ISC/15/SHARKWG-1/04

Spatial and temporal patterns of shortfin mako shark size and sex in the North Pacific Ocean[1]

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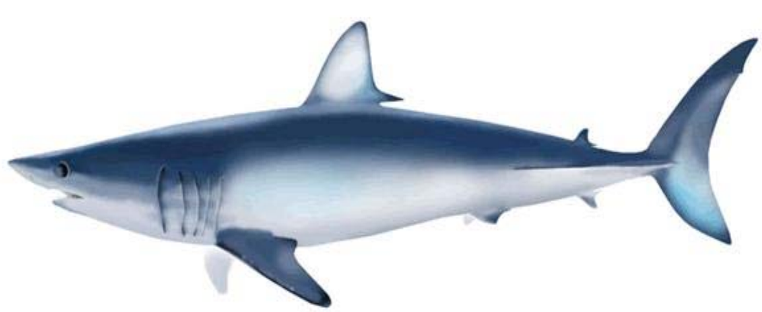

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Abstract

A single stock of shortfin mako shark is assumed within the North Pacific Ocean based on evidence from genetics and tagging data. However, regional differences in sex-specific size distribution have been identified based on analyses of size data from individual nations. Spatially explicit size and sex data from multiple nations and regions have not yet been investigated altogether. This analysis combines data from multiple fisheries distributed across most of the North Pacific to identify population substructure and then looks at temporal patterns in size and sex ratio by region. This information can become part of an evaluation of stock status indicators and provide a basis for research to better understand population distribution and movement.

Introduction

Shortfin mako sharks are assumed to be a single stock in the North Pacific based on genetic (Michaud *et al.* 2011) and tagging data (Sippel *et al.* 2011). Within the North Pacific stock, there is strong evidence of regional substructure by sex and ontogenetic stage (Semba and Yokawa 2011; Semba and Shiozaki 2013; Shiozaki *et al.* 2013; Kai *et al.* 2015). These characteristics are important for stock monitoring as exploitation of different population segments can have different impacts on stock status.

The objective of this working paper is to expand on a previous analysis by Sippel *et al.* (2014) to use spatial patterns in sex-specific size distribution to propose regional population sub-structure which is then analyzed for trends in size and sex ratio through time within these regions. This information can become part of a stock status indicator analysis. Tagging data are also used to look at regional movement patterns.

Materials and Methods

Size by sex data provided for U.S. fisheries (Hawaii-based deep- and shallow-set longline, U.S. West Coast-based drift gillnet and set net, and SWFSC juvenile shark survey) and Japanese fisheries (Kinkai shallow-set longline and research and training vessel operations) were described in Sippel *et al.* (2014). Subsequent to the initial shortfin mako shark size and sex data analysis, additional data have been included from Mexico's longline fishery as described in Castillo-Géniz *et al.* (2014). This analysis is based on records which included spatially explicit size and sex information, but does not include other data, such as port sampling or other data which were not spatially-explicit.

All measurements are presented here in precaudal length. When required, measurements were converted to PCL using the following equations:

$$PCL = (TL \times 0.816) + 0.784$$

$$TL = (FL + 0.397) / 0.913$$

$$FL = (AL \times 2.402) + 9.996$$

The 50% size at maturity ranges of 278-307 cm TL (227.6-251.3 cm PCL) for females and 180-210 cm TL (147.7-172.1 cm PCL) for males, and a length at birth of 70-74 cm TL (57.9-61.1 cm PCL) were assumed (ISC SHARKWG 2014). For the purposes of this analysis, makos were considered immature if less than the midpoint of the assumed 50% maturity ranges (females: 239.5 cm PCL and males: 159.9 cm PCL).

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Spatial analyses are provided on 2x2 degree spatial grids and sex ratios are presented as the ratio of females to males.

Conventional tag-recapture data from NOAA Southwest Fisheries Science Center and Japan National Research Institute of Far Seas Fisheries were included to look at movement throughout the North Pacific. A description of the conventional tagging data was provided to the ISC SHARKWG previously (Sippel *et al.* 2011).

Results

Overall, the proportion of females is between 50-60% in the northwest Pacific Ocean, ranges between 20-60% in the Central Pacific with a small core of 50-70% east of the Hawaiian Islands, and is variable along the West Coast of North America (Figure 1). Mean size of both sexes is smaller (~125 cm PCL) in the northwestern Pacific Ocean off Japan and even a bit smaller in the eastern Pacific Ocean off the West Coast of North America. Overall, mean size of both sexes tends to be larger (~175 cm PCL) in the Central Pacific Ocean south of 30˚N. Sample sizes tend to be largest in the northwestern and eastern Pacific, with less sampling in the central Pacific (Figure 2).

When broken down by quarter, female proportion is consistently highest (>50%) in the northwest Pacific and below 50% in the central Pacific (Figure 3). However, the change in proportion of females is spatially variable with the proportion of females decreasing from Q2-Q3 in the north and central Pacific but increasing south of Hawaii, and is variable in the central Pacific from Q4-Q1 (Figure 4).

Mean female size is consistently around 125 cm PCL in all four quarters in the northwestern and eastern Pacific, with larger females (>175 cm PCL) in the central Pacific (Figure 5). However, female mean size tends to increase from Q1-Q2 and Q2-Q3, and then decrease from Q4-Q1 in the central Pacific Ocean (Figure 6). During Q1 and Q4 female pups are found in the northwest Pacific, north of Hawaii and near the Southern California Bight, with pups also apparent during Q3 and Q4 in the Southern California Bight (Figure 7).

A similar pattern of consistently smaller mean male length across quarters is apparent in the northwestern and eastern Pacific Ocean, with minimum size north of 30˚N between ~50-75 cm PCL in all quarters. Larger sharks, mostly >175 cm PCL, were found in the Central Pacific (Figure 8). Mean size tended to increase in the central Pacific from Q1-Q2 and Q2-Q3. Between Q3-Q4 male sizes decreased north of Hawaii and increased south of Hawaii, and sizes generally decreased north of Hawaii from Q4-Q1 (Figure 9). During Q1 and to a lesser extent in Q2 male pups are found in the northwest Pacific, and near the Southern California Bight in Q3 (Figure 10).

