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ANALYSIS OF TAGGING DATA FOR THE 2022 SKIPJACK TUNA ASSESSMENT: CORRECTIONS 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 condition 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.

Simulations were undertaken to assess the ability of the modelling approach to recover unbiased estimates of tagging condition effects and correction factors, given concerns around the unbalanced nature of the mark-recapture dataset. The simulations suggested that the modelling approach can obtain unbiased estimates for skipjack tuna, if the model specification reflects the processes impacting tag recovery probability.

The estimated correction factors result in substantial reductions (c. 20%) in the number of both RTTP and PTTP tag releases. Uncertainty in correction factors has historically been ignored in assessments of tropical tuna populations in the WCPO. However, there are appreciable levels of uncertainty in estimated correction factors, particularly for RTTP releases. This may translate into uncertainty in the outputs from stock assessment models.

We provide a number of suggestions for further work in relation to the estimation of corrections for tagging conditions, building on discussions at the workshop convened by SPC in December 2021. These suggestions include: extending the simulation analysis to consider a range of plausible operating models, and estimation modelling frameworks; and, considering tagging vessel specific station effects; using cross validation to support model selection.

We invite the Scientific Committee to note that:

- Estimates of correction factors for skipjack releases have appreciable levels of uncertainty, particularly for the RTTP.
- We recommend exploring the sensitivity of skipjack assessment models to plausible ranges of correction factors, to determine whether uncertainty in correction factors should be incorporated in the assessment models of WCPO tropical tunas.
- We recommend that correction factors for Central Pacific tagging cruises should be estimated separately to other PTTP tagging cruises. An approach to correct releases from Central Pacific tagging cruises will be required for the next bigeye and yellowfin assessments.

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). 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. These imbalances may lead to difficulties in separating the effects of the different variables, and so lead to bias in correction factors. A workshop was convened by SPC in December 2021 to review the mark-recapture dataset and the modelling approach that has been used to generate correction factors, and discuss potential improvements and changes to the methodology in the context of the characteristics of the dataset.

This Information Paper describes the estimation of correction factors for the 2022 skipjack assessment and other associated analyses, including those arising from recommendations from the workshop.

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 2020 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. 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 (95,261 individuals) and PTTP (287,897 individuals).

As per Berger et al. (2014), individual taggers with fewer than 200 skipjack releases were removed from the modelled dataset. Additionally, any levels of candidate categorical variables with fewer than

200 skipjack releases were removed. Tagging events with fewer than 30 remaining skipjack releases were then removed. Finally, we removed tag release events with no reported tag recoveries, to avoid perfect separation in the modelled dataset. This left 85,435 skipjack releases from 546 RTTP tagging events, and 279,156 skipjack releases from 1,070 PTTP tagging events. All data analysis was undertaken in R v4.1.1 (R Core Team, 2021).

2.1 Simulation analysis

Following recommendations from the workshop, simulations were undertaken to assess the extent to which the imbalanced nature of the dataset impacts the ability of the current modelling approach to recover correction factors. Two sets of simulations were undertaken, both based on tag data from PNG tagging cruises undertaken during the PTTP in order to reduce computational time. The first set of simulations was designed to reflect an idealised situation with minimal multicollinearity between tagger, station and tagging event. This was achieved by randomly assigning a tagger to each tag release. The second set of simulations used the PTTP dataset without modification, to reflect the observed levels of multi-collinearity between covariates.

The operating model for the simulations reflected a simplification of the selected tagger effects model from Berger et al. (2014), with the proportion of tags recaptured a function of tagger identity, the station where tags were released, and the tagging event. These variables are influential on estimated correction factors, and also adequately represent the main sources of multicollinearity in the PTTP dataset.

The operating model was specified as:

$$\log\left(\frac{p_i}{1-p_i}\right) = \beta_0 + \beta_{event[i]} + \beta_{tagger[i]} + \beta_{station[i]}$$

where p_i is the probability of tag recovery, i refers to a group of tag releases with a shared set of covariate values, and the β's are parameter values that define the underlying 'reality'. The parameter values in the operating model were held constant for all simulations to facilitate comparison of correction factors between simulations.

Samples were drawn at random from the binomial distribution defining the simulated number of tag recoveries for each group i:

$$\hat{y}_{ij} \sim \text{Binomial}(n_i, p_i)$$

where n_i is the number of releases, and $\hat{y}_{ij}$ the simulated number of tag recoveries for a specific random draw j.

The estimation model had the same specification as the operating model, i.e.

$$\hat{y}_{ij} \sim \text{Binomial}(n_i, \hat{p}_{ij})$$

$$\log\left(\frac{\hat{p}_{ij}}{1-\hat{p}_{ij}}\right) = \hat{\beta}_{0j} + \hat{\beta}_{event[ij]} + \hat{\beta}_{tagger[ij]} + \hat{\beta}_{station[ij]}$$

where $\hat{p}_{ij}$ is the estimated probability of tag recovery, and the $\hat{\beta}$ are parameter estimates, for random draw j. The models were constructed using the R package 'mgcv' (Wood, 2011). Correction factors were then generated by calculating the probability of recovery for each tag group under optimal conditions, $\mu_i^{optimal}$, and under the conditions experienced at release, μ_i^{actual}. The 'true' correction factors for each tag group, r_i, were calculated from the parameters defining the operating model:

$$\mu_i^{actual} = \text{logit}^{-1}(\beta_0 + \beta_{event[i]} + \beta_{tagger[i]} + \beta_{station[i]})$$

$$\mu_i^{optimal} = \text{logit}^{-1}(\beta_0 + \beta_{event[i]} + \beta_{opt\_tagger} + \beta_{opt\_station})$$

$$r_i = \frac{\mu_i^{actual}}{\mu_i^{optimal}}$$

where opt_tagger and $opt\_station$ refer to the 'optimum' tagger and station levels. The estimated correction factors for each tag group and random draw, $\hat{r}_{ij}$, were also calculated:

$$\hat{\mu}_{ij}^{actual} = \text{logit}^{-1}(\hat{\beta}_0 + \hat{\beta}_{event[ij]} + \hat{\beta}_{tagger[ij]} + \hat{\beta}_{station[ij]})$$

$$\hat{\mu}_{ij}^{optimal} = \text{logit}^{-1}\left(\hat{\beta}_{0j} + \hat{\beta}_{event[ij]} + \hat{\beta}_{opt\_tagger_j} + \hat{\beta}_{opt\_station_j}\right)$$

$$\hat{r}_{ij} = \frac{\hat{\mu}_{ij}^{actual}}{\hat{\mu}_{ij}^{optimal}}$$

where opt_tagger_j and $opt\_station_j$ were draw-specific optimum tagger and station levels.

Optimal levels of the tagger and station effect were determined by first filtering for covariate levels with at least 4,000 associated releases and then taking the level with the highest parameter value. This approach prevents taggers and stations with relatively few releases, and so imprecise parameter estimates, from being considered as optimal.

The 'true' and estimated correction factors were then aggregated to coarser resolutions to facilitate comparisons, including a tagging cruise leg resolution, and assessment model tag release groups, i.e. combinations of model region, year, quarter and 2cm length class. Correction factors were aggregated by taking the weighted mean correction factor across tag groups, weighted by the number of releases n_i.

2.2 Estimation of correction factors

Logistic regression models were used to estimate the effects of tagging conditions on the probability of tags being recaptured, starting from the selected models of Berger et al. (2014). The models were constructed in the R package 'mgcv' (Wood, 2011). RTTP and PTTP data were modelled separately. The specification of the initial RTTP and PTTP models from Berger et al. (2014) was:

$$y_i \sim \text{Binomial}(n_i, p_i)$$

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

where i refers to a group of tag releases with a shared set of covariate values, p_i is the probability of tag recovery and n_i and y_i are the number of releases and recaptures respectively. Categorical covariates were included for: the tagging event, *event*; 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 thin-plate regression spline denoted $f(\,)$. A backwards selection procedure was used to assess support for the inclusion of each tagging condition covariate using AIC. Tagging event and release length were always included. We also tested for the inclusion of tagger experience as a continuous variable, modelled with a thin-plate regression spline. The experience effect was included in addition to the *tagger* effect.

