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Analysis of longline size frequency data for bigeye and yellowfin tunas in the WCPO

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1. Executive Summary

The most important longline size frequency datasets for the bigeye and yellowfin tuna assessments in the West and Central Pacific Ocean are from the Japanese longline fleet. There is considerable spatio-temporal variation in size frequencies within stock assessment regions which makes it difficult to model using MFCL, which assumes constant selectivity of fisheries, as there is a tradeoff between controlling unwanted variation from unbalanced sampling of sizes within a region and ensuring the assessment model removes fish from the population at the correct sizes.

The independent review of the 2011 WCPO bigeye tuna stock assessment recommended weighting individual spatial cells within a region based on catch rather than CPUE which was used in 2011. This paper presents the methods used to meet this recommendation and shows the resulting changes to the size frequencies that will be used for the "all flags" fisheries for bigeye and yellowfin in the 2014 assessments. In addition, reweighting of size frequency data for other longline fisheries was undertaken to prevent variation from unbalanced sampling of sizes across fleets from unduly impacting the size frequencies used for those fisheries.

2. Introduction

Size frequency data are extremely important when fitting catch-at-length models used for the stock assessments of tuna in the WCPO. There are some size frequency data available for most fisheries used in the MULTIFAN-CL (MFCL) models. The most important longline size frequency datasets for the bigeye (BET) and yellowfin (YFT) tuna assessments, are those associated with the “all flags” fisheries in each assessment region (Davies *et al.* 2011, Langley *et al.* 2011). These data come from the Japanese longline (JPLL) fleet and are highly unbalanced temporally and spatially both within and between regions.

Uneven spatio-temporal size sampling within a region is particularly problematic because there is considerable fine-scale spatial size variation (see Figure 1 for an example). Region-wide aggregated size frequencies therefore contain temporal variation from a spatial source when they should represent variation in the population size frequency. If the regional size frequency distribution changes as a result of changing sampling area MFCL will interpret these changes as changes in the underlying population size distribution. This is because selectivity is always assumed to be constant across the model time-period.

One method to account for uneven spatial sampling is to calculate weightings for different spatial cells within a region and use these to calculate a weighted mean size distribution across cells. This effectively ensures that each spatial cell has the same influence on the aggregate distribution at each time-step. This approach was utilised to calculate the size frequencies that were used in the 2011 BET and YFT stock assessments where the weightings were calculated based on the relative standardised CPUE of aggregated JPLL data for each 10×20° spatial cell over the period 1960-1986.

A recommendation of the independent review of the WCPO bigeye tuna stock assessment (bigeye review) (Ianelli *et al.* 2012) was to investigate the spatial weighting of JPLL size frequencies by long-term catch in spatial cells within a region. The re-weighting by CPUE was intended to remove variation from unbalanced sampling of spatial cells with the added benefit that aggregated size distributions will be more representative of the sizes being caught and thus MFCL will remove fish from the population at the correct sizes.

Furthermore, despite recommendations in the past (e.g. Harley *et al.* 2010), few attempts have been made to investigate issues relating to the size frequency data of other longline fisheries. Issues surrounding changes in where size samples for a fleet come from within a region are particularly problematic. These differences occur through changes in the quality of the data provided by fishing nations and changes in the number of size samples provided for different fleets, which changes their influence in the model over time. This would not be problematic if the size samples of each fleet were always very similar, which they are not. However, while similar selectivity is partly the basis of grouping fleets into fisheries, other factors such the disparity in how management measures are applied to fleets is also considered.

Despite this, there will remain differences between fleets particularly when temporal changes in the size distribution vary between fleets.

Harley *et al.* (2010) raised the possibility of accounting for some variability in size frequencies through an assessment of the relative number of size samples available for different fleets over time. One proposal was to weight size samples by the catch of individual fleets, so that their relative contributions to the observed size distribution of the fishery remain constant over time.

This paper will present the methodology used to reweight size frequency data for longline fisheries used in the 2014 stock assessments of BET and YFT. The methods of spatially weighting JPLL size data by catch and the weighting of multiple-fleet size frequencies by fleet-specific catches will be outlined, and the consequences for the size distributions and effective sample sizes of the datasets will be shown.

3. Methods

3.1. JPLL spatially weighted size frequencies

3.1.1. Japanese longline size frequency data

All JPLL BET and YFT size frequency data held by SPC, and within the stock assessment boundaries, were extracted and separated into the assessment regions. The data are available at different scales, for example 5×5°, 4×10° and 10×20° spatial cells. Due to the irregular sizes of these cells it is possible for data to come from a cell that straddles two assessment regions. In these cases, the size frequencies were given 0.5 of the weight of data that did not straddle boundaries, and the size data were included in both regions. All data were then aggregated to the 10×20° spatial cell resolution.

