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Spatial analysis of shortfin mako shark size compositions in the North Pacific Ocean[1]

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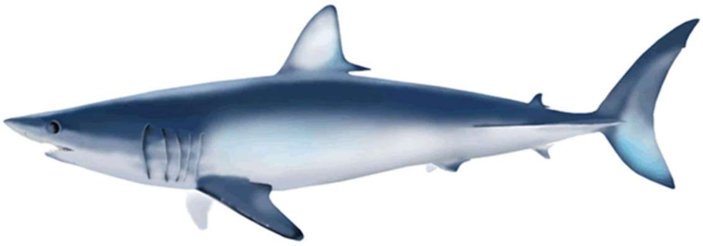

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[1] This working paper was submitted to the ISC Shark Working Group Intercessional Workshop, 29 November – 7 December 2023, held at the Fisheries Resources Institute, Japan Fisheries Research and Education Agency, Kanagawa, Japan.

ABSTRACT

In preparation for the next stock assessment of north Pacific shortfin mako shark in 2024, the ISC SHARKWG is developing a conceptual model of the NP-SFM stock and using it to improve the 2024 assessment model. This study follows up on the conceptual model work and used a series of regression tree analyses, using the R package 'FishFreqTree', to examine the size compositions used in the 2018 assessment (1981 through 2016), as well as updated data through 2022 for some fisheries. These data were from 10 fisheries: 1) Japan Kinkai Shallow Longline (JPLL_KK); 2) Japan Coastal Longline (JPLL_C); 3) Japan Deep Longline (JPLL_D); 4) US Shallow Longline (USLL_S); 5) US Deep Longline (USLL_D); 6) Mexico Longline North (MXLL_N); 7) Mexico Longline South (MXLL_S); 8) Japan Drift Gill Net (JPDGN); 9) US Drift Gill Net (USDGN), and 10) Taiwan Large-scale Longline (TWLL). The aim is to identify areas with more consistent size compositions for each fishery and these areas with consistent size compositions could be used as candidate fishery definitions. The analyses were focused on three groups of fisheries in three regions.

Based on the results of this study, we made 9 recommendations to the WG for consideration. We recommended that:

1) the WG perform analyses for each fishery to select the appropriate bin size for each fishery and minimize potential biases from the aliasing;
2) the WG consider using data from the JPLL_D and/or USLL_D fisheries to develop an index for subadult/adult female sharks;
3) the WG examine and understand the source of the JPLL_D data.
4) the USDGN fishery be separated into two fisheries, with one covering the nursery area in the SCB and possibly sharing selectivity with the MXLL_N fishery;
5) the WG consider using fishing area rather than port to separate the MXLL_N and MXLL_S fisheries;
6) the USLL_S be separated into two fisheries, with one north of 30°N and one to the south; and
7) the WG consider splitting the JPLL_S and USLL_D fisheries at around 20-25°N.
8) the WG consider separating the JPLL_KK fishery into two fisheries, with one west of 165°E and one to the east.
9) the WG consider separating the TWLL fishery into two fisheries, with one north of 20-25°N and one to the south.

INTRODUCTION

The ISC SHARKWG last assessed the North Pacific stock of shortfin mako shark (NP-SFM) in 2018 (SHARKWG 2018). In preparation for the next assessment in 2024, the ISC SHARKWG is developing a conceptual model of the NP-SFM stock and using it to improve the 2024 assessment model (SHARKWG 2023). Discussions on the NP-SFM conceptual model showed that NP-SFM life history is complex and still highly uncertain in many aspects. These discussions indicated that the stock exhibit ontogenetic (and seasonal) shifts in spatial distribution. For example, as juvenile NP-SFM age into the sub-adult stages, they tend to move from coastal habitats off Japan and Southern California towards habitats further offshore in the central North Pacific.

A fleets-as-areas approach (Hurtado-Ferro et al. 2014) was used in the 2018 assessment, with the fleet structure of the assessment model largely based on combinations of country, gear, and fishery operational characteristics (e.g., deep-set vs shallow-set). Some of the fleets from the 2018 assessment have large operational areas that likely overlap the spatial distributions of multiple life history stages identified in the conceptual model. These 'composite' fleets likely have catches from multiple life history stages with proportions that vary with fishery operations. Therefore, the size composition data from these fleets may be poorly fit by a model assuming fixed selectivities and may in turn, bias the results of the assessment. There are three main strategies to deal with poor fits to these 'composite' size composition data and/or reduce potential bias: 1) use flexible and time-varying selectivity patterns; 2) downweight the size composition data; and 3) subdivide the 'composite' fleets into their constituent components. Each of these strategies have pros and cons, and may be used solely or in combination, depending on the characteristic of the fleet and/or assessment.

In this study, we examine the size composition data from the 2018 NP-SFM assessment for each fleet in finer spatial scales, and identify areas with more consistent size compositions for each fleet. If the abovementioned third strategy (i.e., subdivide the 'composite' fleets into their constituent component fleets) is used by the SHARWG for a specific fleet, these areas with consistent size compositions could be used as candidate fleet definitions. Furthermore, this analysis could help inform the SHARKWG discussions on the conceptual model for the assessment.

MATERIALS AND METHODS

Data

The data for this study were primarily the length data used in the 2018 assessment from 1981 through 2016, as well as updated data through 2022 for the Taiwan Large-scale Longline fishery. These data (131,302 fish) were from 10 fisheries: 1) Japan Kinkai Shallow Longline (JPLL_KK; 95,337 fish); 2) Japan Coastal Longline (JPLL_C; 1,346 fish); 3) Japan Deep Longline (JPLL_D; 2,609 fish); 4) US Shallow Longline (USLL_S; 947 fish); 5) US Deep Longline (USLL_D; 747 fish); 6) Mexico Longline North (MXLL_N; 2,830 fish); 7) Mexico Longline South (MXLL_S; 1,191 fish); 8) Japan Drift Gill Net (JPDGN; 8,233 fish); 9) US Drift Gill Net (USDGN; 13,121 fish), and 10) Taiwan Large-scale Longline (TWLL; 4,941 fish).

Spatial resolutions (longitude x latitude) of the data were variable and included: 1) set-specific locations (22,126 fish); 2) locations in 1° x 1° blocks (3,821 fish); 3) locations in 5°x5° blocks (53,566 fish); 4) locations in 20°x10° blocks (49,830 fish); and 5) missing latitude and/or longitude (1,959 fish). Data with spatial resolutions of 5°x5° or finer, were aggregated into 5°x5° blocks (Fig. 1). Data with missing locations or in 20° x 10° blocks were excluded from the spatial analysis because this study focused on elucidating finer scale spatial patterns. The exclusion of the data with 20° x 10° resolution reduced the data from the JPLL_KK, JPLL_C, and JPDGN fisheries by 49,483, 111, and 236 fish respectively. Given that the impacts of excluding data with 20°x10° resolution were largely limited to the JPLL_KK fishery, we compared the spatial coverage and size distributions of samples from 20°x10° blocks with those from 5°x5° blocks or finer for the JPLL_KK fishery (Fig. 2 & 3).

Size composition data used in this analysis were predominantly sex-specific, with 31,889 female, 35,274 male, and 14,309 unidentified fish. The 2018 assessment and all analyses in this study were based on precaudal length (PCL cm) but the vast majority (77.9%) of observations were of dorsal length (DL cm; distance between the origins of the first and second dorsal). Besides PCL and DL, it should be noted that some observations were also based on alternate lengths (5.8%), fork lengths (4.1%), and total lengths (3.8%). Conversions from one length type to another can lead to aliasing of the size data. Preliminary visual examination of the size composition data indicated aliasing of the data (e.g., Fig. 3). Using a larger bin size of 7 cm PCL (bin edges: 10, 17, 24, … , 374, 381, 388+ cm PCL) appeared to reduce aliasing for all the fisheries (Fig. 4). However, **it is recommended that the SHARKWG perform analyses for each fishery to select the appropriate bin size for each fishery and minimize potential biases from the aliasing**.

Spatial analyses

The main objective of the spatial analyses was to identify areas that had relatively consistent size compositions for each fishery, without considering temporal effects like year and season. While we would ideally include year and season effects for all fisheries, the data for many fisheries were too sparse for spatiotemporal analyses. Nevertheless, results from spatial analyses could be useful for improving the NP-SFM assessment.

The analyses were focused on three groups of fisheries in three regions (see Fig. 1): 1) the coastal eastern Pacific Ocean (EPO) group, with the MXLL_N, MXLL_S, and USDGN fisheries; 2) the central and eastern Pacific Ocean group (CEPO), with the JPLL_D, USLL_D, and USLL_S fisheries; and 3) the western Pacific Ocean (WPO) group, with the JPLL_KK, JPLL_C, and JPDGN fisheries. This study treated each region independently to reduce analytical complexity but should be thought of conceptually as a single population ranging from the WPO to the EPO. In addition to these three groups, the TWLL fishery was analyzed separately because the data was received separately. Depending on the group and region, some fisheries were combined for the analyses while others were kept separate (see details below).

The size data were first aggregated into 5°x5° blocks, for all years and seasons, by fishery or group of fisheries (Fig. 1). Blocks with <30 fish were considered poorly sampled and excluded from the spatial analyses. Each data stratum was the size composition in 7 cm bins for each 5°x5° block, aggregated over all years and seasons, for a specific fishery or group of fisheries.

Regression trees (RTs) were subsequently used to sequentially split these data into two or more spatial groups with more within-group homogeneity (Lennert-Cody et al. 2010). The number of groups is subjective and dependent on a judgement of the improvements in within-group homoegeneity, differences in resulting size compositions, and characteristics of the fishery or group of fisheries. It is important to note that the objective of the analyses is to guide the decision making of the WG in terms of the fleet structure for the assessment, and the final decision will be a trade off between homogeneity of the size data versus complexity and tractability of the assessment model. The analyses were performed using the R package 'FishFreqTree' (Lennert-Cody et al. 2010; Xu and Lennert-Cody 2023).