Correction factors for each modelled tag release group, r_i, were then generated from the selected tagger effects models:

$$\mu_i^{actual} = \text{logit}^{-1}\left(\beta_0 + \beta_{event[i]} + \beta_{tagger[i]} + \beta_{station[i]} + +\beta_{condition[i]} + \beta_{quality[i]} + f(length[i])\right)$$

$$\mu_i^{optimal} = \text{logit}^{-1}\left(\beta_0 + \beta_{event[i]} + \beta_{tagger[BML]} + \beta_{station[port\ bow]} + \beta_{condition[good]} + \beta_{quality[good]} + f(length[i])\right)$$

$$r_i = \frac{\mu_i^{actual}}{\mu_i^{optimal}}$$

where $\mu_i^{optimal}$ and μ_i^{actual} are the probability of recovery for each tag group under optimal conditions, and the conditions experienced at release, respectively. Optimum conditions were defined based on estimated effect size, as well as number of tag releases for tagger. For the PTTP, optimal conditions were '*BML*' for tagger, '*port bow'* for station, and '*good'* for both condition and quality. For the RTTP, optimal conditions were '*KNB*' for tagger, '*starboard bow'* for station, and '*good'* for both condition and quality. Tagging event and length were not adjusted when calculating $\mu_i^{optimal}$, 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, respectively.

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 used the median tag event effect when calculating μ_i^{actual} and $\mu_i^{optimal}$. In cases when the tagger had been excluded from the modelled dataset, we used the median tagger effect when calculating μ_i^{actual} and $\mu_i^{optimal}$.

The correction factors were then aggregated to coarser resolutions to facilitate comparisons, including tagging cruise legs, and assessment model tag release groups, i.e. combinations of model region, year, quarter and 2cm length class. Correction factors were aggregated by taking the weighted mean correction factor across tag groups, weighted by the number of releases n_i.

There were a limited number of assessment model tag release groups (with 28 RTTP and 13 PTTP tag releases) 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.

2.3 Estimation of uncertainty in correction factors

The number of tag releases varies both between taggers, and between tag release events. As such, there are coefficients in the tagging condition effects models that have relatively high associated uncertainty. This may translate into appreciable levels of uncertainty in correction factors. Estimates of the uncertainty in correction factors were generated by drawing 500 sets of parameters at random from the multivariate normal distribution $N_k(\boldsymbol{\beta}, \boldsymbol{\Sigma})$, defined by the vector of estimated parameter means $\boldsymbol{\beta}$ and their covariance matrix $\boldsymbol{\Sigma}$, where k is the number of estimated parameters. Correction factors were then estimated for each set of parameters, to obtain distributions of correction factor estimates.

2.4 Exploration of models with random intercepts

The workshop suggested the use of random intercepts in models of tagging condition effects. This may lead to more accurate estimates of tagger and tag release event coefficients in the models of tagging condition effects, particularly for taggers or release events with comparatively few releases, and so improve estimation of correction factors.

Models were fitted to the PTTP datasets with random intercepts for both tagging event and tagger. A fixed effect was also included for tagging cruise, to increase normality in the tagging event random effects. The specification of the model was:

$$y_i \sim \text{Binomial}(n_i, p_i)$$

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

where $\alpha_{event[i]} \sim N(0, \sigma_e)$ and $\alpha_{tagger[i]} \sim N(0, \sigma_t)$.

When estimating correction factors for unmodelled tagging events or taggers, the random intercept was set to zero. Otherwise, correction factors were generated using the approach set out in Section 2.2.

3 Results

3.1 Simulation analysis

The imbalance in the PTTP dataset did not result in biased estimates of either the parameters from the operating model, or correction factors (Figure 1). Additionally, the precision in estimates of correction factors at a tagging cruise leg resolution were generally comparable for the ‘balanced’ dataset, and the ‘imbalanced’ dataset. However, there were tagging cruise legs with relatively broad distributions for correction factors for the ‘imbalanced’ dataset, i.e. PG1-05, PG1-10 and PG5-2, due to the relatively low proportions of releases from highly experienced taggers, and vice versa.

3.2 Correction factor estimates

AIC supported the inclusion of all effects from the Berger et al. (2014) model specification for both RTTP and PTTP models (Table 1). Inclusion of the tagger effect had the most support for both the RTTP and PTTP models based on AIC. The fitted effects for the selected RTTP and PTTP models are provided in Figure 2 and Figure 3. The relationships between release length and recapture probability for the RTTP and PTTP models were similar, with the highest estimated recapture probability for release lengths of c. 50cm. The tagger effects demonstrated between-tagger variation for both the RTTP and PTTP, though the parameters were imprecise for taggers with relatively few releases. The starboard bow station had the highest estimated recapture probability during the RTTP, with no clear differences in recapture probability for the port bow, midships and stern stations. During the PTTP, the port bow station had the highest estimated recapture probability, followed in descending order by stern, starboard bow, midships and archival bow. The effect of fish condition on estimated recapture probability was similar for the RTTP and PTTP models, with lower recapture probabilities for fish that were bleeding or dropped on deck. There was no evidence for reduced recapture probabilities for fish with mouth damage or shark bites. Both RTTP and PTTP models estimated lower recapture probabilities for badly placed tags. The imbalanced nature of the RTTP and PTTP datasets was reflected in relatively strong correlation between parameters for the selected models (e.g. see Figure A 1 and Figure A 2).

Inclusion of tagger experience, in addition to tagger identity, was supported by AIC for both the RTTP (ΔAIC = -8.1) and the PTTP (ΔAIC = -68.6). However, the fitted experience smooths were not considered to be plausible, particularly the oscillating pattern for the PTTP (Figure A 3). We note that both smooths suggested declining probability of tags being recaptured with increasing tagger experience after 10-15,000 tag release. Additionally, the effect of experience was relatively limited for lower experience levels. Additional PTTP model runs were undertaken with experience capped at 40,000 tags, given the relatively limited observations available for higher experience levels. This did not result in a more plausible experience effect. As such, we did not include experience effects in the selected models of tagging condition effects.

Estimated correction factors from the selected RTTP and PTTP models were similar, with correction factors for most assessment model release groups ranging from 0.9 to 0.6, i.e. a 10 to 40% reduction in release numbers (Figure 4). Overall, the estimated correction factors result in a 21.8% reduction in releases for the PTTP, compared to a reduction of 18.4% for the RTTP.

Correction factor distributions at a tagging event resolution were correlated, such that a parameter set giving a relatively high correction factor for a given tagging event tended to give relatively high correction factors for all tag events, and vice versa (Figure A 4). Estimated correction factors were more precise for the PTTP than the RTTP (Figure 5 and Figure 6). Coefficients of variation (CVs) for RTTP cruise legs were generally less than 0.1, with a mean of 0.067, whereas the mean CV for PTTP cruise legs was 0.025. The overall correction factor for RTTP releases had a CV of 0.05, compared with 0.017 for the PTTP.

3.3 Tagging condition effects models with random intercepts

Replacing the tagging event and tagger fixed effects with random intercepts resulted in modest changes in estimated correction factors for assessment model tag release groups, particularly for release events with limited number of tag releases (Figure 7a). However, there was clear evidence of violation of distributional assumptions for the random intercepts for tagger. Estimated correction factors were relatively insensitive to replacing the tagging event fixed effects with random intercepts (Figure 7b).

4 Discussion

The results of the simulation exercise suggest that the modelling approach of Berger et al. (2014) can recover unbiased estimates of parameter estimates and correction factors for PTTP skipjack tuna, despite multicollinearity between covariates in the modelled dataset, if the model specification reflects the processes impacting tag recovery probability. Extending the simulation exercise to include a variety of plausible operating model specifications would enable a more robust determination of the performance of the current modelling approach. Alternative modelling approaches may also be worth considering for the tagging condition effects models, including approaches that have more flexibility for interactions between covariates, or better characterise uncertainty in estimated quantities. The testing of different modelling approaches could be incorporated into the extended simulation analyses.

Estimated correction factors result in a c. 20% reduction in tag 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). Estimates of correction factors have not been generated for Central Pacific (CP) tagging cruises from the PTTP, 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 (0.816) to SSAP releases. Additionally, we recommend applying the overall PTTP correction factor (0.782) to JPTP releases and CP tagging cruises.

Uncertainty in correction factors has historically been ignored in stock assessments of WCPO tropical tunas, with point estimates used. However, analyses reported here suggest appreciable levels of uncertainty in correction factors, particularly for the RTTP. The uncertainty in correction factors implies uncertainty in the proportions of available tag releases that are recaptured, and so uncertainty in estimates of fishing mortality. We recommend assessing the sensitivity of the assessment model to plausible ranges of correction factors, to determine whether uncertainty in correction factors should be represented in assessment models of WCPO skipjack, and tropical tunas more broadly.

As recommended by the workshop, we did not include data from CP tagging cruises when estimating correction factors for PTTP tag releases. CP cruises have tended to use a different pool of taggers compared with other PTTP cruises. Additionally, the CP tagging cruises have used different tagging platforms, such that tagging stations are not directly comparable with other PTTP tagging cruises. We note that it will be necessary to develop an approach to generate correction factors for CP tagging cruises for use in the next bigeye and yellowfin assessments.

