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Analysis Of Tagging Data For The 2025 Skipjack Assessment: Corrections To Tag Releases For Tagging Conditions

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Executive summary

Mark-recapture tagging data are adjusted prior to use in assessments of WCPO tropical tuna to account for tagging-induced mortality and tag shedding, which mitigates against downwards bias in fishing mortality estimates. A range of variables have been shown to impact the probability of recapturing tagged fish, including tagger experience and identity, the quality of tag placement and the condition of a tagged fish at release. The reduction in recapture probability caused by these tagging effects is assumed to reflect the combination of tag shedding and tagging-induced mortality.

Here, we fit statistical models to estimate the effects of these variables on the probability of tag recovery. The statistical models were then used to generate ‘correction factors’ which are used to reduce tag release numbers to account for the apparent additional tag shedding and tagging-induced mortality resulting from the specific conditions of each tag release, over and above base rates.

The estimated correction factors result in substantial reductions (c. 20%) in the number of both RTTP and PTTP releases of skipjack used in the 2025 skipjack assessment.

We invite the Scientific Committee to:

- Note the use of combined modelling of skipjack, yellowfin and bigeye releases that enabled separate estimation of correction factors for Central Pacific PTTP tagging cruises.
- Note the substantial reductions in effective tag releases used in the assessment, and the subsequent impact on apparent fishing mortality rates.

1 Introduction

SPC have tagged and released tropical tuna in the Western Central Pacific Ocean (WCPO) since 1977 across three tagging programmes: the Skipjack Survey and Assessment Programme (SSAP), 1977 to 1981; the Regional Tuna Tagging Programme (RTTP), 1989 to 1992; and, the current Pacific Tuna Tagging Programme (PTTP), from 2006 onwards. Mark-recapture tagging data are adjusted prior to use in assessments of WCPO tropical tuna to account for tagging-induced mortality and tag failure. This includes base-rates of tagging-induced mortality and tag shedding (e.g. Hampton, 1997; Vincent et al., 2019), as well as additional tagging-induced mortality and tag-shedding over and above base rates as a result of the specific conditions at release for each tagged fish. This mitigates against downwards bias in fishing mortality estimates (e.g. see Vincent et al., 2019). A range of variables have an apparent effect on the probability of recapturing tagged fish, including tagger experience and identity, the quality of tag placement and the condition of a tagged fish at release (Hoyle et al., 2015). We refer to these variables as 'tagging effects'. In combination, these variables reduce the probability of recapturing tagged fish, which is assumed to reflect a combination of tag shedding and tagging-induced mortality. Statistical models are used to estimate the effects of these variables on the probability of tag recovery, and generate 'correction factors' which are used to reduce tag release numbers to account for the apparent additional tag shedding and tagging-induced mortality resulting from the specific conditions of each tag release.

In the context of the estimation of corrections for tagging conditions, the mark-recapture dataset is relatively imbalanced (Scutt Phillips et al., 2020). There is limited overlap between taggers and tagging stations, with experienced taggers tending to tag from different stations than those with less experience. Additionally, there is a relatively large pool of taggers within a tagging programme but limited overlap between taggers and tagging events or tagging cruises, as well as differences in tagging platforms between tagging cruises with implications on the equivalence of tagging stations. This led to concerns that the imbalanced nature of the dataset may lead to difficulties in separating the effects of the different variables, and so lead to bias in correction factors.

SPC convened a tagging effects workshop in December 2021 to review the mark recapture dataset and modelling approach that has been used generate correction factors, and identify potential improvements and changes to the methodology in the context of the characteristics of the dataset. The workshop recommended that Central Pacific tagging cruises be treated separately to other PTTP tagging cruises, as the Central Pacific tagging cruises have used different tagging platforms, such that tagging stations are not directly comparable. Additionally, the Central Pacific tagging cruises have used a different pool of taggers and have different overall objectives.

Recent simulations using PTTP skipjack releases have suggested that the tagging effects modelling framework from Hoyle et al. (2015) and Berger et al. (2014) can separate the effects of key variables, giving unbiased estimates of correction factors, despite the correlation between covariates, assuming the model structure is appropriate (Peatman et al., 2022).

In this information paper we apply a similar modelling framework to Hoyle et al. (2015) and Berger et al. (2014), based on that used for the 2023 bigeye and yellowfin assessments (Peatman et al., 2023), to estimate correction factors for use in the 2025 skipjack stock assessment. This includes separate estimation of correction factors for the limited number of skipjack releases on Central Pacific tagging cruises.

2 Methods

Tag release and recovery information for tropical tuna were extracted from SPC's master tuna tagging database for the SSAP, RTTP and PTTP. The dataset consisted of mark-recapture data from conventional tag releases; fish instrumented with archival or sonic tags were not included. PTTP releases from 2023 onwards were removed, to mitigate against bias due to delays in the reporting and processing of tag recovery data. RTTP and PTTP tag releases from purse seine vessels were excluded, as were releases from Japanese research tagging cruises. The cumulative total number of tropical tuna released by each tagger (across all three programmes) at the end of each tagging event was calculated. This was then used to define the 'experience' of each tagger for a tagging event, set at the mean of their cumulative releases at the beginning and the end of the tagging event in question. The tagging dataset was then filtered for skipjack releases from the RTTP (n = 100,958), with all PTTP releases of tropical tuna retained (304,965 skipjack, 113,804 yellowfin, and 58,979 bigeye).

As per Berger et al. (2014), data filtering rules were applied to exclude levels of candidate categorical variables with insufficient releases to inform robust estimation of model parameters. For models fitted to skipjack only: individual taggers with fewer than 200 skipjack releases were removed; tagging events with fewer than 30 skipjack releases were removed; and, any levels of covariate levels with fewer than 200 skipjack releases were removed. For models fitted to skipjack, yellowfin and bigeye releases: individual taggers with fewer than 100 total releases were removed; tagging events with fewer than 15 total releases were removed; and, any levels of covariate levels with fewer than 100 total releases were removed.

All data analysis was undertaken in R v4.4.1 (R Core Team, 2024), with tagging effects models fitted using the R package 'glmmTMB' (Brooks et al., 2017).

2.1 Selection of tagging effects models

Model selection was informed by a stratified repeated random sub-sampling procedure. For each draw the modelled dataset was split at random into 10 folds, stratified by tagging event. The first fold was then held back as a testing dataset to validate the model, with the remaining 9 folds used as the training dataset to fit the model. Predictions were then generated from the fitted model for the testing dataset, and the Area Under the Receiver Operating Characteristic curve (AUROC) extracted. This process was repeated 256 times.

First, we selected models for: RTTP releases of skipjack and PTTP releases of skipjack from Western Pacific (WP) tagging cruises (i.e. not Central Pacific tagging cruises).