For the coastal EPO, we focused on the question whether the fishery structure used in the 2018 assessment was adequate or using spatial definitions would improve the consistency of size compositions. To answer this question, we first analyzed the size compositions from the MXLL_N, MXLL_S, and USDGN in turn and examined if splitting the size compositions of each fishery spatially would be a substantial improvement. Next, we combined the MXLL_N and MXLL_S fisheries into a single fishery and analyzed the size compositions. Lastly, we combined all three fisheries into a single fishery and analyzed the size compositions. Details of the coastal EPO group of fisheries and their size data can be found in previous working papers (Castillo-Geniz et al. 2017; Kinney et al. 2017).

For the CEPO, we asked similar questions for the JPLL_D, USLL_D, and USLL_S fisheries. The spatial distributions of the JPLL_D and USLL_D size data overlapped substantially (Fig. 1) and were both deep-set longline gears. The spatial distribution of the USLL_S fishery overlapped partially with the other two but used shallow-set longline gears (Fig. 1). First, we examined if splitting the size compositions of each fishery spatially would be a substantial improvement. Next, we combined the JPLL_D and USLL_D fisheries into a single fishery and analyzed the size compositions. Lastly, we combined all three fisheries into a single fishery and analyzed the size compositions. Details of the US and Japan longline fisheries and their size data can be found in previous working papers (Kinney et al. 2017; Semba 2017).

A different strategy was taken for the WPO because the JPLL_KK spanned a very large area and had very large number of samples compared to the JPLL_C and JPDGN fisheries (Fig. 1). Therefore, these three fisheries were analyzed independently, although comparisons of the size compositions were made. However, the large number of samples of the JPLL_KK fishery allowed us to analyze sex-specific differences in the JPLL_KK fishery as well. In addition, we performed one more analysis with combined JPLL_KK and USLL_S size data because there was relatively little overlap in the two data sets and the USLL_S data could be considered as a longitudinal extension of the JPLL_KK data (Fig. 1).

RESULTS AND DISCUSSION

The sex-specific size compositions from the 2018 assessment are shown in Figure 4. Importantly, two of the fisheries in the CEPO (JPLL_D and USLL_D) have substantially larger average sizes of shortfin mako sharks and substantially larger proportions of females >200 cm PCL (Table 1). It is interesting that the samples from these two fisheries largely come from the central Pacific Ocean (Fig. 1), which is consistent with the conceptual model proposed by the WG. This indicates that, among all the fisheries in this study, the catch and effort from the JPLL_D and USLL_D fisheries in the central Pacific Ocean will likely be the most useful at tracking the trends of the subadult/adult female population. Therefore, **we recommend that the**

WG consider using data from the JPLL_D and/or USLL_D fisheries to develop an index for subadult/adult female sharks. However, it should be noted that the aims of this study did not include abundance index development and did not consider other important factors (e.g., misreporting, changing regulations and fishing operations) in abundance index development (Hoyle et al. 2024). Nevertheless, if tracking the trends of the subadult/adult female population is important for the upcoming assessment, it would likely be useful for the WG to develop and consider candidate indices from these two fisheries. Interestingly, the majority of the JPLL_D data is from the east of 180 °E, which is inconsistent with the operational characteristics of the fishery and may be more consistent with the operations of the Japan training and research longline vessels. It is therefore **recommended that the WG examine and explore the source of the JPLL_D data**.

Interestingly, three of the fisheries (JPLL_KK, USLL_S, and USDGN) have bimodal size compositions (Fig. 4). These bimodal size compositions likely indicate that these fisheries are composite fisheries fishing on different groups of fish. It may be useful to try separating these into their constituent fisheries to improve the consistency of the size compositions. Several of the fisheries (JPLL_KK, MXLL_N, USDGN, and USLL_S) also have relatively large proportions of fish <100 cm PCL, which indicate that at least part of the distributions of these fisheries overlap with the habitat of age-0 and age-1 fish.

For the coastal EPO group of fisheries, the regression tree results of individual fisheries (Fig. 5) suggest that the USDGN may be better split into two fisheries because the part of the fishery within the southern California Bight (SCB) catches substantially smaller fish than outside the SCB. On the other hand, the separation of the Mexico longline into two fisheries (MXLL_N and MXLL_S) was well supported (Fig. 6). However, an alternative to basing the separation on home port (Ensanada and Mazatlan) would be to use the fishing area because there is some overlap to the fishing areas of the two fisheries (Fig. 1 and 5). The SCB is known to be a nursery area for mako sharks (Runcie et al. 2016; Nasby-Lucas et al. 2019) and extends from Point Concepcion, California to Punta Colonet, Baja California Norte. Therefore, it is not surprising that if we look at the regression tree results of the combined size compositions from all three fisheries (Fig. 6), there is a clear separation of the SCB size composition data, with smaller fish, and the areas north and south of the SCB (Fig. 6). In addition, the fishing effort of the USDGN fishery had shifted spatially and decreased over the years due to regulations (Urbisci et al. 2017). Overall, **we would recommend that the USDGN be separated into two fisheries, with one covering the nursery area in the SCB and possibly sharing selectivity with the MXLL_N fishery**. We also **recommend that the SHARKWG consider using fishing area rather than port to separate the MXLL_N and MXLL_S fisheries**. However, it should be noted that the USDGN fishery uses different gear from the MXLL_N fishery and it may not be desirable to combine them. It should also be noted that there is also a Mexico drift gill net fishery in the area but the data was not included in this analysis.

The regression tree results of individual fisheries in the CEPO group indicate that the size compositions of the USLL_S fishery north of 30°N are distinct from and smaller than the size compositions from the USLL_D and JPLL_D fisheries (Fig. 7). However, the size compositions from the USLL_D and JPLL_D fisheries are relatively similar, with a potential split around 20-25°N. Surprisingly, the fish south of 20-25°N appeared to be slightly smaller than the fish north of this split (Fig. 7 & 8). When the size compositions of all three fisheries in the CEPO group (USLL_D, USLL_S, and JPLL_D) are combined and subjected to three splits (Fig. 8), the results suggest that the area north of 30°N and east of 205°E have fish smaller than the other areas. However, this interpretation may be incorrect because the split at 205°E is likely due to the mixing of size compositions from different fisheries with different fishing depth. This suggests that fishing depth (deep-set vs shallow-set) is an important factor in segregating different sized fish. Importantly, size compositions north of 30°N and west of 205°E include USLL_D and JPLL_D data while the area east of 205°E do not. Additional analyses would be necessary to examine longitudinal differences in size compositions in the areas north of 30°N. Overall, **we would recommend that the USLL_S be separated into two fisheries, with one north of 30°N and one to the south. We would also recommend that the WG consider splitting the JPLL_S and USLL_D fisheries at around 20-25°N.** If a reduction in assessment model complexity is desired, the WG may consider sharing the selectivities of these fisheries.

For the WPO group of fisheries, the JPLL_KK fishery is substantially larger in operational area and catches substantially more shortfin mako sharks than the JPLL_C and JPDGN fisheries (Fig. 1). The regression tree results for the JPLL_C and JPDGN fisheries indicate that the within fishery size compositions are relatively consistent, which is not surprising given the small operational area for both fisheries (Fig. 9). Interestingly, the JPLL_C size composition appear to be slightly larger than the JPLL_KK fishery, even within the same general area. For the JPLL_KK fishery, the sharks from the more coastal area appear to be substantially smaller than the offshore area (Fig. 9). The average size and size associated with the first mode of the JPLL_KK size composition appear to be smaller than the EPO fisheries (Table 1 & Fig. 4) but the cause of this is currently unclear. The sex-specific regression tree results of the JPLL_KK fishery (Fig. 10) appear to be relatively consistent with each other. When the JPLL_KK and USLL_S are combined in the regression tree analysis (Fig. 11), the results indicate that the size compositions do not overlap greatly, in contrast to the JPLL_D and USLL_D fisheries. Even though both JPLL_KK and USLL_S operate in similar latitudes and distances from the coasts, the size of fish caught by the USLL_S, especially in the first mode, appear to be smaller. Overall, we **would recommend that the WG consider separating the JPLL_KK fishery into two fisheries, with one west of 165°E and one to the east.**

The TWLL fishery spans the largest area among the fisheries in this study but many areas were sparsely sampled (Fig. 1). The TWLL fishery can be broadly separated into two fisheries, with one targeting albacore tuna in temperate waters and one targeting tropical tunas in tropical waters with deep-set gear. The regression tree results for the TWLL fishery broadly reflects this separation (Fig. 12). Overall, we **would recommend that the WG consider separating the TWLL fishery into two fisheries, with one north of 20-25°N and one to the south.** Interestingly, the fish in the tropical area appears to be largely a mode around 100 cm PCL.

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Table 1. Sex-specific mean lengths and proportions of shortfin mako sharks larger than 200 cm PCL by fishery. *TWLL does not include any sex-specific size data.

