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Analysis of North Pacific Shark Data from Japanese Commercial Longline and Research/Training Vessel Records

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Abstract

This paper analyses North Pacific longline operational data from research and training vessel surveys (1992-2008) and commercial longline logbook records (1993-2008) provided by Japan for onsite analysis in Shimizu during January-March 2011. Both data sets required filtering to remove records believed to under-report actual shark catches. The analysis was based on 7,974 sets representing 10 vessels in the research and training vessel surveys and 88,129 sets representing 112 vessels in the commercial longline fleet. Application of different filtering methods could result in larger sample sizes, but this benefit would need to be weighed against the probability of increasing the presence of under-reported catches in the filtered database. When considering the selection and application of data filters it is important to recall that if vessels began releasing/discarding (and not reporting) sharks in recent years, filtering may not fully correct for this effect, and declining catch rate trends would thus potentially be exaggerated. On the other hand, if reporting practices do not change but shark stock abundance actually does diminish over time, declining catch rates would be expected. The challenge is to apply a filter which removes those catch records which are under-reported, but retains those which are low but accurate.

Filtered data were examined in terms of five potential indicators of fishing pressure: distribution, catch composition, catch rate, targeting and size. Blue sharks, which dominate the shark catch in the North Pacific, showed declining catch rates in research and training vessel surveys but a strong trend of increase in commercial records until 2005 and declines thereafter. Evidence of blue shark targeting was found in the increasing concentration of effort in areas of high catch rates. Mako sharks comprise a small proportion of the catch (<10%) but "effective" targeting may be increasing as a result of targeting of co-occurring blue sharks. Mako catch rates showed an increasing trend in both data sets until 2006 for the main commercial fishing grounds in the western North Pacific. Decreasing catch rate trends were shown for makos in both the central North Pacific and western North Pacific since 2006. Oceanic whitetip and silky shark catch rates showed declines in the research and training vessel data and were rarely recorded after 2005. There was also some evidence for a trend of decreasing size of both males and females of these species in recent years. Thresher sharks were analysed as a group and results are expected to mainly reflect the status of bigeye thresher. An increasing trend was found in the research and training vessel data and an inconclusive pattern in the commercial data.

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1. Introduction

This paper is the product of collaborative analysis between the Secretariat of the Pacific Community (SPC) and Japan's National Research Institute for Far Seas Fisheries (NRIFSF) in support of the Western and Central Pacific Fisheries Commission's (WCPFC) Shark Research Plan (Clarke and Harley 2010). For the purpose of advancing the Commission's understanding of the status of shark stocks in the Pacific, NRIFSF kindly made available the full contents of two comprehensive databases, described below, for on-site analysis in Shimizu, Japan. These analyses were conducted between January-April 2011, and are reported to the WCPFC Scientific Committee as part of the Shark Research Plan's indicator and status plot work components (Existing Data Steps 1 and 2). It is also planned to use the data "products" contained in this paper in the upcoming stock assessments (Existing Data Step 3) beginning in the second half of 2011.

Analyses focused on the WCPFC key species being assessed under the Shark Research Plan, i.e. blue shark (*Prionace glauca*), the makos (*Isurus* spp.), oceanic whitetip shark (*Carcharhinus longimanus*), silky shark (*Carcharhinus falciformis*), and the threshers (*Alopias* spp.). In order to maximize compatibility with parallel analyses being conducted on SPC data holdings, the geographic extent of the analyses conformed to the WCPFC Statistical Area and the delineation of regions within the area (see Clarke et al. 2010) was kept as consistent as possible.

After a description of the characteristics and handling of the data sets provided by Japan, this paper presents analyses of the following potential indicators of shark population status in the North Pacific:

- Distribution;
- Species Composition;
- Catch Rate;
- Targeting; and
- Size and Sex Ratio.

These indicators are also being assessed against other fisheries data sets held by SPC and the results of these analyses are presented separately. In addition, species-specific estimates of shark catches for the entire WCPFC Statistical Area, i.e. including the North Pacific, are presented in Lawson (2011).

2. Data Description and Handling

Two data sets from longline operations were provided by Japan:

- Set-by-set (operational) research and training vessel (RTV) logsheet data for 1992-2009 (n=32,053)
- Set-by-set (operational) commercial longline vessel logsheet (LLL) data for 1993-2009 (n=1,215,299)

Basic features, as well as special handling practices, are described for each data set below. There are no species-specific records for shark catches by Japanese purse seine fleets.

2.1 Research and Training Vessel (RTV) Data Set

This dataset is compiled from logsheets recorded by research vessels belonging to, or chartered to, national or prefectural fisheries research institutes, and from logsheets compiled and voluntarily submitted by vocational training vessels attached to "fisheries high schools" throughout Japan. There is no formal distinction in the database between these two sources.

2.1.1 Data Formatting and Cleaning

Before using the dataset a number of checks and conversions were undertaken:

- Replacing the numeric species codes used by Japan with the FAO three-digit alphabetic species codes;
- Converting date fields and constructing a field for trimester;
- Formatting latitude and longitude points to a consistent grid both east and west of 180^{o} longitude and assigning each set to a 5^{o} by 5^{o} cell;
- Assigning each set to a region as defined in Clarke et al. (2010);
- Calculating hooks per basket from the number of hooks and the number of baskets;
- Creating a unique vessel identifier from the set identifier code;
- Creating new taxonomic categories for "makos" and "threshers" (i.e. genus-specific categories for comparison to commercial records which do not distinguish these sharks to species);
- Calculating reporting rates for each cruise; and
- Examining histograms of values in all essential fields for outliers and missing values.

In addition, a number of records were removed to improve the consistency of the data:

- Records from outside Regions 1-6 were removed;
- Records from 2009 were removed (as these were likely to be incomplete);
- Records from sets which were fished with <12 or >13 hooks per basket were removed (77% of all sets were fished with 12 or 13 hooks per basket);
- Records from vessels which fished for less than four of the 17 years in the dataset were removed (most of these had <20 sets in total);
- Records describing sets in which <500 hooks were fished were removed (some cruises may have been designed to test new gear and thus would fish only a small number of hooks).

These checks and deletions resulted in a dataset containing 20,838 records (i.e. sets) representing 28 vessels over 17 years.

2.1.2 Data Description for Cleaned but Unfiltered RTV Data

The distribution of samples represented by the RTV dataset was concentrated in just two of the regions defined for the Pacific-wide shark analyses initiated by Clarke et al. (2010): Region 2 (30%) and Region 4 (65%). Regions 1, 3 and 6 contained <=393 sets each (Figure 1). Over time, the range of RTV set locations has contracted, reportedly to minimize vessel fuel costs, but the waters around Hawaii remain popular due to reputedly calm sea conditions and the attractiveness to students of a Honolulu port call.

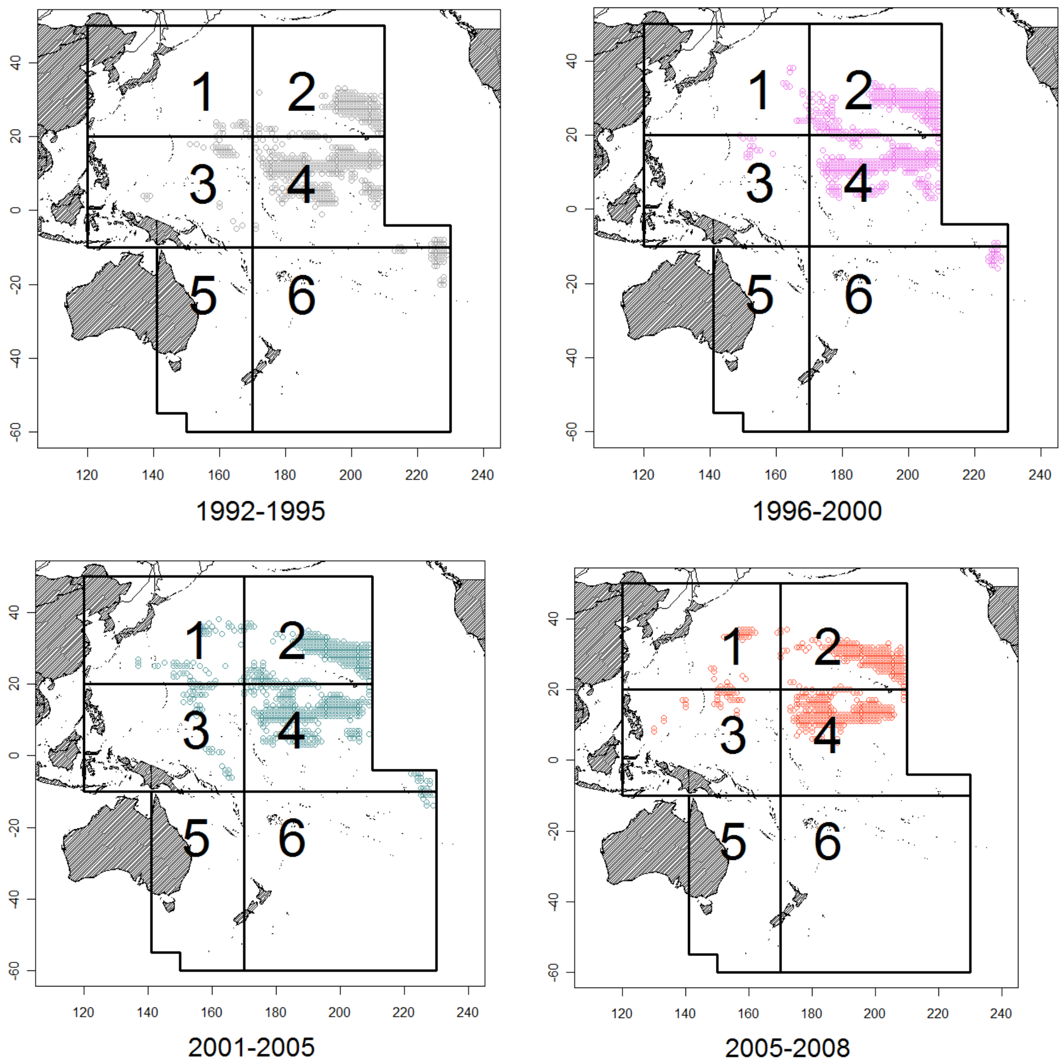

Figure 1. Location of RTV Sets in six regions over four time periods from 1992-2008. Each point represents one set.

Another obvious pattern in the RTV data is the seasonality of sampling in Regions 2 and 4 (Figure 2). Sampling was concentrated (number of sets > 1000) in the months of January-February, May-June, and September-November, and when the data were classified by trimester (i.e. December-March, April-July and August-November) it was observed that while coverage of Region 4 occurred throughout the year, Region 2 was frequently sampled only in Trimester 3 (i.e. August-November). Seasonal patterns in RTV operations are believed to be driven by a desire to avoid interference with commercial fishing operations but still encounter sufficient catches for research and training purposes.

At the initiation of this study, RTV cruises were believed to record all shark catches and to identify sharks to species whenever possible. However, examination of the data revealed that reporting rates for sharks appeared to decrease after 2000, and it has been suggested that perhaps RTV vessels began at that time to release or discard sharks without recording them (see further discussion below). The RTV dataset contains 59 categories for recording sharks, including non-species specific categories. Data on leader material (e.g. wire versus nylon) has been recorded by some vessels since 2000 and of the sets for which it was recorded (40%), 84% used wire leaders. Further information on the gear types used by RTV vessels is limited, and the materials and methods used by RTV vessels are not necessarily similar to those used by the commercial fleet.

A total of 258,824 sharks are recorded in the RTV dataset of which 195,097 (75%) were blue sharks (Figure 3). Mako, oceanic whitetip and silky sharks comprised only 2-4% each of the total shark catch (5,462; 9,591; and 5,634 sharks respectively), whereas threshers, primarily bigeye threshers (89% of the total thresher catch), accounted for 15% of the total shark catch (38,016). Only 4% of the sets in the cleaned RTV database recorded no sharks of any species.

2.1.3 Reporting Rates and Filtering

Under-reporting can be a major obstacle to understanding the true catch rates of shark species. One potential solution to this problem is to calculate a shark reporting rate and apply it as a filter to remove those sets which appear to be under-reporting shark catches. This method is described in Nakano & Clarke (2006) and was used in the recent North Pacific blue shark stock assessment (Kleiber et al. 2009). In the latter example, the reporting rates were calculated per cruise on the basis of total shark catches. For example, the percentage of sets in one cruise for which at least one shark of any species was reported (RRA) was taken to be the cruise-specific reporting rate, that reporting rate was assigned to all sets in that cruise, and sets with a reporting rate of less than 80% were not used in the analysis. It was considered appropriate to apply a reporting rate without regard to species since the majority of sharks in the catches were expected to be blue sharks and blue sharks were the subject of the analysis (Kleiber et al. 2009). A similar all-species approach is applied in the current study.

There was initially no reason to suspect under-reporting in the RTV data set. However, reporting rates in the RTV data set were closely examined in order to set an appropriate reporting rate filter for the commercial LLL database as described in the following section. As expected, the RTV reporting rates based on at least one shark of any species per set (RRA), were very high: over 85% of the sets derived from cruises with reporting rates greater than 95%[3].

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[3] Less than 5% of the sets were derived from cruises with reporting rates of 70% or less

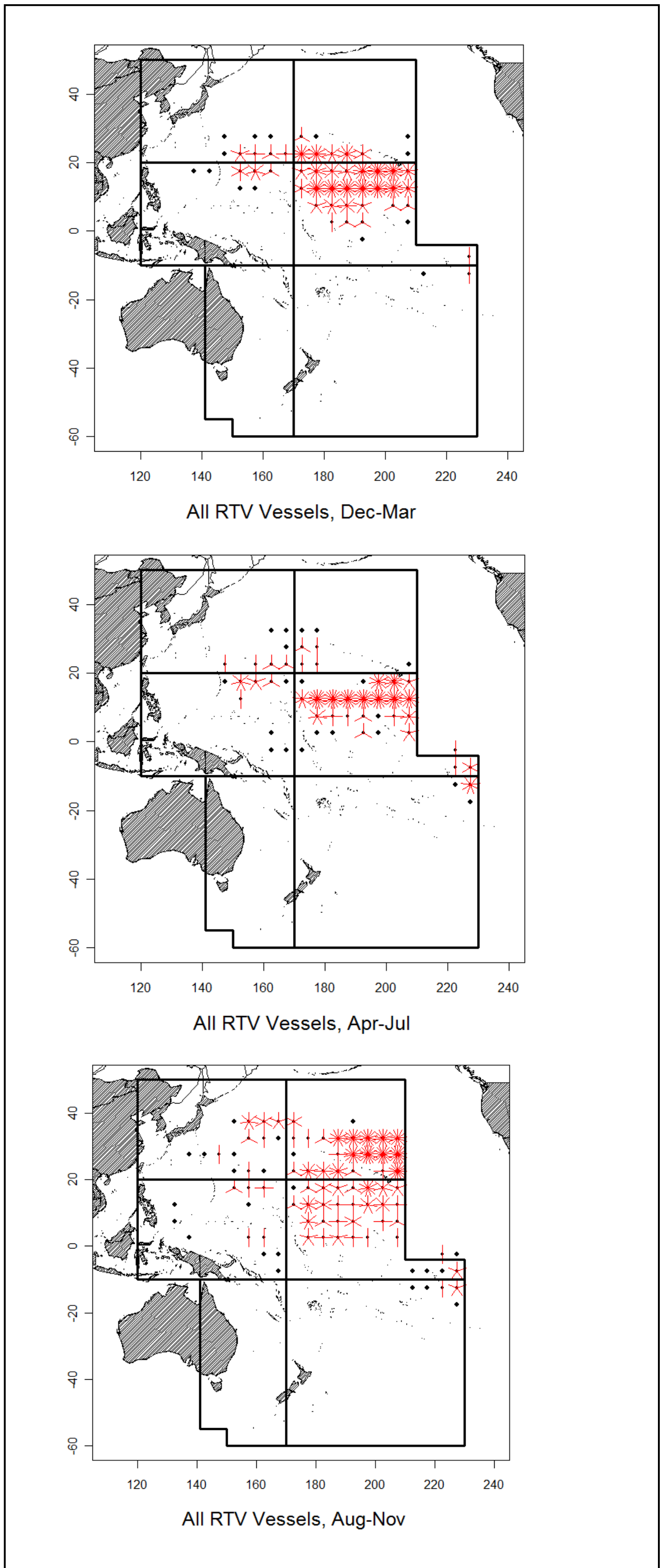

Figure 2. RTV set locations assigned to a 5° by 5° grid with the number of rays on the rosette in each cell of the grid representing the number of years in which that cell was sampled, 1992-2008. Rosettes plotted outside Region 4 represent data south of 4 degrees south latitude but are plotted at the center of the 5° by 5° grid.

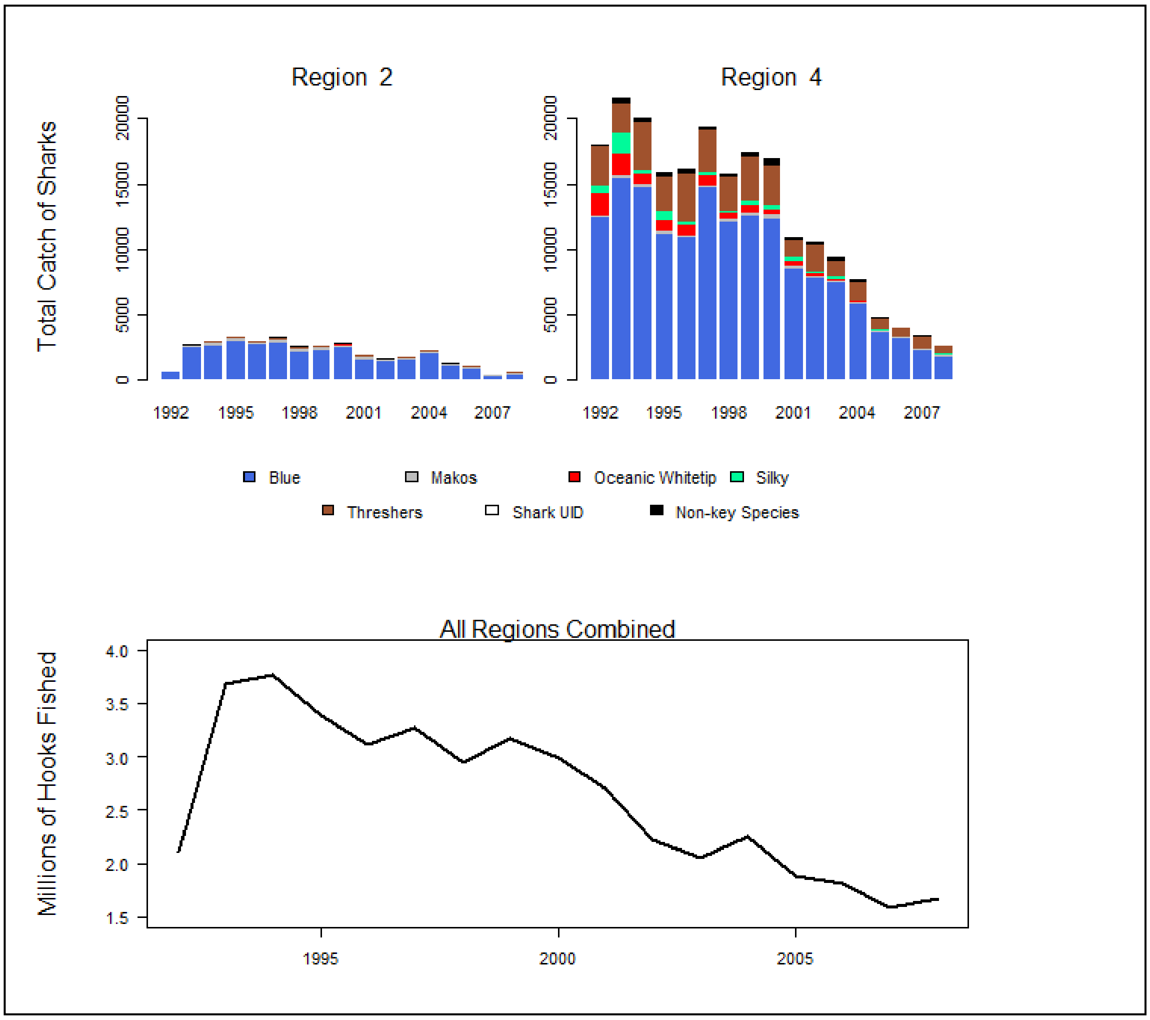

Figure 3. Shark species composition in number of sharks in the entire RTV dataset in Region 2 (30% of all sets) and Region 4 (65% of all sets) (upper panel), and total hooks fished by RTV vessels, 1992-2008.

Several further issues surrounding reporting rate filters were considered in connection with the RTV data set. First, it was noted that the annual mean reporting rate (RRA) declined from 100% in 1992-1999, to 95% in 2004, and to 69% in 2008. While it is possible that operational factors have led to this decline, it is also possible that a decline in the abundance of sharks in the fishing grounds could lead to a greater number of sets reporting "true" zero catches. When setting a reporting rate filter it is important to balance the risk of removing sets with "true" low shark catch rates against the risk of retaining sets with "false" low shark catch rates. For example, a very high reporting rate filter would exclude cruises which accurately reported shark catches but fished in areas without many sharks. In contrast, very low reporting rates are unlikely to be accurate given the observed encounter rate of sharks in most RTV sets.

Second, when defining a reporting rate filter based on RTV data for application to LLL data it is important to compare only the catch rates of those sharks which are recorded in both data sets. Since the LLL vessels were required from 1994 onward to record blue, mako and porbeagle/salmon sharks, and were required from 1999 onward to record oceanic whitetip and thresher sharks (see following section) [4], reporting rates for the RTV dataset were calculated for the same two time periods based on these species only (RRX and RRY, respectively). A composite reporting rate (RRZ)

[4] Data for years prior to implementation of these requirements are partial and should be used for reference only.

was formed from RRX for 1994-1998 and RRY for 1999-2008 and is used in the following analyses instead of RRA. Since the majority of sharks recorded are blue sharks (Figure 3), the main difference between RRA and RRZ relates to the exclusion of thresher sharks prior to 1999.

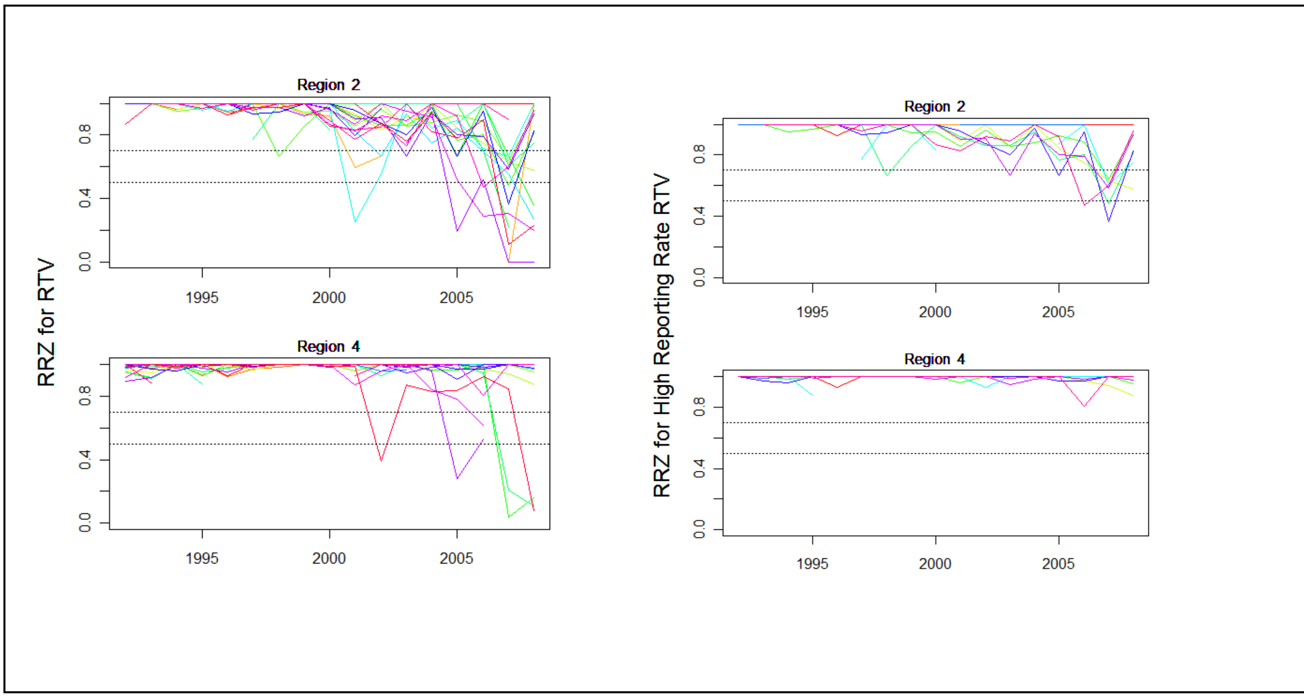

Figure 4. Reporting rates by vessel and year for the RTV data, 1992-2008, for 28 RTV vessels in the left panel and 10 high average reporting rate vessels in the right panel. RRZ is a composite of RRX (the percentage of sets in a cruise in which at least one blue, mako or porbeagle/salmon shark was recorded) and RRY (percentage of sets in a cruise in which at least one blue, mako, porbeagle/salmon, oceanic whitetip or thresher shark was recorded) for the years 1993-1998 and 1999-2008, respectively.

