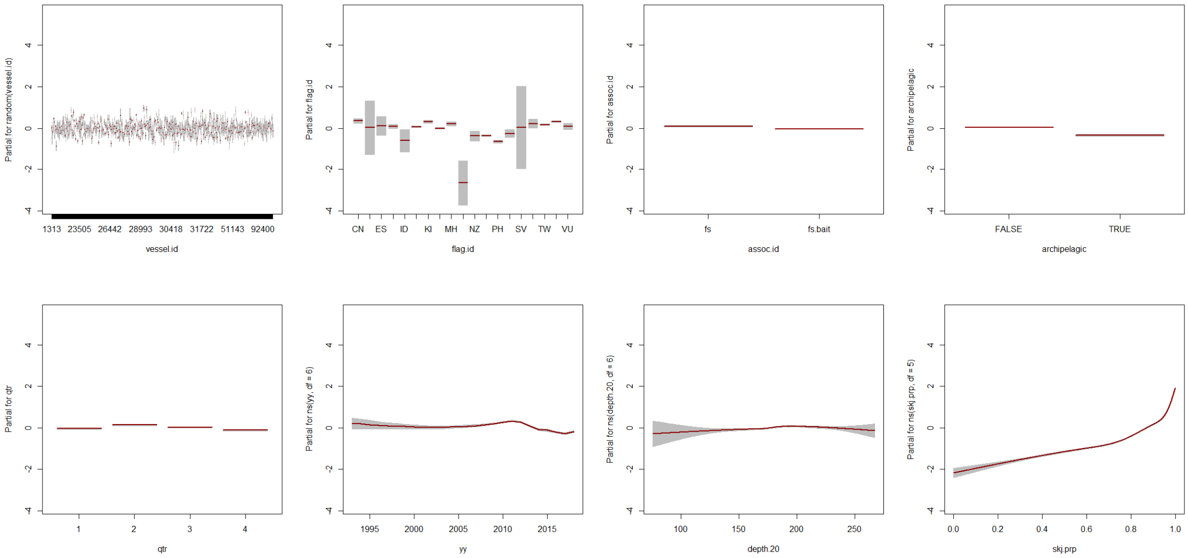

Figure 12 Effects on the zero-inflation component of the yellowfin free-school model. Top row, left to right: random intercept for vessel ID; flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters. Bottom row, left to right: quarter; year; isotherm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

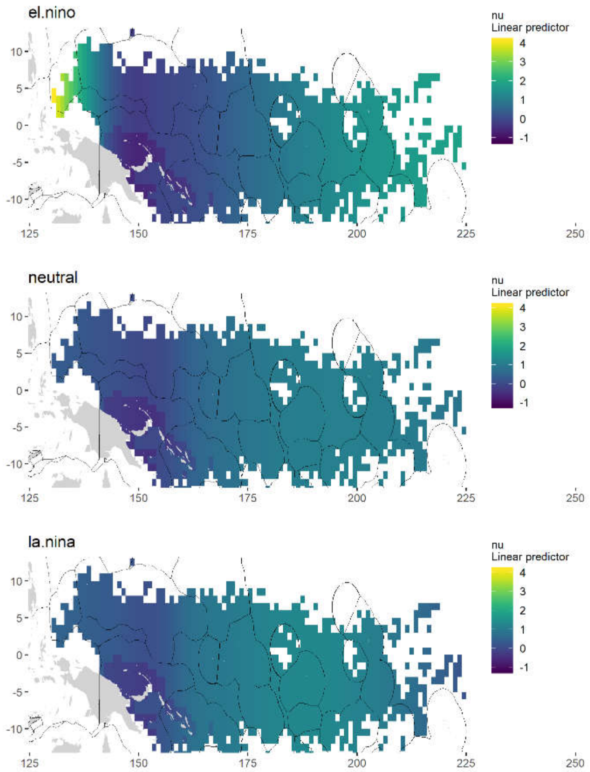

Figure 13 The combined effect of the archipelagic term and the longitude:ONI interaction on the zero-inflation component of the yellowfin free-school model.

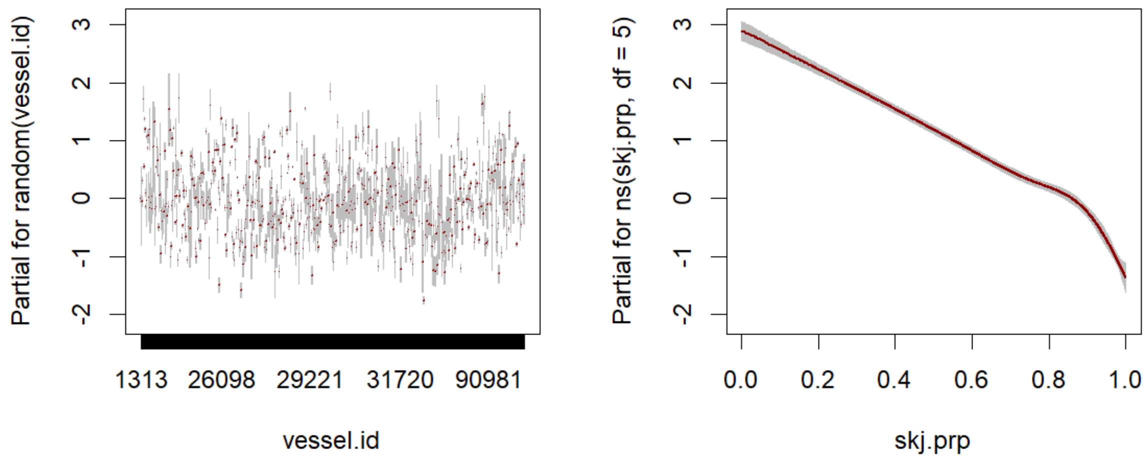

Figure 14 Effects on the one-inflation component of the yellowfin free-school model: random intercept for vessel ID (left); and, uncorrected skipjack proportion from vessel logbooks (right).

Bigeye – free school

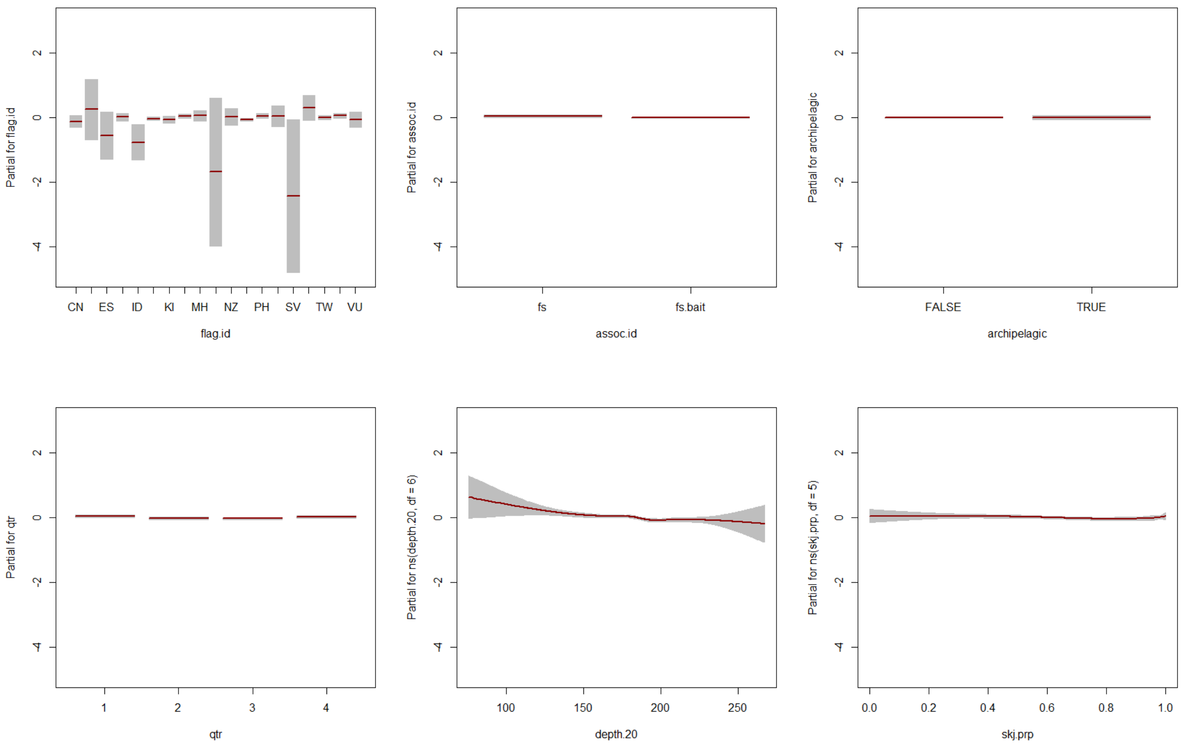

Figure 15 Effects on the mean of the beta-component of the bigeye free-school model. Top row, left to right: flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters. Bottom row, left to right: quarter; isotherm depth; and, uncorrected skipjack proportion from vessel logbooks.

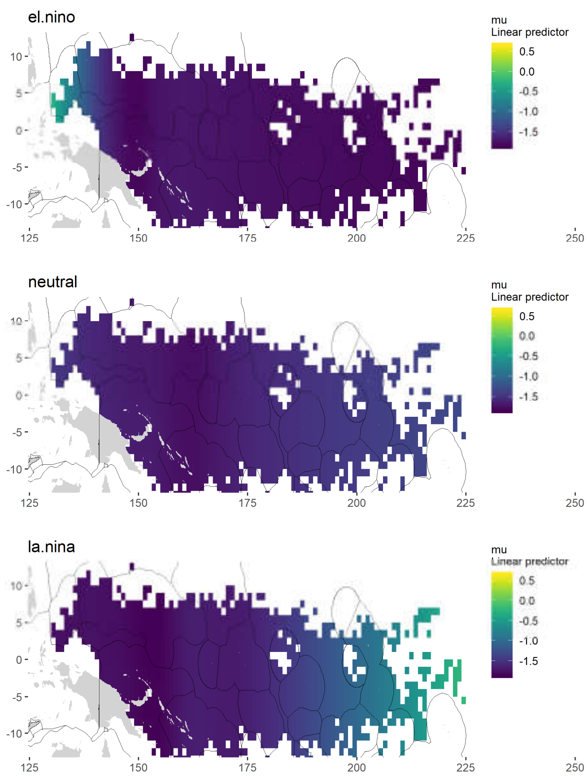

Figure 16 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the bigeye free-school model.