Based on these patterns, a five region stratification of the north Pacific shortfin mako shark population is proposed. This stratification takes regional patterns in mean size by sex into consideration, and subsequently enables the geographic operations of fisheries that take makos to be identified within these strata (Figure 11).

When broken down by region, no strong increasing or decreasing trends in mean size and sex ratio across fisheries are apparent. However, some trends are noisier than others, for example, in the Hawaii deep-set fishery mean size for both sexes fluctuated by as much as 50 cm in Region 2, with sex ratio also quite variable. In Regions 2 and 4, the mean size of both sexes caught by the Hawaii deep-set longline fishery was roughly 25 cm larger than those caught in the Hawaii shallow-set longline, Japanese research and training vessels and Kinkai-shallow set longline fisheries. The Kinkai shallow-set fishery catches

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slightly smaller (by 10-20 cm) makos than the Hawaii shallow-set and Japanese research and training vessels. In the eastern Pacific, mean size for both sexes has been stable (~125 cm PCL) in the US drift gillnet fishery, which is comparable to sizes recently sampled from the Mexican longline fishery (Figure 12).

A total of 326 tag recaptures are included in this analysis (312 from USA, 14 from Japan), and 36 of those recaptures were at liberty for less than 30 days. Of the 312 tagged in Region 5, 21 were recaptured in a different region after times at liberty ranging from 313 to 1939 days. Of those tagged in Regions 1-4, only four were recaptured in different regions after times at liberty ranging from 38-594 days (Figure 13). All but one of the conventional tag recaptures came from animals tagged as juveniles or sub-adults.

Discussion

This analysis extends previous analysis of size and sex patterns by incorporating multi-national data from fisheries spanning most of the North Pacific Ocean. By using the data to propose a spatial stratification of the North Pacific stock, it was possible to look at regional size and sex ratio trends both spatially and temporally.

The consistently smaller sizes of shortfin makos found in the northwest and eastern Pacific Ocean suggests that these may be nursery grounds. The presence of larger females and males in the central Pacific and variable sex ratios suggest that mating may occur there but further investigations are needed to fully understand the spatial and temporal dynamics.

Mean size trends through time across all regions were mostly flat and do not appear to show shifts in population size structure through time. Regional trends in sex ratios through time were noisy, making changes in sex structure difficult to detect. However, the substantially larger animals being caught by Hawaii deep-set fisheries than other fisheries in Regions 2 and 4 may indicate different size selectivities of the fisheries. Additional analysis of quarterly size trends by the fishery were also provided in the Appendix of Sippel et al. (2014).

A generalized schematic for sex-specific population structure was proposed by Semba and Yokawa (2011). Kai et al. (2015) also looked at sex-specific size distribution and growth rates in the North Pacific based on the Japan longline fisheries. The current analysis concurs with the previously proposed pupping grounds in the northwest and eastern Pacific Ocean with mating grounds in the central Pacific, but we also take the analysis a step further by combining a greater amount of data across the North Pacific. This provides a more comprehensive assessment of the spatio-temporal distribution of mako size across the Pacific. The heterogeneity of sizes and sexes has important implications for the stock as it implies that more complex models may be needed to assess the population, rather than assuming a single well mixed stock. The species appears to be reproductive across a broad region which may explain why mean size has been mostly stable through time.

Conventional tagging provides some very limited sex-specific mako shark movement information across regions. However, the majority were tagged in Region 5 and more than a quarter of those were at liberty less than 90 days. Electronic tagging from the US West Coast has showed movement from Region 5 into Region 4 of sub-adult females and males, as well as adult males (Urbisci *et al.* 2013). Better understanding of sex-specific mako shark movement dynamics with respect to ontogeny would require a tagging research program distributed across their range.

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Figures

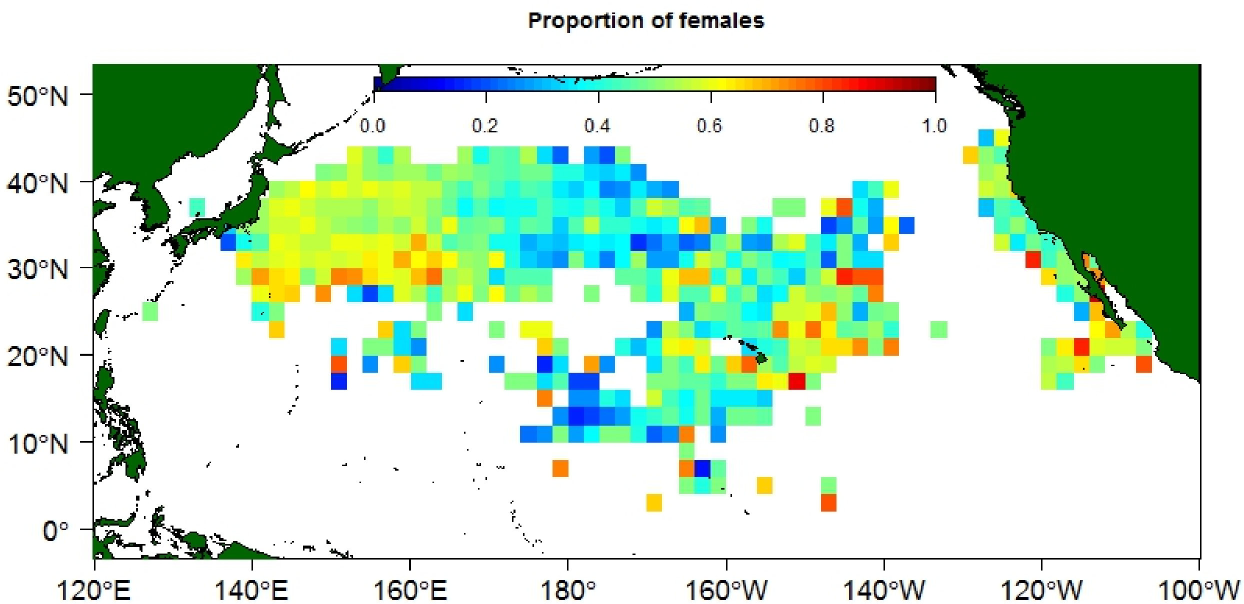

Figure 1. Proportion of female shortfin mako sharks caught in the North Pacific Ocean.