The inclusion of random intercepts in tagging condition effects models does not appear to lead to better estimates of correction factors, based on our preliminary analyses. Additionally, it does not appear to be appropriate to assume a normal distribution for the tagger random intercepts, particularly given that the taggers with the highest tag releases tend to have relatively high intercepts and so are at the margins of the distribution. This could lead to upwards bias in intercepts of taggers with fewer releases, resulting in a tendency to under-estimate correction factors (e.g. see Figure 7). At this stage, further consideration of models with random intercepts does not appear to be an immediate priority.

In general, the estimated tagging condition effects from the RTTP and PTTP models demonstrate consistent relationships with recapture probability. An exception to this are the station effects, which differ markedly between the two programmes. It remains an open question as to why the tagging station should impact recapture probabilities. Suggested mechanisms include differences in time out of the water for fish tagged at different stations, varying levels of predation for fish released from different stations, and correlation between station and catchers, taggers, and tagger assistants (Hoyle et al., 2015). These mechanisms may vary between tagging platforms, for example due to differences in the layouts of the fishing deck between vessels. As such, tagging vessel specific station effects could be considered in future analyses.

We tested models including effects for a tagger's experience, defined as their cumulative releases across all tropical tuna species and tagging programmes. The experience effects suggested increasing recapture probability with increasing experience at lower experience levels, with the opposite at higher experience levels. These experience effects are inconsistent with those from previous studies (Hoyle et al., 2015; Scutt Phillips et al., 2020). Given the unlikely oscillating nature of the PTTP experience smooth, we did not include experience effects in the models used to obtain correction factors. It appears likely that tag shedding and tagging induced mortality varies between taggers, and is also a function of a tagger's experience. Future work could consider alternative ways of including experience in models of tagging condition effects, for example species-specific experience metrics, or using cumulative tag releases over a shorter time-window to reflect an assumption that recent experience is more important.

AIC was used to assess support for the inclusion of covariates in models of tagging condition effects. The models of tagging condition effects are ultimately used to predict probabilities of tag recovery, with which to estimate correction factors. As such, the use of cross validation for model selection should be considered in future analyses, to assess the predictive performance of different model specifications.

We invite the Scientific Committee to note that:

- Estimates of correction factors for skipjack releases have appreciable levels of uncertainty, particularly for the RTTP.
- We recommend exploring the sensitivity of skipjack assessment models to plausible ranges of correction factors, to determine whether uncertainty in correction factors should be incorporated in the assessment models of WCPO tropical tunas.
- We recommend that correction factors for Central Pacific tagging cruises should be estimated separately to other PTTP tagging cruises. An approach to correct releases from Central Pacific tagging cruises will be required for the next bigeye and yellowfin assessments.

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Tables

Table 1 Comparison of AIC and ΔAIC values for the backwards selection procedure.

a) RTTP

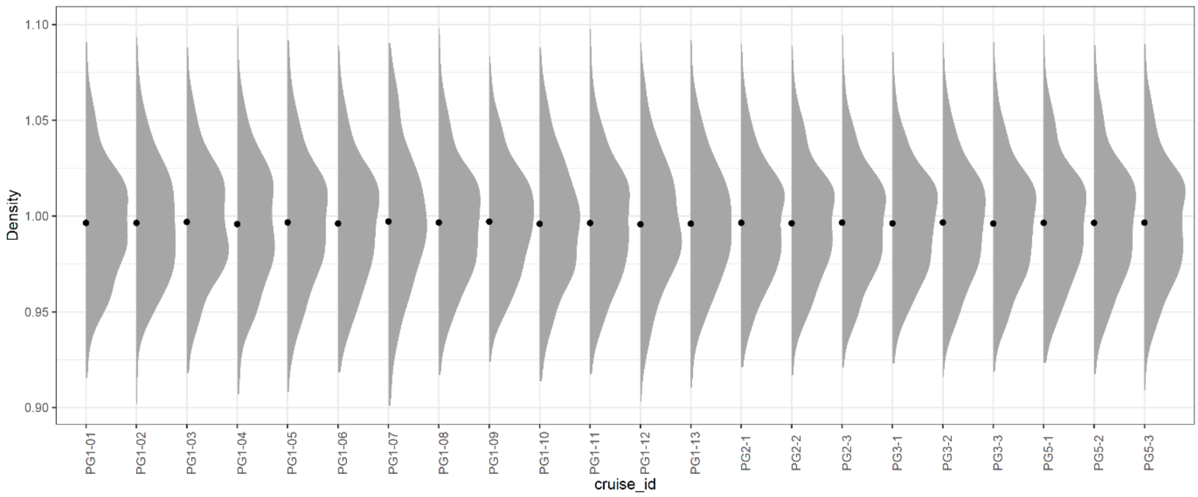
Model Specification	AIC	df	ΔAIC
~ tagging_event + tagger + station + cond + qual + s(len)	29398.7	581.5	0.0
~ tagging_event ~~+ tagger~~ + station + cond + qual + s(len)	29429.5	560.4	30.8
~ tagging_event + tagger ~~+ station~~ + cond + qual + s(len)	29409.7	578.5	11.0
~ tagging_event + tagger + station ~~+ cond~~ + qual + s(len)	29405.4	576.5	6.8
~ tagging_event + tagger + station + cond ~~+ qual~~ + s(len)	29422.4	580.5	23.8

b) PTTP

Model Specification	AIC	df	ΔAIC
~ tagging_event + tagger + station + cond + qual + s(len)	87291.5	1133.6	0.0
~ tagging_event ~~+ tagger~~ + station + cond + qual + s(len)	87769.9	1086.7	478.4
~ tagging_event + tagger ~~+ station~~ + cond + qual + s(len)	87427.2	1129.7	135.7
~ tagging_event + tagger + station ~~+ cond~~ + qual + s(len)	87480.2	1129.6	188.8
~ tagging_event + tagger + station + cond ~~+ qual~~ + s(len)	87480.1	1132.6	188.6

Figures

a) 'Balanced dataset' simulation



b) 'Imbalanced dataset' simulation

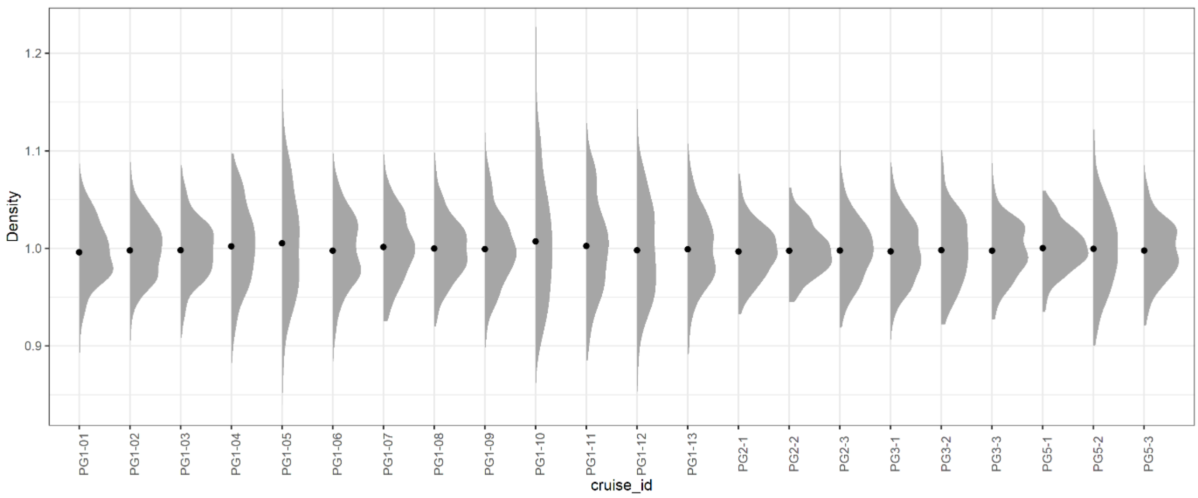


Figure 1 Distributions of tagging cruise leg resolution correction factors, expressed as a proportion of the 'true' correction factor, for simulations with a) the idealised 'balanced' dataset, and b) the 'imbalanced' dataset reflecting the actual PTTP dataset. The mean of each distribution is provided (black points).