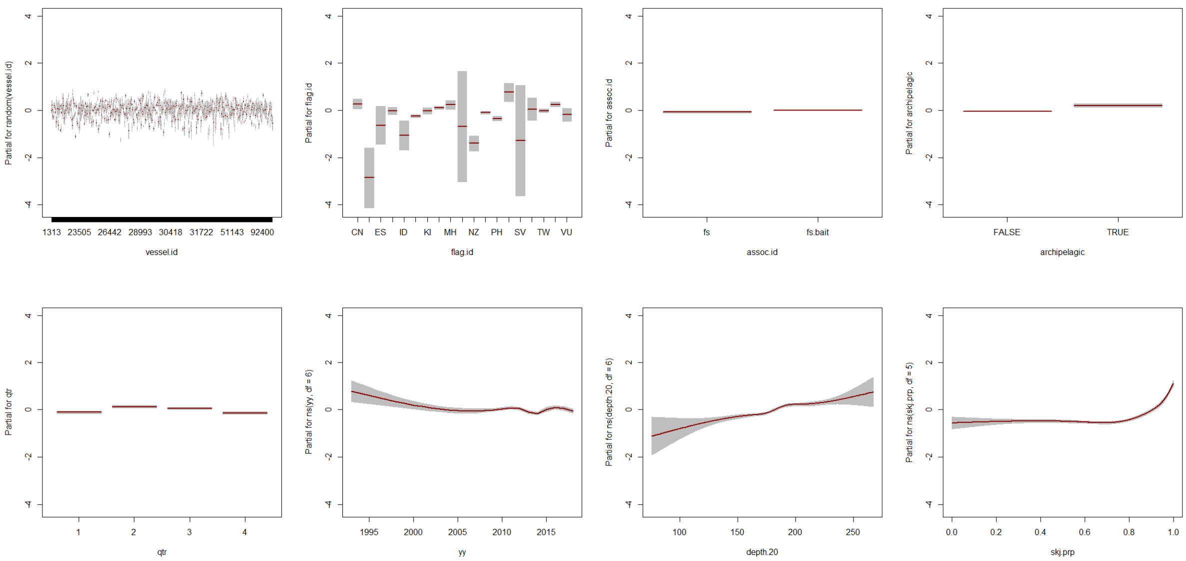

Figure 17 Effects on the zero-inflation component of the bigeye free-school model. Top row, left to right: random intercept for vessel ID; flag; association type (free school – fs, and free school feeding on baitfish – fs.bait); archipelagic waters. Bottom row, left to right: quarter; year; isotherm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

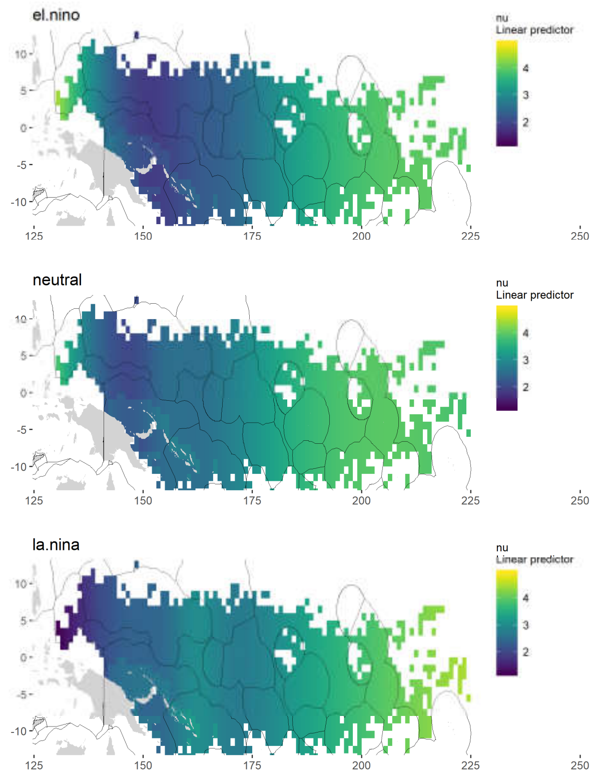

Figure 18 The combined effect of the archipelagic term and the longitude:ONI interaction on the zero-inflation component of the bigeye free-school model.

Skipjack – associated

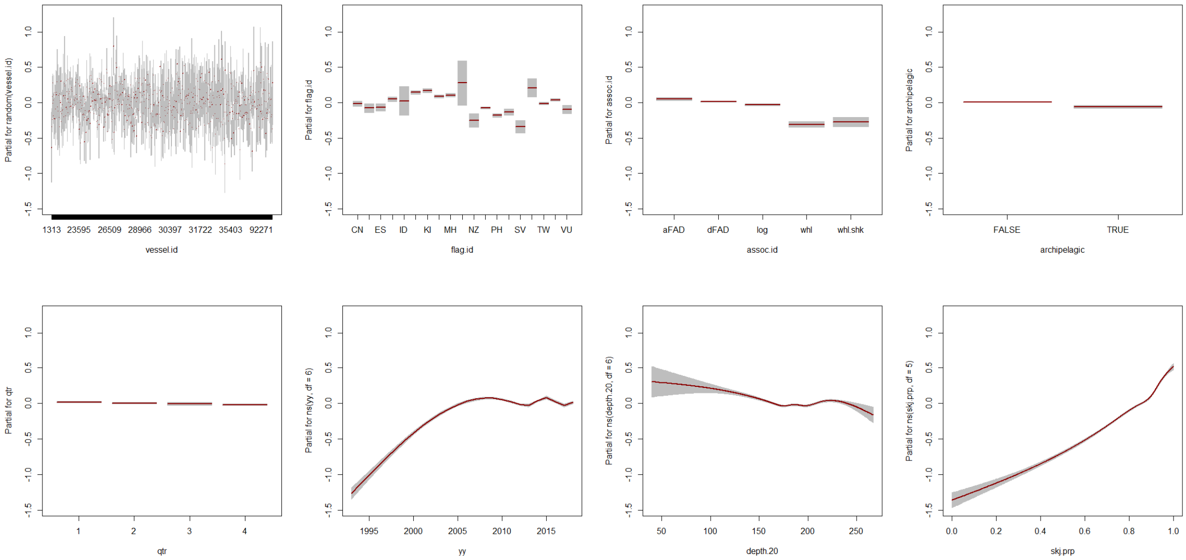

Figure 19 Effects on the mean of the beta-component of the skipjack associated model. Top row, left to right: random intercept for vessel ID; flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters. Bottom row, left to right: quarter; year; isotherm depth; and, uncorrected skipjack proportion from vessel logbooks.

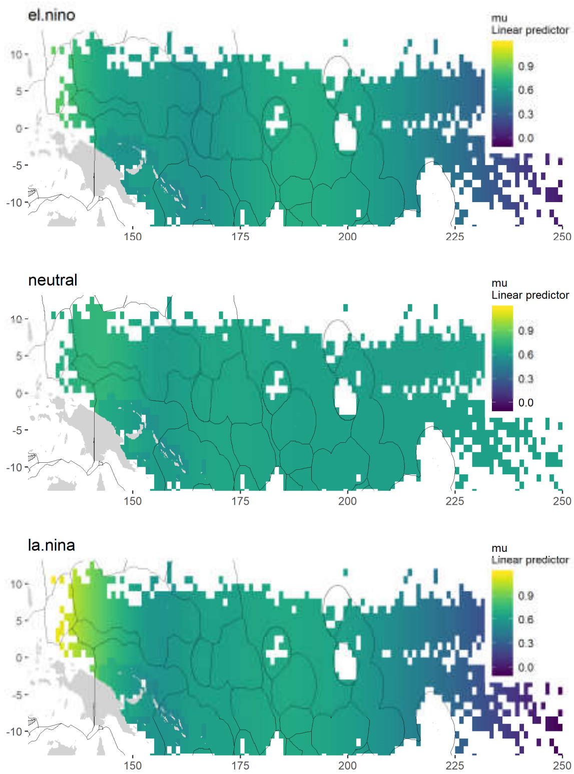

Figure 20 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the skipjack associated model.

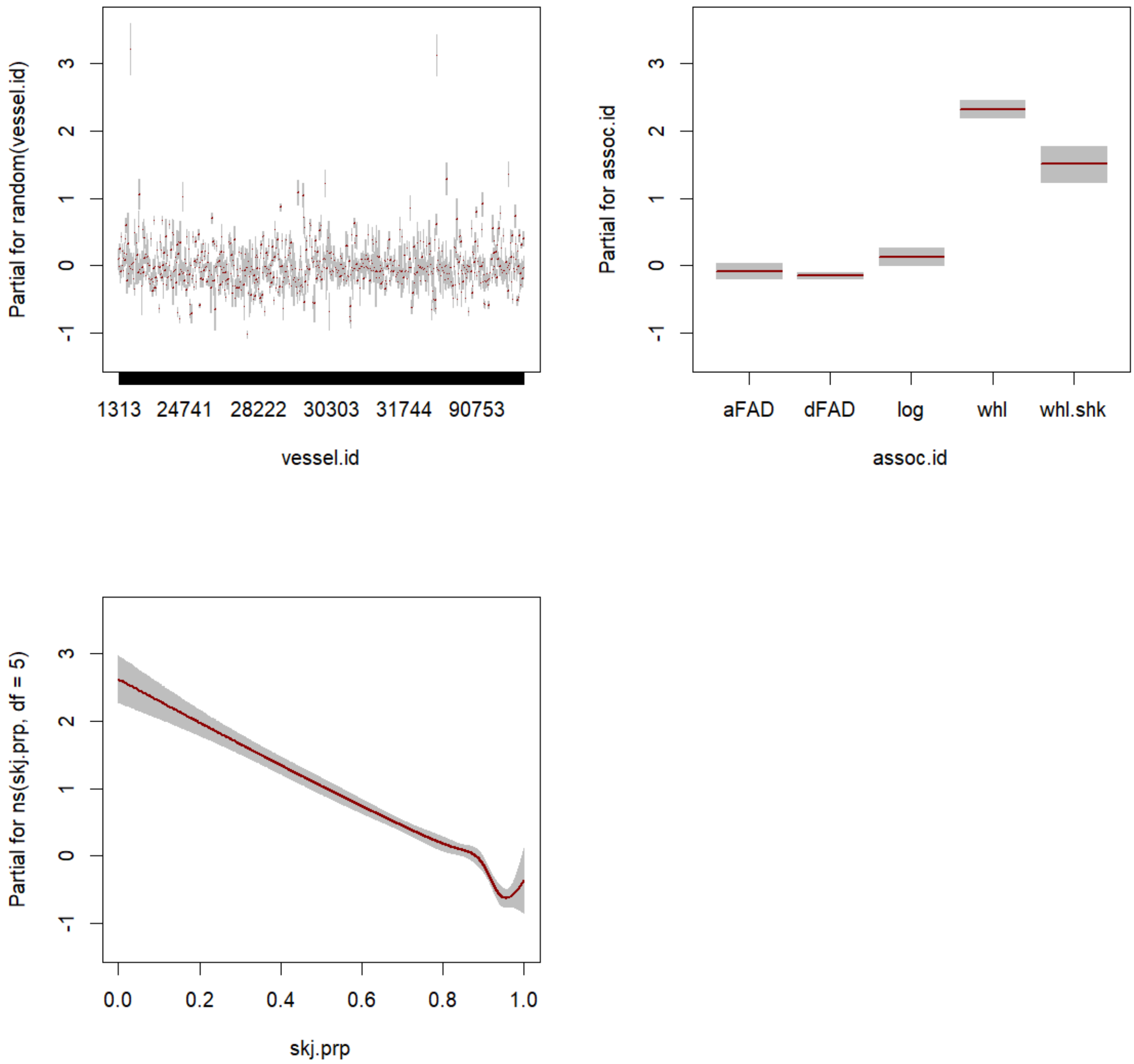

Figure 21 Effects on the zero-inflation component of the skipjack associated model: random intercept for vessel ID (top left); association type (top right - anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk) and, uncorrected skipjack proportion from vessel logbooks (bottom left).