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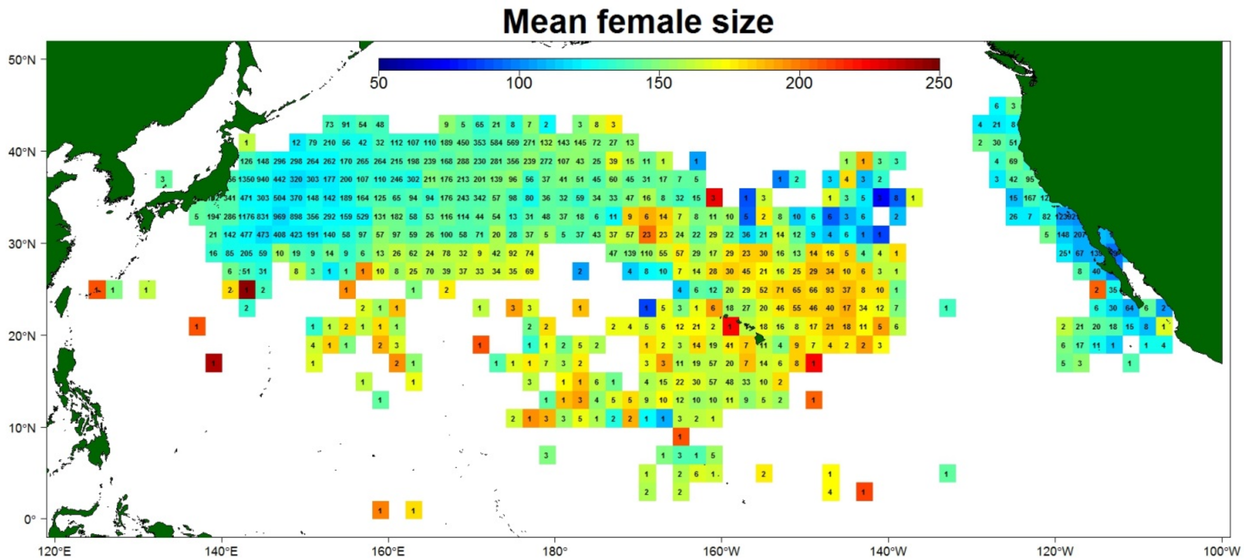

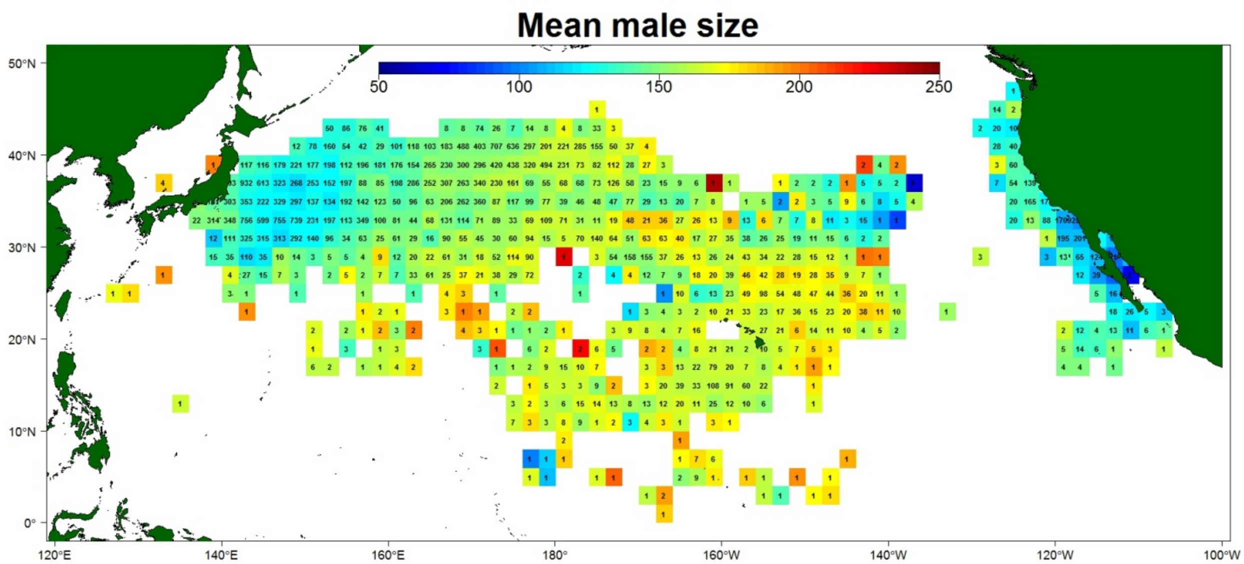

Figure 2. Mean size of female (top) and male (bottom) shortfin mako sharks across all fisheries with sample sizes for each 2x2 grid cell printed within each cell.