RRZ reporting rates by vessel by year for the RTV data from Regions 2 and 4 show a clear pattern of 90-100% reporting rates for most vessels until 2000 and widely varying rates thereafter (Figure 4, left panel). It is clear that some vessels in the latter period are not accurately recording sharks because their annual reporting rate averages are well below 50% and at times as low as 0%. However, some of these vessels may have actually encountered fewer sharks in later years and recorded this accurately. A linear model of reporting rate (RRZ) with factors year and vessel indicated that ten vessels showed a change of less than 5% over time (n=7,974 sets; Annex 4[5]). As these ten vessels were able to maintain high reporting rates throughout the time period, it is likely that their reporting practices did not change over time. There is also no evidence to suggest that these ten vessels changed their fishing operations toward greater intentional or unintentional targeting of sharks. As shown in Figure 5, with the exception of a greater concentration of samples at higher latitudes in Region 4 in the August-November trimester by the high reporting rate RTV vessels, differences in fishing effort between the two groups of vessels are indistinguishable. On this basis it was decided to conduct catch rate analyses for the RTV data set using data from these ten high reporting rate vessels which showed little change in reporting rates over time. It may be worthwhile exploring and testing other reporting rate filters for RTV data, however, without a reference database representing "true" shark catch rates (e.g. a representative observer dataset), it is likely that selection of the "best" filter will remain problematic.

[5] It should be noted that data were insufficient to support standardization by year, vessel, area and season simultaneously. For this analysis the most important factors were year and vessel as the objective was to isolate the effect of vessel over a range of areas and seasons which were generally similar (Figure 5).

Having thus effectively filtered the RTV data set, a remaining issue concerned the selection of a filter for application to the commercial LLL data set. It is not possible to use the slope of the regression of reporting rates over time as a filter, as was applied to RTV, since some of the LLL vessels have dubious low reporting rates throughout the time period. Furthermore, as illustrated in Figure 4b, some of the high average reporting rate RTV vessel have low reporting rate averages in some regions and years, even though only ~5% of their sets derive from cruises with reporting rates below 80%. In other words, this suggests that low shark catch rates may occur even for high reporting rate vessels. Given these issues, there were two possibilities: a) define a number of different reporting rate filters based on high average reporting rate RTV data stratified by area and time; or b) define a more generic filter based on a vessel-averaged reporting rate which allows for a reasonable amount of spatial and temporal variation. While the first option has the potential to be more precise, it requires reliable reporting rate information for all areas of commercial fishing and such information is only available for some portions of Regions 2 and 4. Therefore, the option of applying a reporting rate filter to individual vessels was selected.

The lowest vessel-based average reporting rate (RRZ) for the high reporting rate RTV data set was 94.6%. This filter, though higher than that applied in previous assessments on a set by set basis, is based on a vessel average and thus allows for sporadic lower reporting rates if the vessel happens to fish in areas where shark abundance is low. However, this filter removes data from vessels with average reporting rates lower than 94.6% even if that vessel sometimes demonstrates high reporting rates. Maintaining consistency at the vessel level reduces the number of data points available for analysis but should improve the quality of the dataset. Application of this reporting rate filter to the commercial LLL data set is described in the following section.

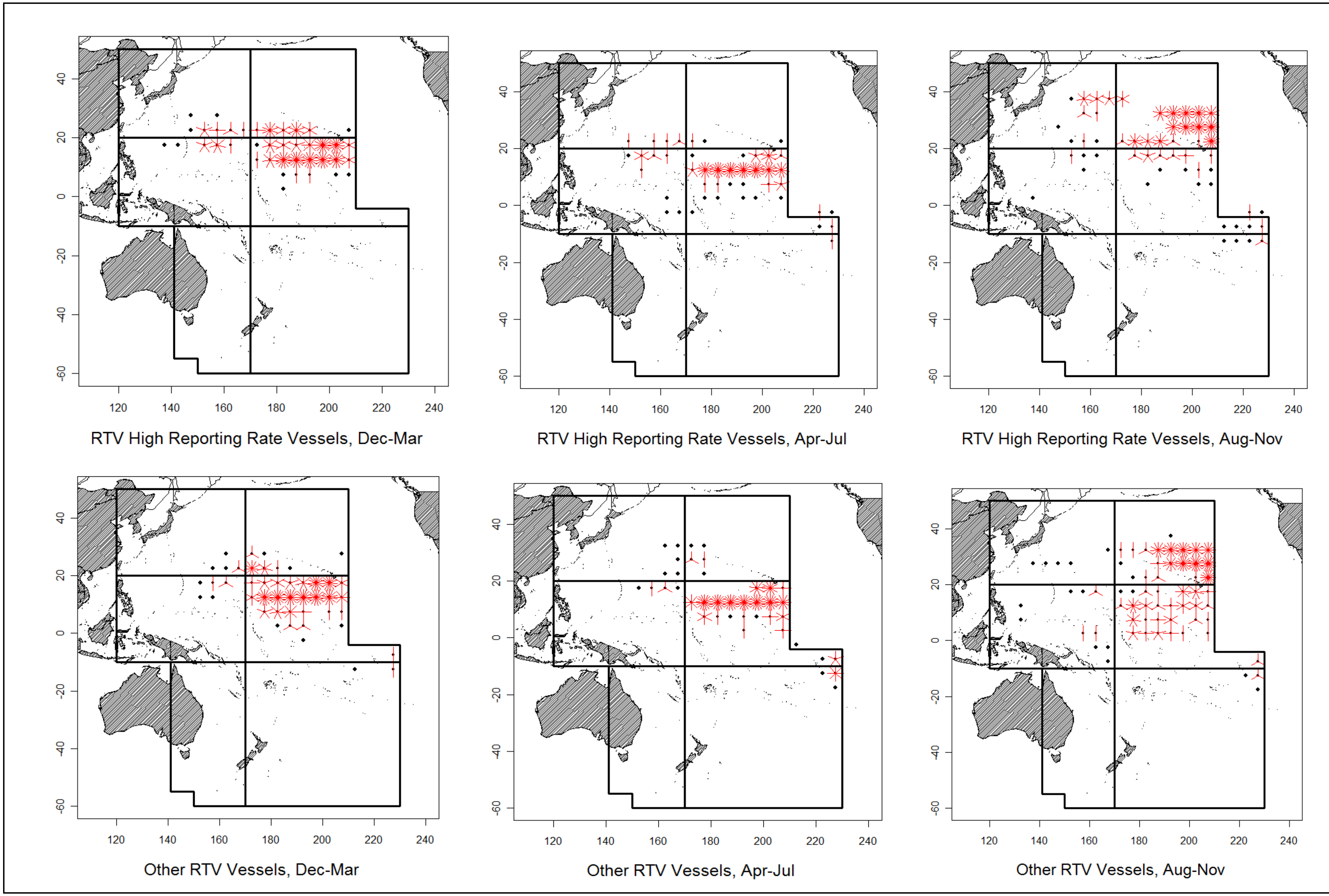

Figure 5. Fishing effort of ten high reporting rate RTV vessels as compared to eighteen other RTV vessels by trimester, 1992-2008. Rosettes plotted outside Region 4 represent data south of 4 degrees south latitude but are plotted at the center of the 5° by 5° grid.

2.2 Longline Logsheet (LLL) Data Set

This dataset is compiled from logsheets submitted by vessels comprising Japan's distant water (*enyo*) and offshore (*kinkai*) longline fleets. Logsheet formats were modified to include four shark categories (blue, mako, porbeagle/salmon and others sharks) in 1993, with implementation in 1994 (1993 data for reference only). In 1998-1999, additional categories for oceanic whitetip and thresher sharks were included on the logsheets. There are no species-specific data for silky sharks available in the commercial LLL data set.

2.2.1 Data Formatting and Cleaning

The same checks and conversions were undertaken for the LLL data set as for the RTV data set. Similarly, records from outside the WCPO Statistical Area, records from 2009, and records with hooks per basket of zero or >40 were removed from the data set before analysis. These checks and deletions resulted in a dataset containing 658,923 records (i.e. sets) representing 1,025 vessels over 16 years.

2.2.2 Data Description for Cleaned but Unfiltered LLL Data

Over 70% of the unfiltered LLL sets were conducted in Regions 4 (29%), 1 (24%) and 3 (20%) (Figure 6). Region 2 only accounted for 10% of the unfiltered LLL sets and showed less fishing effort in Trimester 2 (i.e. April-July) (Figure 7, left). There has been little fishing effort by the Japanese longline fleets in Region 6 and thus this region is not considered further in this analysis.

The leader type was recorded for all but 94 of the unfiltered LLL sets: 40% of the sets were made with nylon leaders and 60% with wire leaders. A field within the LLL data set is designed to indicate whether the set targeted swordfish, shark or another species (usually referring to tuna). In the unfiltered data set, the mean of the annual averages indicates that ~15% of the sets targeted swordfish, <2% of the sets targeted sharks, and 84% of the sets targeted "other" species.

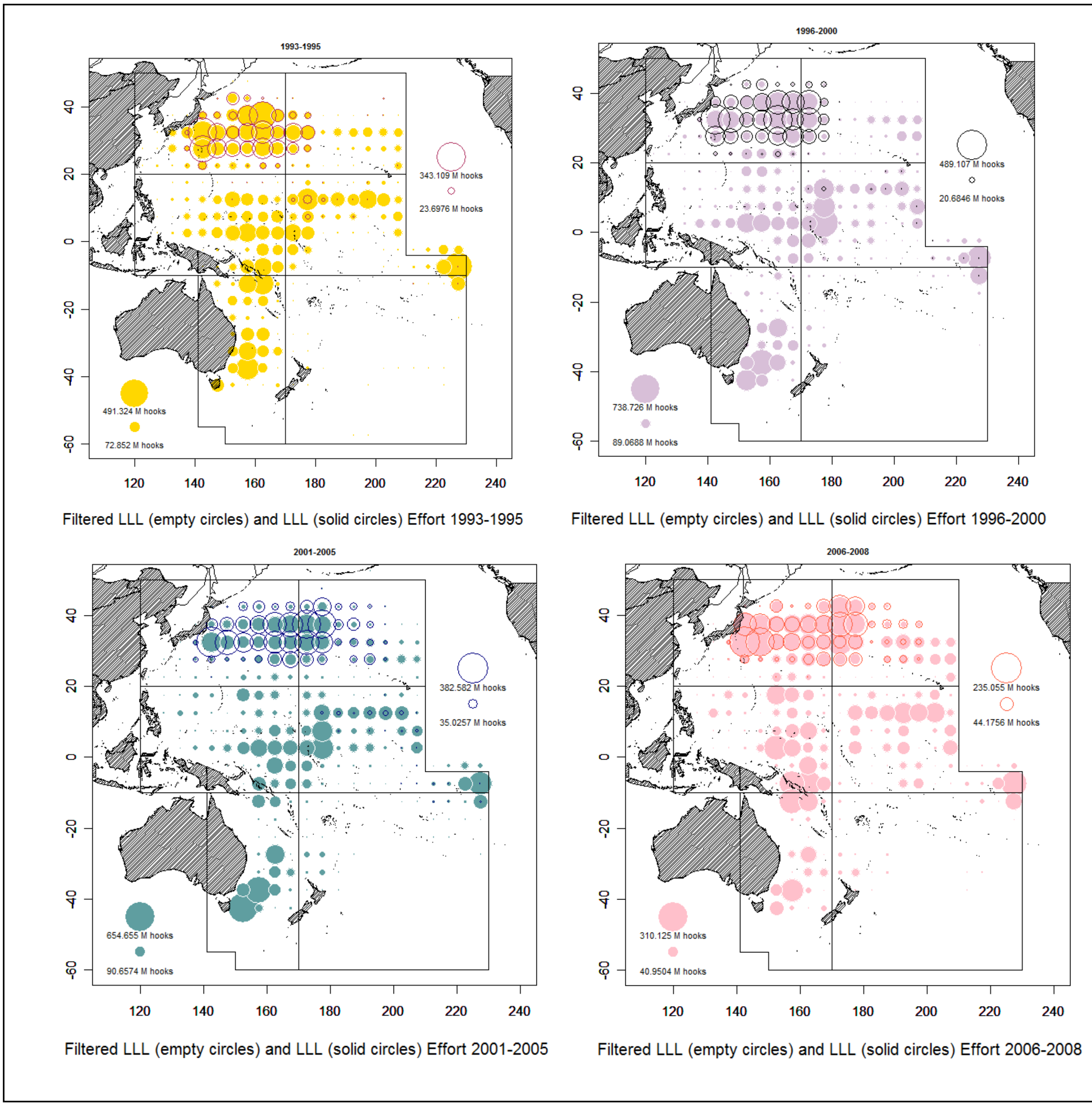

Figure 6. Location of unfiltered (solid circles) and filtered (empty circles) LLL sets in six regions over four time periods from 1993-2008. Size of the circles represents the proportion of unfiltered and filtered effort (in million hooks) in each 5° x5° cell.

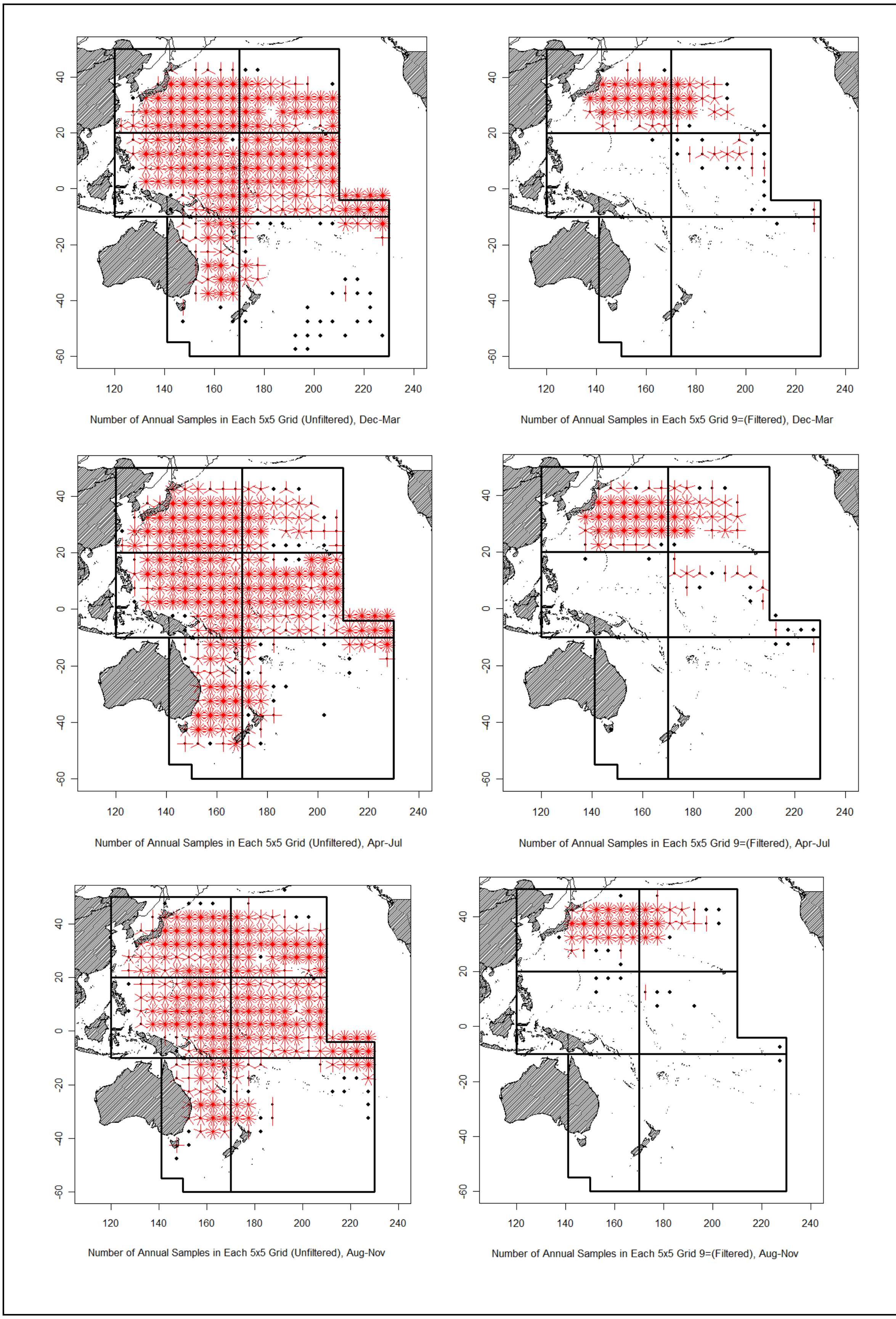

Figure 7. Unfiltered and filtered LLL set locations assigned to a 5° x 5° grid with the number of rays on the rosette in each cell of the grid representing the number of years in which that cell was sampled, 1993-2008.

Catch tallies and species composition calculations for unfiltered LLL data are likely to be both under-reported and biased toward the more valuable species which are more likely to be recorded in the logbooks (e.g. makos). In particular, of the total number of sets (n=658,923), 65% recorded no sharks at all. Although it is not thus expected to be an accurate representation of catches, Figure 8 (left) shows the sharks recorded in the unfiltered LLL data. Blue sharks are the most commonly reported species in Regions 1 and 2, but makos are the predominant species in Region 5. Oceanic whitetips are most often observed in sets from Region 3 and threshers are most often observed in Region 4. Decreasing trends in total catches appear in many cases to be related to decreasing fishing effort (Figure 8, right). Overall, nearly 9.8 million sharks are recorded in the unfiltered LLL data set of which 94% are blue sharks, 3% are makos and 2% are "other" sharks. The number of porbeagles, oceanic whitetips and threshers recorded each comprise less than 1% of the total.

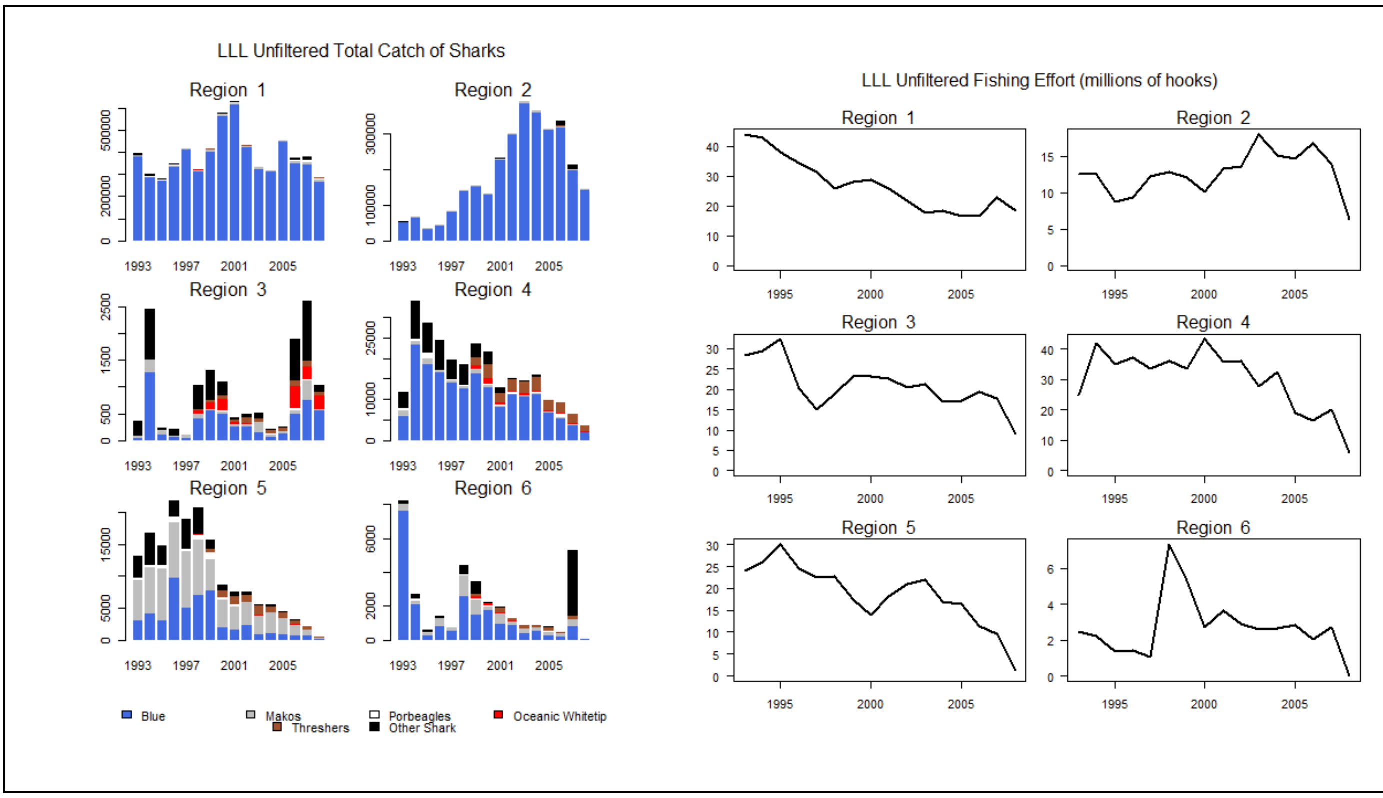

Figure 8. Species composition (left) and fishing effort (right) for unfiltered LLL data, 1993-2008.

2.2.3 Reporting Rates and Filtering

As described above (Section 2.1.3), a reporting rate filter of 94.6%, applied as a vessel average, was identified using RTV data for high average reporting rate vessels. Application of this filter to the LLL data set resulted in 88,129 set-by-set LLL records representing 112 vessels over 16 years. Annual average vessel reporting rates for LLL vessels passing the reporting rate filter are shown in Figure 9. In contrast to the RTV reporting rates which exhibit a trend toward increasing variance with time, the 112 LLL vessels which pass the filter have higher variance in the early part of the time series and more constant reporting rates in recent years. As will be shown in Section 6, this may be due to important differences between the RTV and LLL vessels regarding shark targeting. For both datasets, exploration of alternative filtering methods may be worthwhile in future, but definitive selection of the "best" method will likely require ground-truthing datasets (e.g. representative observer data) which are not currently available.

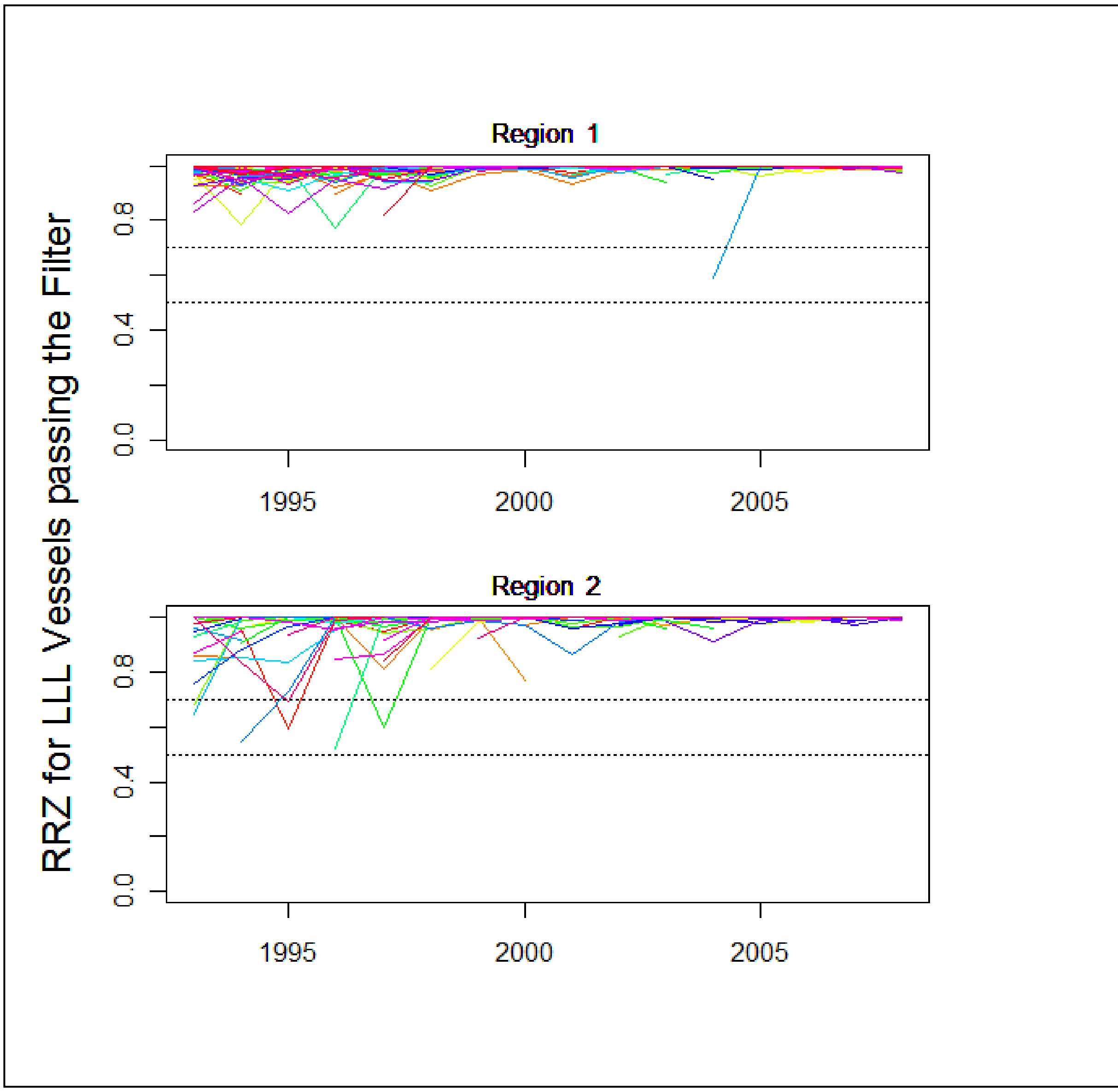

Figure 9. Annual vessel-specific reporting rates for 112 LLL vessels passing the reporting rate filter, 1993-2008. The reporting rate RRZ is a composite of RRX (the percentage of sets in a cruise in which at least one blue, mako or porbeagle/salmon shark was recorded) and RRY (percentage of sets in a cruise in which at least one blue, mako, porbeagle/salmon, oceanic whitetip or thresher shark was recorded) for the years 1993-1998 and 1999-2008, respectively.