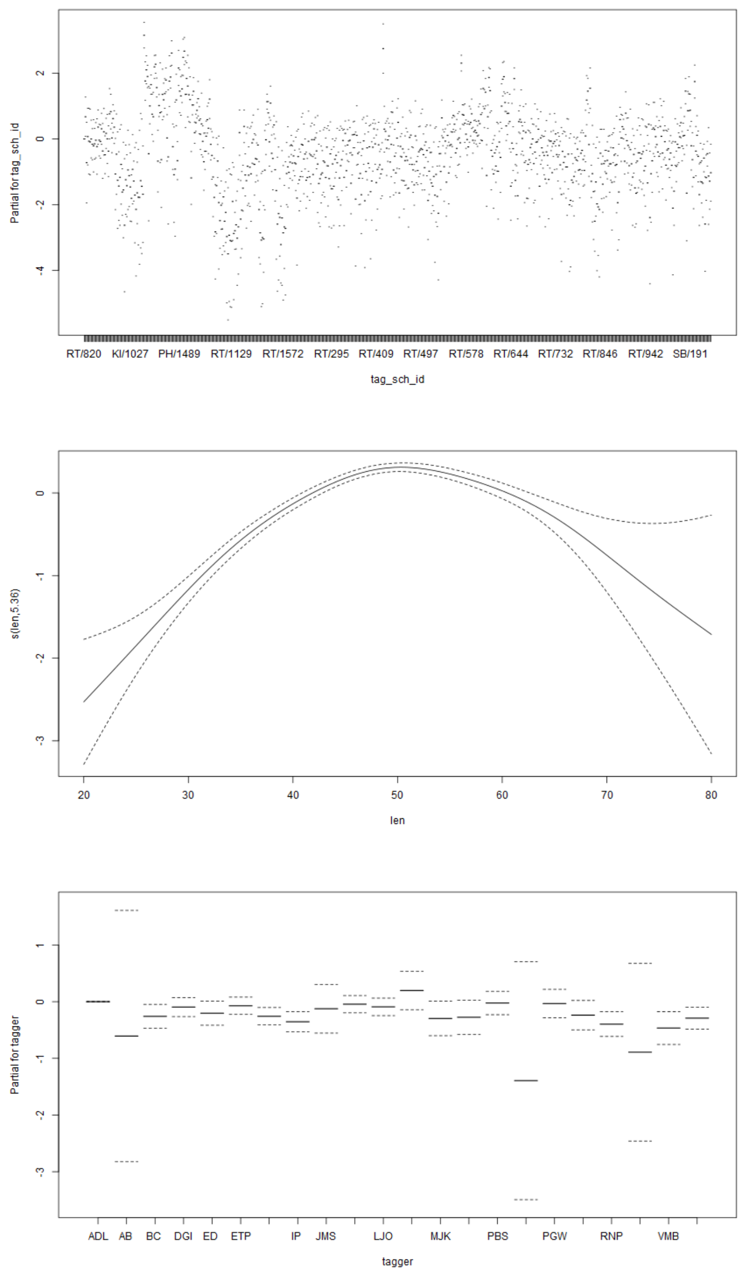


Figure 2 Effect plots for the selected RTTP model of tagging condition effects. The effects are (from top panel to bottom): tagging event, length, tagger, station, condition and quality. **Continued on following page.**

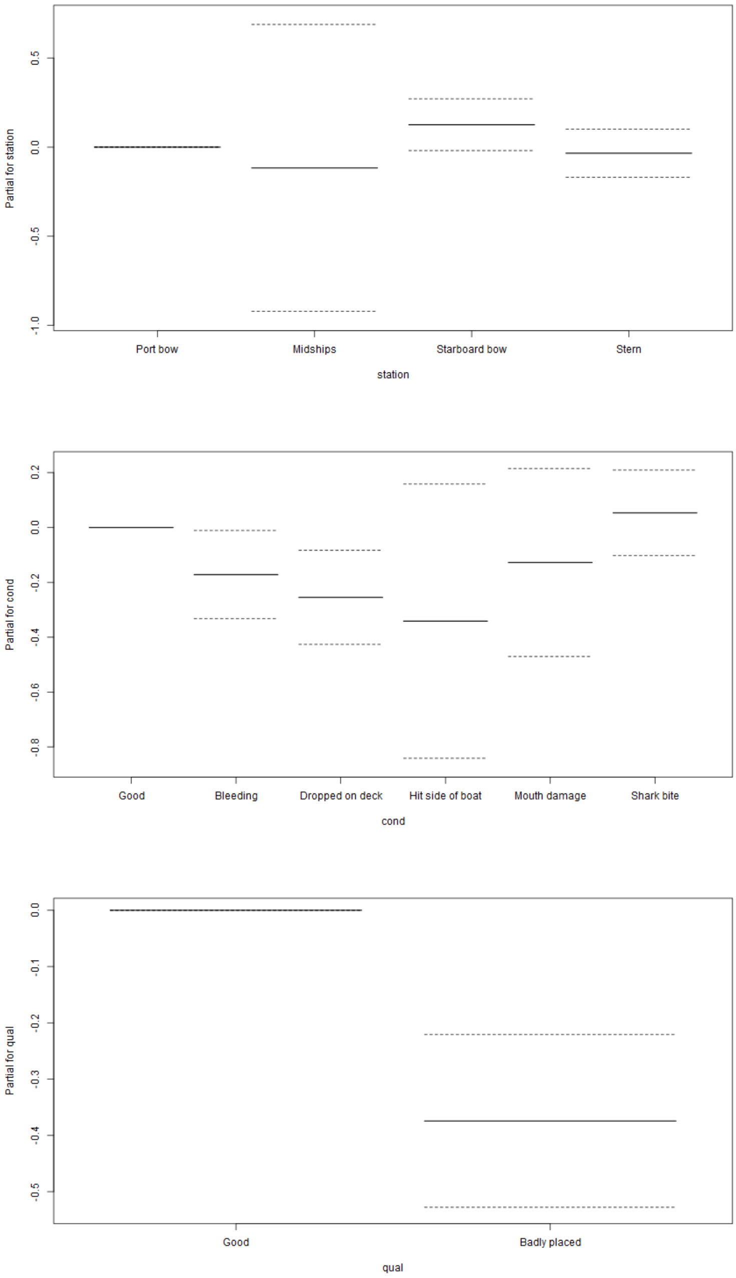


Figure 2 continued.

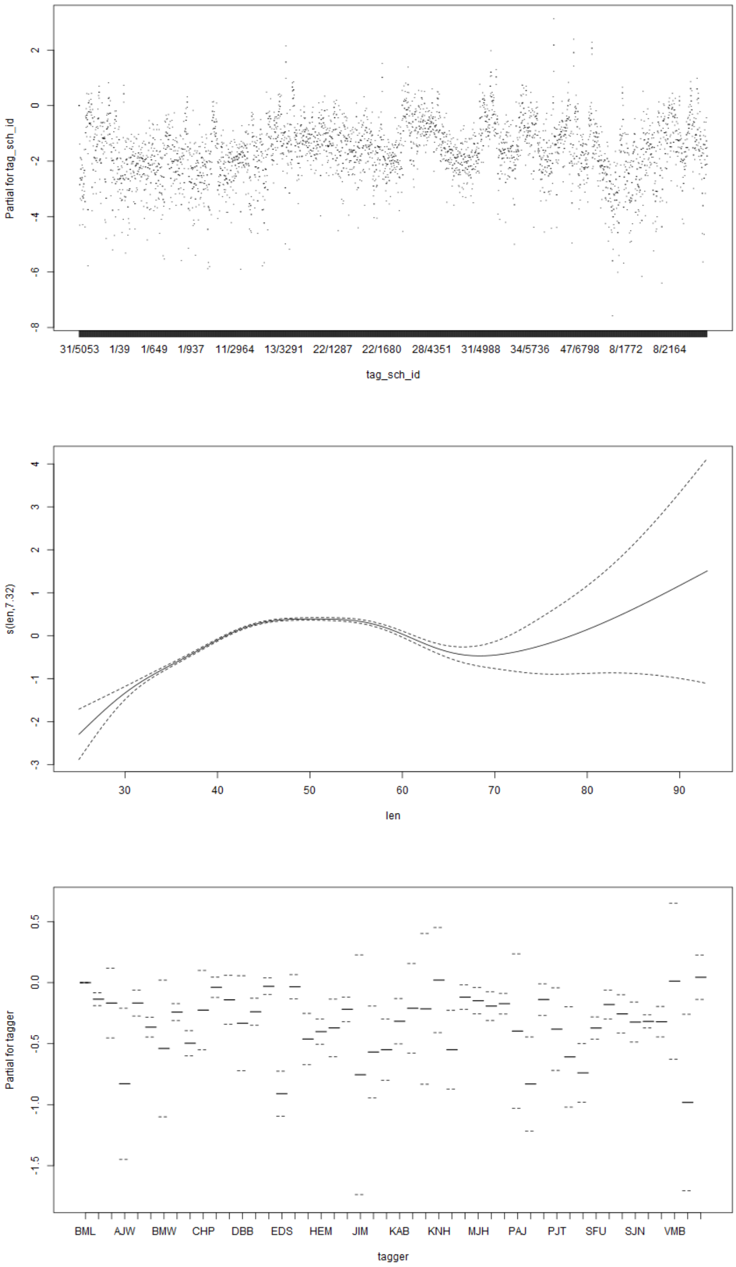


Figure 3 Effect plots for the selected PTTP model of tagging condition effects. The effects are (from top panel to bottom): tagging event, length, tagger, station, condition and quality. **Continued on following page.**