The starting point for the model selection procedure for RTTP and WP PTTP skipjack was:

$$y_{ij} \sim \text{Binomial}(n_{ij}, p_{ij})$$

$$\alpha_{event[j]} \sim \text{Normal}(0, \sigma_e)$$

$$\log\left(\frac{p_{ij}}{1-p_{ij}}\right) = \beta_0 + \beta_{cruise[i]} + \beta_{tagger[i]} + \beta_{station[i]} + \beta_{condition[i]} + \beta_{quality[i]} + f(length[i]) + \alpha_{event[j]}$$

where i refers to a group of tag releases with a shared set of covariate values from tagging event j, p_{ij} is the probability of tag recovery and n_{ij} and y_{ij} are the number of releases and recaptures respectively. Categorical covariates were included for: the tagging cruise leg, *cruise*; the individual that tagged the fish, *tagger*; the station where the fish was tagged, *station*, the condition of the fish on release, *condition* (i.e. good, eye damage, mouth damage, bleeding, dropped on deck, shark bite); and, the quality of tag placement, *quality* (i.e. good, badly placed). The *length* of the tagged fish was included as a continuous variable, modelled with a natural cubic spline denoted $f(\,)$. Tagging *event* was included as a random intercept. We note that tagging cruise was included to improve the distribution of the tagging event intercepts.

The starting point for the model selection procedure for CP PTTP skipjack, yellowfin and bigeye releases was:

$$y_{ij} \sim \text{Binomial}(n_{ij}, p_{ij})$$

$$\alpha_{event[j]} \sim \text{Normal}(0, \sigma_e)$$

$$\log\left(\frac{p_{ij}}{1-p_{ij}}\right) = \beta_0 + \beta_{species[i]} + \beta_{gear[i]} + \beta_{assoc[i]} + \beta_{tagger[i]} + \beta_{condition[i]} + f(length[i]) + \alpha_{event[j]}$$

with additional categorical covariates for *species* (skipjack, yellowfin, bigeye), *gear* (troll, handline) and school association (anchored FAD, drifting FAD, island or reef, and, tagging vessel). Tagging cruise was not included in the initial model specification of the CP PTTP model, given difficulties with model convergence experienced by Peatman et al. (2023) when including this term for models of CP PTTP data.

For model selection, we first tested for removal of tagger and station effects. We did not test for removal for condition and quality effects, as we *a priori* considered that these should influence tag-induced mortality and tag shedding rates, and so recapture probabilities. We then tested for inclusion of tagger:station interactions (if both effects were in the model), included as a random intercept.

For models fitted to data from all three species, we then tested for inclusion of species-specific tagger and condition effects, included as a random intercept. We then tested for the addition of species-specific tagging event, gear and association effects, included as random intercepts, and, species-specific release length effects, included as species-specific natural splines. We did not test for species-specific quality effects, as there were generally limited releases outside of the 'good' level for CP PTTP releases.

Tagging event, tagging cruise and release length were included in models to control for variation in recapture probability caused by temporal-spatial variation in fishing effort relative to release locations and selectivity of fishing gear. These effects are not considered to reflect rates of tagging induced mortality or tag shedding. These effects were included in all models in the model selection process. Gear and association effects were included as the nearest proxy to tagging cruise for the CP PTTP models, and so were also kept in all CP models in the model selection process.

Exploratory model runs including experience splines detected significant experience effects. However the shapes of the effects were counter-intuitive and considered to be unlikely, e.g. U-shaped relationships with the highest recapture probabilities for the lowest and highest levels of experience. As such, we did not include experience effects in the model selection process.

For all models, we rounded release lengths to the nearest 2cm, to reduce the number of records in the modelled datasets. Quantile residual diagnostics were used to assess model fits, with residuals conditional on fitted random effects.

2.2 Estimation of corrections to releases

Species-specific tagging effects models were used where available to estimate correction factors, otherwise the combined-species tagging effects models were used. For example, the model of RTTP skipjack was used to estimate correction factors for RTTP skipjack releases, and the model of CP PTTP skipjack, yellowfin and bigeye releases was used for CP PTTP skipjack.

Correction factors for each modelled tag release group, r_{ij}, were generated from the selected tagger effects models by first estimating the probability of recovery with the actual conditions at release (μ_{ij}^{actual}). Then, the probability of recovery was estimated with tagging effects set to their optimal levels ($\mu_{ij}^{optimal}$), i.e. the levels of tagger, station, condition and quality effects with the highest recovery probability. The correction factor was then:

$$r_{ij} = \frac{\mu_{ij}^{actual}}{\mu_{ij}^{optimal}}$$

Optimal conditions were defined based on estimated effect size, along with consideration of the number of releases for different levels as well as the precision of the estimated parameters as a proxy for their reliability. For example, there were taggers with high mean effect sizes but high standard errors due to limited release numbers. These taggers were not considered when setting optimal conditions. Tagging cruise, tagging event and length were not adjusted when calculating $\mu_{ij}^{optimal}$, as these effects are assumed to reflect the spatial and temporal distribution of tag releases relative to fishing effort, and the selectivity of the fisheries recapturing tags in the case of release length. Similarly for models of CP PTTP data, gear and association were not adjusted, as these were included as a proxy for cruise.

For tagging events that were not in the modelled dataset due to the data filtering, we used a similar approach to estimate correction factors. We first excluded all tags with station, condition and quality covariate levels not included in the modelled dataset due to the sample size filters. For the remaining tags we set the tagging event effect to zero (the mean of the assumed distribution for the random intercept) when calculating μ_{ij}^{actual} and $\mu_{ij}^{optimal}$. In cases when the tagger had been excluded from the modelled dataset, we used the median tagger effect when calculating μ_{ij}^{actual} and $\mu_{ij}^{optimal}$.

The correction factors were then aggregated to assessment model tag release groups, i.e. combinations of model region, year, quarter and 2cm length class, by taking the weighted mean correction factor across tag groups, weighted by the number of releases n_{ij}.

There were a limited number of assessment model tag release groups with no corresponding estimated correction factors, reflecting tagging event and length combinations that were filtered from the modelled dataset when excluding other covariate levels with low sample sizes. In these cases, we used the (weighted) mean correction factor for the tagging event in question where available, and otherwise the (weighted) mean correction factor for the tagging programme.

3 Results

3.1 Model selection process

The model selection process for RTTP skipjack releases and WP PTTP skipjack releases both selected the starting models, with no support for dropping tagger or station effects, or adding tagger:station interactions.

The model selection process for CP PTTP skipjack, yellowfin and bigeye releases did not support inclusion of species-specific tagger effects. However, there was relatively weak support for inclusion for species-specific tagging event effects (AUROC = 0.699 compared with 0.698). There was no support for the addition of species-specific gear or association effects.

3.2 Summaries of selected tagging effects models

3.2.1 Tagging effects models of RTTP releases

The effects from the selected model of RTTP skipjack releases are provided in Figure 1. There was substantial variation in recapture probability between cruise legs. Recapture probabilities increased with increasing release lengths up to 50cm, then decreased with increasing lengths. Recapture probabilities varied between taggers, with a suggestion that the most experienced taggers had higher recapture probabilities. Releases from the starboard bow were associated with the highest recapture probabilities, and tags released midships the lowest. Individuals that were dropped on deck or hit the boat had the lowest recapture probabilities, with fish in good condition or with cookie-cutter shark bites having the highest recapture probabilities. Badly placed tags were associated with reduced probability of recapture.