3.1.2. Calculation of cell weightings

Catch of BET and YFT by the JPLL fleet within the stock assessment boundaries were extracted at the 5×5° resolution and separated into the assessment regions. The data were then aggregated to the 10×20° spatial-cell-scale to match the spatial resolution of the size frequency data. If the 10×20° cell straddled a region boundary only catch within the region contributed to calculation of the weightings for that region. Initially the sum of the catch for each cell i, for each year-quarter t, denoted $C_{i,t}$, is simply $C_{i,t} = \sum_{j=1}^{J_{i,t}} c_j$ where c_j is the extracted catch in numbers of fish in an individual 5×5° cell, and $J_{i,t}$ is the total number of 5×5° cells within 10×20° cell i, in year-quarter t (eight if there is catch in each cell).

Cell weightings $W_{i,t}$ can then be calculated by dividing the cell- and year-quarter-specific catch totals by the total catch in that year-quarter, i.e.

$$W_{i,t} = \frac{\sum_{t-k}^{t+k} C_{i,t}}{\sum_{i=1}^{M} \sum_{t-k}^{t+k} C_{i,t}}$$

where k is a time-period that must be defined and essentially represents a moving sum of catch that the weightings are calculated over. The window is $k \times 2 + 1$ quarters in length and so the weightings are determined by the relative catch between spatial cells over this window. If the window is very long the weightings will remain relatively constant and a cell will have a very similar influence on the aggregate size frequency over time. If the window is very short and the distribution of catch over the cells changes, then the relative weightings will also be able to change and the influence of a cell on the aggregate size frequency may vary. Note that the $t + k$ weightings at the start and end of the time-period will be constant as there are no data before and after t, respectively, to sum over.

The time-period of 11 quarters (k=5) was chosen for the moving sum to allow size frequencies to be largely reflective of the size of fish in cells where the catch was being taken in that year-quarter, but also to be long enough to prevent short-term variability in the spatial distribution of catch from producing size indices that vary greatly from where they were sampled rather than the underlying population. This time-period was chosen after examining the re-weighted size frequencies and comparing them to other time-periods for the weightings, including weightings calculated from catch over the entire period of data availability.

3.1.3. Reweighting size data

For each 10×20° cell in each year-quarter there is a vector of size frequencies determined by the size bins used in the stock assessment model (for BET/YFT the bins were 10,12,14,…,198cm), and so the count of fish in size bin *l*, in cell *i*, in year-quarter *t* is denoted $n_{i,t,l}$. An upper limit of 1,000 fish was set for a year-quarter to prevent extremely high sample sizes in certain year-quarters from being overly influential. Normalised weightings were converted to weightings by fish $F_{i,t}$ by calculating $F_{i,t} = W_{i,t} \times 1000$ to ensure this condition was met. The size frequencies were then multiplied by the ratio ($r_{t,l}$) of cell weighting to the total number of fish sampled in that cell-year-quarter $N_{i,t,l} = n_{i,t,l} \times r_{t,l}$, where $r_{i,t} = F_{i,t} / \sum_l n_{i,t,l}$. From this the aggregate, region-wide size distribution was calculated by summing over the weighted cell-specific size frequencies, i.e. $N_{t,l} = \sum_{i=1}^{M} N_{i,t,l}$, where M is the number of 10×20° spatial cells in the region. These are the size frequencies that are used for the longline fishery that includes the JPLL fleet in each assessment region. It should be noted that size frequencies calculated in this manner will often not be integers, but this is not a requirement in MFCL.

Two extra steps were added to the calculations above. Firstly, often there are no size frequencies available for some spatial cells in a year-quarter and it is impossible to reweight a size distribution with zero fish. In these cases the size distribution in the cell with missing data is ignored and so in an extreme case there might only be size data from cells with very little catch. Thus, size frequencies aggregated to the region-scale may be significantly different than if size data were available for all cells. A limit on the lowest total weighting for a year-quarter can be imposed to prevent this situation occurring, as was used in previous assessments (e.g. Hoyle and Langley 2011). For example, if the limit was set at 0.5 and the sum of the normalised weightings for the cells with data available was <0.5 then all data for that region in that year-quarter are rejected and the stock assessment model treats the data as missing. Choice of the limit is relatively arbitrary and was decided by examining the nature of "missingness" of data for spatial cells and by comparing raw and reweighted regional-scale size frequencies. A balance is required between preventing the loss of data from too many year-quarters (if a high limit is imposed, e.g. 0.8) and preventing undesirable temporal variation in size distributions when different cells with different sizes contribute to the region-scale size distribution (if a low limit is imposed, e.g. 0.1).