Fishery	Mean length (cm PCL)	Female mean length (cm PCL)	Male mean length (cm PCL)	Females >200 cm PCL (%)	Males >200 cm PCL (%)
JPDGN	124.9	124.8	128.3	0.2	0.3
JPLL_C	139.2	139.2	141.7	0.6	1.8
JPLL_D	175.8	180.8	173.3	18.2	10.6
JPLL_KK	135.3	134.5	139.5	0.9	2.2
MXLL_N	105.2	104.7	106.0	0.5	0.5
MXLL_S	120.0	118.8	121.9	0.0	0.0
USDGN	109.6	108.3	108.3	0.6	0.2
USLL_D	168.4	171.3	165.1	15.6	7.0
USLL_S	128.9	109.7	144.1	4.2	17.9
TWLL*	133.5			1.9*	1.9*

FIGURES

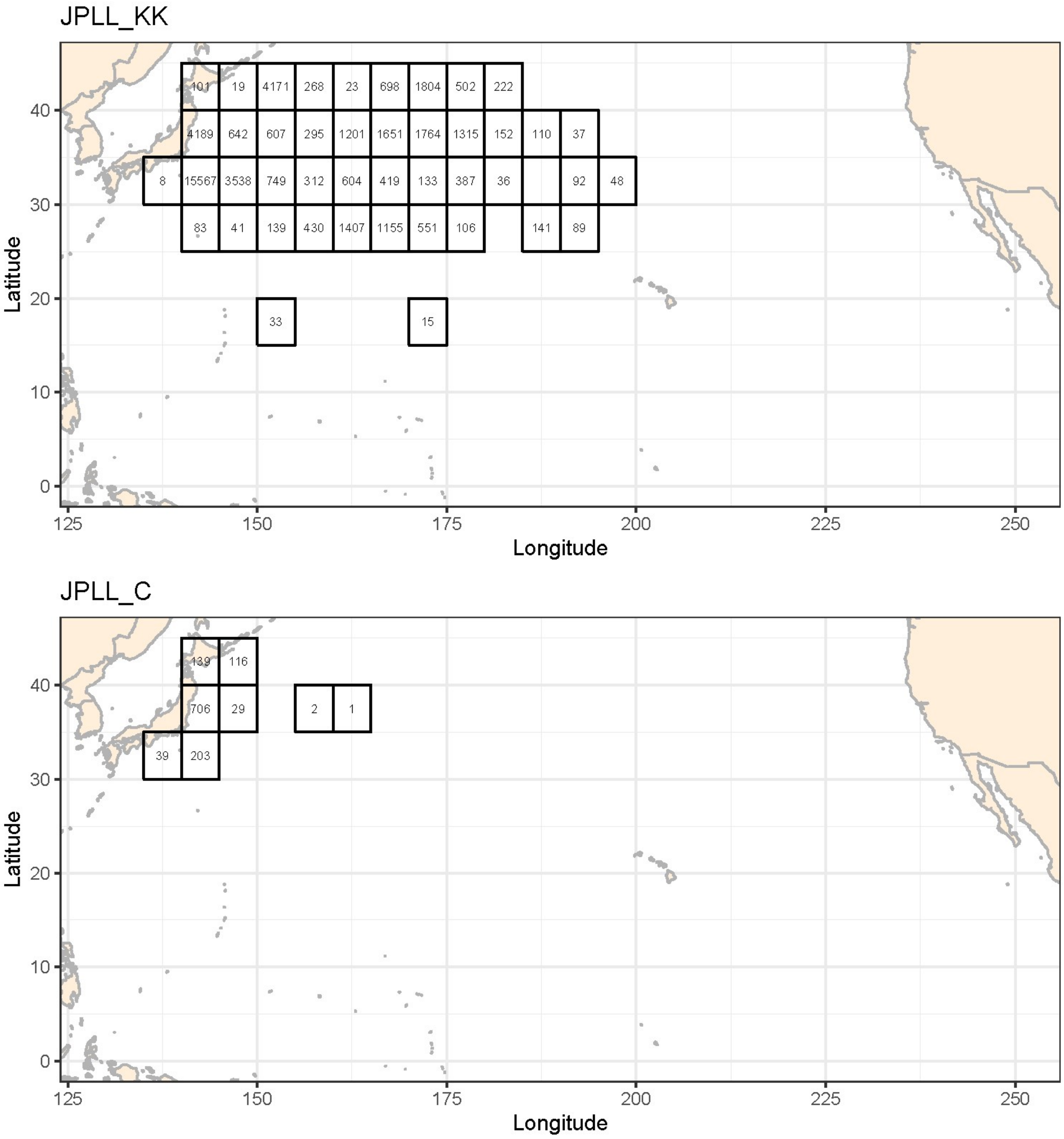
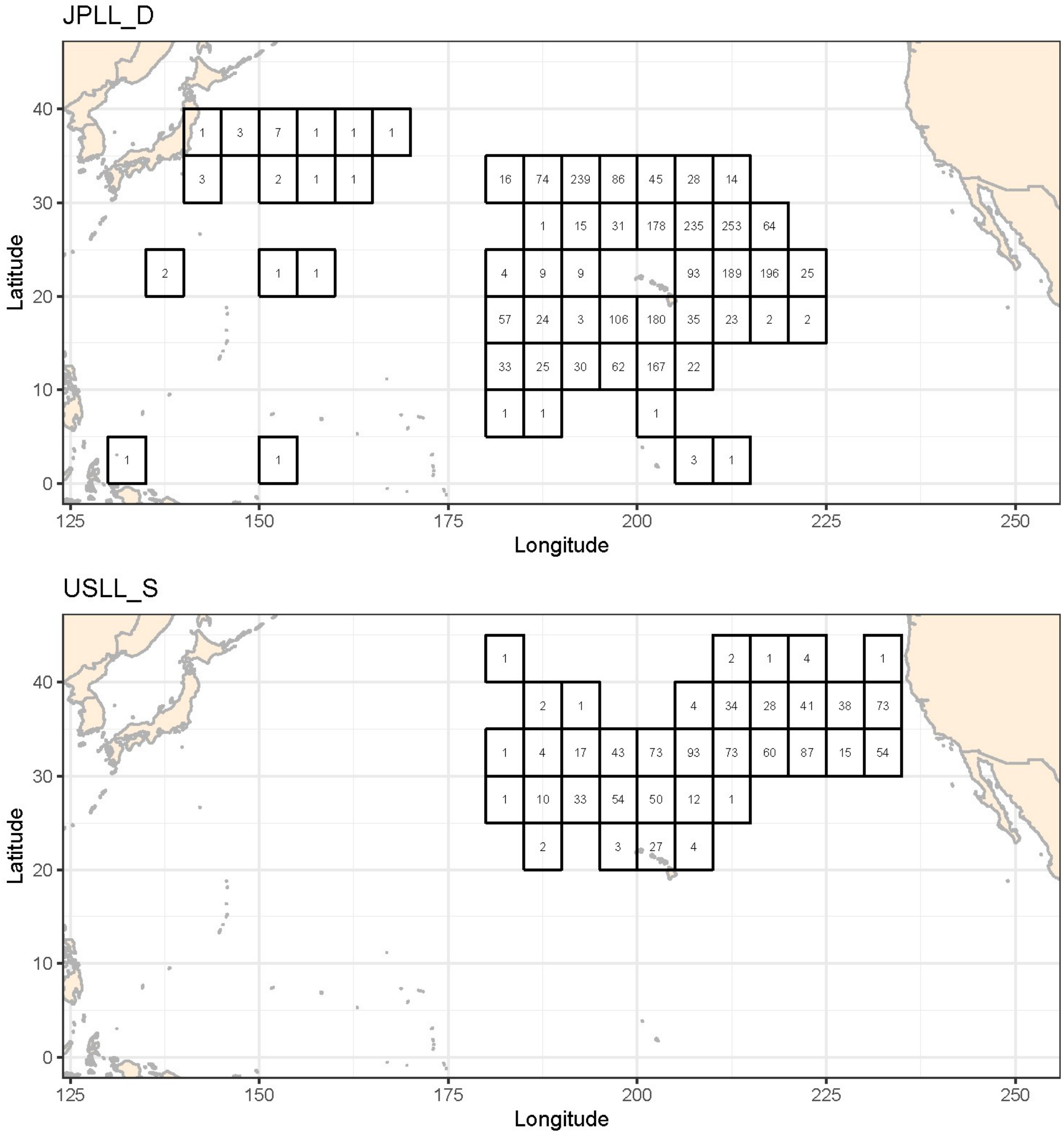


Figure 1. Spatial distribution of the size composition samples by fishery with spatial resolutions of 5°x5° or finer. Numbers indicate number of fish sampled within each area. Blocks with <30 samples were not used for spatial analysis. Upper left corner of each panel indicate the fishery. See text for description of each fishery.



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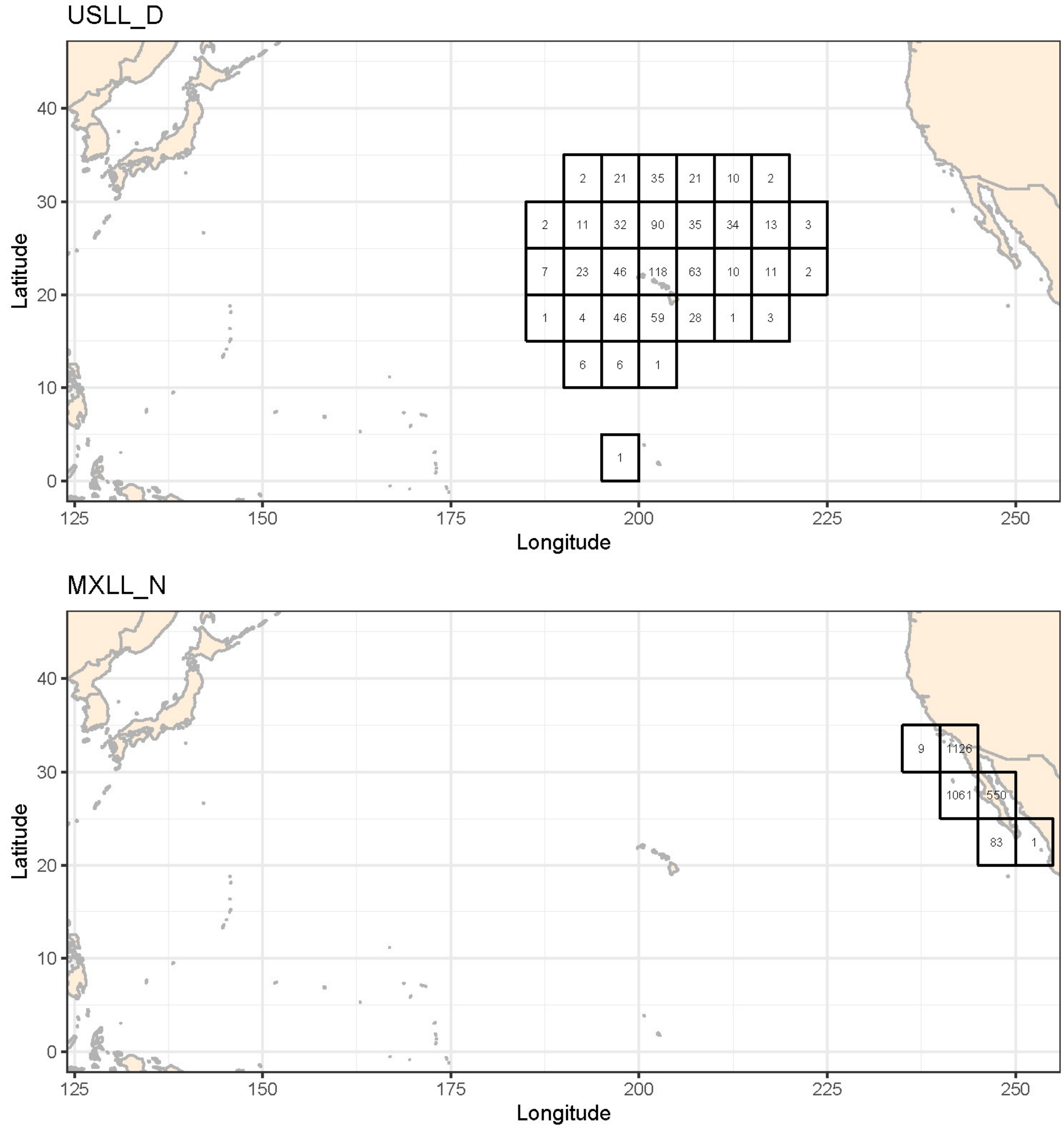