3.2.2 Tagging effects models of PTTP releases from western Pacific cruises

The effects from the selected model of WP PTTP skipjack releases are provided in Figure 2, and were generally similar to the effects from the RTTP models (Section 3.2.1). There was substantial variation in recapture probability between cruise legs. Recapture probabilities increased with increasing release lengths up to 50cm, then decreased with increasing lengths. Recapture probabilities varied between taggers, with a suggestion of lower recapture probabilities for the least experienced taggers, though with appreciable levels of variability. In contrast to the RTTP models, releases from the port bow had the highest recapture probabilities, with releases midships and from the archival bow station associated with the lowest recapture probabilities. Individuals that were dropped on deck, hit the side of the boat, or were bleeding, had reduced recapture probabilities. Mouth damage and cookie cutter shark bites were not associated with substantially reduced recapture probabilities. Individuals that were tagged too slow were associated with reduced recapture probabilities, as were individuals with badly placed tags to a lesser extent.

3.2.3 Tagging effects models of PTTP releases from central Pacific cruises

The effects from the selected model of CP PTTP bigeye releases are provided in Figure 3. Handline releases (rod & reel) were associated with slightly reduced recapture probabilities. Releases from schools associated with drifting FADs, and islands or reefs, had lower recapture probabilities than those associated with anchored FADs (or TAO buoys) or the tagging vessel. Recapture probabilities were highest for release lengths of 55cm, with relatively strong declines in recapture probability for smaller and larger fish. There was relatively limited variability in recapture probabilities between taggers, compared to the WP PTTP models. Releases that hit the side of the boat, had eye or tail damage, and to a lesser extent those that were bleeding or were dropped on deck, were associated with lower recapture probabilities. Recapture probabilities were highest for bigeye, with intermediate probabilities for yellowfin, and the lowest probability of recapture for skipjack.

3.3 Estimated corrections to tag releases

Optimal levels used to estimate correction factors were:

- RTTP: tagger ='KNB', station = 'starboard bow', condition = 'good', quality = 'good'.
- WP PTTP: tagger ='BML', station = 'port bow', condition = 'good', quality = 'good'.
- CP PTTP: tagger ='BML', condition = 'good', quality = 'good'.

We note that DGI provided an alternative optimal tagger level for CP PTTP, with a higher estimated tagger coefficient. However, BML was retained on the basis of the greater number of releases, and the consequent increase in precision for estimated probability of recovery.

Estimated correction factors were broadly equivalent for the RTTP and PTTP (Figure 4). For RTTP releases, the 90% interval of correction factors at an assessment model release group resolution spanned 0.64 to 0.91, compared with an interval of 0.66 to 0.97 for PTTP yellowfin releases. Overall, the estimated correction factors resulted in a 20.6% reduction in RTTP skipjack releases, and a 21.3% reduction in PTTP skipjack releases. For the PTTP, correction factors for assessment regions 4 and 8 were weaker than those for regions 5 to 7, driven by relatively weak corrections to releases from Central Pacific tagging cruises (Figure 5).

4 Discussion

The estimated correction factors resulted in a c. 20% reduction in skipjack releases across the RTTP and PTTP tagging programmes. This represents a significant level of apparent additional tag shedding and/or tagging induced mortality over and above base rates (c. 14% combined – see Vincent et al., 2019). The reductions in release numbers were relatively weak for CP PTTP releases compared to WP PTTP releases, which may reflect the relatively strong down-weighting of WP releases from 'suboptimal' tagging stations. Estimates of correction factors have not been generated for the JP tagging programme (JPTP) or the SSAP. However, additional levels of tag shedding and/or tagging induced mortality over and above base rates appear likely for these tagging programmes. Following Vincent et al. (2019), we recommend applying the overall RTTP correction factor (0.794) to SSAP and JPTP releases.

In this analysis, we estimated correction factors for Central Pacific (CP) PTTP tagging cruises separately to WP PTTP tagging cruises, by fitting models to the combined releases of skipjack, yellowfin and bigeye, with inclusion of species-specific effects where supported by the data. This approach allows direct estimation of CP PTTP releases, whereas in previous skipjack assessments, an overall Western Pacific (WP) PTTP correction factor was applied to CP PTTP releases. This may lead to more appropriate correction of Central Pacific releases, noting that the estimated corrections factors are on average higher than those for the Western Pacific releases. However, we note that the low numbers of Central Pacific releases, particularly for skipjack, suggests that the estimated correction factors are uncertain.

Tagging data are an important data input to assessments of the WCPO skipjack stock, and so the correction factors for tagging effects have the potential to be influential on the assessment model outputs. However, the move to the current modelling framework for the estimation of correction factors for tagging conditions resulted in similar correction factors to those used in previous assessments. Additionally, application of the 2025 tagging condition models to the dataset used in the 2022 skipjack assessment gave similar estimated correction factors to those used in 2022.

Releases from trolls (danglers) were associated with higher recapture probabilities than those caught on handlines (rod and reel). This may reflect tagged individuals experiencing greater stress when caught on handlines, e.g., spending longer times on the hook, or being caught at greater depths, in which case it would be appropriate to control for the effect of release gear when estimating correction factors for Central Pacific tagging cruises. This should be considered when estimating correction factors for use in the next bigeye and yellowfin assessments.

There are a number of hypotheses for causes of station effects on recapture probability, which often relate to the station directly or indirectly influencing the condition of fish arriving at the tagging cradle, e.g. differing chains of handling teams or assistants, or delays to fish being delivered to the station (e.g. Hoyle et al., 2015). As noted in earlier analyses (e.g., Peatman et al., 2022), the inconsistency in station effects for RTTP and WP PTTP skipjack releases is difficult to explain.

It appears likely that tag shedding and tagging induced mortality varies between taggers, and is also a function of a tagger's experience (e.g. Hoyle et al., 2015). We explored the inclusion of experience effects, defined as their cumulative releases across all tropical tuna species and tagging programmes. As described in Section 2, experience effects were not included in the model selection process as fitted relationships in exploratory model runs were considered unlikely. However, we note that there were suggestions of increasing recapture probabilities for taggers with the highest number of releases. As discussed in Peatman et al. (2022), alternative metrics of tagger experience may allow better representation in tagging effects models, e.g. species-specific experience metrics.

Predictive accuracy was used to support the model selection process. The difference in predictive accuracy between different model specifications was often relatively small. Future analyses should consider increasing the number of draws used in the cross-validation process, or fit each candidate model specification to the same draws of the training dataset, to mitigate the risk of random noise influencing the model selection procedure.

We invite the Scientific Committee to:

- Note the use of combined modelling of skipjack, yellowfin and bigeye releases that enabled separate estimation of correction factors for Central Pacific PTTP tagging cruises.
- Note the substantial reductions in effective tag releases used in the assessment, and the subsequent impact on apparent fishing mortality rates.