Secondly, the calculations above could lead to the effective number of fish in a spatial cell being higher than the actual number measured. This would be the case in cells with high weightings but very few fish measured. To prevent this a conditional statement is added to the algorithm whereby if any of the ratios $r_{t,l}$ are above one then an adjusted weighting ratio is calculated as $r^{*}_{t,l} = r_{t,l}/r^{max}_{t,l}$ where $r^{max}_{t,l}$ is the maximum of the $r_{t,l}$. Finally the reweighted size frequencies in each cell are calculated $N_{i,t,l} = n_{i,t,l} \times r^{*}_{t,l}$ and these are then aggregated to the region-scale by again calculating $N_{t,l} = \sum_{i=1}^{M} N_{i,t,l}$.

3.1.4. *Size frequencies used and fisheries fitted to data*

Inconsistencies between JPLL length and weight frequency data are well documented (Hoyle and Langley 2011, Ianelli *et al.* 2012) and appear to be related to differences in the fishing operations collecting the size samples. The length frequency data are considered less representative of the commercial longline fleet as the majority comes from training vessels while the weight frequency data are obtained from dedicated commercial vessels. The bigeye review suggested omitting the length frequency data and so the analyses presented here are largely restricted to weight frequency data, but the same methods apply to both and it is trivial to undertake calculations on both simultaneously. The exception is in region 4 after 1990 when length frequency data were spatially reweighted and used in the assessment model to address the lack of weight frequency data for that period.

The reweighted size frequency data are attributed to the fisheries in each region that include the JPLL fleet which are the "all flags" fisheries. These are fisheries 1, 2, 4, 9, 12, 13, 7, and 8, in regions 1 to 8 respectively (McKechnie *et al.* 2014).

3.2. Multiple fleets size frequencies weighted by catch

For longline fisheries other than the "all flag" fisheries, size frequencies used in MFCL are the raw frequencies as extracted from SPC databases and so the frequencies are the sum over the various fleets within the fishery. In some cases these data may have been down-weighted in comparison to the all flag fisheries data to reflect uncertainty in the quality of sampling and whether they are representative of fish size caught in the fishery. Particularly where there is inconsistency in sample sizes provided by some fleets over time. Please see the individual assessment reports for details of data treatment.

Size frequency data for several additional fisheries were reweighted for the 2014 assessments using similar methods to those described in section 3.1.3. The only difference in the algorithm is that weightings were calculated for individual fleets within a fishery rather than for spatial cells within a region. Cell weightings $W_{i,t}$ were consequently calculated

$$W_{i,t} = \frac{\sum_{t-k}^{t+k} C_{i,t}}{\sum_{i=1}^{M} \sum_{t-k}^{t+k} C_{i,t}}$$

where $C_{i,t}$ is the catch of fish in numbers by fleet *i* in year-quarter *t*, *M* is the number of fleets in the fishery, and *k* is a time-period that must be defined (it was set at 5 year-quarters for all fisheries) and represents a moving sum of catch for that fleet. All other calculations described in section 3.1.3 are used to derive the aggregated size frequency for the fishery. The lower limit on the sum of weightings for a year-quarter was not imposed as there were nearly always size samples for most of the fleets catching significant numbers of fish.

Fisheries (see McKechnie et al. 2014 for definitions and further details of the fisheries) for which reweighting occurred were:

1. Fishery 5 (“offshore fleets”, region 3). Weight frequency data were reweighted for the whole time-period after removing Chinese Taipei offshore data from 2004 onwards due to a major, unexplained shift in size frequencies for this fleet at that time.
2. Fishery 6 (“offshore fleets”, region 7). Weight frequency data were reweighted for the whole time-period.
3. Fishery 12 (“all flags”, region 5). Very little JPLL size data were available after the mid-1990s in this region and so from 1995-2012 weight frequencies were aggregated over all fleets for which data were available using the fleet reweighting method. The resulting weight frequencies were used in MFCL for this time period for this region, with the reweighted JPLL weight frequencies (calculated in section 3.1.3) used for the period prior to 1995.
4. Fishery 13 (“all flags”, region 6). The situation for this fishery is the same as for fishery 12, and an identical process was undertaken for the same time periods.

4. Results and Discussion

The reweighting of the JPLL size frequencies resulted in largely similar distributions to the unweighted distributions (Figure 2, Figure 3). The temporal variation in size was generally reduced slightly and in the cases where higher variation occurred (e.g. region 5, YFT; Figure 3 a) the effective sample sizes of the more extreme reweighted datasets were very low, and thus can be expected to have low influence on the stock assessment model.