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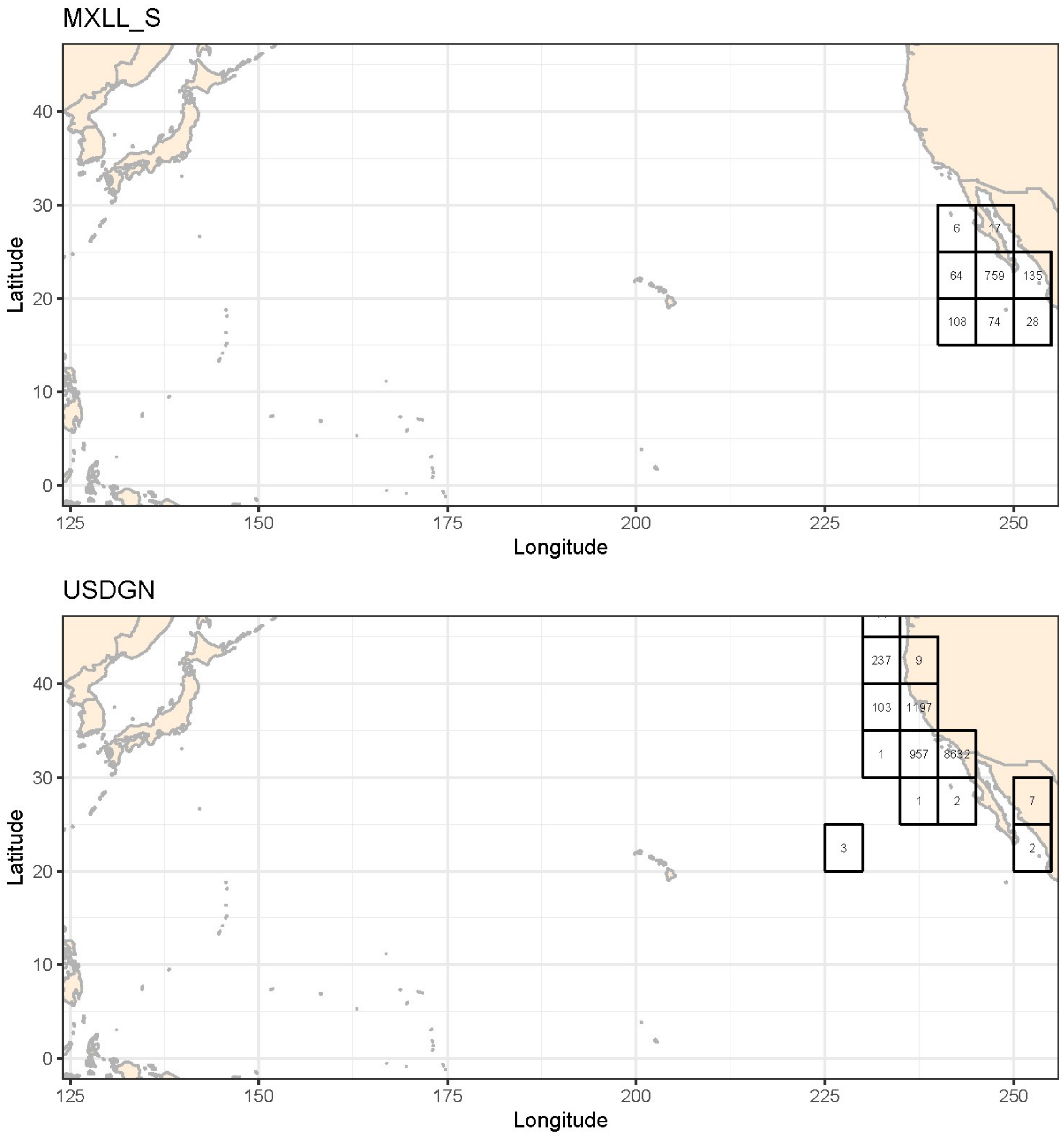

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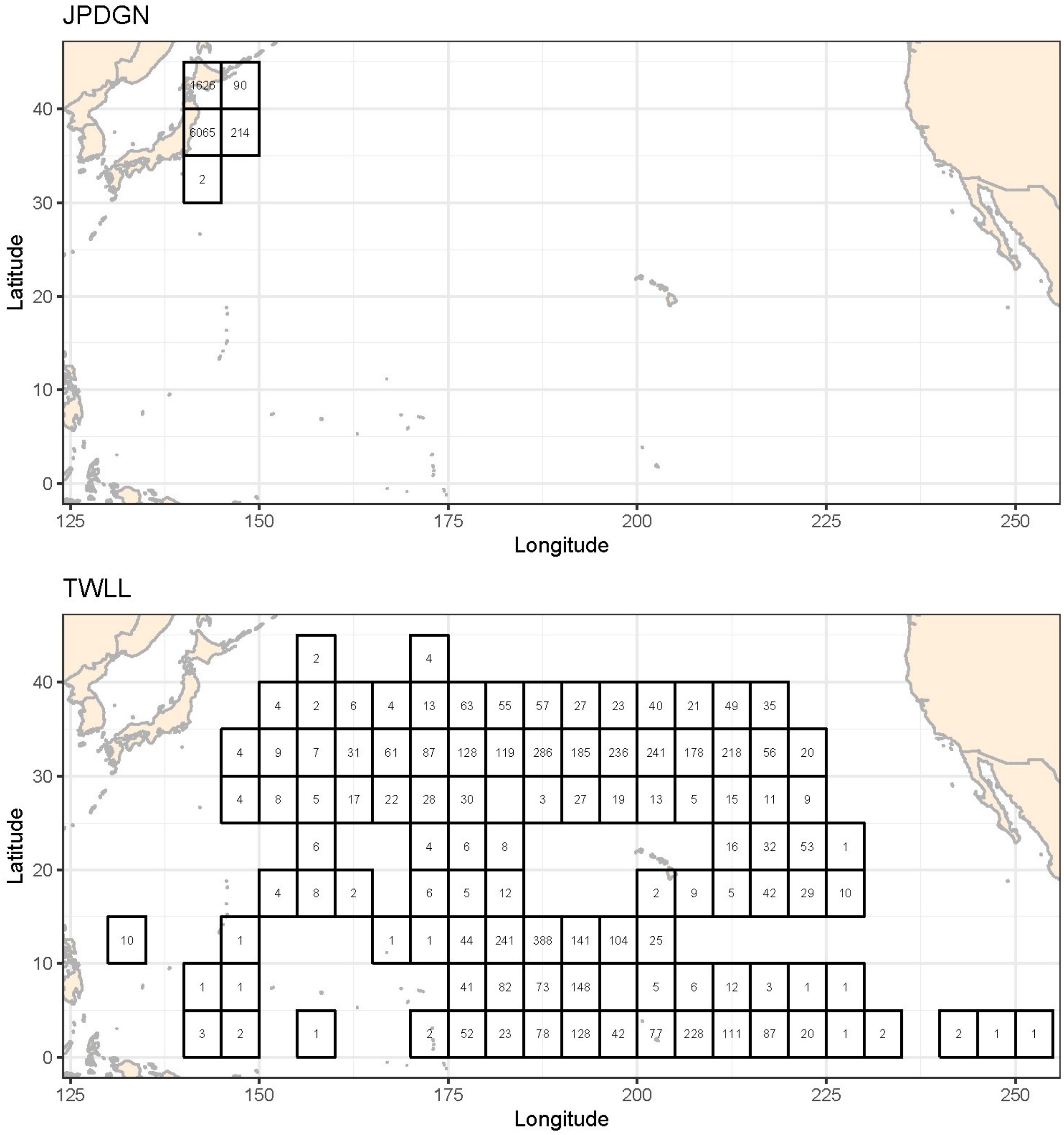