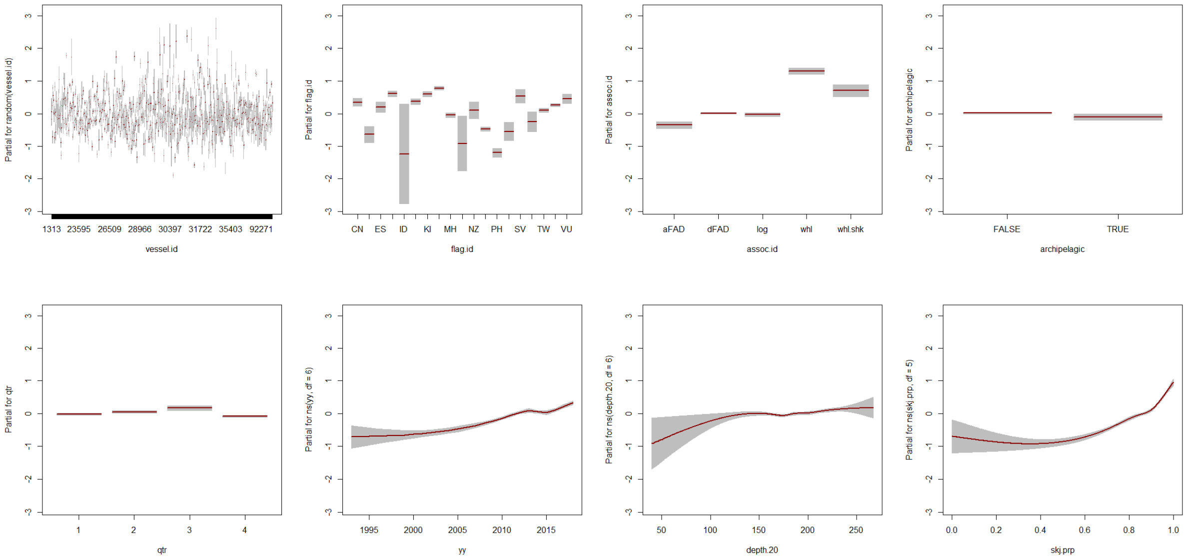

Figure 22 Effects on the one-inflation component of the skipjack associated model. Top row, left to right: random intercept for vessel ID; flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters. Bottom row, left to right: quarter; year; isotherm depth; and, uncorrected skipjack proportion from vessel logbooks.

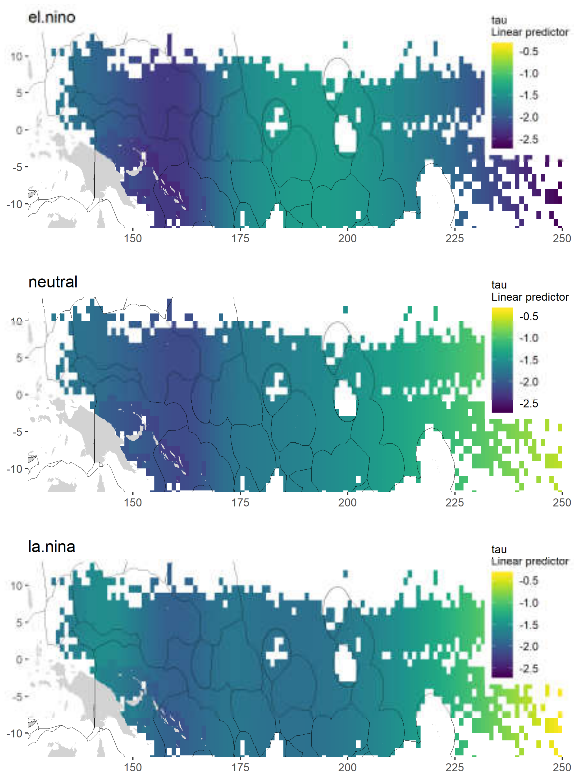

Figure 23 The combined effect of the archipelagic term and the longitude:ONI interaction on the one-inflation component of the skipjack associated model.

Yellowfin – associated

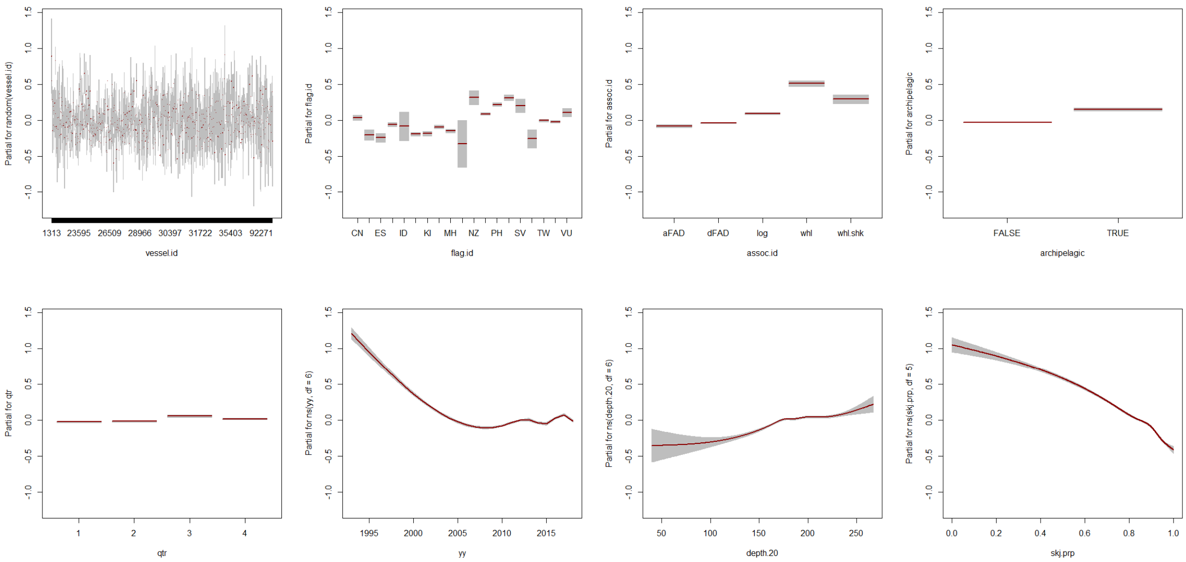

Figure 24 Effects on the mean of the beta-component of the yellowfin associated model. Top row, left to right: random intercept for vessel ID; flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters. Bottom row, left to right: quarter; year; isotherm depth; and, uncorrected skipjack proportion from vessel logbooks.

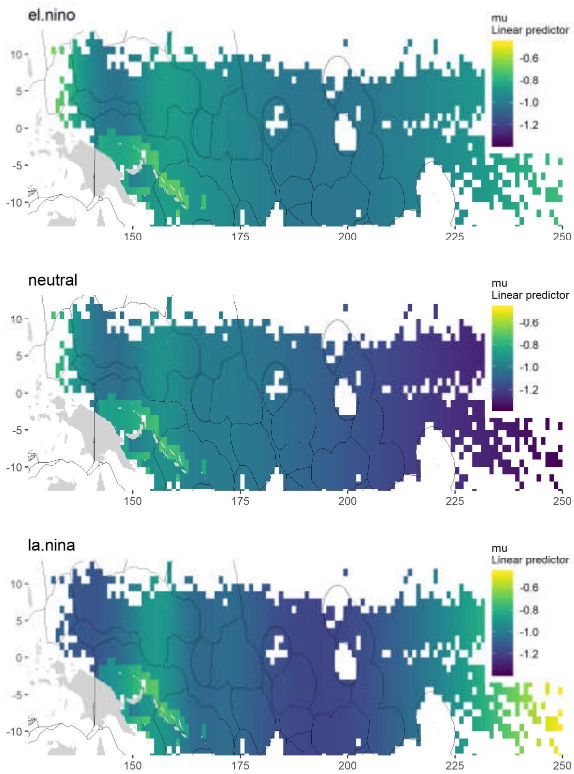

Figure 25 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the yellowfin associated model.

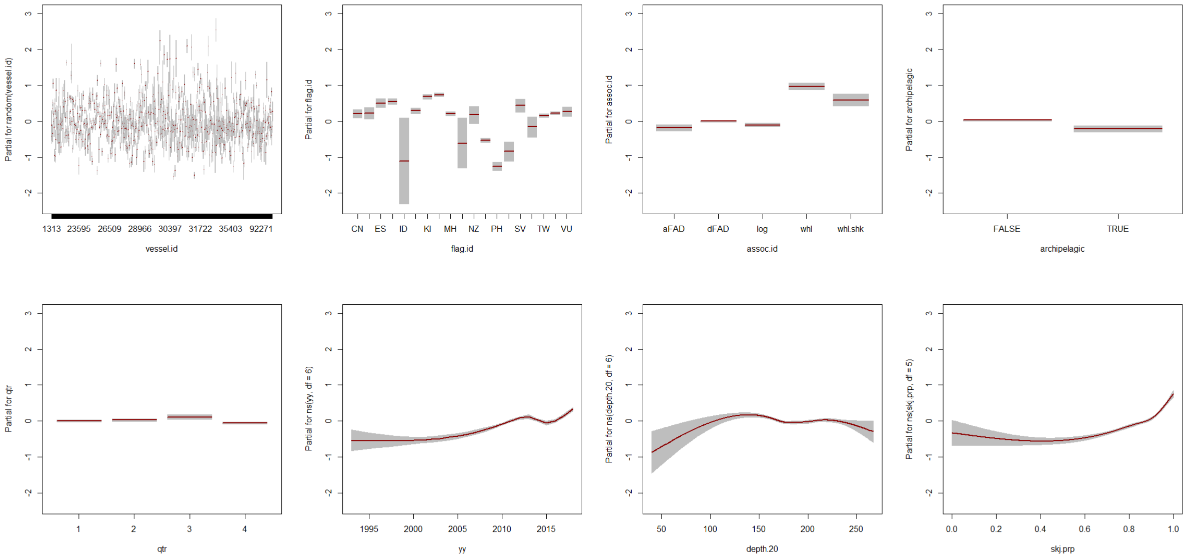

Figure 26 Effects on the zero-inflation component of the yellowfin associated model. Top row, left to right: random intercept for vessel ID; flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters.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

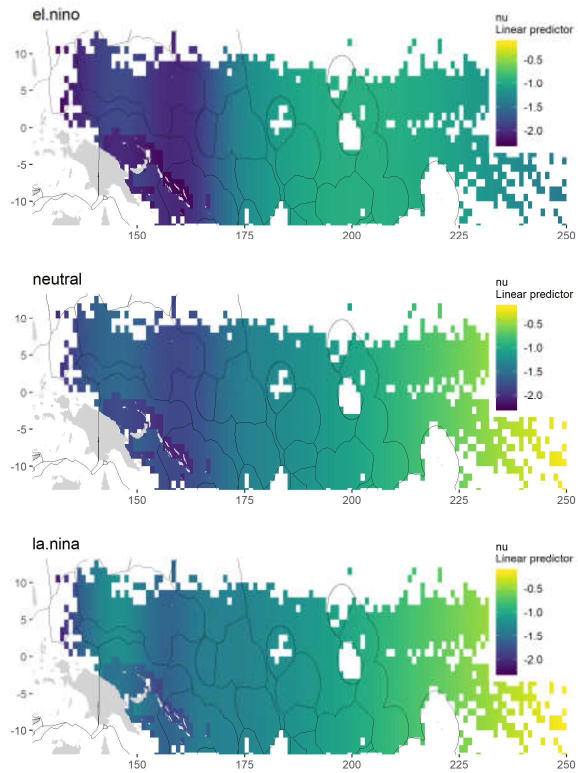

Figure 27 The combined effect of the archipelagic term and the longitude:ONI interaction on the zero-inflation component of the yellowfin associated model.

