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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 2017 Scientific Committee. The main activities undertaken since SC13 were: updating the availability model currently used to correct grab sample bias; updating a simple multinomial model initially proposed during external reviews of Project 60 in 2012; negotiations to recommence obtain paired spill/grab sampling trips with in-port unload sampling; and, revisiting models of species compositions used to estimate purse seine catch compositions when observer coverage is insufficient to use grab sampling based estimates directly.

Multinomial model estimates of grab sample bias, referred to as 'correction factors', were broadly consistent with estimates of 'availability' – small individuals are underrepresented in grab samples, with large individuals overrepresented. The fit of the availability model was generally poor. The multinomial model estimates of grab sample bias are more intuitive, and tackle the issue of grab sample bias more directly. Comparison of corrected grab sample compositions against a corrected landings slip dataset for 776 Japanese purse seiner trips from 2010 to 2015 demonstrated that correction factors gave the least biased estimates of species composition at aggregated level. Exploratory analyses based on multinomial model based estimates of grab sample bias, referred to as 'correction factors' provided some evidence of stronger bias of grab samples from associated sets, compared to sets on free schools. This warrants further investigation through simulation modelling.

Generalised Additive Models are currently used to estimate purse seine species compositions for strata with low observer coverage. The resulting estimates of catch compositions are used in stock assessments, along with other analyses. We implement preliminary models of species composition with an inflated beta response, which give superior fits compared to the existing models, particularly for bigeye tuna.

The report concludes with a proposed work plan for Project 60 for 2019 and 2020, along with recommendations to SC, including:

- Multinomial model based correction factors be used to correct existing and future grab sample data, rather than the estimates of 'availability'
- Simulation modelling be undertaken to explore: a) the potential bias resulting from between brail variability; and, b) whether correction factors should be estimated separately for species and/or set association
- Existing models of species compositions be replaced with beta-response models, building on the preliminary models presented here; and
- Stratification used to estimate species compositions directly from aggregated observer data be revisited – specifically the whether to stratify by flag.

1 Introduction

1.1 Project Objective

The objective of the project is to improve the collection and representative nature of species composition data for tuna (skipjack, yellowfin and bigeye) caught by purse-seine fisheries in the WCPO in order to improve 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). This decision in 2017 also reflects the changing focus of Project 60 from simply investigating spill/grab sampling to focus on better estimates of purse seine catch composition. In the absence of robust precise total by species catch reporting, estimates of purse seine catch composition will always be required, and obviously given their impact on stock assessments better estimates will always be desirable.

1.3 Project 60 Scope

The scope of work 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 2017 were that the Scientific Service Provider should proceed with the proposed work plan in Peatman et al. (2017a), with reporting to SC14. This paper sets out work that was undertaken for Project 60 during the period July 2017 to August 2018, and proposes activities for August 2018 onwards. SC13 also recommended that the Scientific Services Provider explore opportunities to undertake comprehensive comparisons of corrected grab sample based species compositions with accurate estimates from in-port sampling with CCMs holding the required data.

2 Correction of grab samples

2.1 Context

WCPFC ROP observers on purse seine vessels currently collect length measurements for skipjack, yellowfin and bigeye using the grab sampling protocol. Grab samples have been demonstrated to be biased, with smaller fish underrepresented and larger fish overrepresented in samples (see Lawson, 2013 and references therein). This bias in grab samples results in overestimation of yellowfin and bigeye, and underestimation of skipjack, when using grab samples to obtain species composition estimates (Lawson, 2014a; Peatman et al., 2017a, 2017b). Currently, grab samples are corrected for bias using estimates of ‘availability’, defined as the probability of a fish being grab sampled from among fish of the same length interval. Availability should be invariant of size (and species) if grab samples are to provide unbiased estimates of catch compositions. However estimates of availability from paired grab and spill sampling trip data have demonstrated a non-linear and increasing trend in availability with size (Lawson, 2013 and references therein). Two independent reviews of Project 60 were undertaken in 2012 (Cordue, 2013; Powers, 2013). Both reviews recommended that a multinomial based approach be used to correct grab samples. McCardle (2013) implemented the simple multinomial model proposed by Cordue (2013), which was subsequently tested in simulations by Lawson (2013). The simulations suggested that catch compositions obtained from ‘availability’ corrected grab samples were less biased than those corrected using the multinomial model, particularly for sets on unassociated schools.

We revisited the models of availability and the multinomial model with the intention of comparing the estimates of species compositions to the Japanese corrected landing-slips dataset used in Peatman et al. (2017b). We also looked for evidence of differences in bias in grab samples between species and school association types, using the multinomial model. We refer to the multinomial model estimates of bias as ‘correction factors’, for consistency with terminology used by Lawson (2013).

2.2 Methods

We updated the existing model of availability described in Lawson (2013), with the up to date dataset from paired grab/spill trips. We made two changes to the model. First, we included an intercept. If grab samples are unbiased, then availability should be length invariant (and greater than zero). Suppressing the model intercept forces estimated availability to increase with increasing size, at least for comparatively small fish, regardless of the signal in the observations. We prefer to include an intercept. Secondly, we used natural cubic splines, with 3 interior knots at the 25th, 50th and 75th quantiles of length, compared to Lawson (2013) who used cubic splines with no interior knots.

First, we describe the revised model of availability. Following Lawson (2013), let observed availability for length bin j in set k, denoted Y_{jk} be defined as

$$Y_{jk} = \frac{n_{jk}\overline{w}_j}{W_k T_{jk}}$$

where n_{jk} is the number of grab sampled fish of length bin j in set k, $\overline{w}_j$ is the average weight of fish of length bin j, W_k is the total weight of set k and T_{jk} is the (assumed) true proportion of fish by weight. Note that T_{jk} is calculated from the spill sampling data.

The revised model of availability can then be described as

$$E\left[Y_{jk}\right] = \mu_{jk} \qquad\qquad Var\left[Y_{jk}\right] = \sigma^2$$

$$\mu_{jk} = \beta_0 + f\left(\bar{L}_{jk}\right)$$

where β_0 is the intercept, $\bar{L}_{jk}$ is the mean length of fish in length bin j in set k (again from spill samples) and $f(\,)$ is a natural cubic spline as described above.

We now describe the simple multinomial model implemented by McCardle (2013). Keeping n_{jk} as the number of grab sampled fish of length bin j in set k (as above), with n_k the total number of grab samples from set k. Let N_{jk} be the number of spill sampled fish of length bin j in set k, with N_k the total number of spill samples from set k. The bias in grab samples of length bin j in set k is then the ratio of the grab sample and spill sample proportions:

$$\frac{{n_{jk}}/{n_k}}{{N_{jk}}/{N_k}}$$

Grab sample bias is then estimated by aggregating samples across the paired grab spill dataset and calculating the resulting bias by length bin r_j as

$$r_j = \frac{{\sum_k n_{jk}}/{\sum_k n_k}}{{\sum_k N_{jk}}/{\sum_k N_k}}$$

Uncertainty in grab sample bias was incorporated by bootstrapping from the observations, first by resampling from trips, and then resampling from sets within the trip. We refer to the estimated grab sample bias as ‘correction factors’, to remain consistent with the terminology of Lawson (2013). Species specific correction factors were obtained by taking the ratio of grab sample and spill sample proportions by species (rather than aggregating across species). Free school and associated set specific correction factors were obtained by taking the ratio of (aggregated) grab and spill sample proportions only from sets of the school association of interest.

Initial attempts to estimate correction factors used fourteen length bins consistent with those used by Lawson (2013), i.e. < 35 cm, 5 cm bins for lengths of 35 to 79 cm (i.e. 9 bins), 10 cm bins for lengths 80 to 109 cm (i.e. 3 bins), and ≥ 110 cm. Estimated correction factors for length bins ≥ 70 cm demonstrated excessive uncertainty, as a result of the limited number of sampled fish ≥ 70 cm. The length bins were simplified to < 40 cm, 40 – 44 cm, 45 – 49 cm, 50 – 55 cm, 55 – 60 cm, 60 – 70 cm and ≥ 70 cm. Note that length measurements are upper jaw to fork in tail.

Peatman et al (2017b) estimated species compositions for Japanese purse seiners based on grab samples, and compared these estimates to landings slips data corrected for species misclassification using market sampling data. We have updated the comparisons to include alternative approaches to correcting the grab samples, namely the updated model of availability, and the use of correction factors with corrections applied at the set-level, and at a trip and school association (free school v associated) level. The process of applying correction factors is described in Appendix D.

2.3 Results

2.3.1 Updated availability model

The fit of the availability model was poor with strong heteroscedasticity and skewed residuals (Figure 1). We note that this is true for both the 2013 specification of the model and the update presented here. Availability was estimated to increase with increasing length, with a relatively strong increase in availability for fish smaller than 50 cm and greater than 75 cm (Figure 2). The uncertainty in availability for smaller lengths was higher than the 2013 specification, as a result of including an intercept in the model specification.