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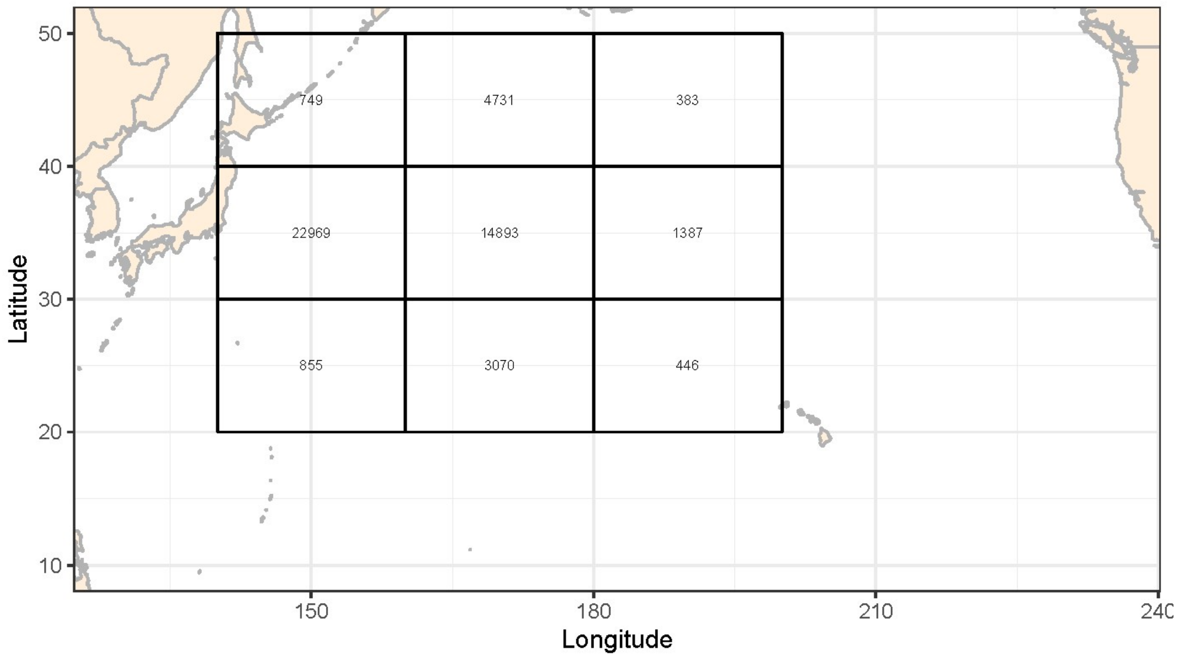

Figure 2. Spatial distribution of the size composition samples of the Japan Longline Kinkai Shallow fishery (JPLL_KK) with 20°x10° spatial resolution. Numbers indicate number of fish sampled within each area. Samples with 20°x10° spatial resolution are not used for further analysis in this study.

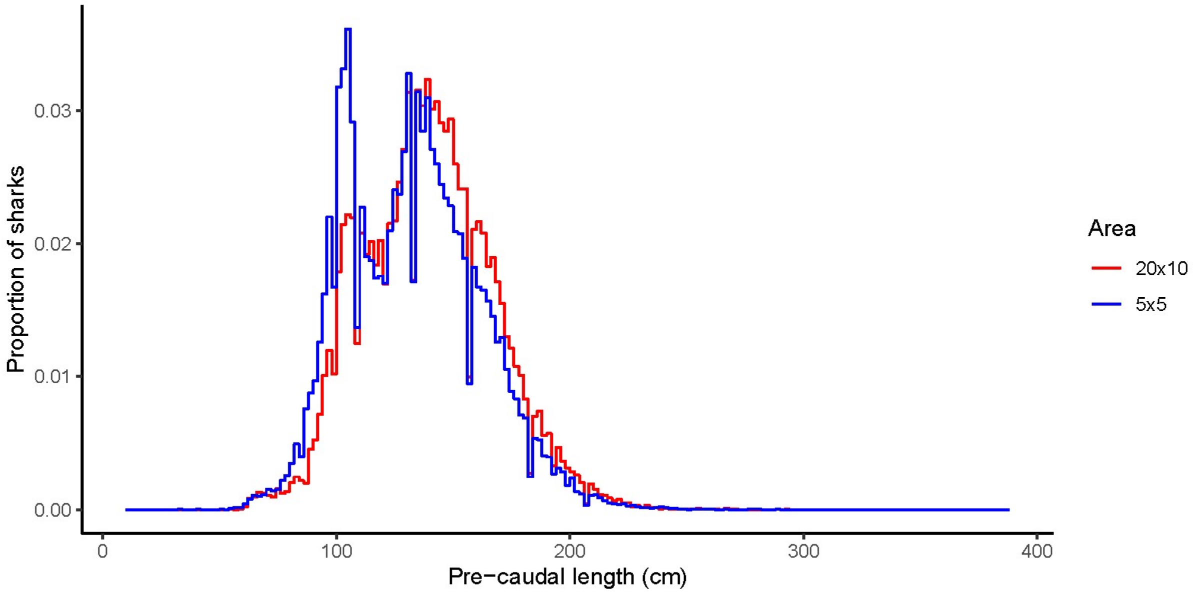

Figure 3. Distributions of size composition samples of the Japan Longline Kinkai Shallow fishery (JPLL_KK) with 20°x10° (red) and 5°x5° or finer (blue) spatial resolutions. Size distributions are based on pre-caudal length in 2 cm bins.

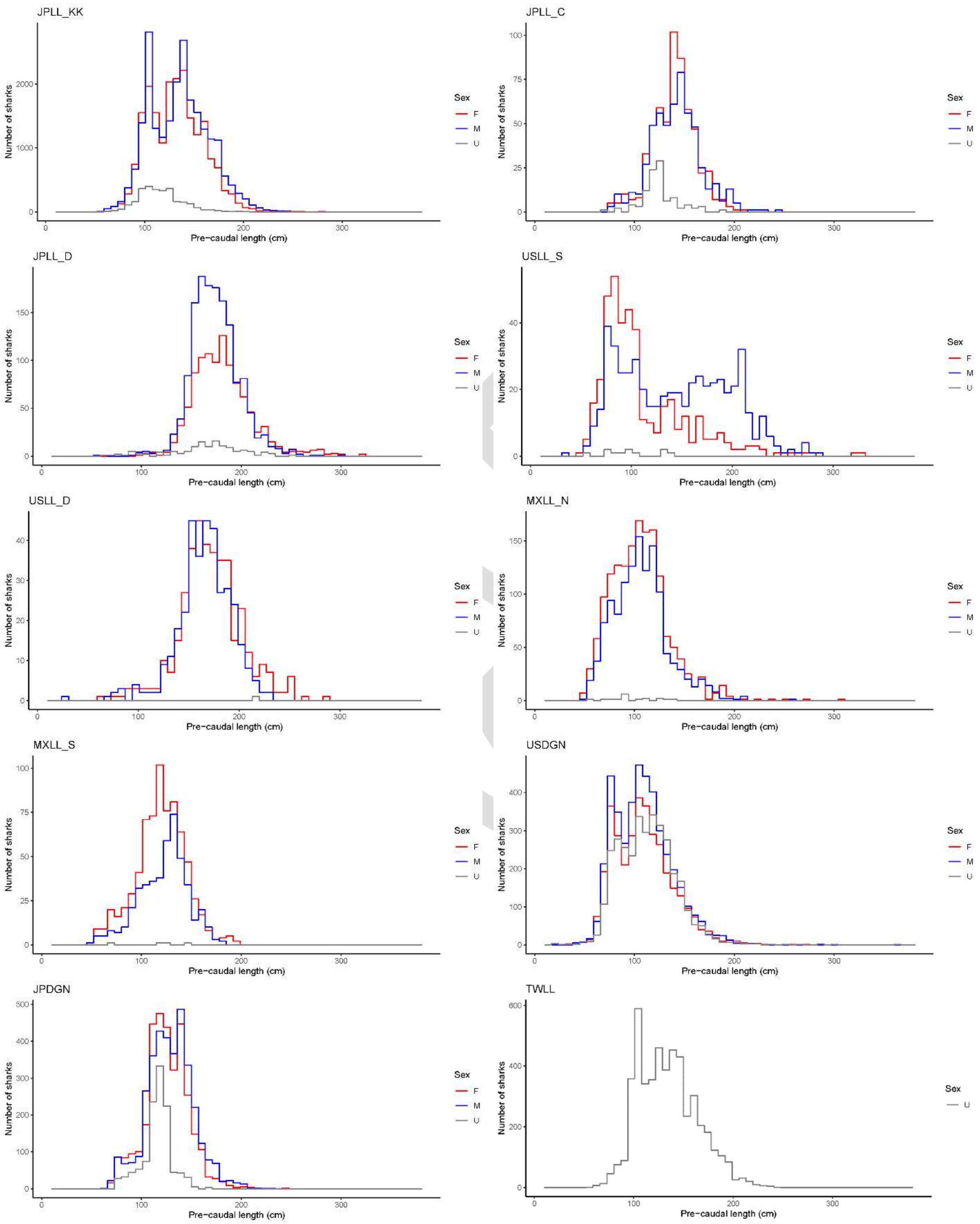

Figure 4. Sex- and fishery-specific size compositions using 7 cm bins. Only data with spatial resolutions of 5°x5° or finer are shown. Upper left corner of each panel indicate the fishery. See text for description of each fishery.