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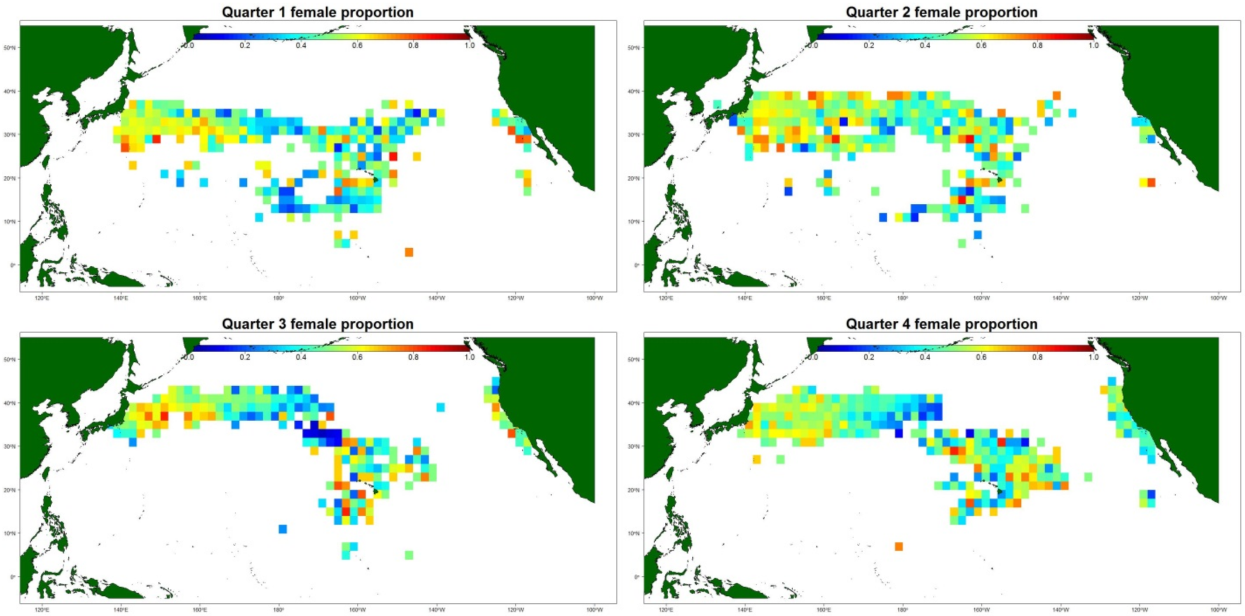

Figure 3. Quarterly proportion of females (sex ratio). Proportion is scaled 0-1 (0% females to 100% females).

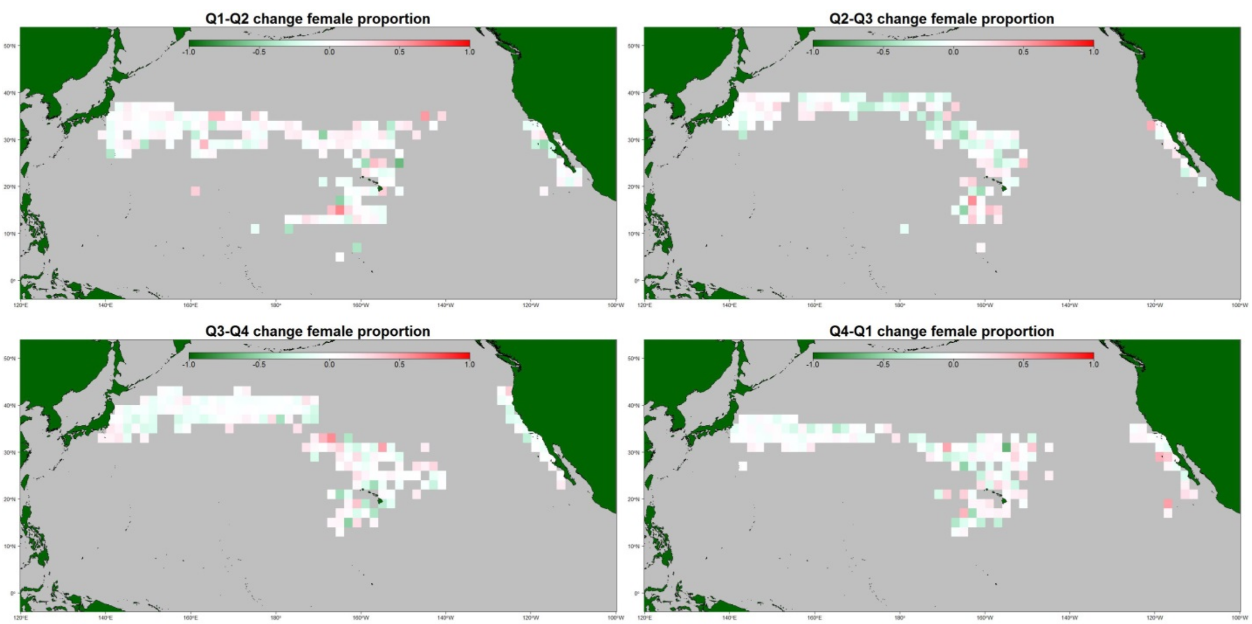

Figure 4. Quarterly change in proportion of females (sex ratio). The difference is calculated by subtracting the former quarter from the latter (e.g. top left panel is calculated as Q2-Q1), so reds represent increases in female proportion and greens denote decreases.

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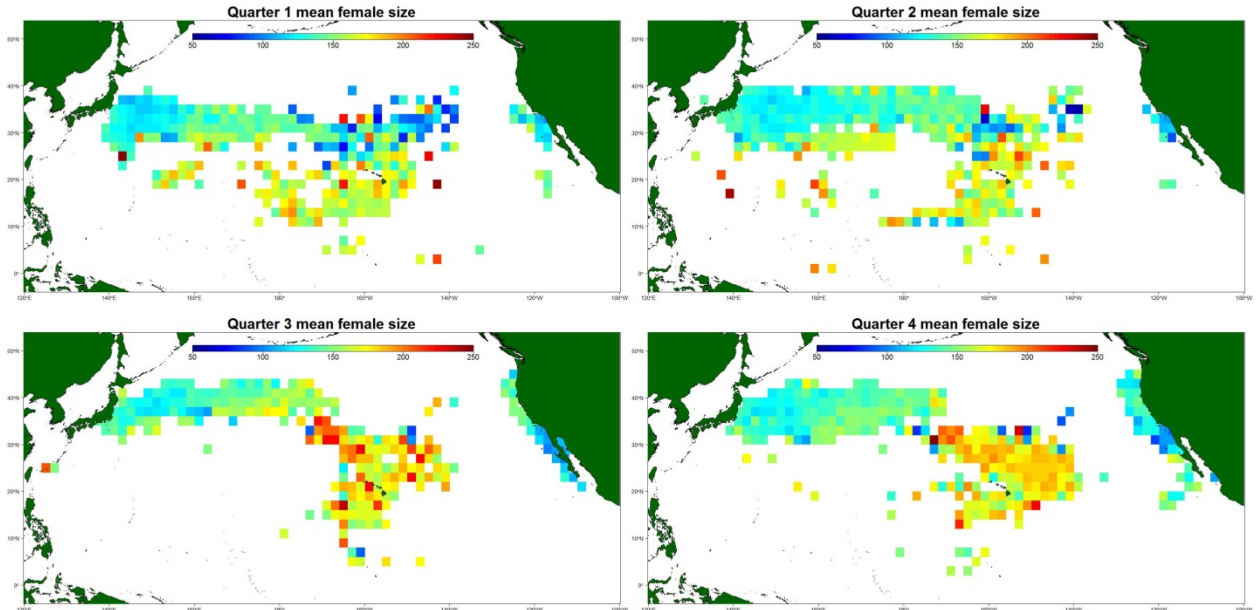

Figure 5. Quarterly mean length (cm PCL) of female shortfin mako sharks across the North Pacific.

