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Background analyses for the 2019 stock assessment of skipjack tuna

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Contents

Executive Summary

This paper describes the data used in the 2019 stock assessment of skipjack tuna *Katsuwonus pelamis* in the western and central Pacific Ocean. This report contains all analyses of input data where stand-alone papers were not considered warranted in each case. Descriptions of the following model components and data inputs are contained within this report:

- Approach used to format the tagging data used in the assessment model.
- Investigation of various methods for interpolating the release length for the Japanese tagging program.
- Estimation of tag correcting factors such as tag shedding and tagger effects.
- Detailed description of the reporting rates assumed for each fishery within the stock assessment model.
- Estimation of a length-weight relationship used to transform numbers at age to weight within the stock assessment model.
- Methodologies used to create the length frequency data for the purse seine fisheries that are scaled by catch within a region by 5° × 5° cells.

The procedures used for creating the tag files for the 2019 skipjack stock assessment closely followed the methods used by McKechnie et al. (2016b). An investigation of methods to provide release lengths for the Japanese tagging program that were missing this information was conducted. The method that provided the most reasonable size at release was sampling from the existing measured release lengths. The analysis conducted for the 2019 assessment also differed from the 2016 assessment in that the minimum number of tags released required to be included as a release event within a region was increased from a minimum of 10 tags released to 100 tags released.

Compared to the 2016 tag file, an additional 65 release events were added to the tagging file, which was the result of additional release events that were previously missing length at release of fish and the change in the spatial structure, i.e., addition of more regions. These changes to the tagging file contributed an extra 52,250 effective releases and 3,136 usable recaptures. The corrections of tag releases for usability, tag shedding and tag-induced mortality reduced the effective number of releases to 0.77, 0.60, 0.50 and 0.61 of the raw releases for the SSAP, RTTP, PTTP, and JPTP tagging programs respectively, giving a total of 329,812 effective releases and 56,092 usable recaptures in the 2019 tagging file.

The length-weight relationship was estimated from a mixture of multiple data sources available. The estimated relationship of length-weight was very similar to the relationship used in the 2016 skipjack tuna assessment with minutely smaller weight at length. The collection of length and weight measurement from a single fish for a variety of sampling programs should be continued.

Experiments should be conducted to determine if/how the length of a fish changes depending on the state of the fish, e.g, after being frozen, frozen and then thawed, and put on ice, and estimate appropriate correction factors. Additionally, the state of the fish when measured should be recorded in the future when collecting samples.

The analysis of length composition used the same methodologies as the 2016 skipjack tuna stock assessment but extended the data through to the end of 2018.

1 Introduction

Stock assessments for tuna in the Western and Central Pacific Ocean (WCPO) conducted by the Pacific Community (SPC) generally utilize the statistical software MULTIFAN-CL (Fournier et al., 1998; Hampton and Fournier, 2001; Kleiber et al., 2019). These models have extensive data requirements and specific formats for input files. This paper describes the data and its pre-processing that were used in the 2019 stock assessment of skipjack tuna *Katsuwonus pelamis* in the WCPO where stand-alone manuscripts were not considered warranted in each case. Each discrete set of analyses is presented with the background, methods, results, and discussion within each section.

This report should not be viewed as the only inputs used in the 2019 skipjack assessment. Instead, readers should also refer to the standardized CPUE analyses for the Japanese pole-and-line fisheries (Kinoshita et al., 2019), the associated purse seine fishery near Papua New Guinea (Vidal et al., 2019) and the Philippine and Indonesian purse seine fishery (Bigelow et al., 2019), the analysis of length composition data from the Japanese pole-and-line fishery (Kiyofuji et al., 2019), catch data from Japanese coastal fisheries (Fujioka and Kiyofiju, 2019), estimation of reporting rate priors (Peatman, 2019), and the definition of the two spatial structures and respective fisheries (Vincent, 2019).

2 Tagging data background

Tagging data are an important component of stock assessments carried out by SPC because it provides information regarding the fishing mortality and movement of fish among model regions. This is particularly the case for skipjack tuna, for which a very large number of fish have been tagged with a significant number of recaptures reported. Previous assessments have emphasized the importance of tagging data in influencing important model quantities, including those used in providing management advice (Hoyle et al., 2011; Rice et al., 2014; McKechnie et al., 2016a). Tag release and recovery data used in the 2019 skipjack stock assessment come from two sources: the Japanese tagging program and programs conducted by SPC. These two tagging programs are stored in different databases and thus were processed in a slightly different manner.

Despite their value, the tagging data pose several problems for inclusion in a stock assessment. For a recapture to be included in the tagging input file it must not only be caught, but also reported. In addition, these reported tags must have relevant information available so that they can be assigned to a recapture fishery and model time-step. Non-reporting of recaptures is undesirable, but can be addressed to some extent by tag reporting rate parameters. These parameters can be estimated within the stock assessment model in conjunction with analyses of tag seeding experiments (Peatman, 2019). However, reported tags that lack information necessary to attribute them to a recapture category within that release event are an additional obstacle to overcome. The minimal information required is the recapture time-step (generally - year and quarter), location (at the assessment-region-scale), and recapture gear (e.g. purse seine vs. longline).

The procedure for producing tagging data for stock assessments carried out by SPC involves the extraction and filtering of data, including assignment of tag recaptures to fisheries defined in the stock assessment model, and the subsequent formatting of data for the software MULTIFAN-CL. A significant aspect of the process involves attempting to correct the number of releases downwards to account for tag shedding, tag-induced mortality and the prevalence of unusable tag recaptures (those with missing information that prevents them from being assigned to recapture fisheries), all of which lead to fisheries mortality estimates being biased low if left unmodified. For this reason, attempts have been made to correct for "usability" of tags in previous stock assessments (Berger et al., 2014; McKechnie et al., 2016a).

The full set of procedures followed to create the tagging data files for use in MULTIFAN-CL were:

1. Extraction and filtering of release/recapture data.
2. Correction of releases for base tagging-induced mortality and additional tagging event mortality.
3. Correction for tag shedding.
4. Correction for tag recaptures that are unusable in a stock assessment (missing information such as recapture fishery).
5. Consideration of grouping of fisheries/tagging programs for tag recaptures and reporting rates.
6. Construction of tag reporting rate priors from tag seeding experiments.

The methods presented by Berger et al. (2014) to calculate the additional tagging event mortality above the base mortality estimates were conducted with additional release events. We direct readers to Berger et al. (2014) for further details of the modelling approaches utilized to produce these correction factors, but will provide a brief summary below. An updated estimate of tag shedding was conducted incorporating additional tags from the Pacific Tuna Tagging Program (PTTP) and is presented in Section 2.6. The construction of tag reporting rate priors (Table 3) is outlined in Peatman (2019). We will not discuss this analysis but rather we discuss the assumed values used for the fisheries in the assessment model that were not estimated by that analysis.

2.1 The tagging process

Over the course of a tagging program, one or more tagging cruises can occur in a year, with the cruise usually targeting a certain geographic area for tagging fish. The cruise may last for a substantial period of time (often several months) with tagging occurring when schools of fish are encountered - either free-school or on fish aggregation devices (FADs). A "tag school" is defined as a discrete period of tagging activity on a school of fish, or FAD, during which time tagging is relatively continuous and no transit of the tagging vessel is undertaken. Often a tag school will relate to a daily tagging event on a specific aggregation of fish, but it is common to have tagging of two or more tag schools in a day if transit occurs between periods of tagging activity, and further schools of fish are encountered after the original school is left, or lost.

While tagging data are often assigned to tag schools, the unit of tagging data that is the focus of MULTIFAN-CL is a "tagging event", which is all tagged fish aggregated to the level of tagging program, assessment region and time-step (typically year-quarter for pelagic species in the WCPO). Generally this will include data aggregated over numerous tag schools, and potentially multiple tagging cruises if more than one cruise occurs in that region and model time-step. If an individual tagging cruise crosses a stock assessment region boundary, or extends over the boundary of a model time-step, then that cruise will contribute to more than one tagging event in the assessment.

2.2 Tagging programs with data available

Skipjack tagging data held by SPC are the result of several discrete tagging programs; the Skipjack Survey and Assessment Program (SSAP; 1977–1982), the Regional Tuna Tagging Project (RTTP; 1989–1992) and the PTTP (2006–ongoing). These programs are typically restricted to the tropical area of the WCPO - Regions 5–8 of the stock assessment (Figure 1). Further tagging programs that are available but are not used in the skipjack stock assessment (due to the low numbers or absence of skipjack tagged) include the Coral Sea bigeye tuna tagging project (Evans et al., 2008) and the Hawaiian tagging project (Adam et al., 2002). Additional data are available for the ongoing Japanese tagging program (JPTP), but these data are not held by SPC and updated datasets are provided just prior to each stock assessment. Due to numerous differences between these data and those from programs held by SPC, they are processed separately, and the methods used for the JPTP are presented in detail below.

2.3 Overview of 2019 Japanese tagging data and methods

Japanese scientists of the National Research Institute of Far Seas Fisheries have maintained an extremely valuable long-term tagging program for tropical and temperate tunas (JPTP) which has run since the 1960's and is ongoing. The data obtained through the program are particularly valuable for skipjack tuna stock assessments in the WCPO due to wide temporal and spatial coverage and numerous recaptured tags reported.

There are several aspects of the Japanese tagging program data that require special handling, including: the database of the program is not directly accessible to SPC, original data formatting which has specific definitions of important fields such as recapture flag and gear, and lengths of fish at release are unavailable for much of the duration of the program. For those reasons, the procedure of processing raw data into a usable format for MULTIFAN-CL is carried out in a way specific to the JPTP data.

JPTP data for the 2019 skipjack stock assessment were updated from 2016 and the outline of the filtering processes applied to the JPTP data is presented in Figure 2, which mostly filtered out duplicate records in release and recapture, any tags for other species, and all tags without reliable date or location.

Within JPTP records prepared for the 2019 stock assessment, lack of information on length at release in the early portion of the program was an issue. This problem was also mentioned in the 2016 stock assessment (Figure 3; McKechnie et al., 2016a). Categories of methods other than "Measured length" are as follows: "Estimated length" (estimated by recorders, but the method used for the estimation is unknown), "Unknown" (whether these were estimated or measured is unknown), and "No FL data" (no fork length data, i.e., blank data). MULTIFAN-CL requires releases to be in a format of number of releases by length bin, thus data without a release length cannot be included in the assessment. In the 2016 skipjack stock assessment, difficulties in recreating the 2014 tag file, which included Japanese tags that were lacking release lengths, resulted in these data being excluded from the assessment. Therefore, methods that can assign a fork length at release for these missing records would increase the available number of records in the assessment model. The method that yielded what were considered the most reasonable estimates of release lengths was to randomly sample from the body length compositions obtained from the available "Measured FL" data (See Section 2.4 for details).

The records in the Japanese tagging database (Figure 3), prior to 1988 were relatively few as the data input into the database for the period was not fully completed. Figure 4 shows the proportion of effective tags released that were recaptured in all time periods, after one quarter of mixing, and after 2 quarters of mixing from 1989 to 2018. The locations of tag recaptures with greater than 91 days of mixing from the JPTP are presented in Figures 5 and 6, and the release positions of recaptured tags in each region are shown in Figure 7.

2.4 Trials to estimate individual release lengths

Several methods of estimating FLs at release where no information existed in the historical data were compared. Although these alternative methods were not used in the 2019 stock assessment, it is worth documenting the methods conducted, which could contribute to future improvements. To test the validity of these methods, we applied them to the data with "Measured FL" records. By using records with known lengths at release, a comparison of the estimated release FL could be conducted for the various methods used.

2.4.1 Interpolation by Japanese logbook

The first approach used to estimate FL at release was interpolation based on the approximate weight obtained from Japanese pole-and-line logbooks in the same "region" on the same day. These logbooks contain fishery locations ($1° \times 1°$), daily catch of skipjack and an approximate weight of caught individuals for each vessel. Definition of the "same region" was determined by defining a maximum difference (in degrees) in latitude and longitude between the data and the Japanese logbook. The finest scale was within 1° in both latitude and longitude. But if the data corresponding to the same region were not found at this scale, the scale was increased by 1° incrementally up to 5°. If data were not found within 5° then the entry was not given any FL and that entry would be excluded from the assessment. After finding corresponding data, approximate weight and catch of skipjack were extracted for all vessels available. Then, a catch-weighted average of the approximate weight was calculated and converted to FL based on the length-weight relationship, $W = 0.0113 \times FL^{3.16}$, where W is weight in grams and FL is fork length in centimeters (Kawasaki, 1952). This interpolated FL was then applied to all tags that were released in this "region". By looking at comparisons between "Measured FL" (true values) and "Estimated FL" (interpolated by this method; Figure 8), length estimated by the logbook interpolation tended to derive larger FL than "Measured FL", which led to the conclusion that this method is not suitable for estimating lengths.

2.4.2 Interpolation by body length composition from the same research cruise

The second approach was the interpolation of alternative lengths by using length composition data obtained by research vessels (R/V). The tagging cruises are mainly conducted by R/Vs and length composition data are often collected on the same day of the cruise as tagging. In this approach, the mean length and randomly sampled length records were both tested as options to use in cases of missing values. The data estimated from mean length had a narrower size distribution compared to the measured length. Additionally, the distribution for the mean length method resulted in multiple "modes" of more prevalent lengths above 50 cm. However, lengths from randomly sampling the measured lengths on the same day were more consistent with "Measured FL" (Figure 9). Subsequently, this method was applied to the data without released length records (Figure 10). Using this method, the imputed lengths indicated more fish in larger size bins than the measured FL. This resulted in a different distribution compared to the measured FL, so we raise the possibility that this method may over/underestimate the prevalence of large and small release lengths respectively.

2.4.3 Interpolation by body length composition from the same cruise with size selection preference

The third approach aimed to improve the second approach that gave extremely high or low lengths compared to the true values. We attempted to correct the shortcomings of the second method by comparing the measured FL for tagged skipjack to the body length composition measured on the same cruise. The comparison of these two length measurements indicated that some preferences may have existed to tag and release small fish from those that were available (Figure 11). Such preferences were corrected by applying a sampling function when drawing the length at release from the measured body size composition of the same vessel. The sampling function was calculated by comparing the proportion in each 2 cm bin of "Measured FL" to the length compositions collected on the same cruise. Subsequently, spikes were removed by adjusting length bins of 24 cm, 26 cm, 28 cm, 80 cm and 84 cm to values that were consistent with the other estimated proportions, to values of 5, 5, 5, 1.4 and 1.4 respectively (left panel in Figure 12), which gave us a function representing the proportion in each length bin. The final sampling function was produced by smoothing with a Loess curve and replacing negative values with 0 (right panel in Figure 12). Tag release lengths were sampled from body size composition in the same location on the same date (if not available, in the same quarter and cells of degree 1 up to 5) based on the assumption that the sampling function represented the preference of taggers for selection of certain sized fish. The resulting overall distribution of estimated release lengths did not appear unreasonable (Figure 13); however, investigation of the distributions of the predicted length by each cell indicated substantial differences from tags with measured release lengths (Figure 14). We therefore concluded that this method did not improve the issues raised in the second approach. This was due to the small sample sizes of the length composition data (Figure 15). As the sample size was small and not might not represent the entire size distribution present, the correction function was not effective in properly estimating a FL that corresponded well with the measured FL.

2.4.4 Sampling of release length from measured FL

Given the problems associated with the other three methods presented above, release lengths sampled from existing "Measured FL" tag releases were assigned to those with missing information or designated as "Estimated FL". This resulted in a distribution very similar to the measured release lengths of tagged fish and was ultimately used to create the tag file used in the 2019 skipjack stock assessment (Figure 16).

We compared several methods of estimating the FL for those data with no reliable release or recaptured FL; we concluded that random sampling of FL from all tags with measured fork length at release was the best approach available for the 2019 skipjack stock assessment. The method randomly samples with a set seed so that the tag file produced in the future can replicate the tag file created in 2019 exactly. The final method used is simple, but the conclusion to use this method resulted from consideration of various other methods which produced unrealistic outcomes. This document serves as a valuable reference for estimation of length by combining research and fishery data and can provide insight for future analysis. The simple sampling of measured release lengths could be improved by ensuring that the length at release is less than or equal to the measured length at recapture, if available. Alternatively, if a growth curve for skipjack is available, the release length could be back-calculated from available recapture lengths. The inclusion of tags from the JPTP that do not have a release length provide valuable information to the stock assessment and is an improvement from the 2016 stock assessment.

2.5 Extraction of data and the occurrence of "unusable" tags

SPC-held data are stored in two databases; the RTTP and SSAP data are held together in a historical database on the SPC network, and the PTTP is held in a live, private web-based database that continues to be updated as tag releases and recoveries occur. The software for extracting data from SPC databases (catch, effort, size composition and tagging; Long, 1994), known as MUFDAGER, is used to extract, aggregate, and correctly format input files for MULTIFAN-CL (known as the .frq and .tag files). The process it uses for the tagging data is displayed graphically in Figures 17 and 18 and is briefly summarized as follows:

1. Make temporary copies of the two SPC-held tagging databases (step [a]; Figure 17).
2. Perform separate SQL queries (one each for releases and recaptures, and separately for PTTP and SSAP/RTTP) that extract the appropriate data and perform some filtering, for example removing releases without locational data (step [b]; Figure 17).
3. Undertake further filtering of data using FoxPro scripts to remove data that cannot be assigned correctly to model release events or recapture categories (step [c]; Figure 17).
4. Aggregate all usable data to categories required by MULTIFAN-CL and assign recaptures to stock assessment model-defined fisheries (step [c]; Figure 17).

The methods used in creation of the 2016 skipjack stock assessment tagging file were followed when making the 2019 tag file. This involved two separate versions of each SQL query performed within R for each of the tagging databases (Figure 17). One is identical to that used by MUFDAGER and is only executed to ensure the output matches the MUFDAGER tagging file (to prevent occurrences such as mismatches in data extractions if fisheries were changed, or new recaptures were added to the live database). The second query (step [d]; Figure 17) is identical to the first but relaxes the conditions of the filtering for those that can be assigned to MULTIFAN-CL's required recapture categories. In other words, the second query includes tag recaptures that are missing recapture locations, dates, or the fishing gear by which they were recaptured and come from valid release events. The basic premise of correcting for this usability is to calculate the ratio of usable recaptures relative to total recaptures at the most appropriate scale. (i.e., the number of recaptures taken straight from the tagging file produced by MUFDAGER relative to recaptures from the second query with additional processing in R). The associated releases for the recaptures are adjusted by this ratio (step [e]; Figure 17) so that the observed recapture rate more accurately reflects the recapture rate occurring in practice. Further corrections for tag shedding and tag-induced mortality are also applied to the releases (step [f]; Figure 17). The specifics of this entire process are detailed in McKechnie et al. (2016b). We highlight the difference between the 2016 and 2019 assessment in terms of the correction factors applied.

2.6 Estimation of tag shedding rate

Tag shedding is an important aspect of mark-recapture data analysis that if not accounted for can result in biased estimates of fishing mortality and other population dynamics parameters. During tagging cruises conducted by SPC as part of the RTTP and PTTP, a number of fish were double tagged with a tag on each side of the fish. The methods and tagging technique are described in Hampton (1997) for the RTTP and were similar for the PTTP. A total of 481 bigeye tuna, 7760 skipjack tuna, and 1977 yellowfin tuna were tagged in the RTTP of which 77 bigeye tuna, 695 skipjack tuna, and 218 yellowfin tuna were recovered. From the PTTP, 11 bigeye tuna, 682 skipjack tuna and 456 yellowfin tuna were released with double tags of which 6 bigeye tuna, 138 skipjack tuna, and 59 yellowfin tuna were recaptured. For fish with only a single tag at recapture, a comparison of whether the first or the second tag remained on the fish did not indicate that one was more prone to shedding than the other.

From these double tagged fish, one can determine the rate of shedding by comparing the number of fish that were recaptured with only a single tag to those with both remaining. A simple tag shedding model (Hampton, 1997) was used that defines the probability (Q) of a tag being retained after release as:

$$Q = 1 - \rho \tag{1}$$

where ρ is the immediate type-1 shedding rate. This parameter can be estimated from the double tagging experiment based on the assumption that all tags not immediately shed have identical shedding probabilities that are independent of the status of the companion tag. The probabilities that both tags (P_2), one tag (P_1), or neither tag (P_0) are retained, given the assumption of independence can be calculated as:

$$\begin{aligned} P_2 &= Q^2 \\ P_1 &= 2 \times Q \times (1 - Q) \\ P_0 &= (1 - Q)^2. \end{aligned} \tag{2}$$

If the number of tags that are recaptured with two tags is defined as m and the number of tags recaptured with a single tag is n, then the instantaneous shedding rate (ρ) can be estimated by minimizing the likelihood equation:

$$L = -m \times ln\left(\frac{P_2}{1 - P_0}\right) - n \times ln\left(\frac{P_1}{1 - P_0}\right) \tag{3}$$

The model was fit to data pooled across species and tagging program. The model estimated the instantaneous tag shedding to be 0.0697. This was a higher rate than the value presented in Hampton (1997) and used in the 2016 stock assessment of 0.058. The difference between the value in Hampton (1997) and that estimated here can be attributed to the addition of more samples and the difference in tag shedding equation used. This analysis did not include the chronic shedding of tags of the previous analysis, which would explain the higher estimate of the instantaneous tag shedding.

Additional models that separated species and tagging program were also fit to the data but did not provide a significantly improved fit to the data to warrant the additional parameters as indicated by a likelihood ratio test (p $>$ 0.10). Similarly, a likelihood ratio test for the model that estimated a chronic tag shedding rate per year suggested that the simpler model with only the instantaneous tag shedding model was preferred (p $>$ 0.10). Additionally, MULTIFAN-CL does not have the capability to account for the chronic shedding of tags within the model, thus it is appropriate to use the model with only the instantaneous tag shedding.

2.7 Estimation of tagger effects

The impacts of tagging conditions, over and above a base rate of tagging-induced mortality, were estimated by Berger et al. (2014). An identical analysis to estimate these tagger effects was conducted for the 2019 skipjack stock assessment that included the recent tag release events. For a detailed description of the methods conducted for the analysis, we point the reader to Berger et al. (2014), but will briefly describe the methods and results.

A generalized linear model (GLM) was used to evaluate which explanatory variables significantly influenced recovery rates and to estimate the mean effect (change in recovery rate) that resulted from the observed conditions. Only the analysis for the PTTP was updated as the tag returns for the RTTP have remained unchanged since the last assessment. For the PTTP, the response variable (y_i) was the number of tags recovered from the number of tags released in that event (n_i), and thus was assumed to be binomially distributed. The probability of recapture was modeled with a logit link and the following factors: *Event*: the temporal and spatially unique tagging event during which the fish was tagged and released (i.e., discrete tagging episodes on individual schools of tuna); *Tagger*: the individual that tagged the fish; *Condition*: the overall health or condition of the fish upon release, categorized as "good", "bleeding", "dropped on deck", "eye damage", "hit side of boat", "long time on hook", "mouth damage", "shark bite", and "tail damage"; *Quality*: the quality of tag placement categorized by "good", "badly placed", or "too slow"; *Station*: the location of the tagging station on the vessel categorized as "port bow", "starboard bow", "midships", or "stern"; and *Length*: the length of fish measured in the cradle before release. The model with all variables included was chosen by AIC and the backward removal selection process. The equation for that model is given by

$$
\begin{aligned}
y_i &\sim \text{Binomial}(n_i, p_i) \\
log\left(\frac{p_i}{1-p_i}\right) &= \beta_0 + \beta_{Condition[i]} + \beta_{Event[i]} + \beta_{Tagger[i]} + \beta_{Quality[i]} + \beta_{Station[i]} + f(Length_{[i]})
\end{aligned}
\tag{4}
$$

where i is an aggregated group of fish for each unique set of categorical levels across the explanatory variables in the model and the function of length is a spline with 4 nodes. The correction factor was calculated as the ratio of the estimated return rate given the actual conditions relative to the predicted return proportion under optimal conditions (e.g., condition and quality as "good"). These correction factors were then applied at the scale used by MULTIFAN-CL as the weighted mean by number of tags released over schools within an MULTIFAN-CL- defined tagging event (i.e., year quarter and region of release). The distribution of the estimated correction factors for the RTTP and PTTP used in the 2019 skipjack stock assessment is presented in Figure 19.

The median correction factor for the specific tagging program was assumed for release events where there was no estimate of tagging-induced mortality (insufficient data for estimation, lack of covariate data to fit models etc., see Berger et al., 2014 for further details). The median correction factors for the RTTP and PTTP were assumed for the SSAP and JPTP tagging events, respectively, as no estimates were available for either of these programs.

2.8 Temporal cut-off for including release events

The inclusion of tag release events within the stock assessment are only warranted when there has been sufficient time for the recaptured tags to be processed and entered into the SPC database. For bigeye tuna and yellowfin tuna, tag releases that occur within 2 years prior to the end of the assessment model are typically excluded. For the skipjack assessment in 2014 the cutoff date was the second quarter of 2012 and in the last assessment the cutoff date was the end of 2014 (i.e., only excluded releases in the last year). In preliminary tests of the model for the 2019 skipjack assessment, tag releases through the end of 2017 were included. However, this resulted in an unrealistic spike in recruitment in the last year of the assessment due to the very low ($\sim 1\%$) return rate for one of the release events in 2017 (Table 1). It was discovered that there were a few hundred tag recaptures by multiple CCMs that had not yet been returned or entered into the SPC database. Efforts to remedy this problem occurred too late for the data to be included into the assessment and there still remain concerns that a large number of tags have not been returned to SPC. Therefore, this assessment excluded tag releases that were conducted by SPC prior to the end of 2016. Conversely, no such concerns regarding the return rate from the Japanese tagging program were discovered and thus tags through the end of 2017 from that program were included in the assessment (Table 1).

This difficulty in securing the returned tag data highlights the importance of the cooperation of all member countries in the WCPFC. We urge the continued advertisement, publication, and endorsement of returning tags both to SPC and Japan to the fisheries community (fishermen, canneries, etc.) by all CCMs. Specifically, tagging cruises will be conducted by SPC near Palau, Indonesia, and the Philippines in 2019. Tag returns from this area are often lower than returns from other areas and we recommend continued efforts to advertise the reward (a shirt, a hat, or US$ 10) for the return of tags with valid recapture information (date, location, and gear) within this region.