The lower limit on the total weighting for a year-quarter was set at 0.3 for calculation of size frequencies that will be used in reference case stock assessments. Using this low limit prevented data from too many year-quarters being rejected while not appearing to allow much more temporal variation in size frequencies than if a limit such as 0.7 was used (Figure 2 b, Figure 3 b). It is important to note that even with the low limit, data for some year-quarters were still rejected and for some regions datasets were sparse even before reweighting. This is particularly the case for regions 4, 5 and 6 where there was little JPLL weight frequency data available after about the 1990s. This is the reason that length data were used in later years for region 4, and multiple-fleets data were used from 1995 for regions 5 and 6.

The choice of values for parameters such as the lower limit on total weightings and the length of the window for calculating weights are relatively arbitrary and are determined by trying to balance several conditions; preventing discarding data from too many year-quarters, reducing temporal size variation introduced by unbalanced spatial sampling, ensuring reweighted size frequencies provide a good representation of the sizes of fish being removed by the catch. While our choices attempt to meet these conditions we also recommend considering alternative parameter values in sensitivity analyses of the stock assessments to ensure that these choices do not have a profound effect on estimates of stock status and the formulation of management advice.

The reweighted multiple-fleets size frequencies were also similar to the raw frequencies (Figure 4, Figure 5), although the effective sample sizes were often substantially reduced, especially for fishery 6. This is a consequence of few size data being available in some year-quarters for fleets catching a lot of the fish. We recommend further investigation of the reasons for the sudden increase in size samples for the Chinese Taipei longline fleet in fishery 5 in region 3 after the mid-2000s. A first approach might involve investigation of the spatial distribution of the size samples at a finer scale than the region level.

5. References

Davies, N., Hoyle, S., Harley, S., Langley, A., Kleiber, P., Hampton, J. (2011). Stock assessment of bigeye tuna in the Western and Central Pacific Ocean. WCPFC-SC7-2011/SA-WP-02.

Harley, S. J., Hoyle, S., Williams, P., Hampton, J. (2010). Background analyses in the development of the 2010 WCPO Bigeye Tuna assessment. WCPFC-SC6-2010/SA-WP-01.

Hoyle, S. D., Langley, A. D. (2011). Spatial size data stratification for length-based stock assessments. WCPFC-SC7-2011/SA-IP-09.

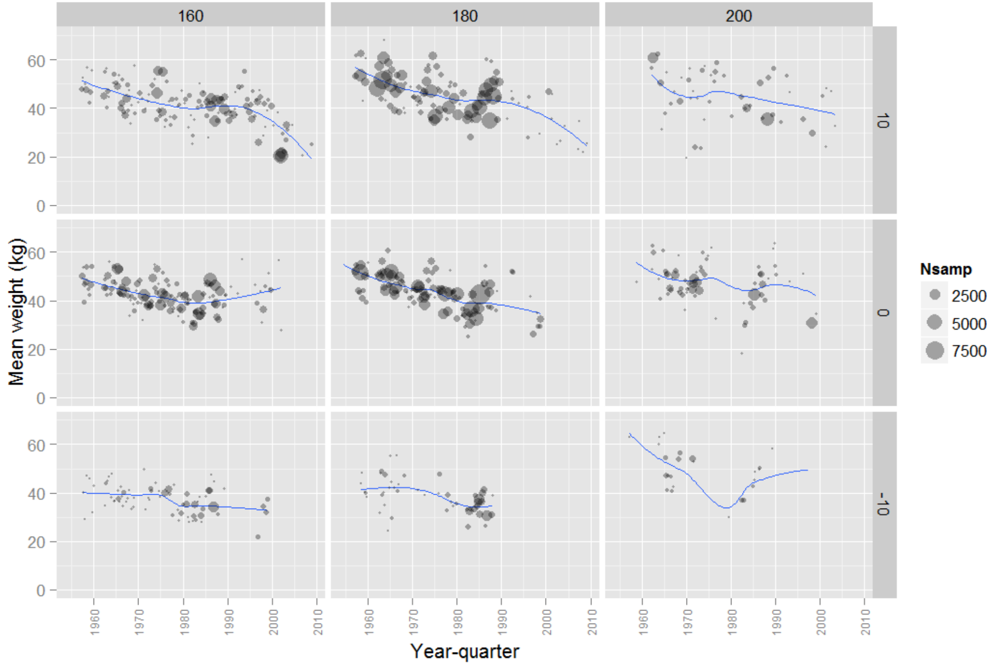
Ianelli, J., Maunder, M., Punt, A. (2011). Independent review of 2011 WCPO Bigeye Tuna assessment. WCPFC-SC8-2012/SA-WP-01.

Langley, A., Hoyle, S., Hampton, J. (2011). Stock assessment of yellowfin tuna in the Western and Central Pacific Ocean. WCPFC-SC7-2011/SA-WP-02.