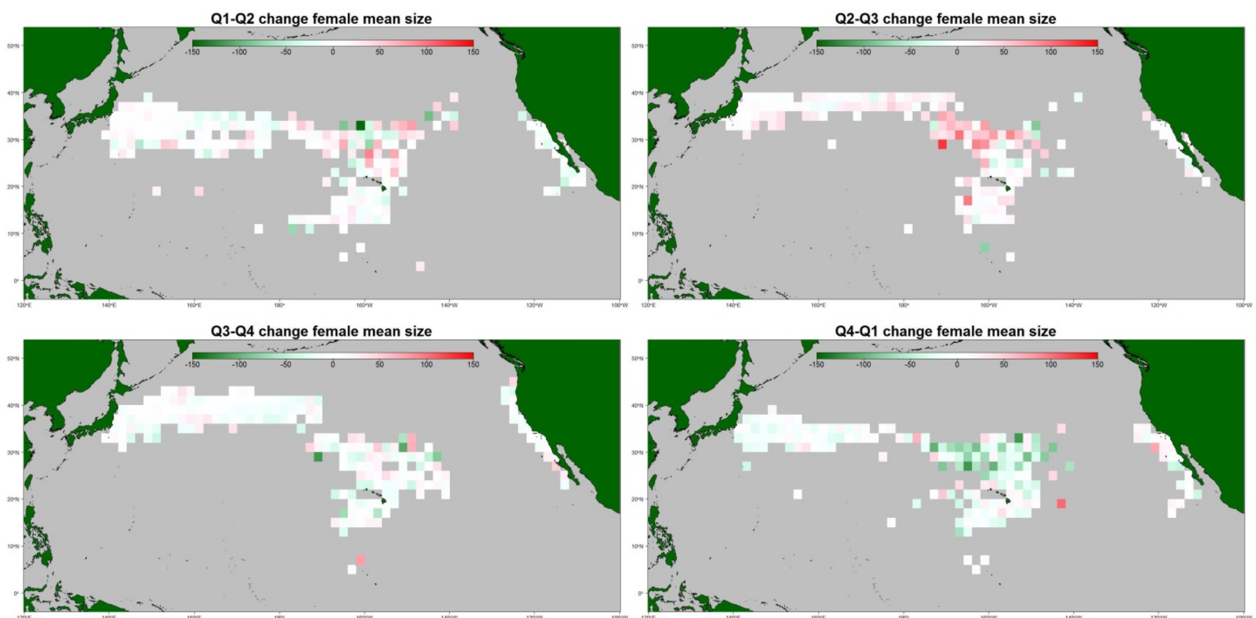

Figure 6. Quarterly changes in female mean size (cm PCL). The difference is calculated by subtracting the former quarter from the latter (e.g. top left panel is calculated as Q2-Q1), so reds represent increases in mean size and greens denote decreases.

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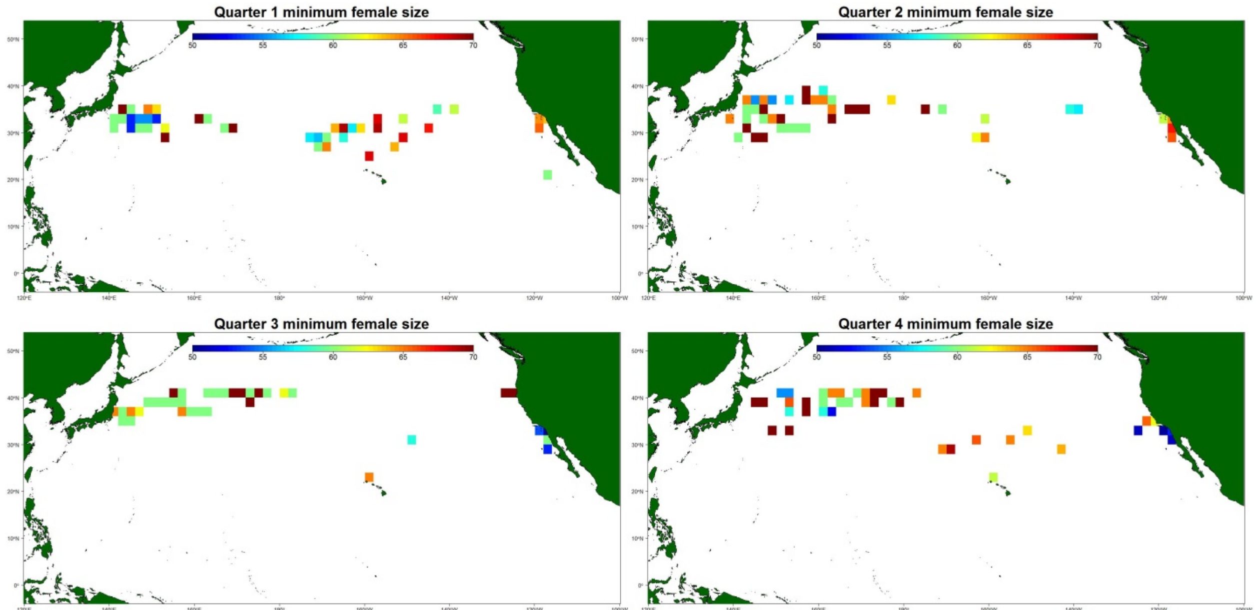

Figure 7. Quarterly minimum length (cm PCL) of female shortfin mako sharks across the North Pacific. Note that pixels are scaled between 50-70 cm to emphasize the presence of pups (neonates).