2.9 Reporting rates

The objective function of MULTIFAN-CL requires that the observed and predicted recaptures can be compared. Ideally, the tags would be assigned at the fishery level. However, typically for tropical tunas in the WCPO there is insufficient information to determine whether a tag caught by a purse seine vessel was from an associated or unassociated set. Therefore, the observed and predicted tag recaptures were aggregated over the associated and unassociated purse seine fisheries within a region and assigned to the associated fishery. The groupings and prior distributions (mean and penalty value in MULTIFAN-CL) for the 2019 skipjack tuna stock assessment are presented in Table 3. The reporting rate of the Japanese pole-and-line fisheries and longline fisheries were assumed to share a common reporting rate of tags to reduce the number of estimated parameters.

Tag seeding studies provide some information on the magnitude of tag reporting rates for some of the purse seine fisheries in the assessment (see Peatman, 2019 for how these are estimated). During the SPC Pre-assessment workshop (Pilling and Brouwer, 2019), it was noted that the reporting rates in the 2016 stock assessment model were hitting the upper bounds for some of the purse seine fisheries that were not provided informative priors (e.g., purse seine fishery in Region 5). As described in the analysis of Peatman (2019), the penalties for the reporting rates in the 2019 assessment were higher than those in the 2016 skipjack stock assessment due to a change in the formulation of the penalty calculation and the addition of more tag seeding experiments for purse seine fisheries in Regions 6, 7, and 8. In preliminary model development, these updated penalties assisted in preventing the reporting rate parameters for these purse seine fisheries from hitting the upper bound, but other problematic fisheries were identified.

The purse seine fisheries in Region 5 (F13 SA-ALL-5 and F14 SU-ALL-5) and the miscellaneous Philippines and Indonesian fisheries (F10 Z-PH-5 and F11 Z-ID-5) were identified as estimating reporting rates on the upper bounds. Therefore, the reporting rate estimated by combining the tag seeding data in Regions 7 and 8 for the PTTP was used as the mean of the prior distribution for these fisheries in the PTTP. Given the uncertainty and extrapolation to a fishery different from that which the prior was calculated for, the MULTIFAN-CL variance penalty was specified at half that originally estimated. Similarly, the mean reporting rate estimated for the RTTP purse seine in Regions 6, 7, and 8 (Hampton, 1997), was also assumed as the mean for the purse seine fisheries in Region 5 for the RTTP and for all purse seine fisheries during the SSAP. The MULTIFAN-CL variance penalty of the prior for the purse seine fisheries in the SSAP and in Region 5 of the RTTP was specified at half of the estimated value from Hampton (1997) due to the uncertainty in using these values. Two additional reporting rate parameters were identified as hitting the upper bound during preliminary investigation of the assessment: the domestic Philippine fishery for the RTTP and the purse seine fishery in Region 5 for the JPTP. The mean for these two fisheries remained at 0.5 like the other uninformed reporting rate parameters, but a small penalty of 20 was applied to these fisheries in an attempt to prevent them from hitting the upper bound. These small penalties still allowed the model the freedom to estimate any parameter value but places a penalty when attempting to estimate reporting rates higher than the expected reporting rate.

2.10 Summary and comparison to 2016 tag file

The 2019 skipjack tagging file is comprised of 329,812 effective releases from 269 tag release events, reduced from 568,389 raw releases before corrections for tagging mortality, tag shedding and usability are accounted for. Tagging occurred in all stock assessment regions, with nearly 40% of tags released in Region 6 (Figures 20 and 22). There were observations of movement between most combinations of release and recapture regions, but for the majority of cases tagged fish were primarily re-caught in the same region from which they were released (Figure 21). The most prevalent observed movement was from Region 4 to Region 7, but there were relatively few recaptures from releases in Region 4 (Figure 21).

Preliminary stock assessment models had difficulty converging and estimating model parameters when the tags that were missing release lengths were included in the model. It was discovered that the 8 region model with all Japanese tagging data resulted in many small tag release events; this in turn greatly increased the computation demands of MULTIFAN-CL and resulted in model instability. Therefore, tag events with less than 100 tags released were excluded from the tag file, which removed a large number of tagging events in which there were no tag recaptures. These tag releases were then adjusted using the methods described above for usability (Section 2.5), a tag shedding rate of 0.0697 (Section 2.6), a tagging mortality of 0.07 (Berger et al., 2014), and tagger effects (Section 2.7). The proportion of tags returned from these adjusted release numbers for all returns, after one quarter mixing, and after two quarters of mixing are presented for the Japanese and SPC tagging programs separately (Figures 4 and 23)

Compared to the 2016 tag file, an additional 65 release events were added to the tagging file, which contributed an extra 52,250 effective releases and 3,136 usable recaptures. Of the additional tag release events included in the tagging file, 18 were from tagging that took place since the cutoff used in the 2016 assessment, primarily from the JPTP (Table 1). A detailed description of the number of releases, recaptures, and effective correction factors by tagging program are shown in Table 2. The location of recaptures from the JPTP with a time at liberty of at least 91 days are shown in Figure 5 and tag recaptures from all tagging programs that were recaptured greater than 1,000 nautical miles from release location are shown by region of release in Figure 24 and program of release in Figure 25.

3 Length-weight relationship

The length-weight relationship for skipjack tuna is an important factor in the assessment model. In combination with the growth curve, the length-weight relationship converts the predicted number of fish caught into weight, which is the unit of reported harvest for the fisheries. The length-weight relationship was recalculated because the previous value used in the 2016 could not be recreated. This analysis gathered length and weight data from three sources: the skipjack stock assessment program (SSAP) and port sampling data available from SPC and Japanese databases. The SSAP conducted cruises from 1977 through 1980 during which fish were tagged and biological samples were collected, including measurement of length and weight of specimens (Kearney, 1983; Kleiber and Kearney, 1983). Port sampling of length and weight from individual fish in SPC databases are from completion of the SPC - FFA data collection form (SPC and FFA, 2019). Samples from the ports extend from 1996 through 2015 with the majority of length-weight samples from 2012 through 2014. Collection of length and weight information for skipjack also occurred by the Japanese commercial pole-and-line fishery and research vessels between 1953 and 2017 (Kiyofuji et al., 2019). These data were filtered to be over the assessment period starting in 1972 and for latitudes between 10°S and 10°N. These data were filtered to be in the equatorial region because this is where the majority of the skipjack tuna population is believed to reside, but we note a large portion of the total data were collected outside of this area.

The following linear regression was fit to combined data from the three sources:

$$ln(W) = a \times ln(L) + b + \epsilon \tag{5}$$

where W is weight, L is length, ϵ is the natural variation among individuals and a and b are the estimated parameters. The estimated regression parameters were bias corrected for use on the normal scale within the assessment. The b parameter does not require bias correction but the a parameter was bias corrected by the equation:

$$A = e^{a+\frac{1}{N}\times\sum r^2} \tag{6}$$

where A is the bias corrected estimate, N is the number of samples, and r is the residuals (difference between the model predicted weight and observed weight). The bias corrected estimated length-weight relationship that was used in the stock assessment was

$$W = 1.1437e^{-5} \times L^{3.1483} \tag{7}$$

The estimated bias corrected length-weight relationship and data used in the estimation are presented in Figure 26.

Data held by SPC where both the length and weight of an individual fish were measured are relatively sporadic temporally and spatially. The majority of SPC held length-weight data came from the SSAP cruises in the late 1970s, with some collection of samples in ports between 1996 and 2015. The analysis conducted above was heavily reliant on the extensive sampling conducted by the Japanese port sampling and research vessels for recent samples of length and weight. Additional sources of length-weight data such as from tag recoveries reported to SPC, observer measurement on-board purse seine vessels, and published literature (e.g., Jin et al., 2015) were investigated for inclusion in the relationship, but were ultimately excluded because they were either too variable or did not match with the relationship observed from other data sources. Continued and ongoing measurement of both length and weight for all commercially harvested species in the WCPO is recommended. Project 90 (collection of biological samples) could be used to fill this data gap and provide necessary information to the stock assessment.

When length and weight samples are measured, the fish can be in a variety of different states; live, flash frozen, or stored on ice. Experiments with bigeye (*Thunnus obesus*) showed a decrease in length of fish that had been placed in brine wells and frozen, then were subsequently thawed and measured (Schaefer and Fuller, 2006). Inclusion of a shrinkage factor was considered in the length-weight relationship but insufficient information regarding the state of fish when measured were available to conduct such analysis. Additionally, there were concerns that the conversion factor for large bigeye (between 60–140 cm) would not hold true for smaller skipjack. Investigation regarding the conversion of both length and weight measurements at different states when measured should be investigated. In addition, the state of the fish when measured should be recorded to allow the appropriate conversion of these measurements in the future.

4 Length composition data

Size data for the purse seine fishery in the WCPO are an important input into the stock assessment because its provides information on important biological processes such as growth and recruitment variability. The methods presented in Abascal et al. (2014) were repeated for the 2019 assessment with the inclusion of data through the end of 2018. A brief summary of the data and methodology are presented here.

The purpose of the preparatory analysis conducted on the length composition data was to ensure the data are representative of the size composition of the catch. There are two biases that are corrected for through the analysis:

1. the systematic bias in the grab samples traditionally collected by observers aboard purse seiners in both species composition and length frequency (Lawson, 2013); and

2. the spatial distribution of the sampling effort and catch.

Data from the observer programs that are provided to SPC's Oceanic Fisheries Program (OFP) by member countries or regional programs were corrected (both species composition and length frequency distribution) for selectivity bias by grab samples. These data were combined with the port sampling data from the US Multilateral Treaty program, which is the only source of information on size composition of the purse seine catch prior to the mid-1990's. These merged data were then filtered for skipjack tuna samples and stratified by year, quarter, $5° \times 5°$ square, and set type. Strata with less than 30 fish sampled were excluded from the analysis and the sample size per stratum was limited to a maximum of 1000 measured fish. The rescaling of the size data within each assessment model region was conducted through the following steps:

1. The length-weight relationship in Equation (7) was multiplied by the number of samples in each length bin and then divided by the total weight of the samples, which is the percent weight in each length bin.

2. Cells with no size information for each stratum of year, quarter, $5° \times 5°$ square, set type, and length bin that were within the convex hull (i.e., boundary of observed data points) were calculated by linear interpolation.

3. The weight of the catch in each stratum was multiplied by the percent weight in each length class from above to yield the weight caught in each length class for every stratum.

4. The weight caught in each length bin was summed across $5° \times 5°$ square within a region to provide the weight of the catch by length class, year, quarter, type of association, and region.

5. These weights by regional stratum were divided by the average weight of each length class to get the number of fish caught by length class in each stratum.

6. The number of fish caught by length bin stratum was then divided by the total number of fish caught by the purse seine fishery in that region stratum to give the proportion caught by length bin within the region stratum.

7. Finally, the value above was multiplied by the number of samples measured in each $5° \times 5°$ square adjusted by the proportion of catch in that square and then summed within a region.

The number and distribution of length samples from the raw SPC extracts and the adjustment factor analysis are presented for the purse seine fisheries in the 8 region model in Figures 27 to 46. There are a number of years where there are samples within the SPC database, but insufficient records were available for that strata for the adjustment factor analysis and thus were not included within the assessment. Typically, the sample sizes from the adjustment factor analysis are smaller than the raw data, with the exception of some strata where no raw data were available.

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5 Tables

Table 1: Summary of the new tagging release events and subsequent recaptures that have become available since the cutoff date of the 2016 assessment (quarter 4, 2014), and whether they are included or omitted from the 2019 assessment.

Programme	Region	Year	Qtr	Releases	Recaptures	Retained
PTTP	8	2015	3	33	0	Omitted
PTTP	8	2015	4	121	6	Included
PTTP	7	2016	3	24	0	Omitted
PTTP	8	2016	3	41	2	Omitted
PTTP	7	2016	4	9	0	Omitted
PTTP	8	2016	4	4	0	Omitted
PTTP	6	2017	3	5193	73	Omitted
PTTP	4	2017	4	51	0	Omitted
PTTP	6	2017	4	16130	4280	Omitted
PTTP	7	2017	4	4155	335	Omitted
PTTP	7	2018	3	11	0	Omitted
PTTP	8	2018	3	54	0	Omitted
JPTP	3	2015	1	1888	327	Included
JPTP	1	2015	2	479	1	Included
JPTP	2	2015	2	359	88	Included
JPTP	3	2015	2	100	3	Included
JPTP	3	2015	4	19	1	Omitted
JPTP	1	2016	1	40	0	Omitted
JPTP	3	2016	1	3701	102	Included
JPTP	1	2016	2	87	2	Omitted
JPTP	2	2016	2	260	9	Included
JPTP	3	2016	2	192	2	Included
JPTP	1	2016	3	319	3	Included
JPTP	2	2016	3	39	1	Omitted
JPTP	3	2016	3	22	0	Omitted
JPTP	1	2016	4	364	1	Included
JPTP	1	2017	1	6	0	Omitted
JPTP	3	2017	1	170	0	Included
JPTP	1	2017	2	507	43	Included
JPTP	2	2017	2	40	2	Omitted
JPTP	3	2017	2	383	3	Included

Table1– Continued from previous page

Programme	Region	Year	Qtr	Releases	Recaptures	Retained
JPTP	1	2017	3	249	6	Included
JPTP	3	2017	3	30	0	Omitted
JPTP	6	2017	3	138	0	Included
JPTP	1	2017	4	12	0	Omitted
JPTP	3	2017	4	186	0	Included
JPTP	4	2017	4	66	0	Omitted
JPTP	6	2017	4	596	0	Included
JPTP	7	2017	4	342	0	Included
JPTP	3	2018	1	420	0	Omitted
JPTP	1	2018	2	290	13	Omitted
JPTP	2	2018	2	121	4	Omitted
JPTP	3	2018	2	108	2	Omitted
JPTP	1	2018	3	140	3	Omitted
JPTP	3	2018	3	38	0	Omitted
JPTP	1	2018	4	102	0	Omitted
JPTP	3	2018	4	79	0	Omitted
JPTP	4	2018	4	14	0	Omitted
JPTP	3	2019	1	1	0	Omitted
JPTP	7	2019	1	819	0	Omitted
JPTP	8	2019	1	196	0	Omitted
JPTP	1	2019	2	23	8	Omitted

Table 2: Summary of the tagging file used in the 2019 diagnostic case model, showing the raw number of usable releases, the corrected effective number of releases, the correction ratio, and the raw and effective recapture rates by tagging program

Programme	Raw	Effective	Recaptures	Correction	Raw.rate	Eff.rate
JPTP	127353	78321	5524	0.61	0.04	0.07
PTTP	271698	136158	35432	0.50	0.13	0.26
RTTP	90667	54808	10899	0.60	0.12	0.20
SSAP	78671	60525	4237	0.77	0.05	0.07
Total	568389	329812	56092	0.58	0.10	0.17

Table 3: Reporting rate groupings and prior mean and penalties placed on each fishery for the 8 region spatial structure in the 2019 skipjack stock assessment.

Fishery	Region	SSAP Group	RTTP Group	PTTP Group	JPTP Group	SSAP Mean	RTTP Mean	PTTP Mean	JPTP Mean	SSAP Pen	RTTP Pen	PTTP Pen	JPTP Pen
F1 P-ALL-1	1	1	10	19	28	0.5	0.5	0.5	0.5	1	1	1	1
F2 S-ALL-1	1	1	10	19	28	0.5	0.5	0.5	0.5	1	1	1	1
F3 L-ALL-1	1	1	10	19	28	0.5	0.5	0.5	0.5	1	1	1	1
F4 P-ALL-2	2	1	10	19	28	0.5	0.5	0.5	0.5	1	1	1	1
F5 S-ALL-2	2	1	10	19	28	0.5	0.5	0.5	0.5	1	1	1	1
F6 L ALL 2	2	1	10	19	28	0.5	0.5	0.5	0.5	1	1	1	1
F7 P-ALL-3	3	1	10	19	28	0.5	0.5	0.5	0.5	1	1	1	1
F8 S-ALL-3	3	1	10	19	28	0.5	0.5	0.5	0.5	1	1	1	1
F9 L-ALL-3	3	1	10	19	28	0.5	0.5	0.5	0.5	1	1	1	1
F10 Z-PH-5	5	2	11	20	29	0.5	0.5	0.5	0.5	1	20	1	1
F11 Z-ID-5	5	3	12	21	30	0.5	0.5	0.5	0.5	1	1	1	1
F12 S-ID.PH-5	5	4	13	22	31	0.5	0.586	0.5604	0.5	1	122	291	1
F13 P-ALL-5	5	1	10	19	28	0.5	0.5	0.5	0.5	1	1	1	1
F14 SA-DW-5	5	5	14	23	32	0.586	0.586	0.5604	0.5	122	122	291	20
F15 SU-DW-5	5	5	14	23	32	0.586	0.586	0.5604	0.5	122	122	291	20
F16 Z-VN-5	5	6	15	24	33	0.5	0.5	0.5	0.5	1	1	1	1
F17 L-ALL-5	5	1	10	19	28	0.5	0.5	0.5	0.5	1	1	1	1
F18 P-ALL-6	6	1	10	19	28	0.5	0.5	0.5	0.5	1	1	1	1
F19 SA-ALL-6	6	7	16	25	34	0.586	0.586	0.6841	0.5	122	244	638	1
F20 SU-ALL-6	6	7	16	25	34	0.586	0.586	0.6841	0.5	122	244	638	1
F21 L-ALL-6	6	1	10	19	28	0.5	0.5	0.5	0.5	1	1	1	1
F22 P-ALL-4	4	1	10	19	28	0.5	0.5	0.5	0.5	1	1	1	1
F23 L-ALL-4	4	1	10	19	28	0.5	0.5	0.5	0.5	1	1	1	1
F24 P-ALL-7	7	1	10	19	28	0.5	0.5	0.5	0.5	1	1	1	1
F25 SA-ALL-7	7	8	17	26	35	0.586	0.586	0.5749	0.5	122	244	362	1
F26 SU-ALL-7	7	8	17	26	35	0.586	0.586	0.5749	0.5	122	244	362	1
F27 L-ALL-7	7	1	10	19	28	0.5	0.5	0.5	0.5	1	1	1	1
F28 P-ALL-8	8	1	10	19	28	0.5	0.5	0.5	0.5	1	1	1	1
F29 SA-ALL-8	8	9	18	27	36	0.586	0.586	0.5433	0.5	122	244	793	1
F30 SU-ALL-8	8	9	18	27	36	0.586	0.586	0.5433	0.5	122	244	793	1
F31 L-ALL-8	8	1	10	19	28	0.5	0.5	0.5	0.5	1	1	1	1

6 Figures

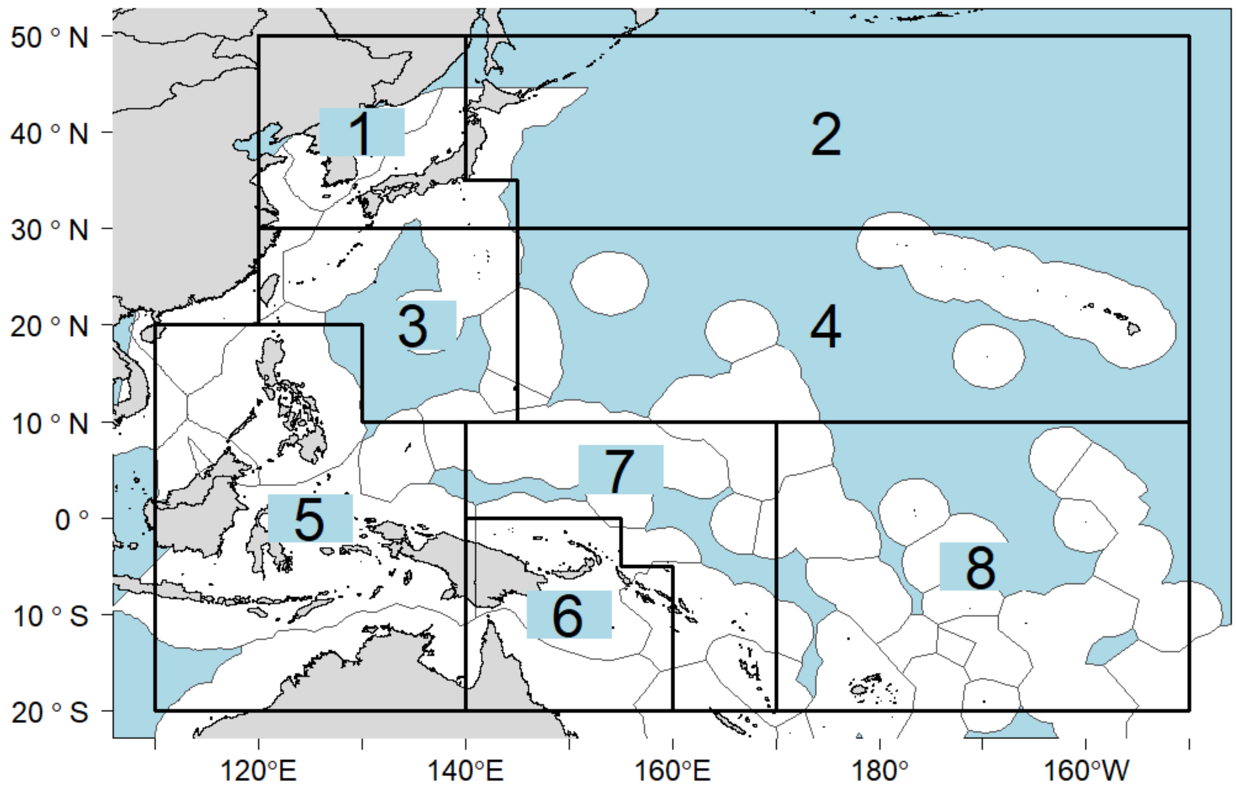


Figure 1: The geographical area covered by the stock assessment and the boundaries for the 8 region assessment model.

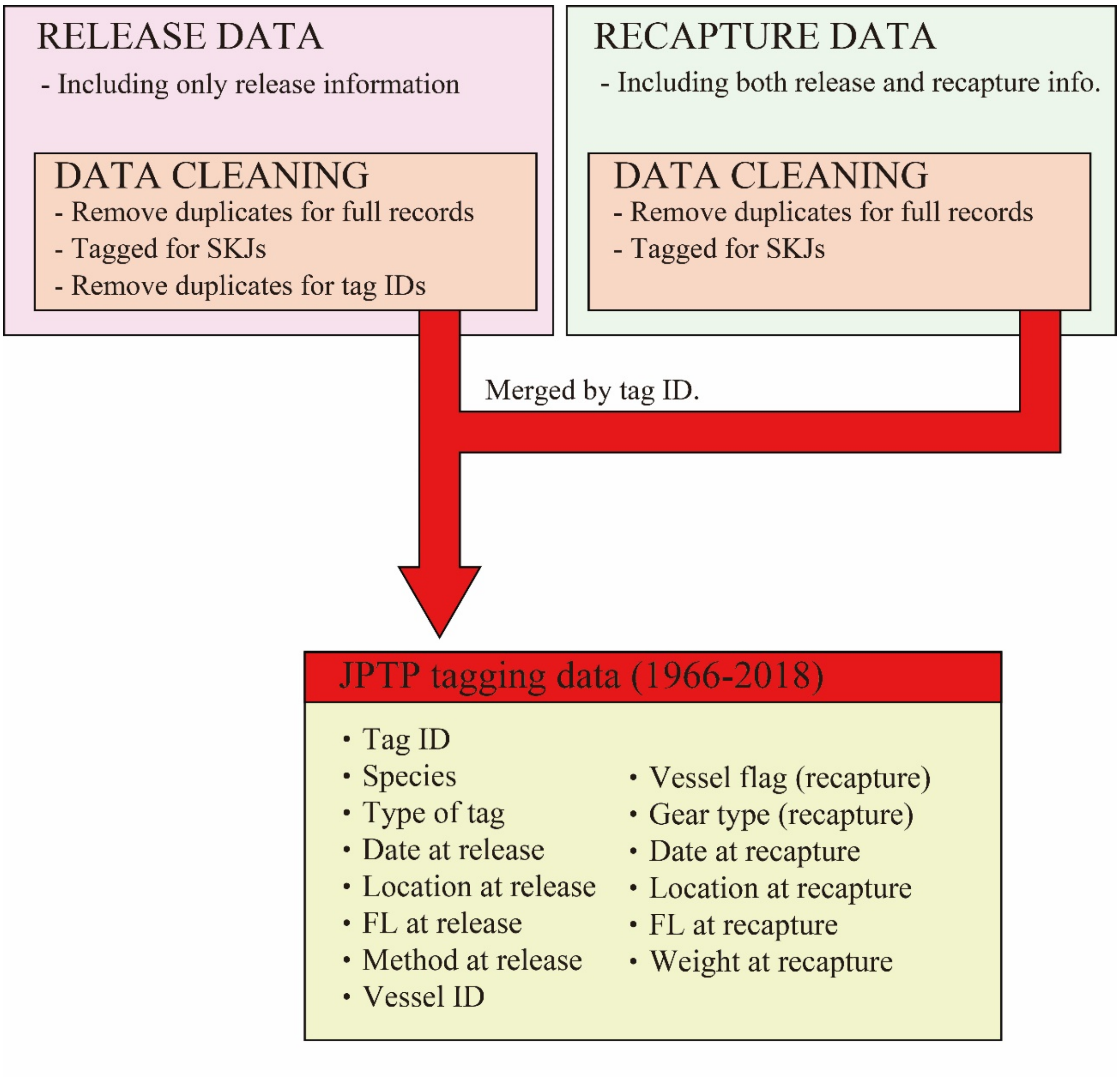


Figure 2: Diagram of the process of constructing the JPTP data component for the tagging file used in the 2019 skipjack stock assessment.