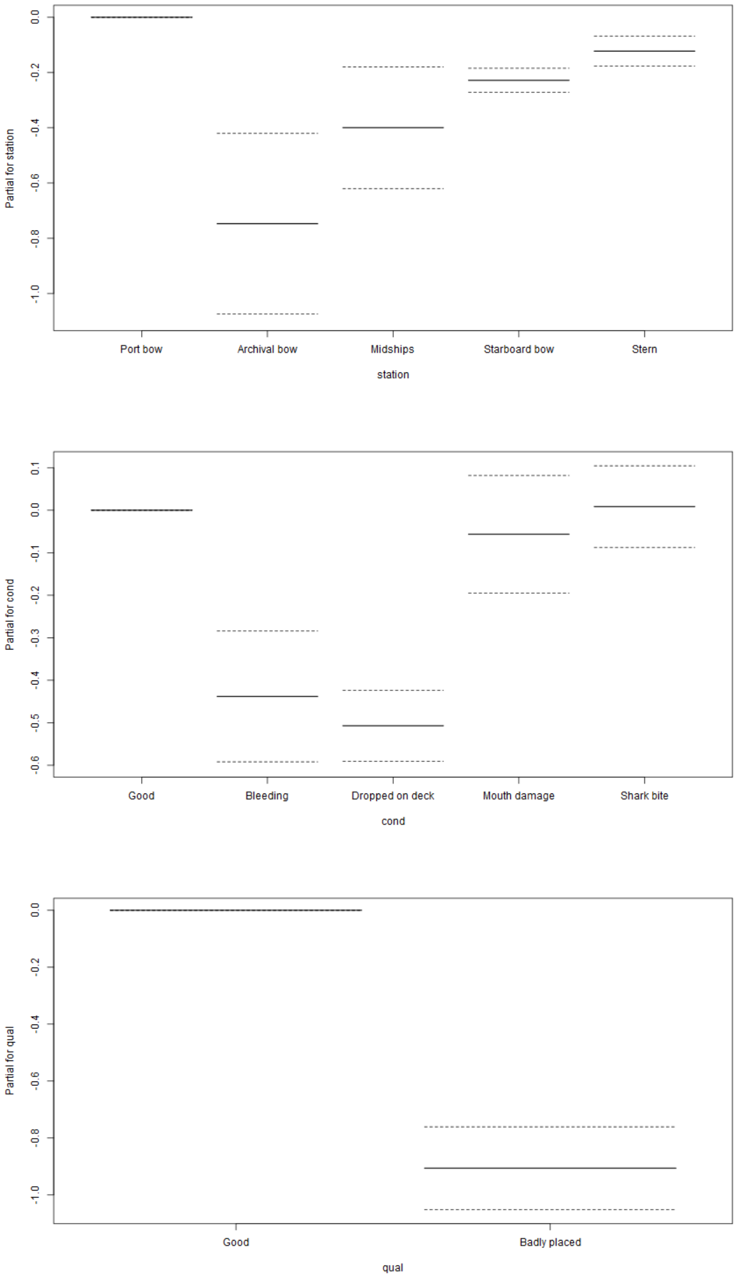
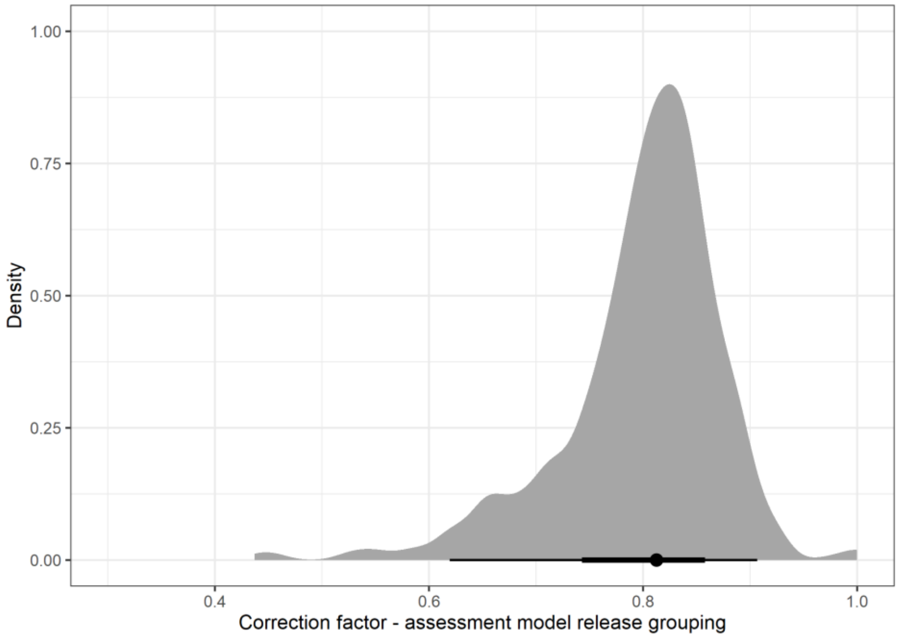


Figure 3 continued.

a) RTTP



a) PTTP

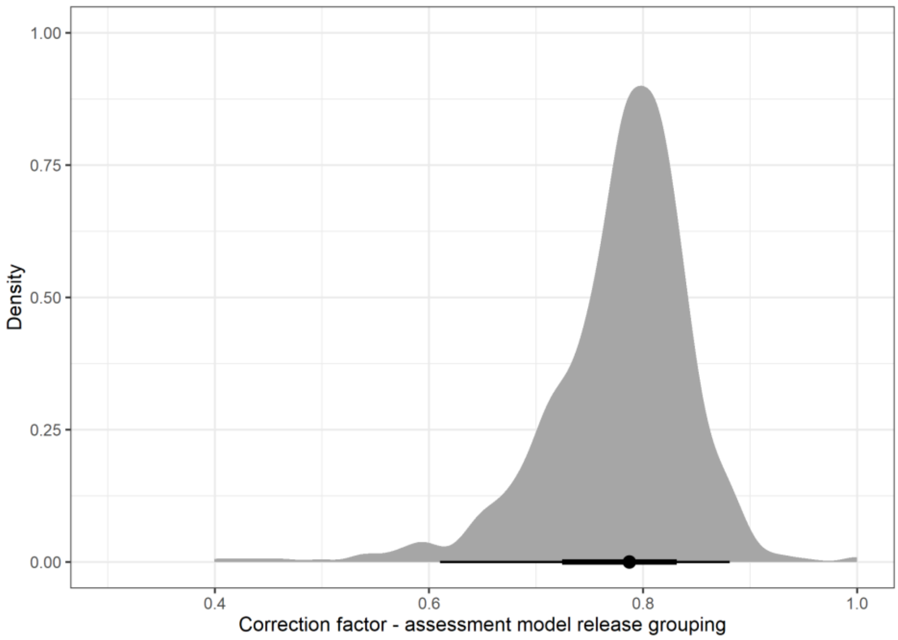
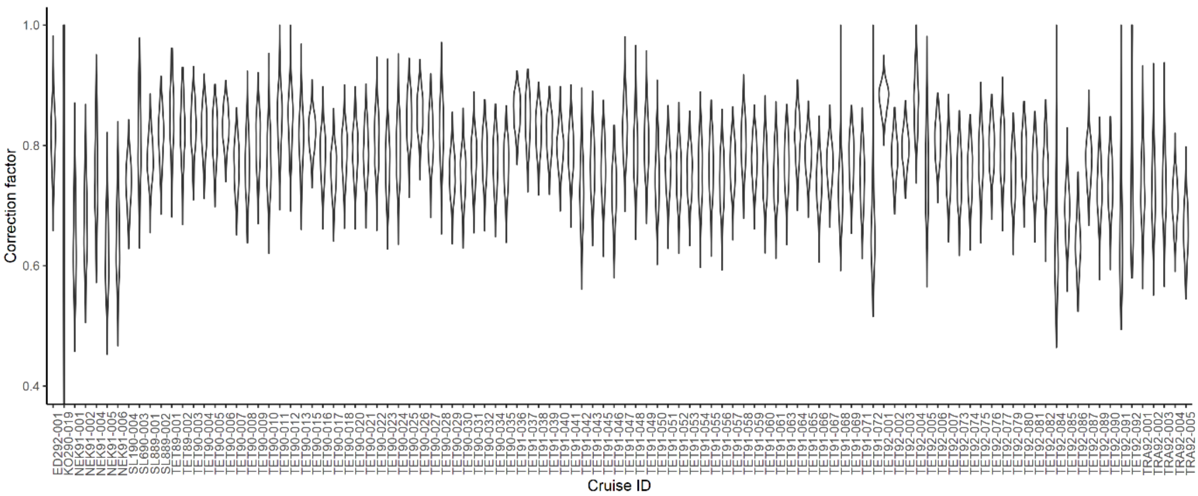