Comparison of the unfiltered and filtered set locations by year and by trimester indicates that in contrast to the unfiltered data which is concentrated in Regions 4, 1 and 3, the filtered data is predominantly concentrated in Region 1 (74%) and the western-most portion of Region 2 (24%) (Figures 6 and 7). To the extent that there are filtered data available for Region 4, these data are mainly for Trimesters 1-2 (i.e. December-July (Figure 7)). Over time the filtered data contract from Region 4 and the area of concentrated sets in Regions 1 and 2 extends further eastward into Region 2. While there are substantial numbers of LLL records for Regions 3 and 5, almost none of these records remain after filtering, particularly in later years.

Further examination of the effects of the filtering was undertaken using histograms showing the proportion of sets in each region with reporting rates (RRZ) by 5% interval (Figure 10). Region 1, and to a lesser extent Region 2, show a large proportion of sets derived from cruises with reporting rates of >95% and <5% and very few from cruises with intermediate values. Region 3, and to a lesser extent Region 4, show the vast majority of sets derive from cruises with reporting rates of <5%. Since almost no sets passed the filter in Region 5 this region was not analysed further.

An analysis of the port of registration of vessels fishing in each of the four regions indicated that vessels fishing in Regions 1 and 2 are mainly based in Miyagi prefecture (northeast Japan), whereas as those fishing in Region 3 are based in Oita prefecture (southwest Japan) and those fishing in Region 4 are primarily far seas (*enyo*) vessels based in a wide range of ports. One of the potential reasons for high reporting rates for sharks could be a commercial interest in documenting catches. High reporting rates in Regions 1 and 2 may thus be explained by the presence of Japan's largest shark market at Kesennuma, Miyagi prefecture and the fact that many of the vessels fishing in these regions are based at or near that port. The lack of a market for sharks in other parts of Japan, such as Oita prefecture, may partially explain the low reporting rates in Regions 3 and 4. Higher reporting rates in Regions 1 and 2 may also be explained by the relatively higher abundances, and thus catch rates, of blue and shortfin mako sharks in these areas (Nakano 1994, Semba et al. 2011).

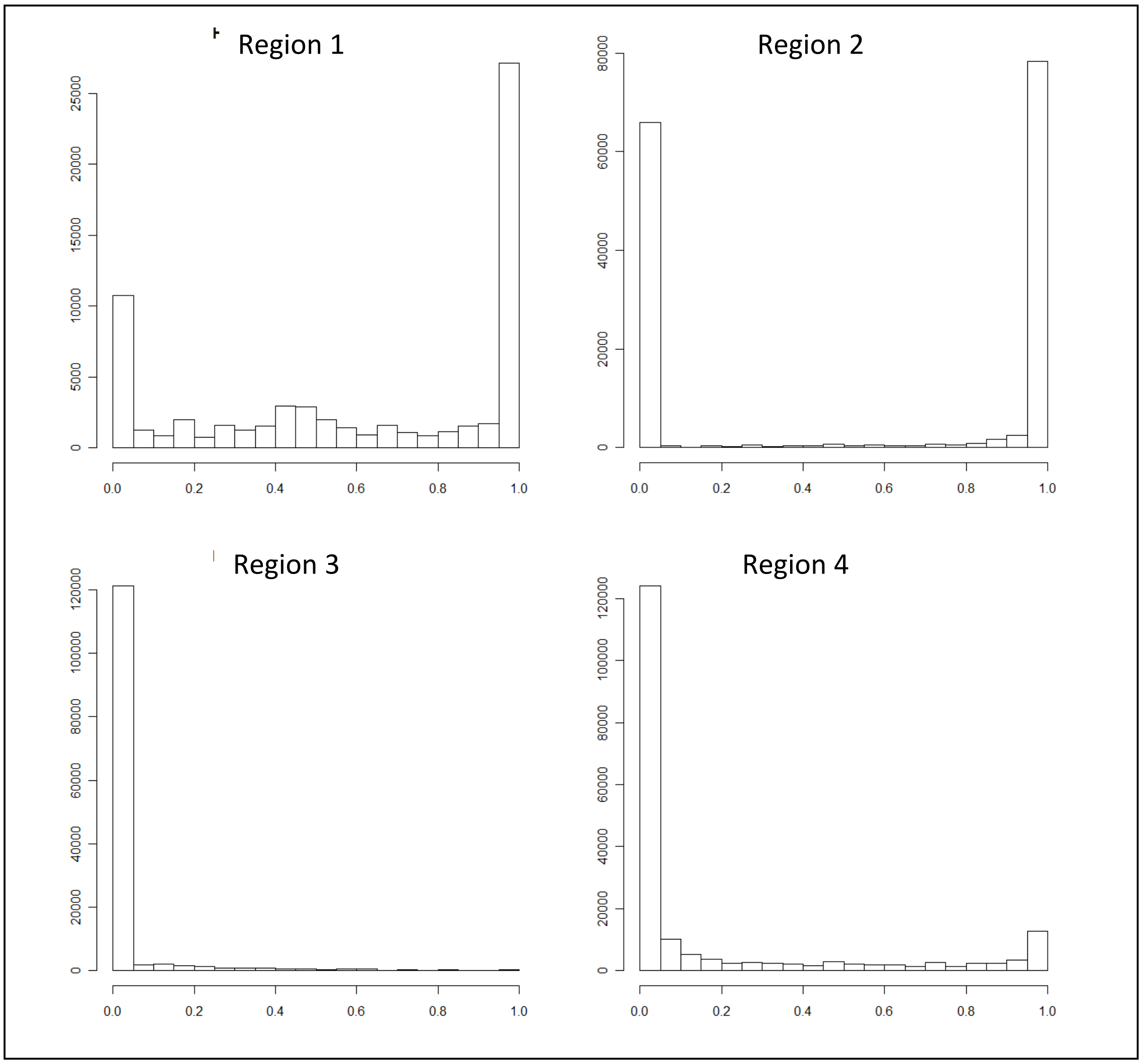

Figure 10. Histograms of unfiltered LLL data reporting rates (0-100% RRZ by 5% intervals) for Regions 1-4, 1993-2008.

Recalling that only 1% of the unfiltered LLL sets indicated shark targeting in the targeting field on the logsheet, the filtered data were examined to determine whether vessels with consistently high shark reporting rates indicated they were targeting sharks. Of the sets which passed the filter only 5% indicated shark targeting. Of these, 55% of these were in Region 1 and 45% were in Region 2. Leader type was recorded for all but 28 of the filtered sets with the majority (77%) composed of wire and the remainder (23%) composed of nylon.

2.3 Comparability of RTV and LLL Records

The filtered RTV and LLL data sets described in the preceding sections form the basis of the remaining analysis. Data preparation and filtering was undertaken to attempt to remove errors and biases but because one data set is based on training cruises and the other is commercial, it may be expected that they will show different signals. One particular concern is that the RTV operations try to minimize conflicts with commercial fishing operations and thus may avoid key fishing grounds and seasons. Another concern is that the commercial data set will reflect targeting strategies (e.g. implemented through selection of location, depth, and/or gear type) based on the economic value of various species whereas the RTV data set would not. These factors may or may not contribute to differences in catch rates and other indicators from these two data sets.

To some extent potential differences between the two data sets can be minimized through the standardization models applied in the following sections. These models include factors such as cell (latitude-longitude), leader type (nylon or wire), and hooks per basket (a proxy for fishing depth, and potentially, target species). However, such standardization can only be expected to minimize differences between the data sets if it can be assumed that both sample the same underlying population. To explore whether it should be expected that RTV and LLL data sets produce similar indicators for North Pacific sharks, plots of sampling coverage and catch per unit effort (CPUE) were prepared. The effort plot (Figure 11) shows that while there are some locations that are sampled by both fleets these are small in number and mainly in recent years when the RTV vessels moved closer to Japan and the LLL vessels expanded operations eastward across the North Pacific. Using the most abundant shark, blue shark, as an example, nominal CPUEs were computed and plotted on a relative scale by year in Figure 12. These plots reveal that blue shark CPUE is highest in the LLL data set along the boundary between Regions 1 and 2, an area not sampled by the RTV fleet operations in Region 2. By the end of the time period the expansion of the LLL fleet's fishing grounds eastward through Region 2 results in some overlap with the RTV fleet operations north of Hawaii but catch rates appear to differ perhaps due to targeting. An area of moderate blue shark CPUE is found for both fleets between 5^{o} and 10^{o} south latitude (Region 4); this area is routinely sampled by the RTV fleet but only rarely by the LLL fleet (2003-2005) (Figure 12). Based on these patterns, it is considered appropriate for analysis of RTV and LLL North Pacific data to extend the eastern boundary of Region 1 to 180^{o} longitude. This will allow the block of LLL effort in Region 1 and the western-most portion of Region 2 to be estimated as a unit, and avoid biasing the whole of Region 2 with a concentration of fishing effort which occurs at its western boundary. The new boundaries, to be applied in the remainder of this analysis, are shown in Figure 13.

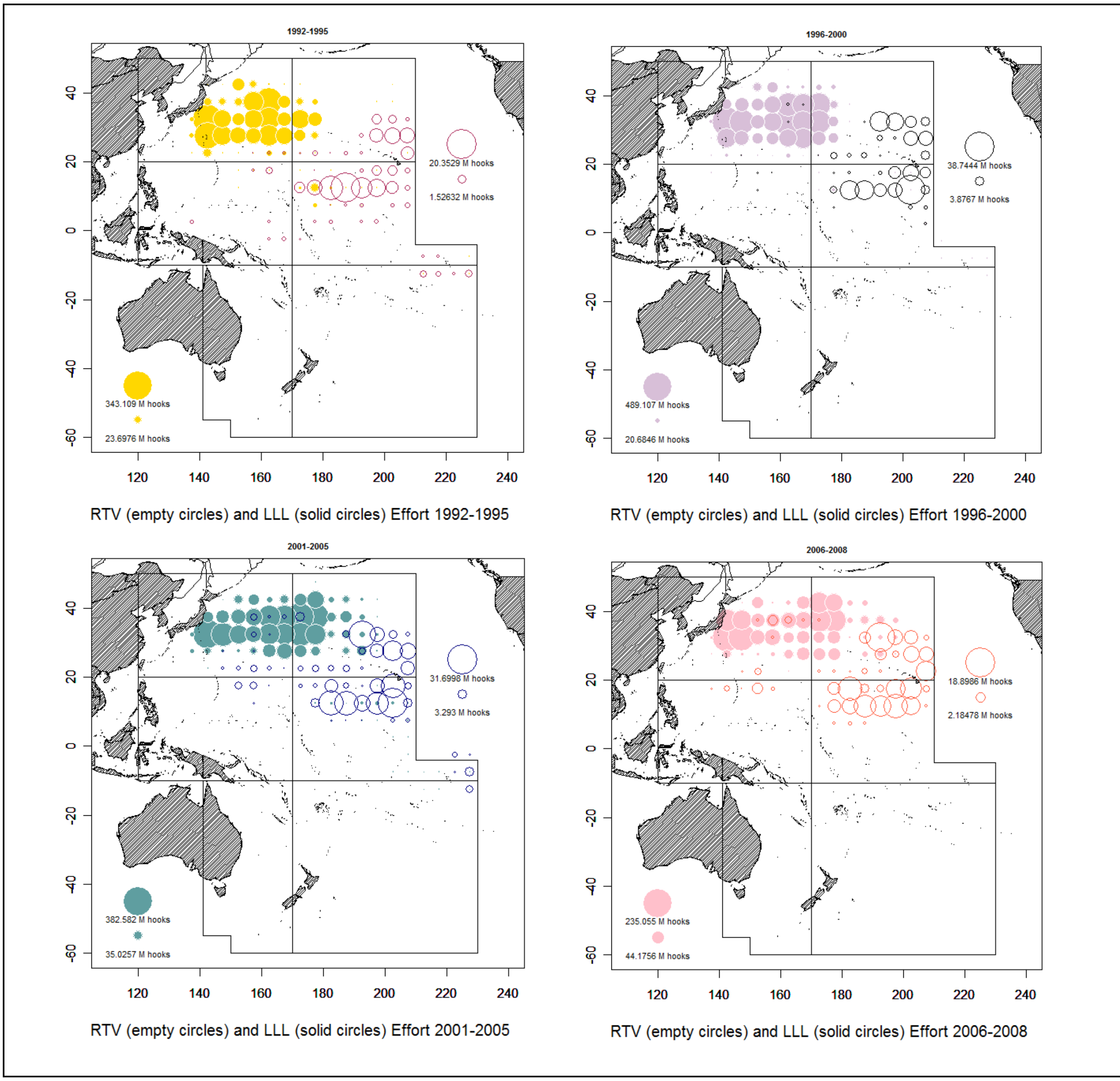

Figure 11. Location of filtered LLL (solid circles) and filtered RTV (empty circles) sets in six regions over four time periods from 1993-2008. Size of the circles represents the proportion of filtered LLL and filtered RTV effort (in million hooks) in each 5^{o} x5^{o} cell.

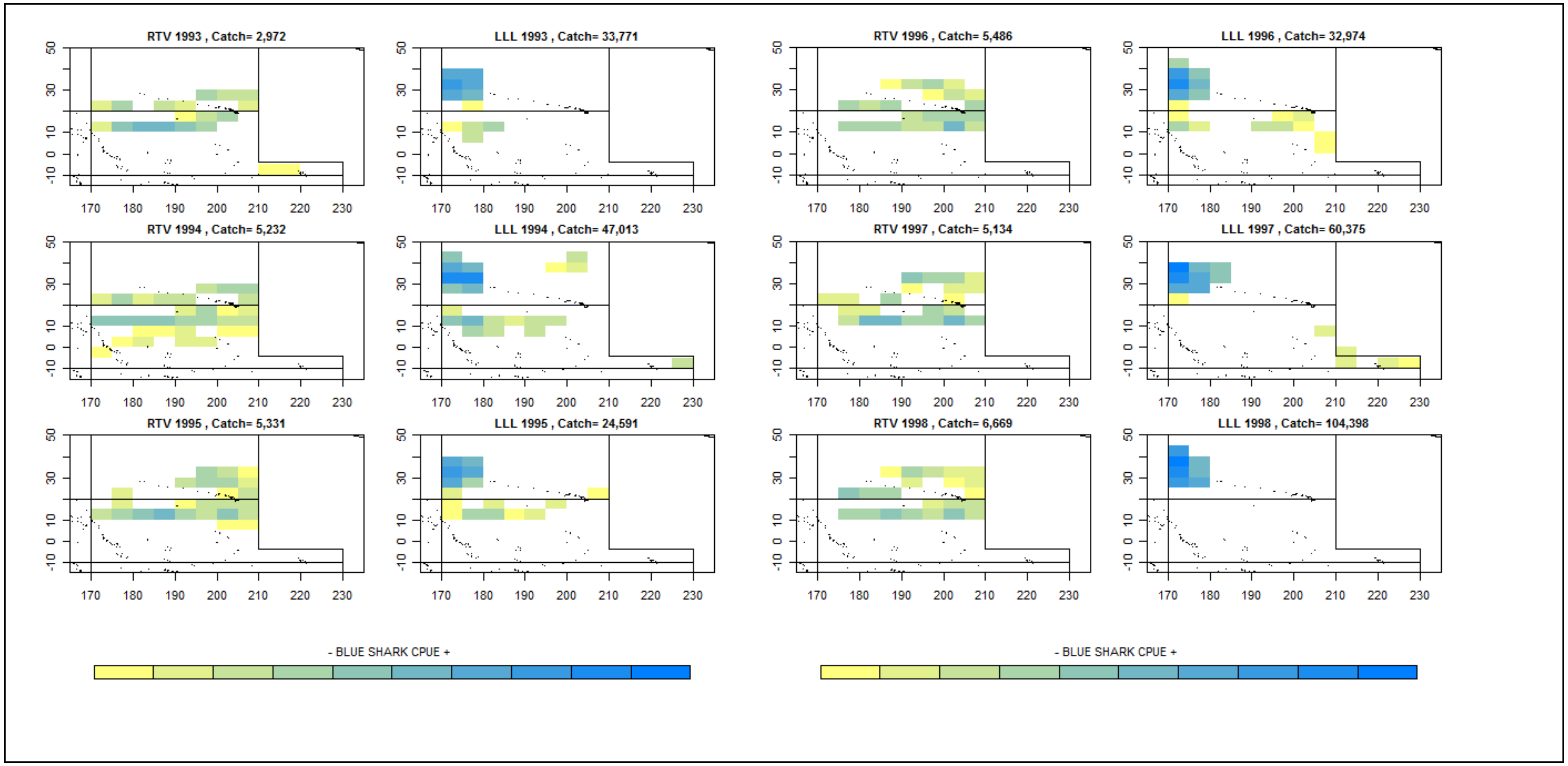

Figure 12. Comparison of blue shark catch per unit effort (1000 hooks) for filtered RTV and filtered LLL data sets in Regions 2 and 4, 1993-1998. The color scale indicates low (yellow) to high (blue) CPUE based on the distribution of CPUEs in the filtered LLL data.

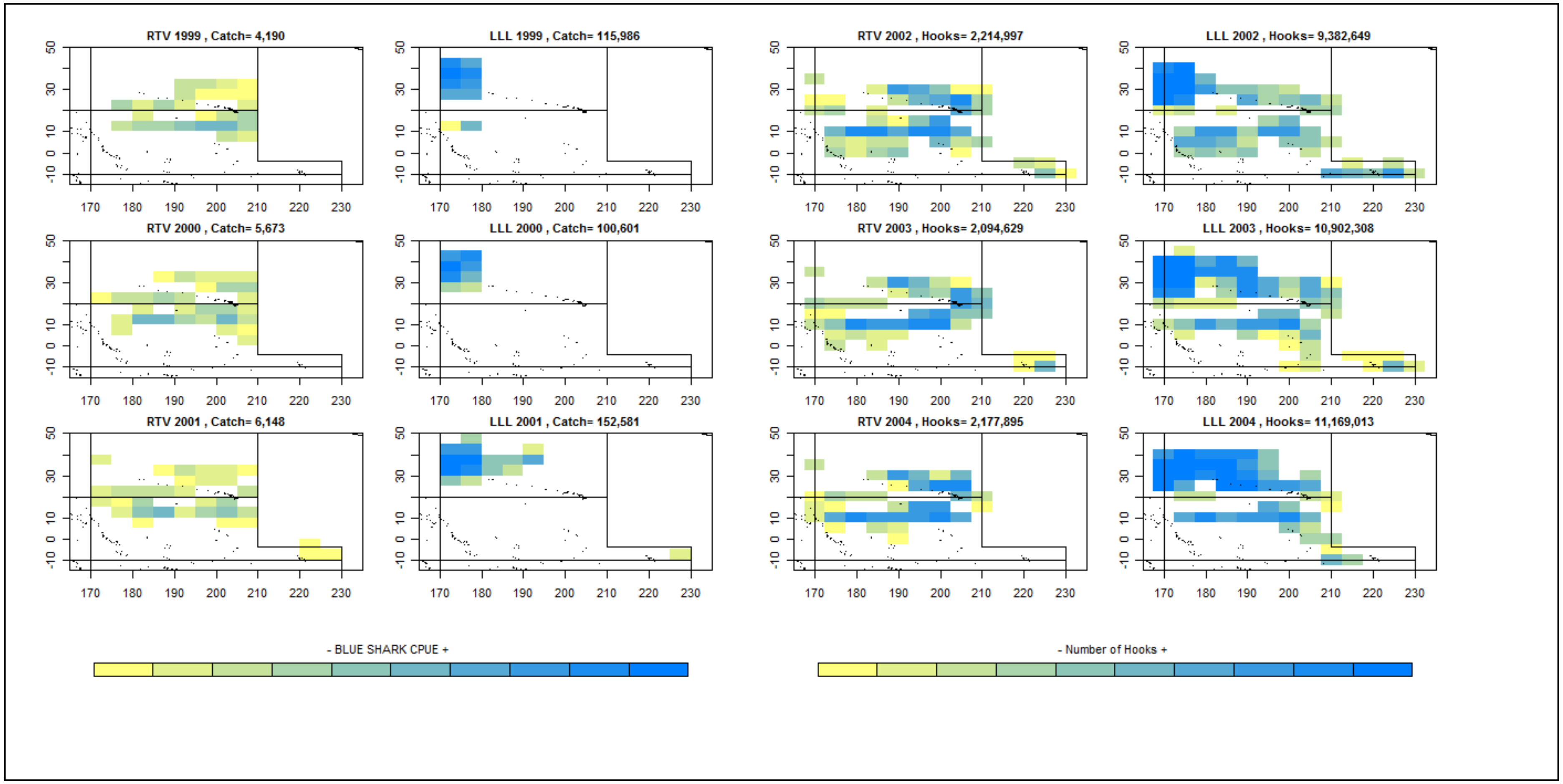

Figure 12. (cont) Comparison of blue shark catch per unit effort (1000 hooks) for filtered RTV and filtered LLL data sets in Regions 2 and 4, 1999-2004. The color scale indicates low (yellow) to high (blue) CPUE based on the distribution of CPUEs in the filtered LLL data.

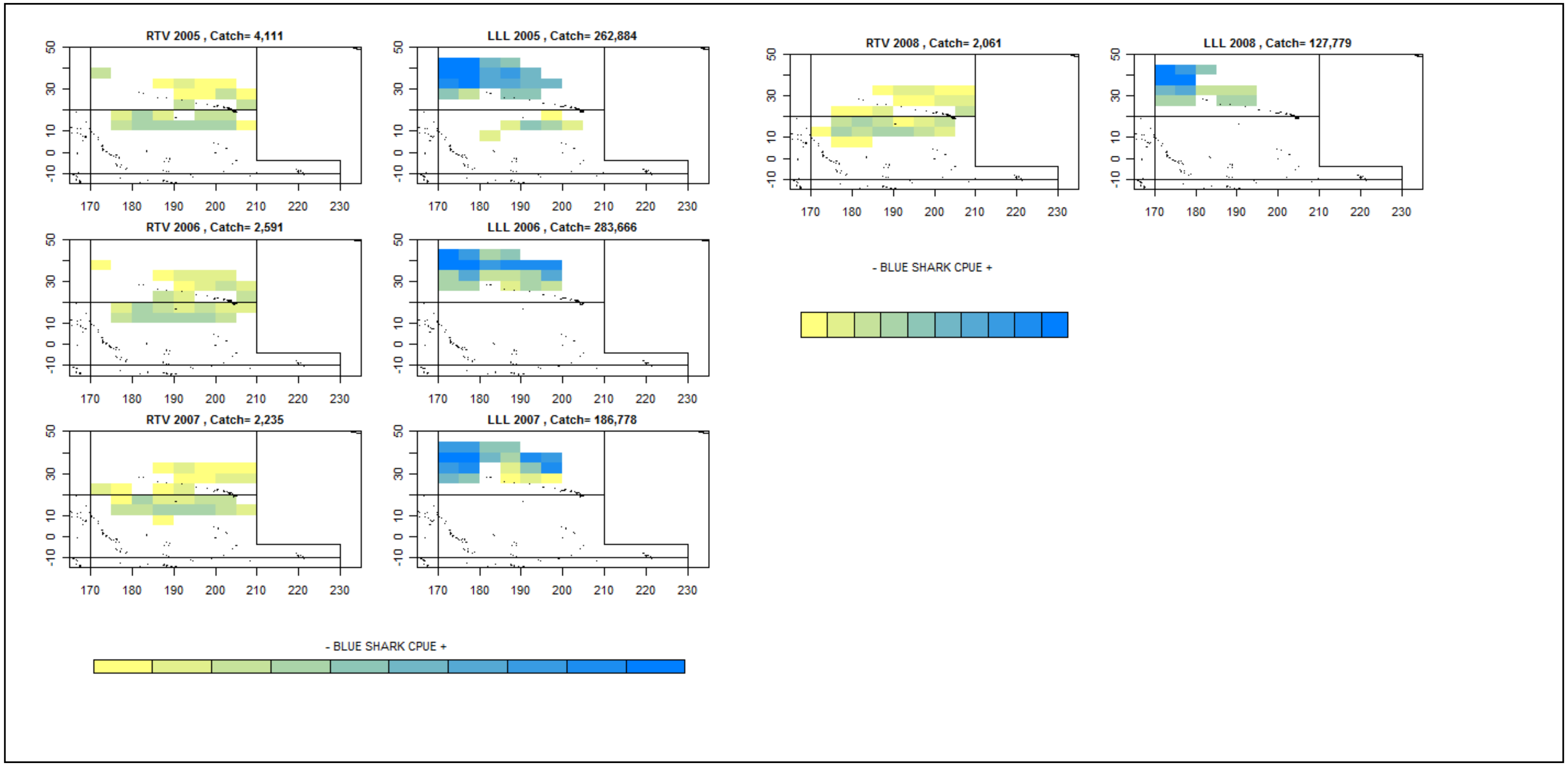

Figure 12 (cont). Comparison of blue shark catch per unit effort (1000 hooks) for filtered RTV and filtered LLL data sets in Regions 2 and 4, 2005-2008. The color scale indicates low (yellow) to high (blue) CPUE based on the distribution of CPUEs in the filtered LLL data.