2.3.2 Correction factors

Estimated correction factors pooled across species and association types demonstrated downwards bias in grab samples for smaller individuals (< 50 cm) and upwards bias for larger individuals, i.e. smaller individuals (< 50 cm) were underrepresented in grab samples with larger individuals overrepresented (Figure 3). Association type specific correction factors (pooled across species) demonstrated some suggestion of greater bias for associated sets for fish between 60 cm and 70 cm (Figure 4). Species-specific correction factors (pooled across association types) displayed similar trends with generally overlapping confidence intervals (Figure 4). For skipjack, there was some suggestion of greater bias for sets on associated schools relative to sets on free schools for fish larger than 50 cm (Appendix A, Figure 6). It was not possible to undertake meaningful comparisons of association type-specific correction factors for bigeye and yellowfin due to the relatively low numbers of samples from free school sets.

2.3.3 Comparisons of species compositions

The landings slips dataset for Japanese purse seiners analysed in Peatman et al. (2017b) provides an opportunity to explore the bias in grab sample derived species compositions across a relatively large number of trips. Correction of grab samples with the updated availability model increased the bias in bigeye, skipjack and yellowfin species compositions compared to corrections with the 2013 availability model (Table 1). The largest difference was for bigeye, with an overestimation of 4.6%, compared to 3% when applying the 2013 availability model. The least biased grab sample based estimates were obtained when applying correction factors at a set level, with bigeye and skipjack overestimated by 1.9 and 0.8% and yellowfin underestimated by 3.7 %. The most biased grab sample based estimates were obtained when applying correction factors at a trip and school association level.

2.4 Discussion

Analyses undertaken through Project 60 indicate that the correction of grab samples using model estimates of 'availability' has likely reduced bias in purse seine catch compositions, and thus purse seine catch indices in aggregate data. However, the availability models have a range of issues. First, the models do not explicitly account for sample size or the number of fish in the set (Cordue, 2013). Additionally, both the 2013 model of 'availability' and the updated model specification presented here do not fit well to observations. The multinomial-based (correction factor) approach developed by McCardle (2013) provides an alternative method for correcting grab samples. The multinomial-based approach explicitly accounts for sample size, and estimates bias in a more direct and intuitive way. We also note that the use of correction factors gave the least-biased grab-sample based estimate of species composition for the Japanese purse seine dataset analysed by Peatman et al. (2017b). As such, we see no reason to continue to use the 'availability' models, and recommend that grab samples be corrected by correction factors.

The correction factor approach implemented here used a single set of length-based correction factors, which were applied for all three species and for sets on associated and unassociated schools. This is consistent with the way that 'availability' estimates have been implemented. However there was some indication that the bias in grab samples may differ between associated and unassociated sets, particularly for skipjack. There was also evidence of stronger between-brail variability for sets on associated schools relative to those on unassociated schools based on spill samples (Peatman, 2017a), which might lead to increased bias in grab samples from associated schools. This should be explored in more detail through simulation.

It is not currently clear why correction factors performed well for the available dataset of Japanese purse seine trips, and yet performed poorly when tested in previous simulation experiments (Lawson, 2013). We speculate that the poor simulated performance of correction factors might have resulted from the specification of the simulation model itself. Regardless, set-level comparisons indicated that availability and correction factors corrections to grab samples generally gave similar species compositions, at least for sets where the majority of grab sampled fish were between 44 and 89 cm (Figure 5a), which suggests that the performance of both methods should be similar.

We note that there were larger differences in species compositions for sets where the majority of grab sampled fish were < 44 or ≥ 90 cm (Figure 5b). This is caused by the fact that the availability estimates are a continuous function of length, whereas correction factors apply to all fish within a given length bin, regardless of length. For example, the availability for a 110 cm fish is higher than for a 90 cm fish, whereas the same correction factor is applied to a 90 cm and a 110 cm fish. As noted by McCardle (2013), this is one area where the availability models have an advantage over the correction factor approach - we might expect that the bias in a grab samples is a (relatively) smooth function of length.

3 Review of models used to estimate species compositions in cases of low observer coverage

3.1 Context

Grab 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 domestic fisheries of Indonesia, Philippines and Vietnam, and the Japanese fleet which submits corrected catch data. The estimation method depends on the level of observer coverage, and also the year in question. The methodology is described in full in Lawson (2012, 2013) with a clear 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), 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, generalised additive models (GAMs) are used to predict species proportions, with the models fitted to grab sample based species compositions, again with corrections for grab sample bias, 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).

The generalised additive models (GAMs) are described in Lawson (2013). Separate models were fitted for each combination of species and school association (free school vs. associated), and there were three different parameterisations of mean species proportion of increasing complexity, i.e. 18 models in total. We provide the model specifications here for convenience, using skipjack as an example; the models for yellowfin and bigeye have the same parameterisation for mean proportion.

The simplest parameterisation of species proportion, used to estimate species proportions for 1967 to 1995, was:

$$E[SKJ_{at}] = \mu_{at} \qquad Var[SKJ_{at}] = \sigma^2$$

$$\mu_{at} = \begin{cases} \beta_0 + Flag_{at} + \beta_2 Qtr_{at} + \beta_3 prop_{SKJ} + f(lat_{at}, lon_{at}) \text{ when } a = \text{unassociated} \\ \beta_0 + \beta_1 Flag_{at} + \beta_2 Qtr_{at} + \beta_3 prop_{SKJ} + \beta_4 assoc_{at} + f(lat_{at}, lon_{at}) \text{ when a} = \text{associated} \end{cases}$$

where subscripts a and t denote association (free school v associated), SKJ_{at} is the grab sample based proportion of skipjack, $Flag$ is the flag of the vessel, Qtr is the (categorical variable) quarter with the highest catch (for the trip and association class), $prop_{SKJ}$ is the uncorrected proportion of skipjack from aggregate catch and effort data[1], $f(lat_{at}, lon_{at})$ is a 2-dimensional thin-plate regression spline

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[1] The unadjusted proportion of skipjack was determined for the stratum of year – quarter – 2° x 2° grid – school association (associated or unassociated); vessel flag was not considered in the stratification. See Lawson (2013) for more information.

with 13 degrees of freedom fitted and lat_{at}, lon_{at}, are the catch-weighted averages of set-level latitude and longitude, and $assoc$ is the type of association (i.e. schools associated to anchored FADs, drifting FADs, logs, whales and whale sharks).

A categorical year effect was added for models used to estimate species proportions for 1996 to 2002, i.e. for free school sets:

$$E[SKJ_{at}] = \mu_{at} \qquad Var[SKJ_{at}] = \sigma^2$$

$$\mu_{at} = \beta_0 + \beta_1 Flag_{at} + \beta_2 Yr_{at} + \beta_3 Qtr_{at} + \beta_4 prop_{SKJ} + f(lat_{at}, lon_{at})$$

and similarly for associated sets with the additional $assoc$ effect.

Interactions between year and quarter, and year and the 2011 skipjack assessment region (i.e. region 2 = 20°S to 20°N, 110°E to 170°E; region 3 = 20°S to 20°N, 170°E to 150°W) were added for models used to estimate species proportions for 2003 onwards, i.e. for free school sets:

$$E[SKJ_{at}] = \mu_{at} \qquad Var[SKJ_{at}] = \sigma^2$$

$$\begin{aligned}\mu_{at} = \beta_0 + \beta_1 Flag_{at} + \beta_2 Yr_{at} + \beta_3 Qtr_{at} + \beta_4 prop_{SKJ} + \beta_5 Yr_{at} Qtr_{at} + \beta_6 Yr_{at} Region_{at} \\ + f(lat_{at}, lon_{at})\end{aligned}$$

The contribution of each observation to the likelihood was weighted by the number of sets it represents, i.e. observations representing more sets have a higher weighting.

3.2 Method

In Section 3.1, we provide the specification of the GAMs introduced by Lawson (2013) which are used to estimate species compositions for strata with low observer coverage. Gaussian errors were assumed, which causes some issues when modelling proportional responses with observations close to, or lying on, the bounds of the response, i.e. 0 and 1. We note that this is particularly an issue for GAMs of bigeye proportions, which are generally low and frequently zero. Proportional response models provide a more statistically robust approach. Here we implement beta response models, again fitted to each species separately, with zero and one inflation to account for observations with an absence of a species in grab samples (normally bigeye) or ones (normally skipjack). We implement the models using the R package gamlss (Rigby and Stasinopoulos, 2005). As with the GAMs, we fit separate models to species and association specific (free school v association) proportions, for two levels of complexity in the model specifications.

The base zero inflated beta response models for skipjack for unassociated sets, intended to be analogous to the simplest GAMs of Lawson (2013), are specified as:

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

where the mean of the beta distribution, μ_{at}, was parameterised

$$\ln\left(\frac{\mu_{at}}{1-\mu_{at}}\right) = \beta_0 + \beta_1 Flag_{at} + \beta_2 Qtr_{at} + \beta_3 prop_{SKJ} + f(lon_{at}) + f(isotherm_{at})$$

the zero inflation component, υ_{at}, was parameterised

$$\ln(\upsilon_{at}) = \beta_0 + \beta_1 prop_{SKJ}$$

the one inflation component τ_{at}, was parameterised

$$\ln(\tau_{at}) = \beta_0 + \beta_1 Flag_{at} + \beta_2 Qtr_{at} + \beta_3 prop_{SKJ} + f(lon_{at}) + f(isotherm_{at}) + g(sets_{at})$$

and a variance parameter

$$\ln\left(\frac{\sigma_{at}}{1-\sigma_{at}}\right) = \beta_0 + g(sets_{at})$$

where we keep the same notation used for the description of the GAMs, $isotherm_{at}$ is the catch weighted depth of the 20°C isotherm, $sets_{at}$ is the number of sets represented by the observation, $f(\,)$ are P-spline smoothers and $g(\,)$ are natural cubic splines with three (inner) knots. For associated sets, we added $assoc$ terms to the beta mean and one-inflation components. We also fitted models for skipjack with $f(Yr_{at})$ terms to the beta mean and one-inflation components, intended to be analogous to the two sets of GAMs with year effects and with/without year interactions. It is worth stressing that the zero-inflation, υ_{at}, does not directly reflect the probability of a zero response, this is given by $\upsilon_{at}(1+\upsilon_{at}+\tau_{at})^{-1}$. Similarly, the probability of a one response is $\tau_{at}(1+\upsilon_{at}+\tau_{at})^{-1}$.