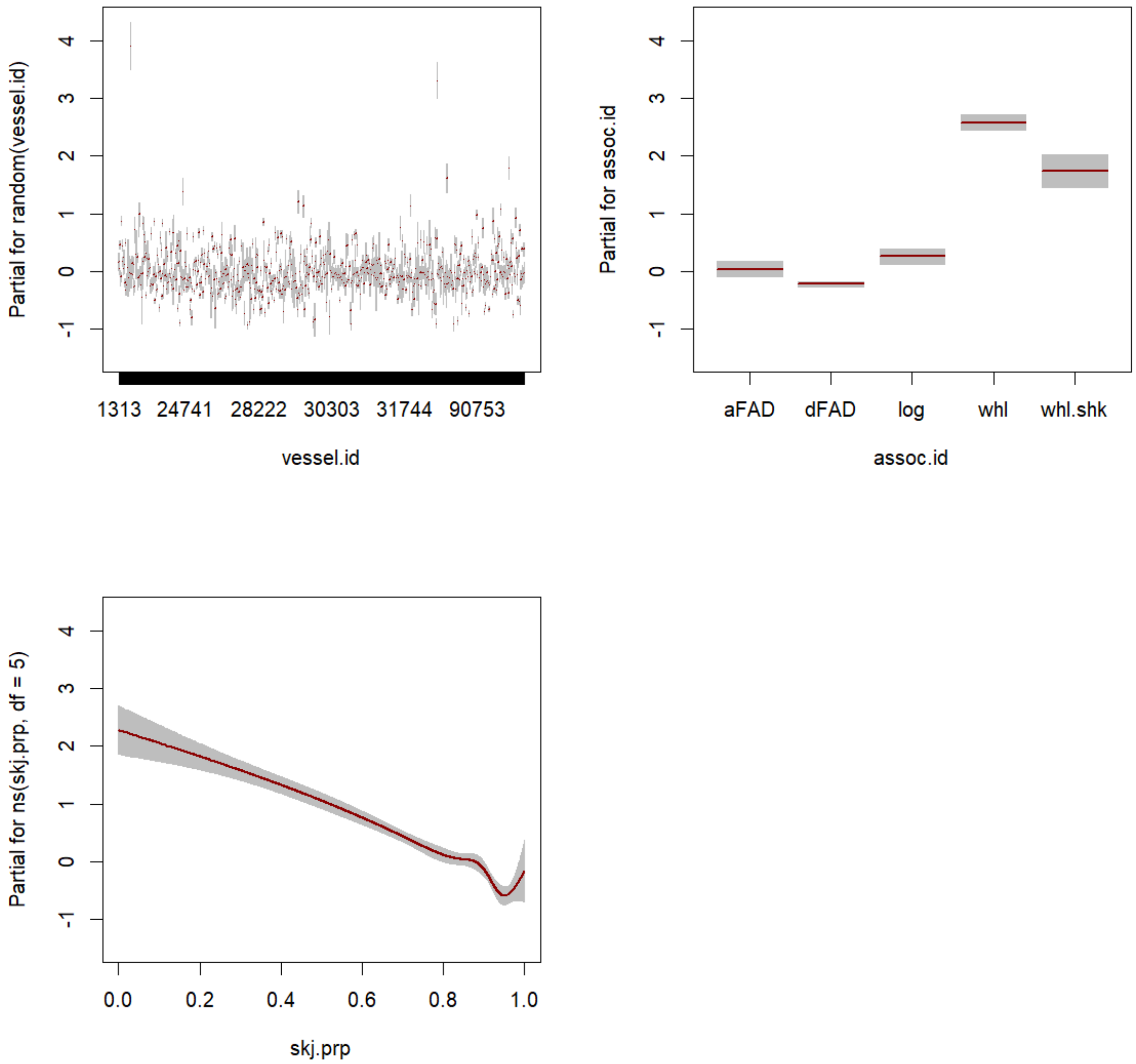

Figure 28 Effects on the one-inflation component of the yellowfin associated model: random intercept for vessel ID (top left); association type (top right - anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk) and, uncorrected skipjack proportion from vessel logbooks (bottom left).

Bigeye – associated

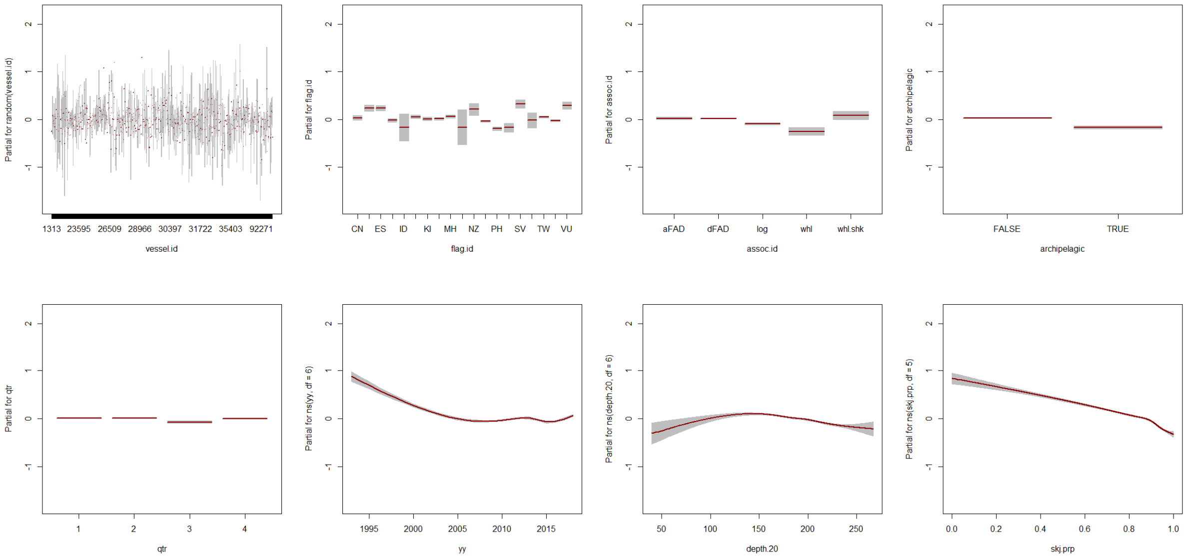

Figure 29 Effects on the mean of the beta-component of the bigeye associated model. Top row, left to right: flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters. Bottom row, left to right: quarter; isotherm depth; and, uncorrected skipjack proportion from vessel logbooks.

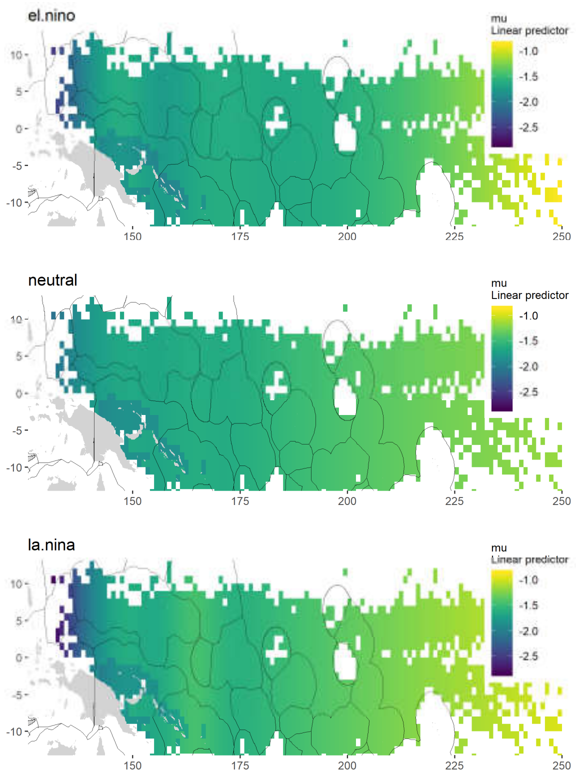

Figure 30 The combined effect of the archipelagic term and the longitude:ONI interaction on the mean of the beta component of the bigeye associated model.

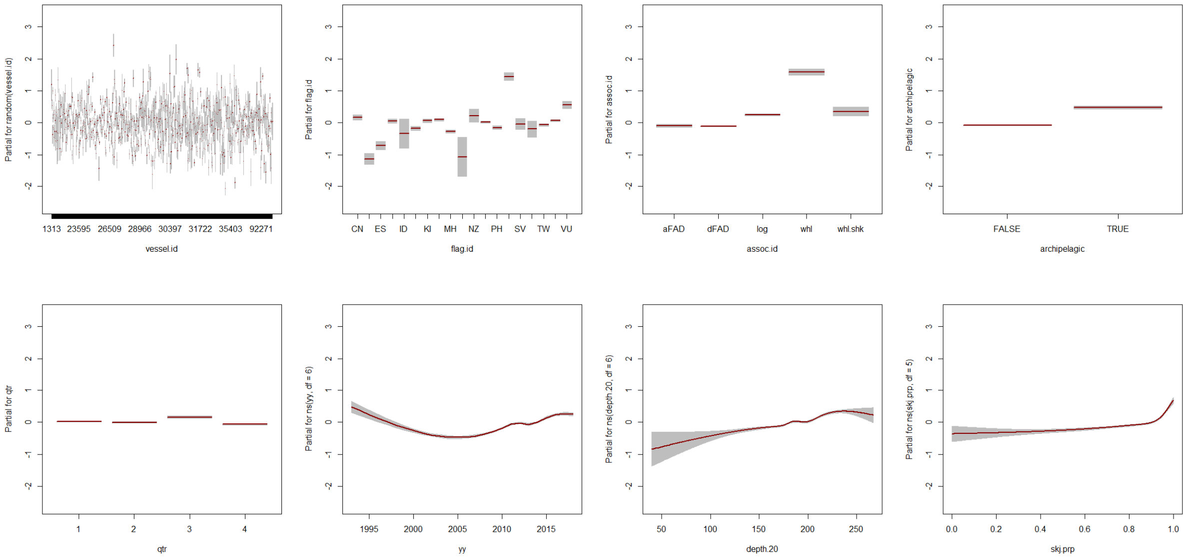

Figure 31 Effects on the zero-inflation component of the bigeye associated model. Top row, left to right: random intercept for vessel ID; flag; association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk); archipelagic waters. Bottom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

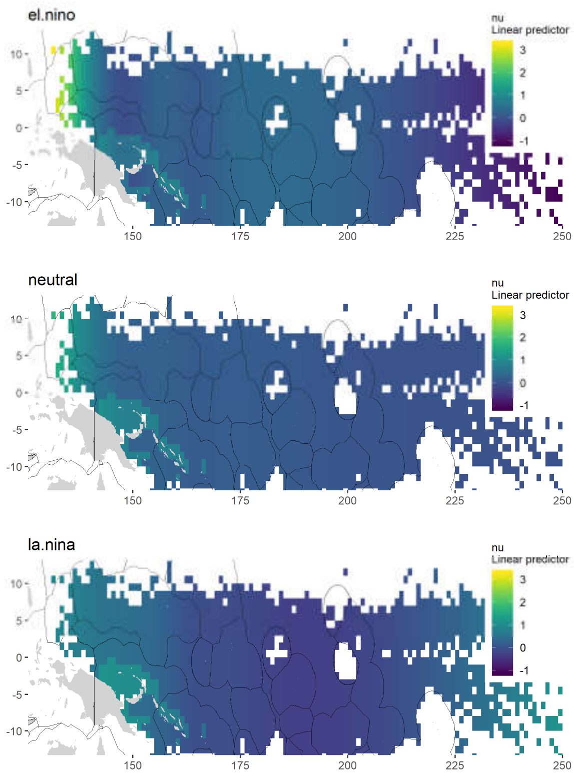

Figure 32 The combined effect of the archipelagic term and the longitude:ONI interaction on the zero-inflation component of the bigeye associated model.