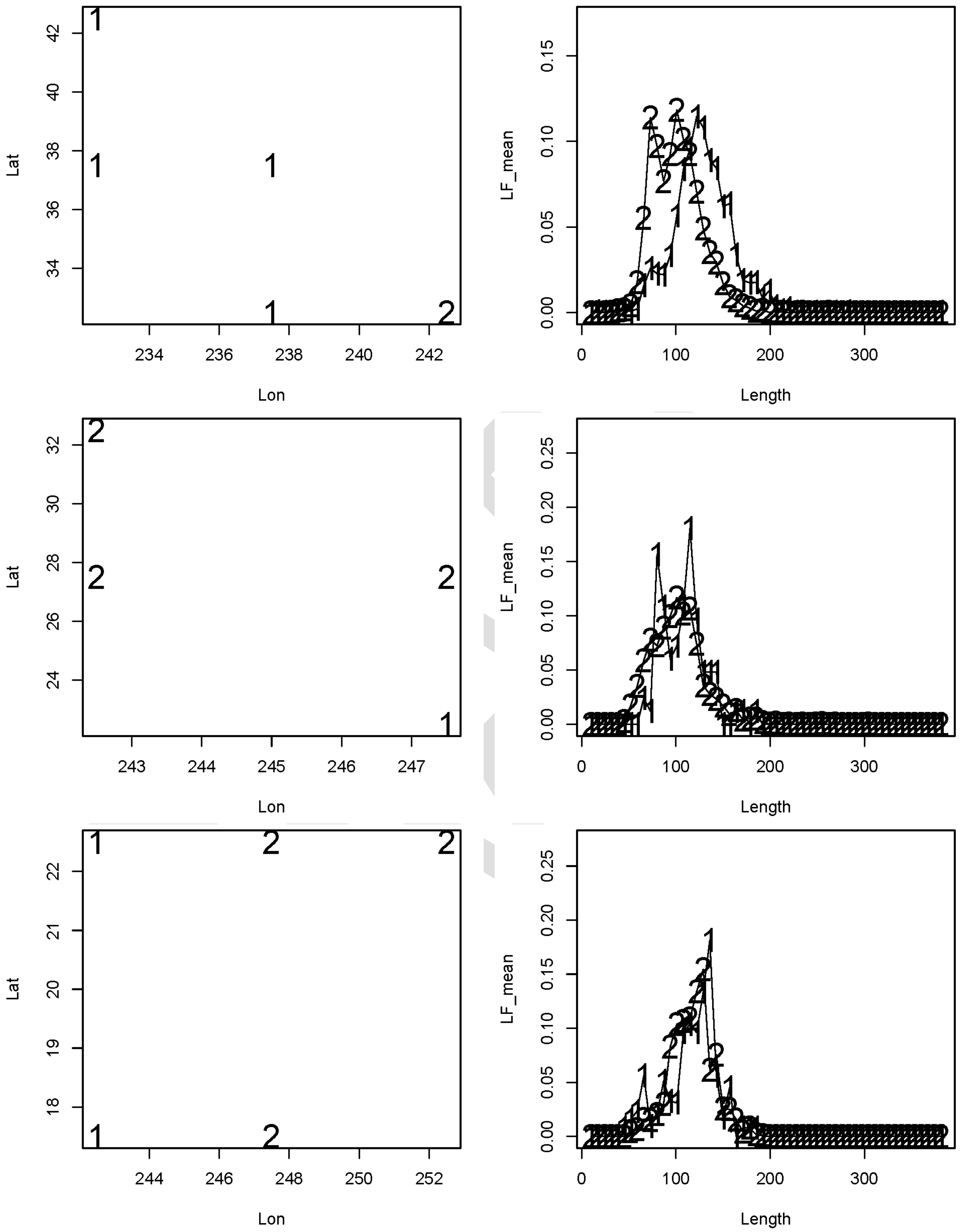

Figure 5. Regression tree groupings (left) and mean length compositions of groups (right) for USDGN (top), MXLL_N (middle), and MXLL_S (bottom). Note that latitude and longitude axes for each panel may differ.

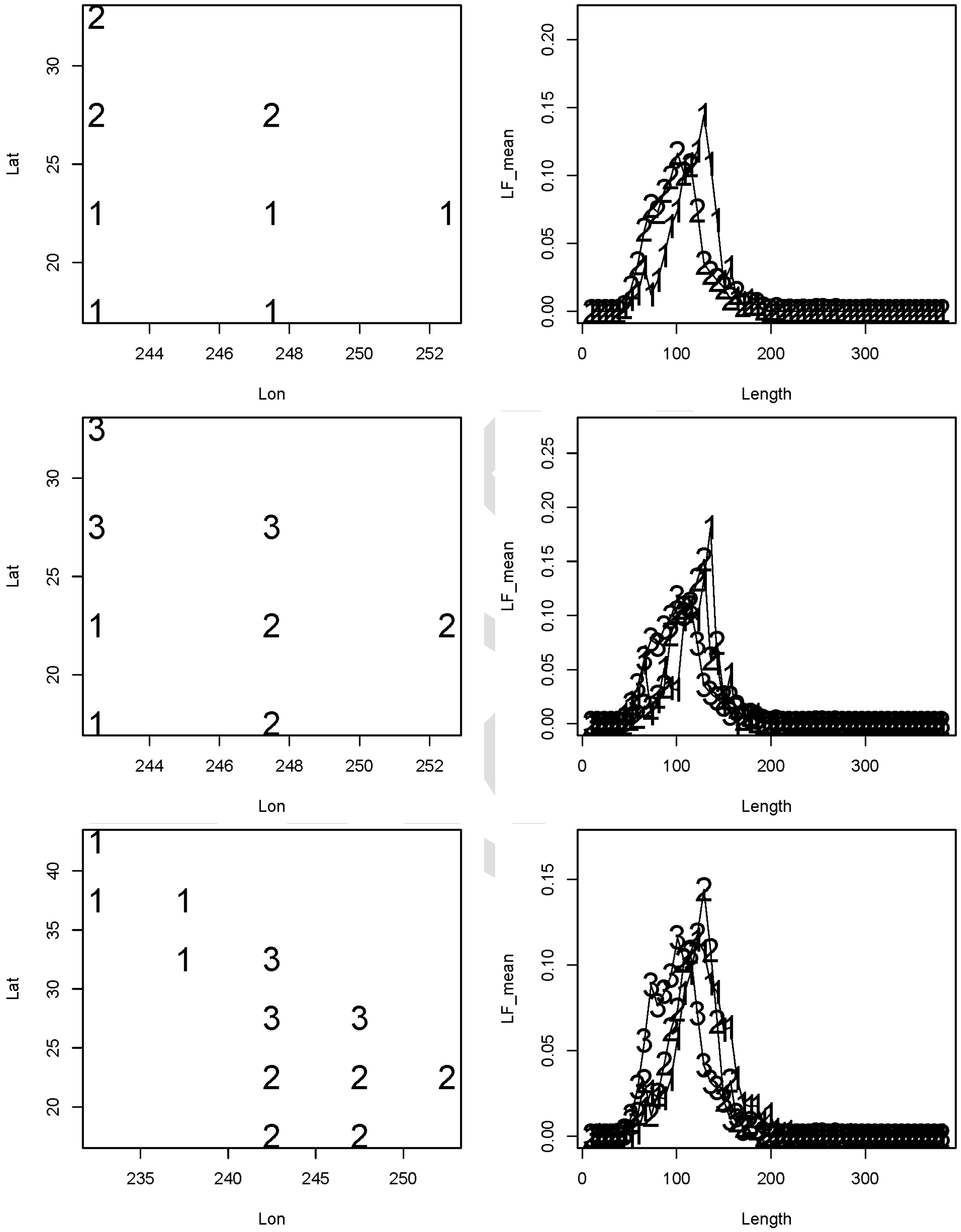

Figure 6. Regression tree groupings (left) and mean length compositions of groups (right) for combined MXLL_N-MXLL_S with one split (top) and two splits (middle), and for combined MXLL_N-MXLL_S-USDGN with two splits (bottom). Note that latitude and longitude axes for each panel may differ.