The specifications of the yellowfin models were equivalent to the skipjack models, though with a switching of the zero-inflation and one-inflation components:

the zero inflation component, υ_{at}, was parameterised

$$\ln(\upsilon_{at}) = \beta_0 + \beta_1 Flag_{at} + \beta_2 Qtr_{at} + \beta_3 prop_{SKJ} + f(lon_{at}) + f(isotherm_{at}) + g(sets_{at})$$

the one inflation component τ_{at}, was parameterised

$$\ln(\tau_{at}) = \beta_0 + \beta_1 prop_{SKJ}$$

The specification of the bigeye models were equivalent to the yellowfin models, though with a simplified one-inflation component:

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

Note that we fitted the (inflated) beta response models and the GAMs to species compositions from grab samples, with corrections for grab sample bias using correction factor estimates pooled across species and school association (Figure 3).

3.3 Results

Residuals of the GAMs for skipjack and yellowfin proportions were reasonably skewed, as a result of the bounded nature of the proportional response variable and the assumption of normal errors (see for example Figure 7). The residuals for models of bigeye were highly skewed, a result of the low proportion of bigeye in catches and the frequency of zeros (see for example Figure 7b). Substantial improvements in fit were realised with the use of beta response models, particularly for bigeye (see for example Figure 8).

We now summarise the effects of inflated beta model for skipjack proportion in free-school sets, as an example. The effects of the beta mean component of the model indicate (Figure 9): a weak increase in mean skipjack proportion as fishing location shifts eastwards; increasing skipjack proportions as the 20°C isotherm deepens; a strong increase in skipjack with increasing proportions of skipjack in (uncorrected) aggregate data; weak variability between quarters; and, some variability between flags. The variance of the beta response demonstrates a significant asymptotic reduction as the number of sets increases (Figure 10a). The zero-inflation component of the model had decreasing proportions of strata with zero skipjack catch with increasing skipjack proportions in aggregate data (Figure 10b). The effects of the one-inflation component of the model (Figure 11) were: increasing incidence of pure skipjack catch with eastward shifts in fishing location; increasing incidence of pure skipjack catch as the 20°C isotherm deepens; a strong increase in pure skipjack incidence with increasing skipjack proportions in aggregate data; a strong decrease in pure skipjack incidence with increasing number of sets; and, some variability between quarters and flag.

3.4 Discussion

The generalised additive models of species compositions are currently used to estimate species compositions for strata with low observer coverage. The models assume Gaussian errors for a proportional response, and as a result have difficulty achieving robust fits to the observations, particularly for strata with proportions that are equal, or close, to 0 and 1. The fits of the models for bigeye proportions are particularly poor. This is a concern given that small changes in estimates of bigeye catch proportions can lead to relatively large changes in overall estimated bigeye catch in the purse seine fishery. We note that Dr Lawson was well aware that proportional response models would be most appropriate, suggesting the use of Dirichlet response models (Lawson, 2013). Dirichlet response models would allow simultaneous fitting to proportions of the three species, rather than fitting models to each species individually. However the Dirichlet model would need to account for both zero and one inflation. We are not aware of any implementations of such a model. Here, we show that zero and one inflated beta response models are capable of achieving satisfactory fits to catch proportions of all three species, and as such provide a robust alternative to the existing models of species compositions. We recommend that the beta response models be further developed and used to estimate species compositions for strata with low observer coverage. In particular, the use of mixed effects models fitted to set-level data should be explored in more detail. Initial attempts suggest that models with random trip effects are worth exploring.

Comparisons of predicted species compositions from the GAMs and the preliminary inflated beta models suggests that the two modelling frameworks provide similar catch compositions at aggregate levels, but with slightly lower proportions of bigeye and yellowfin, and higher proportions of skipjack (Figure 12). As such, at this stage it appears unlikely that a move to beta response models would substantially alter catch indices at aggregated levels, though changes at finer resolutions may occur, e.g. flag-specific indices.

We also recommend exploring alternative ways of capturing spatial and temporal variation in species compositions, rather than the two-dimensional surfaces used by Lawson (2013). The WCPO is a dynamic environment with strong inter- and intra-annual variability in oceanographic conditions. As such, we may not expect there to be a time-invariant spatial effect on species compositions – in other words, we might expect species compositions at a given location to change between and within years. The preliminary models presented here use the 20°C isotherm depth to capture some spatial and temporal variation, along with a longitude effect to capture any underlying spatial variation. This may not be the most appropriate way to tackle this issue, but provides an example of how it might be done.

4 Overall discussion and implications on future work

The updated spill sampling protocol is provided in Appendix C. We note that the changes from the previous protocol (Lawson, 2014b) are minor. We also provide a summary of the instructions for the grab sampling protocol for comparison (Appendix B).

Discussions with members regarding paired grab/spill sampling trips are ongoing, with no trips undertaken from August 2017 to July 2018. It is hoped that based on discussions to date some paired grab/spill trips will occur in the second half of 2018. The collection of additional paired grab/spill data is the immediate priority, particularly in light of the uncertainty in collection factor estimates.

It is not currently clear if grab sample bias differs between species, or between sets on free and associated schools, or both. We propose that this be explored in more detail through simulation modelling. Spill sample data demonstrates substantial between-brail variability in size distributions for some sets, with some suggestion that between-brail variability may be stronger on associated sets (Peatman et al, 2017a). The simulation model should be designed to allow exploration of grab sample bias resulting from different levels of between-brail variability, which would be parameterised using available spill sampling data. The recommended size of the spill sampling bin for future trials (Appendix C) is smaller than the bin size used for previous spill sampling, which should allow a more detailed analysis of between-brail variability in the future as there should be more sets with spill samples from more than one brail.

Currently, species composition estimates for 2010 onwards are mainly estimated directly from stratified (corrected) grab samples, due to the high levels of observer coverage. The stratification does not currently take account of flag. Models of species compositions suggest that there can be differences in catch compositions between fleets (Figure 9 and Figure 11, and also see Lawson, 2012). It appears likely that flag-level species compositions could be improved with revision of the strata.

We have recommended that grab samples be corrected for bias using multinomial model estimates of bias (see Section 2.4). Furthermore, we recommend that the existing GAMs of species composition be replaced with beta-response models that better explain variation in species compositions (see Section 3.4). We propose that estimates of species compositions be presented to SC15 using step-wise changes in the estimation method, to summarise the effects on aggregate catch data, and catch indices (i.e. in a similar fashion to Hampton & Williams, 2015).

As noted last year, we suggest that a cost-benefit analysis should also be considered in future, to ensure that at-sea sampling is preferable to in-port based sampling for the estimation of purse seine species compositions in the longer-term.

4.1 Work plan for August 2018 onwards

We propose the following activities for Project 60 from August 2018 onwards, with reporting to SC15:

Activity	**2019**	**2020**	**Priority**
1. Paired grab-spill trips • Targeting fleets with likely availability of comprehensive landings slips data	**X**	**X**	High
2. Simulation model • Exploration of potential bias from between-brail variability in size • Inform need for set and/or species specific correction factors	**X**		High
3. Finalise beta-response models of species composition	**X**		Medium
4. Revisit stratification of aggregated grab samples used to estimate species composition estimates with > 20 % observer coverage • i.e. need for stratification by flag	**X**		Medium
5. Report species composition estimates to SC15 with step-wise changes from the existing approach, including: • Grab sample bias correction using correction factors • Beta response models of species compositions • (Potential) Stratification by flag for strata with > 20% observer coverage	**X**	**X**	High
6. Continue to explore opportunities for collaboration with members	**X**	**X**	High
7. Cost-benefit analysis of alternative sampling approaches for long-term estimation of species compositions (i.e. at-sea sampling vs port sampling)		**X**	Medium

5 Recommendations

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

- The revised spill sampling protocol be used for paired grab spill trips
- Multinomial model based correction factors be used to correct existing and future grab sample data, rather than the estimates of ‘availability’
- Simulation modelling be undertaken to explore: a) the potential bias resulting from between brail variability; and, b) whether correction factors should be estimated separately for species and/or set association
- Existing models of species compositions be replaced with beta-response models, building on the preliminary models presented here; and
- Stratification used to estimate species compositions directly from aggregated observer data be revisited – specifically the whether to stratify by flag.