McKechnie, S., Berger, A., Harley, S., Davies, N., Rice, J., Williams, P. (2014). Basis for regional structures used in the 2014 tropical tuna assessments, including regional weights. WCPFC-SC10-2014/SA-IP-02

6. Figures

a Bigeye



b Yellowfin

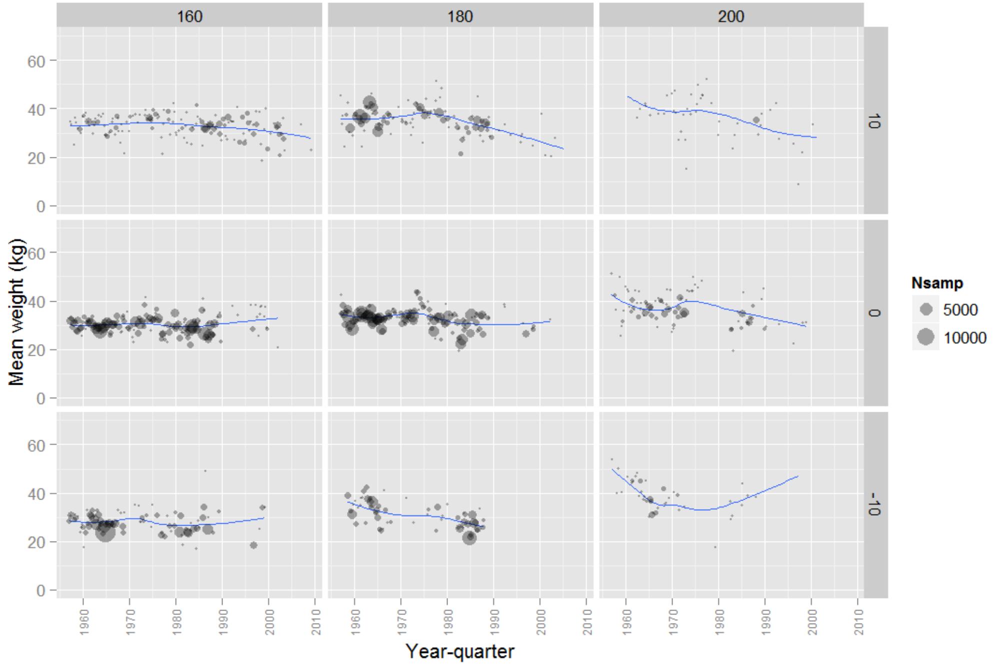
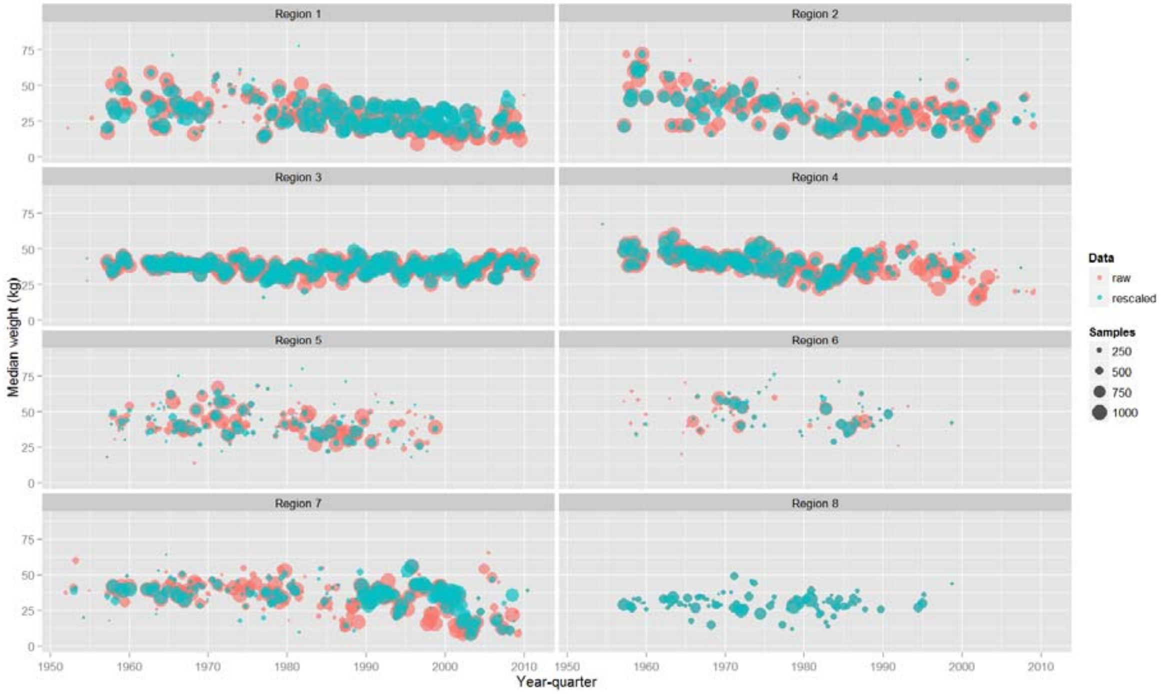