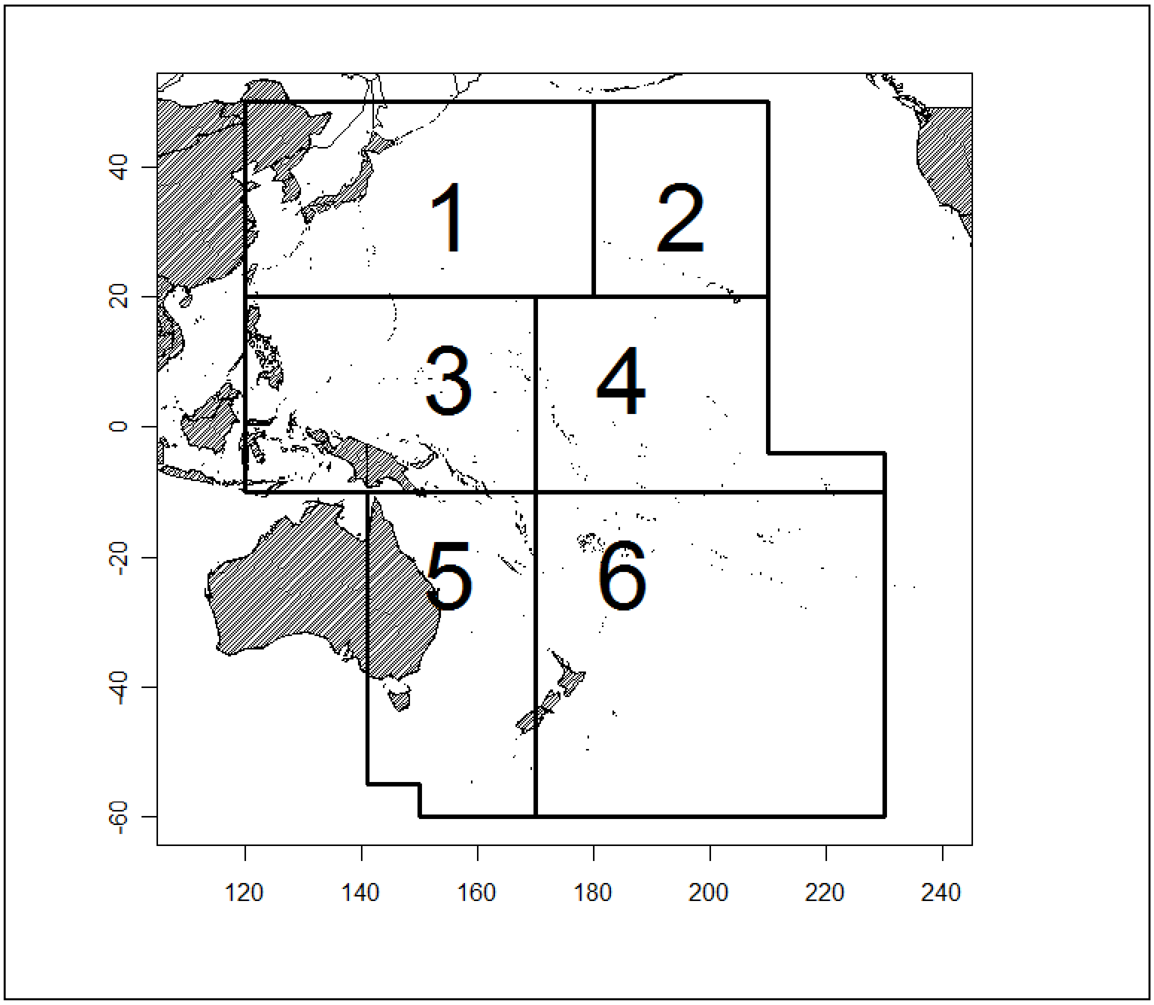

Figure 13. Regional boundaries as revised based on analysis of coverage patterns in the RTV and LLL data sets.

3. Distribution

3.1 Distribution Patterns by Species

This indicator examines the geographic range of each species and the habitat usage (in terms of location only; oceanographic variables are not considered), by different life stages (adult/juvenile) and sexes. This type of analysis can identify range contractions or expansions which may be linked to fishing activities. In addition, since many pelagic shark species are known to exhibit sex- and age-specific distribution patterns (Camhi et al. 2008, Mucientes et al. 2009) it can highlight areas which are important to key life stages (e.g. presence of adult females and juveniles may indicate pupping grounds; presence of juveniles only may indicate nursery grounds).

Given the high reliability of its species-specific reporting, the entire RTV data set was applied to the distribution indicator analysis, even if, as indicated in the previous section, some of the RTV vessels under-reported sharks. In order to expand the coverage of the species distribution analysis, the RTV data were supplemented by filtered LLL records for the easily distinguished blue (since 1993) and oceanic whitetip (since 1998) sharks only. However, as the LLL records did not include information on size or sex, the life stage and sex analysis was based on RTV data only.

Maps showing the presence and absence of WCPFC key shark species are provided in Annex 1 (Figure A1). The presence of the species is indicated by a coloured point such that the oldest records are in the palest shades and the more recent records are superimposed in darker shades. It should be noted that these maps do not necessarily represent the entire distribution of each species as they are based on only those locations for which there was a set conducted and the species identification was considered reliable. Potential changes in geographic range over time, e.g. a halo of pale points around a darkly shaded core area, may also be explained by changes in patterns of fishing effort.

The following points were noted from the distribution plots:

- Blue sharks are widely distributed throughout the North Pacific and commonly encountered but there is a suggestion that either the stock or the fishing effort is moving northward in Region 1 over time.
- The concentration of shortfin and longfin makos in Regions 2 and 4 reflects the fact that in order to plot by species, only the RTV data were used and this data set is focused on these regions. It appears that while both species are commonly encountered southwest of Hawaii, recent longfin makos records from north of Hawaii are sparse.
- Oceanic whitetip sharks are found throughout the North Pacific but there are a large number of contiguous zero catch records in the eastern portion of Region 2.
- Silky sharks appear to be sparse north of 20^{o} N latitude and recorded encounters are mainly from the earlier years in the time series.
- The most frequently encountered thresher shark is the bigeye thresher which is widely distributed. The pelagic thresher is commonly encountered only in the area south of 20^{o} N latitude (i.e. the same area as where the silky shark is found). Common threshers are rarely recorded.
- A regional boundary at 20^{o} N latitude appears well-suited to many of the species' distributions as shown in the plots.

3.2 Distribution Patterns by Life History Stage and Sex

Patterns in distribution by life history stage and sex are explored in Annex 2 (Figure A2). Seven of the eight key species were plotted; common thresher is not included due to lack of data. The data for each species in each cell where it was observed were partitioned into four subsets: adult females, adult males, juvenile females and juvenile males. Each cell was then shaded based on the proportion observed in each of the four subsets with darker colours indicating higher proportions. For example, if all of the silky sharks observed in a given cell were adult females the adult female panel would show a darkly shaded cell whereas the other three panels would show only the lightest shading (i.e. even zero proportions receive the lightest colour shading). In order to account for seasonal changes, four-panel plots are presented separately for each trimester (Dec-Mar; Apr-Jul; and Aug-Nov). The data used to partition sharks into adults and juveniles are described in Table 2 in Section 7.

As for the presence/absence distribution plots above, the analysis is limited to those cells for which there was RTV effort and for which the species was observed. In addition, data were screened so that cells with less than 20 individuals of the species encountered over the 17-year sampling period were excluded from the shading but counted in the captioned tally. This is why, for example, there is no shading for longfin makos in Trimester 3 even though some individuals of this species were observed.

The following points were noted from the life stage and sex distribution plots:

- Adult males were the most commonly observed subset of blue sharks; juveniles of both sexes were observed in considerably lower proportions.
- Juvenile male shortfin makos were frequently encountered south of Hawaii in Trimesters 1 and 2, and north of Hawaii in Trimester 3.
- Longfin makos were mainly observed as juveniles south of Hawaii, but the risk of misclassification of adults and juveniles is high given the lack of knowledge about this species' biology.
- No particular subset of life stage or sex dominated the oceanic whitetip or silky sharks' distribution.
- For bigeye threshers, juvenile males appeared to dominate the catch in the area south of Hawaii except for Trimester 3 during which a high proportion of adults were found north of Hawaii.
- Sample sizes for pelagic threshers were limited but appeared dominated by juveniles.

3.3 Summary of Distribution Findings

Analysis of distribution patterns is complicated by the influence of changes in fishing effort, and perhaps other operational factors (e.g. depth and leader material) during the sampling period. Furthermore, samples sizes for length and sex information are quite limited for some species. The most noteworthy findings may be the suggestion of a northward shift in either the catch of blue sharks, or the fishery itself, in Region 1 and the fact that most observed blue sharks in the North Pacific were adult males.

4. Catch Composition

Catch composition in the filtered RTV and LLL data sets was examined to determine whether any changes over time could be observed. For example, reduction in the proportion of a given species in the catch, all other factors remaining equal, could indicate depletion of that species or a change in its range relative to the fishing grounds. Conversely, an increase in the proportion of a given species in the catch, all other factors remaining equal, could signal the population of that species is increasing. It should be noted the absolute catch values are not relevant for examining trends due to filtering and to a reduction of fishing effort over time (see following section for discussion of catch rates).

Use of the filtered RTV and LLL data sets was expected to remove some of the potential reporting biases, particularly in the LLL data, by removing those vessels which did not accurately report sharks. However, the filtering was primarily designed to remove vessels which under-reported sharks and it was unable to ensure that the sharks which are reported are reported in the proper species-specific categories. In particular, in the case of a vessel accurately reporting blue sharks and not other sharks, catch composition based on the filtered data may exhibit a bias toward blue sharks. LLL data from 1999 onward only was examined to avoid biases arising from different species-specific reporting categories before and after 1998-1999.

When interpreting the catch composition statistics it is important to consider operational characteristics of each fleet. As discussed in Section 2, it is not expected that the RTV vessels have changed their operations over time to target any or all sharks. However, these vessels have exhibited some minor changes in fishing grounds over time (see Figures 11 and 12). The LLL vessels have undergone more substantial changes in fishing ground over time (see Figures 11 and 12) and also appear to have changed their targeting practices (see Section 6). For these reasons, catch composition information from the LLL data set must be interpreted with caution.

4.1 Catch Composition from the RTV Data Set

As expected, blue sharks dominated the RTV data set in all regions and all years, comprising on average 83-89% of the catch in Regions 1-3 and 74% in Region 4 (Figure 14, left panel). The second-most abundant sharks were the mako sharks, predominantly shortfin makos, in Regions 1 and 2, and thresher sharks, predominantly bigeye threshers, in Region 4[6]. Oceanic whitetip and silky sharks comprise up to 9% and 3%, respectively, of the catch in Region 4 in some years but their proportion of the catch has decreased to a negligible level in recent years. Very few other shark species appear in the RTV data set despite the existence of 59 shark-specific recording categories.

4.2 Catch Composition from the Filtered LLL Data Set

Similar to the RTV data set, blue sharks dominate the reported shark catch in commercial (filtered) LLL records (Figure 14, right panel). A small proportion of the shark catch is composed of makos and porbeagle/salmon sharks in Regions 1-2, and Region 4 records "other" sharks in considerable proportions in some years. It is not possible to know what species these "other" sharks may have been but based on comparison to the RTV data in Region 4 they were most likely to be thresher or silky sharks. While the former is more likely in terms of apparent abundance in the RTV data set, the presence of an unused reporting category for threshers in the LLL data set suggests they may have been silky sharks (for which there is no reporting category).

4.3 Summary of Catch Composition Findings

Blue sharks consistently dominate catches in all regions in both RTV and LLL fleets. The small proportion of other shark species tends to complicate the identification of trends in these species, however, a reduction in the proportion of catch that was silky or oceanic whitetip is observed in the RTV data set for Region 4 since the early 2000s. These trends are not likely to be explained by the minor changes in RTV fishing grounds during this period and thus may suggest a reduction in abundance. It is not possible to reinforce or rebut this hypothesis using the filtered LLL data because there are very few recorded occurrences of oceanic whitetips and no species-specific category for silky sharks in that data set.

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[6] In Region 4, bigeye threshers comprised on average 93% (range: 77%-99%) of the filtered RTV thresher catch from 1992-2008. Pelagic threshers comprised on average only 5% (range: 1%-14%).

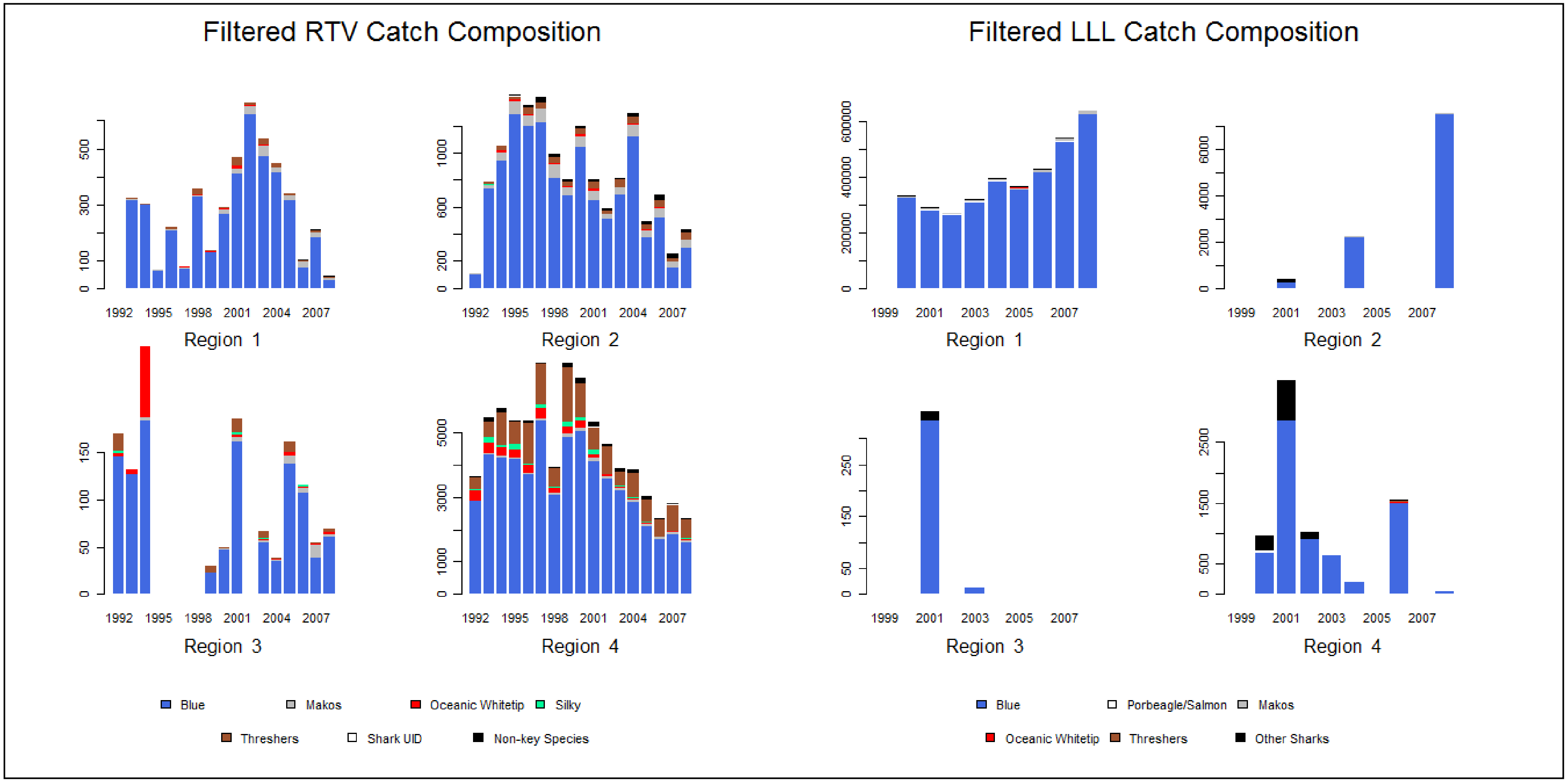

Figure 14. Composition of shark catch from filtered RTV (1992-2008) and filtered LLL (1999-2008) datasets for Regions 1-4.

5. Catch Rate

Catch rate is one of the most commonly used indicators of population status in fisheries science. Catch rate series are also an important input to most stock assessment models. In its simplest form calculation of nominal catch per unit effort (i.e. dividing the catch per species by the number of hooks fished) can provide some insight into population trends. However, nominal catch rates can be easily skewed if changes in fishing effort, e.g. shifts to different areas or depths, or changes in selectivity, e.g. use of different fishing gear or setting practices, are not taken into account. Standardization using statistical models is usually carried out to remove such potential biases where possible, but unknown influences may still remain, e.g. due to lack of relevant operational data.

This section examines both nominal and standardized catch rate series for the key species for filtered RTV and LLL data sets. Due to data limitations, standardization modelling is restricted to Regions 2 and 4 for the RTV data set and Region 1 for the LLL data. It should be noted that the filtering process described in Section 2 is designed to account for negative biases (e.g. under-reporting of sharks) but cannot account for positive biases (e.g. if targeting practices shift in a way that shark catches increase). Fortunately, while the LLL data set reflects targeting changes, the RTV data set should be independent of such commercial pressures. As a result, comparison between the two data sets can provide insight into the influence of targeting on catch rates (also see Section 6).

For the sake of comparison between the RTV and LLL data sets, shark catch rates are analysed by group for makos and threshers (i.e. because the LLL data sets only reports "makos" and "threshers" as a group). As a result, species-specific analyses are presented only for blue, oceanic whitetip and silky sharks.

5.1 Nominal Catch Rates

Nominal catch rates for blue, mako, oceanic whitetip and thresher sharks are presented in composite plots showing filtered and unfiltered RTV and LLL data (Figure 15). The number of sets used in calculating the catch rates are annotated under each plot and it is important to note the sample sizes when interpreting the trends. In particular, the number of filtered RTV sets in Region 1 is limited compared to Regions 2 and 4, and the number of filtered LLL sets in Regions 2 and 4 are limited compared to Region 1.

Blue shark nominal catch rates by the RTV fleet show a declining trend in Regions 1, 2 and 4 of at least 50% over the period 1993-2008. (Due to the scale of plotting the nature of the decline is Region 2 is difficult to discern but the catch rate declines from approximately 3 blue sharks per 1000 hooks at the beginning of the series to <0.7 blue sharks per 1000 hooks at the end of the series.) The RTV catch trend in Region 1 is somewhat uncertain given the sparse nature of the data, but none of the filtered RTV trends differ substantially from the unfiltered RTV trends. Catch rates calculated from RTV data are generally at or below 10 blue sharks per 1000 hooks. Blue shark catch rate trends based on LLL data are strongly upward in Region 1 until 2005 after which time they decline substantially. Blue shark catch rates show no clear trend in Regions 2 and 4, where effort is considerably more limited. Filtered catch rates are approximately double unfiltered catch rates with the highest filtered annual values exceeding 40 blue sharks per 1000 hooks in both Regions 1 and 2 in some years.

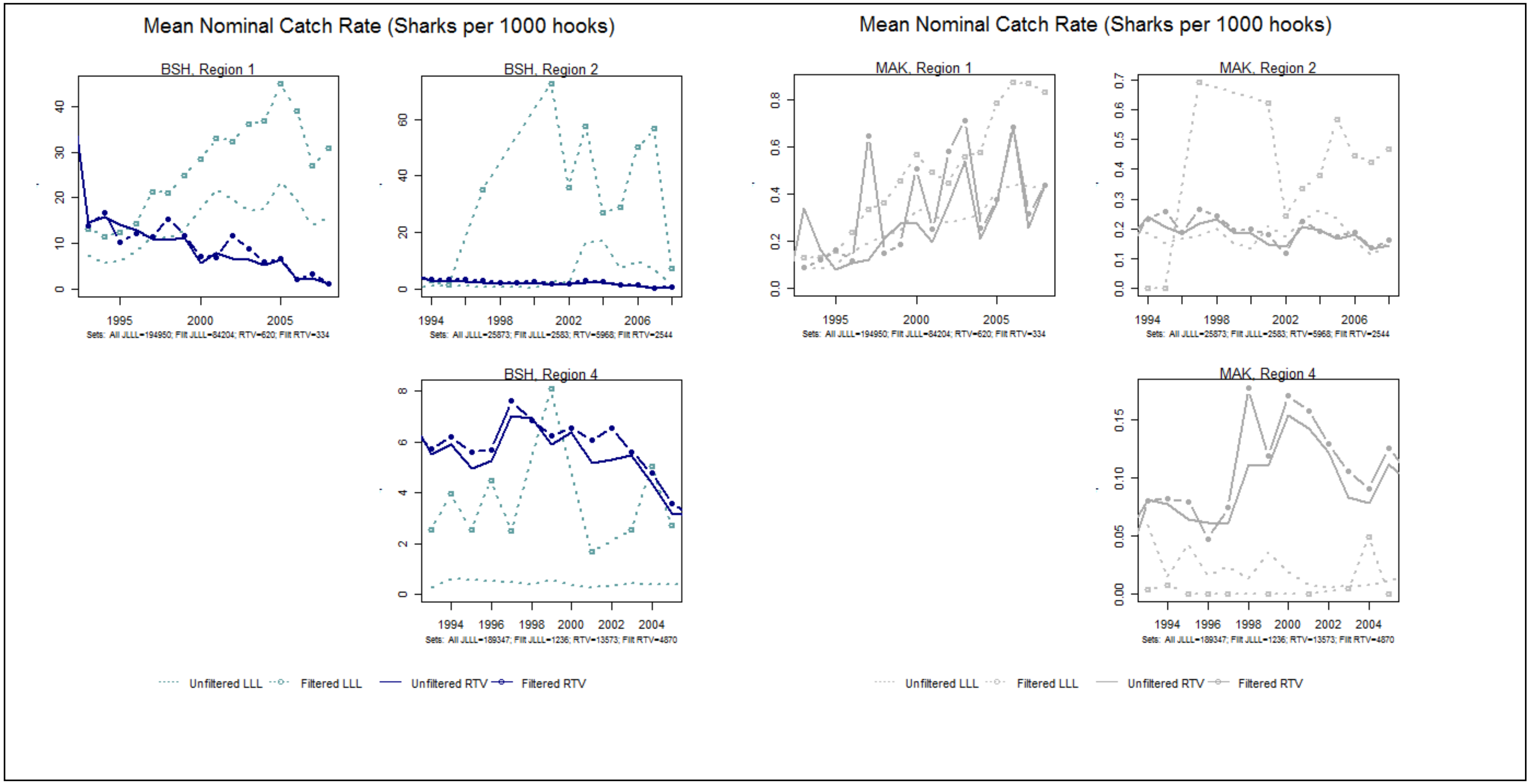

Figure 15. Nominal catch rates for filtered and unfiltered RTV and LLL datasets for blue and mako sharks in Regions 1, 2 and 4 (1993-2008).

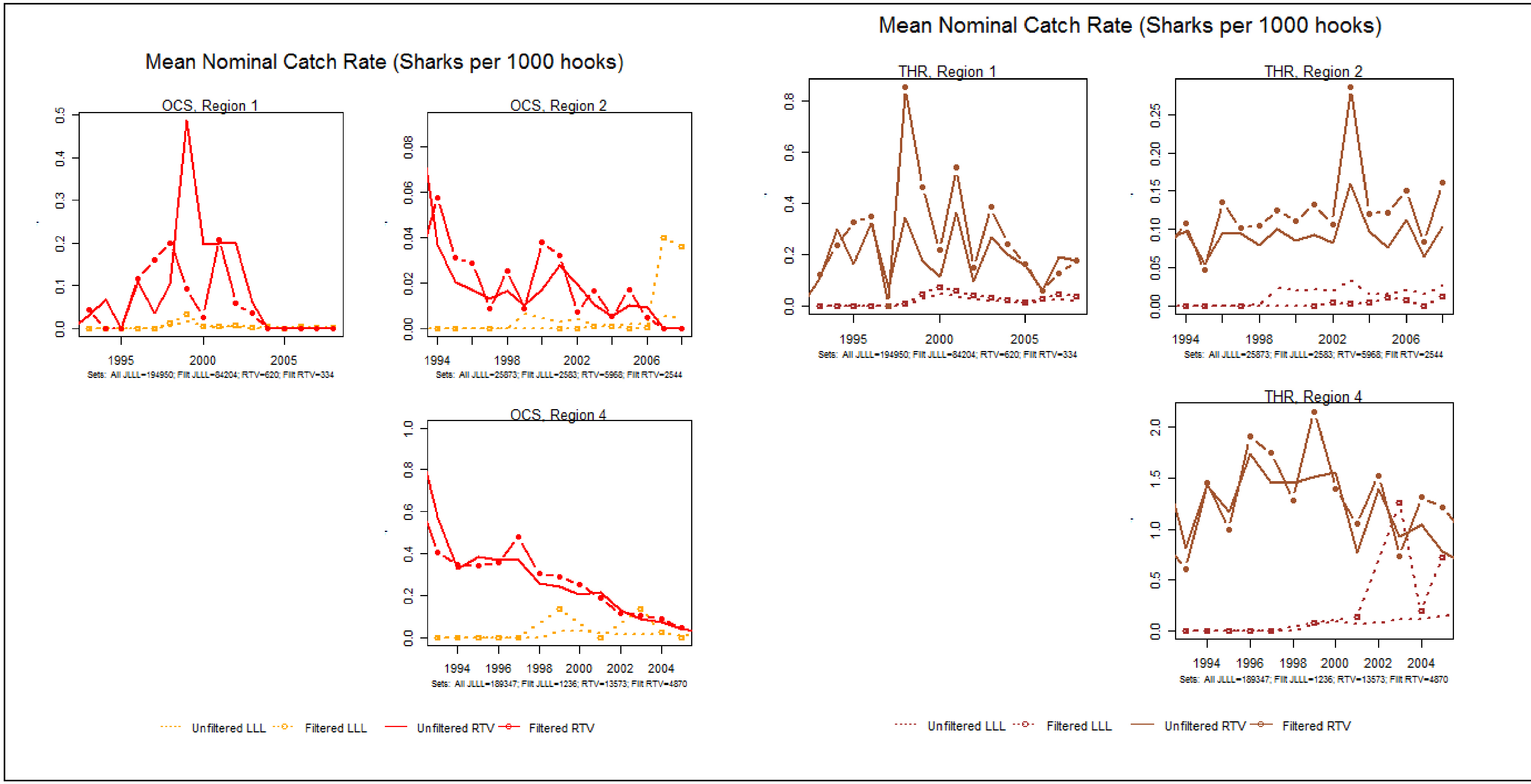

Figure 15 (cont). Nominal catch rates for filtered and unfiltered RTV and LLL datasets for oceanic whitetip and thresher sharks in Regions 1, 2 and 4 (1993-2008).