Figure 4 Estimated correction factors for the a) RTTP and b) PTTP by assessment model release grouping (i.e. combinations of region, year, quarter and release length class). The mean (point), 66% interval (thick line) and 95% interval (thin line) are provided for reference.

a) RTTP



a) PTTP

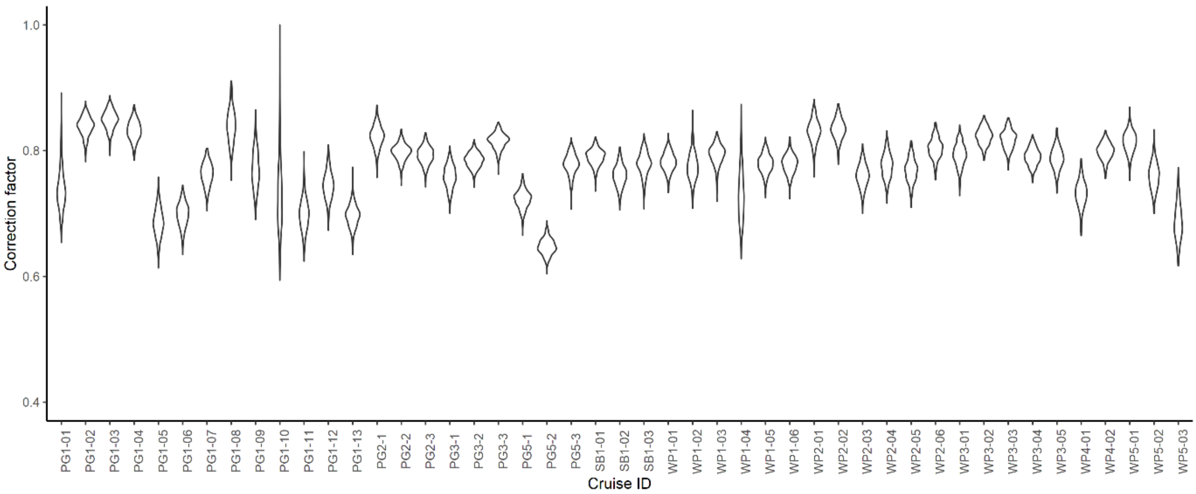
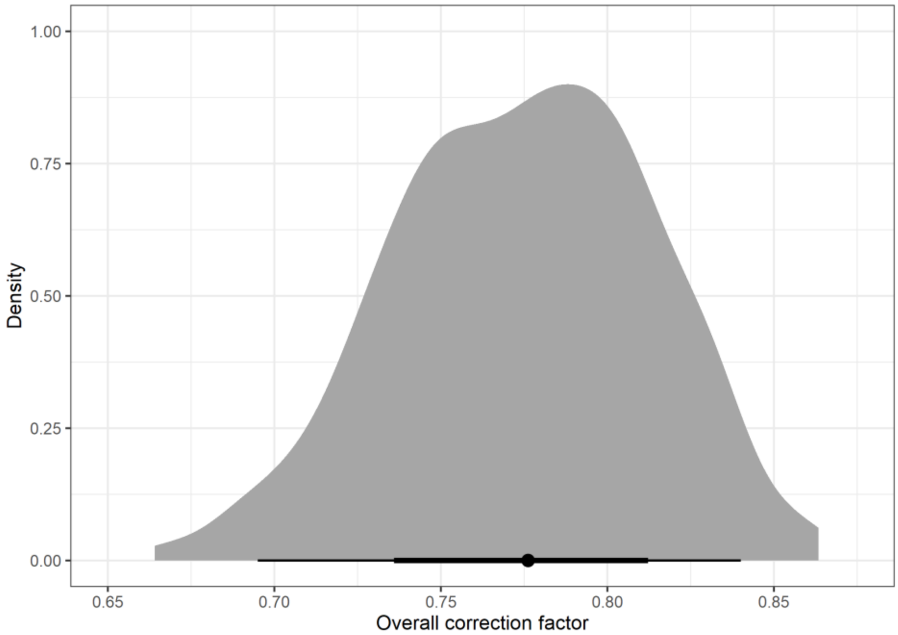


Figure 5 Estimated distributions of correction factors for the a) RTTP and b) PTTP by tagging cruise leg.

a) RTTP



a) PTTP

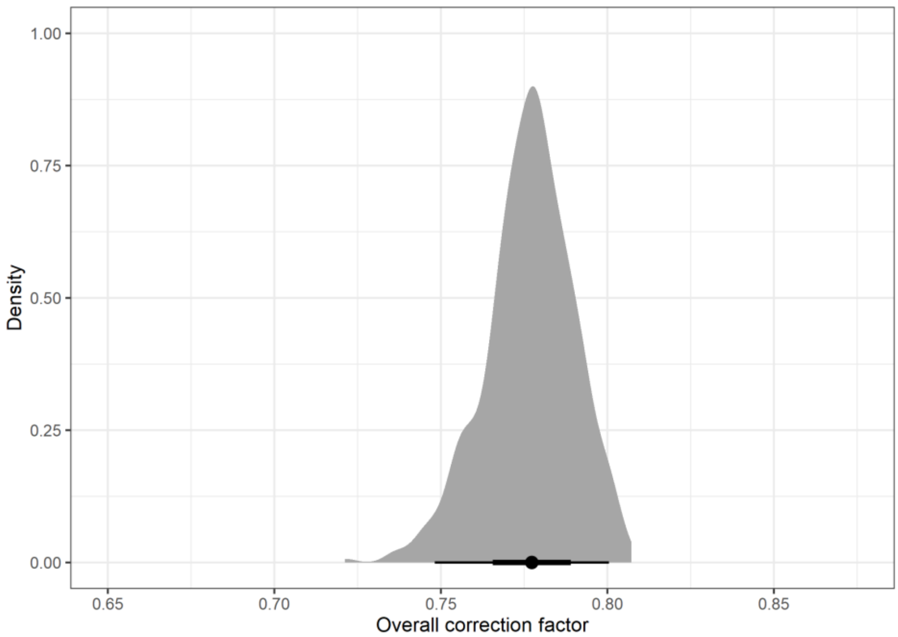
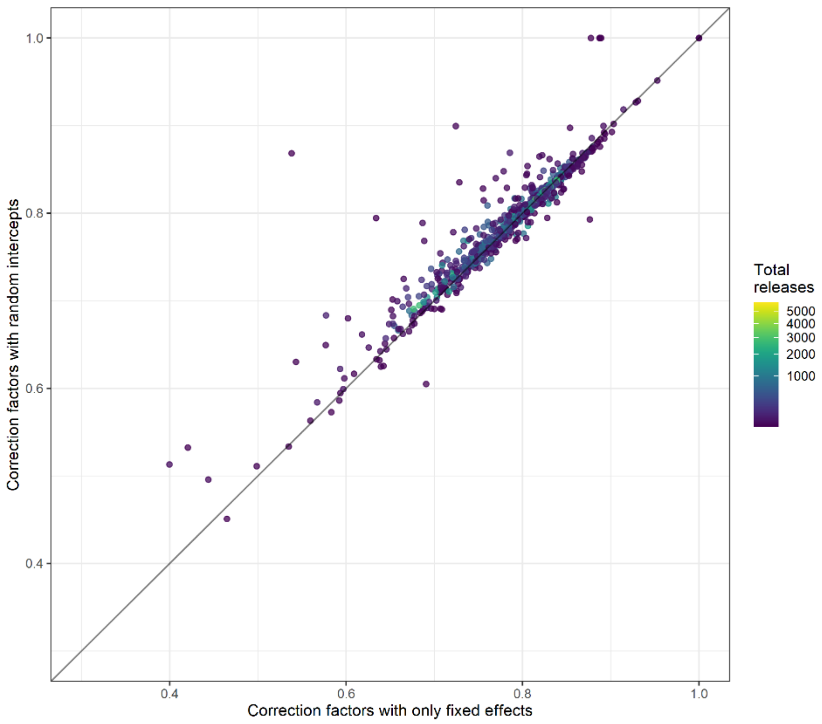