Figure 1: Example of mean weights of BET (top) and YFT (bottom) over time in different 10×20° spatial cells within stock assessment region 4. Each panel represents a different spatial cell, with the longitude and latitude of the Southwest corner of the cell given by the numbers at the top and on the side respectively. Points are the means and the size of the point indicates the number of size samples available for that year-quarter. Note the differences in data availability, sample sizes and changes in mean weight between spatial cells.

a Bigeye; sum of weights >0.3



b Bigeye; sum of weights >0.7

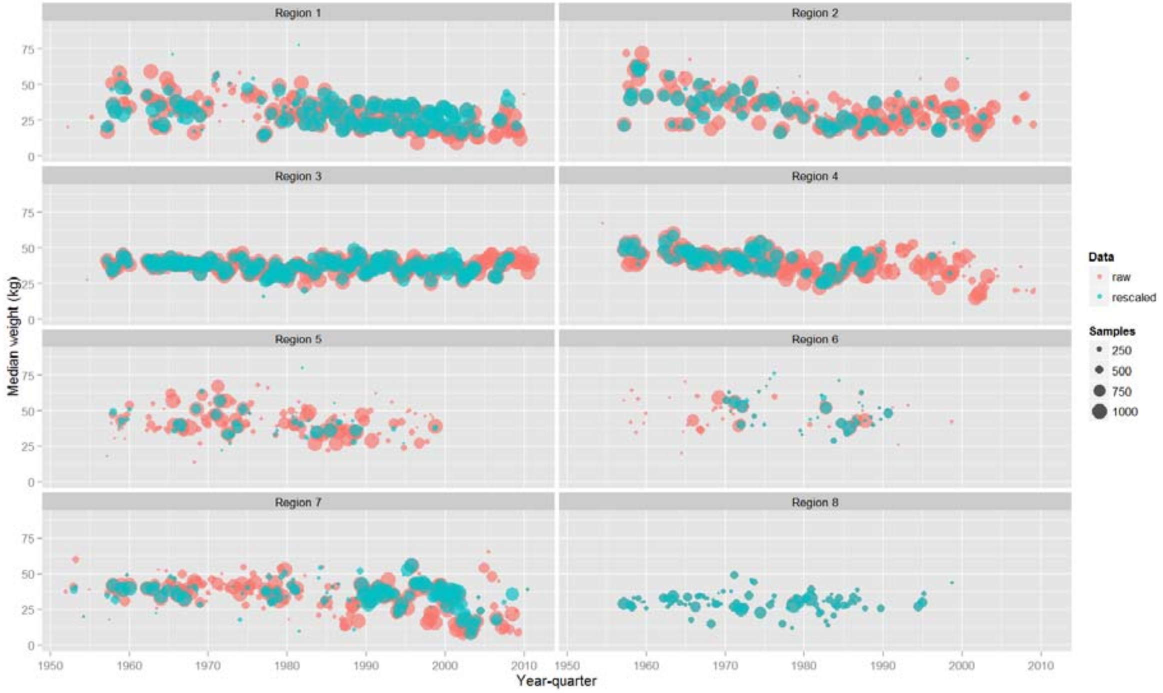
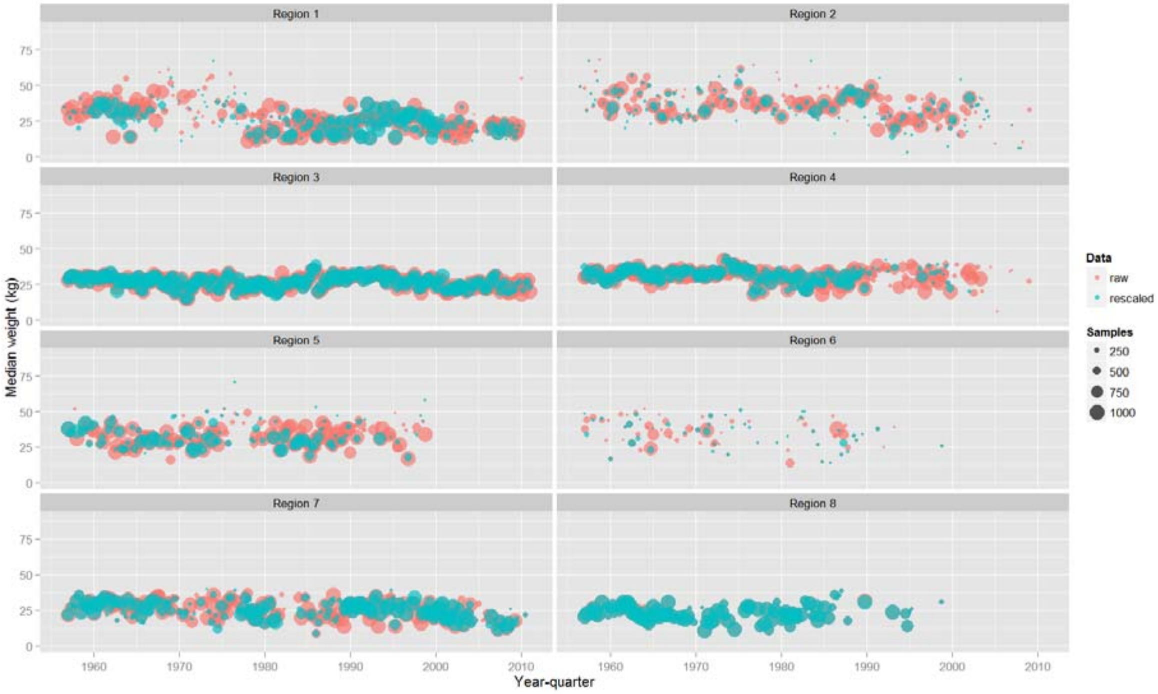