Nominal catch rates of mako sharks based on RTV data show an upward trend in Region 1 (though data are limited), a slightly downward trend in Region 2 and a slightly upward trend in Region 4. Both filtered and unfiltered RTV data show similar trends and levels of approximately 0.1-0.6 mako sharks per 1000 hooks. LLL data show an increasing trend of mako catch rates for Region 1 with filtered catch rates approximately double those calculated from unfiltered data. Filtered LLL catch rates in this region vary between 0.2-0.9 mako sharks per 1000 hooks. LLL catch rate series for mako are uninformative for Regions 2 and 4.

As oceanic whitetip sharks are found more often in Region 4 than in Regions 1 and 2 (Figures A1 and 14), the catch rate series for Region 4 are expected to be the most reliable. Both filtered and unfiltered RTV catch rate trends show a decline of approximately 75% from ~0.4 to ~0.1 oceanic whitetips per 1000 hooks. Filtered LLL catch rates do not show a clear trend with catch rates near zero in most years and peaks of ~0.1-0.2 ocean whitetips per 1000 hooks in some years.

Thresher shark data are concentrated in Region 4 and to a lesser extent Region 2, however, there is no clear trend of increase or decrease in catch rates in either region for either the RTV or LLL data set. As for oceanic whitetips, there is no major difference between filtered and unfiltered LLL catch rates in most years. Based on RTV data, catch rates for threshers are approximately 10 times higher in Region 4 (1 thresher per 1000 hooks) than in Region 2 (0.1 thresher per 1000 hooks).

Silky shark catch rates are only available from RTV data and are shown in Figure 16. As data for this species are mainly available from Region 4 (Figures A1 and 13), these catch rate trends are more indicative of population status than trends in the other regions. RTV catch rates for silky shark in Region 4 show a declining trend with catch rates of ~0.2 silky sharks per 1000 hooks in early years compared to ~0.05 silky sharks per 1000 hooks in recent years.

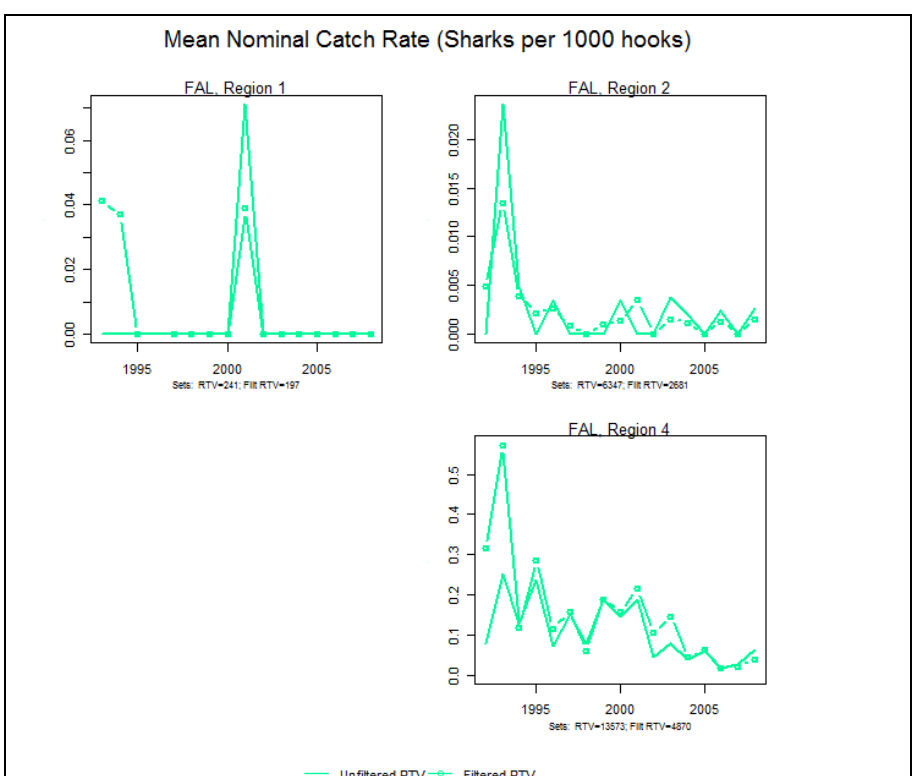

Figure 16. Nominal catch rates for filtered and unfiltered RTV data for silky sharks in Regions 1, 2 and 4 (1993-2008).

5.2 Standardized Catch Rates

Standardization of fisheries catch rates is an important but complex task. In this study, limits on time and data availability constrained exploration of alternative model forms, choice of covariates (and their forms), and the effects of data classification decisions (e.g. regional boundaries, shallow vs deep sets, etc). Furthermore, since this analysis is part of a broader, WCPO-wide effort to apply available data to indicators of fishing pressure and shark stock status, consistency between the RTV and LLL modelling approaches was prioritized to facilitate comparison of results.

Based on the available data in the RTV and LLL datasets, the most useful variables for predicting catch rates were considered to be vessel identifier, year, trimester (or month, when only one trimester's data were available), branch line material (i.e. "leader" - wire, nylon or unknown), hooks per basket (a proxy for hook depth), cell (a factor based on the nearest 5^{o} x 5^{o} latitude/longitude coordinate) and number of hooks fished per set. Applying these variables in a generalized linear model to the filtered RTV and LLL data sets results in estimates of coefficients for each variable, and a plot of the coefficients for the variable "year" gives the annual catch rate series.

Given the large number of zero catches in the data set for most species the delta-log normal form of the generalized linear model was selected. Under this formulation, the presence or absence of the species of interest is estimated using a binomial model and, if present, the number of individuals in the catch is estimated using a log normal model. The back-transformed product of the year coefficients from each model forms the composite year coefficient for the catch rate series.

The full model, i.e. with the seven variables listed above, was applied to filtered RTV data for Regions 2 and 4 and to filtered LLL data for Region 1. Filtered RTV data for Region 1 and filtered LLL data for Regions 2 and 4 (given the new boundaries of Region 2 (see Figure 13)) were too sparse to support estimation. Model evaluation was conducted by serially dropping one variable at a time from the models and examining the Akaike Information Criterion (AIC) to determine which variables were most useful in explaining the observed variance in catch rates. Binomial and log normal models were allowed to take different combinations of explanatory variables. The forms of the model which best explained the variance are shown in Table 1. It was not necessary to include hooks per basket in the RTV models as the data set contained only those sets fished with 12-13 hooks per basket. RTV models for Region 2 used month instead of trimester as a seasonal factor since most RTV sets in Region 2 were conducted within the third trimester (August-November).

The results of the catch rate standardization are shown for RTV in Figure 17 and for LLL in Figure 18. Details of model output and diagnostics are shown in Annex 5. These diagnostics indicate there are some issues with model performance which may be attributable to small sample sizes for some of the less abundant sharks. Also, in some cases the lack of linearity in the q-q plots and the rake-like patterns in the residuals indicate overdispersion is present and the model may be better parameterized as an overdispersed Poisson model of counts. It may also be useful to explore other covariates and combinations, e.g. different definitions of the seasonal term in the model and interactions between season and cell, and between the total number of hooks and the number of hooks per basket. The models presented here should be considered a starting point for further analysis and can be further developed and refined assuming the data can be accessed.

Table 1. Factors tested and used (marked with "X") in the binomial and log normal formulations of a generalized linear model applied to filtered RTV and LLL data for Regions 1, 2 and 4.

Model:	RTV Region 2 Binomial	RTV Region 2 Log Normal	RTV Region 4 Binomial	RTV Region 4 Log Normal	LLL Region 1 Binomial	LLL Region 1 Log Normal
Factor:						
Vessel Identifier	X	X	X	X	X	X
Year	X	X	X	X	X	X
Trimester			X	X	X	X
Month	X	X				
Leader	X		X		X	X
Hooks per Basket	NA	NA	NA	NA	X	
Cell	X	X	X	X	X	X
Hooks	X	X	X	X	X	X

Standardized catch rates for blue shark from RTV data show a declining trend in Region 2 which is consistent with the nominal catch rate trend. Although the RTV nominal catch rates for blue shark in Region 4 also showed a declining trend, the standardized catch rate trend in Region 4 appears affected by a lack of model fit. LLL standardized blue shark catch rates in Region 1 increased overall but exhibited a decrease since 2005; this is generally consistent with the nominal catch rate trends for this region shown in Figure 15. The opposite trends shown in the RTV and LLL data sets for most of the time series point to the potential influence of shark targeting by the LLL fleet in the North Pacific.

The standardized catch rate trends for makos show an increasing pattern for LLL in Region 1 with a decline since 2006. As for blue shark, the increasing trend in the LLL data for makos may result from increased targeting of sharks in the North Pacific in recent years. The RTV data for Region 2 showed a decrease of approximately 50% in standardized mako catch rates during the time series which is more pronounced than the slightly decreasing trend seen in the nominal catch rates. The observed increase in RTV standardized catch rates for makos in Region 4 is consistent with the observed increase in nominal catch rates for makos in that region.

Oceanic whitetip sharks in the RTV data show a clear trend of decrease in standardized catch rates. These trends, which indicate a decline of at least 50%, are consistent between the standardized and nominal RTV results but do not appear in the standardized filtered LLL data. The lack of a trend in the standardized LLL catch rate may arise from the dearth of oceanic whitetip data in the LLL data set in Region 1 (see Figure 14), either due to infrequent occurrence or infrequent recording (or both) for this species.

Standardized catch rate trends for threshers show an increasing trend in the RTV data and an inconclusive pattern in the LLL data. No clear patterns were observed in the nominal catch rates either. These results may arise, in part, from the joint analysis of three thresher species.

Silky shark data were only available from the RTV data set and could only be standardized for Region 4. The results show a noisy trend with an apparent decline in catch rates since 2005.

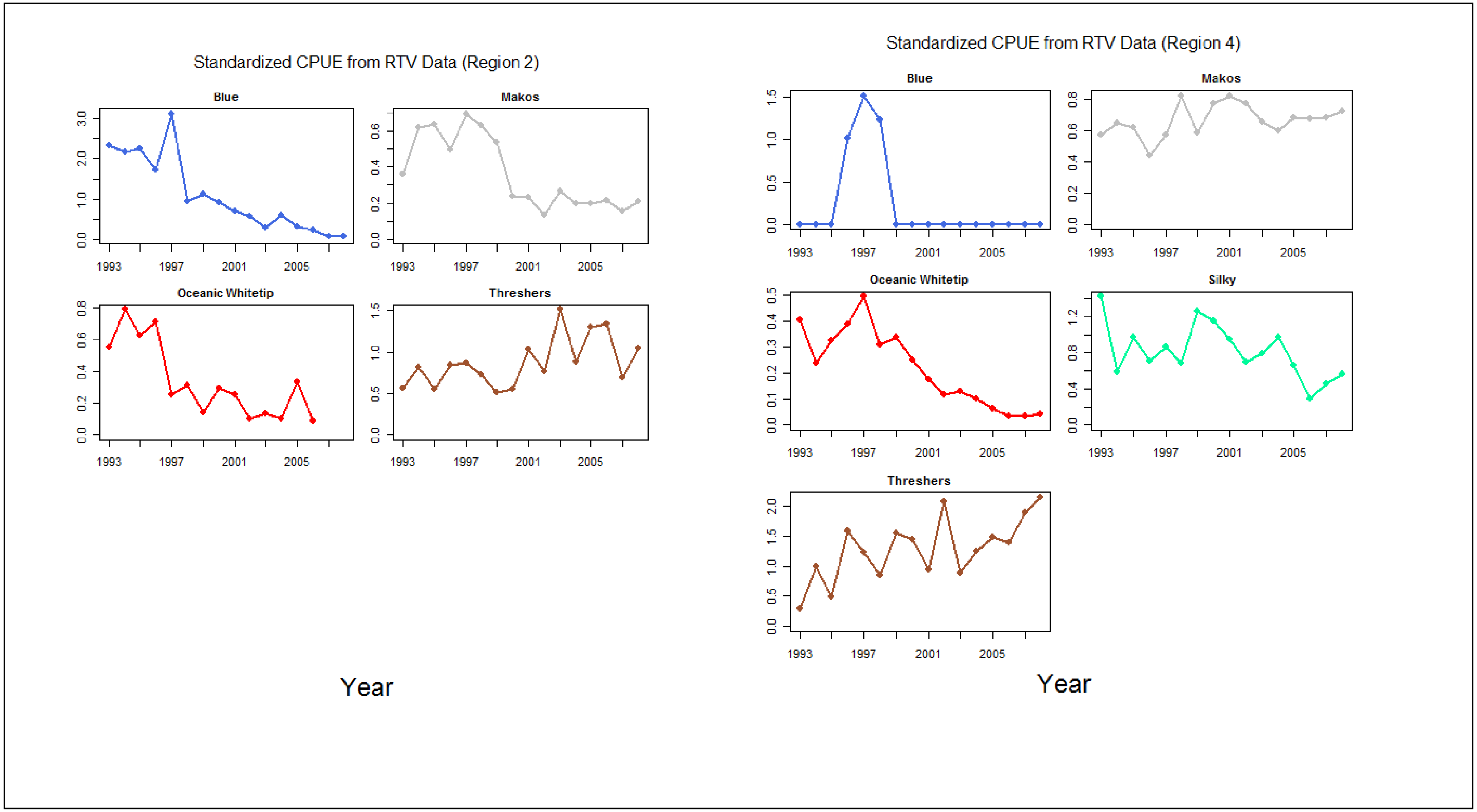

Figure 17. Standardized catch rates for filtered RTV data in Regions 2 and 4 (1993-2008). Data were insufficient to estimate an annual catch rate trend for silky sharks in Region 2.

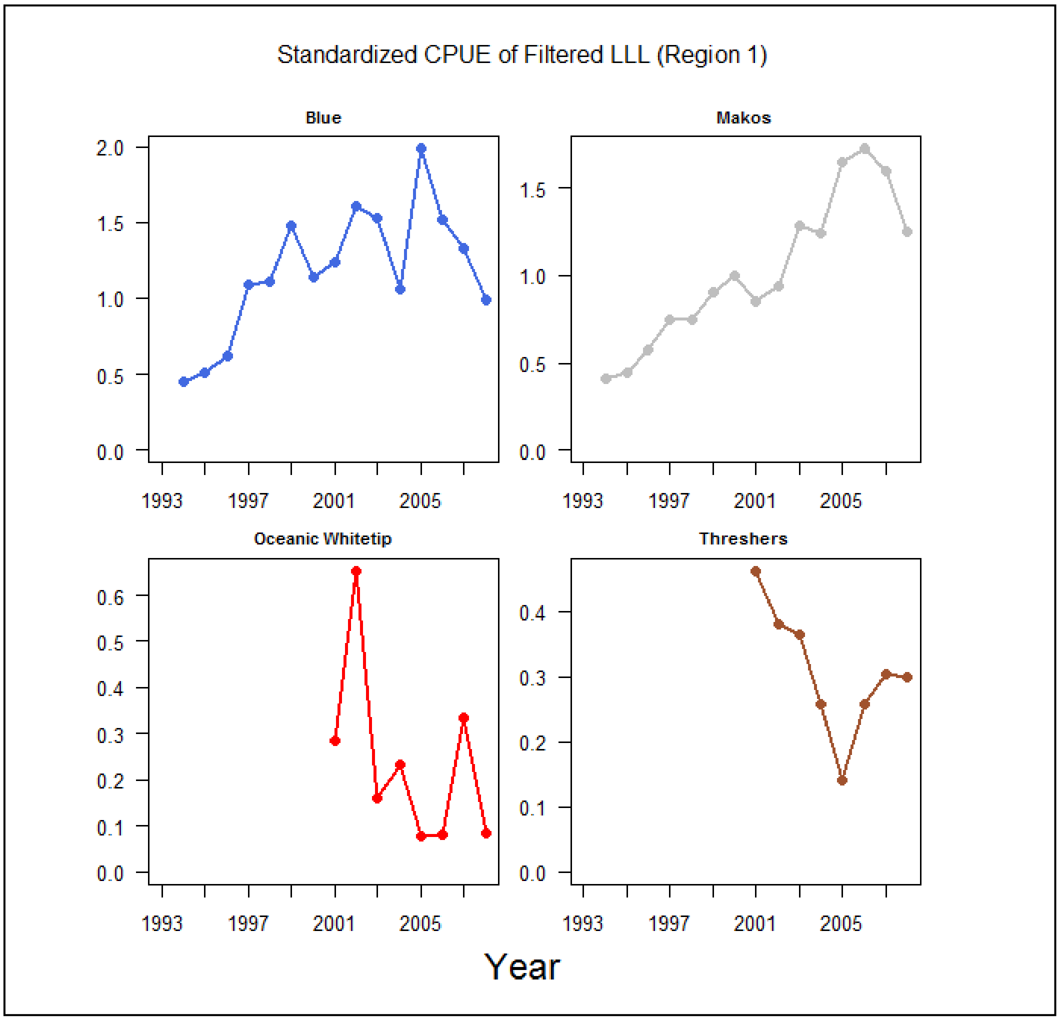

Figure 18. Standardized catch rates for filtered LLL data in Region 1 (1993-2008). Note that there are no data for silky sharks in the LLL data set and data were insufficient to estimate annual catch rate trends for any of the sharks recorded by the LLL fleet in Regions 2 and 4.

5.3 Summary of Catch Rate Findings

The results of the analysis of the catch rate indicators for 1993-2008 can be summarized as follows:

- Catch rates for blue and mako sharks in the western North Pacific (Regions 1) in the commercial fleet (LLL) increased until 2005-2006. This trend may be explained by increased targeting of sharks in recent years which could not be accounted for in the filtering and standardization processes. However, catch rates since that time have declined.
- Catch rates in the RTV data set are declining for blue sharks (based on standardized catch rates for Region 2 and nominal catch rates for Regions 1, 2 and 4). Mako sharks also show a decline in the RTV data set for Region 2 (only). If RTV vessels have been discarding/releasing sharks (and not reporting these) more in recent years, and filtering and standardization have not fully accounted for this, these trends may be exaggerated. On the other hand, this trend may also arise from a "true" decrease in the abundance of these sharks.

- Catch rate trends in the commercial (LLL) data set for oceanic whitetip and thresher sharks tend to be noisy due to lack of data. RTV data show a clear trend of decline for oceanic whitetips in Regions 2 and 4, and a slight increase for threshers in these areas.
- Silky sharks can only be assessed from the RTV data set in Region 4; results suggest that catch rates have declined since 2005.

6. Targeting

The level of overlap between fishing effort and the distribution and density of a given shark species forms one component of the potential risk posed to the stock by fishing. One method of quantifying this overlap was proposed by Gulland (1956) and applied to Pacific tuna longline fisheries by Harley (2009). This index as well as other information is examined in this section in order to explore whether there is any targeting of sharks in the North Pacific. Although targeting is expected to be relevant for the commercial LLL data set, Gulland's concentration index is also applied to the RTV data set as a control for comparative purposes. To facilitate comparison between the RTV and LLL data, sharks were assessed as four groups: blue, makos (shortfin, longfin and unidentified), oceanic whitetip, and threshers (bigeye, common, pelagic and unidentified).

6.1 Gulland's Concentration Index

Gulland's concentration index is a ratio composed of the mean CPUE in a region as the numerator, and the mean of the mean CPUEs of each cell fished within that region as the denominator:

$$I = \frac{\sum_{i=1}^{N} y_i}{\sum_{i=1}^{N} e_i} \bigg/ \frac{\sum_{i-1}^{N} \frac{y_i}{e_i}}{N}$$

where *y* is the catch in the *i*th strata, *e* is the effort in the *i*th strata, and *N* is the number of exploited strata. Values of *I* are calculated separately for each year to form an annual index. The strata for this analysis were taken to be the 5° x 5° fished cells within each region.

The numerator and denominator can be thought of as unweighted and weighted measures of CPUE, respectively. The unweighted measure (numerator) can be heavily skewed by the results of a large number of sets in a small number of cells. The weighted measure (denominator) gives equal weight to all cells which were fished regardless of the amount of effort in each. The concentration index formed by their ratio would be expected to be at or near 1 if each cell's average CPUE is roughly the same as the overall CPUE for the region, i.e. if shark catches and effort are evenly distributed throughout the fishing grounds. If the ratio is considerably below 1 the concentration index indicates that relatively more effort was spent in areas of lower than average shark CPUE, for example, if fishing fleets try to avoid areas with high shark CPUEs. If the ratio is considerably above 1 the concentration index indicates that relatively more effort was spent in areas of higher than average shark CPUE.

Ratios above 1 may not necessarily indicate shark targeting *per se* as such high ratios would be expected if sharks are associated with other longline target species. Therefore it is useful to compare the RTV data set, which is thought to preferentially sample areas outside of the main commercial fishing grounds, with the commercial LLL data set. Since the latter would be expected to focus on areas with high CPUEs for target species, if sharks are associated with these species it would be expected that higher concentration indices would be observed in the LLL data set. It is also useful to examine the trends in the concentration indices. If sharks are naturally associated with target tuna species, it would be expected that concentration indices for each data set would remain reasonably constant over time. An increasing trend in the concentration index for the LLL data set could, however, indicate a shift in targeting toward sharks by the commercial fleet.

Concentration indices were calculated from RTV data for Regions 2 and 4 (Figure 19). While there was some sampling by RTV vessels in Region 1, the catches in some years in some cells were very low and this situation distorted the index by producing extreme values. Therefore, concentration indices for Region 1 are not presented. In Regions 2 and 4, for all but the first of the 17 years in the RTV time series, the concentration index is well below 1 and there is no apparent trend over time. This result conforms to the expectation that there is no targeting by the RTV vessels.

For LLL data, only Region 1 supported the calculation of concentration indices. Despite the large of number of sets conducted in Region 1, catches of oceanic whitetip and thresher sharks in this region are very small (see Figure 14) and contribute to a high degree of variability in the indices. Since blue sharks comprise the majority of sharks reported, the concentration index for this species is the most useful indicator and shows a clear trend of increase over the last ten years of the time series. The concentration index for makos also appears to rise, but to a lesser degree, over the same timeframe.

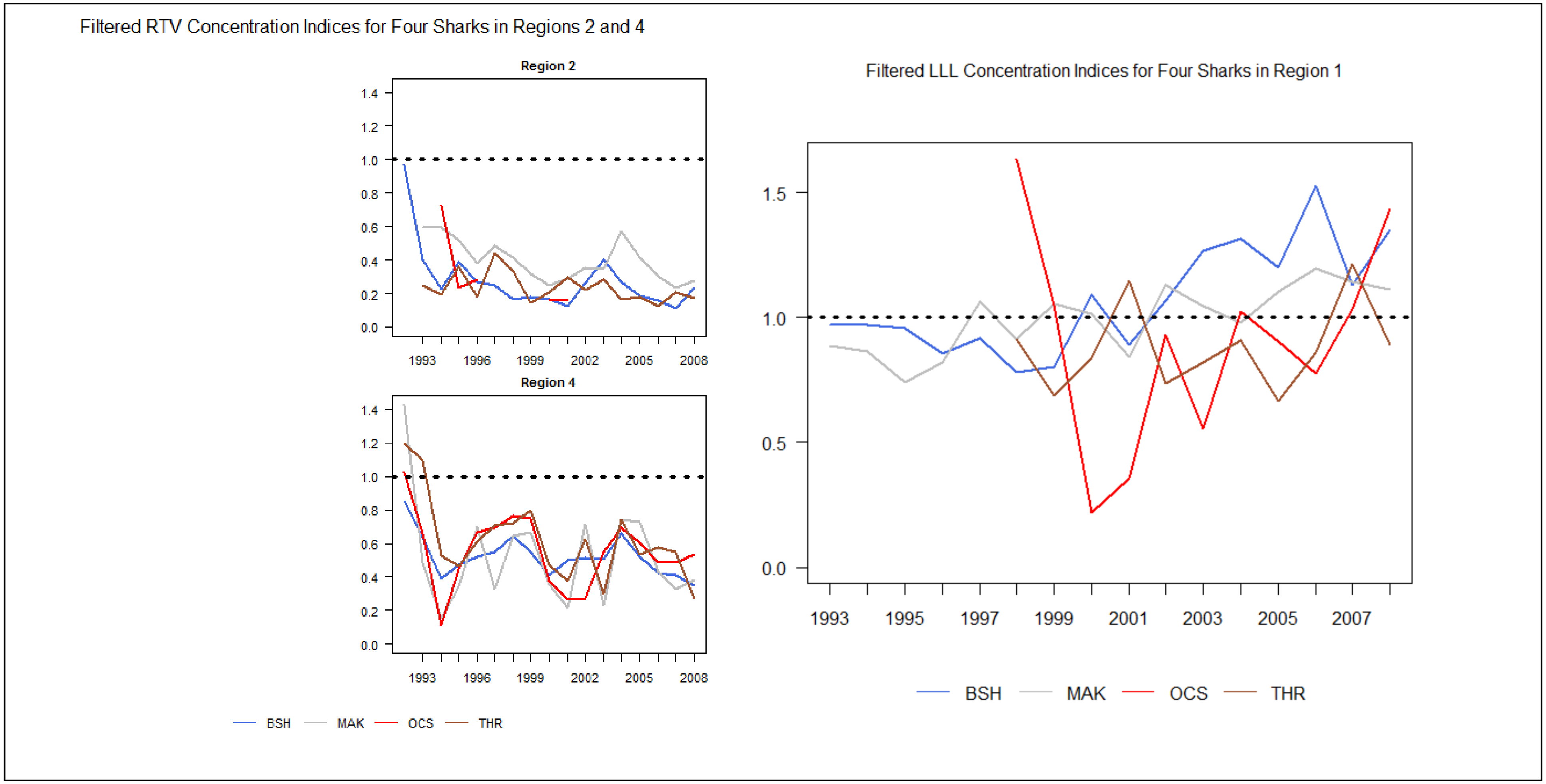

Figure 19. Concentration indices for blue (BSH), mako (MAK), oceanic whitetip (OWT) and thresher (THR) sharks calculated from the RTV data set (1992-2008) for Regions 2 and 4, and from the LLL data set (1993-2008) for Region 1. Values of >1 may indicate shark targeting (please see text for further discussion).