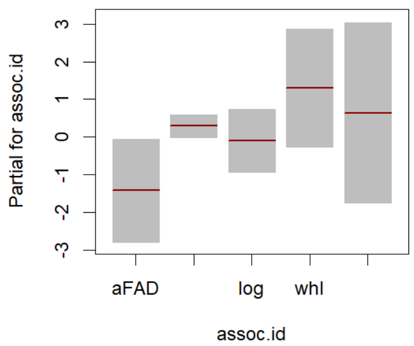

Figure 33 Effects on the one-inflation component of the bigeye associated model for association type (anchored FAD – aFAD, drifting FAD – dFAD, log sets, whale associated – whl, and whale shark associated – whl.shk).

Comparisons of observed vs predicted species compositions from beta response models

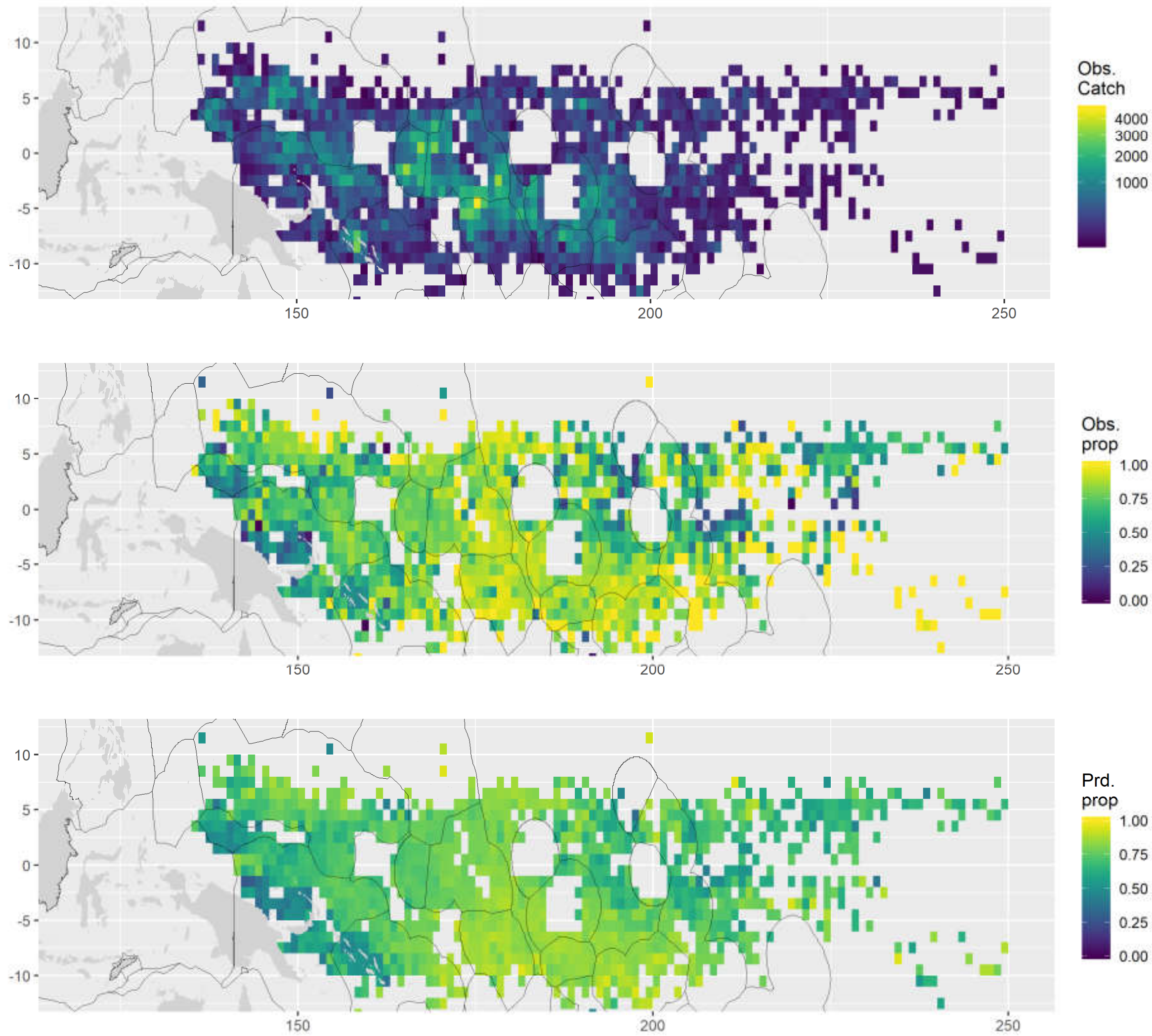

Figure 34 Total observed catch (mt - top), observed skipjack proportion (middle) and beta-response model predicted skipjack proportions (bottom) for associated sets in 2018.

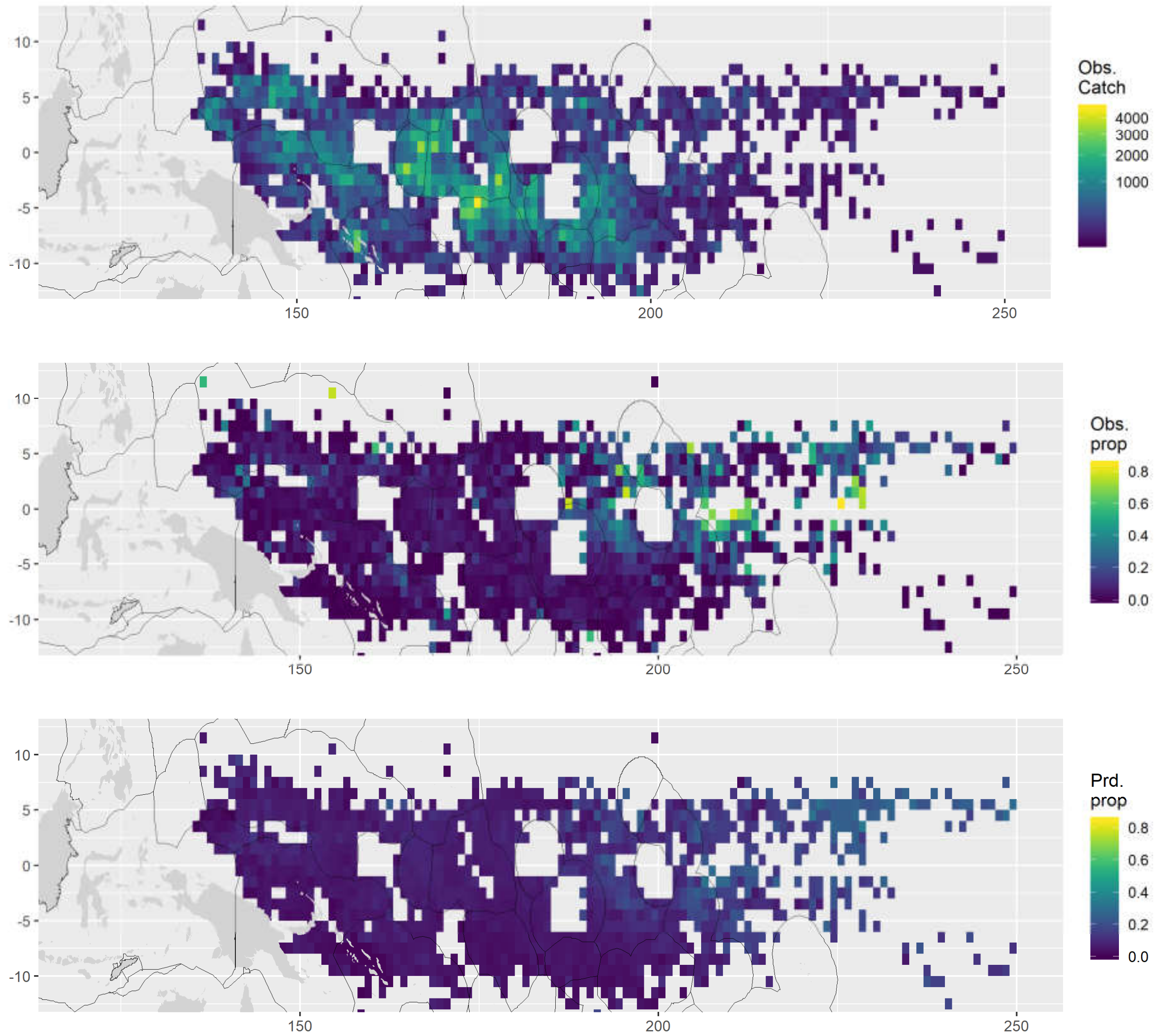

Figure 35 Total observed catch (mt - top), observed bigeye proportion (middle) and beta-response model predicted bigeye proportions (bottom) for associated sets in 2018.