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. We thank our colleagues in Japan, the US and the Solomon Islands for useful discussions. Finally we thank Tim Lawson for all of his earlier work, which has laid strong foundations for Project 60 moving forward.

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Tables

Table 1 Species compositions for 776 trips by Japanese purse seiners from 2010 to 2015, based on: landings data corrected for species misclassification using market sampling data (corrected landings); observer visual estimates; uncorrected grab samples; and, grab samples corrected for bias using the 2013 availability spline, the updated availability spline, and correction factors applied at the set level and at a trip and school association level (free school v associated). The percentage difference in species compositions relative to the corrected landings slips data is provided (ΔBET, ΔSKJ and ΔYFT).

Source	BET %	SKJ %	YFT %	ΔBET	ΔSKJ	ΔYFT
Corrected landings	2.68	79.4	17.9			
Visual estimates	2.78	79.2	18.0	3.73	-0.25	0.56
Uncorrected grab	3.11	77.6	19.3	16.05	-2.3	7.7
Corrected grab - 2013 availability	2.76	79.9	17.3	2.97	0.6	-3.1
Corrected grab - new availability	2.80	80.0	17.2	4.60	0.7	-3.7
Corrected grab - correction factors (set level)	2.73	80.0	17.3	1.94	0.8	-3.7
Corrected grab - correction factors (trip-school strata)	2.62	82.0	15.4	-2.36	3.2	-13.9

Figures

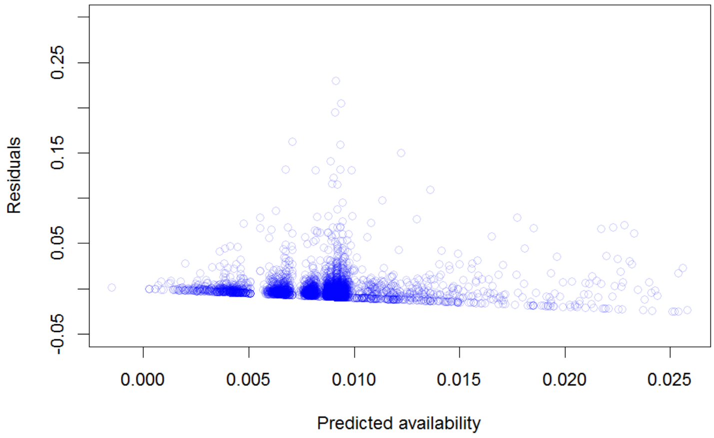


Figure 1 Residuals against predicted availability for the updated availability model.

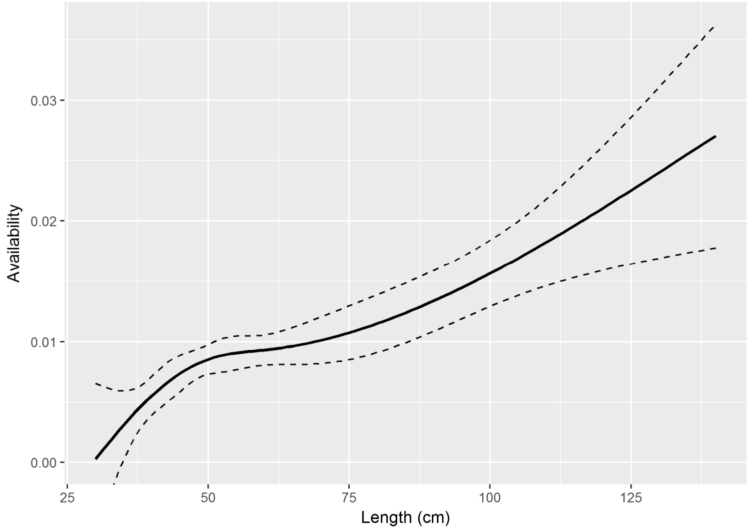


Figure 2 Availability against length for the updated availability model.

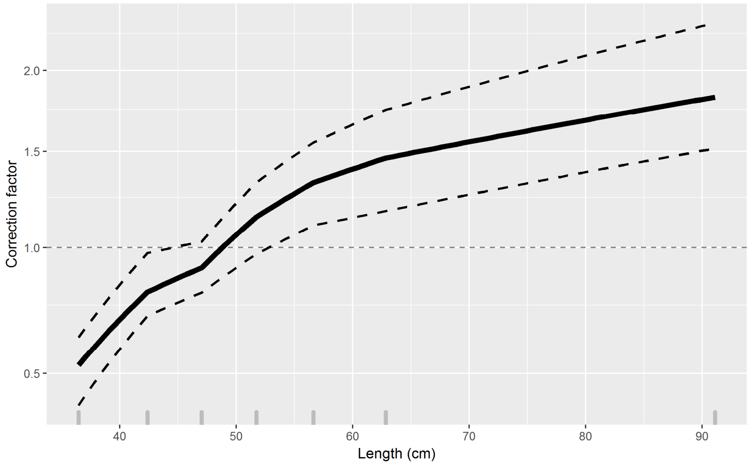
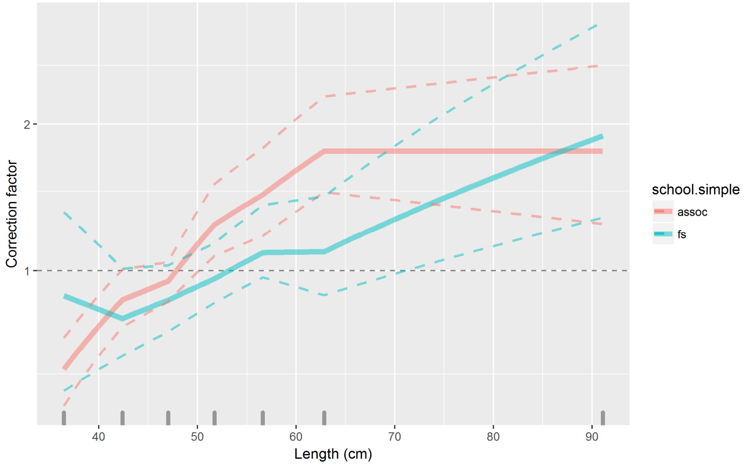


Figure 3 Correction factors pooled across species and association types.

(a) Association type specific (pooled across species)



(b) Species specific (pooled across association types)

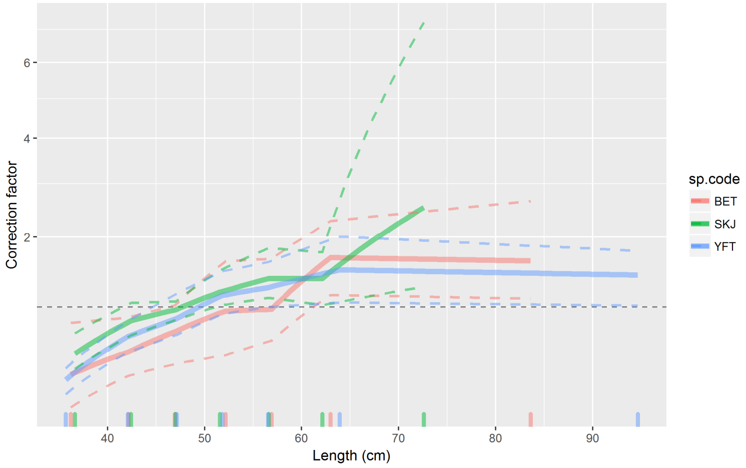


Figure 4 (a) Set association specific correction factors pooled across species (sets on free schools – blue, sets on associated schools red). (b) Species specific correction factors pooled across set association types (bigeye – red, skipjack – green and yellowfin - blue).

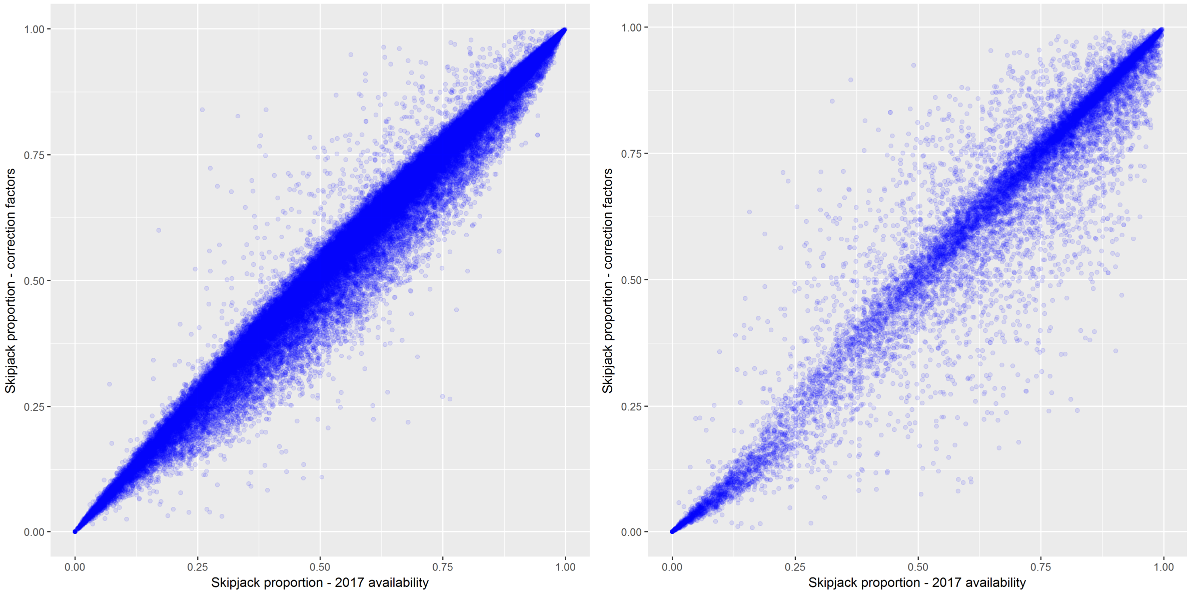
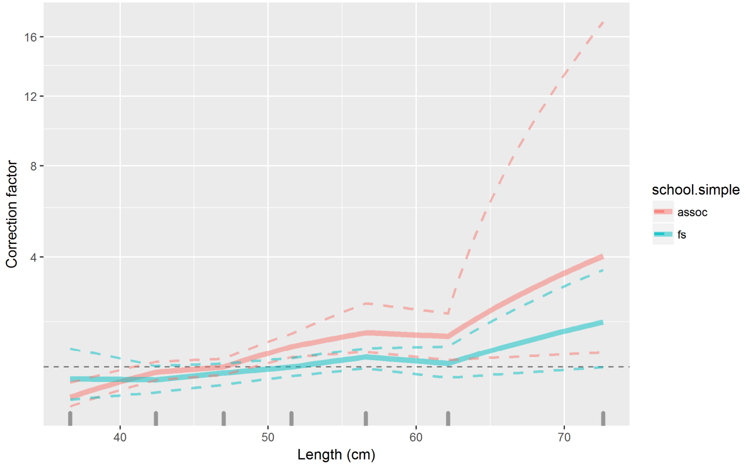