6.2 Other Information Relevant to Targeting

There are several other sources of information which provide indirect insight into the question of shark targeting in the North Pacific:

- As shown in Figure 8 which illustrates catch and effort in the unfiltered LLL database, catches of sharks in Region 1 have remained at or above the level at the beginning of the time series, i.e. 1993, despite a reduction in fishing effort of approximately 50%.
- Nominal and standardized catch rates for blue shark, the main shark species caught in the fishing grounds of the commercial longline fleet (i.e. Region 1) show i) a decreasing trend in the RTV data set and ii) an increasing trend in the commercial LLL data set through 2005 and higher than average catch rates thereafter.
- As mentioned in Section 2.2.2, a field in the LLL data set allows fishermen to indicate their target species for each set. Although the mean of the annual averages of the number of sets indicating shark targeting over the time series 1993-2008 was very low (<2%), the trend in the annual averages was upward (Figure 20).

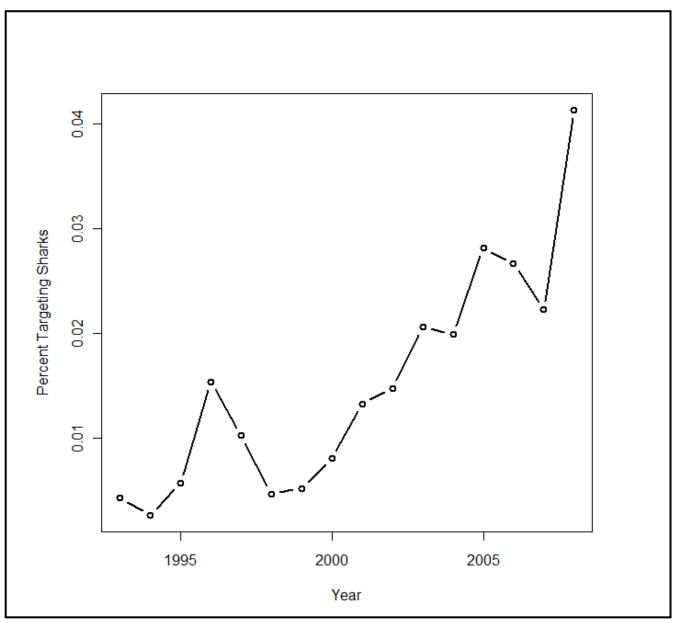

Figure 20. The percentage of sets recorded as shark targeting sets on logsheets contained in the unfiltered LLL data set, 1993-2008.

6.3 Summary of Targeting Findings

Calculation of concentration indices for the LLL fleet provides some evidence for increasing targeting of blue sharks, and perhaps makos, within the main longline fishing grounds in the North Pacific (i.e. Region 1) since the late 1990s. Other information on total catches and catch rates (nominal and standardized), as well as indications from target species information recorded on logsheets, are consistent with this trend.

7. Size by Species

Changes in a standardised measure of fish size can indicate changes in the age and size composition of the population, in particular, a decrease in size is expected in a population under exploitation (Goodyear 2003). The magnitude of such change can, in theory, thus provide information on the level of exploitation that a fish stock is experiencing (Francis and Smith 1995). As the size of sharks differs by sex, it is important to examine indicators on a sex-specific basis. Length, rather than weight, is preferred as a standardized measure of size because it is not as likely to fluctuate with reproductive or other seasonal factors. The median is preferred over the mean as it is less likely to be influenced by outliers in the data set.

Length and sex information is only available from the RTV data set. As discussed above, this data set is consistent over time in its sampling coverage and should not be subject to the influence of targeting. Nevertheless, both nominal and standardized indicators are presented below for comparison. Only those annual, sex-, species- and region-specific strata supported by at least 20 samples are included in the analysis.

Data on length at maturity by sex are taken from the scientific literature rather than from the RTV data set itself. In most cases species-specific lengths at maturity were available for the Pacific Ocean, but these values may not always be representative of conditions in the regions sampled by the RTV. In some cases, length at maturity by sex was not available and thus a single value was used for both males and females. A further source of uncertainty was introduced by the need to convert lengths at maturity given in the literature in total length or fork length, to precaudal length which is the unit used in the RTV data set. The sources of information for length at maturity and length conversion factors used in this analysis are shown in Table 2.

Table 2. Sources of information used in defining maturity and converting between various standards for measurement of shark length (TL=Total Length, FL=Fork Length, PCL=Precaudal Length).

	Length at Maturity	**Reference(s)**	**Conversion Factor(s)**	**Reference(s)**
Blue	Males: 152 PCL (200 TL) Females: 152 PCL (200 TL)	Nakano and Stevens (2008)	PCL=0.9075(FL)-0.3956 FL=0.8313(TL)+1.39	Skomal and Natanson (2003)
Shortfin mako	Males: 163 PCL (180 FL) Females: 249 PCL (275 FL)	Francis & Duffy (2005)	FL = 1.100(PCL)+0.766	Francis & Duffy (2005)
Oceanic whitetip	Males: 120 PCL (168 TL) Females: 125 PCL (175 TL)	Seki et al. (1998)	TL =1.397(PCL)+0	Seki et al. (1998)
Silky	Males: 159 PCL (212 TL) Females: 157 PCL (210 TL)	Joung et al. (2008)	TL=1.31(PCL)+3.64	Joung et al. (2008)
Bigeye Thresher	Male: 141 PCL (270 TL) Females: 175 PCL (332 TL)	Smith et al. (2008)	TL=1.81(PCL)+15.3	Chen et al. (1997)
Pelagic Thresher	Males: 140 PCL (267 TL) Females: 145 PCL (282 TL)	Liu et al. (1999, 2006)	TL=1.93(PCL)+2.34	Liu et al. (1999)

7.1 Trends in Median Length relative to Maturity

The median size of most male and female blue sharks contained in the RTV data set for all regions (1, 2 and 4) is larger than the size at maturity from the literature (Figure A3). However, in Region 1 the median size in 1997 and the 5^{th} percentiles in all years are considerably below the length of maturity.

Other than the particularly small sizes of blue sharks observed in 1997, there is little annual variation in size.

The median size for male shortfin makos is at or above the length of maturity in all regions, but the median female shortfin mako size is well below the length of maturity in all regions. A potential explanation for this pattern is that definition of the length of maturity based on samples from New Zealand may not be appropriate when applied to these samples from the North Pacific.

Oceanic whitetip and silky shark males and females were found in substantial numbers only in Region 4. Annual median values, as well as the majority of all values, indicated these sharks were immature. There is little variation in oceanic whitetip sizes over time, but there is a noticeable, though slight, decline in median sizes of male and female silky sharks between 2000-2005. After that time, very few of either species was observed.

Bigeye threshers observed in Region 2 were nearly all mature individuals, but in Region 4 the majority of the male bigeye threshers and nearly all of the female bigeye threshers were immature. Pelagic threshers were observed only in Region 4 and in that region they, like bigeye threshers, were mostly immature individuals. Although there is little variation in the median size for bigeye threshers, the pelagic threshers exhibit a downward trend until 2002 after which time they were encountered only at very small sample sizes.

7.2 Trends in Standardized Size

In order to account for potential influences on shark size due to changes in sampling effort over time and by year, a generalized linear model was applied to RTV shark length data. This model was formulated based on a normal distribution with factors year and cell (5^o x 5^o latitude-longitude). The estimated model coefficients were used to predict shark lengths for an arbitrarily chosen cell lying near the centre of each region. As the model was unable to estimate coefficients for those species-, sex- and region- combinations which were not adequately supported by the RTV data only some of the potential combinations were estimated: blue (Regions 1, 2 and 4); shortfin mako and bigeye thresher (Regions 2 and 4 only); and oceanic whitetip, silky and pelagic thresher (Region 4 only).

As expected, given the consistency of sampling in the RTV data set, the results of the standardization exercise (Figure 21) are similar to those in the nominal median size analysis discussed in the preceding section. There is little trend in sizes for blue, shortfin mako and bigeye thresher sharks, however it is noted that individuals of both sexes in Region 2 are slightly larger than their counterparts in Region 4. The trends for silky sharks in Region 4 is similar to those in the nominal analysis, i.e. both show a decrease in size in recent years. The standardized size trend for oceanic whitetip shows a slight decline whereas the nominal analysis does not. The standardized size trend for pelagic thresher shows a decline early in the series with considerable variance in the estimates for the most recent years. It is important to note that RTV length data to support estimates for silky, oceanic whitetips and pelagic threshers are very limited in the most recent years of the time series.

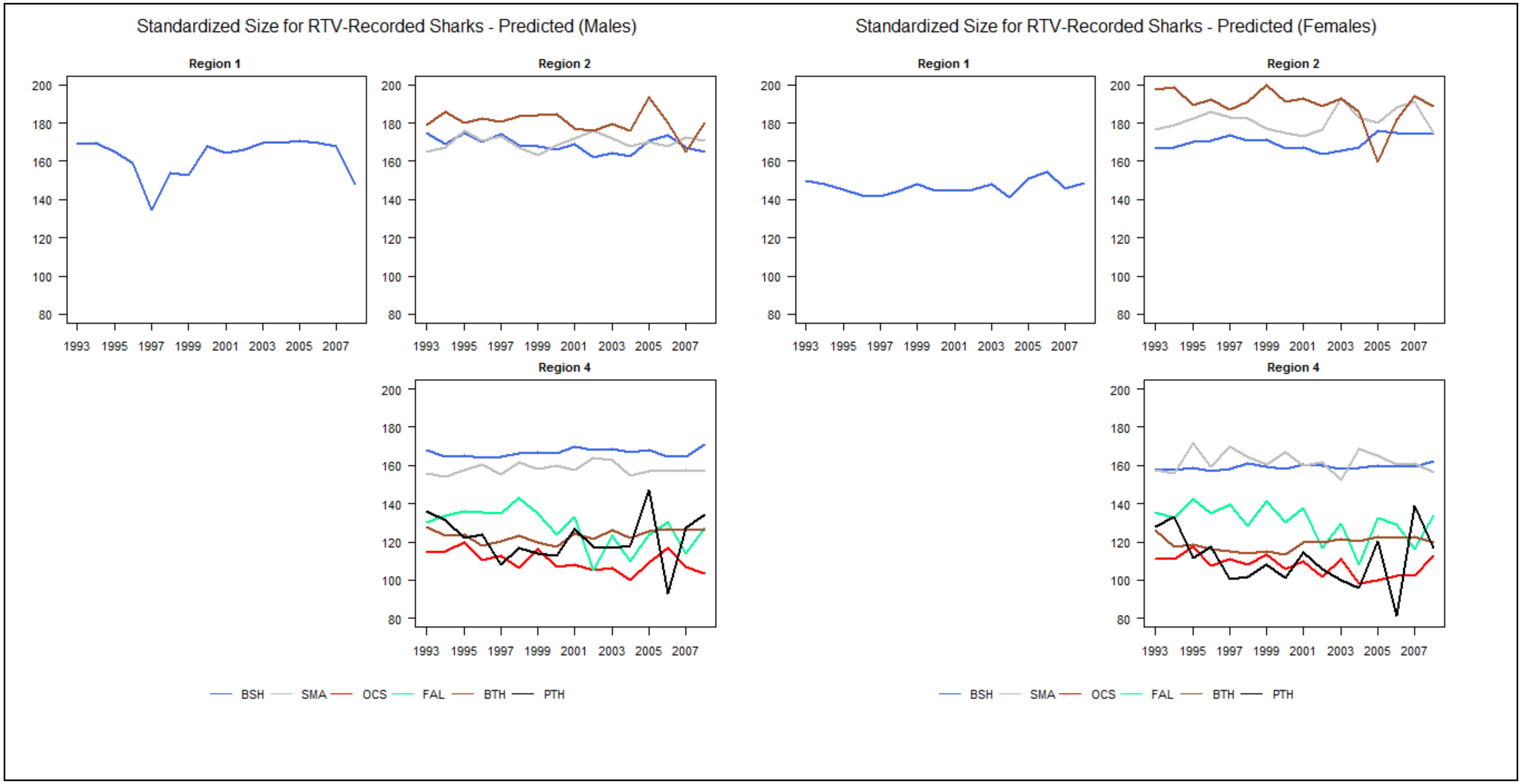

Figure 21. Standardized size estimates for male and female blue (BSH), shortfin mako (SMA), oceanic whitetip (OCS), silky (FAL), bigeye thresher (BTH) and pelagic thresher (PTH) in Regions 1, 2 and 4 based on the RTV data set. Results are only shown for those estimates which could be supported by the data.

7.3 Summary of Size Trend Findings

The results of the analysis of size indicators can be summarized as follows:

- There is no apparent trend in the sizes of blue, shortfin mako or bigeye thresher sharks of either sex.
- There is a slight trend of decreasing size in both sexes of silky sharks, and potentially for pelagic thresher (nominal analysis only) and oceanic whitetips (standardized analysis only) in Region 4 (the only sampled region in which they occur) in the last ten years of the time series.
- Trends for the oceanic whitetip and silky sharks since 2005 and trends for the pelagic thresher shark since 2002 are difficult to evaluate given the very low frequency of these species in the RTV dataset in recent years.

8. Conclusion

This paper analyses North Pacific data from longline operations for eight key shark species (blue; shortfin and longfin mako; oceanic whitetip; silky; and bigeye, common and pelagic thresher) designated by the Western and Central Pacific Fisheries Commission. Comparison of two datasets, research and training vessel surveys (RTV, 1992-2008) and commercial longline logbook records (LLL, 1993-2008), allows for more comprehensive sampling coverage and insights into the influence of commercial factors such as targeting. Initial data exploration revealed that both data sets required filtering to remove records believed to under-report actual shark catches. Application of filtering to the RTV data set reduced the number of records for analysis from 20,838 sets representing 28 vessels to 7,974 sets representing 10 vessels. Due to the greater extent of under-reporting of sharks in the commercial records, the filtering resulted in a reduction from 658,923 sets representing 1,025 vessels to 88,129 sets representing 112 vessels. Application of different filtering methods could result in larger sample sizes, but this benefit would need to be weighed against the probability of increasing the presence of under-reported catches in the filtered database.

When considering the selection and application of data filters it is important to recall that if RTV vessels began releasing/discarding (and not reporting) sharks in recent years, filtering may not fully correct for this effect, and declining catch rate trends would thus potentially be exaggerated. On the other hand, if reporting practices do not change but shark stock abundance actually does diminish over time, declining catch rates would be expected. The challenge is to apply a filter which removes those catch records which are under-reported, but retains those which are low but accurate. The filtering method applied here represents a reasonable attempt to balance these two competing objectives.

Filtered data were examined in terms of five potential indicators of fishing pressure: distribution, catch composition, catch rate, targeting and size. The findings are summarized by species as follows:

- Blue shark: This species dominates the shark catch in the North Pacific. Catch rates showed a substantial decline in the RTV data in all areas. In contrast, catch rates based on commercial records north of 20^{o} north latitude and west of 180^{o} longitude, i.e. the fishing grounds of the Japanese offshore (*kinkai*) longliners, showed a strong trend of increase until 2005.

Commercial catch rates for blue shark declined thereafter but remained well above those in the early part of the time series. This type of pattern suggested the influence of commercial targeting on catch rates, and evidence of targeting was found in the increasing concentration of effort in areas of high catch rates. No changes in the size of either sex of blue sharks over time were detected.

- Mako sharks: Shortfin and longfin makos were analysed as a group where necessary due to lack of data for longfin makos and the desirability of direct comparison with commercial data which does not distinguish between the species. These species comprise a small proportion of the catch (<10%) but based on concentration indices, "effective" targeting may be increasing as a result of targeting of co-occurring blue sharks. Mako catch rates showed an increasing trend in both RTV and commercial data sets (until 2006) for the western North Pacific (west of 180^{o}), i.e. the main commercial fishing grounds. Decreasing catch rate trends were observed in the RTV data for the central North Pacific (north of 20^{o} N and east of 180^{o}). No obvious catch rate trends for makos were observed south of 20^{o} N. No size trends were evident.
- Oceanic whitetip shark: Catches of this species were most frequently observed in the central North Pacific south of 20^{o} N latitude, but this species also occurs in more northerly locations. Oceanic whitetips were rarely recorded after 2005 which may signal a sharp decline in abundance. Catch rates based on RTV data showed sharp declines both north and south of 20^{o} N latitude (Regions 2 and 4) and there was some evidence for a trend of decreasing size of both males and females in recent years.
- Silky shark: Silky sharks are nearly always found in the central North Pacific south of 20^{o} N latitude. As was the case with oceanic whitetip sharks, records since 2005 are very scarce which may signal a decline in abundance. Catch rate analysis was only possible for the RTV data which showed a decline since the early 2000s. Trends in silky shark sizes indicated a slightly declining trend for both sexes.
- Thresher shark: Records for the common thresher were very rare and in most cases this species could not be analysed separately. The bigeye thresher was commonly observed throughout the central Pacific and would appear to comprise the majority of the catch (i.e. commercial records are not species-specific). There were no apparent trends in size for bigeye thresher. Pelagic threshers are mainly found south of 20^{o} N latitude. Nominal size analysis suggested that median size is decreasing but standardized size analysis showed no trend for this species. Catch rates were analysed for threshers as a group and are expected to mainly reflect the status of bigeye thresher. An increasing trend was found in the RTV data and an inconclusive pattern in the commercial data.

These indicators provide a useful first step in assessing the impact of fishing on populations of Pacific sharks. Under the WCPFC's Shark Research Plan, this information from the North Pacific will be compared with other fisheries data being analysed separately and used to formulate input into stock assessment models. The results of these models will then inform discussion by the Commission on the need for further management measures for sharks.

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ANNEX 1.

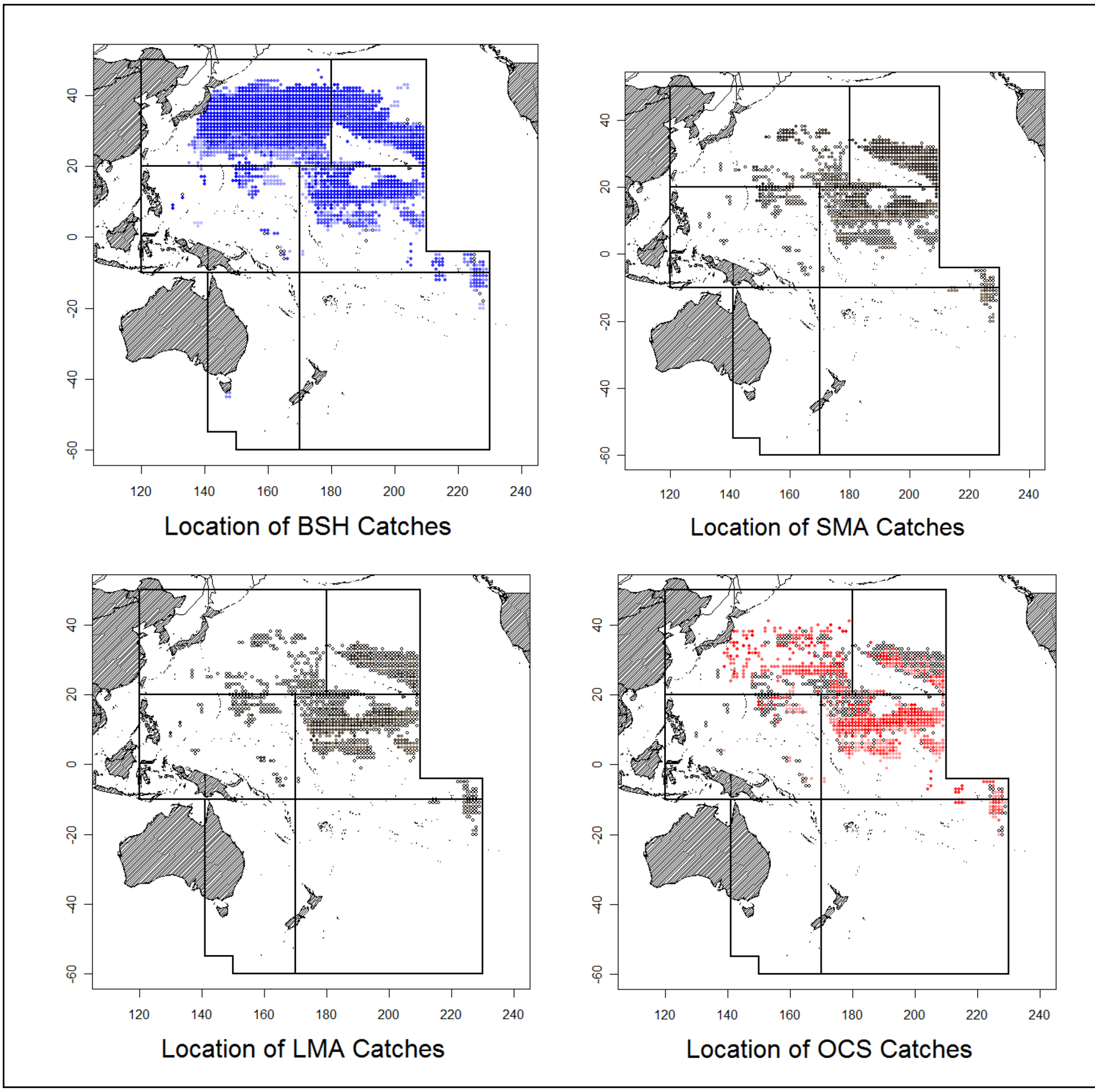


Figure A1. Distribution maps for blue (BSH), shortfin mako (SMA), longfin mako (LMA) and oceanic whitetip (OCS) sharks based on catches recorded in the full RTV data set (1992-2008) and filtered JLLL records for blue (1993-2008) and oceanic whitetip (1998-2008) sharks only. Colored circles represent positive catches (points are shaded by year with more recent catches in the darkest shades); empty circles represent zero catch.

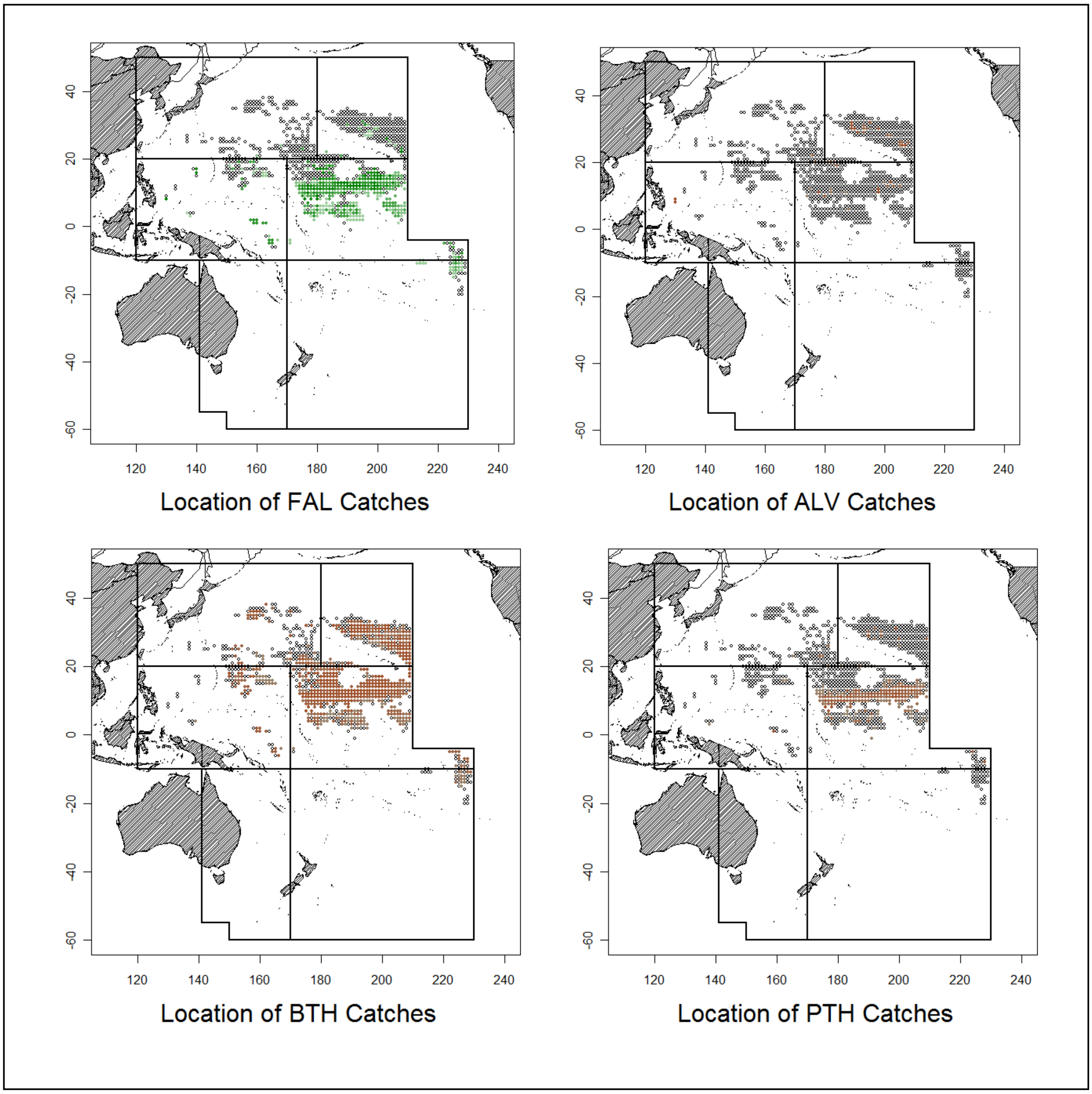


Figure A1 (cont.) Distribution maps for silky (FAL), common thresher (ALV), bigeye thresher (BET) and pelagic thresher (PTH) based on catches recorded in the full RTV data set (1992-2008). Colored circles represent positive catches (points are shaded by year with more recent catches in the darkest shades); empty circles represent zero catch.