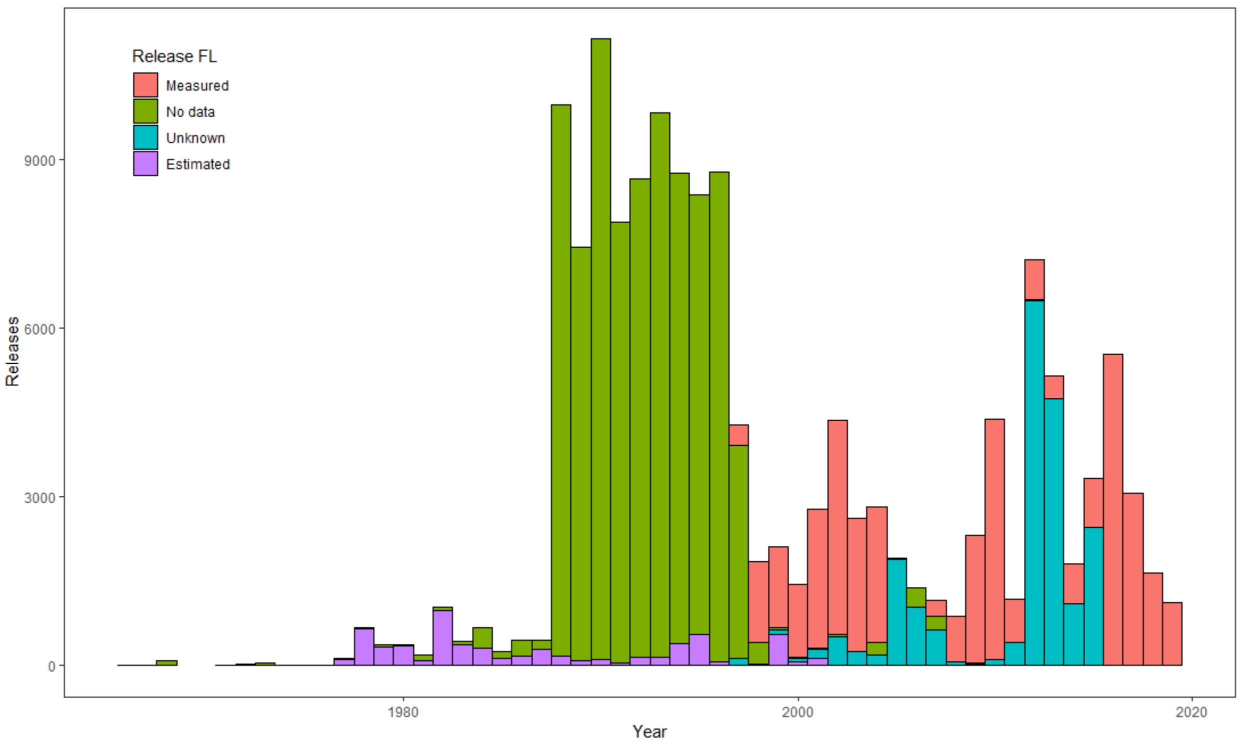


Figure 3: Number of released tagged skipjack through the research years. Each color showed the measured categories that describe how fork length were measured/estimated when recorded.

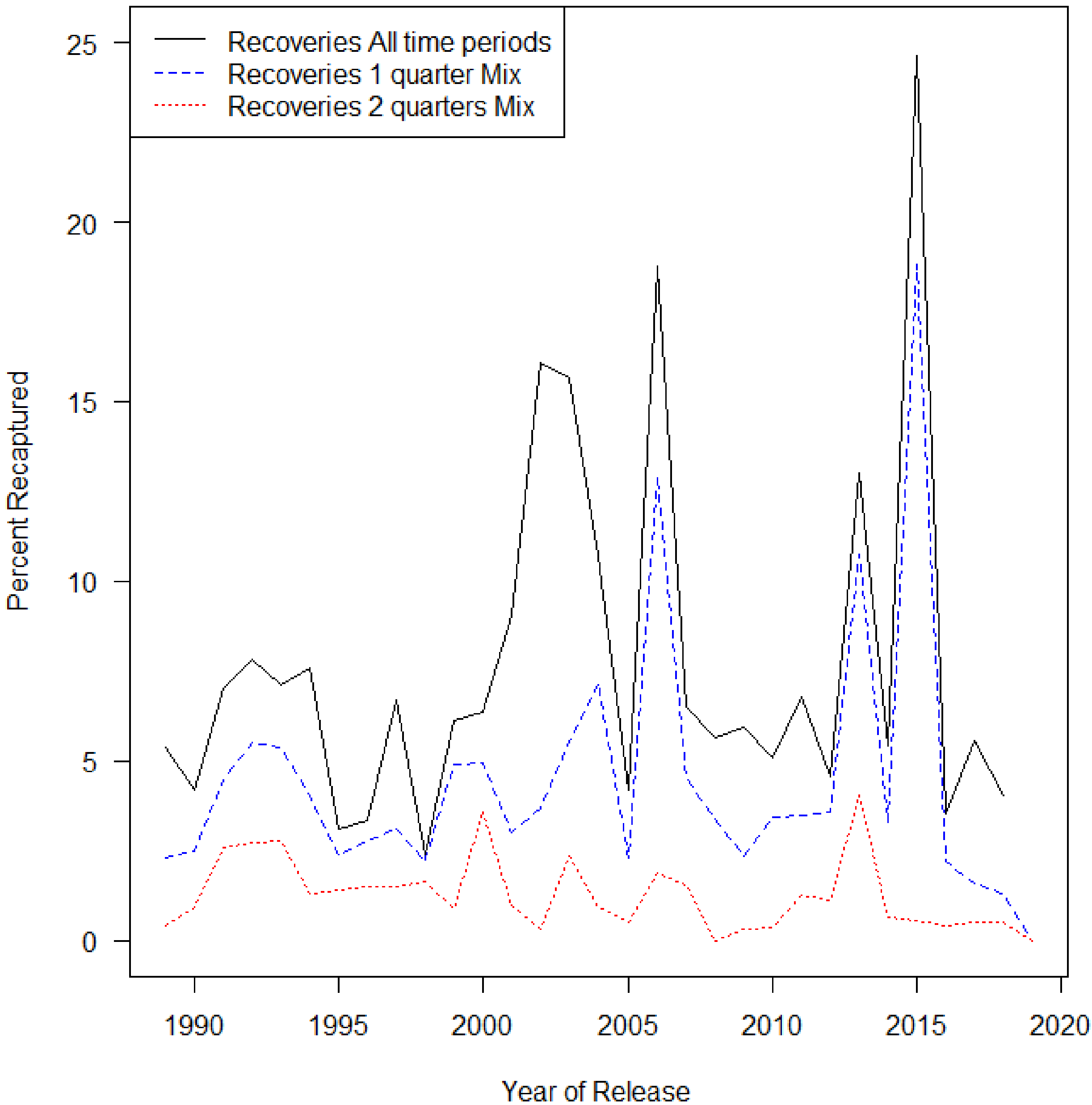


Figure 4: Percent of recaptured tags to released tags through years from 1989 to 2018 for all tags and filtered for one and two seasons of mixing for the Japanese tagging program.

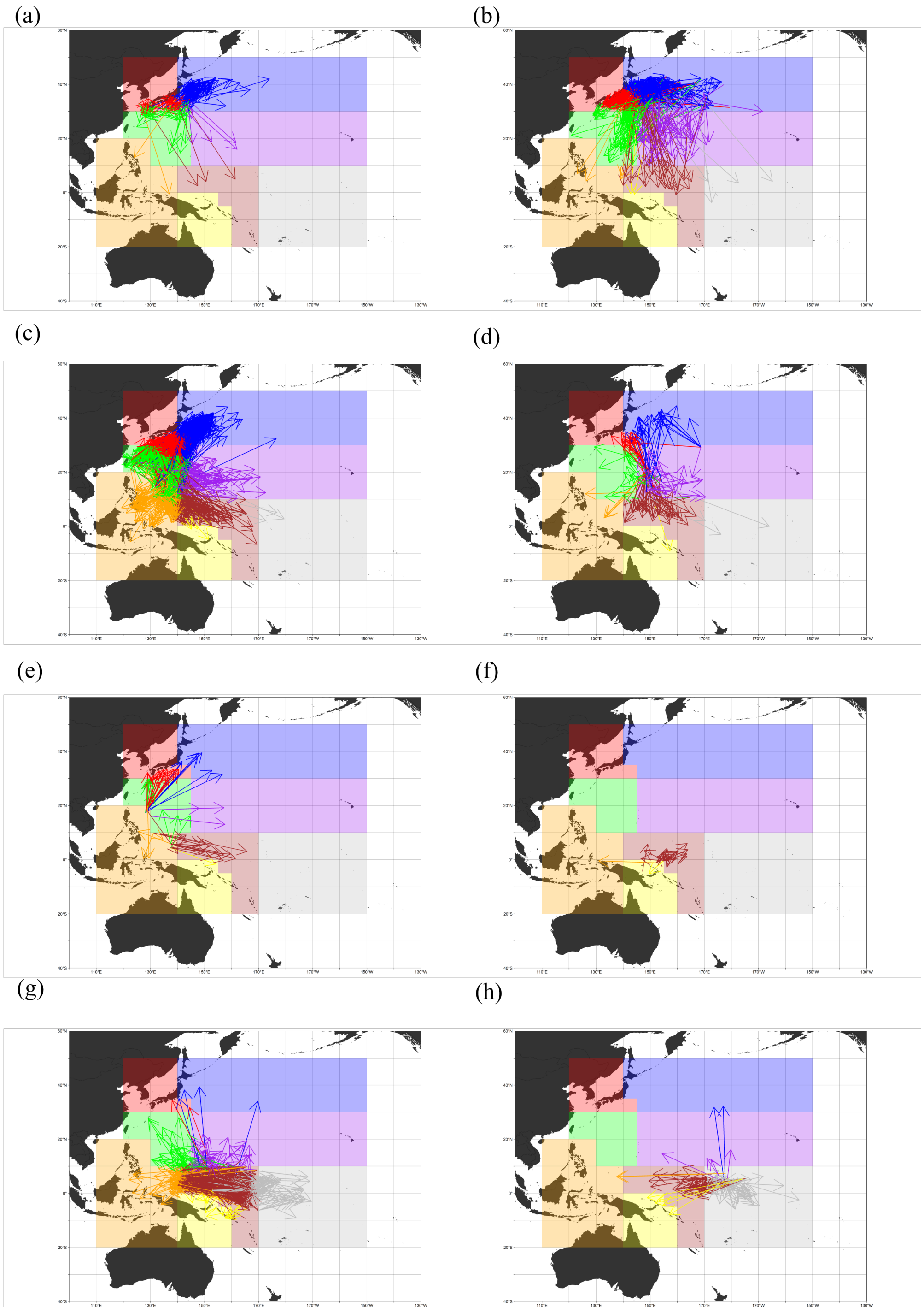


Figure 5: Plots of tag recaptures from the JPTP with greater than 91 days at liberty overlain on the 8-region definition of the stock assessment. Colored rectangles show the regions, arrows indicate the release and recapture location of individuals, and colors of the arrows correspond to the regions of recapture.

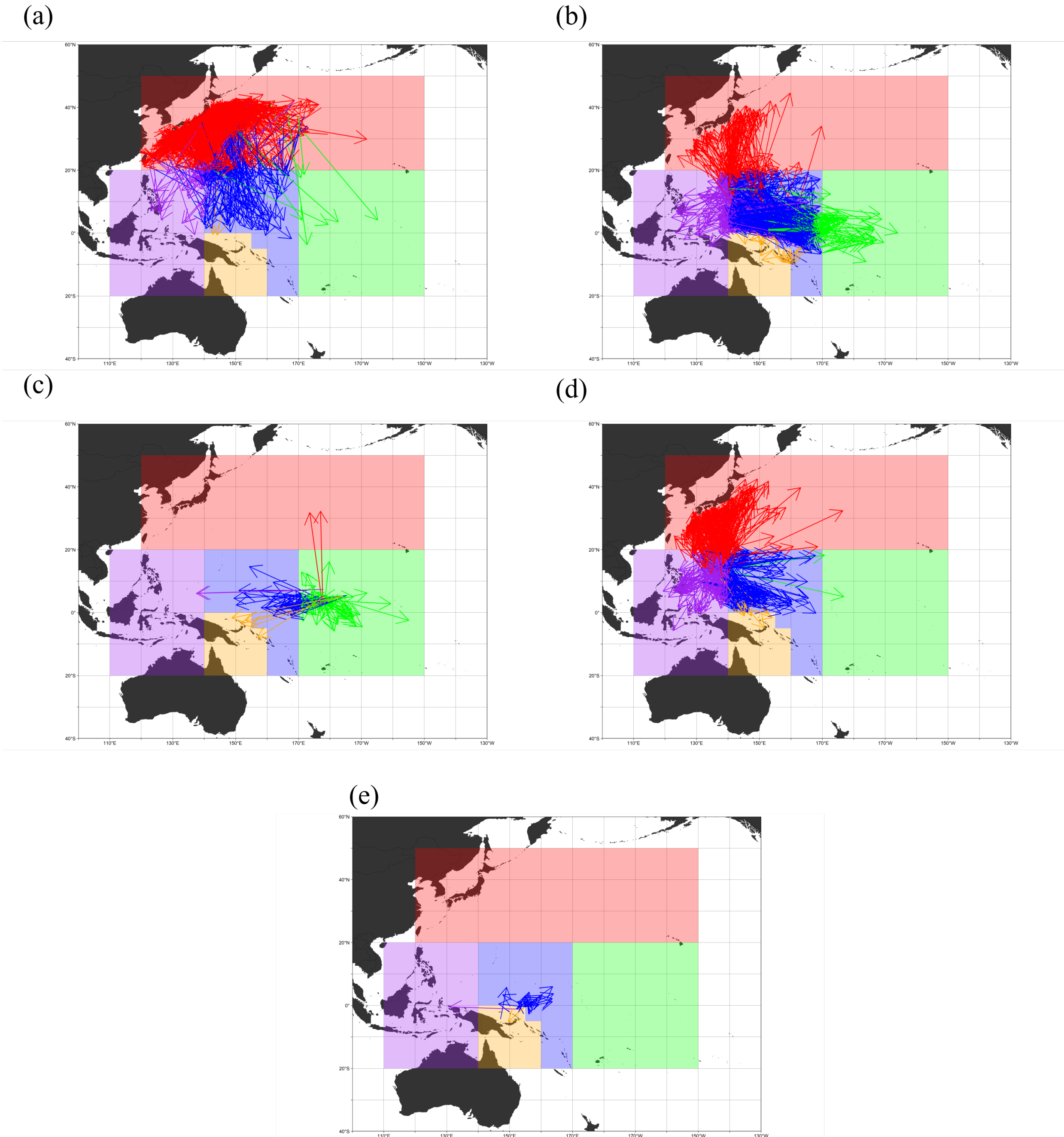
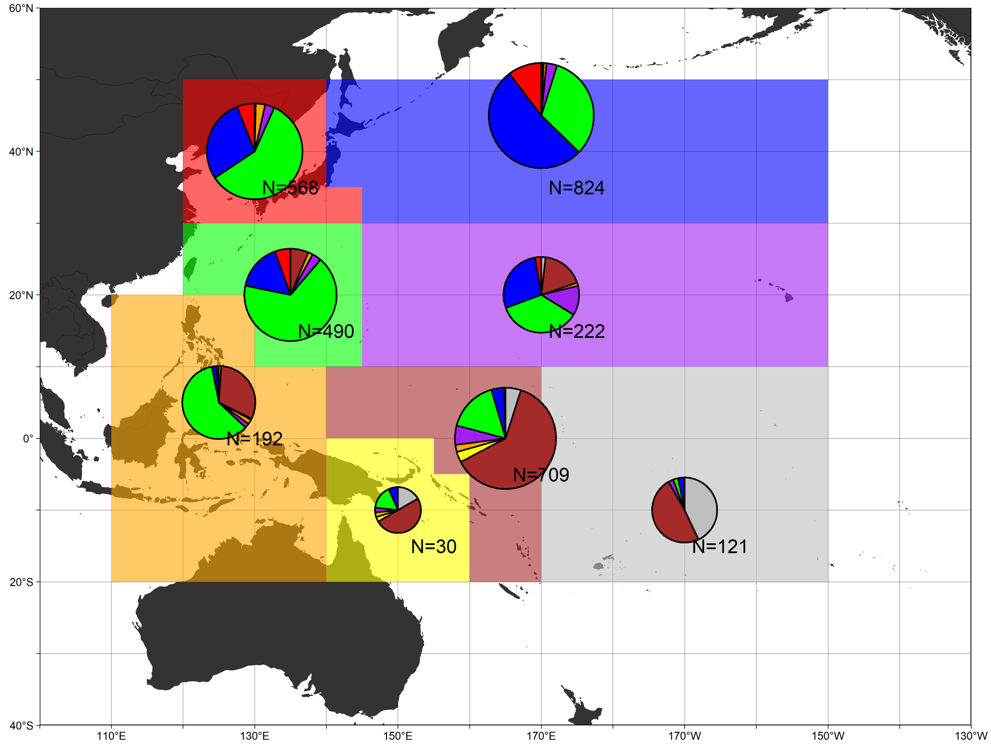
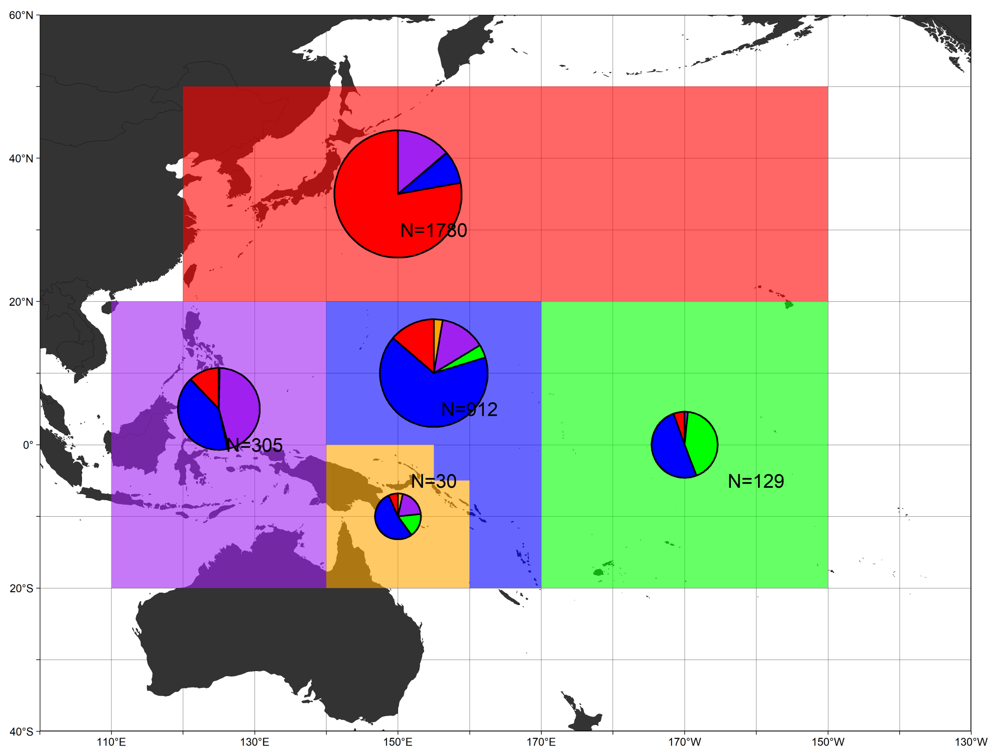


Figure 6: Plots of tag recaptures from the JPTP with greater than 91 days at liberty overlain on the 5-region definition of the stock assessment regions. Colored rectangles show the regions, arrows indicate the release and recapture location of individuals, and colors of the arrows correspond to the regions of recapture.



(a) 8 Region structure



(b) 5 Region structure

Figure 7: The number of recaptured tags and the regions where tags were originally released. The size of pie charts indicates the number of recaptures in each region, and pie chart in each region expresses the ratio of the originally released regions of the recaptured tags.

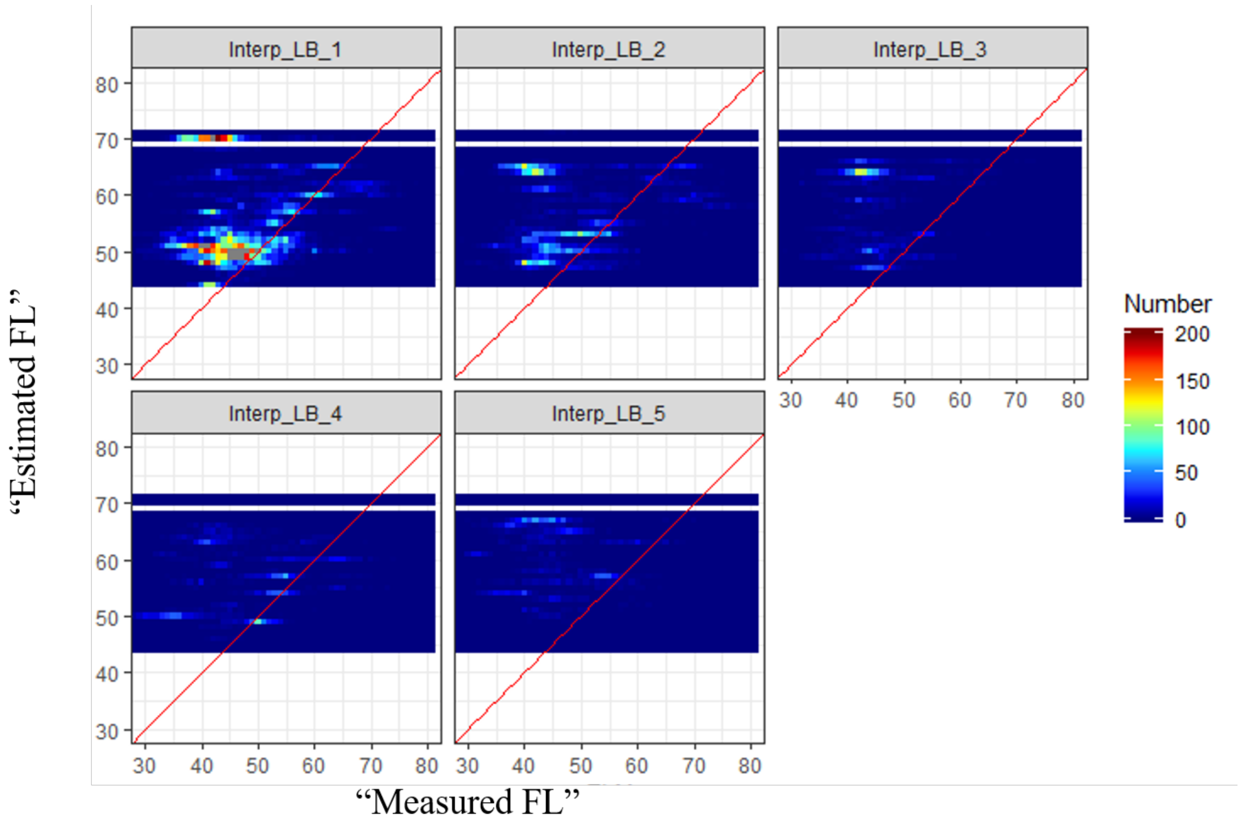


Figure 8: Comparison of the measured fork length with estimated length by interpolation method based on Japanese pole-and-line logbook. Panels indicate how the area definition from 1 to 5 degrees square influenced the estimation. For example, "Interp_LB1" is the result of the length estimation by the interpolation based on logbook with a definition for the tag data and the logbook record were in the "same region" to be within one degree square. Red lines represent the perfect match of the two lengths, which is an intuitive indicator of how well the lengths are estimated. Color tile shows the number of data in each length.

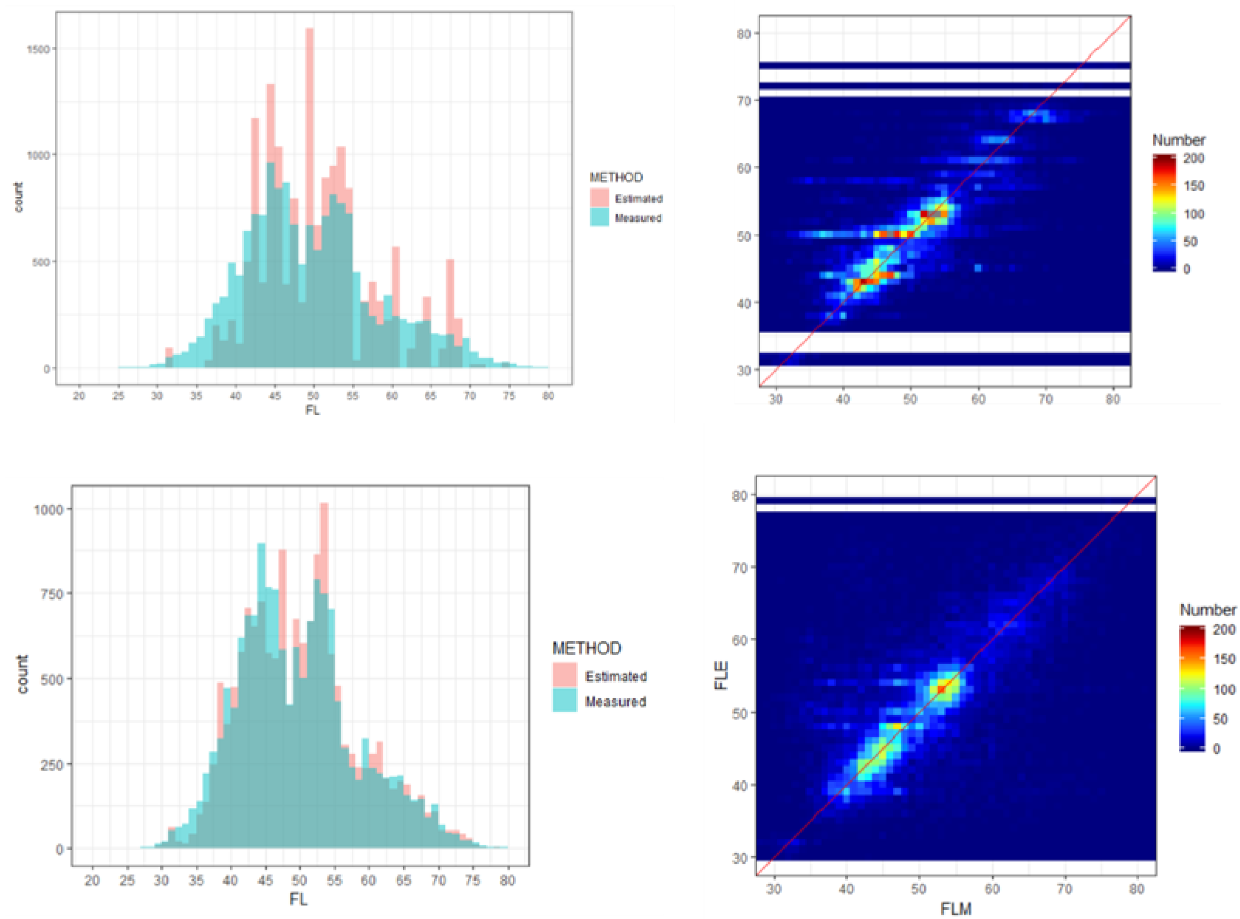


Figure 9: Comparison of the measured fork length (FLM) with estimated length (FLE) from the length composition measured in the same research cruise on the same date. Estimated lengths were calculated as average lengths from the length composition (Upper panel) and as randomly sampled from the length composition (Lower panel). Left panels show the histogram of estimated and measured body lengths, and right panels show a pair plot of the two lengths.