Figure 5 Set level estimated skipjack proportion based on 2017 availability (x-axis) and correction factors (y-axis), for sets where (a) ≥ 50 % of grab sampled fish were 44 to 89 cm (n = 75,509) and (b) < 50 % of grab sampled fish were 44 to 89 cm (n = 15, 975).

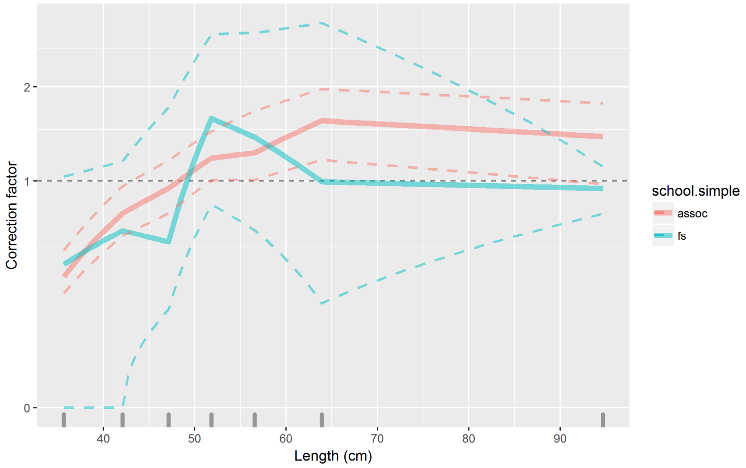
Appendix A

Additional figures

(a) Skipjack



(b) Yellowfin



(c) Bigeye

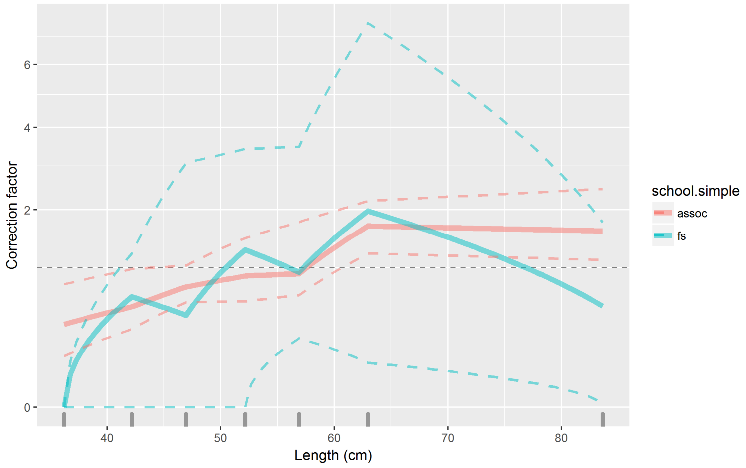
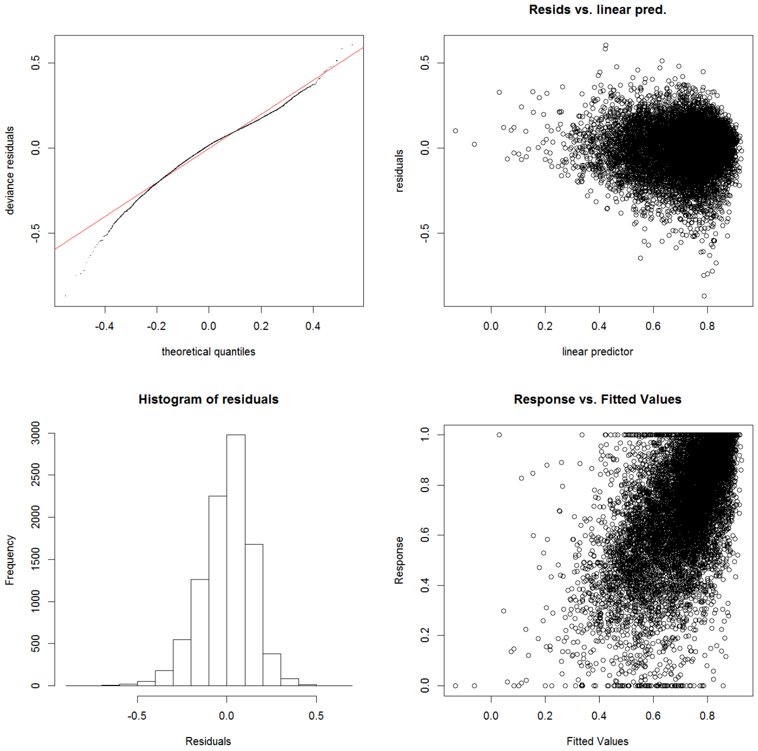


Figure 6 Set association and species-specific correction factors for (a) skipjack, (b) yellowfin and (c) bigeye. Sets on free schools (fs) are light blue and associated schools (assoc) light red.

(a) skipjack – associated with year effect and interactions



(b) bigeye – associated with year effect and interaction

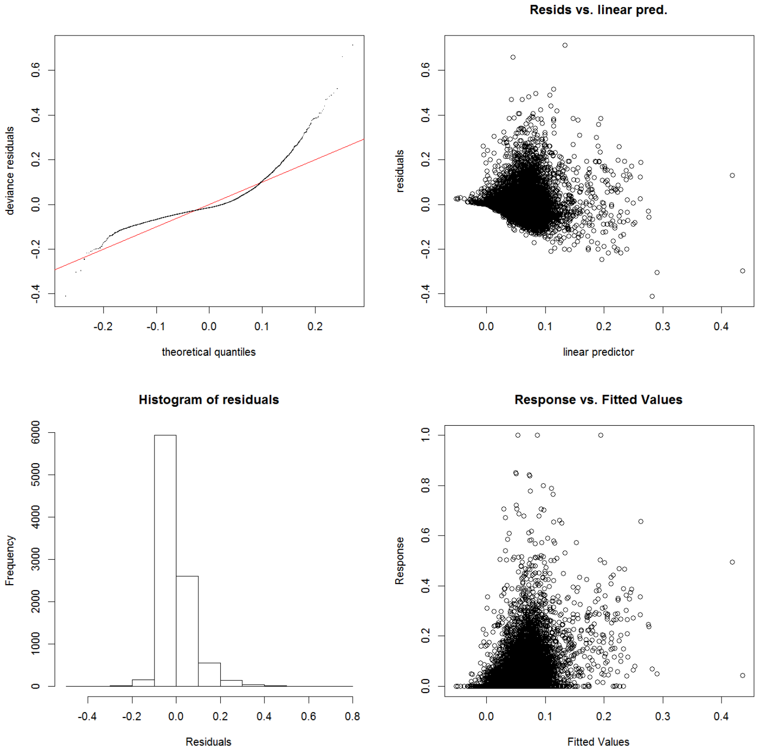
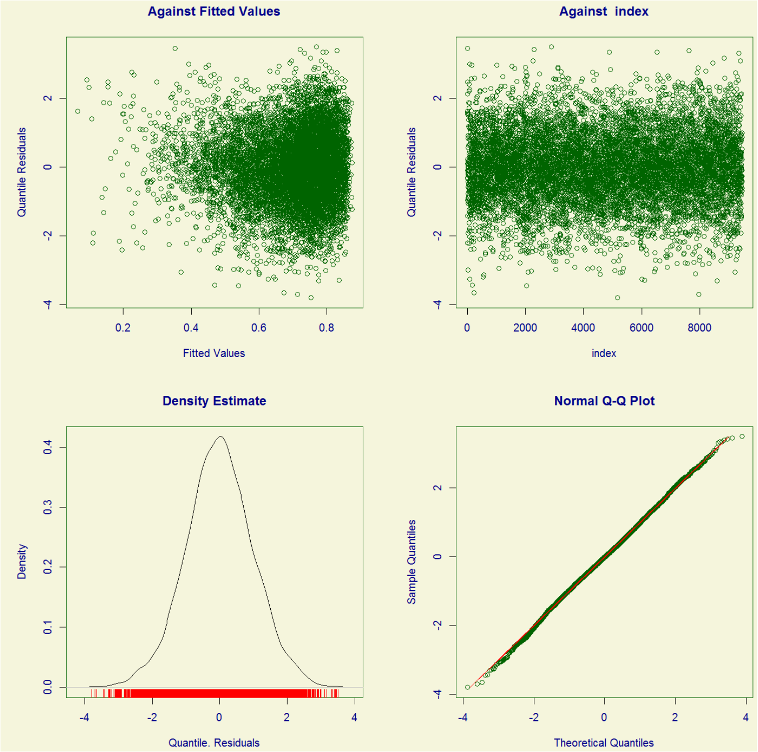


Figure 7 Residual diagnostics for GAMs of (a) skipjack and (b) bigeye proportions for models with year effects and year:quarter and year:area interactions.