ANNEX 2.

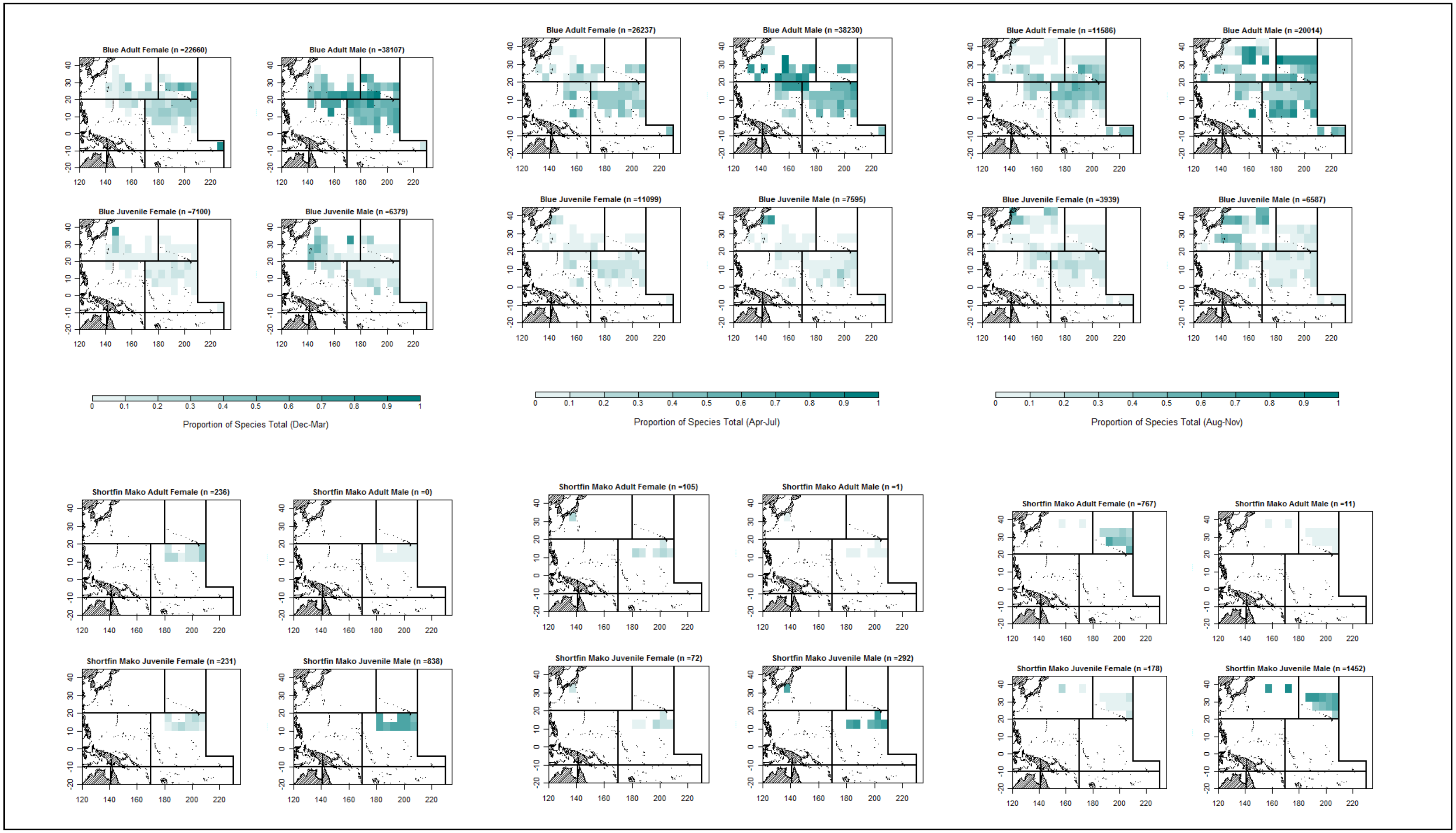


Figure A2. The proportion of blue and shortfin mako sharks observed in each 5 degree x 5 degree cell of Regions 1-4 which were adult females, adult males, juvenile females and juvenile males by trimester (Dec-Mar; Apr-July; Aug-Nov) based on unfiltered RTV data, 1992-2008. Darker shading indicates higher proportions observed.

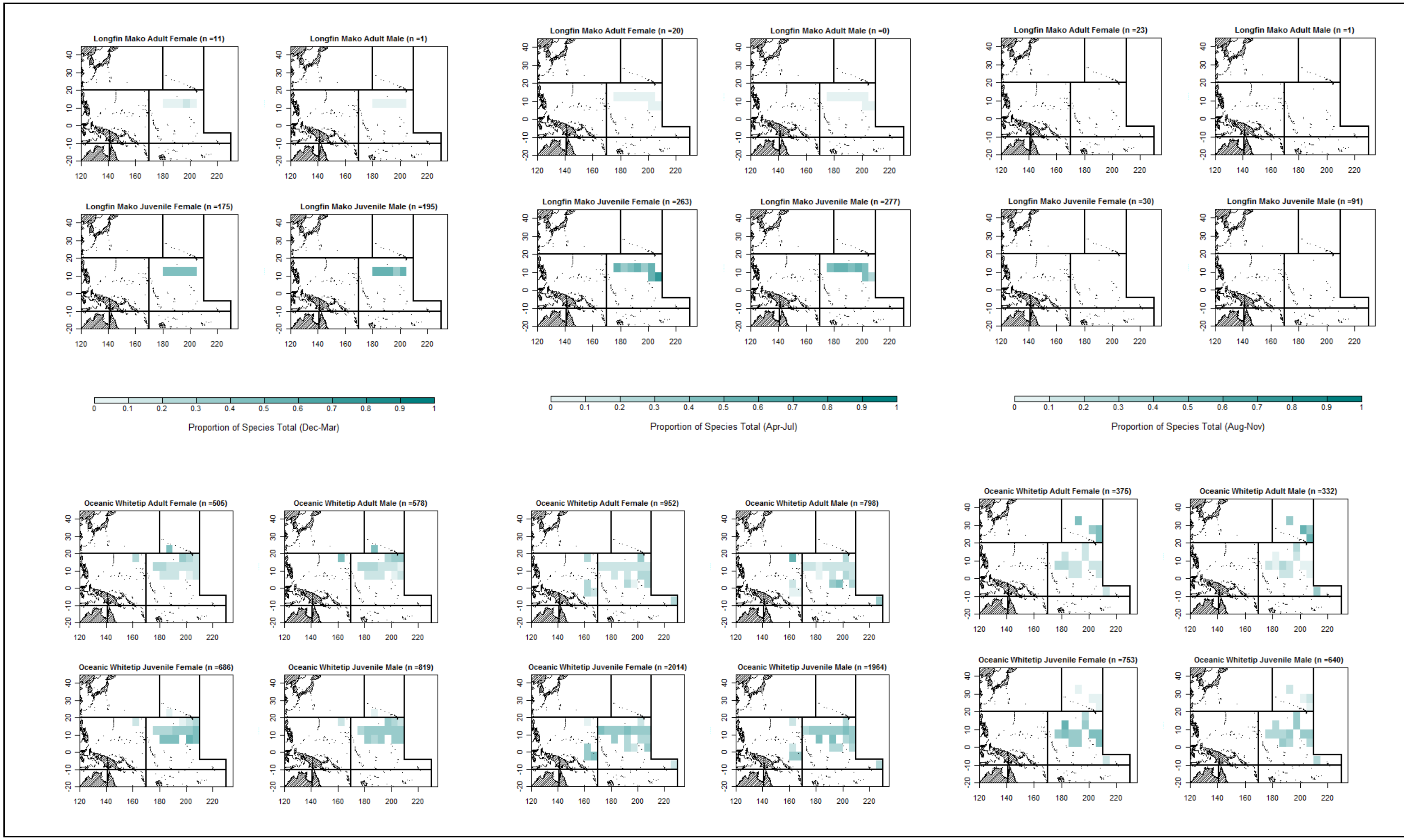


Figure A2 (cont.) The proportion of longfin mako and oceanic whitetip sharks observed in each 5 degree x 5 degree cell of Regions 1-4 which were adult females, adult males, juvenile females and juvenile males by trimester (Dec-Mar; Apr-July; Aug-Nov) based on unfiltered RTV data, 1992-2008. Darker shading indicates higher proportions observed.

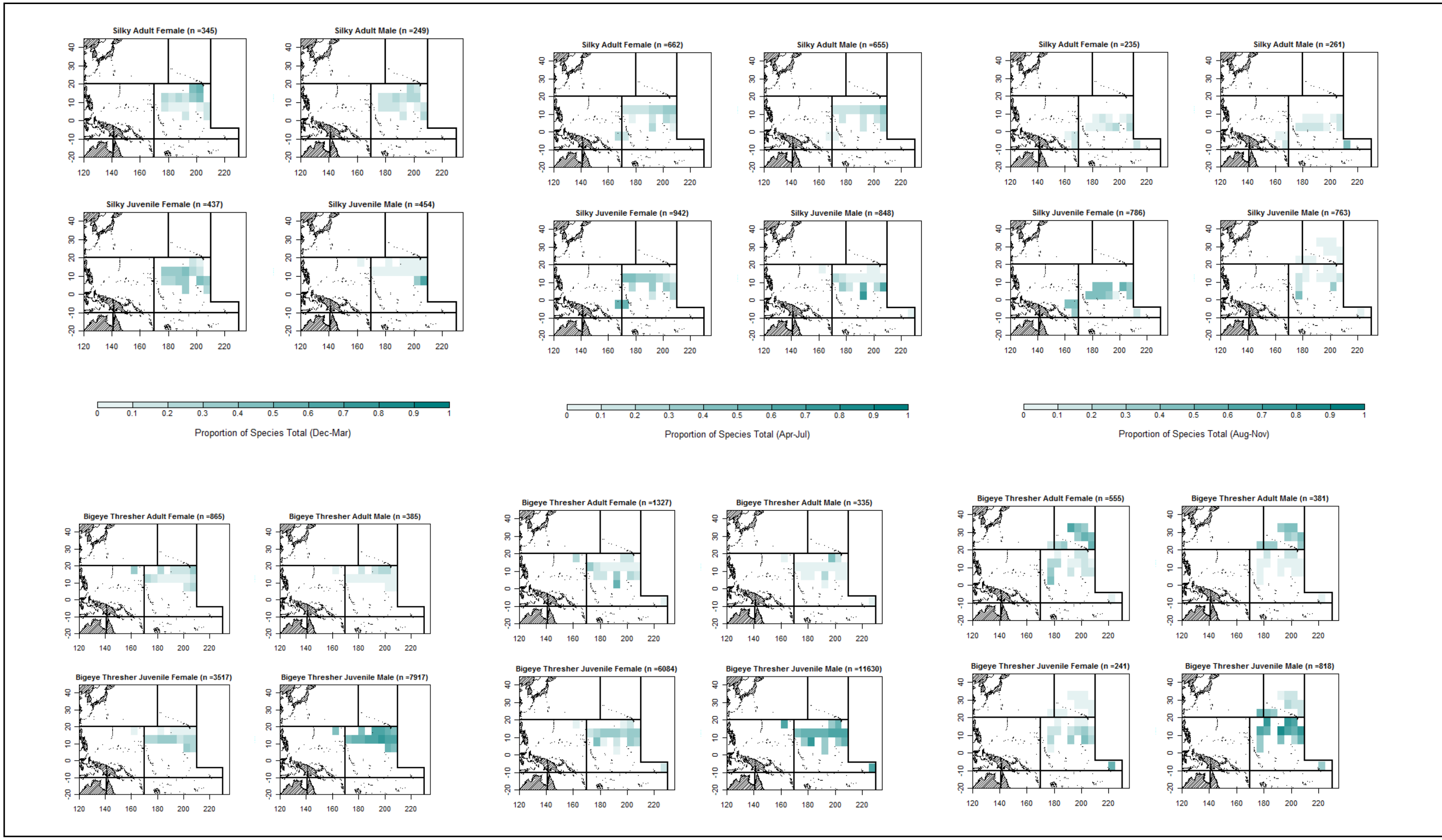


Figure A2 (cont.) The proportion of silky and bigeye thresher sharks observed in each 5 degree x 5 degree cell of Regions 1-4 which were adult females, adult males, juvenile females and juvenile males by trimester (Dec-Mar; Apr-July; Aug-Nov) based on unfiltered RTV data, 1992-2008. Darker shading indicates higher proportions observed.

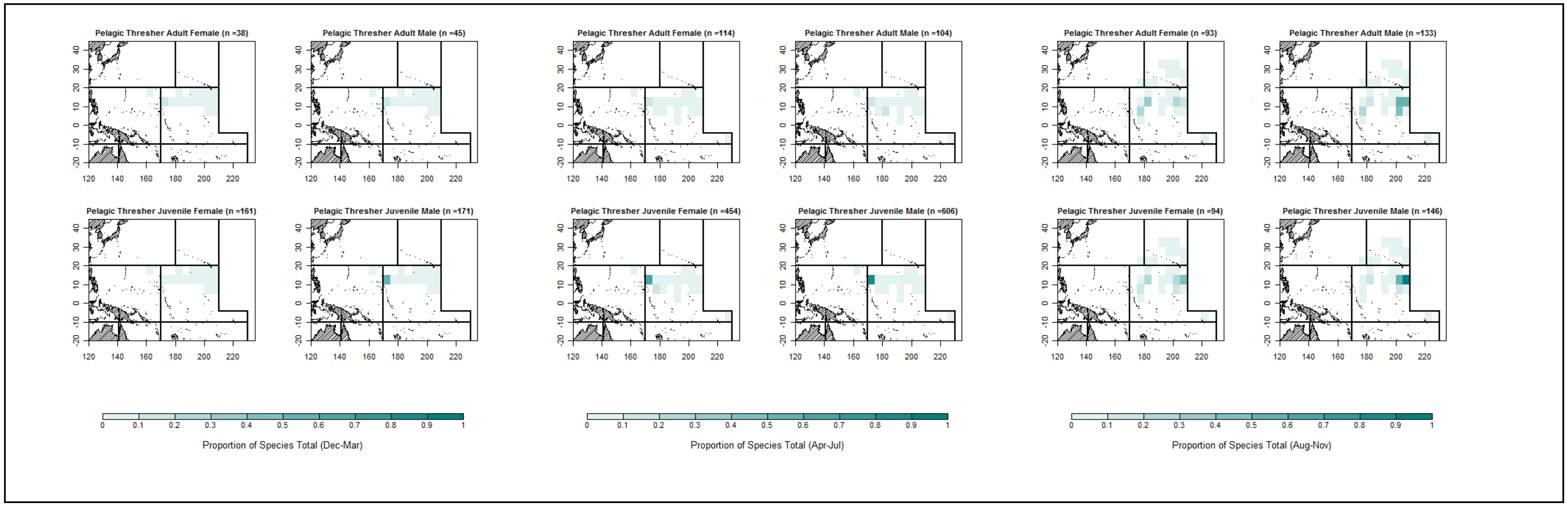


Figure A2 (cont.) The proportion of pelagic thresher sharks observed in each 5 degree x 5 degree cell of Regions 1-4 which were adult females, adult males, juvenile females and juvenile males by trimester (Dec-Mar; Apr-July; Aug-Nov) based on unfiltered RTV data, 1992-2008. Darker shading indicates higher proportions observed.

ANNEX 3.

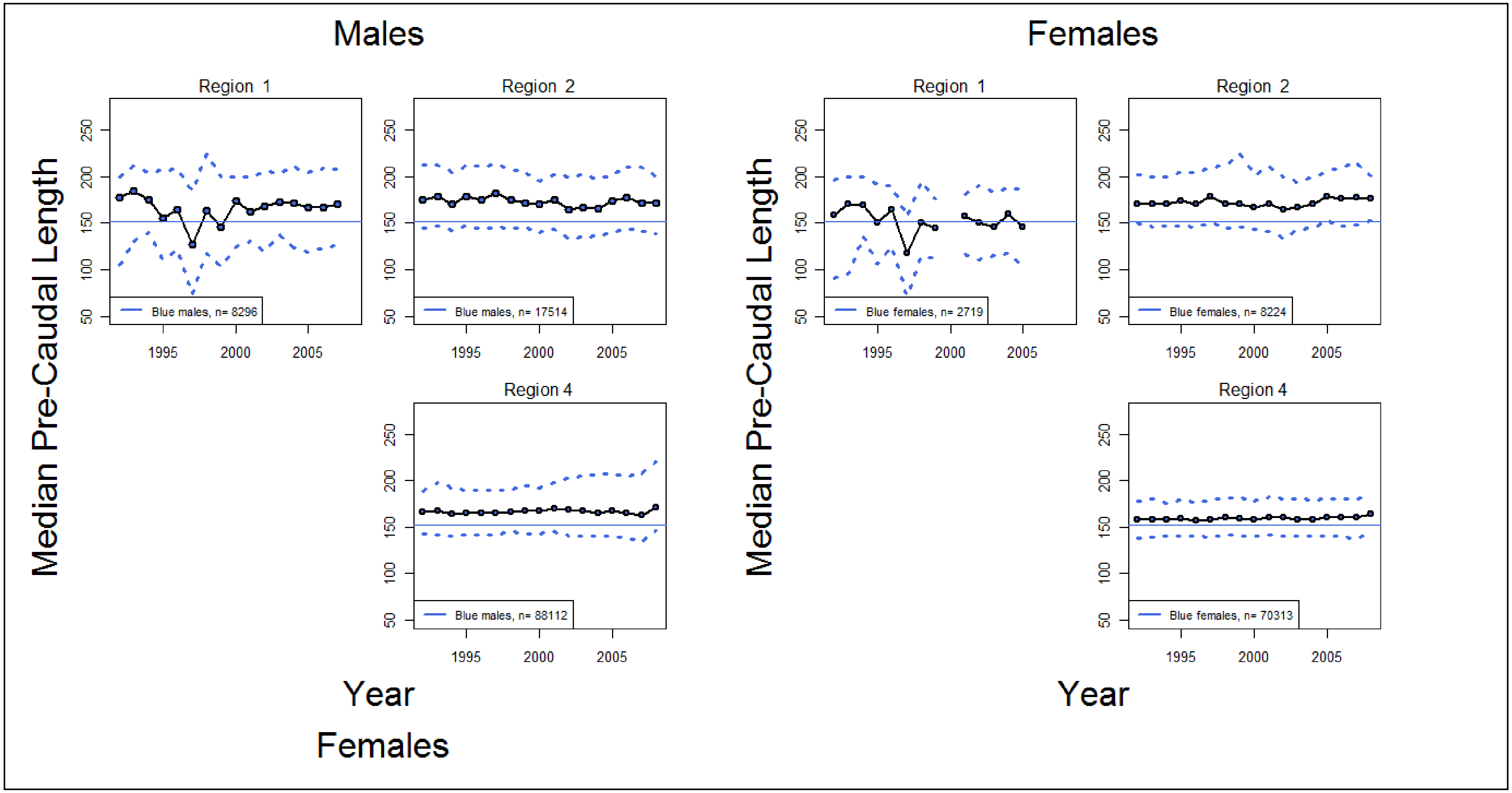


Figure A3. Median length (in pre-caudal length in cm) for male (left panel) and female (right panel) blue sharks by region from the RTV data set, 1992-2008. The 5th and 95th percentiles of the data are shown with dashed lines. The sample size is shown in the inset to each plot. Size at maturity is represented by the solid line.

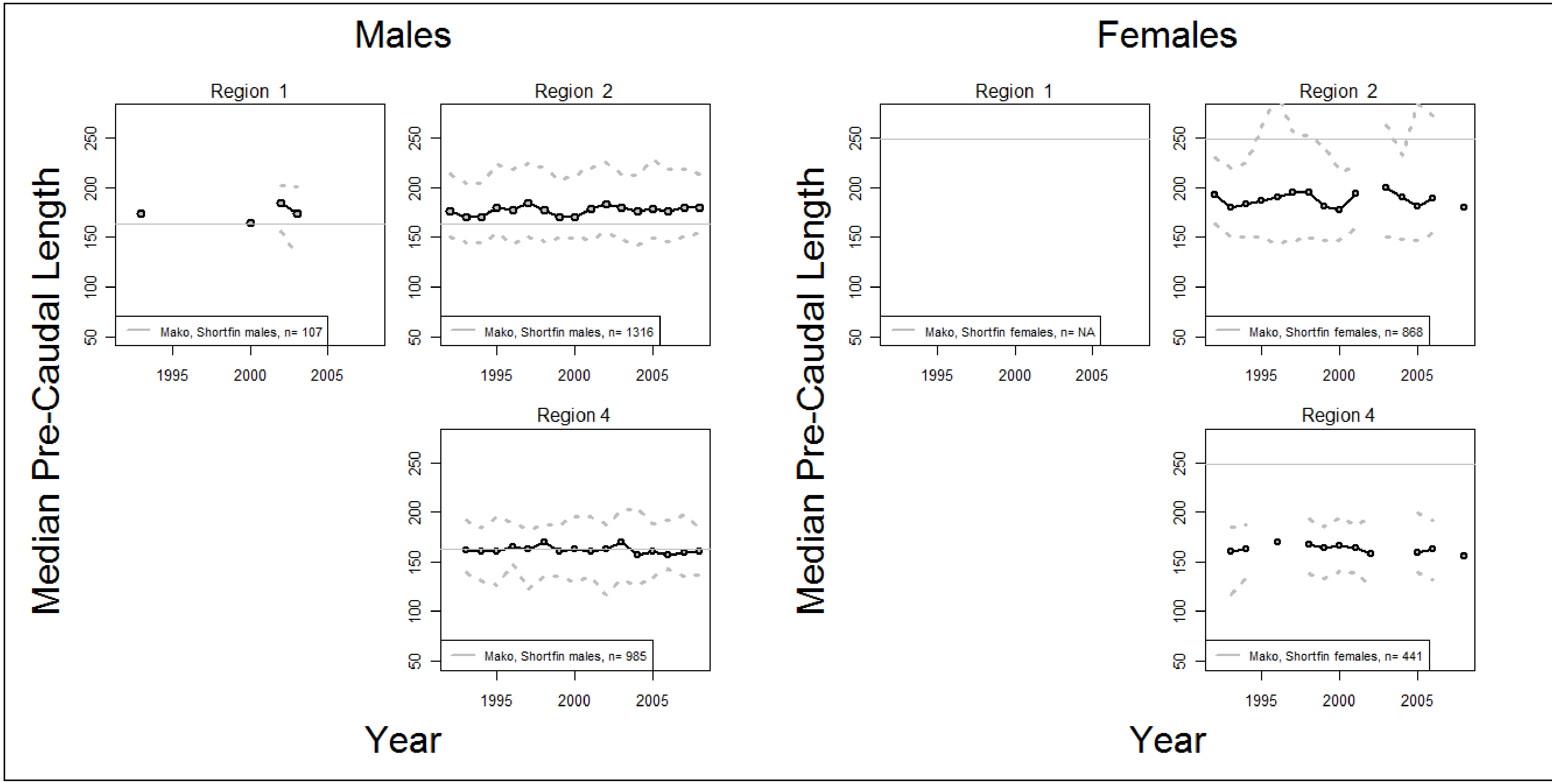


Figure A3 (cont.) Median length (in pre-caudal length in cm) for male (left panel) and female (right panel) shortfin mako sharks by region from the RTV data set, 1992-2008. The 5th and 95th percentiles of the data are shown with dashed lines. The sample size is shown in the inset to each plot. Size at maturity is represented by the solid line.