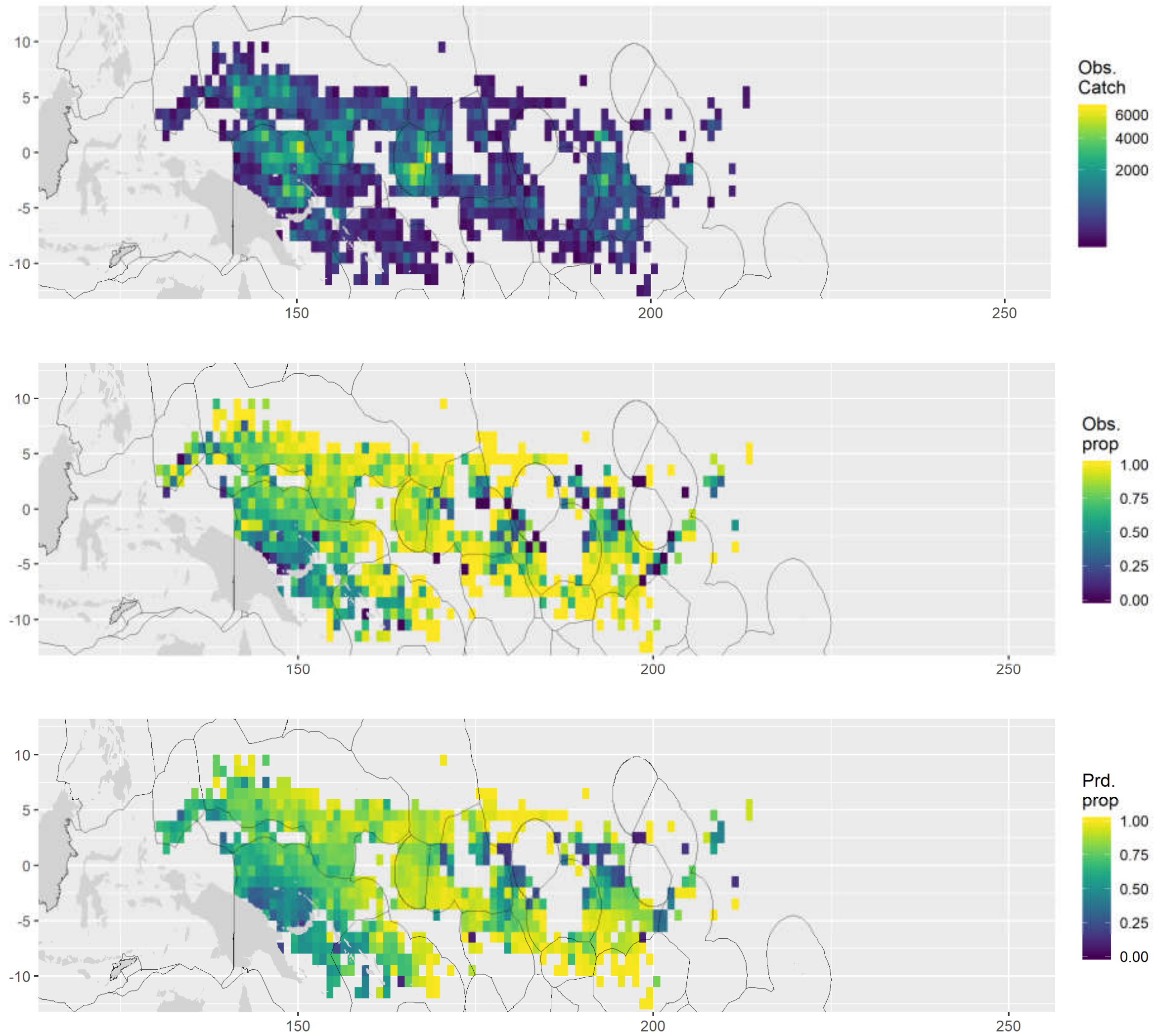

Figure 36 Total observed catch (mt - top), observed skipjack proportion (middle) and beta-response model predicted skipjack proportions (bottom) for free-school sets in 2018.

Appendix B

Additional Figures

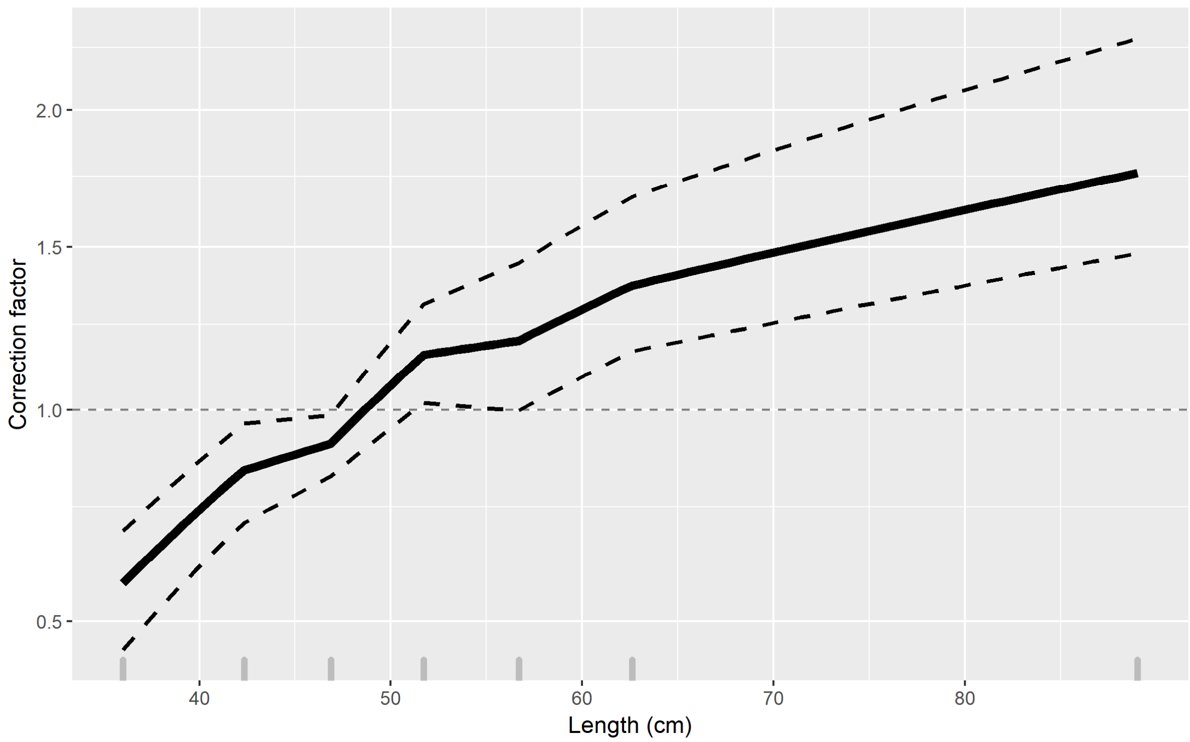

Figure 37 Updated estimates of correction factors with the additional 2019 paired grab-spill sampling trip (broken lines are 95 % confidence intervals).

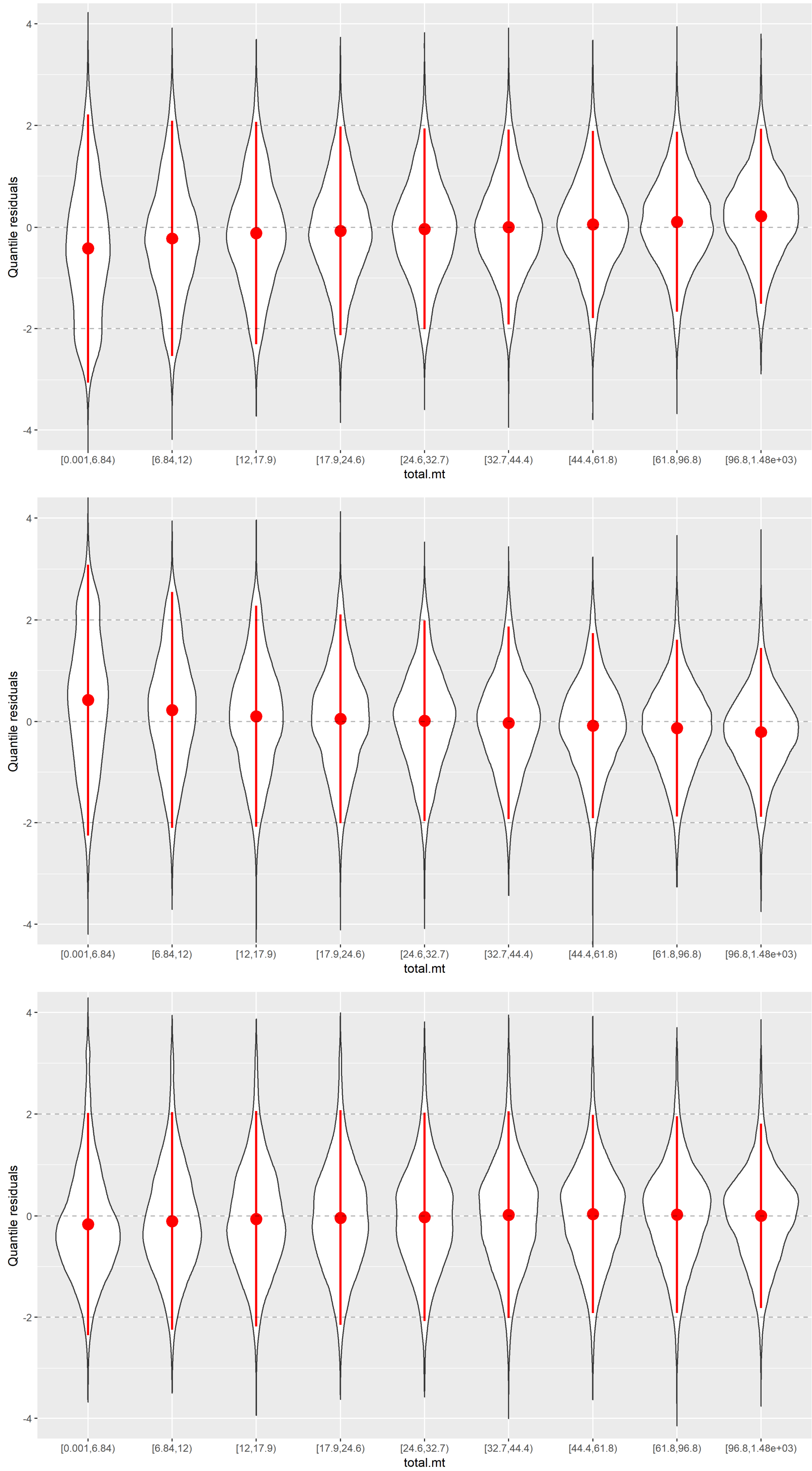

Figure 38 Violin plots of quantile residual distributions against binned set catch volume (total.mt) for beta-response models of skipjack (top), yellowfin (middle) and bigeye (bottom) proportions in associated sets.

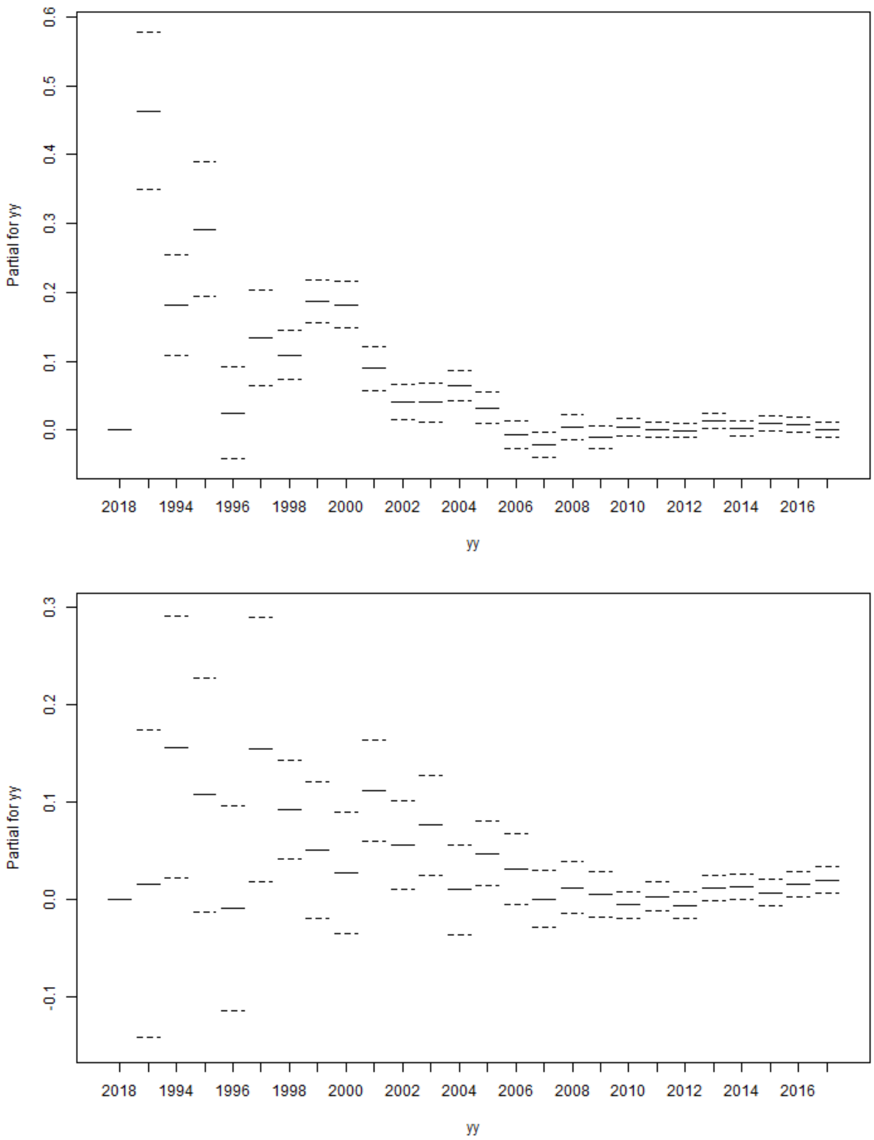

Figure 39 Year effects from the GAMs with year effects but no year interactions, as per Lawson (2012), for yellowfin proportions on associated (top) and free school (bottom sets).