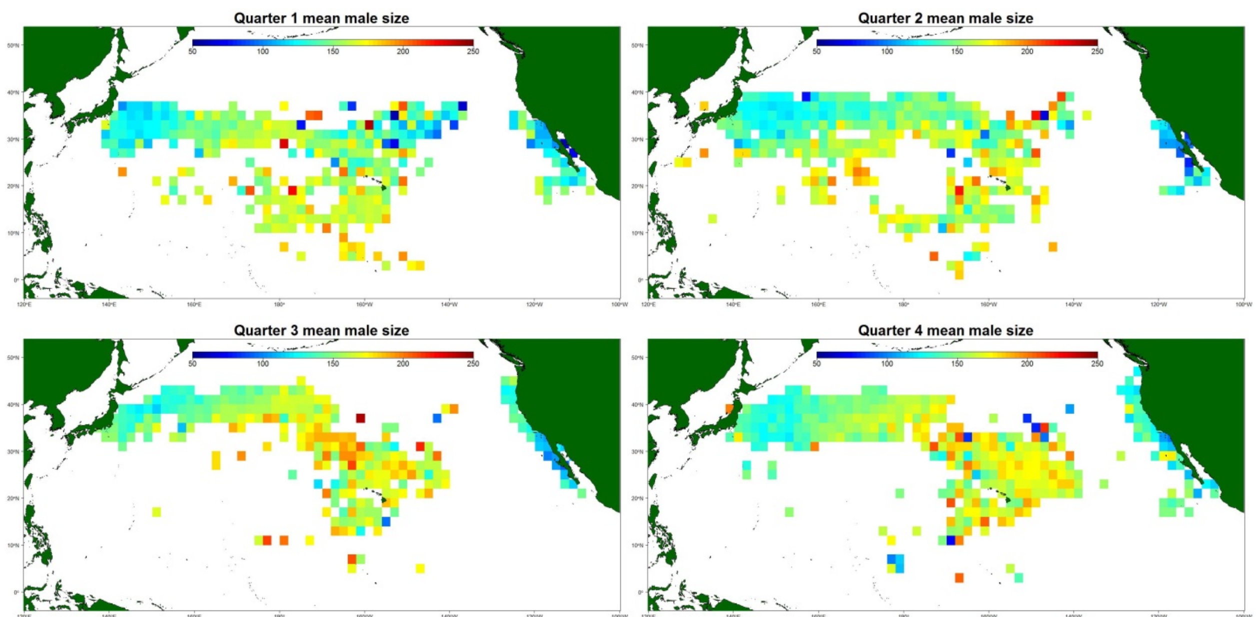

Figure 8. Quarterly mean length (cm PCL) of male shortfin mako sharks across all North Pacific fisheries.

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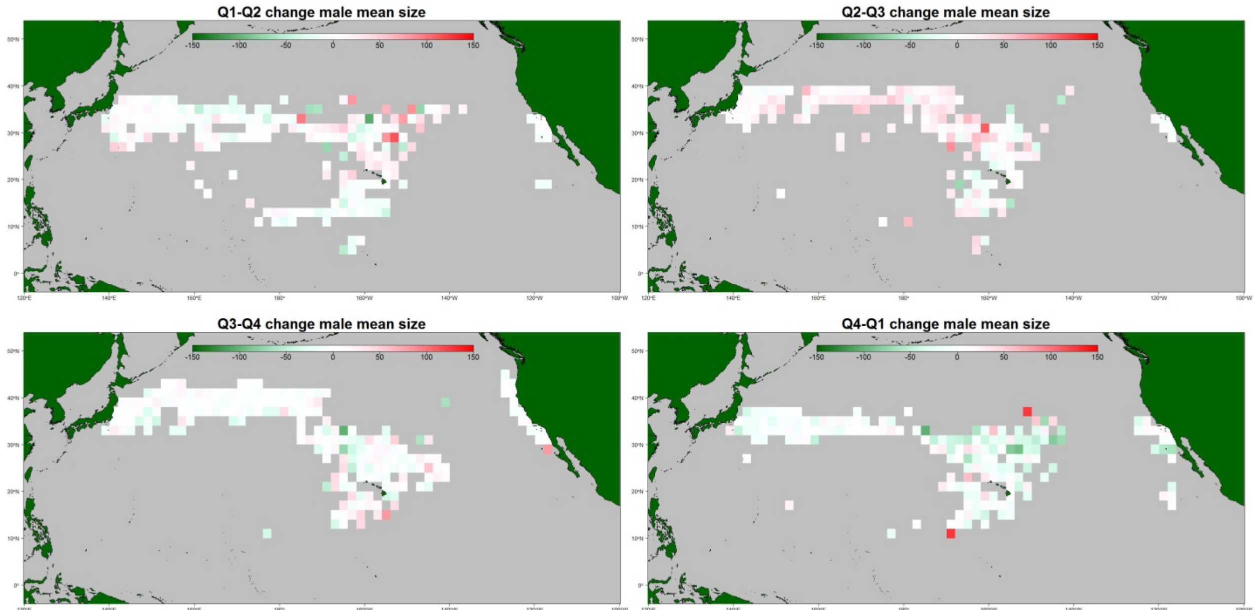

Figure 9. Quarterly changes in male mean size (PCL). The difference is calculated by subtracting the former quarter from the latter (e.g. top left panel is calculated as Q2-Q1), so reds represent increases in mean size and greens denote decreases.