Acknowledgements

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Figures

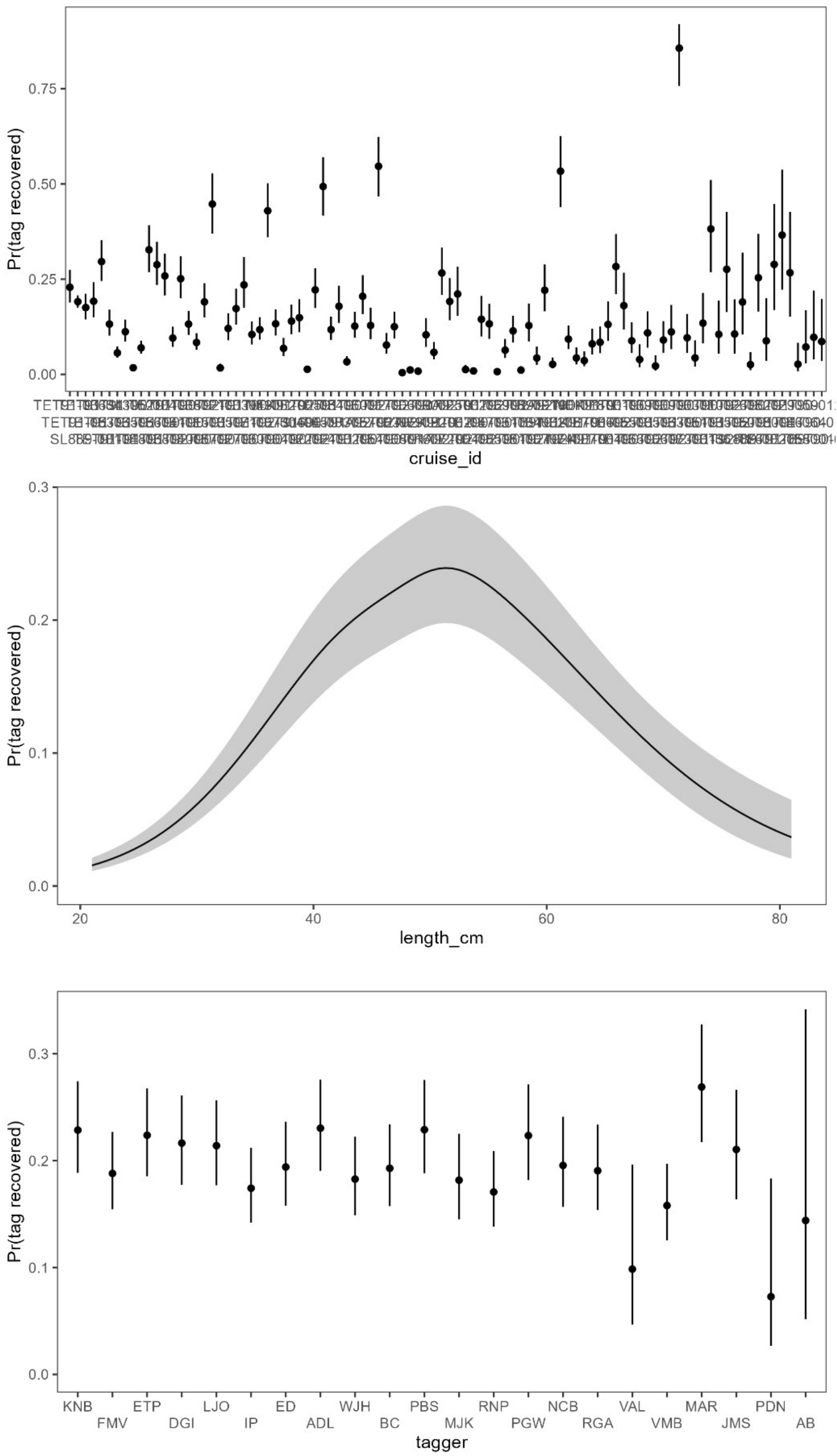


Figure 1 (continued on following page) Effect plots for the selected RTTP model of tagging effects for skipjack (mean ± 1 SE). The effects are (from top panel to bottom): tagging event, length, tagger, station, condition and quality. Levels of categorical variables are ranked in descending order of releases (left to right). For a given term, the predictions were generated with other categorical variables set at the level with the highest releases, and continuous variables were set at their mean.

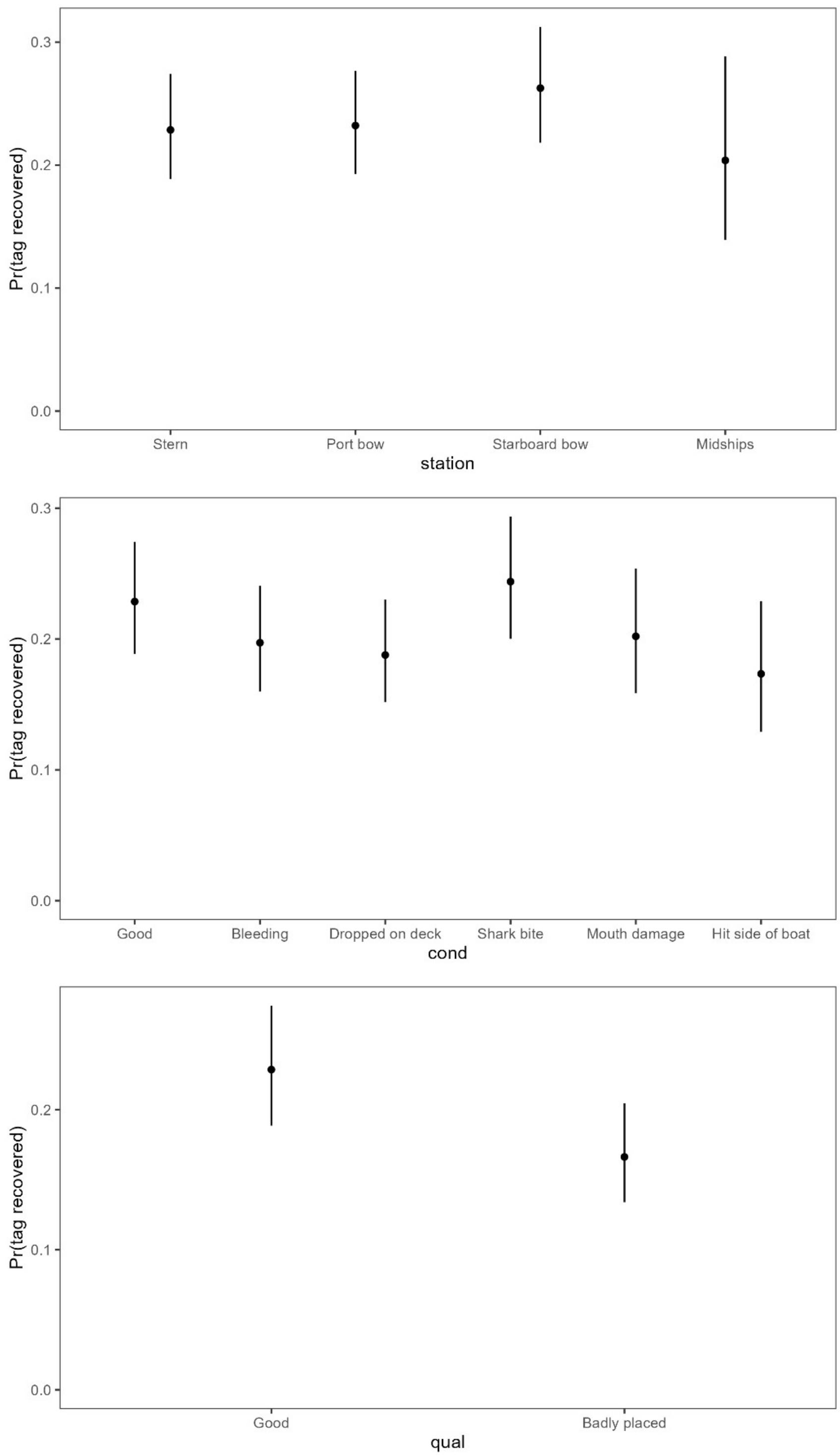


Figure 1 continued.