Figure 2: A comparison of the spatially reweighted (blue) and raw/unweighted (pink) JPLL size frequencies for BET by region, with a limit on the lowest total weighting of 0.3 (a) and 0.7 (b) imposed. Note that there is only one 10×20° spatial cell in region 8 so the raw and reweighted size frequencies are identical. The size of the points indicates the sample size in number of fish that they represent. Note that the maximum point-size was

set at 1,000 fish to prevent raw data points with very high sample sizes (e.g. > 10,000 fish) from obscuring the interpretation of the plots.

a Yellowfin; sum of weights >0.3



b Yellowfin; sum of weights >0.7

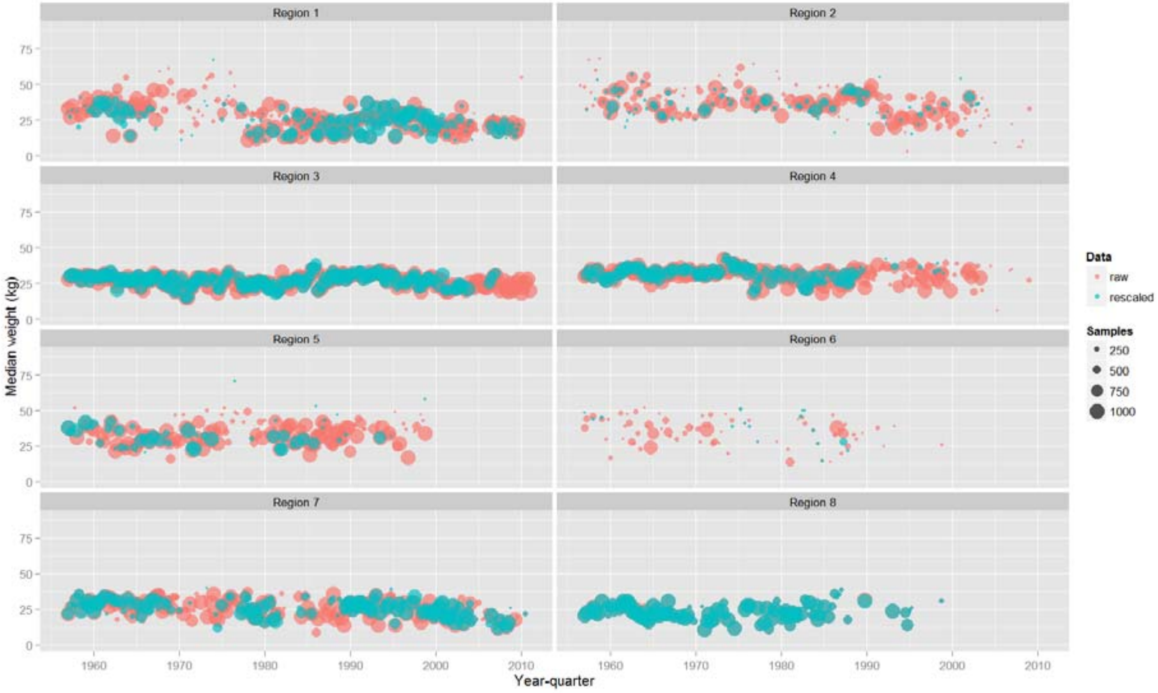
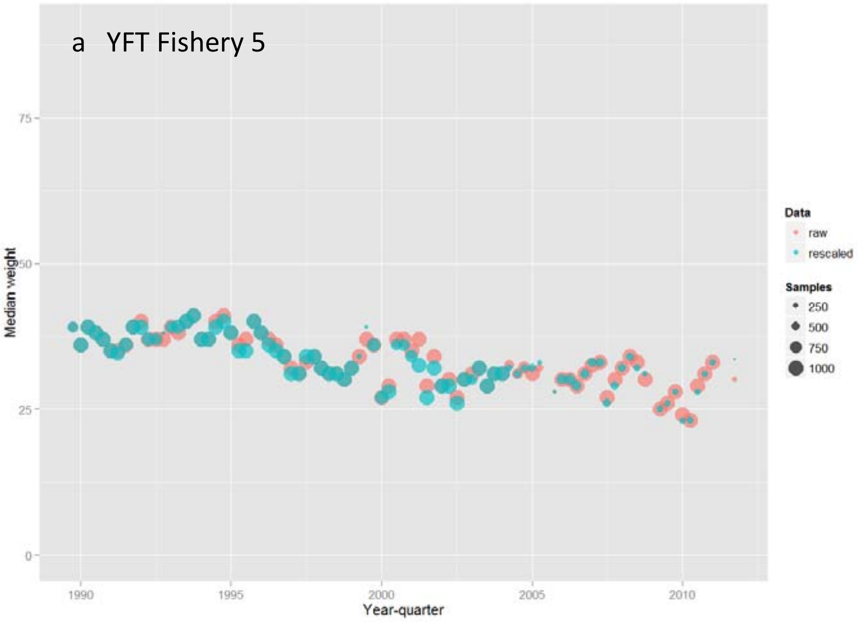