(a) skipjack – associated with year effect



(b) bigeye – associated with year

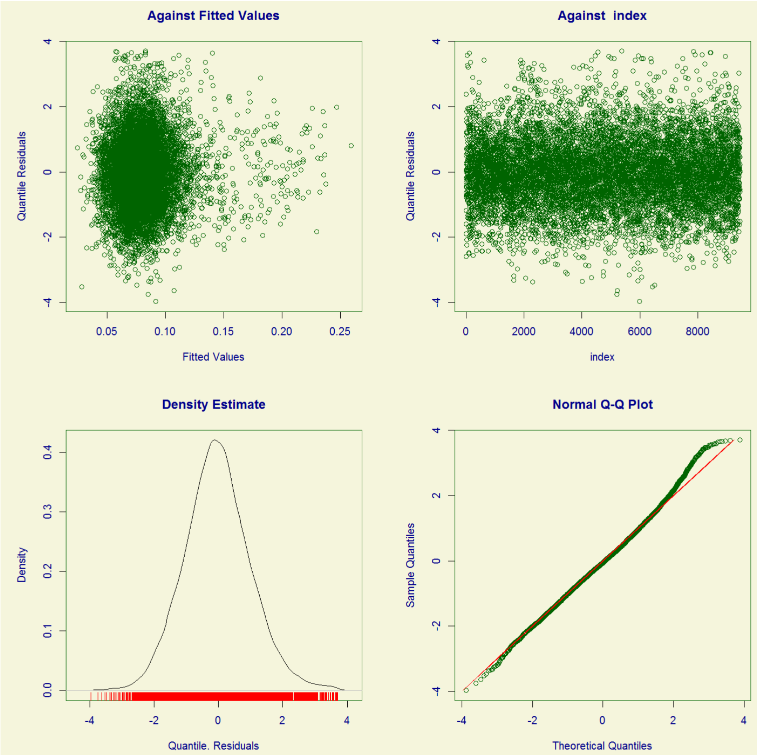


Figure 8 Residual diagnostics for inflated beta models of (a) skipjack and (b) bigeye proportions for models with year effects.

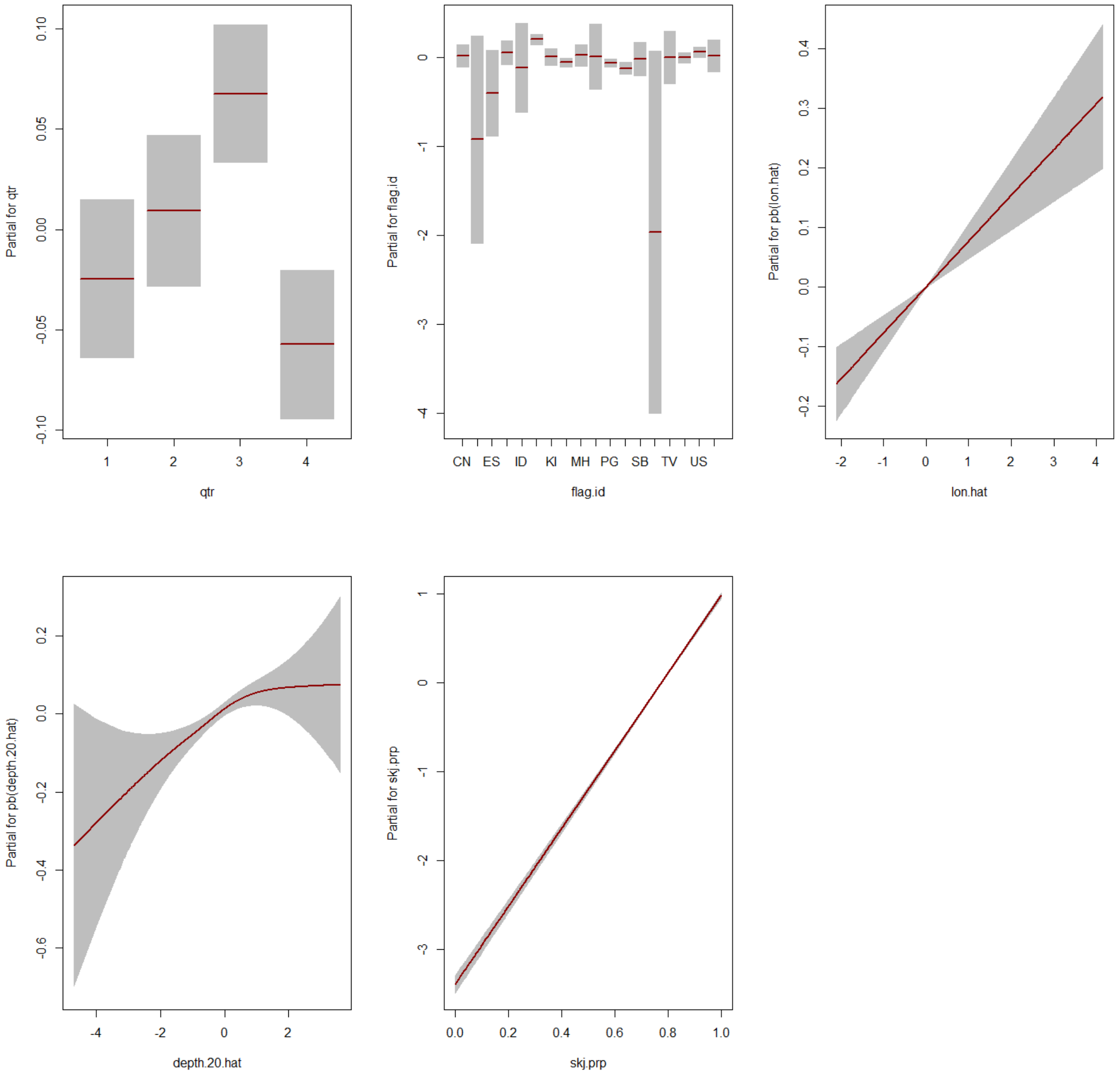
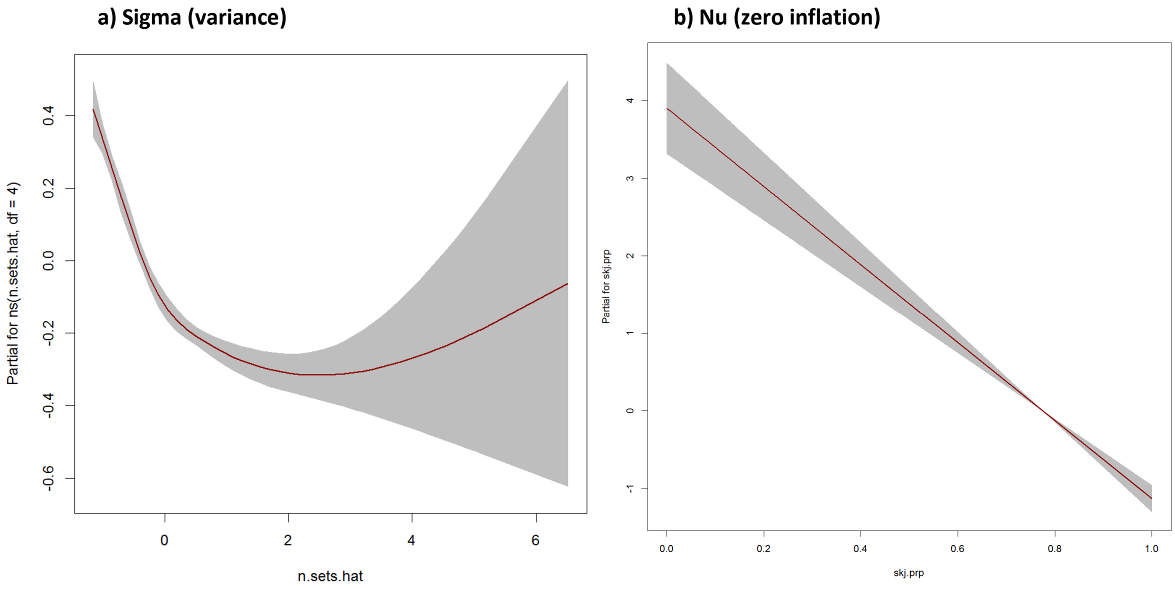


Figure 9 Effect plots for the beta component of the model of skipjack in free school sets. Top left – quarter, top middle – flag, top right – longitude (standardised), bottom left – depth of the 20°C isotherm (standardised), bottom middle – logsheet skipjack proportion.


a) Sigma (variance)

b) Nu (zero inflation)

Figure 10 Effect plots for the (a) sigma component (i.e. the parameterisation of variance) and (b) the nu component (i.e. zero-inflation) of the model for skipjack in free school sets. Left – number of sets (standardised), right - logsheet skipjack proportion.