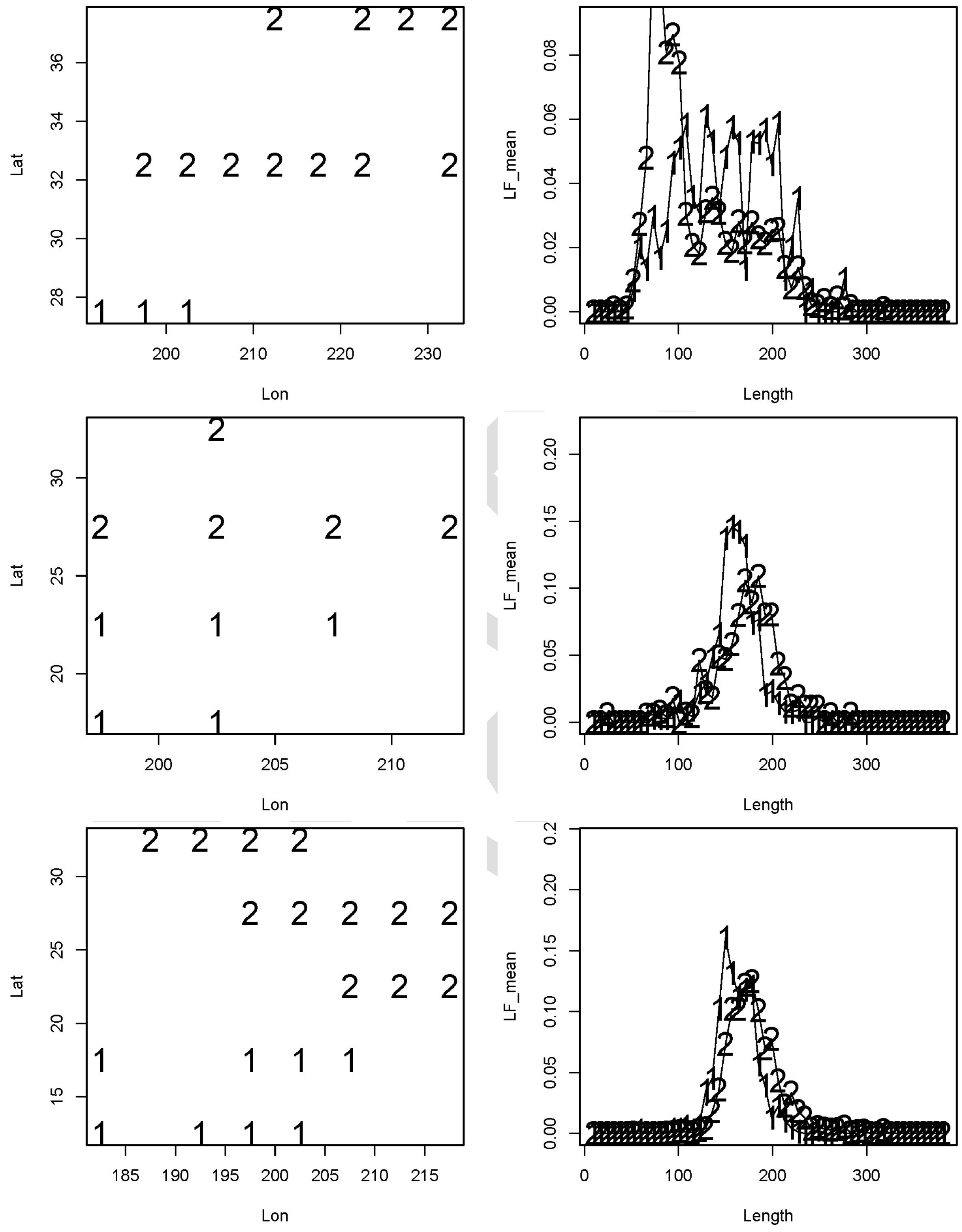

Figure 7. Regression tree groupings (left) and mean length compositions of groups (right) for USLL_S (top), USLL_D (middle), and JPLL_D (bottom). Note that latitude and longitude axes for each panel may differ.

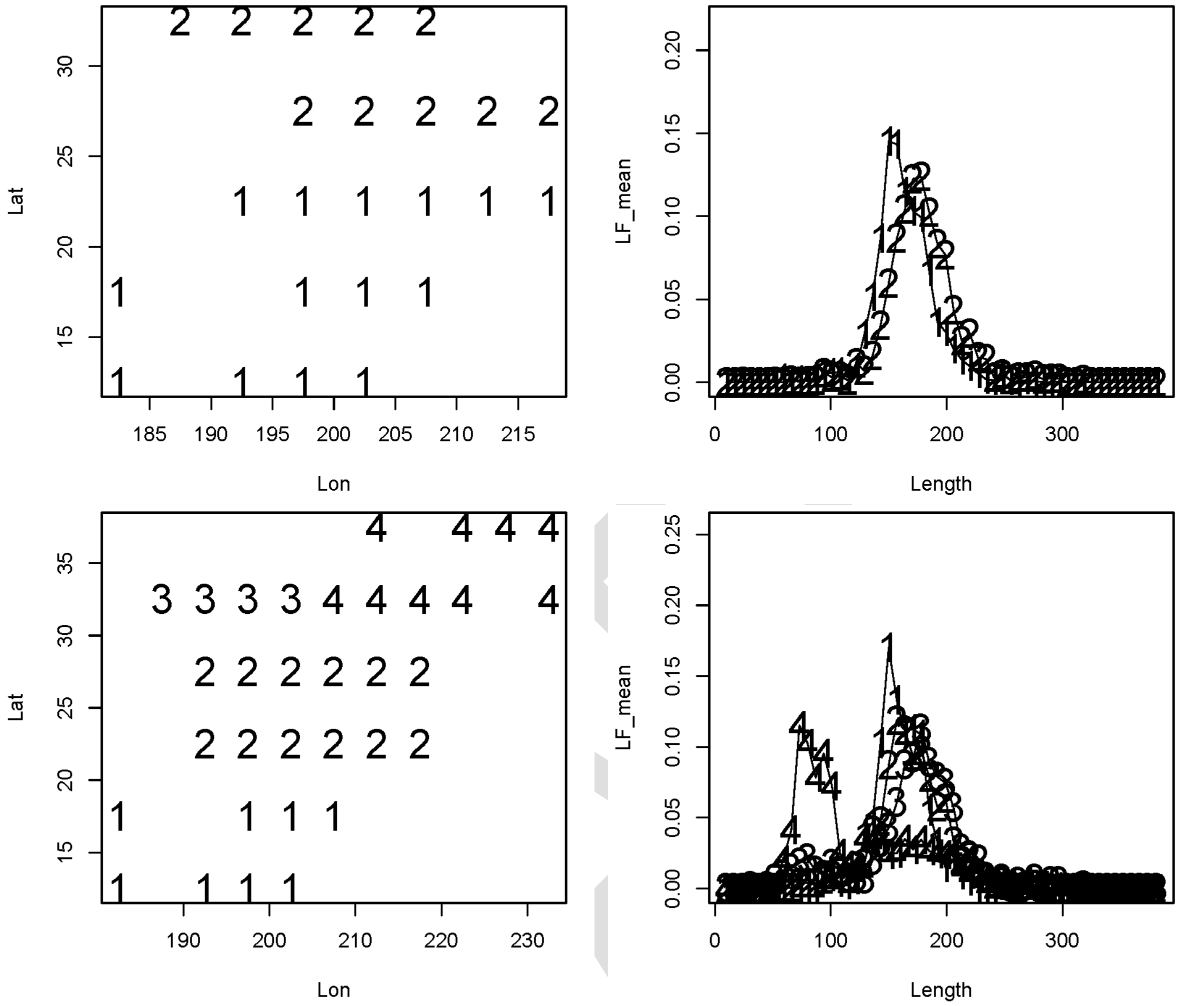

Figure 8. Regression tree groupings (left) and mean length compositions of groups (right) for combined USLL_D and JPLL_D with one split (top), and combined USLL_D, JPLL_D, and USLL_S with three splits (bottom). Note that latitude and longitude axes for each panel may differ.

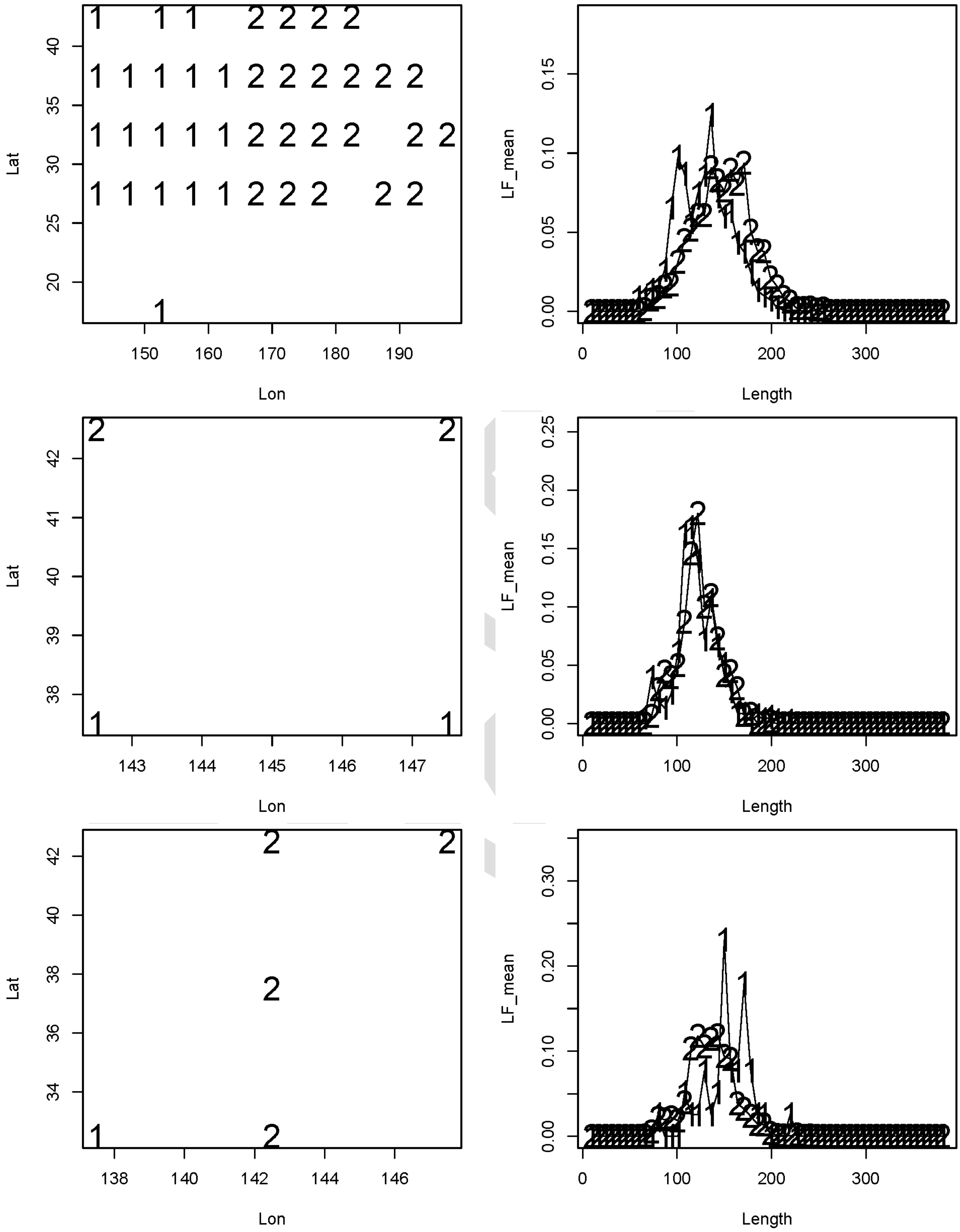

Figure 9. Regression tree groupings (left) and mean length compositions of groups (right) for JPLL_KK (top), JPDGN (middle), and JPLL_C (bottom). Note that latitude and longitude axes for each panel may differ.