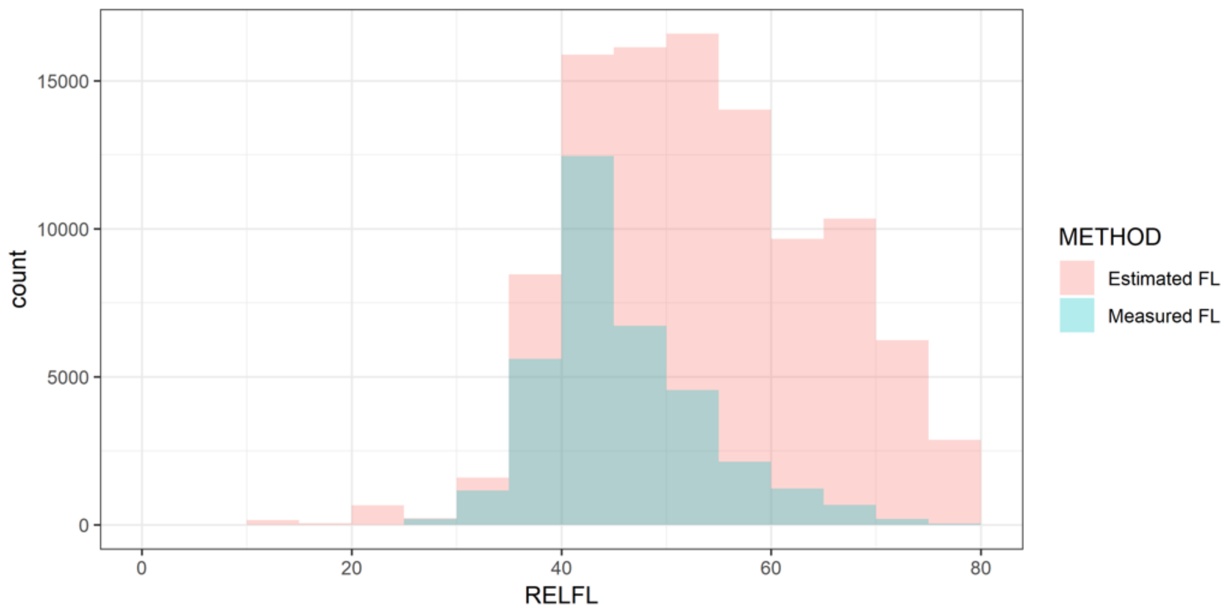


Figure 10: Comparison of the measured and estimated fork lengths (FL) for records with no length data.

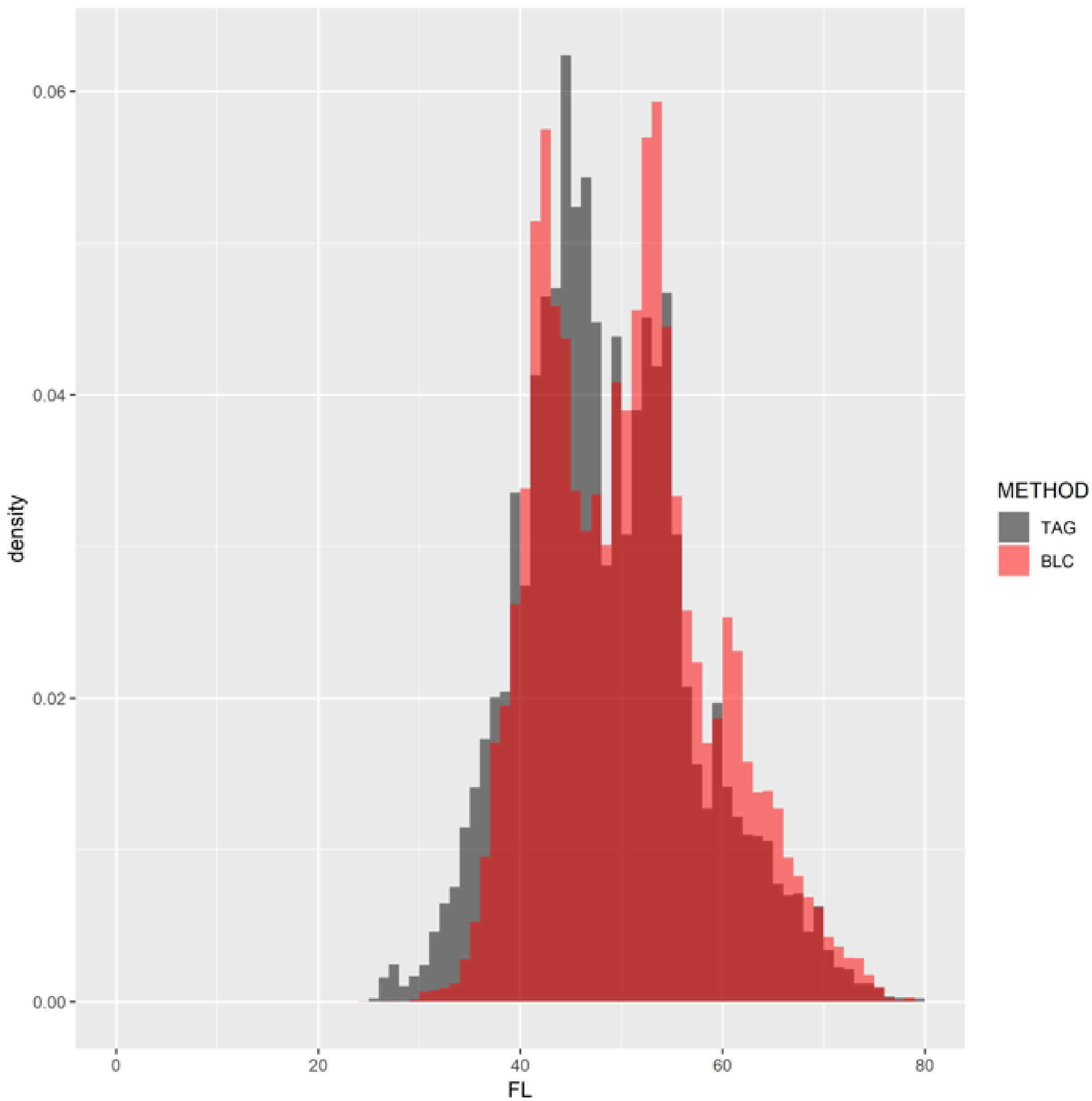


Figure 11: Length composition obtained from measured tag lengths and length composition in the same research cruise on the same date (BLC). As the number of lengths from the length composition is larger than the lengths of the released skipjack, the y scale was converted to the density to make comparison easy.

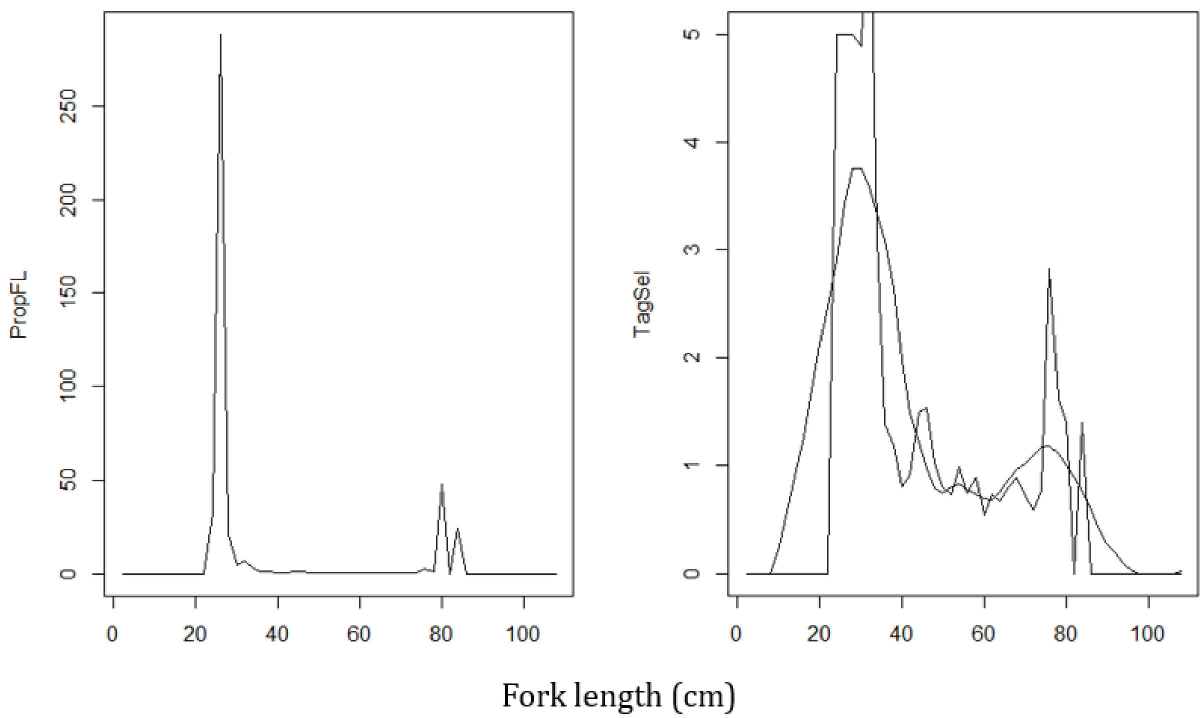


Figure 12: Proportion of measured tag lengths against body length compositions (left panel), and the sampling function after the correction of the spikes (right panel).

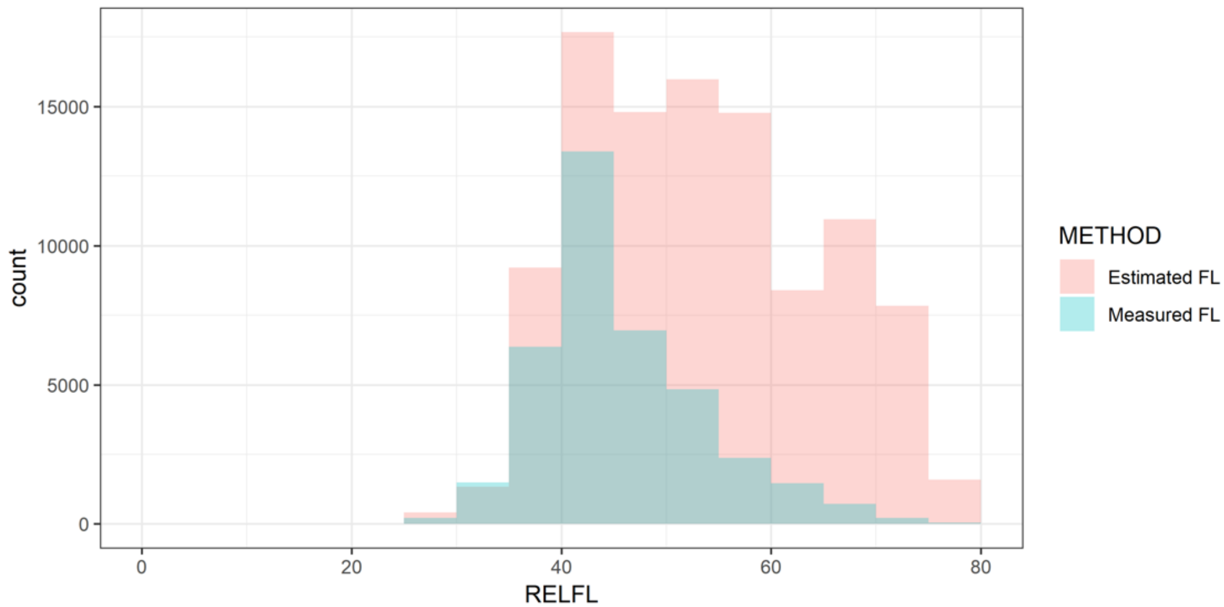


Figure 13: Comparison of the measured and estimated fork lengths (FL) obtained by length composition measured in the same research cruise filtered by a size preference function.

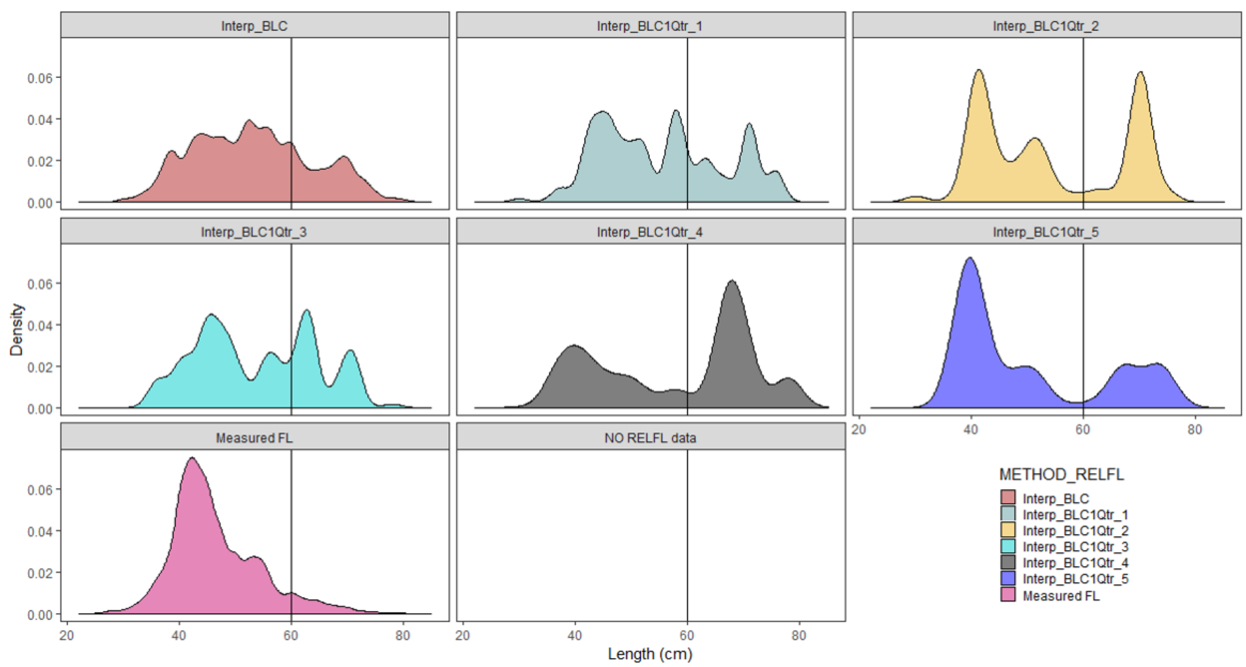


Figure 14: Comparison of the distribution of length at release for tags with measured FL and those sampled values from measured body sizes on R/V on the same day and location (Interp_BC) or with in the same area in a quarter by 1 °cell (Interp_BC1Qrt_1) up to 5 °.

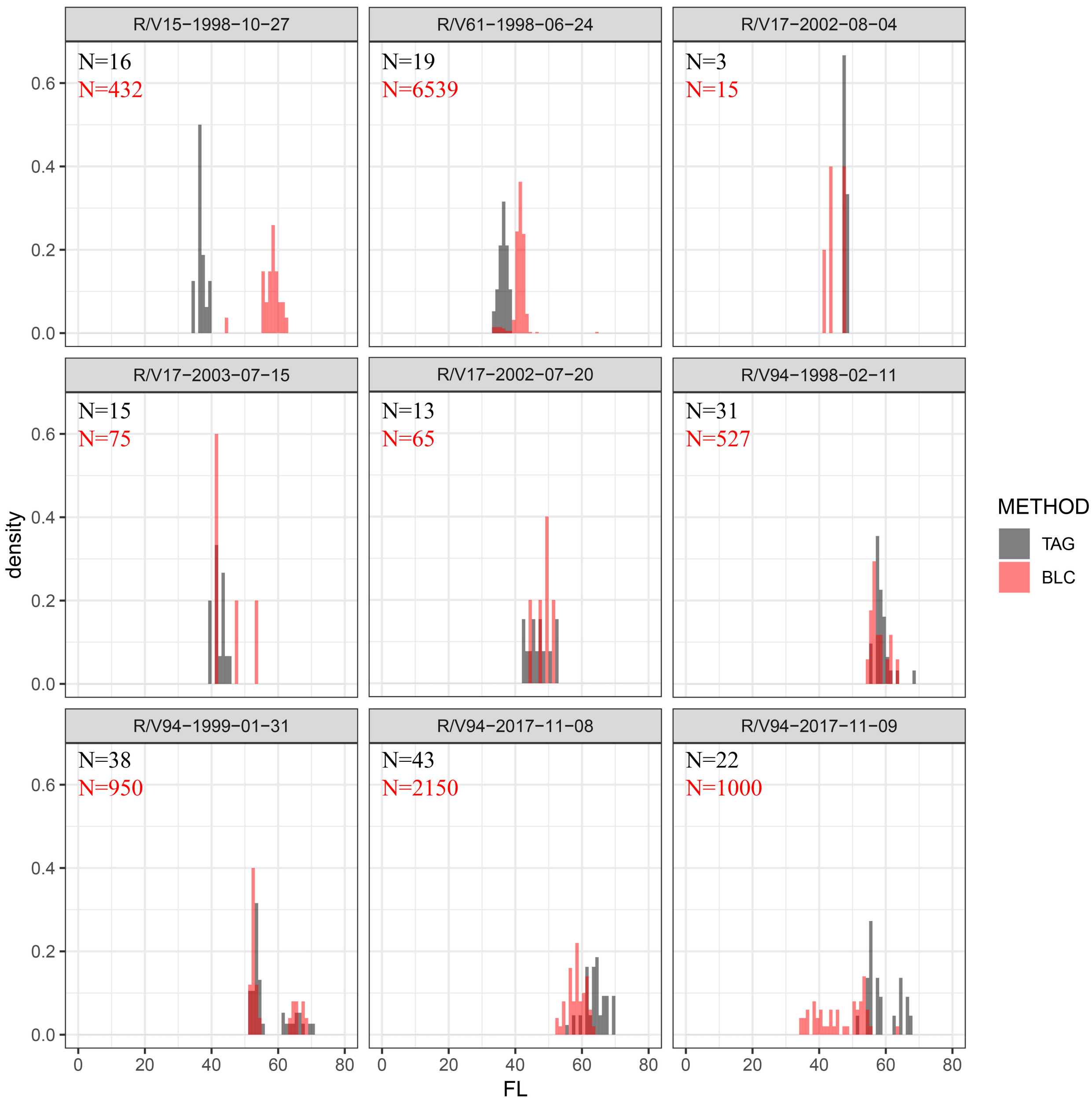


Figure 15: Examples of body length compositions of the measured length at tag release (TAG in gray) compared to the lengths of fish measured in the same trip (BLC in red)i.e., in the same research vessel on the same date. The number at the top left is the number of tags released in gray and number of lengths measured in red.

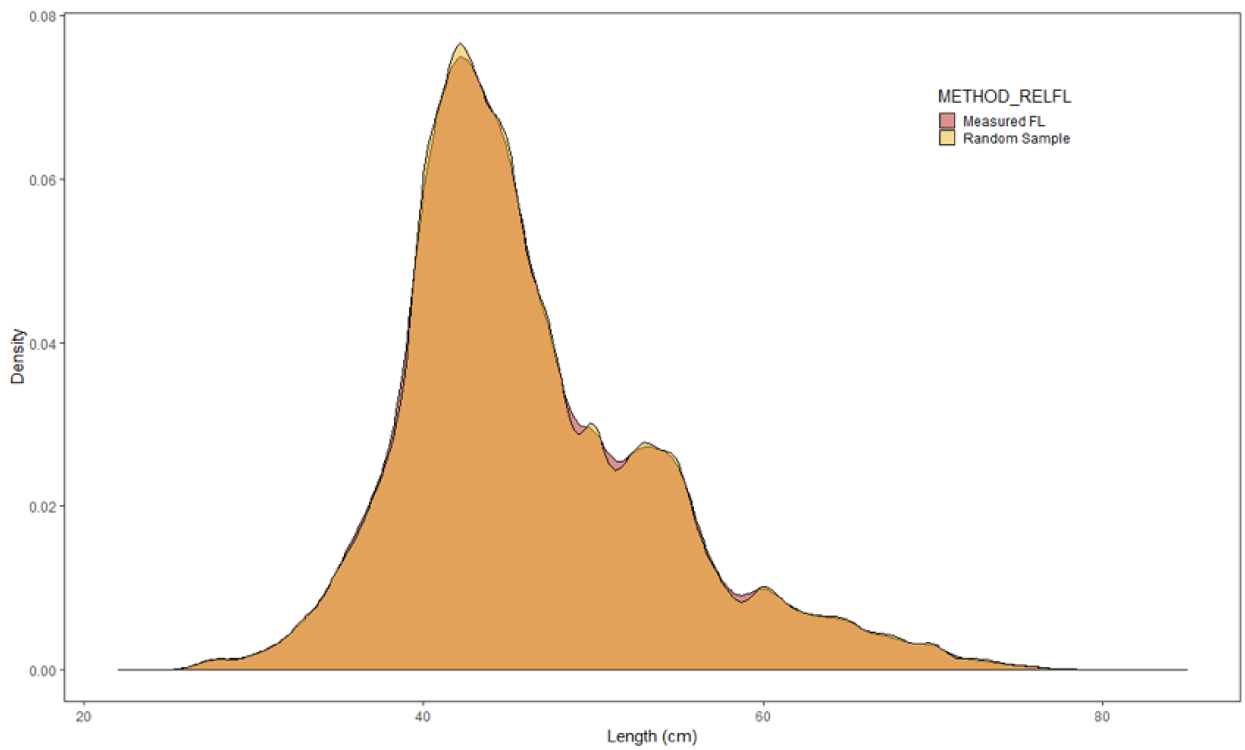


Figure 16: Distribution of the fork length at release of measured tags from the JPTP compared to the distribution of tags assigned a fork length at release from sub-sampling.

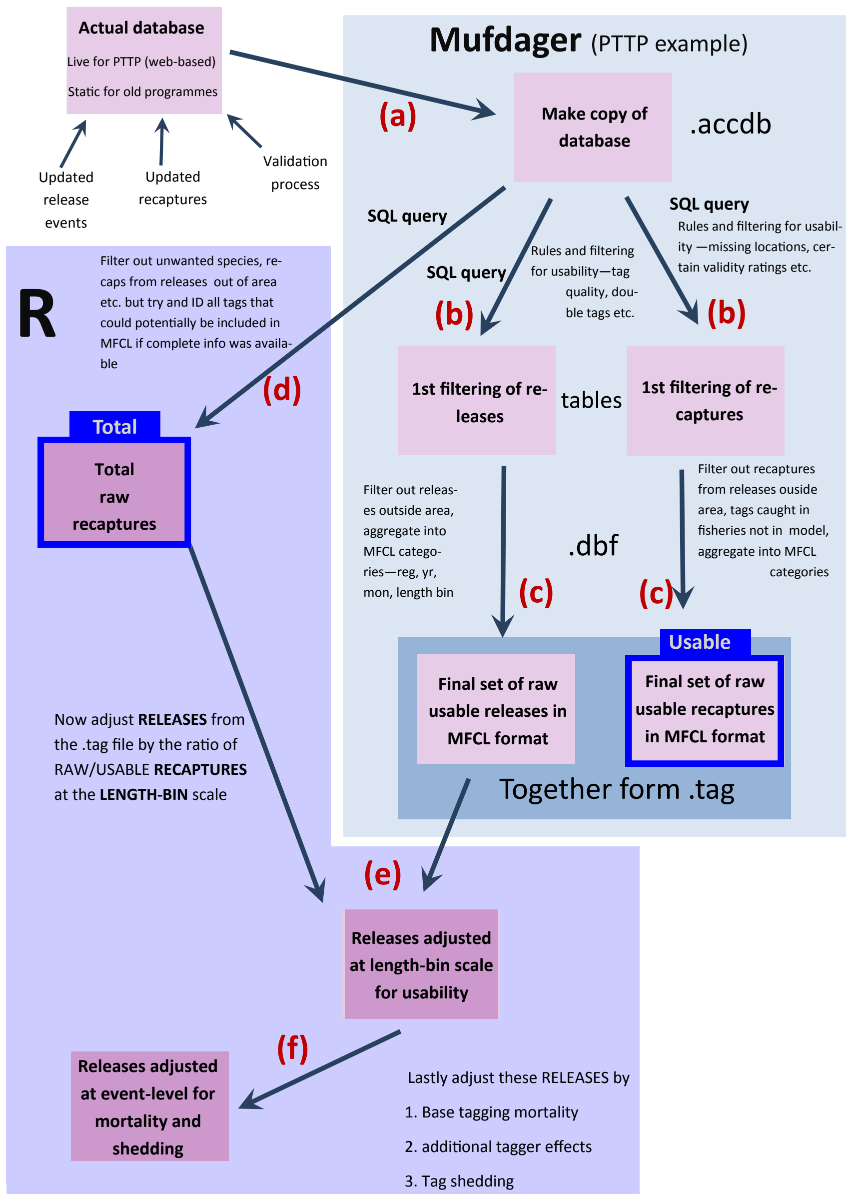


Figure 17: Diagram showing the process by which MUFDAGER produces a tagging file that includes the number of usable recaptures, how R is used to simultaneously calculated the total number of recaptures for a release event, and how the ratio of these sets of recaptures is used to adjust the number of releases. The usability ratio is the ratio of "usable" and "total" recaptures (blue boxes) at the length bin scale within release event.