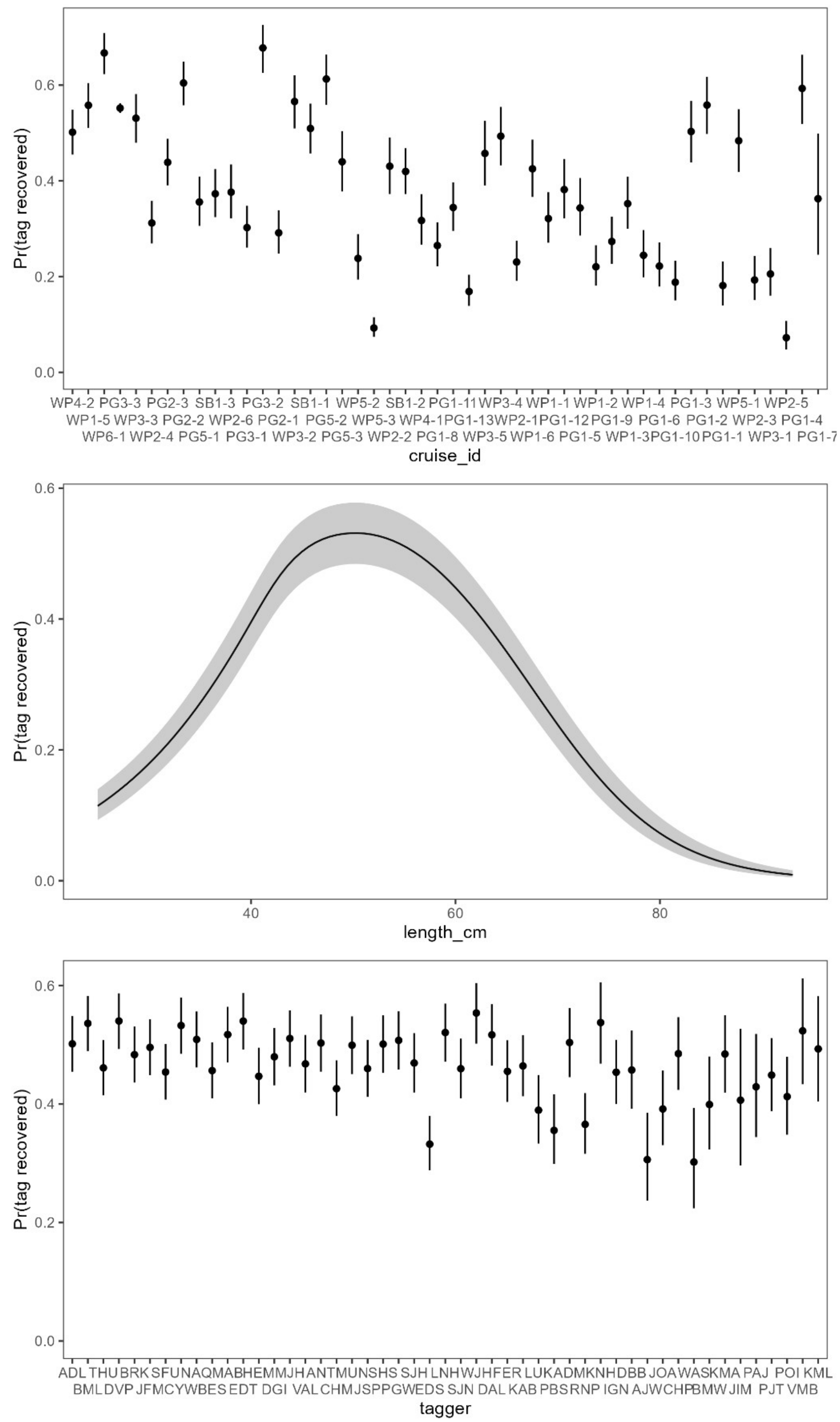
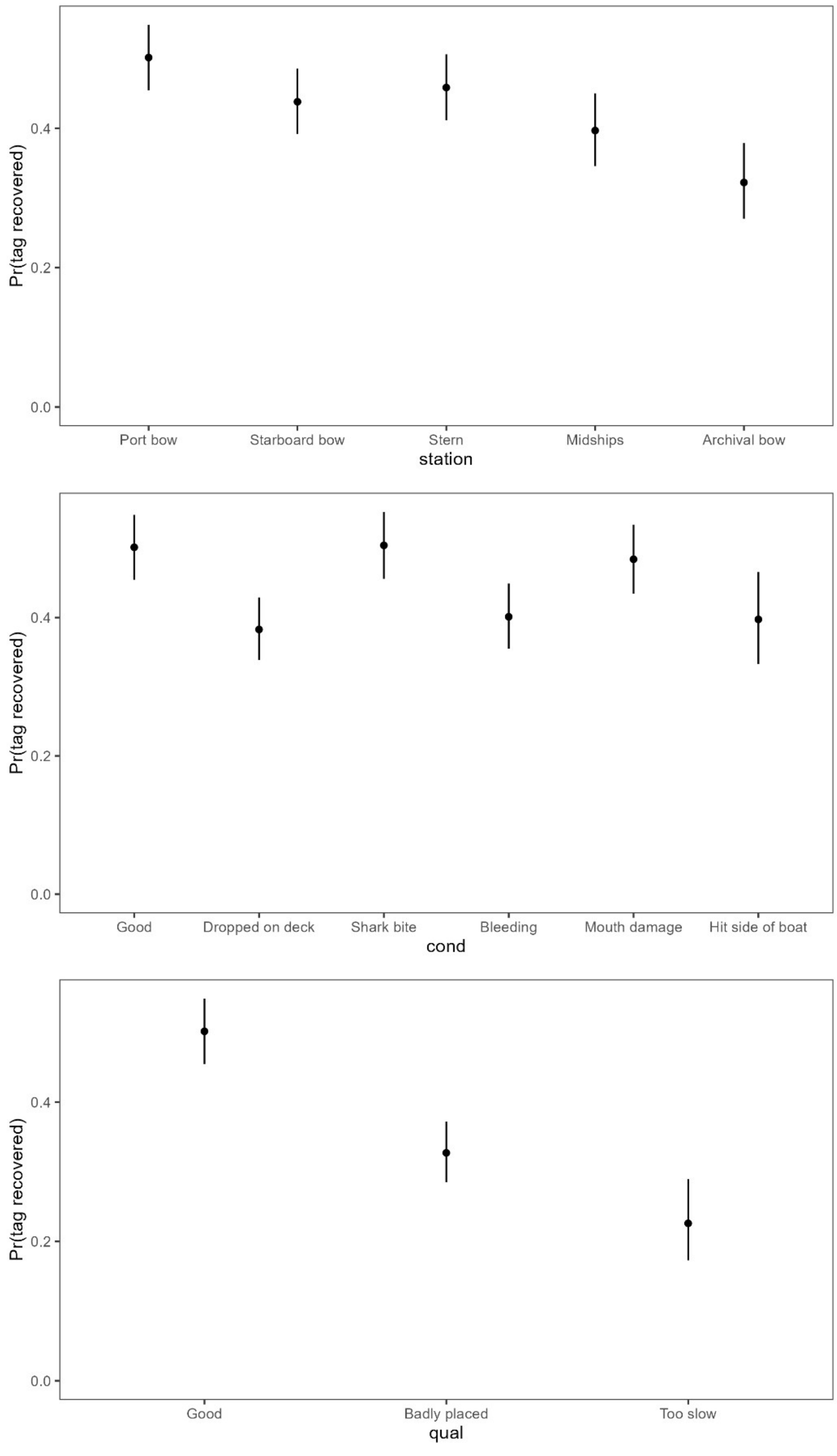