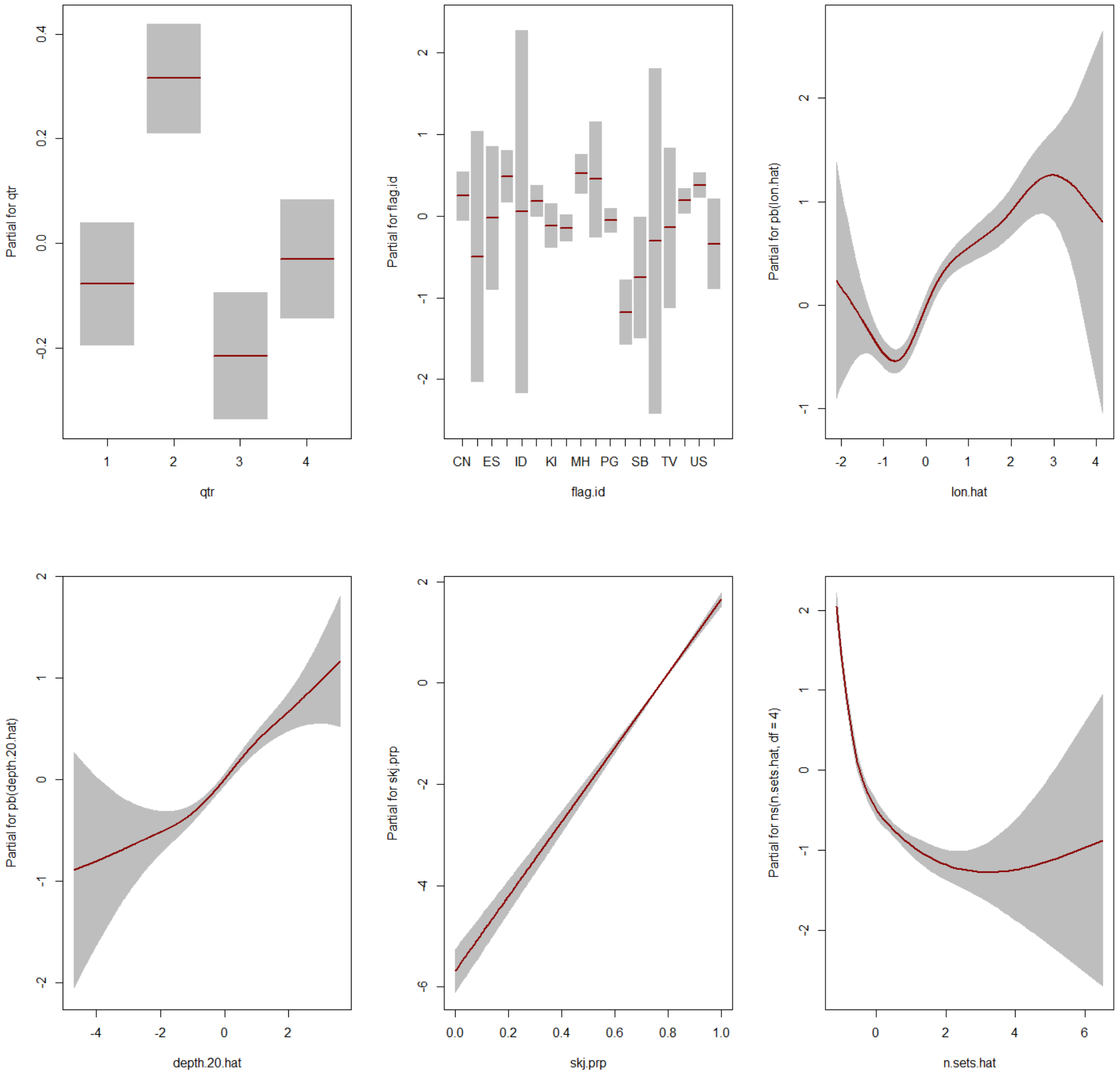


Figure 11 Effect plots for the tau component (i.e. one-inflation) of the model for skipjack in free school sets. Top left – quarter, top middle – flag, top right – longitude (standardised), bottom left – depth of the 20°C isotherm (standardised), bottom middle – logsheet skipjack proportion, bottom right – number of sets (standardised).

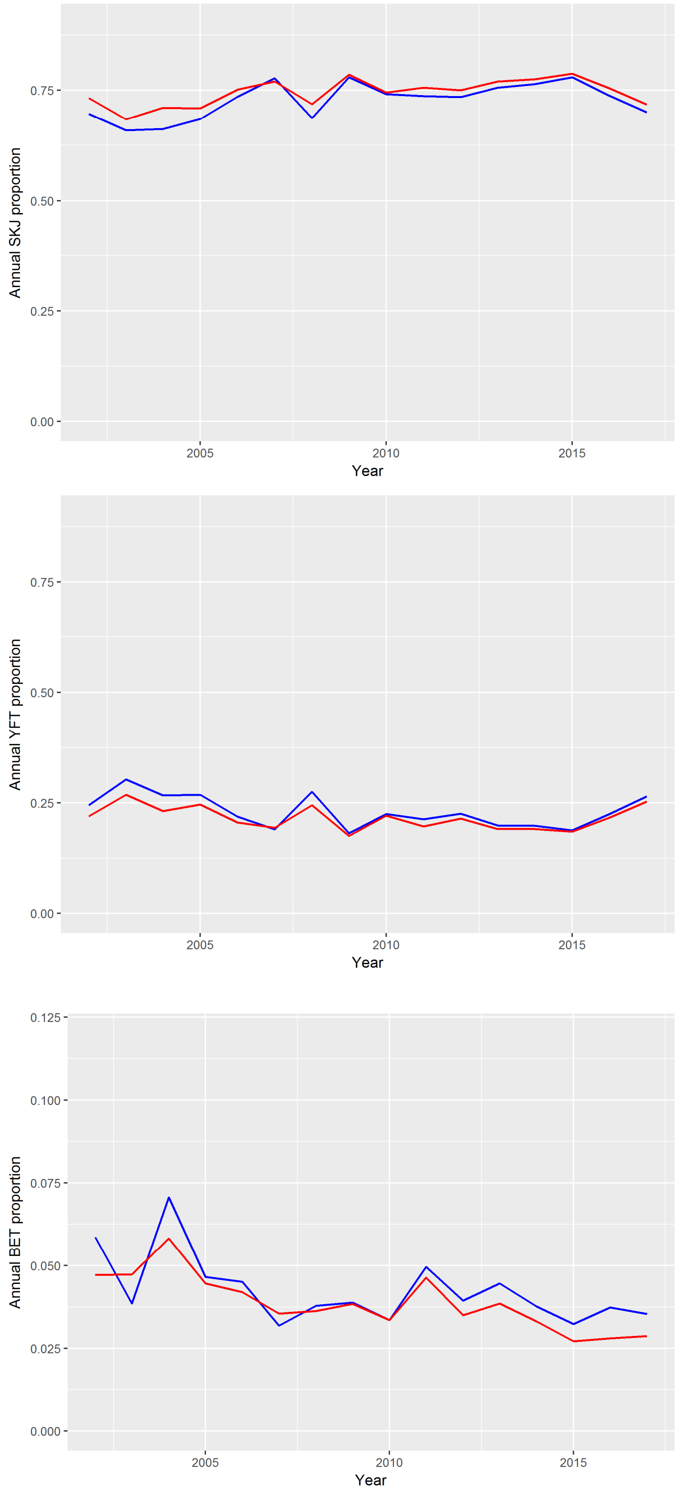


Figure 12 Estimated annual proportions of skipjack (top), yellowfin (middle) and bigeye (bottom) in purse seine catch from 2002-2017 using GAMs (blue) and inflated beta models (red). Both models were fitted to grab sample based species compositions corrected for bias using correction factors.

Appendix B

Summary of grab sampling protocol

Objective of grab sampling

To collect samples that can be used to estimate the species composition and the length frequency of purse seine catch.