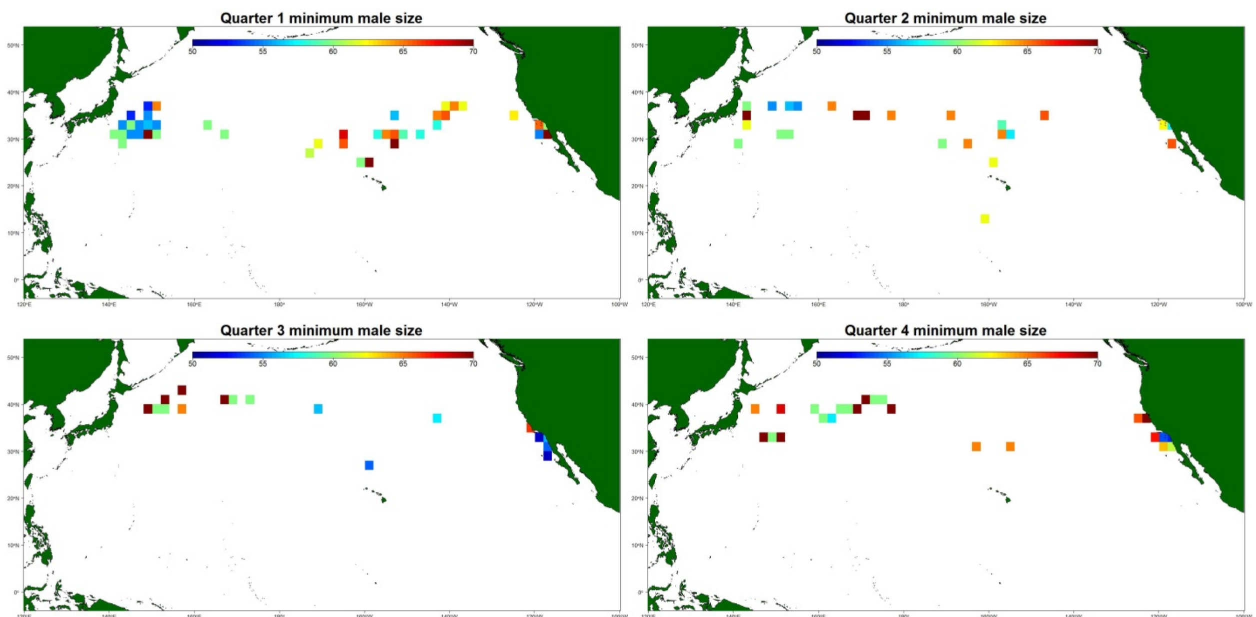

Figure 10. Quarterly minimum length (cm PCL) of male shortfin mako sharks across the North Pacific. Note that pixels are scaled between 50-70 cm to emphasize the presence of pups (neonates).

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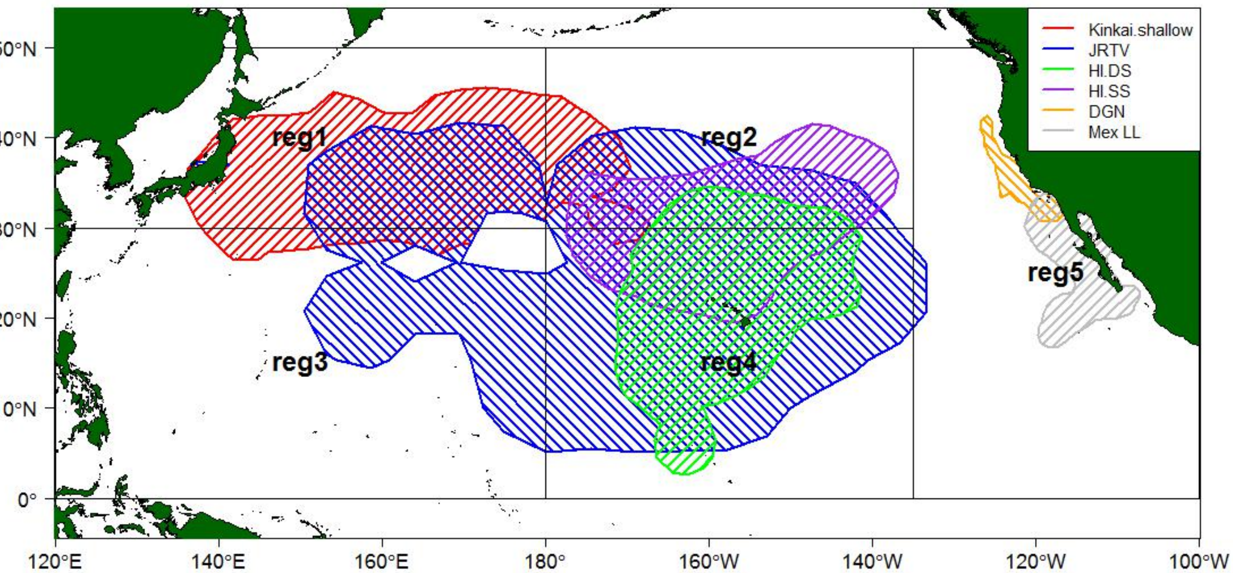

Figure 11. Spatial stratification and extent (95% utilization kernel) of the fishery sources for size by sex data. Regions 1-5 (reg1, reg2 etc.) are proposed for spatial stratification of fishery data based on the observed catch by size and sex. Minor fisheries off the US West Coast, including small-mesh drift gillnet, set net and juvenile shark survey are not depicted, and size data from Taiwanese small and large longline vessels were not spatially-explicit.