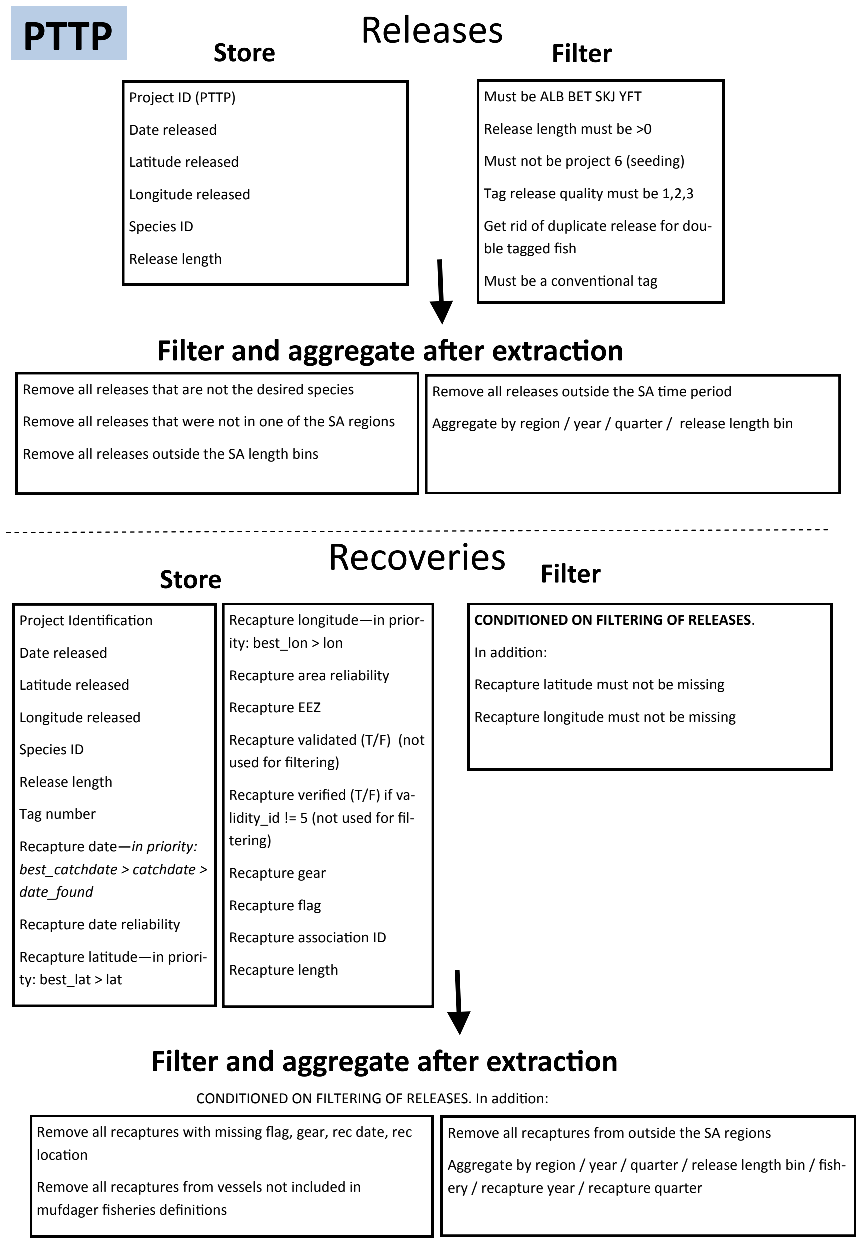


Figure 18: Diagram depicting the process by which MUFDAGER extracts data using SQL queries for releases and recaptures and then performs further filtering and aggregation using FoxPro code. Shown is an example for the PTTP but the process is very similar for the SSAP/RTTP.

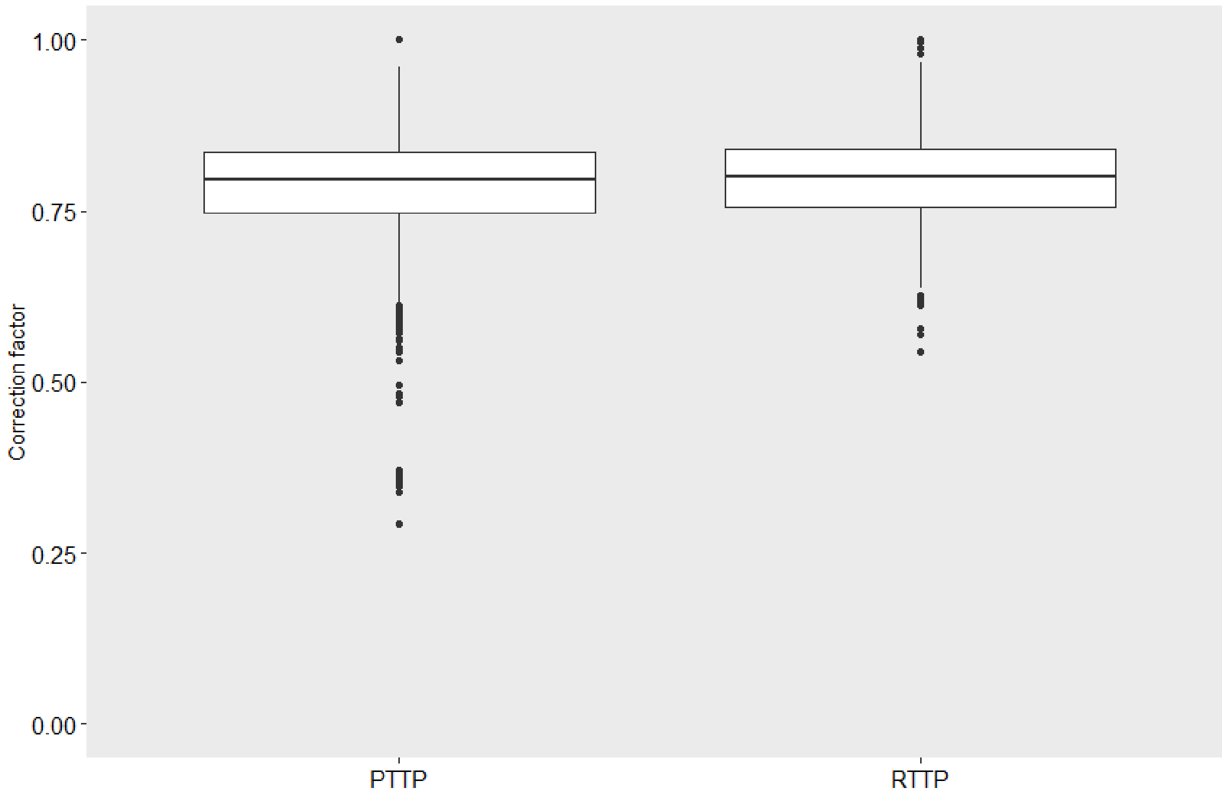


Figure 19: Boxplots showing the range of estimated correction factors that were applied to tag release events to adjust the number of tag releases for the influence of tagger effects on shedding and tag-related mortality for the RTTP and PTTP.

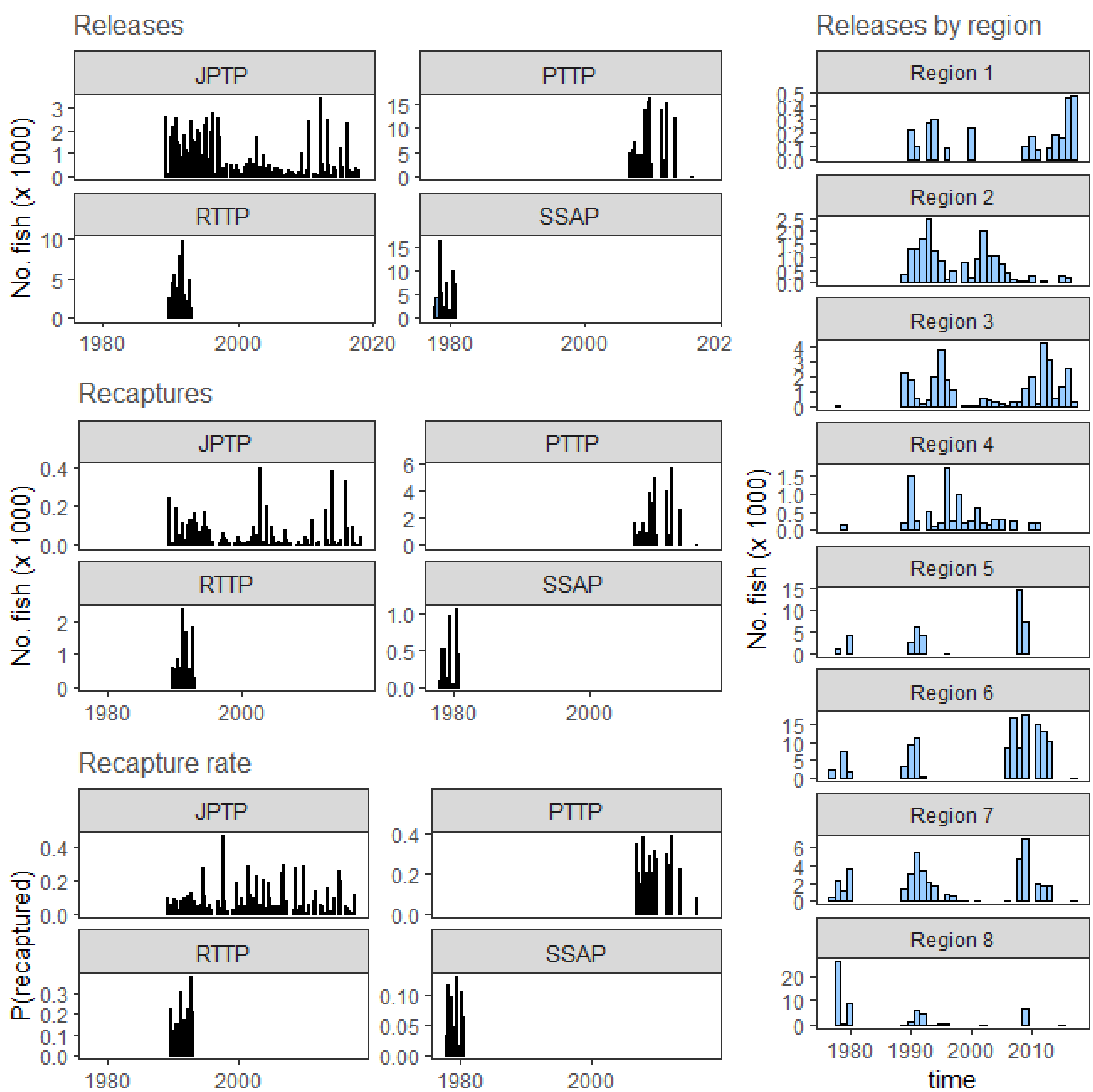


Figure 20: Summary of the .tag file used in the reference case of the 2019 stock assessment of skipjack tuna by tagging program, region and year.

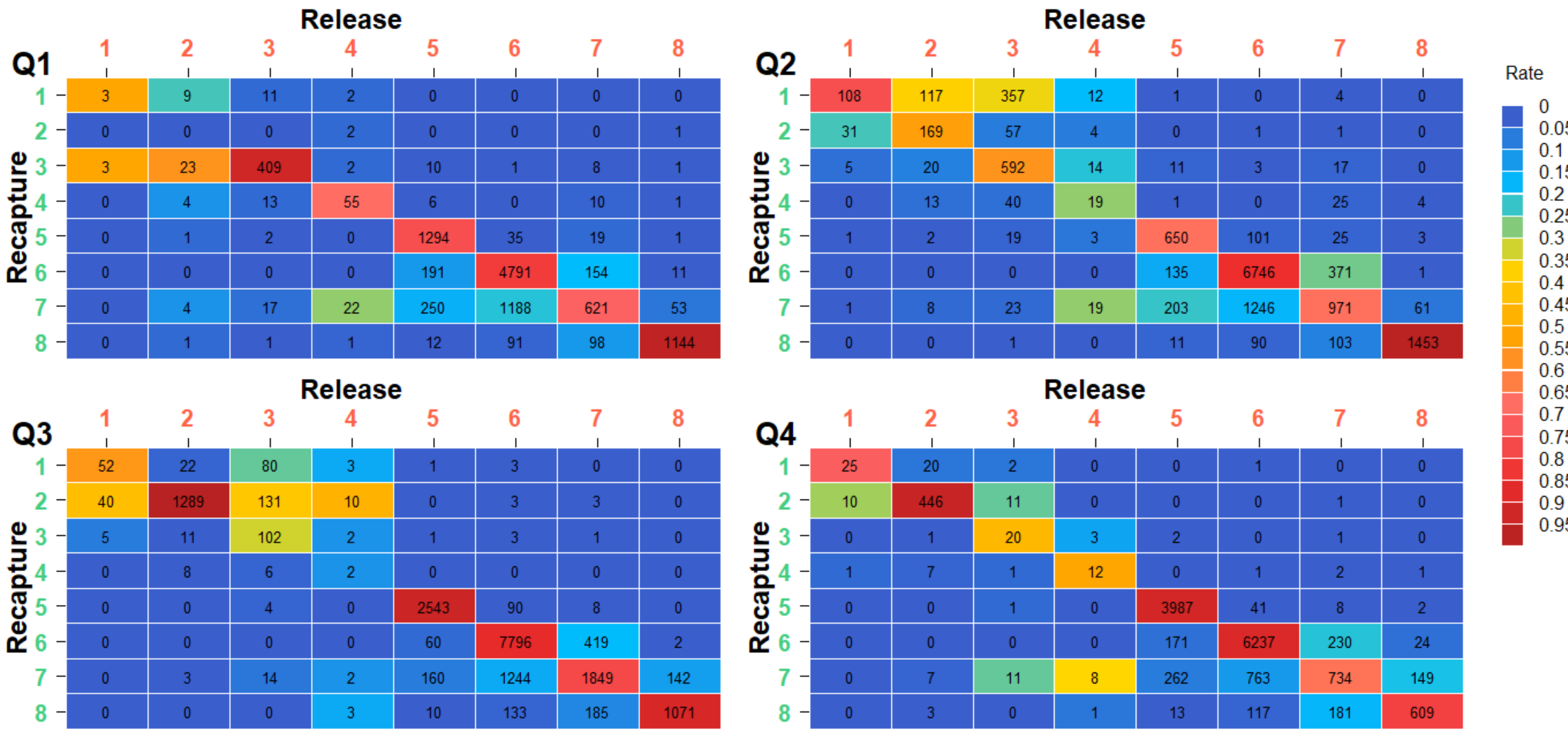


Figure 21: Summary of the number of tags recaptured by region of release (columns), region of recapture (rows), and quarter of recapture (panel). The shade of the tile corresponds to the proportion of tags released from that region that are recovered in the corresponding region.

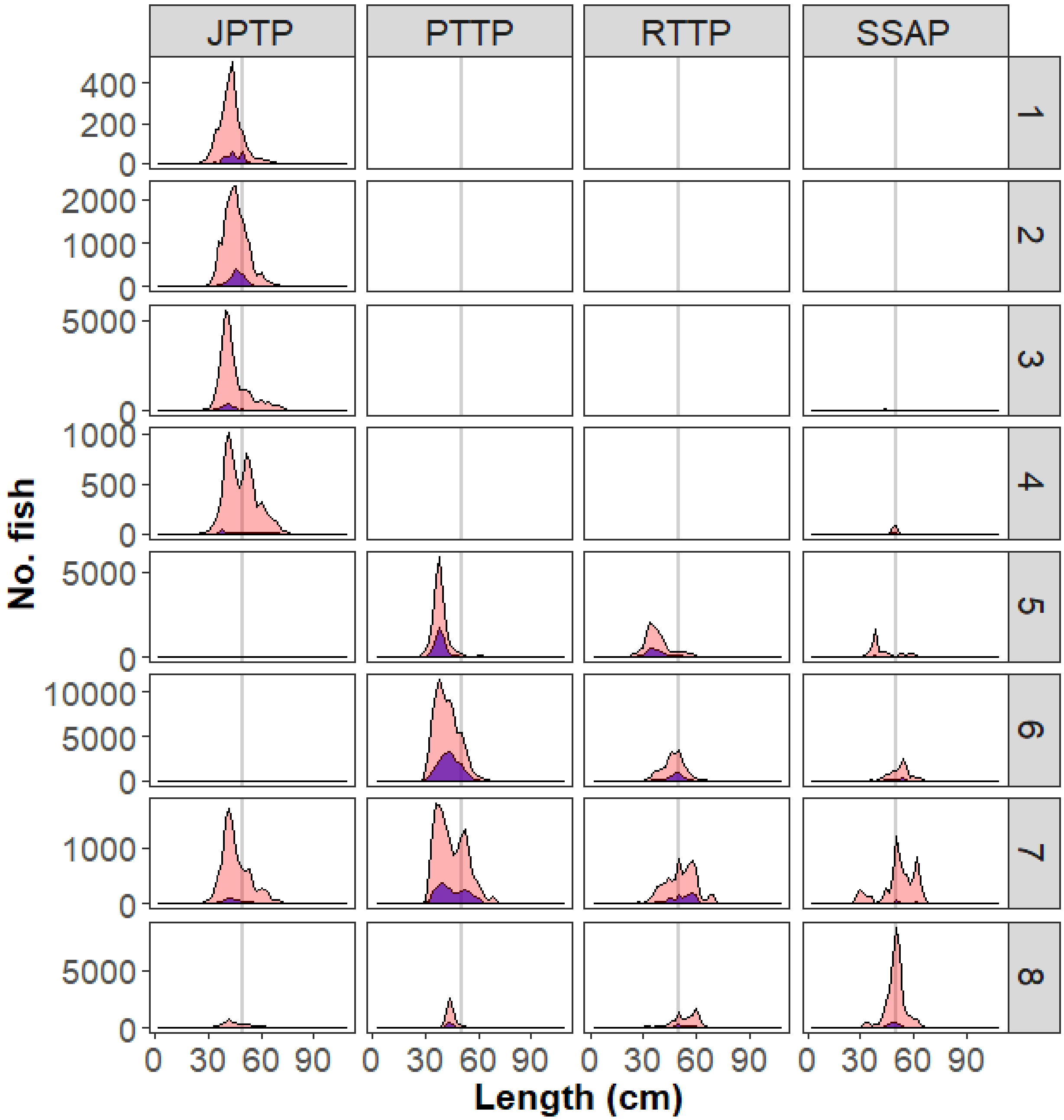


Figure 22: Summary of the .tag file used in the 8 region models in the assessment of the length composition of released (pink) and recaptured (purple) fish for the different tagging programs (columns) and regions (rows).

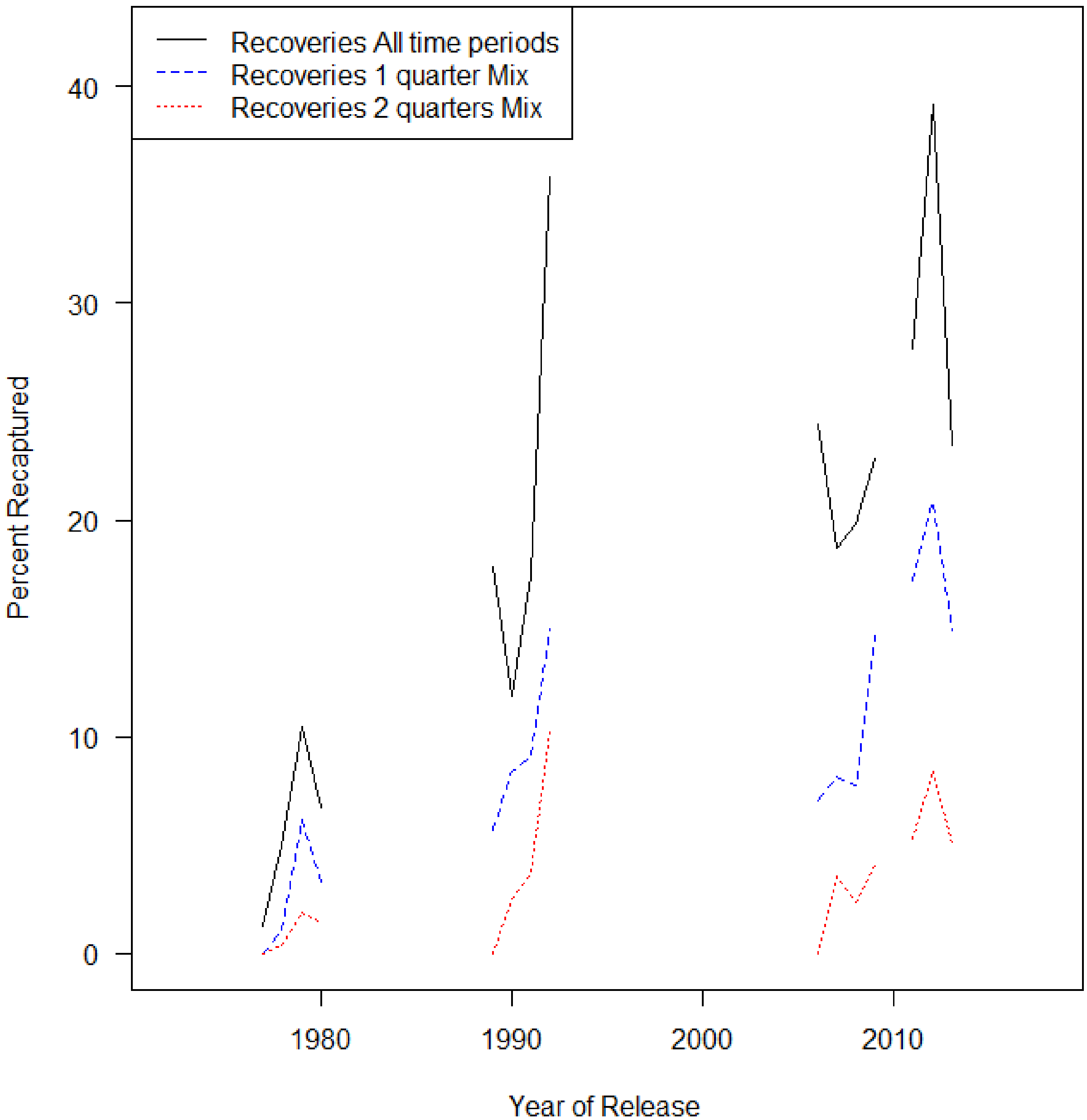
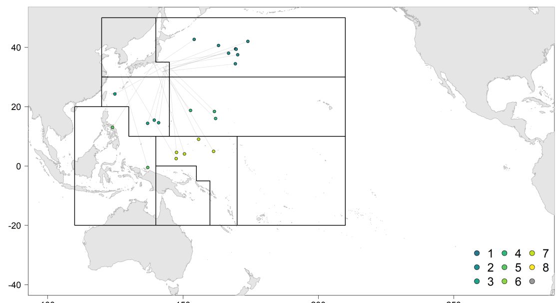
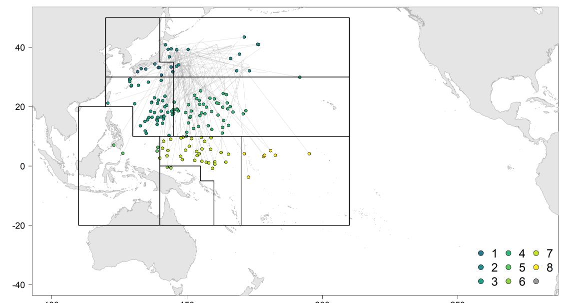


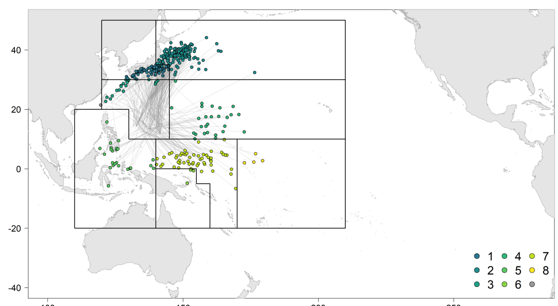
Figure 23: Percent of recaptured tags to released tags through years from 1989 to 2018 for all tags and filtered for one and two seasons of mixing for tagging conducted by SPC.