Figure 6 Estimated distributions of the overall correction factor for the a) RTTP and b) PTTP. The mean (point), 66% interval (thick line) and 95% interval (thin line) are provided for reference.

a) Random intercepts for tagging event and tagger



b) Random intercepts for tagging event

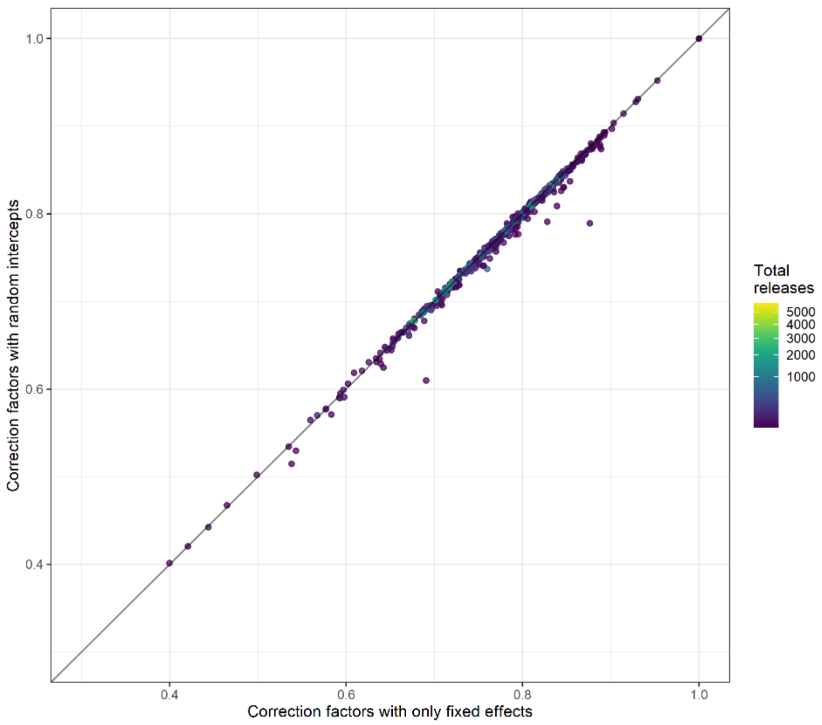


Figure 7 Assessment model tag release group-resolution correction factors generated from tagging condition effects models with a) random intercepts for tagging event and tagger, and b) random intercepts for tagging event only, compared to correction factors from models with fixed effects. The colour of points provides the number of releases.

Appendix A – Additional figures

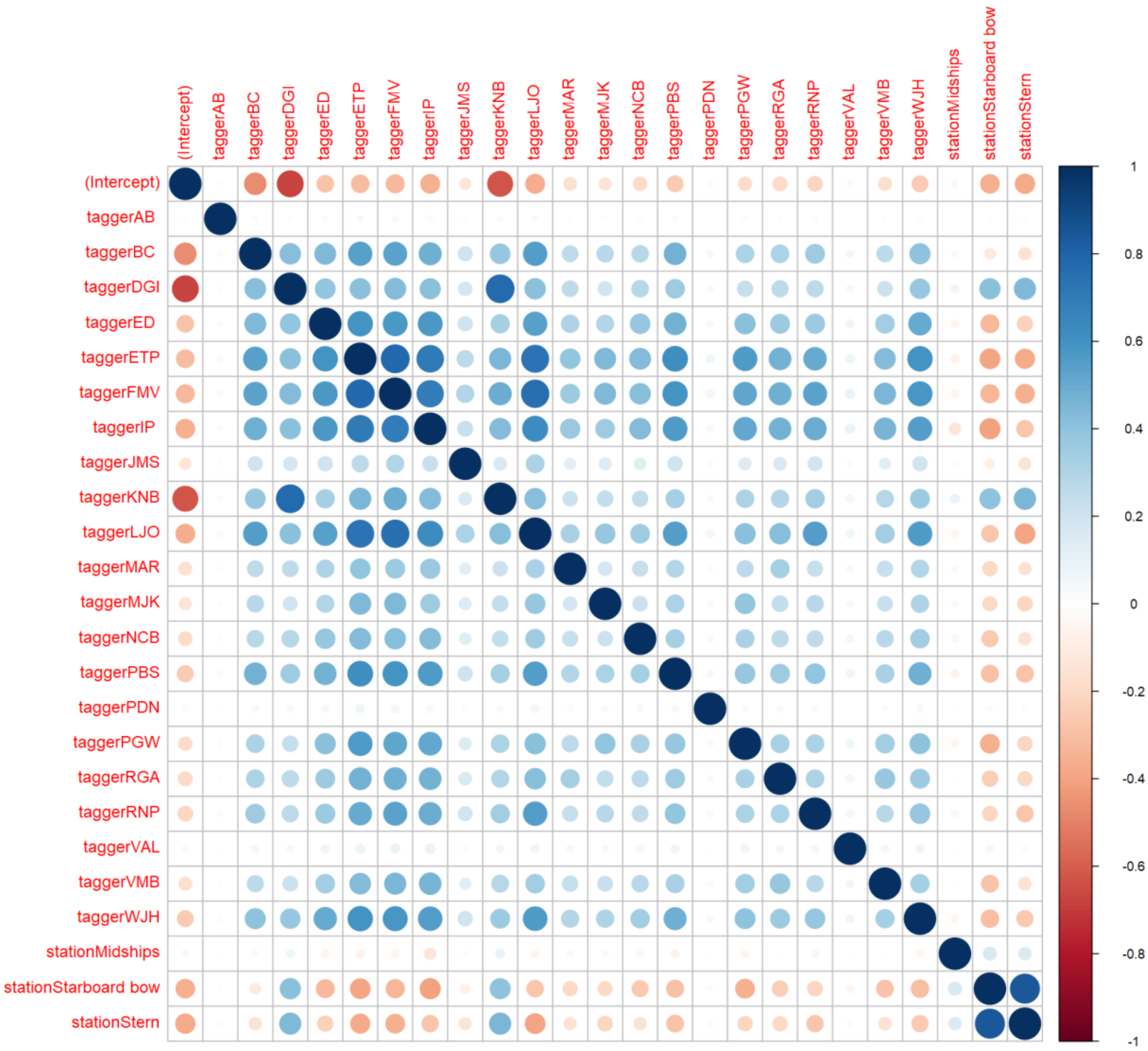


Figure A 1 The variance-covariance matrix for *tagger* and *station* effect parameters of the selected RTTP model.