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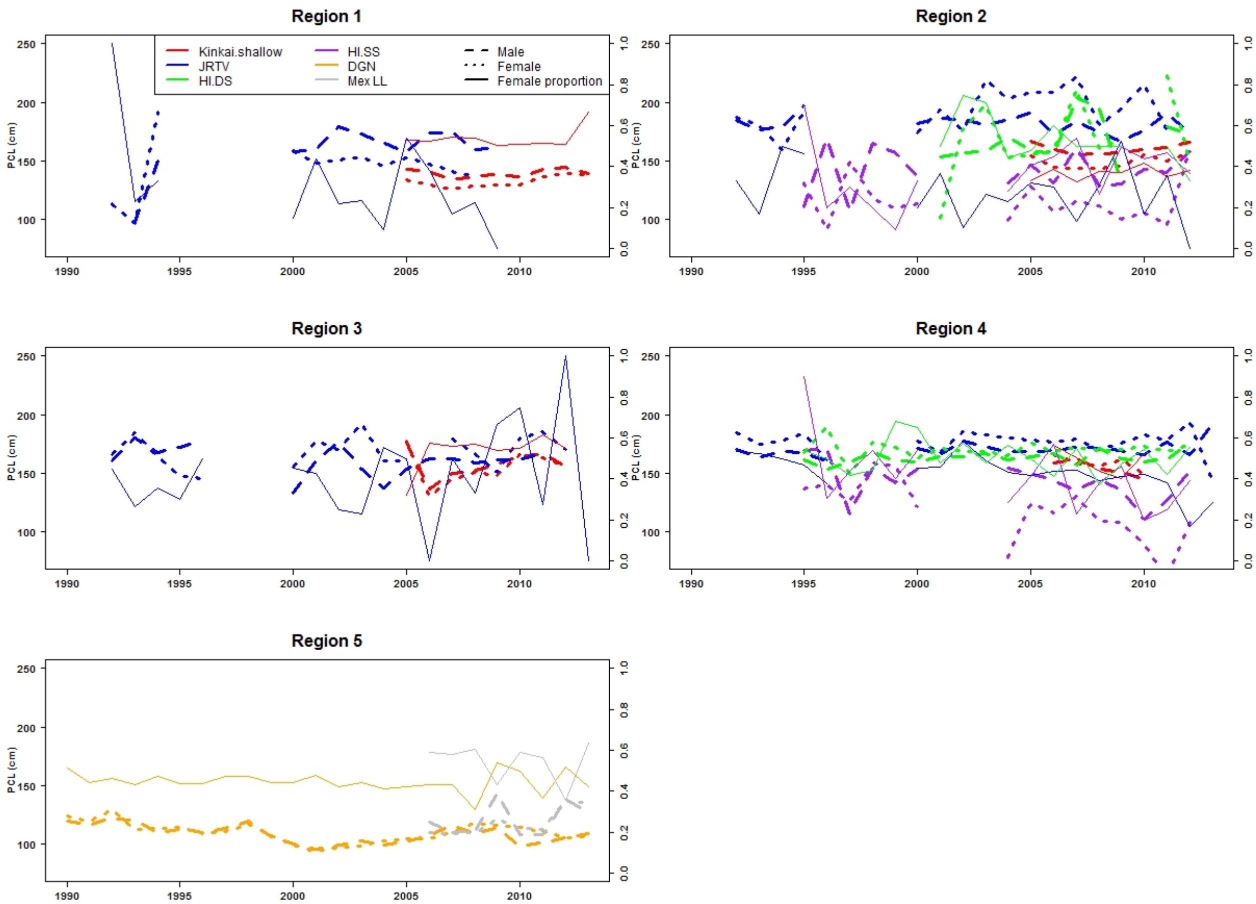

Figure 12. Temporal trends in mean size (cm PCL) and sex ratio (female:male) of shortfin mako sharks in main fisheries across five spatial strata. Fisheries are denoted by different colors, with female sizes represented by dotted lines and male sizes by dashed lines scaled on the primary y-axis. The solid lines denote sex ratio scaled on the secondary y-axis.

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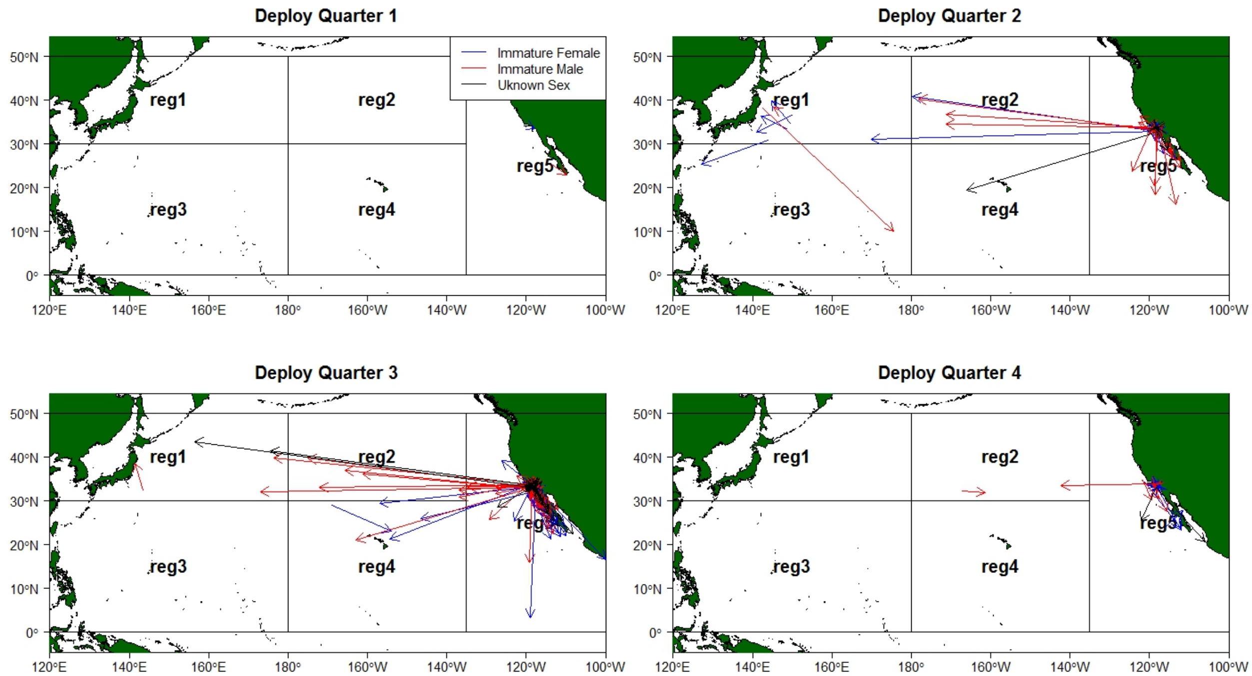

Figure 13. Shortfin mako shark conventional tag recaptures at liberty for at least 30 days, presented by the quarter in which they were released. Females were considered immature if less than 239.5 cm PCL (the midpoint in the range assumed), and males less than 159.9 cm PCL. Based on these criteria, no females were mature and only 1 male was mature.

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