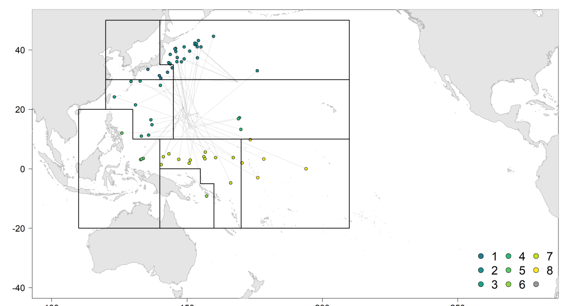
(a) Region 1 releases



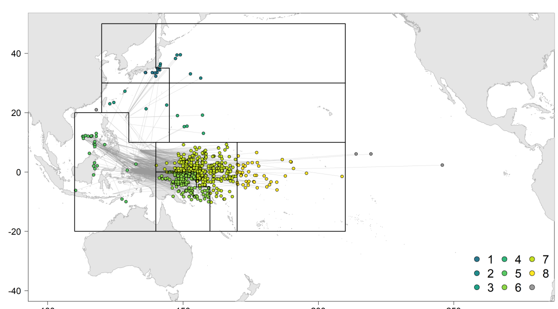
(b) Region 2 releases



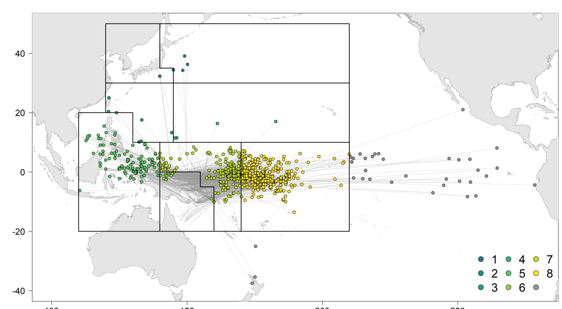
(c) Region 3 releases



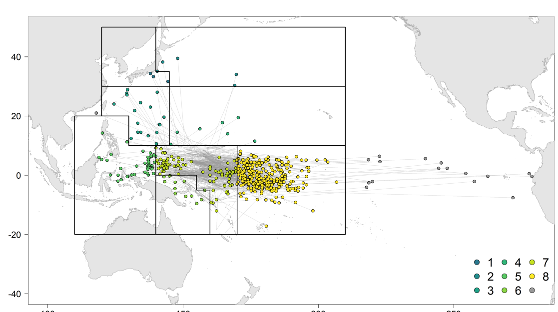
(d) Region 4 releases



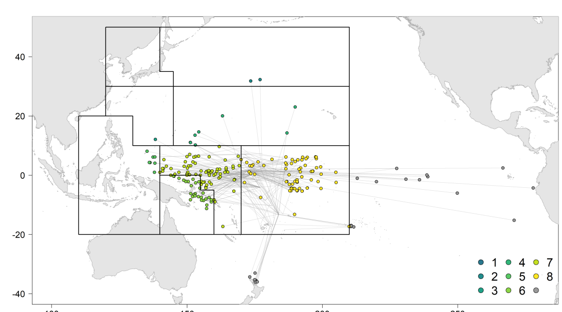
(e) Region 5 releases



(f) Region 6 releases



(g) Region 7 releases



(h) Region 8 releases

Figure 24: Plot of tag recaptures greater than 1,000 nautical miles from point of release for all tagging programs by the region of release for each of the 8 assessment regions. The dot indicates the location of recapture, the gray line shows the direct path between release and recapture, and the color of the dot indicates the region of recapture.

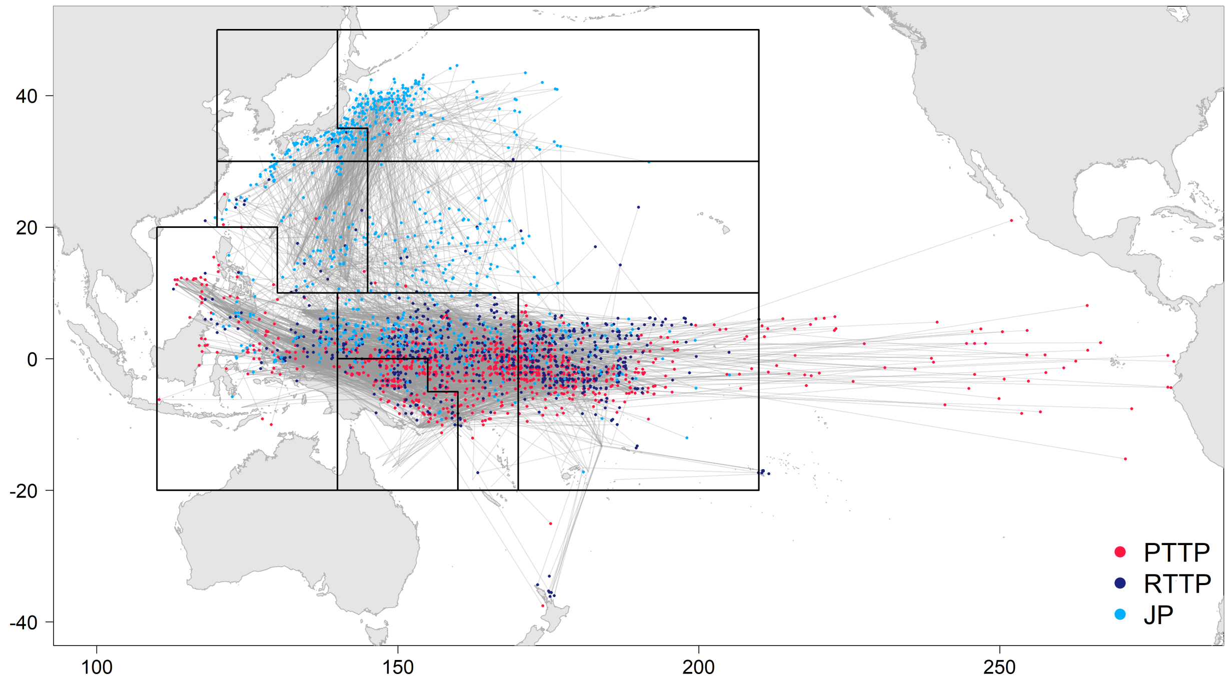


Figure 25: Plot of tag recaptures greater than 1,000 nautical miles from the point of release by the program of release for those tags that were released within the assessment region.

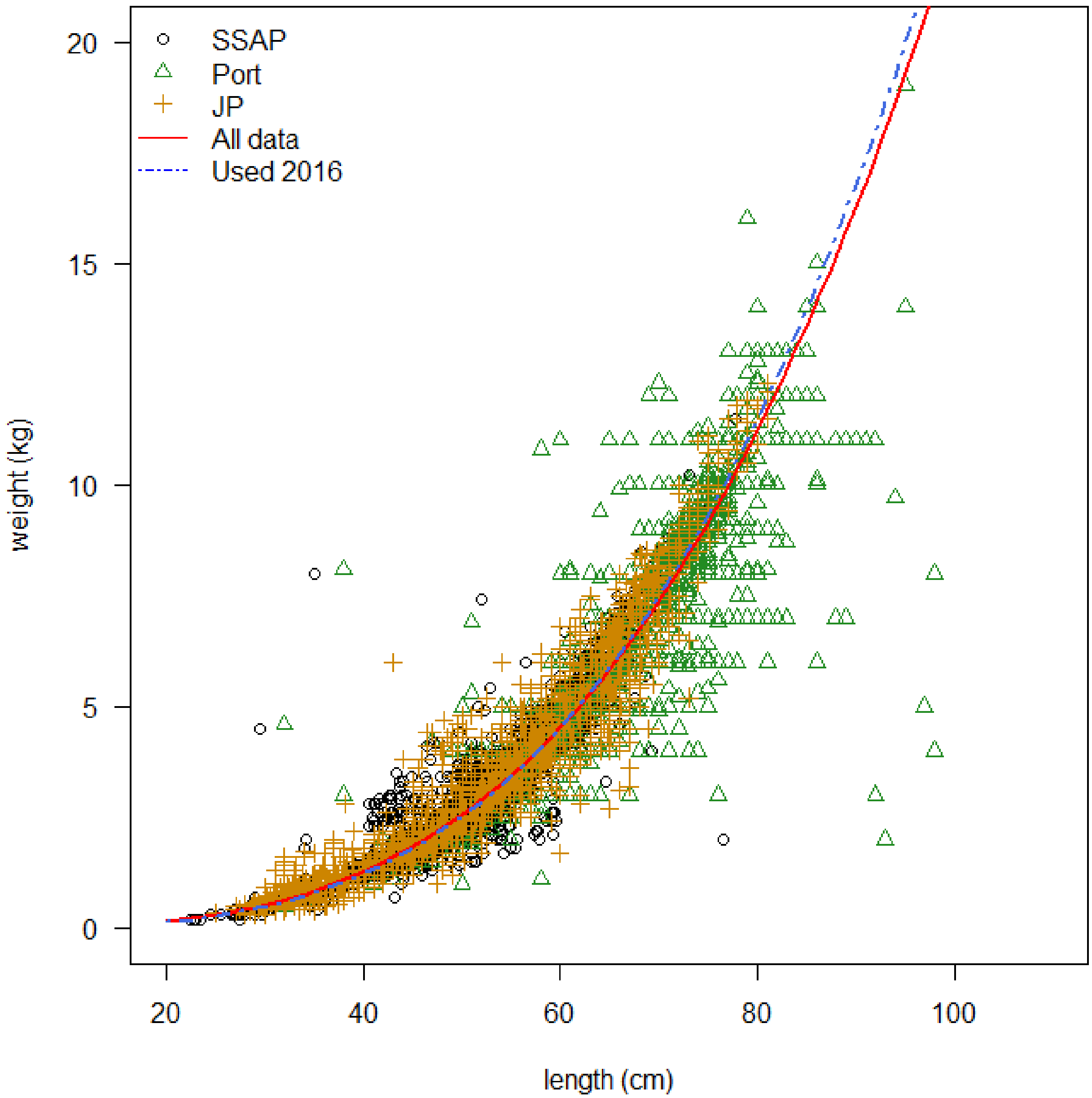


Figure 26: Plot of length and weight data from three sources and a comparison of length-weight relationship used in the 2016 and 2019 skipjack stock assessments.

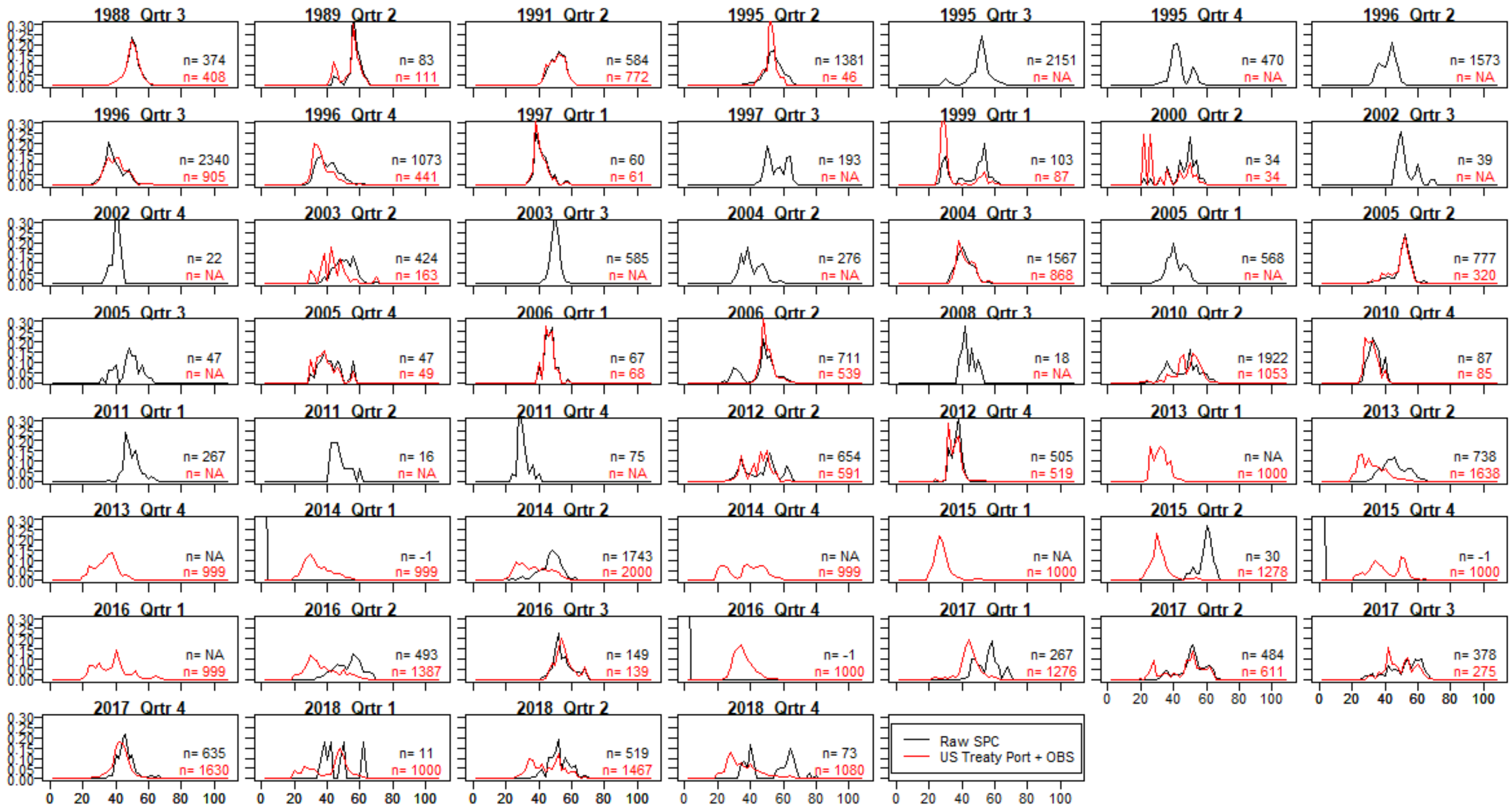


Figure 27: Comparison of the uncorrected and corrected length distribution for the catch for the purse seine associated fishery in region 5 of the 8 region structure for the time range 1972-2018.

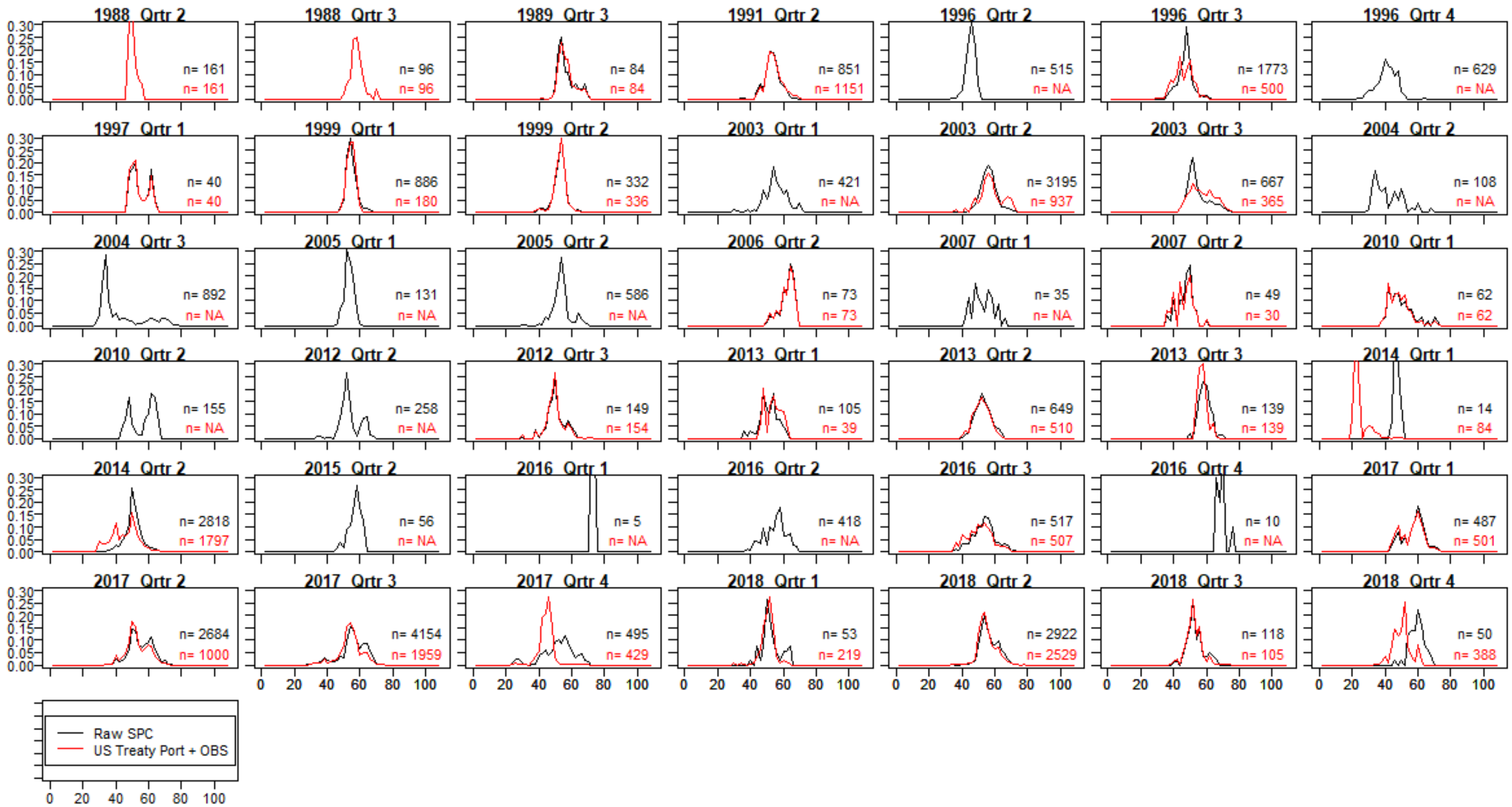


Figure 28: Comparison of the uncorrected and corrected length distribution for the catch for the purse seine unassociated fishery in region 5 of the 8 region structure for the time range 1972-2018.

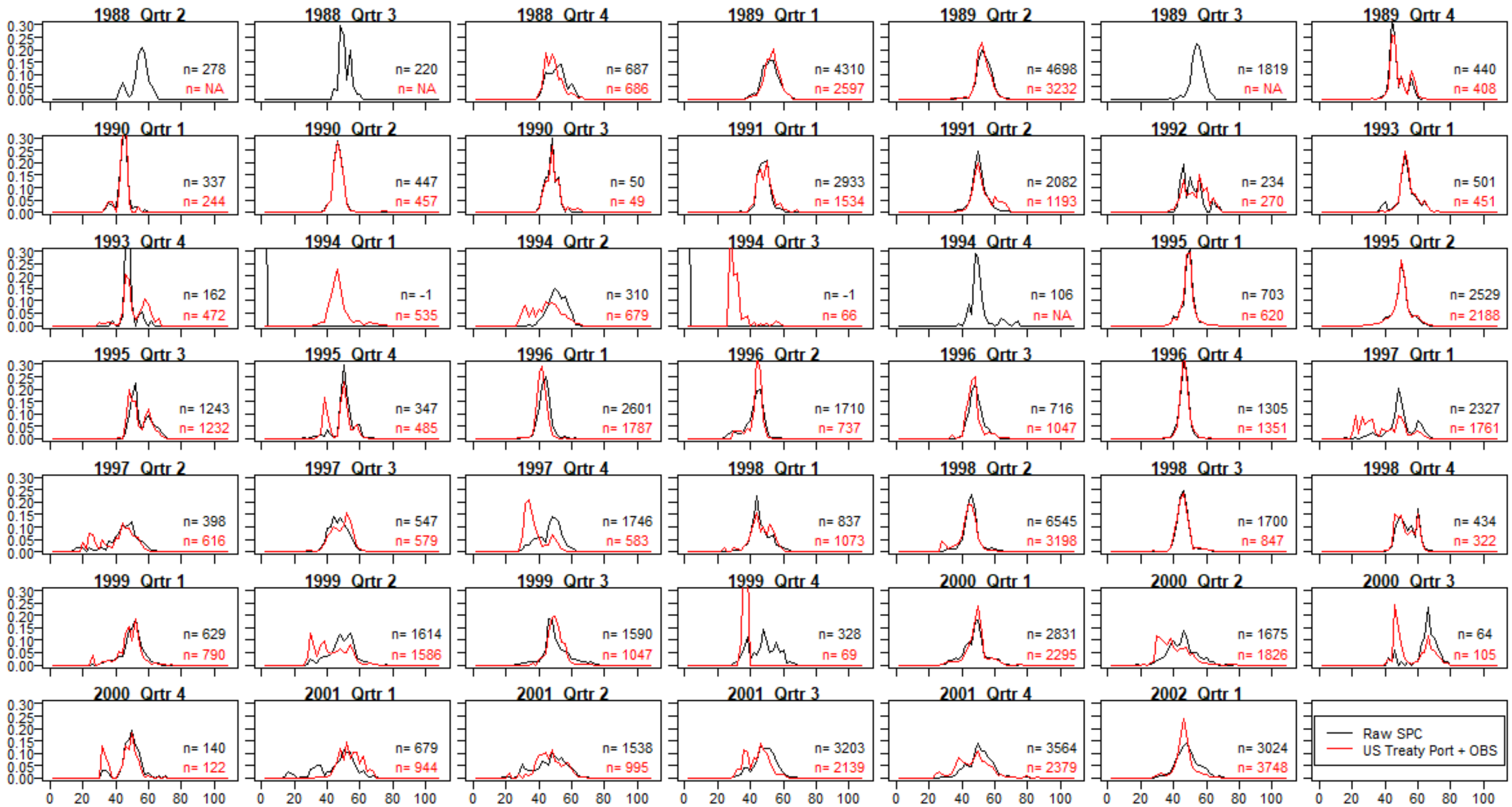


Figure 29: Comparison of the uncorrected and corrected length distribution for the catch for the purse seine associated fishery in region 6 of the 8 region structure for the time range 1972-2002.

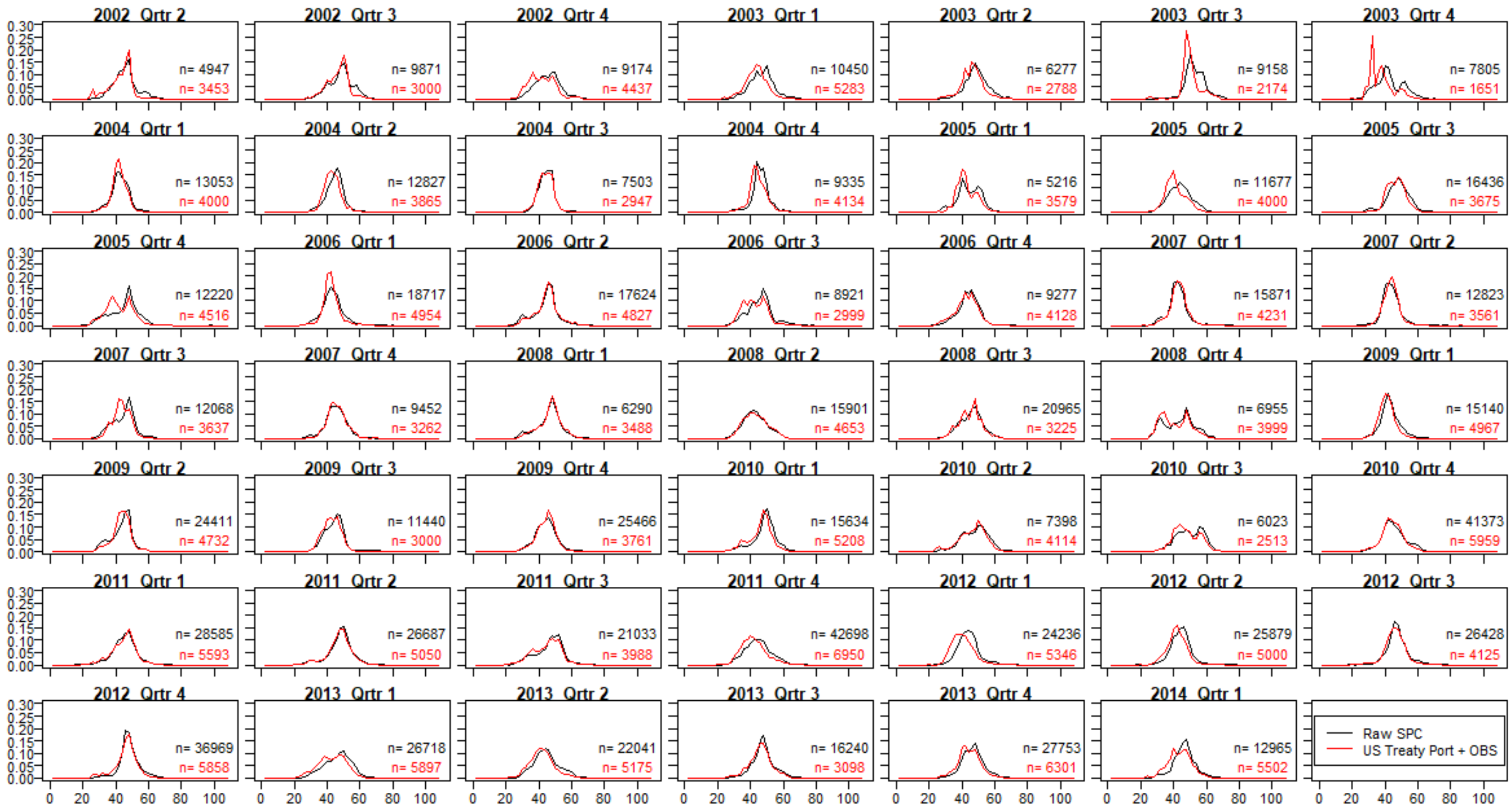


Figure 30: Comparison of the uncorrected and corrected length distribution for the catch for the purse seine associated fishery in region 6 of the 8 region structure for the time range 2002-2014.

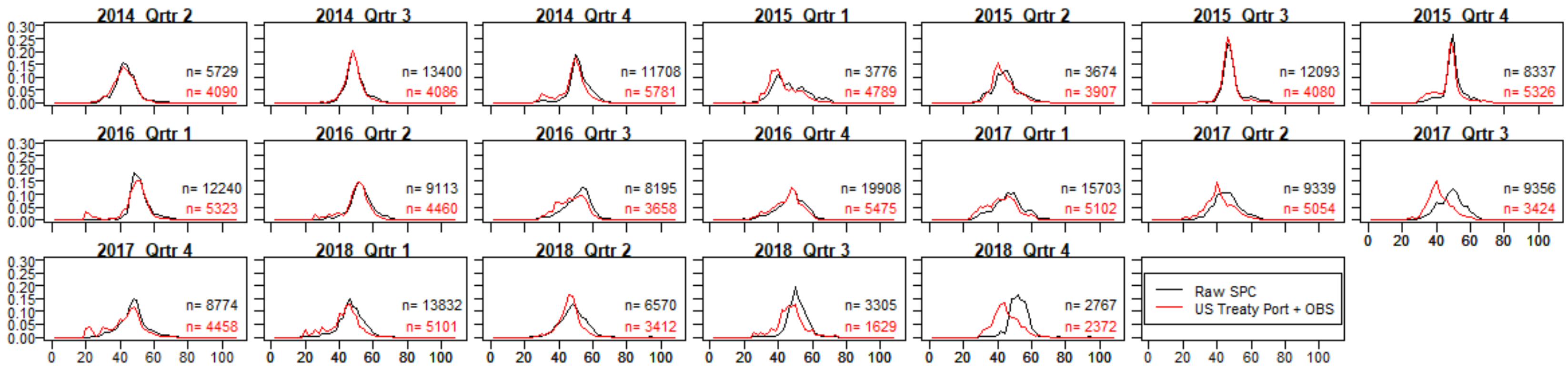


Figure 31: Comparison of the uncorrected and corrected length distribution for the catch for the purse seine associated fishery in region 6 of the 8 region structure for the time range 2014-2018.