Figure 2 (continued on following page) Effect plots for the selected Western Pacific PTTP model of tagging effects for skipjack (mean ± 1 SE). The effects are (from top panel to bottom): tagging event, length, tagger, station, condition and quality. Levels of categorical variables are ranked in descending order of releases (left to right). For a given term, the predictions were generated with other categorical variables set at the level with the highest releases, and continuous variables were set at their mean.



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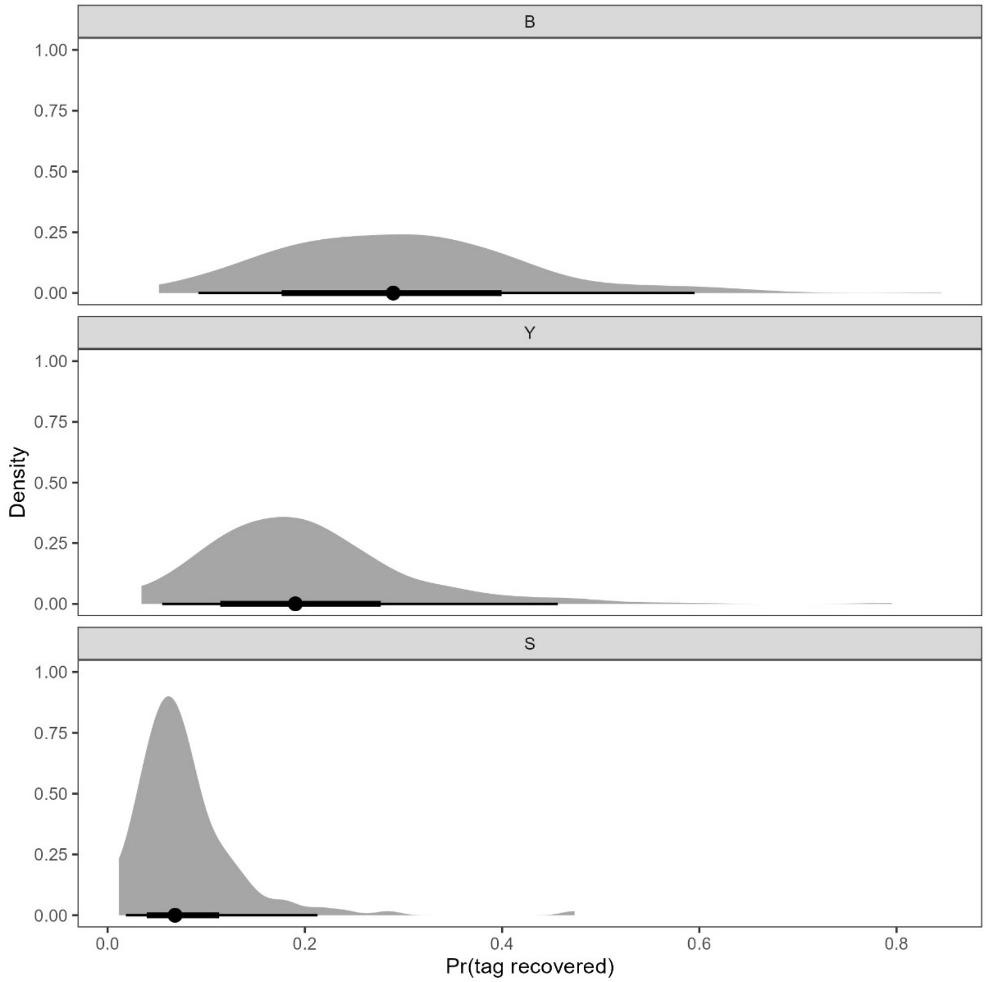


Figure 3 (continued on following pages) Effect plots for the selected Central Pacific PTTP model of tagging effects for skipjack, yellowfin and bigeye (mean ± 1 SE). The effects are (from top panel to bottom): event (species specific), gear, association, length, tagger, condition and quality. Levels of categorical variables are ranked in descending order of releases (left to right). For a given term, the predictions were generated with other categorical variables set at the level with the highest releases, and continuous variables were set at their mean.