General notes

- A grab sample is when the observer **randomly selects** and measures fish from every brail of fish that comes onboard the vessel.
- It is very important that fish are sampled randomly, without influence of shape, colour, species or location in the brail. Random selection of fish is best done by adopting a good sampling method and sticking to it.
- Observers should, where possible, sample five fish from every brail.
- Sampling five fish per brail may be difficult if brailing is fast or the fish are large. Observers should decide at the start of the brailing process how many fish per brail will be sampled for the set. The target number of fish per brail should be as high as possible (but no more than five) and recorded on the PS4 form.
- The observer should try to take the target number of samples from each brail of a set. If a sample is missed, try to get an extra one from the next brail but try to keep the number of tuna steady throughout the sampling process.
- Remember to record the number of samples from each brail.
- Always collect all fish for measurement from the brail, before throwing sampled fish (from the previous brail) back in to the brail. This avoids measuring the same fish twice.
- Do not attempt to measure damaged fish. If a randomly selected fish is damaged, set it aside when you start collecting measurements.
- Do not sample fish that are not in the brail, e.g. those that fall on deck or are caught in the brail net.
- Always select fish for sampling yourself. Do not let crew select fish for you.
- Sometimes, you may see yellowfin and bigeye will be present in the catch, but none are randomly selected in grab samples. Do not worry - this is not a problem.
- Sometimes, randomly selected individuals will include species other than skipjack, yellowfin and bigeye. These should be treated in the same way as the other samples.
- It is very important that juvenile yellowfin and bigeye are correctly identified.
- When the sack is lifted onboard after brailing, treat it as an additional brail (add one to the brail count, estimate the fullness of the sac relative to the brail size, and take the target number of random samples from the net).

Equipment Used

- Calipers, measuring board and data collection forms.

Sampling protocol

1. Determine and record the target number of fish per brail for the set in question. This should be five fish per brail, but may need to be lower (see general notes above).
2. Randomly select the target number of fish from each brail (do not select for species)
3. Record the species and length measurements in the order that the fish were sampled. In particular, do not group the samples by species. This is important as the order of samples can then be used to explore whether there are patterns in species and/or size compositions throughout the brailing process.
4. Some purse seiners have more than one type of brail. Separate PS-4 forms must be used for samples from different brail types.

Appendix C

Spill sampling protocol

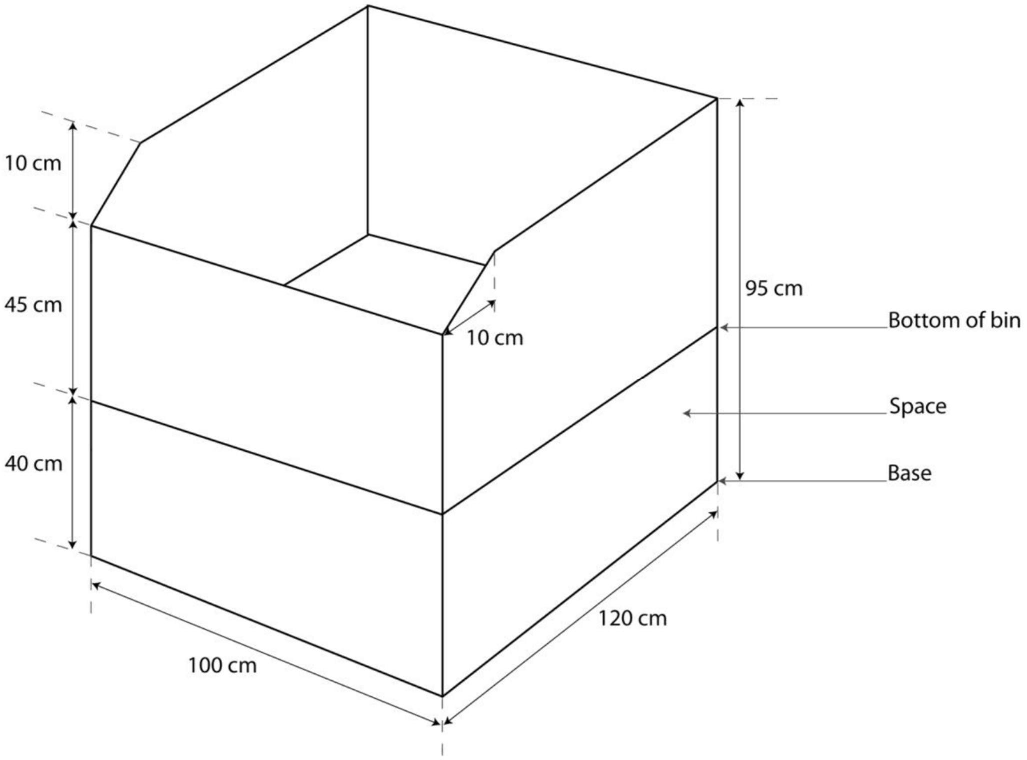
Objective of spill sampling

To collect samples that can be used to estimate the species composition and the length frequency of purse seine catch. The estimates of species composition and length frequency can then be used to assess the accuracy of estimates obtained from grab sampling.

Equipment Used

- Measuring board, callipers and data collection forms.
- Voice recorder, earphones and (aquapac) waterproof housing.
- Spill sampling bin.

Spill sampling bin



The recommended dimensions of the spill sampling bin are illustrated above. The bottom of the bin is raised by 40 cm from the base, while the height of the bin above the bottom is 55 cm, so that the total height is 95 cm; the bottom and top of the bin correspond, more or less, to just below knee level to waist level. The width at the front and back of the bin is 100 cm and the length of the sides is 120 cm. The sides of the bin have a slope towards the front extending 10 cm in height and depth, to allow the excess fish to fall out of the front. The observer stands next to one of the sides of the bin when measuring fish. The bin size may need to be modified to suit the deck layout and the mode of operation of brailing of certain vessels.

Sampling protocol

1. The number of the initial brail to be sampled is changed with each set to avoid the effects of potential layering by species or size. For sets of 20 tonnes or more, the initial brail to be sampled should be one of the first six brails. For sets of less than 20 tonnes, the initial brail to be sampled should be one of the first three brails.
2. Advise the brail winch operator of the brail to be sampled just as the brail is being transferred from the net to the vessel. The brail winch operator must not be warned any further in advance of the brail to be sampled, otherwise he may be tempted to modify his brailing behaviour, which may introduce unwanted bias.
3. Open the selected brail to discharge a portion of the content to fill the sampling bin. It is important that the bin always be filled to the brim, regardless of the size of the fish. The sample size of a spill sample is determined by the volume of the bin; thus, there will more fish in the sample when the fish are small than when they are large.
4. Check that the voice recorder is turned on.
5. Verbally identify the species of each fish in the bin, including non-target species, and measure the fork length by placing the fish on a flat surface, such as a measuring board, and using the measuring board (or callipers for larger fish) to measure the length from the tip of the snout to the fork of the tail.
6. After all fish in the bin have been measured, repeat steps #2 to #5 for the next available brail to come onboard, and repeat until brailing is complete. Use a new set of PS-4 forms for each sampled brail.

Notes:

- It is very important that juvenile yellowfin and bigeye are correctly identified.
- It is important to use separate PS-4 forms for each brail sampled, so that length measurements can be attributed to the specific brail sampled.
- Note the fullness of the sampled brail in the comments field.

Appendix D

Obtaining species compositions from grab samples with bias corrections using correction factors

Here we describe the approach used to estimate species compositions from grab samples, using correction factors to account for grab sample bias. Throughout we use i, j and k to refer to species, 1cm length bin and set respectively. First we describe the process used to obtain (uncorrected) grab sample based species compositions. We then explain how the grab sample based species compositions were corrected for bias using correction factors.

As described in Peatman et al. (2017a), uncorrected grab sample based species compositions were estimated as follows. Grab samples were used to estimate the proportion of fish in set k that were species i and length bin j, denoted α_{ijk}

$$\alpha_{ijk} = \frac{n_{ijk}}{n_k}$$

where n_{ijk} is the number of sampled fish from set k that were species i and length bin j, and n_k is the total number of grab sampled fish from set k. The proportion of catch weight in set k from species i, denoted p_{ik}, was then calculated as

$$p_{ik} = \frac{\sum_j \alpha_{ijk}\, a_i j^{b_i}}{\sum_{ij} \alpha_{ijk}\, a_i j^{b_i}}$$

where a_i and b_i are species-specific length weight parameters (Table 2). Species and set specific catch weight proportions were then applied to the observer's visual estimates of the set-specific catch w_k, to obtain catch weights of species i in set k, denoted w_{ik}

$$w_{ik} = w_k\, p_{ik}$$

The correction of grab sample bias using correction factors is straightforward. We used correction factor estimates pooled across species and association types (i.e. Figure 3). Set-specific corrected proportions by species, length, β_{ijk}, were calculated as

$$\beta_{ijk} = \frac{\alpha_{ijk}/r_j}{\sum_{ij} \alpha_{ijk}/r_j}$$

where r_j is the correction factor that applies to a fish of length j and the denominator ensures that set-specific proportions sum to one. The proportion of catch weight in set k from species i, denoted p_{ik}, was then calculated as

$$p_{ik} = \frac{\sum_j \beta_{ijk}\, a_i j^{b_i}}{\sum_{ij} \beta_{ijk}\, a_i j^{b_i}}$$

and the catch weights of species i in set k, (w_{ik}) recalculated as above.

Table 2 Length-weight parameters used in the analyses, taken from the 2016 skipjack assessment (McKechnie et al, 2016) and the 2014 yellowfin (Davies et al., 2014) and bigeye (Harley et al., 2014) assessments.

Species	a	b
SKJ	8.64E-06	3.2174
YFT	2.51E-05	2.9396
BET	1.97E-05	3.0247