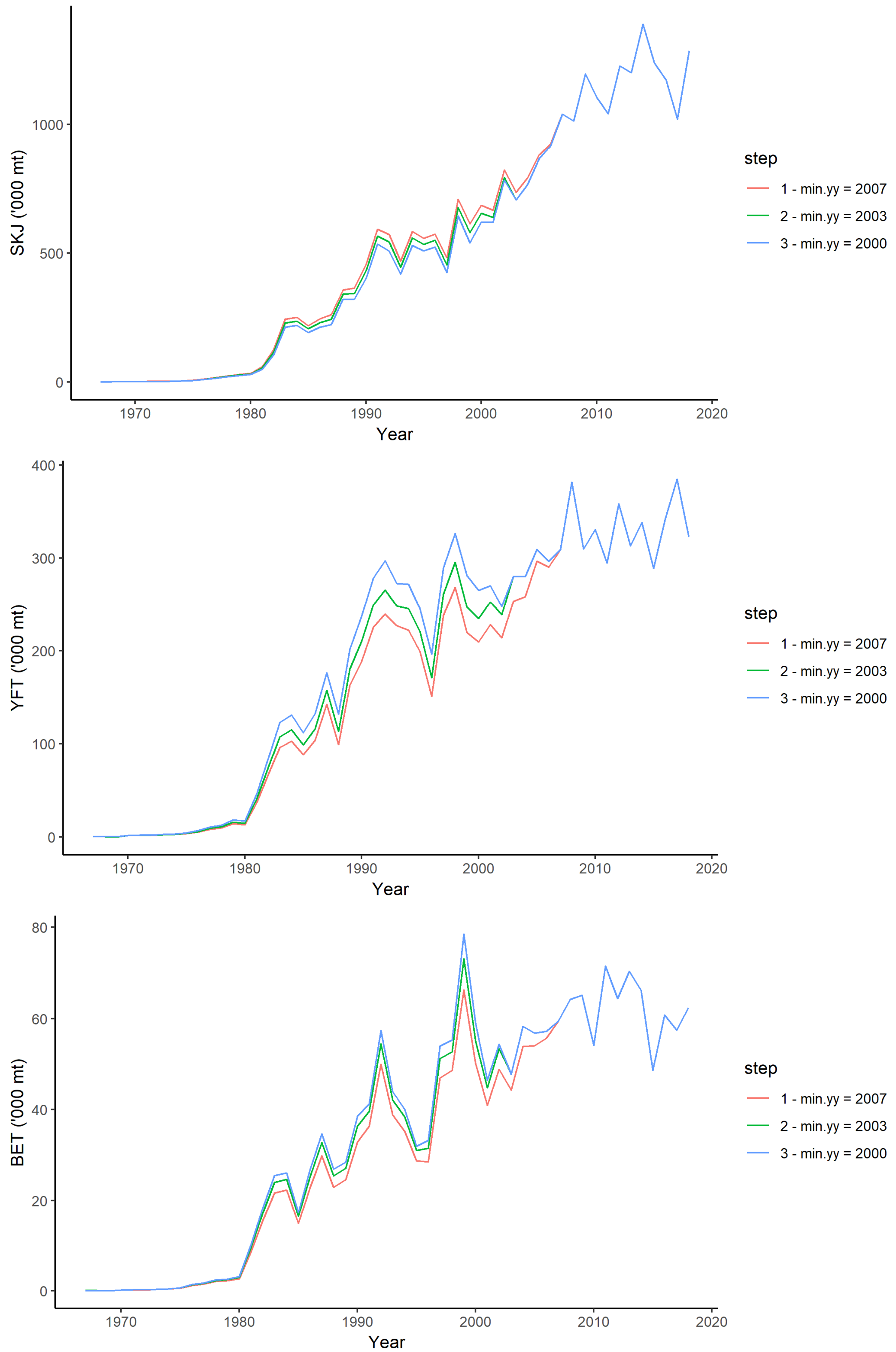

Figure 40 Sensitivity of beta-response based estimates of purse seine catch to fixing year effects at different levels for years with no or limited available observer data: using the 2007 year effect pre-2007 (1 – min.yy = 2007, red); the 2003 year effect pre-2003 (2 – min.yy = 2003, green); and, the 2000 year effect pre-2000 (3 – min.yy = 2000).

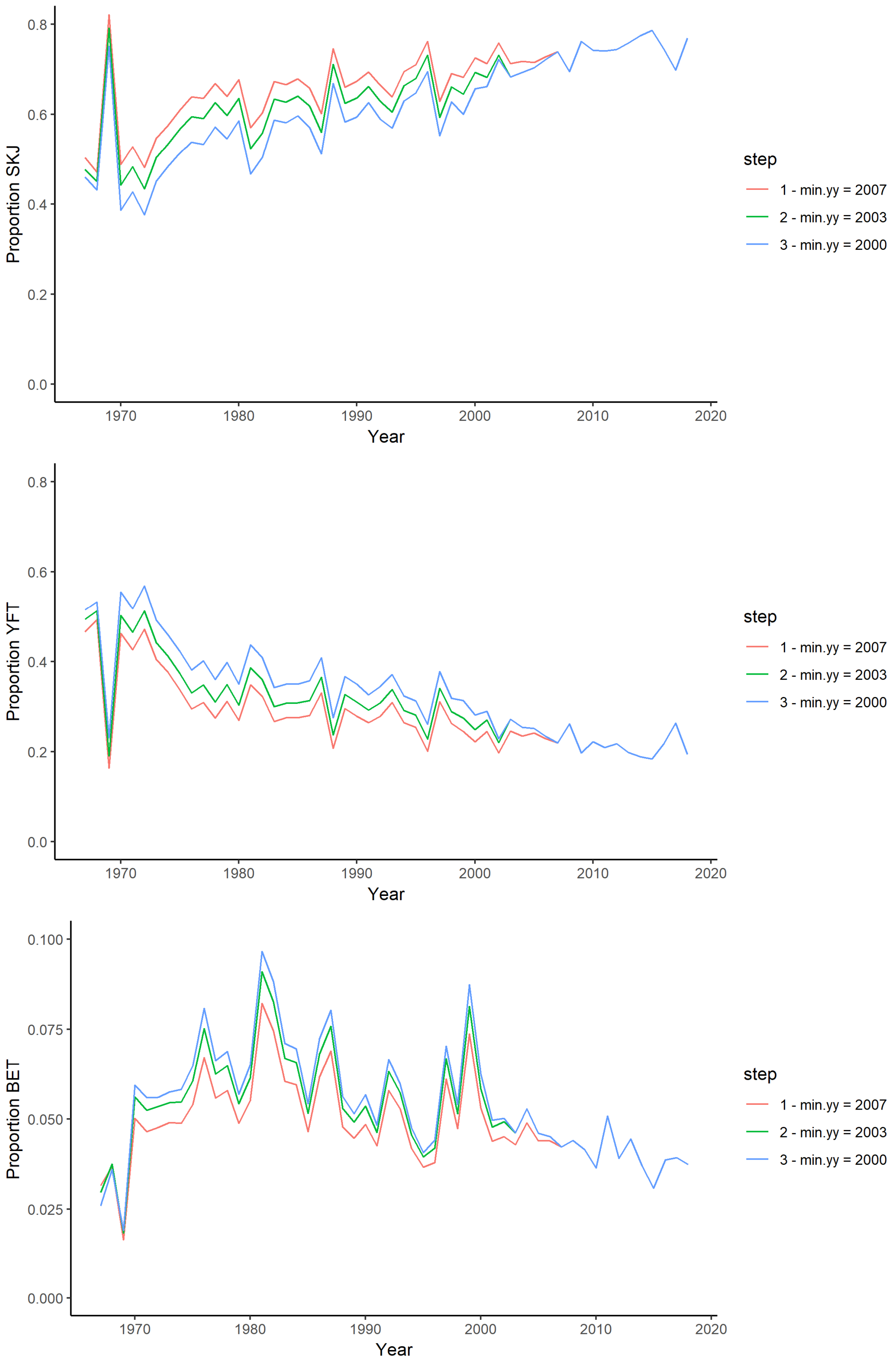

Figure 41 Sensitivity of beta-response based estimates of purse seine catch proportions to fixing year effects at different levels for years with no or limited available observer data: using the 2007 year effect pre-2007 (1 – min.yy = 2007, red); the 2003 year effect pre-2003 (2 – min.yy = 2003, green); and, the 2000 year effect pre-2000 (3 – min.yy = 2000).

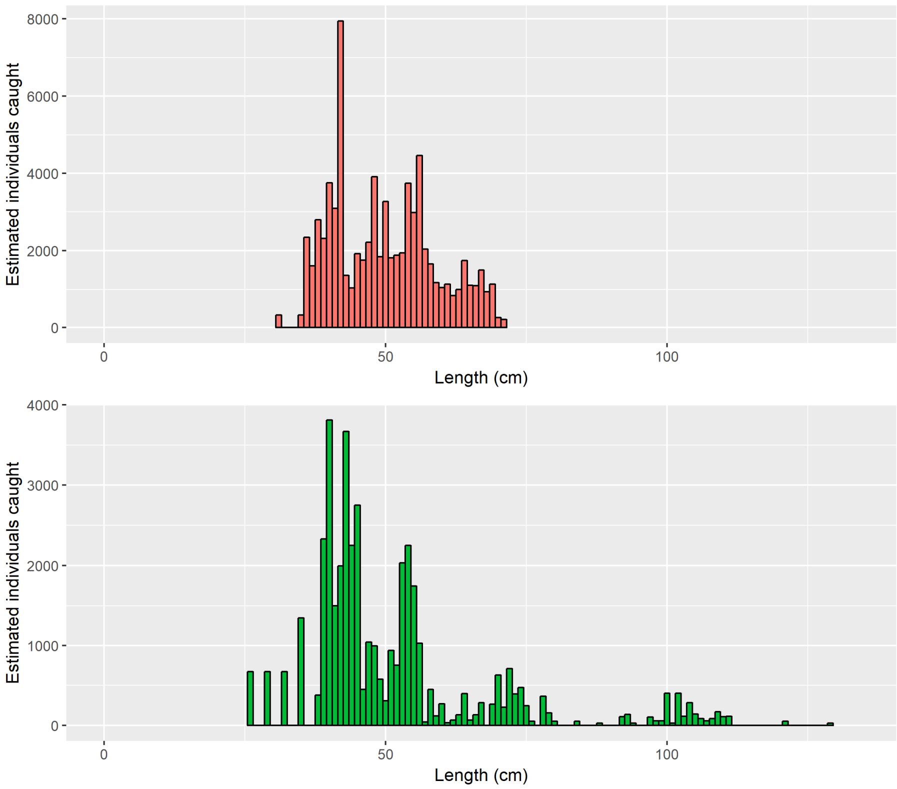

Figure 42 Trip-level corrected grab-sample based estimated length frequency for the 2019 paired grab-spill trip.