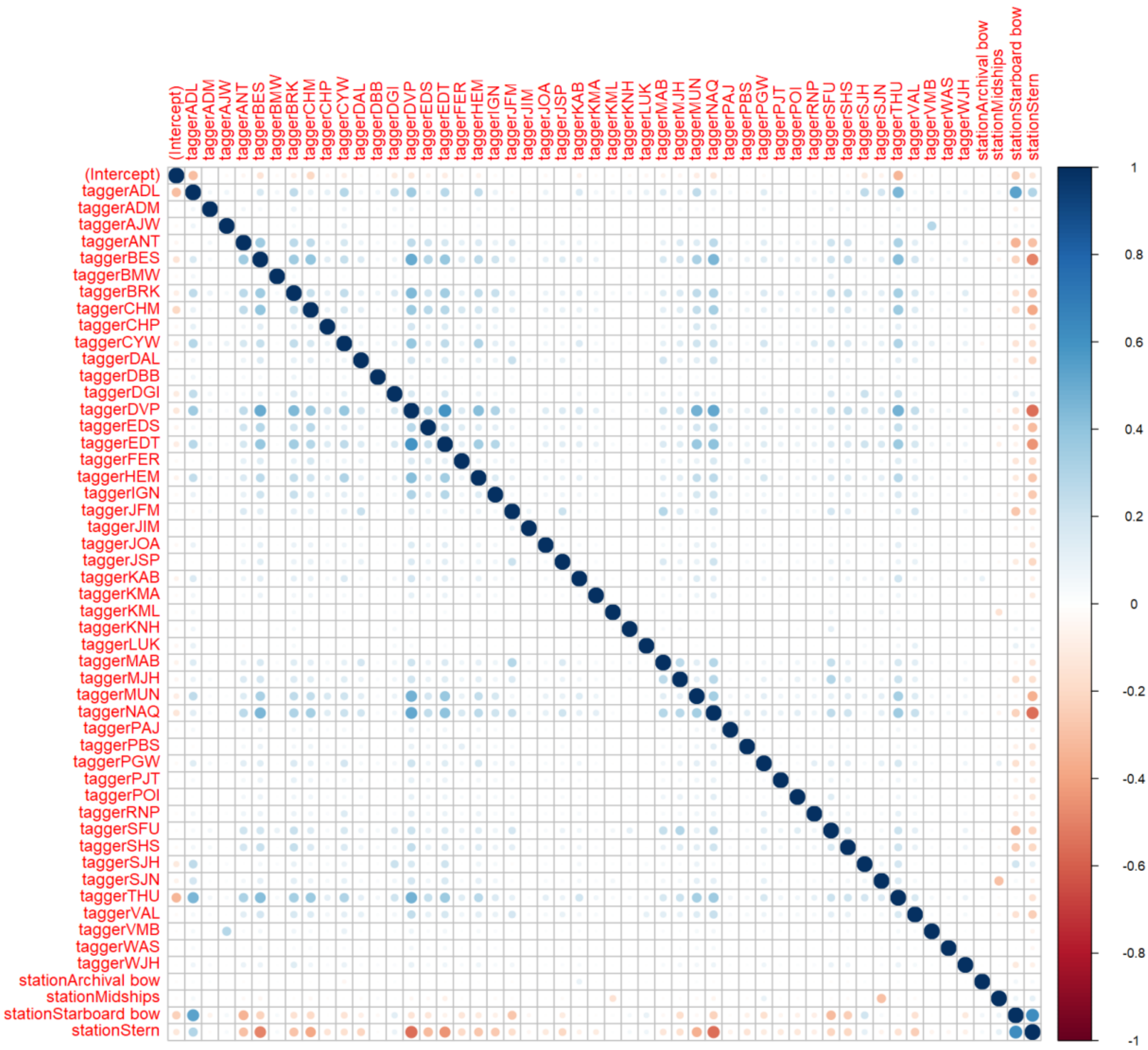
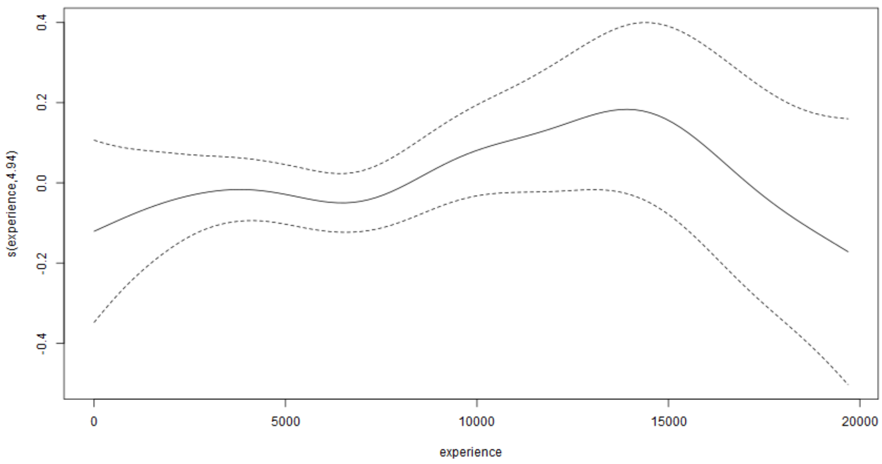


Figure A 2 The variance-covariance matrix for *tagger* and *station* effect parameters of the selected PTTP model.

a) RTTP



b) PTTP

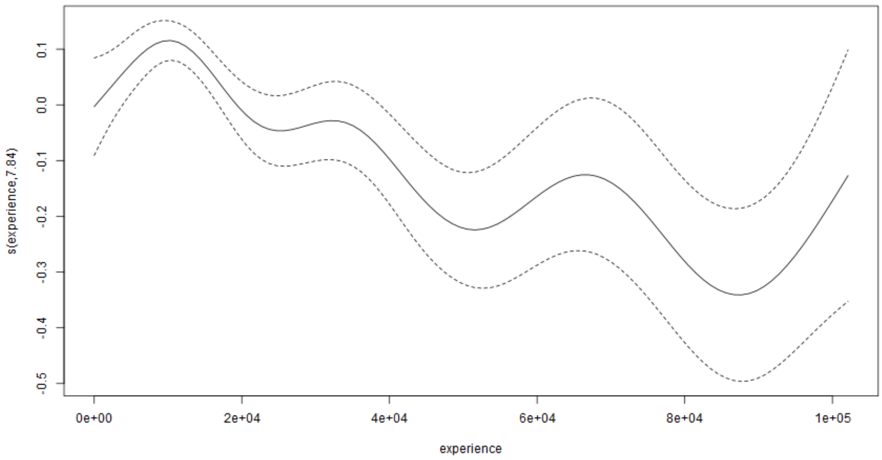
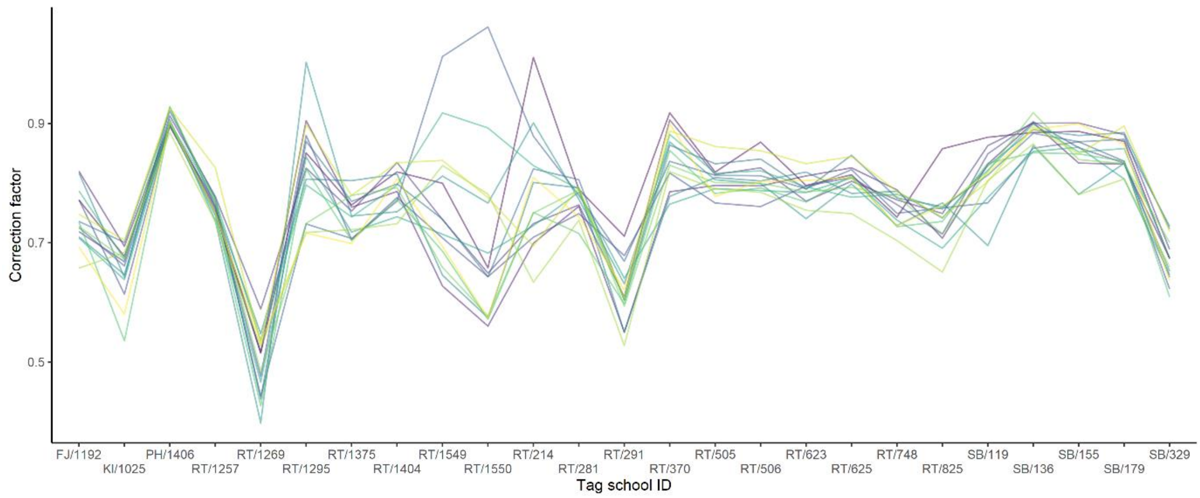


Figure A 3 Effect plots of tagger experience, when added to the tagging condition effects models from Berger et al. (2014). The y-axis is the logit-transformed probability of tag recapture.

a) RTTP



b) PTTP

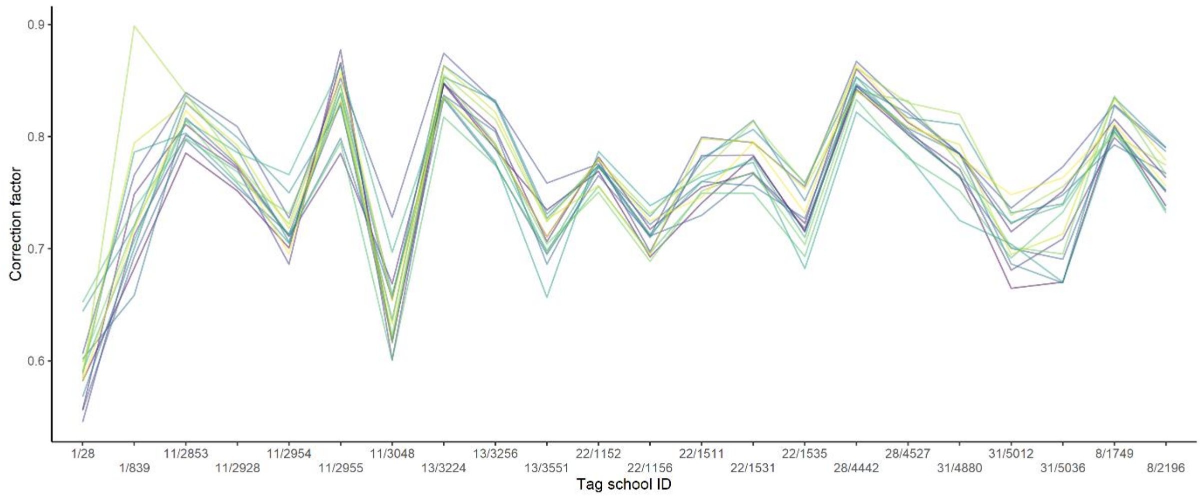


Figure A 4 A random sample of estimated correction factors for a subset of a) RTTP and b) PTTP tagging events. Each line corresponds to a set of parameter values that were used to generate uncertainty in estimated correction factors.