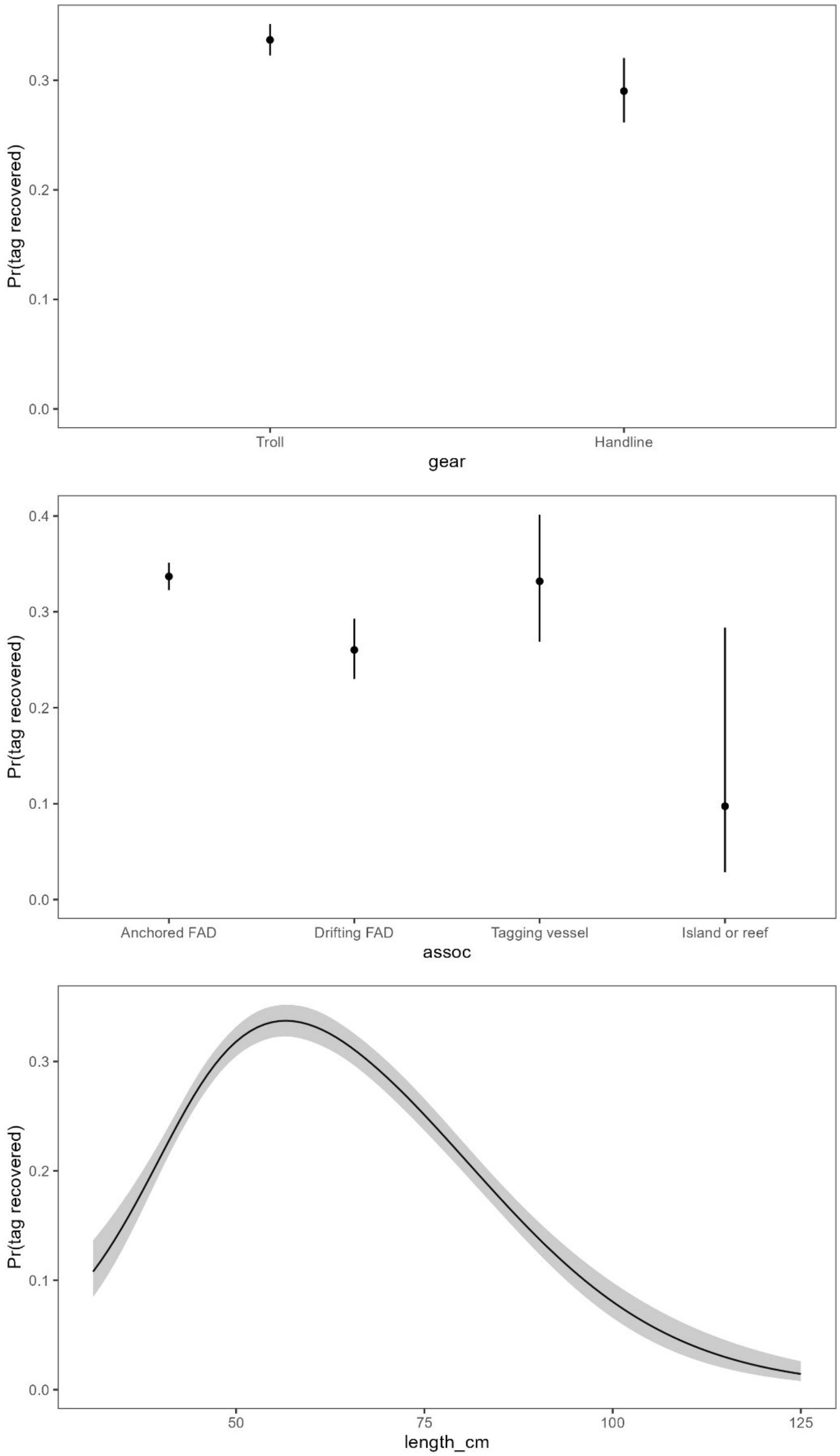


Figure 3 continued.

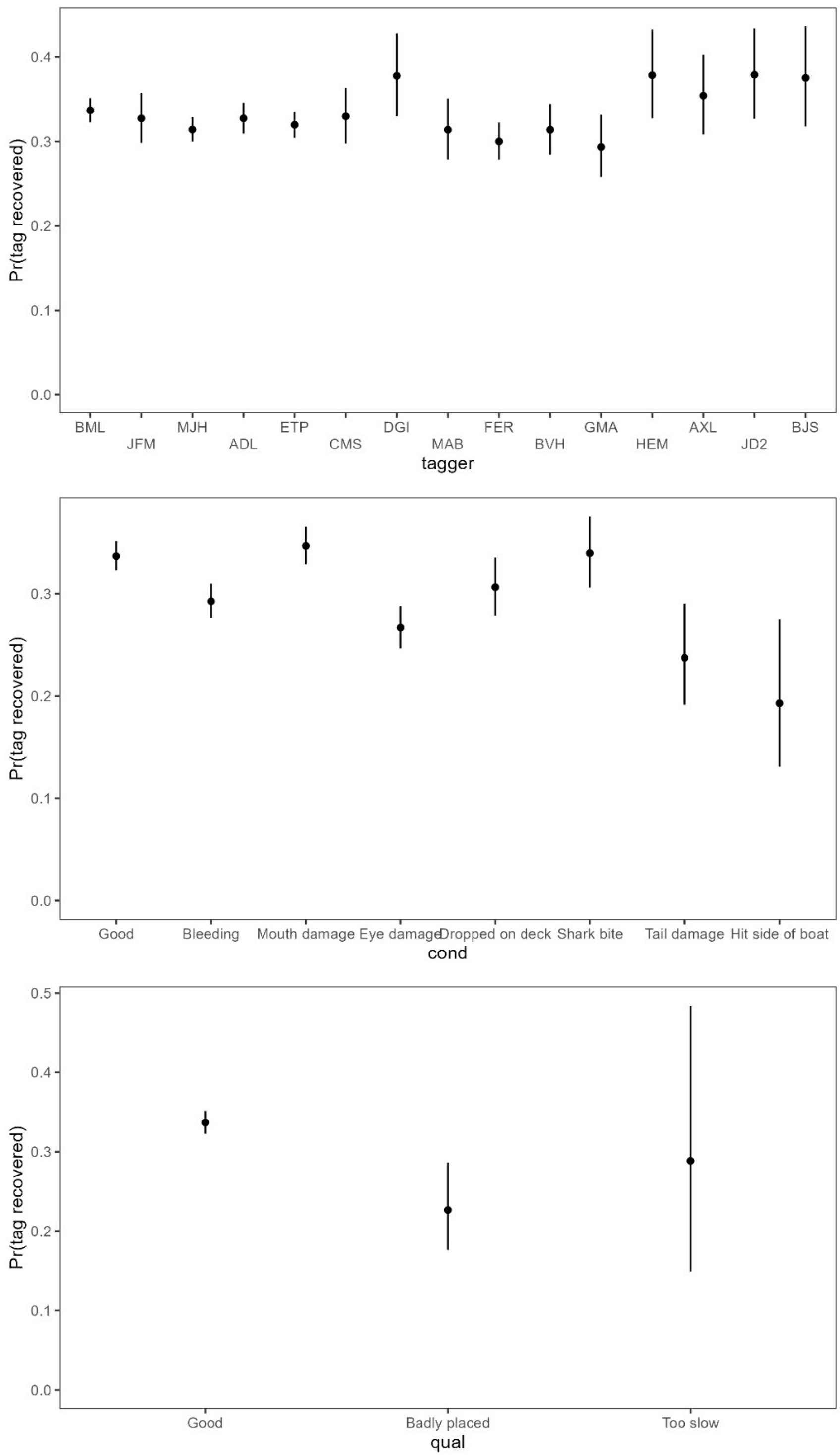
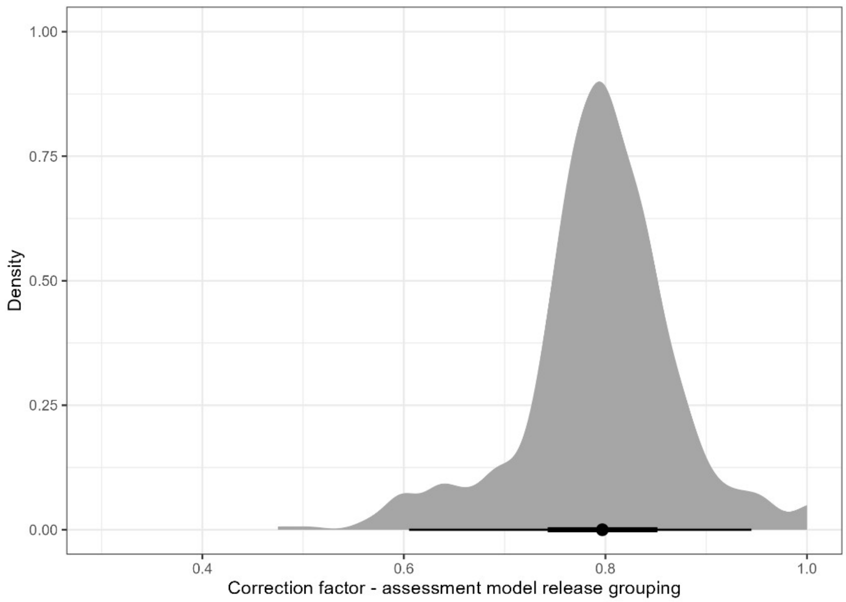