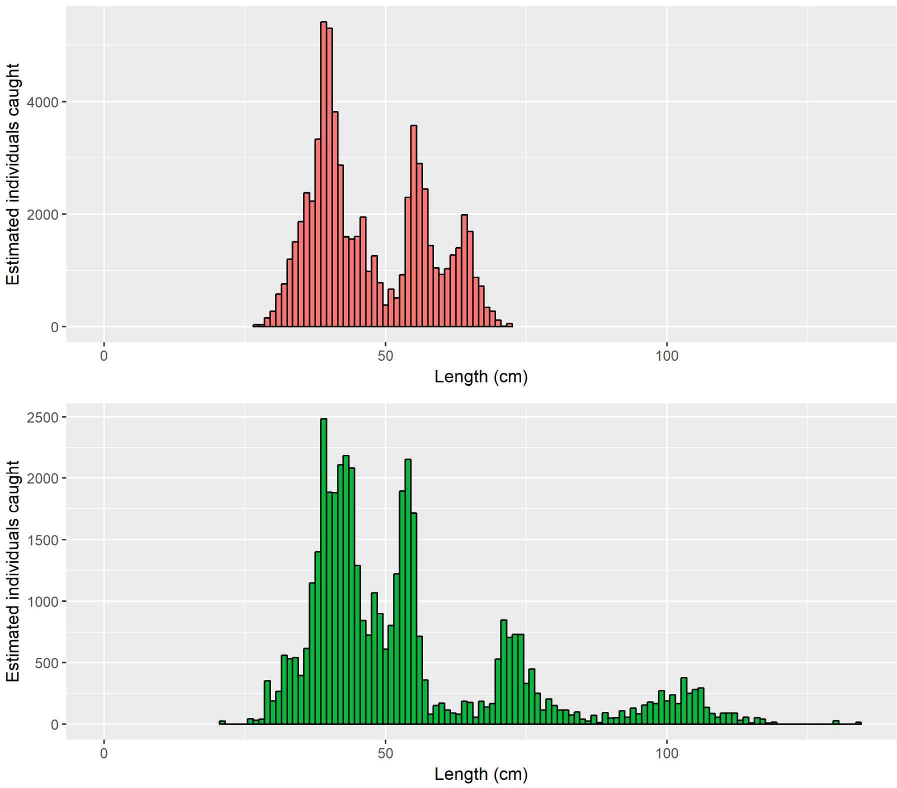

Figure 43 Trip-level spill-sample based estimated length frequency for the 2019 paired grab-spill trip.

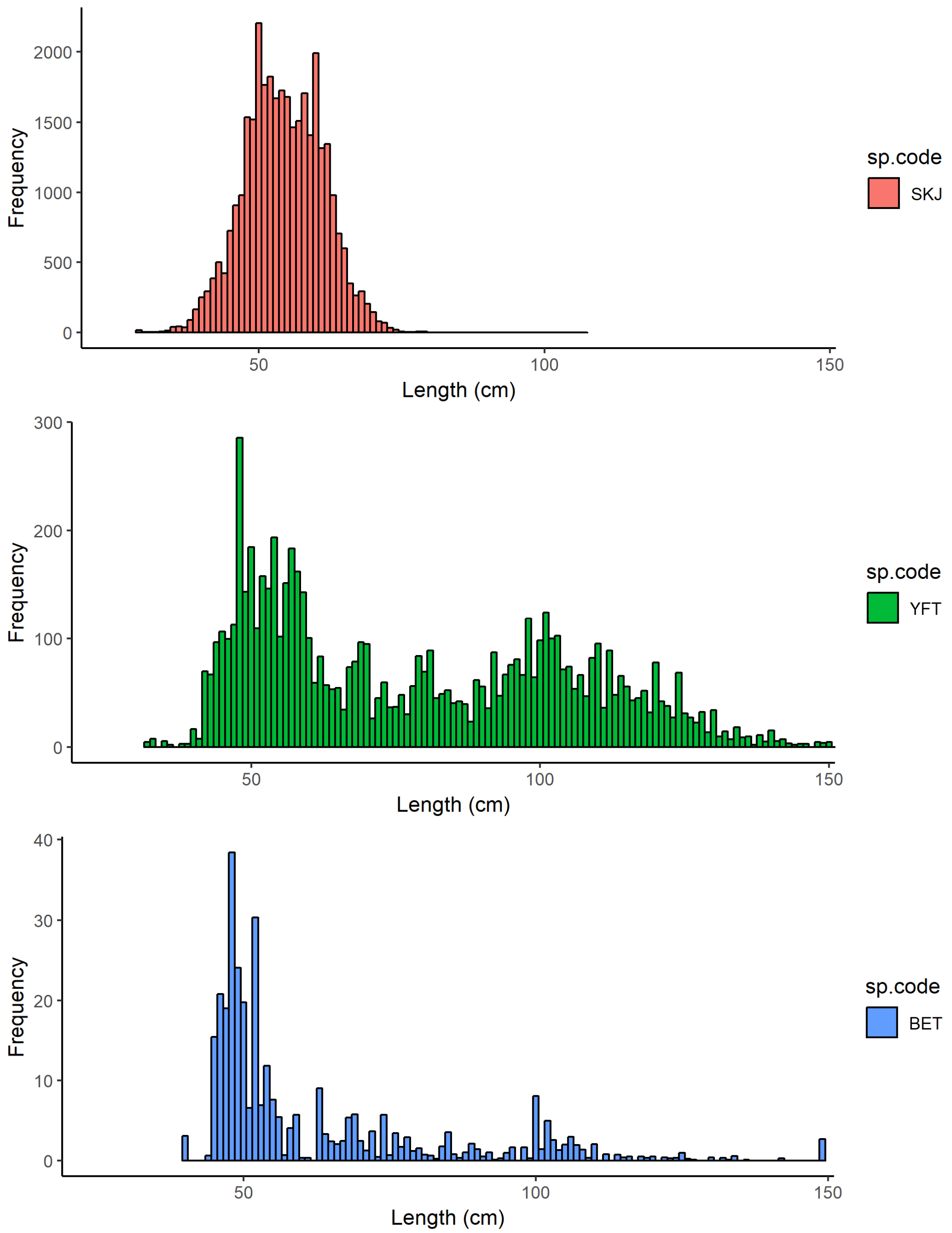

Figure 44 Length frequencies for the unassociated purse seine fishery in MFCL region 2, in the first quarter of 2017.

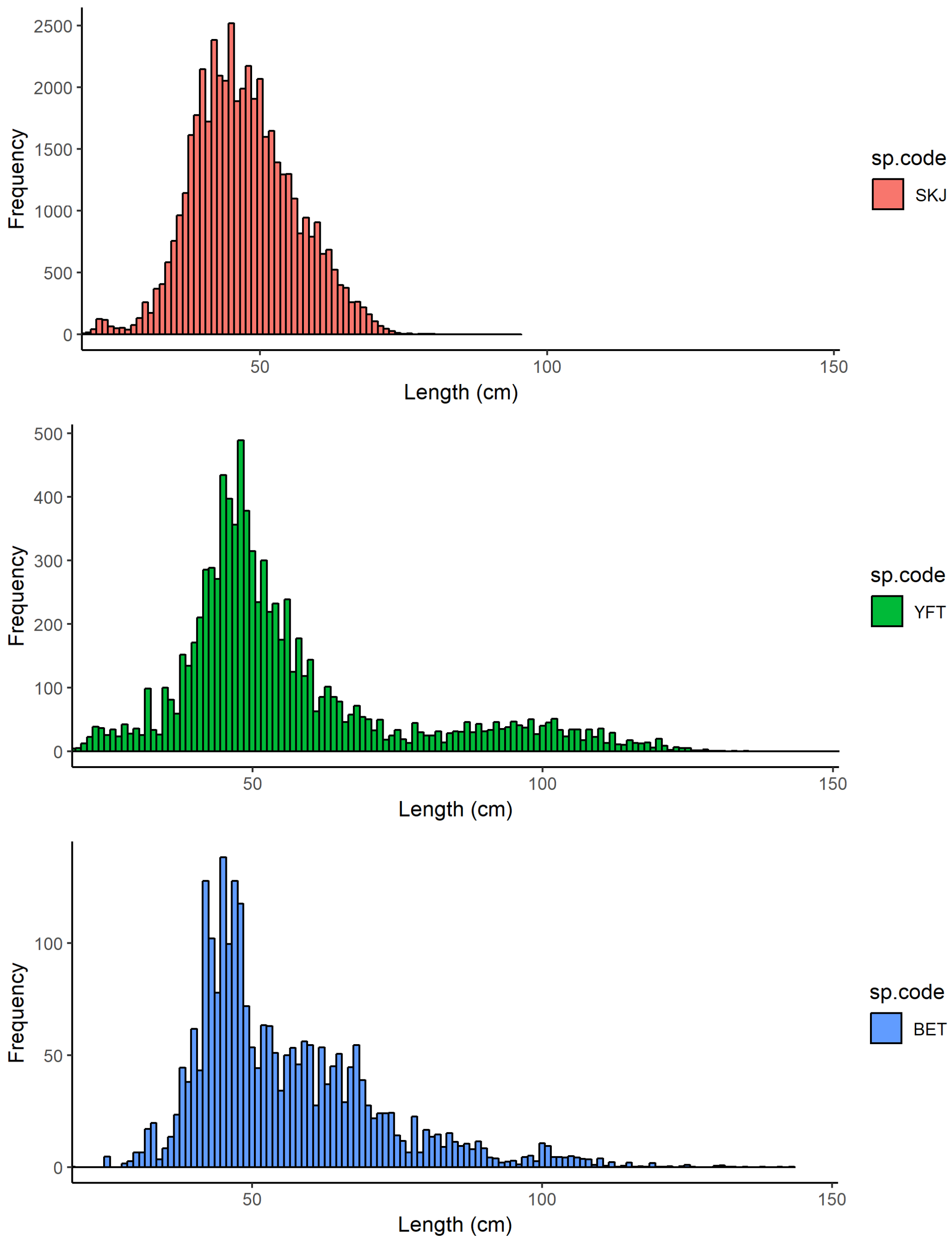

Figure 45 Length frequencies for the associated purse seine fishery in MFCL region 2, in the first quarter of 2017.