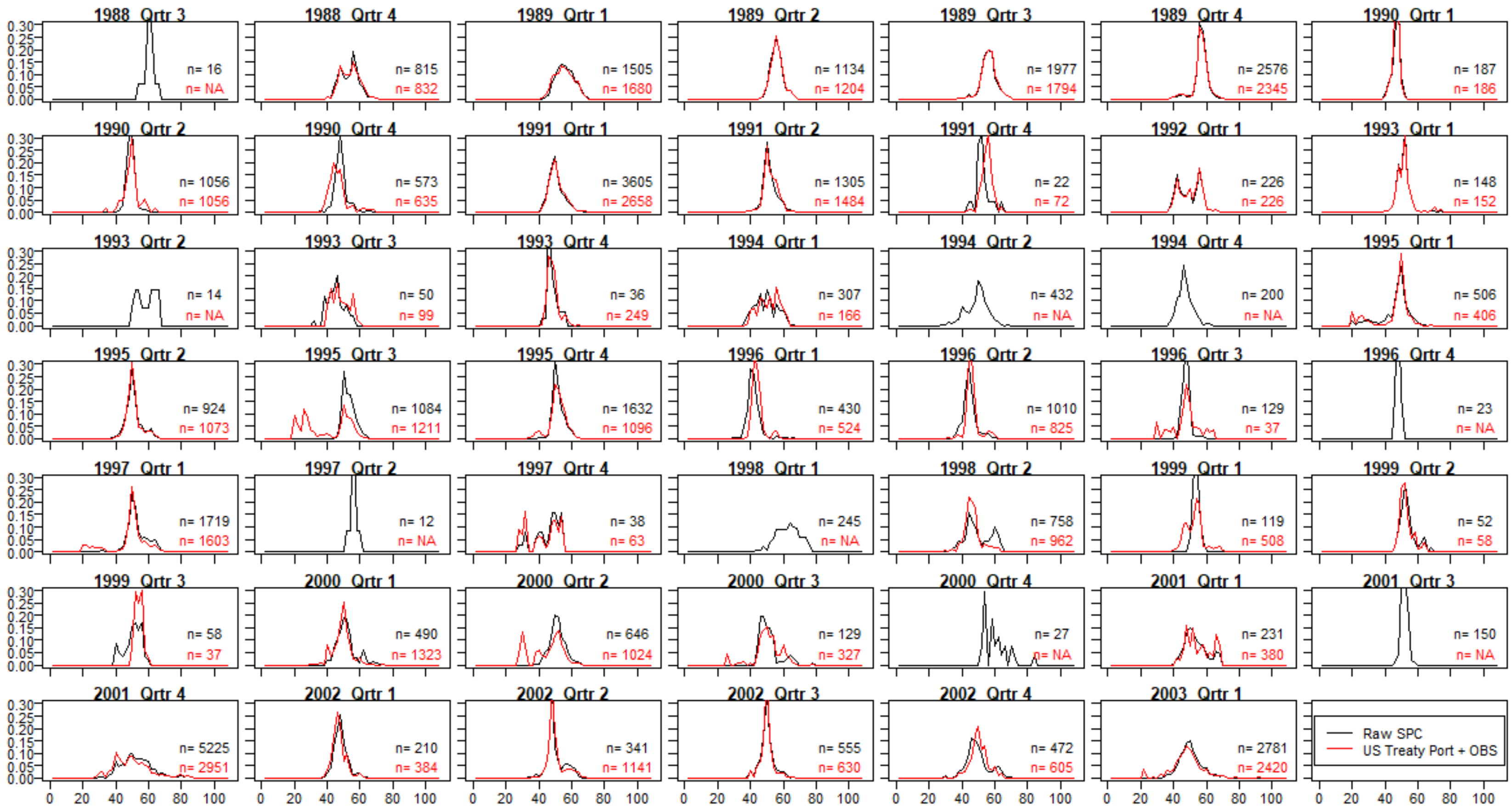


Figure 32: Comparison of the uncorrected and corrected length distribution for the catch for the purse seine unassociated fishery in region 6 of the 8 region structure for the time range 1972-2003.

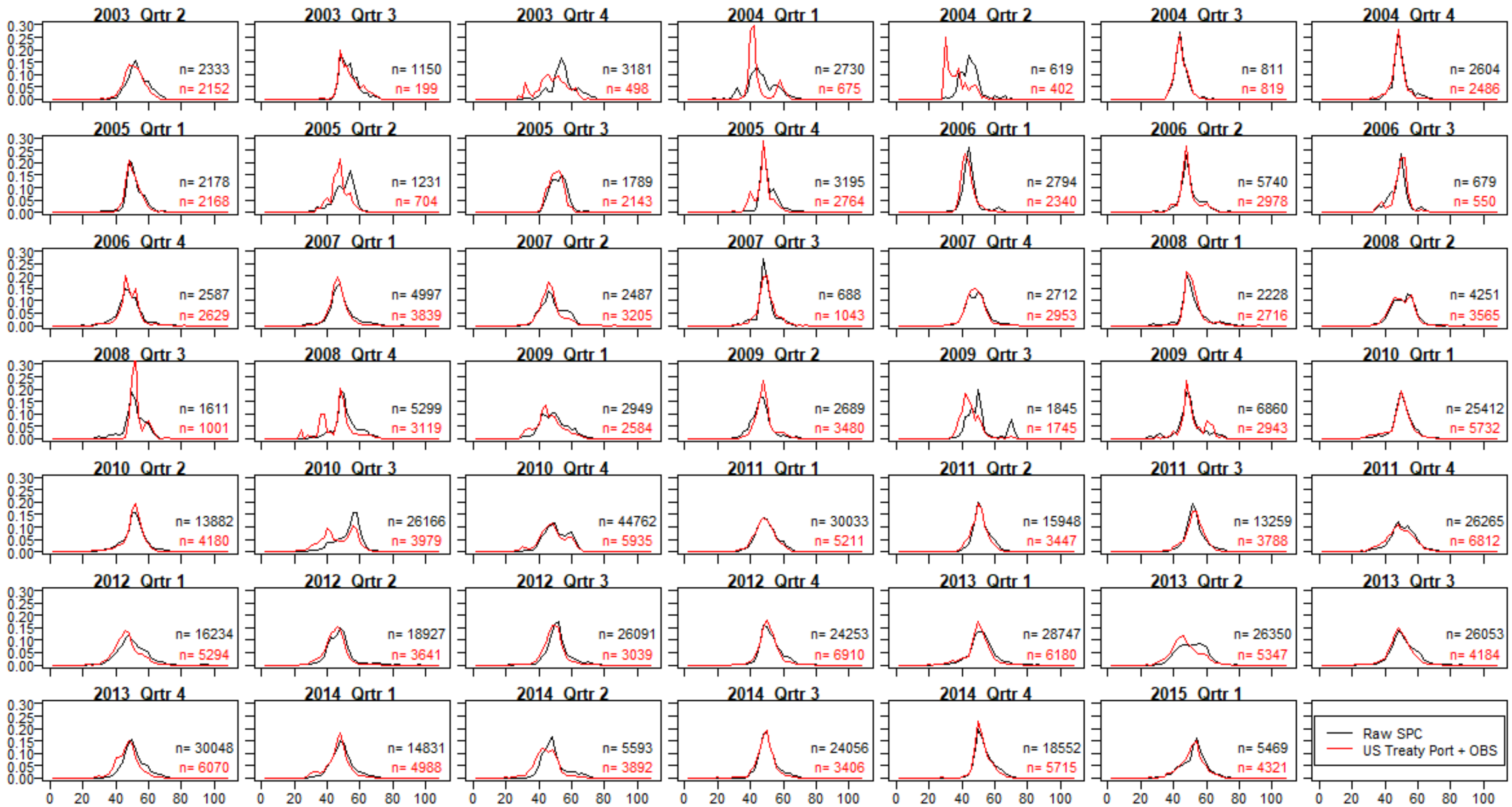


Figure 33: Comparison of the uncorrected and corrected length distribution for the catch for the purse seine unassociated fishery in region 6 of the 8 region structure for the time range 2003-2015.

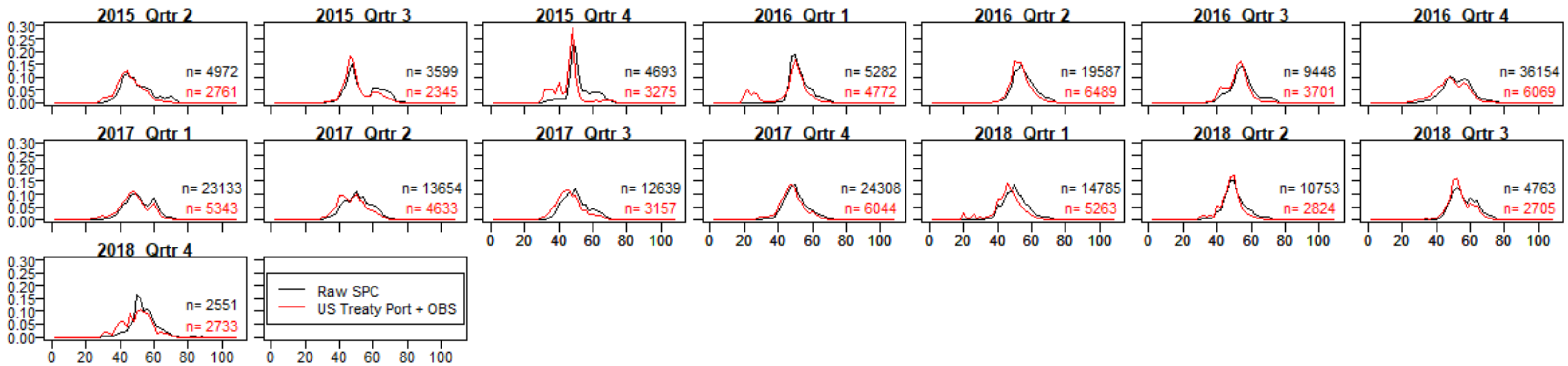


Figure 34: Comparison of the uncorrected and corrected length distribution for the catch for the purse seine unassociated fishery in region 6 of the 8 region structure for the time range 2015-2018.

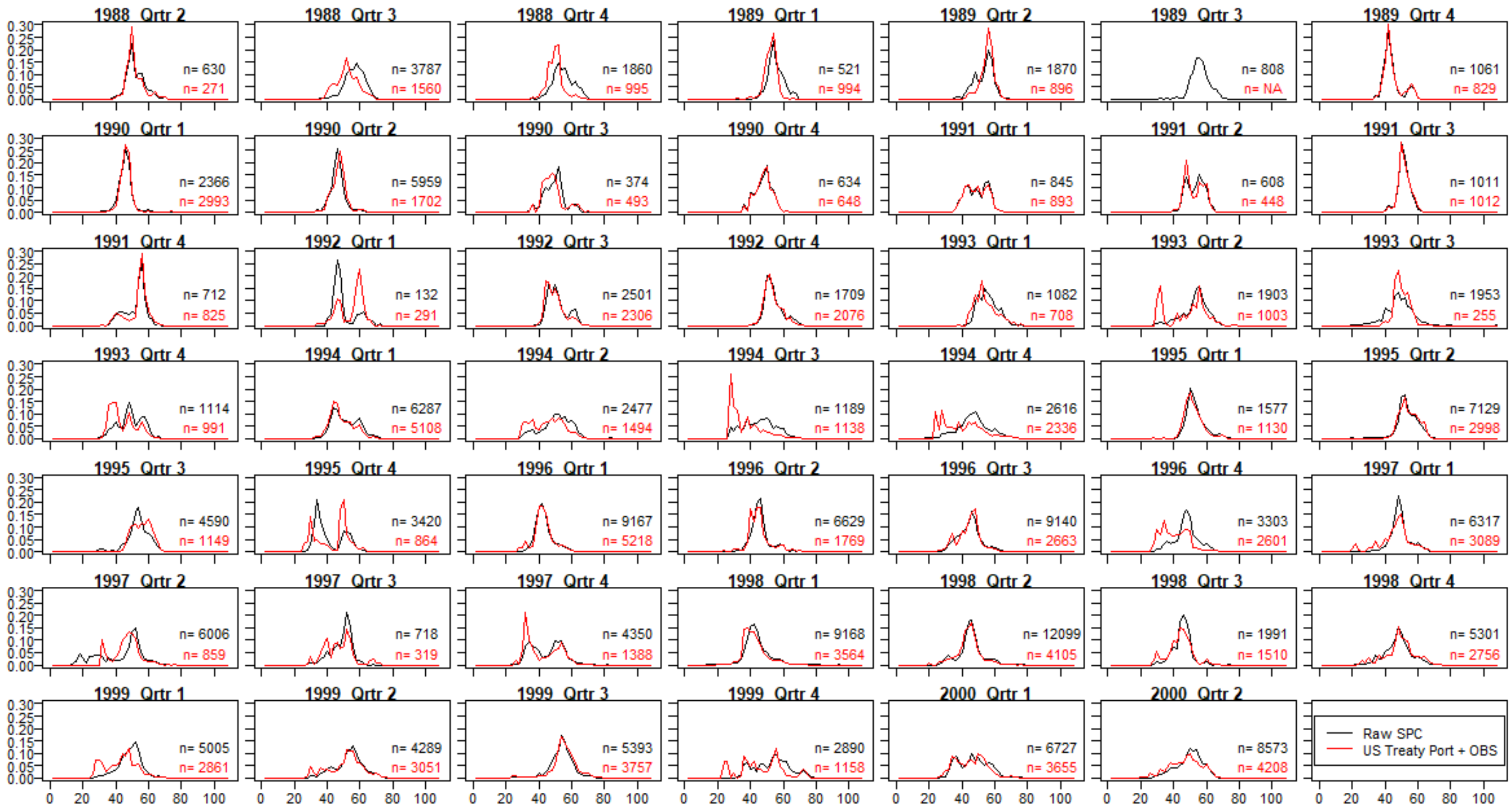


Figure 35: Comparison of the uncorrected and corrected length distribution for the catch for the purse seine associated fishery in region 7 of the 8 region structure for the time range 1972-2000.

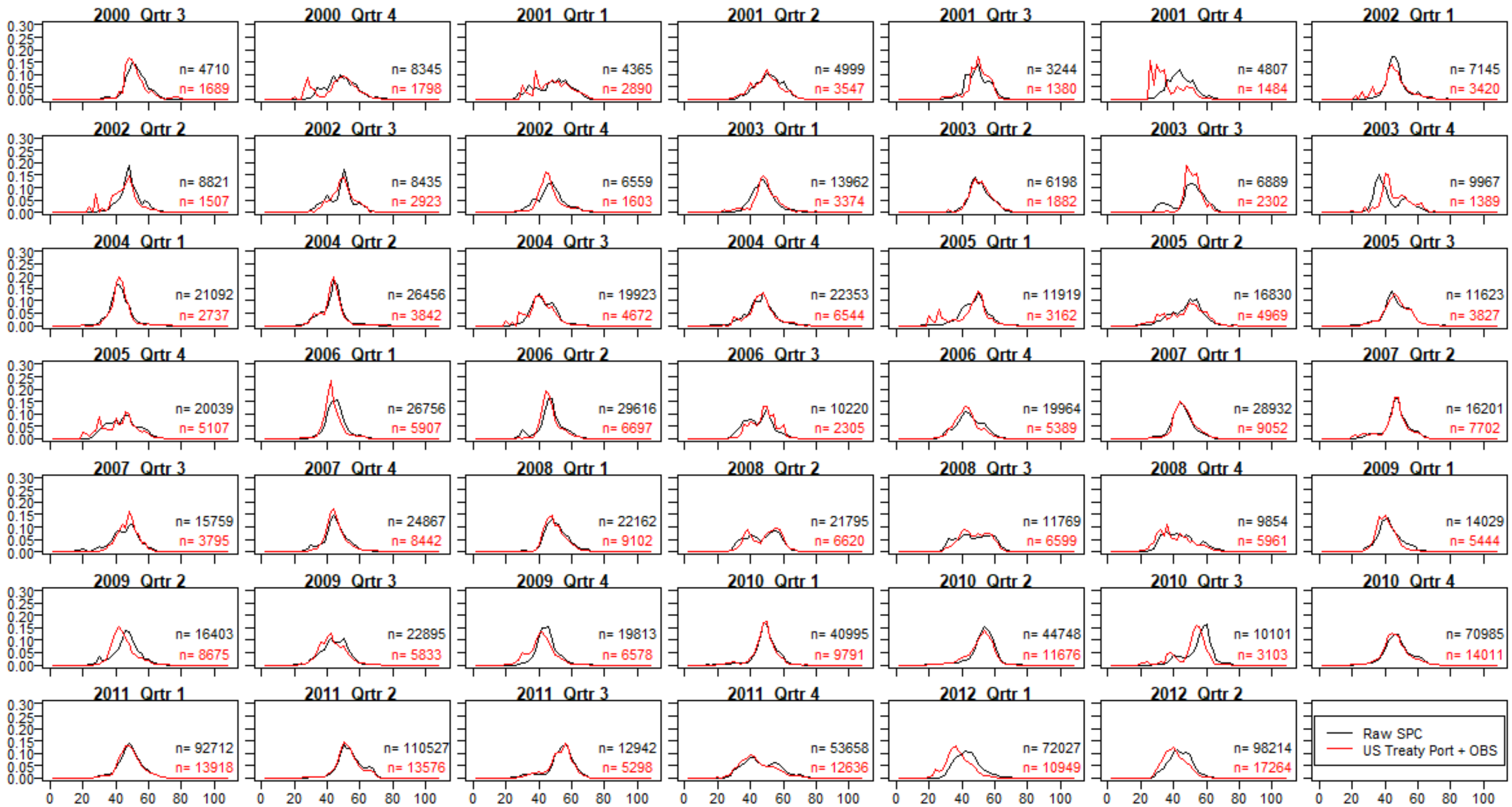


Figure 36: Comparison of the uncorrected and corrected length distribution for the catch for the purse seine associated fishery in region 7 of the 8 region structure for the time range 2000-2012.

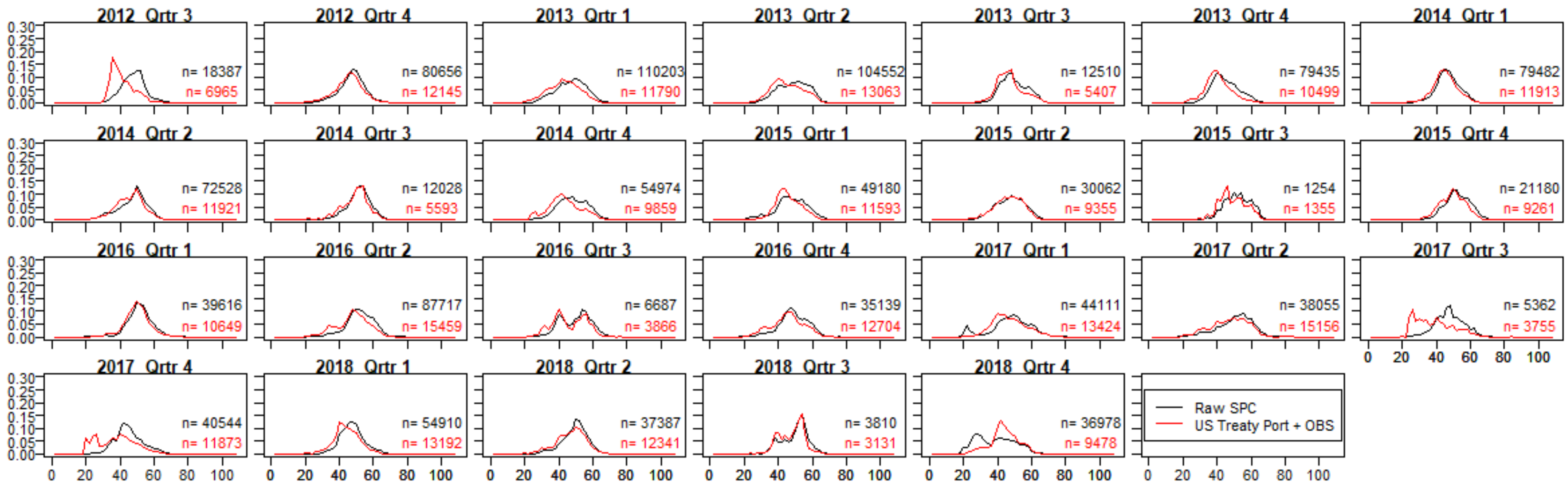


Figure 37: Comparison of the uncorrected and corrected length distribution for the catch for the purse seine associated fishery in region 7 of the 8 region structure for the time range 2012-2018.

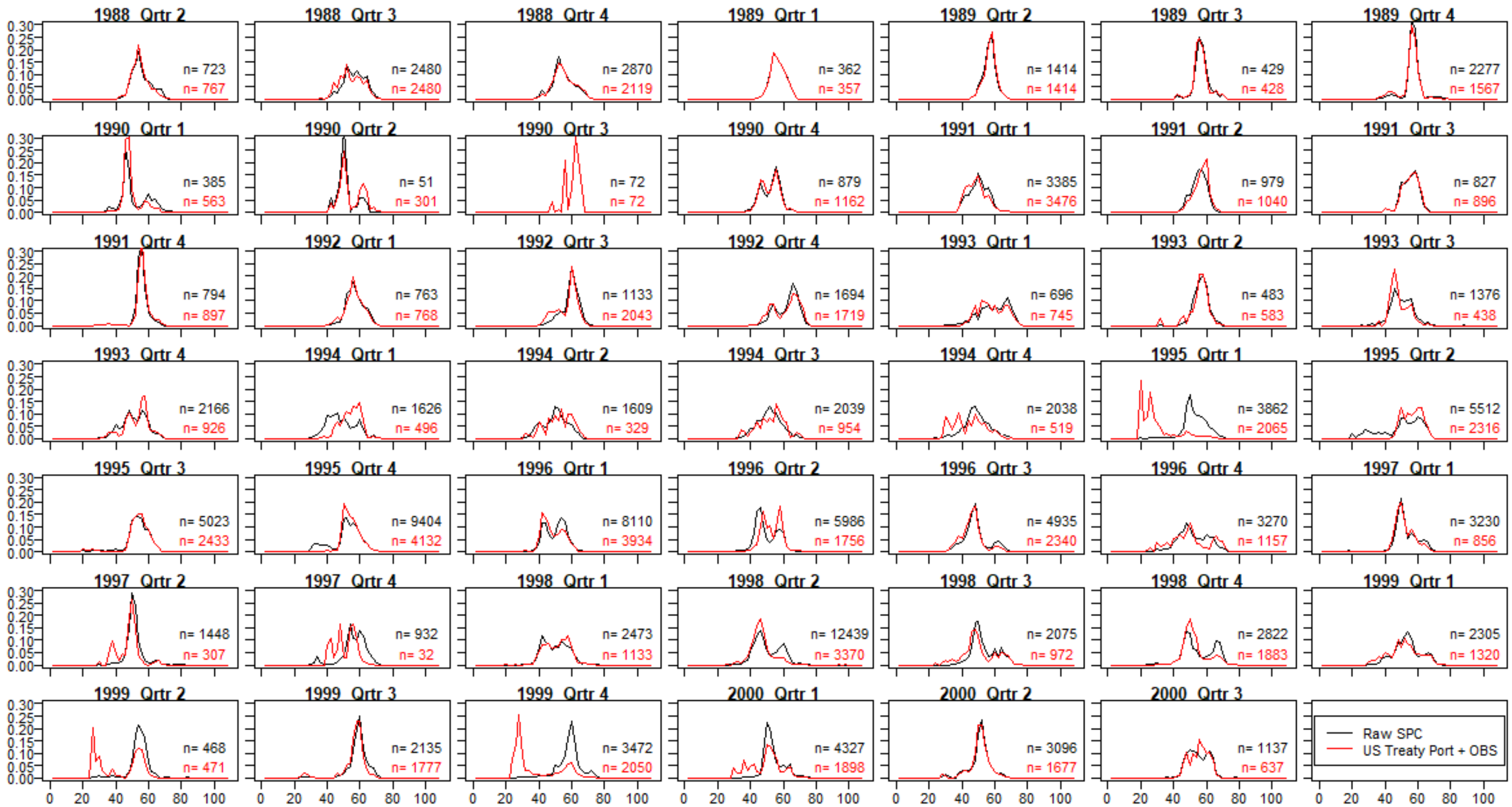


Figure 38: Comparison of the uncorrected and corrected length distribution for the catch for the purse seine unassociated fishery in region 7 of the 8 region structure for the time range 1972-2000.