Figure 3 continued.

a) RTTP



a) PTTP

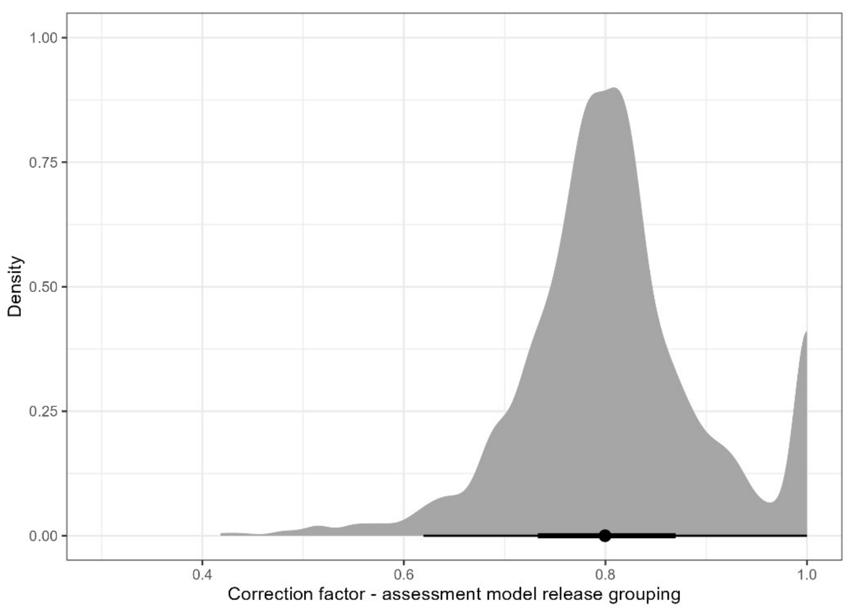


Figure 4 Estimated skipjack correction factors for the a) RTTP and b) PTTP releases by assessment model release grouping (i.e. combinations of region, year, quarter and release length class). The mean (point), 66% interval (thick line) and 95% interval (thin line) are provided for reference.

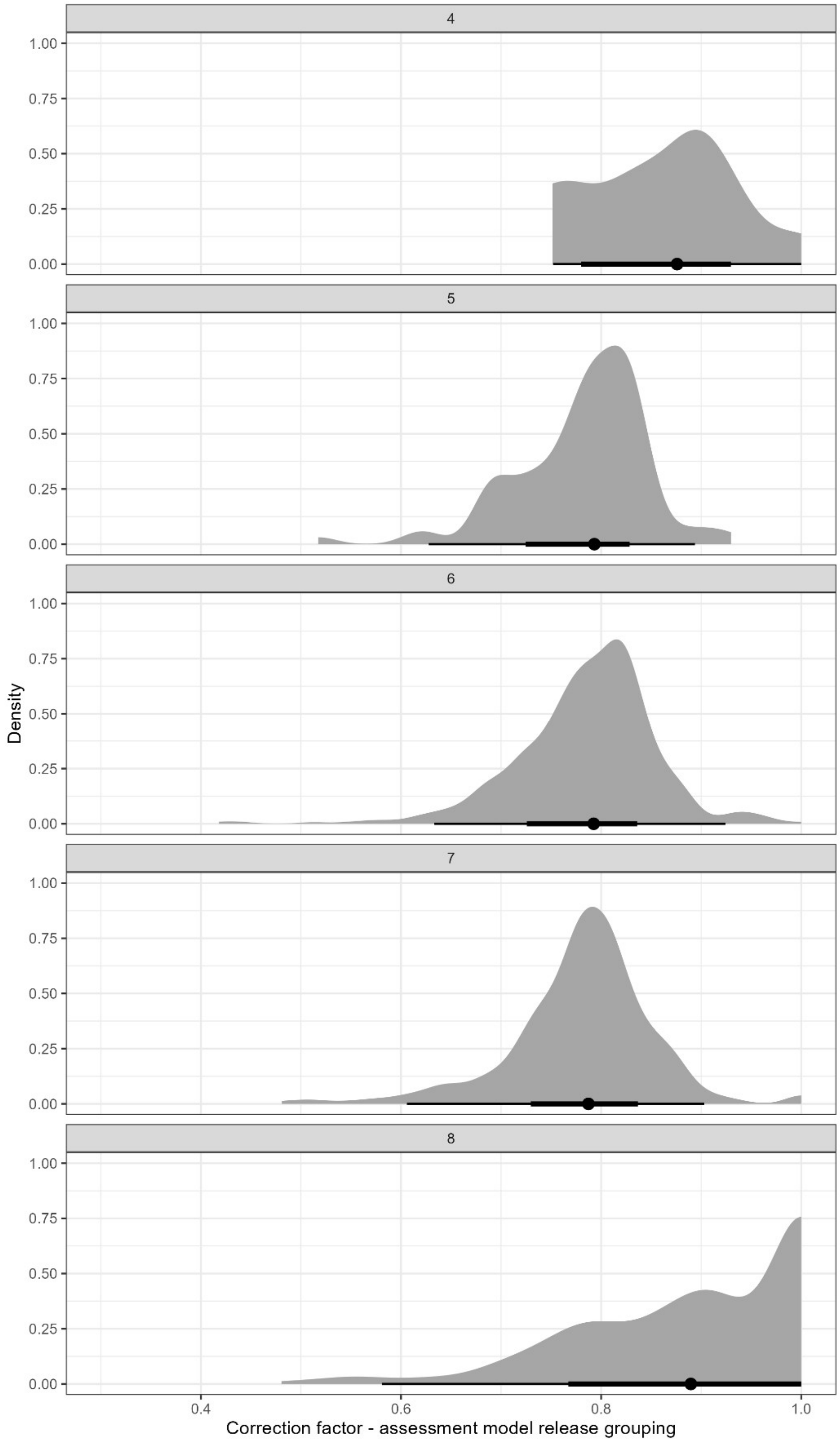


Figure 5 Estimated skipjack correction factors for PTTP releases by assessment model release grouping (i.e. combinations of region, year, quarter and release length class) per region. The mean (point), 66% interval (thick line) and 95% interval (thin line) are provided for reference.