Figure 3: A comparison of the spatially reweighted (blue) and raw/unweighted (pink) JPLL size frequencies for BET by region, with a limit on the lowest total weighting of 0.3 (a) and 0.7 (b) imposed. Note that there is only

one 10×20° spatial cell in region 8 so the raw and reweighted size frequencies are identical. The size of the points indicates the sample size in number of fish that they represent. Note that the maximum point-size was set at 1,000 fish to prevent raw data points with very high sample sizes (e.g. > 10,000 fish) from obscuring the interpretation of the plots.**

Figure 4: A comparison of the fleet-based reweighted (blue) and raw/unweighted (pink) weight frequencies for BET for fisheries 5 (a; region 3) and 6 (b; region 7). The size of the points indicates the sample size in number of fish that they represent. Note that the maximum point-size was set at 1,000 fish to prevent raw data points with very high sample sizes (e.g. > 10,000 fish) from obscuring the interpretation of the plots.



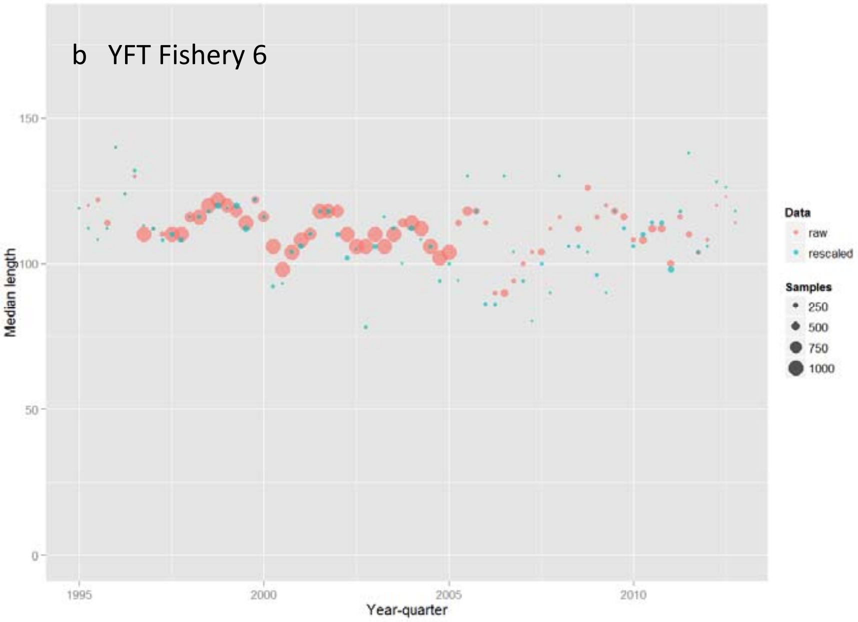


Figure 5: A comparison of the fleet-based reweighted (blue) and raw/unweighted (pink) weight frequencies for YFT for fisheries 5 (a; region 3) and 6 (b; region 7). The size of the points indicates the sample size in number of fish that they represent. Note that the maximum point-size was set at 1,000 fish to prevent raw data points with very high sample sizes (e.g. > 10,000 fish) from obscuring the interpretation of the plots.