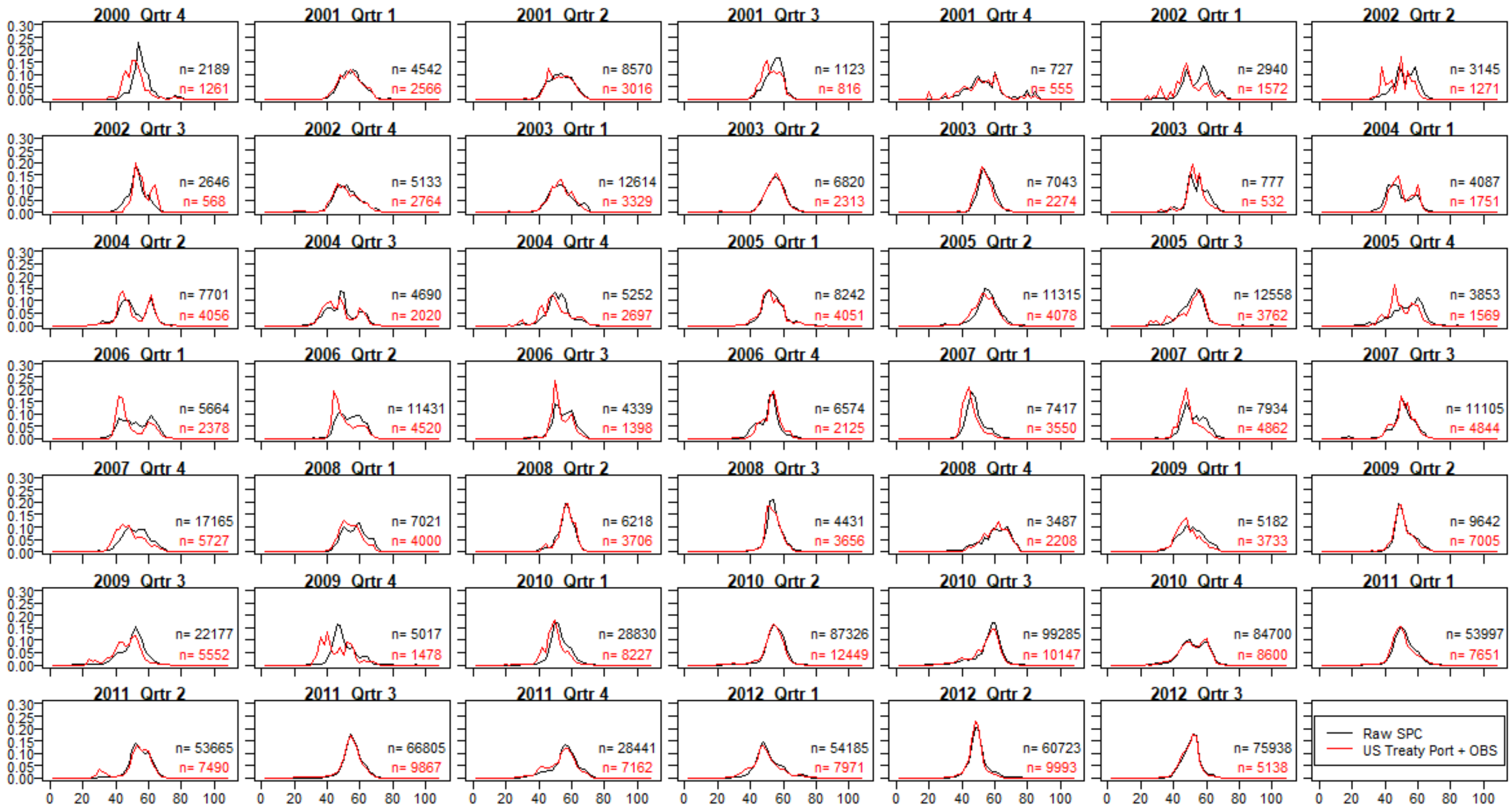


Figure 39: Comparison of the uncorrected and corrected length distribution for the catch for the purse seine unassociated fishery in region 7 of the 8 region structure for the time range 200-2012.

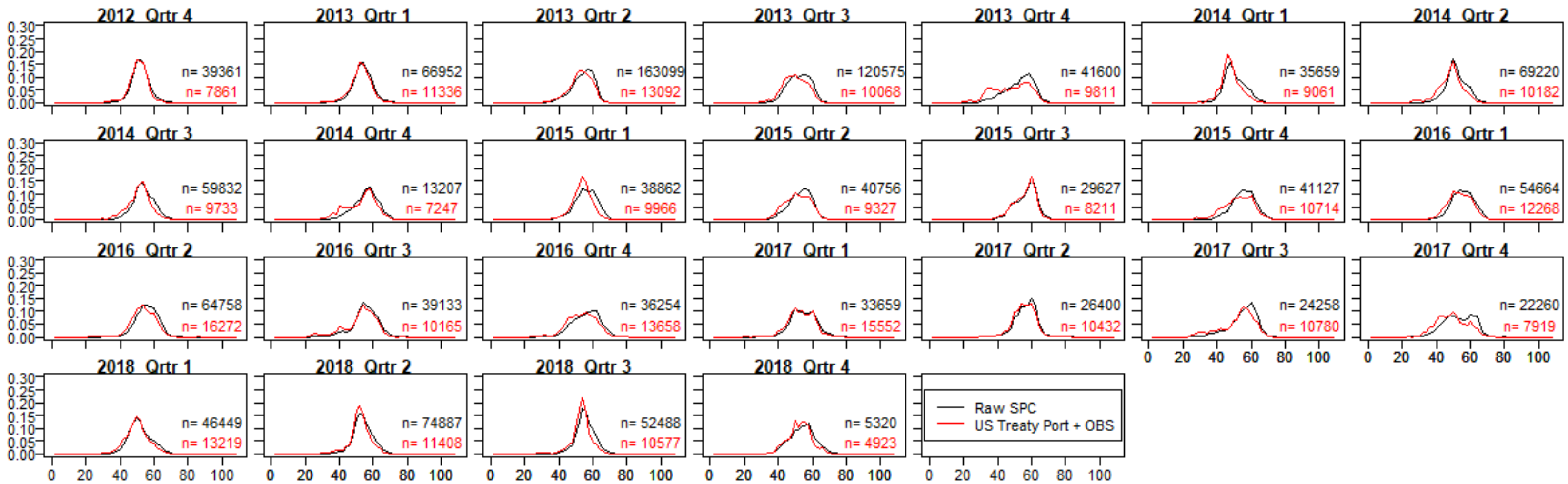


Figure 40: Comparison of the uncorrected and corrected length distribution for the catch for the purse seine unassociated fishery in region 7 of the 8 region structure for the time range 2012-2018.

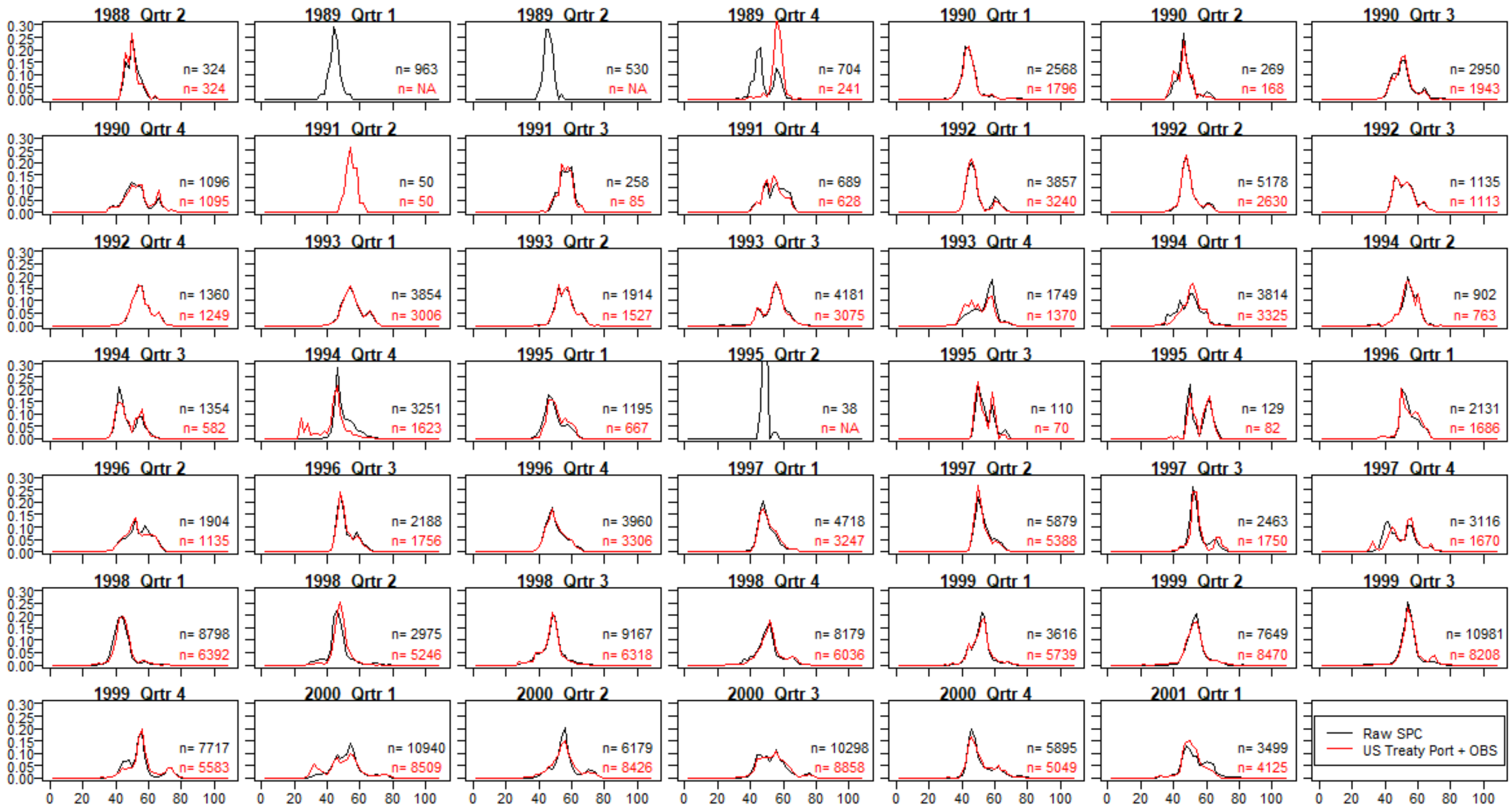


Figure 41: Comparison of the uncorrected and corrected length distribution for the catch for the purse seine associated fishery in region 8 of the 8 region structure for the time range 1972-2001.

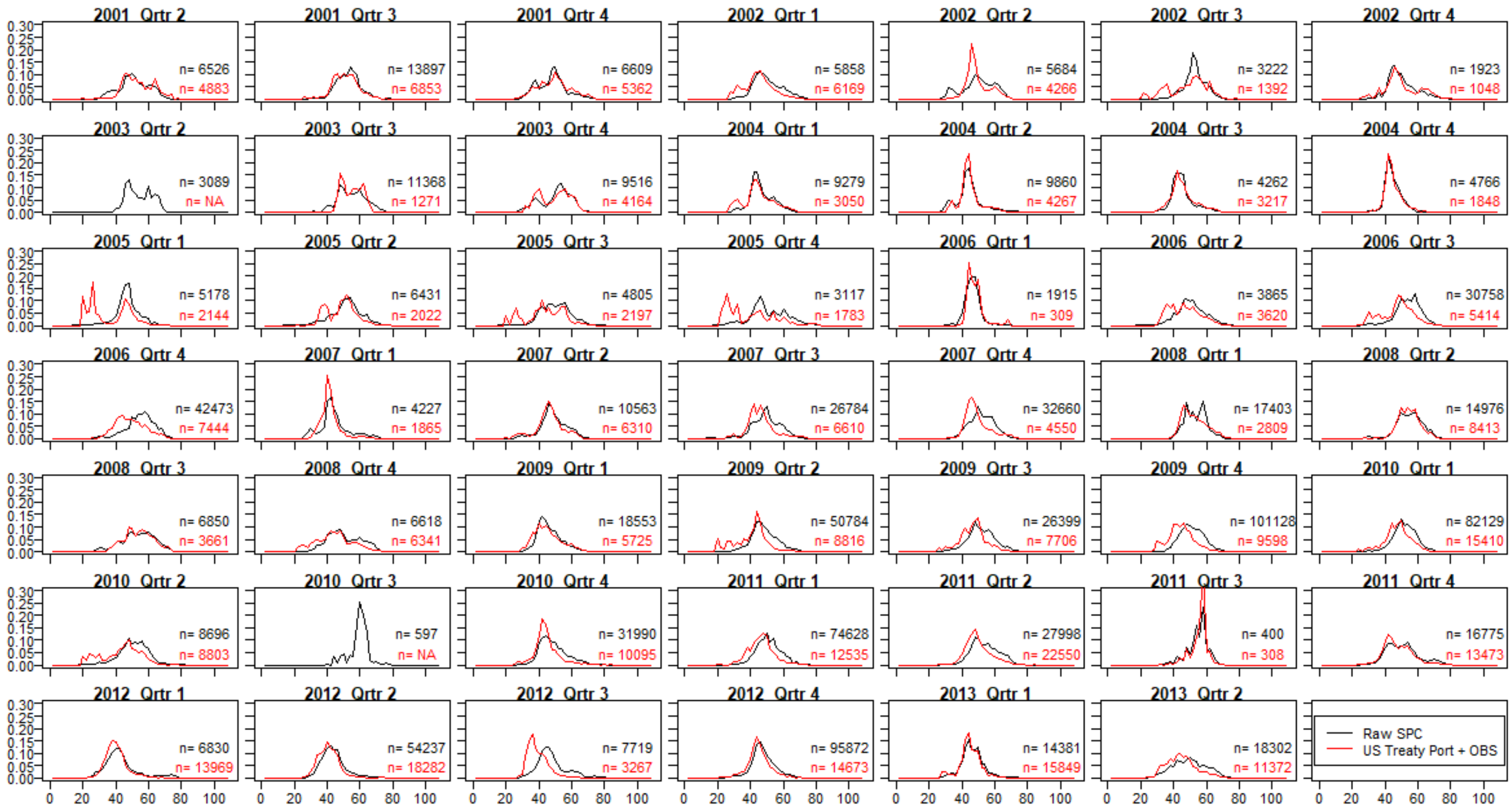


Figure 42: Comparison of the uncorrected and corrected length distribution for the catch for the purse seine associated fishery in region 8 of the 8 region structure for the time range 2001-2013.

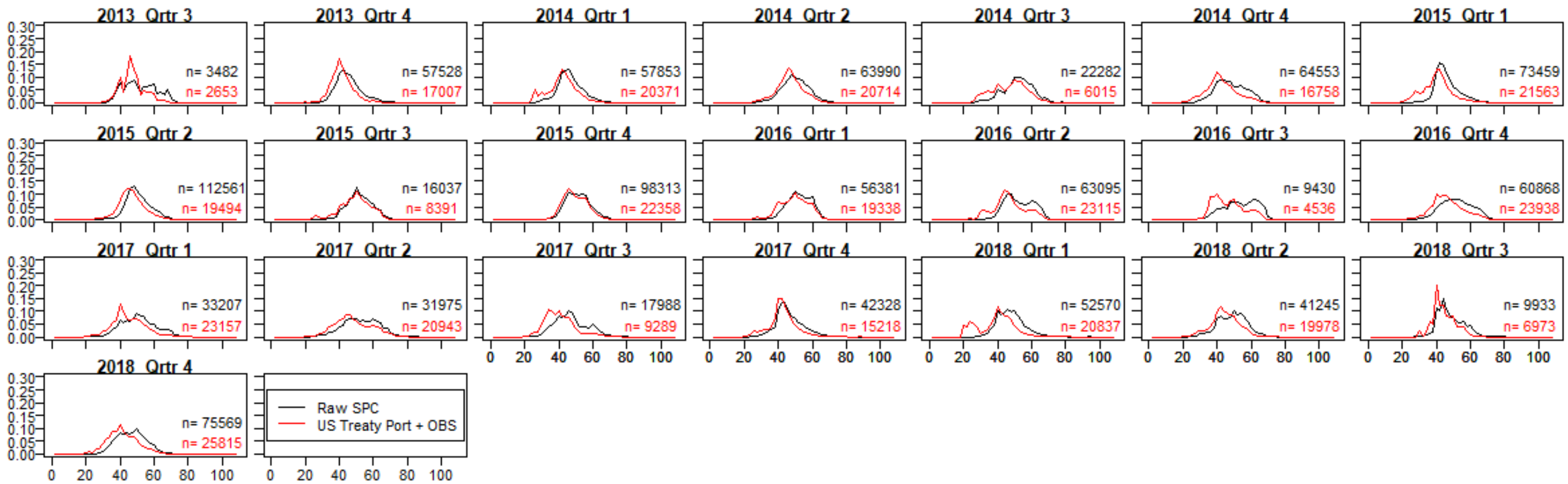


Figure 43: Comparison of the uncorrected and corrected length distribution for the catch for the purse seine associated fishery in region 8 of the 8 region structure for the time range 2013-2018.

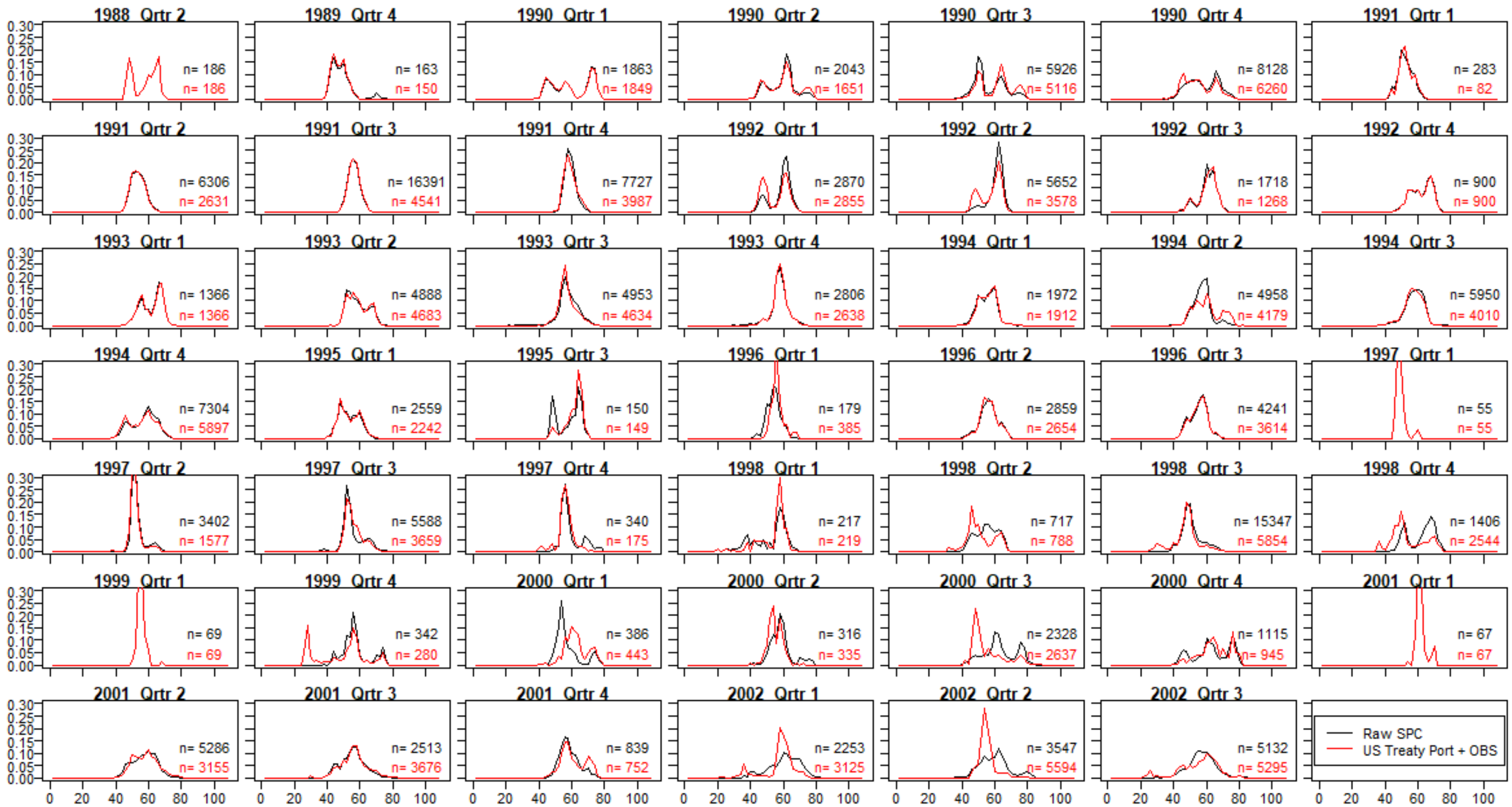


Figure 44: Comparison of the uncorrected and corrected length distribution for the catch for the purse seine unassociated fishery in region 8 of the 8 region structure for the time range 1972-2002.

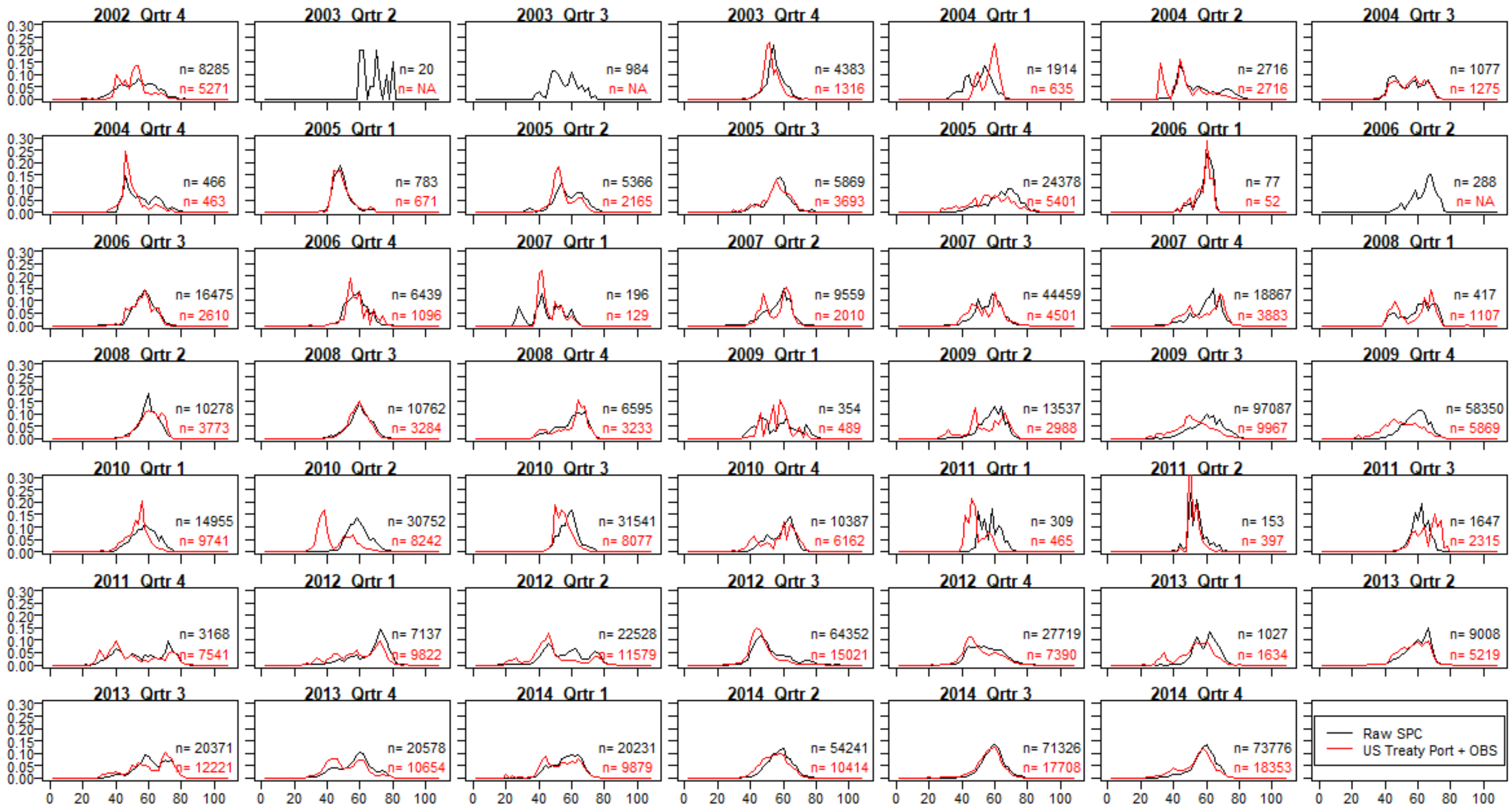


Figure 45: Comparison of the uncorrected and corrected length distribution for the catch for the purse seine unassociated fishery in region 8 of the 8 region structure for the time range 2002-2014.

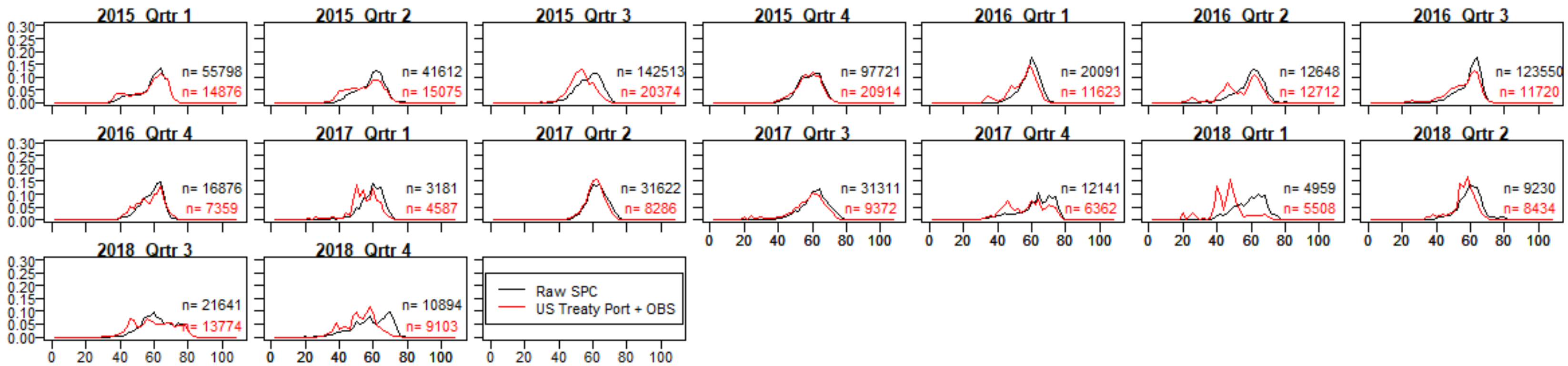


Figure 46: Comparison of the uncorrected and corrected length distribution for the catch for the purse seine unassociated fishery in region 8 of the 8 region structure for the time range 2014-2018.