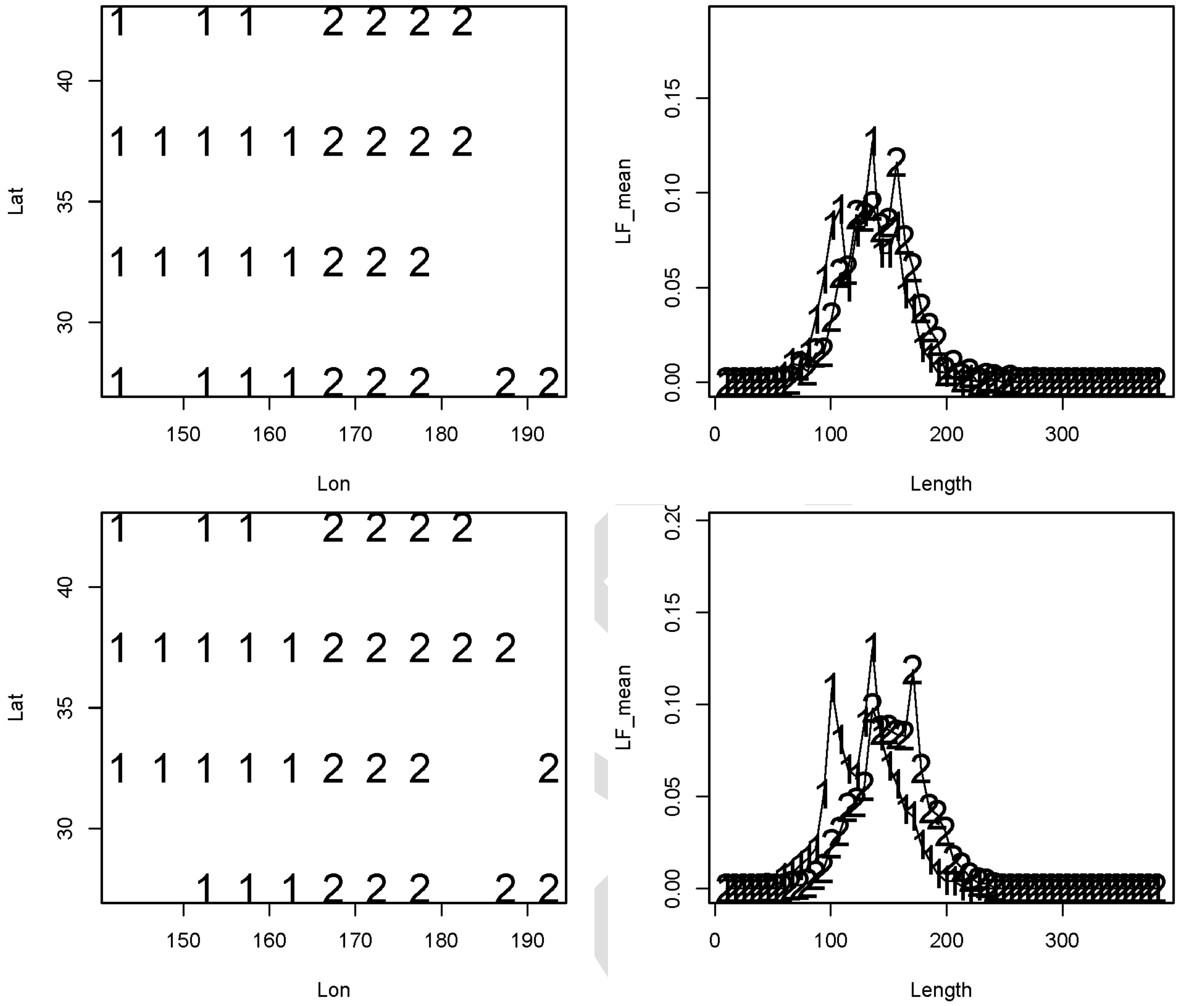

Figure 10. Regression tree groupings (left) and mean length compositions of groups (right) for females (top), and males (bottom) of the JPLL_KK fishery. Note that latitude and longitude axes for each panel may differ.

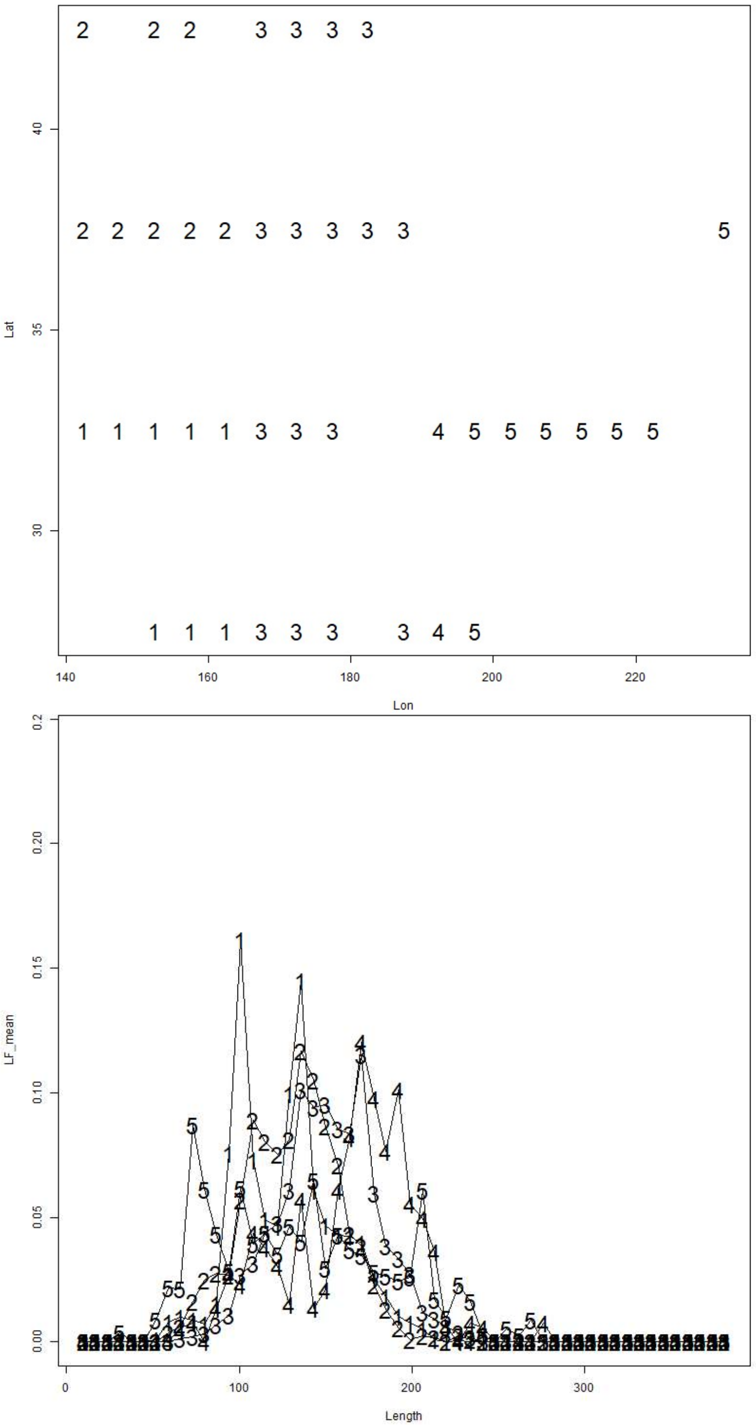

Figure 11. Regression tree groupings (top) and mean length compositions of groups (bottom) for combined USLL_S and JPLL_KK with four splits.

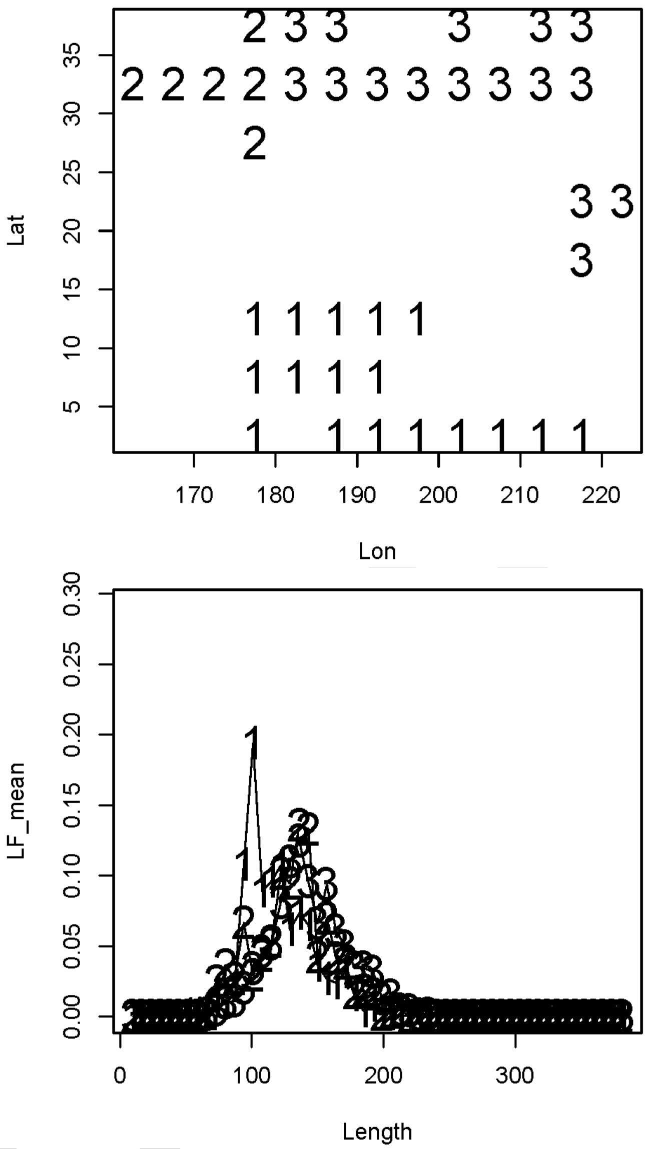

Figure 12. Regression tree groupings (top) and mean length compositions of groups (bottom) for TWLL with two splits.