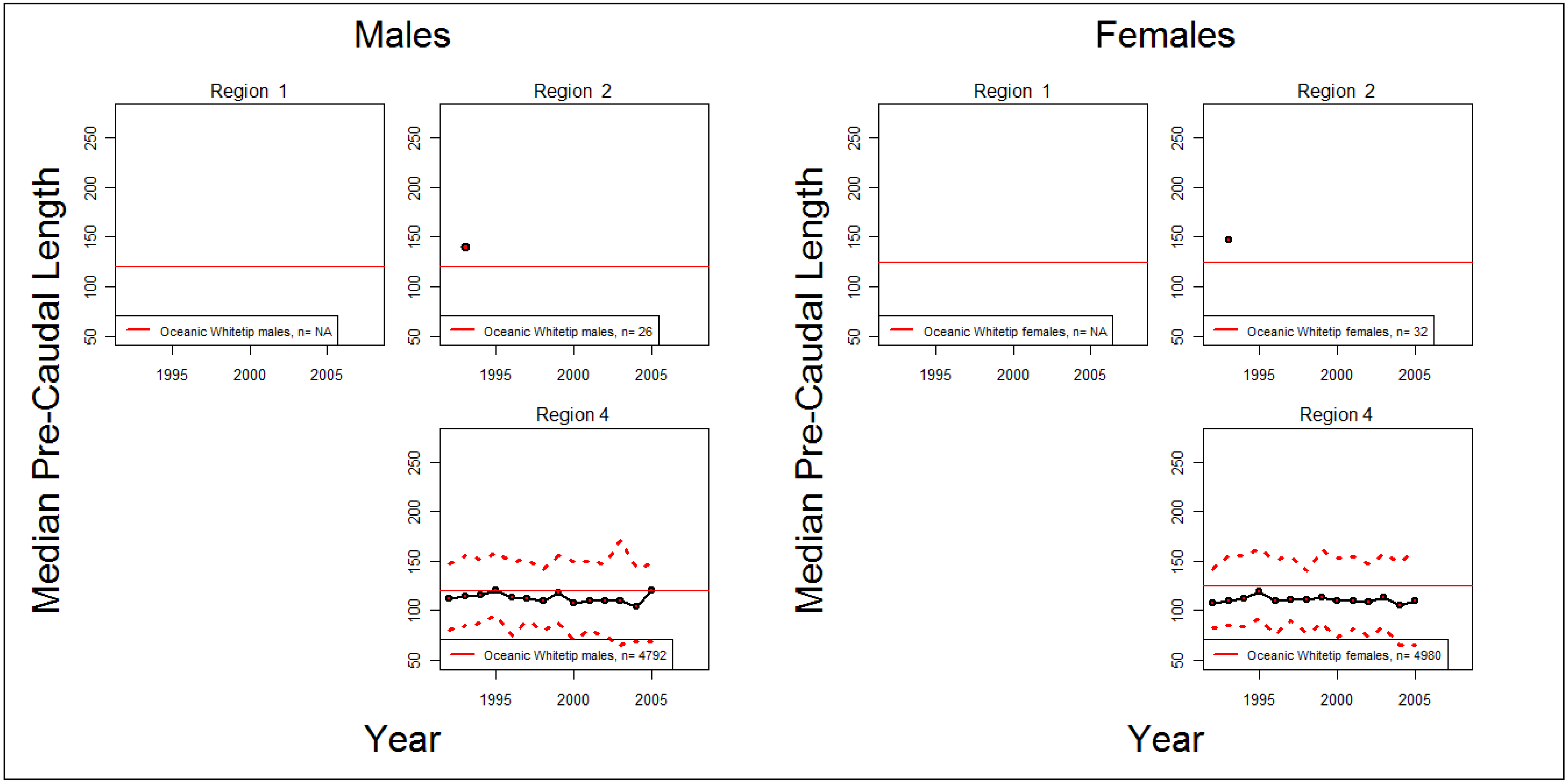


Figure A3 (cont). Median length (in pre-caudal length in cm) for male (left panel) and female (right panel) oceanic whitetip sharks by region from the RTV data set, 1992-2008. The 5th and 95th percentiles of the data are shown with dashed lines. The sample size is shown in the inset to each plot. Size at maturity is represented by the solid line.

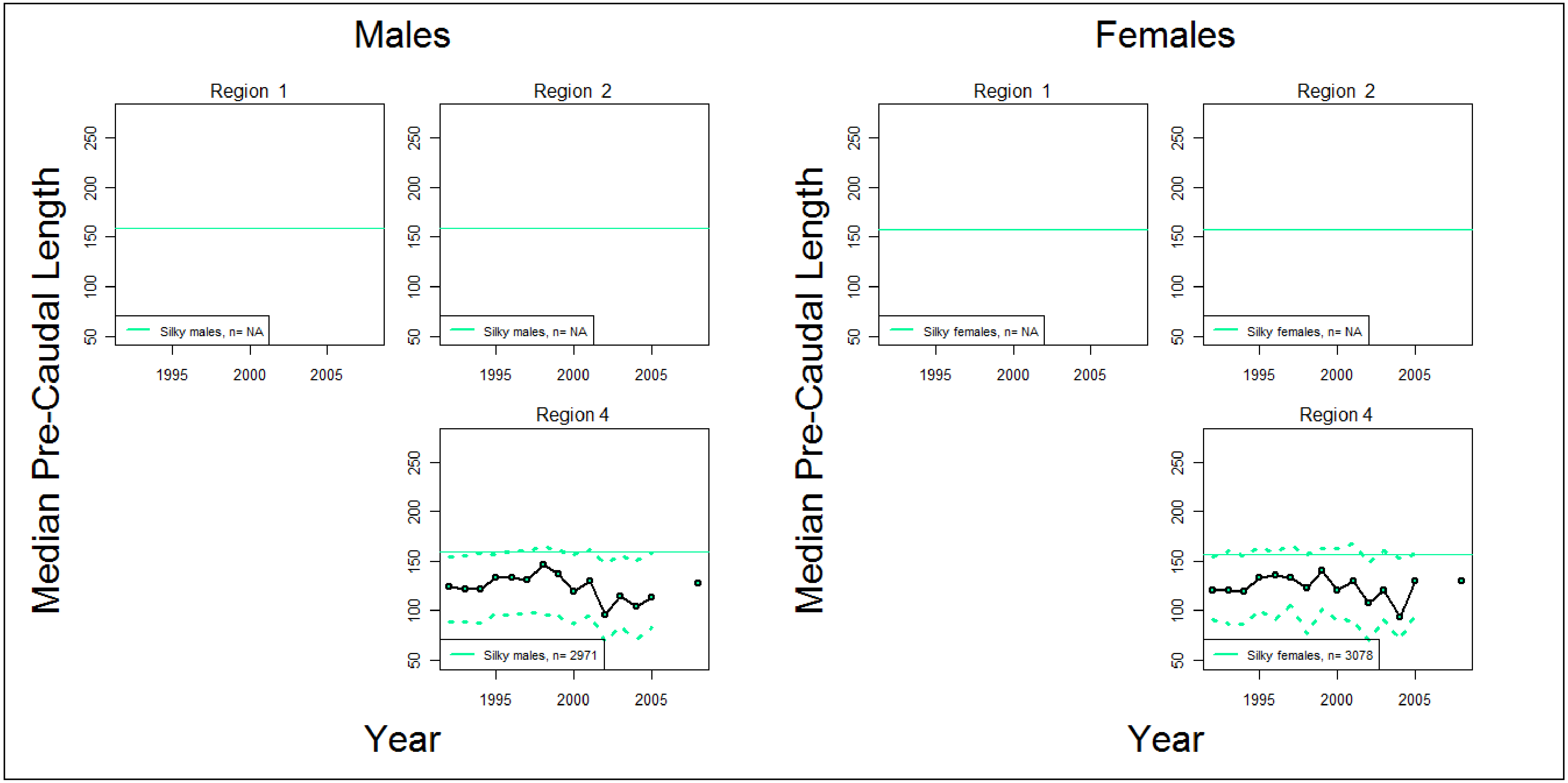


Figure A3 (cont.) Median length (in pre-caudal length in cm) for male (left panel) and female (right panel) silky sharks by region from the RTV data set, 1992-2008. The 5th and 95th percentiles of the data are shown with dashed lines. The sample size is shown in the inset to each plot. Size at maturity is represented by the solid line.

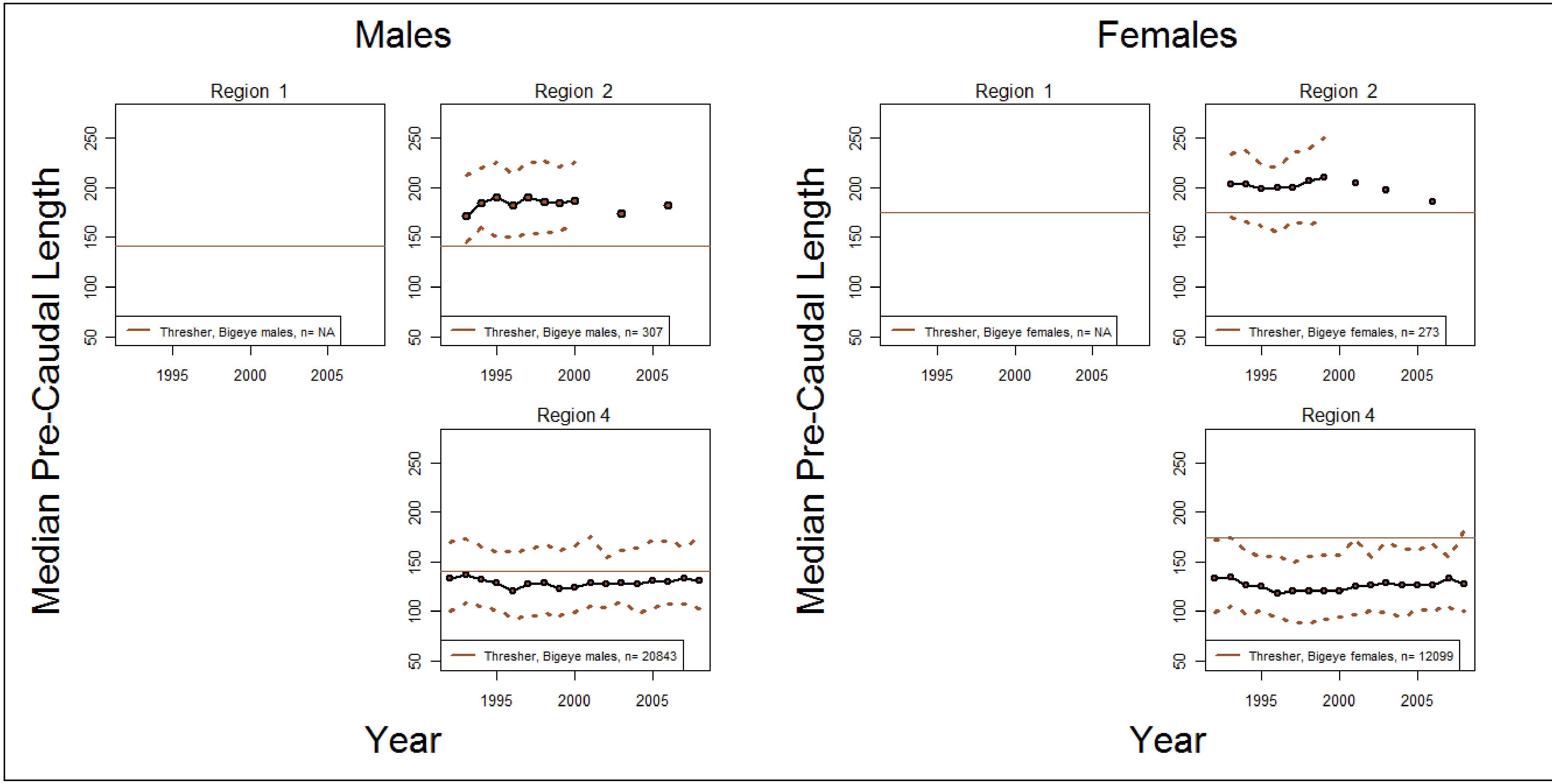


Figure A3 (cont.) Median length (in pre-caudal length in cm) for male (left panel) and female (right panel) bigeye thresher sharks by region from the RTV data set, 1992-2008. The 5th and 95th percentiles of the data are shown with dashed lines. The sample size is shown in the inset to each plot. Size at maturity is represented by the solid line.

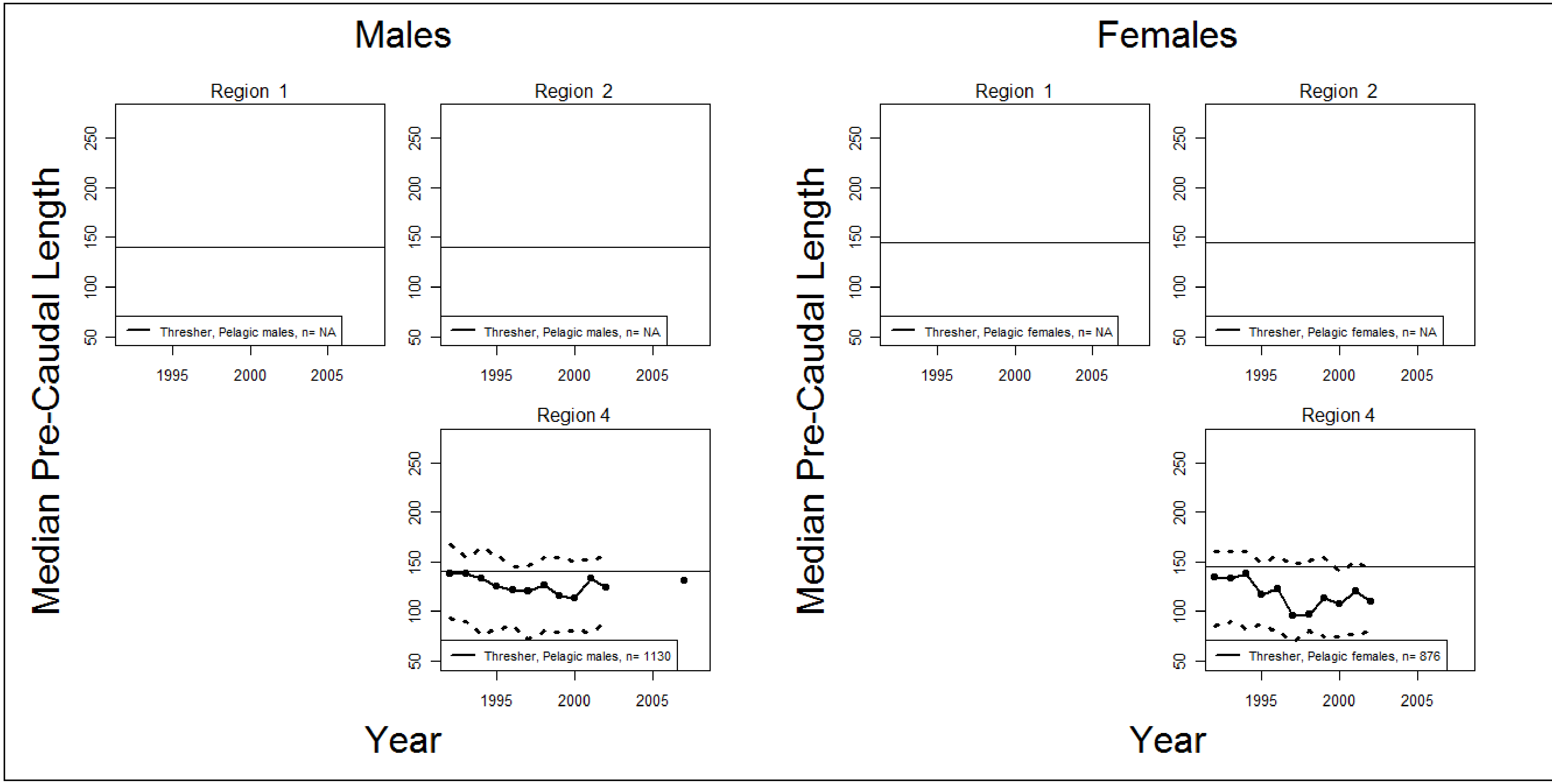


Figure A3 (cont.) Median length (in pre-caudal length in cm) for male (left panel) and female (right panel) pelagic thresher sharks by region from the RTV data set, 1992-2008. The 5th and 95th percentiles of the data are shown with dashed lines. The sample size is shown in the inset to each plot. Size at maturity is represented by the solid line.

ANNEX 4.

Results of a linear model of RRZ (composite reporting rate--see Section 2.1.3 for details) as a function of year and RTV vessel. Vessels with a slope (change in RRZ) of <5% are shown in red. The baseline vessel (0831) also had a change in RRZ of <5%.

```
> p<-lm(RTV$RRZ~ as.factor(RTV$year)+ as.factor(RTV$vessel))
> summary(p)

Call:
lm(formula = RTV$RRZ ~ as.factor(RTV$year) + as.factor(RTV$vessel))

Residuals:
    Min      1Q  Median      3Q     Max
-0.89471 -0.02846  0.01086  0.05233  0.34769

Coefficients:
                    Estimate Std. Error t value Pr(>|t|)
(Intercept)           1.048173  0.008214 127.601  < 2e-16 ***
as.factor(RTV$year)1993   0.004494  0.004964   0.905 0.365244
as.factor(RTV$year)1994   0.023286  0.004953   4.701 2.60e-06 ***
as.factor(RTV$year)1995   0.017597  0.005069   3.471 0.000519 ***
as.factor(RTV$year)1996   0.015732  0.005166   3.045 0.002326 **
as.factor(RTV$year)1997   0.016036  0.005109   3.139 0.001699 **
as.factor(RTV$year)1998   0.020007  0.005202   3.846 0.000120 ***
as.factor(RTV$year)1999   0.020849  0.005128   4.066 4.81e-05 ***
as.factor(RTV$year)2000   0.008736  0.005192   1.682 0.092488 .
as.factor(RTV$year)2001  -0.049172  0.005301  -9.276  < 2e-16 ***
as.factor(RTV$year)2002  -0.042962  0.005526  -7.775 7.90e-15 ***
as.factor(RTV$year)2003  -0.035916  0.005589  -6.426 1.34e-10 ***
as.factor(RTV$year)2004  -0.024583  0.005503  -4.467 7.96e-06 ***
as.factor(RTV$year)2005  -0.112030  0.005723 -19.575  < 2e-16 ***
as.factor(RTV$year)2006  -0.108805  0.005767 -18.867  < 2e-16 ***
as.factor(RTV$year)2007  -0.258088  0.005992 -43.074  < 2e-16 ***
as.factor(RTV$year)2008  -0.303231  0.005934 -51.101  < 2e-16 ***
as.factor(RTV$vessel)0832  0.008787  0.012171   0.722 0.470342
as.factor(RTV$vessel)1331 -0.104295  0.008447 -12.347  < 2e-16 ***
as.factor(RTV$vessel)1434 -0.092638  0.008498 -10.901  < 2e-16 ***
as.factor(RTV$vessel)1511 -0.082646  0.009490  -8.709  < 2e-16 ***
as.factor(RTV$vessel)1531 -0.081362  0.008110 -10.032  < 2e-16 ***
as.factor(RTV$vessel)1631 -0.040444  0.008157  -4.958 7.17e-07 ***
as.factor(RTV$vessel)1731 -0.030017  0.008040  -3.734 0.000189 ***
as.factor(RTV$vessel)1831 -0.040566  0.007899  -5.136 2.84e-07 ***
as.factor(RTV$vessel)1932 -0.120509  0.008867 -13.591  < 2e-16 ***
as.factor(RTV$vessel)2031 -0.097244  0.010496  -9.265  < 2e-16 ***
as.factor(RTV$vessel)2032 -0.090980  0.008104 -11.227  < 2e-16 ***
as.factor(RTV$vessel)2231 -0.037805  0.008993  -4.204 2.64e-05 ***
as.factor(RTV$vessel)2431 -0.031909  0.008243  -3.871 0.000109 ***
as.factor(RTV$vessel)2531 -0.084670  0.009138  -9.266  < 2e-16 ***
as.factor(RTV$vessel)2631 -0.063524  0.007956  -7.984 1.49e-15 ***
as.factor(RTV$vessel)2831 -0.061847  0.008680  -7.125 1.07e-12 ***
as.factor(RTV$vessel)3331 -0.063718  0.012471  -5.109 3.26e-07 ***
as.factor(RTV$vessel)3430 -0.060619  0.018348  -3.304 0.000955 ***
as.factor(RTV$vessel)3532 -0.043474  0.008032  -5.413 6.28e-08 ***
as.factor(RTV$vessel)3931 -0.053760  0.007859  -6.841 8.09e-12 ***
as.factor(RTV$vessel)4031 -0.021430  0.007928  -2.703 0.006877 **
as.factor(RTV$vessel)4131 -0.151256  0.007926 -19.084  < 2e-16 ***
as.factor(RTV$vessel)4231 -0.162654  0.008721 -18.650  < 2e-16 ***
as.factor(RTV$vessel)4331 -0.048198  0.008332  -5.784 7.38e-09 ***
as.factor(RTV$vessel)4731 -0.079371  0.008522  -9.313  < 2e-16 ***
as.factor(RTV$vessel)4831 -0.087403  0.008670 -10.081  < 2e-16 ***
as.factor(RTV$vessel)4931 -0.122849  0.007752 -15.847  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.1213 on 20803 degrees of freedom
Multiple R-squared: 0.3393,     Adjusted R-squared: 0.338
F-statistic: 248.5 on 43 and 20803 DF,  p-value: < 2.2e-16
```

ANNEX 5

Output and Diagnostics for Catch Rate Standardization Model presented in Section 5.2.

RTV Data, Region 2, Blue Shark, Binomial Portion

```
Call:
glm(formula = x != 0 ~ as.factor(cell) + as.factor(month) + as.factor(vessel) +
    as.factor(year) + as.factor(Leader) + ns(log(Hooks), df = 10),
    family = binomial, data = RTVNo, na.action = na.omit)


Analysis of Deviance Table (Type II tests)

Response: x != 0
                     LR Chisq Df Pr(>Chisq)
as.factor(cell)        114.829 12  < 2.2e-16 ***
as.factor(month)        11.984  5  0.0350016 *
as.factor(vessel)       27.074  8  0.0006866 ***
as.factor(year)         98.684 16  6.109e-14 ***
as.factor(Leader)        6.357  3  0.0954924 .
ns(log(Hooks), df = 10)   10.222 10  0.4212092

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-3.02726  0.08454  0.29095  0.51841  1.82243

Coefficients:
                     Estimate Std. Error z value Pr(>|z|)
(Intercept)           1.44097 3915.66777   0.000   0.9997
as.factor(year)1993  16.13482  670.17271   0.024   0.9808
as.factor(year)1994   2.11107    1.49948   1.408   0.1592
as.factor(year)1995   1.33630    1.26578   1.056   0.2911
as.factor(year)1996   1.02297    1.17367   0.872   0.3834
as.factor(year)1997   1.11820    1.16962   0.956   0.3391
as.factor(year)1998  -0.14075    1.11770  -0.126   0.8998
as.factor(year)1999   0.77054    1.15007   0.670   0.5029
as.factor(year)2000  -0.20070    1.21677  -0.165   0.8690
as.factor(year)2001  -0.69926    1.18865  -0.588   0.5563
as.factor(year)2002  -1.02863    1.19080  -0.864   0.3877
as.factor(year)2003  -1.81443    1.18946  -1.525   0.1272
as.factor(year)2004  -0.89408    1.22202  -0.732   0.4644
as.factor(year)2005  -1.67523    1.21444  -1.379   0.1678
as.factor(year)2006  -1.95168    1.19890  -1.628   0.1035
as.factor(year)2007  -2.33750    1.20833  -1.934   0.0531 .
as.factor(year)2008  -2.06145    1.20097  -1.716   0.0861 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 2216.9  on 2543  degrees of freedom
Residual deviance: 1612.1  on 2488  degrees of freedom
AIC: 1724.1

Number of Fisher Scoring iterations: 17
```

RTV Data, Region 2, Blue Shark, Log Normal Portion

```
Call:
glm(formula = posx ~ as.factor(month) + as.factor(vessel) + as.factor(year) +
    as.factor(cell) + ns(log(Hooks), df = 10), family = gaussian(link = "log"),
    data = posdat, na.action = na.omit)

Analysis of Deviance Table (Type II tests)

Response: posx
                        LR Chisq Df Pr(>Chisq)
as.factor(month)          60.95  5  7.719e-12 ***
as.factor(vessel)        145.01  8  < 2.2e-16 ***
as.factor(year)          420.33 16  < 2.2e-16 ***
as.factor(cell)          375.56 12  < 2.2e-16 ***
ns(log(Hooks), df = 10)   33.69 10  0.0002087 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


Deviance Residuals:
     Min        1Q    Median        3Q       Max
-17.9738   -2.2312   -0.4896    1.6089   28.7559

Coefficients:
                     Estimate Std. Error t value Pr(>|t|)
(Intercept)           1.62582    0.42790   3.800 0.000149 ***
as.factor(year)1993   0.83994    0.23767   3.534 0.000418 ***
as.factor(year)1994   0.88577    0.23792   3.723 0.000202 ***
as.factor(year)1995   1.04504    0.23483   4.450 9.03e-06 ***
as.factor(year)1996   0.84414    0.23645   3.570 0.000365 ***
as.factor(year)1997   1.42151    0.23750   5.985 2.54e-09 ***
as.factor(year)1998   0.69962    0.23961   2.920 0.003540 **
as.factor(year)1999   0.48828    0.23988   2.035 0.041928 *
as.factor(year)2000   0.70240    0.23699   2.964 0.003073 **
as.factor(year)2001   0.72929    0.24086   3.028 0.002493 **
as.factor(year)2002   0.76083    0.24321   3.128 0.001782 **
as.factor(year)2003   0.66134    0.23943   2.762 0.005793 **
as.factor(year)2004   0.70254    0.23925   2.936 0.003356 **
as.factor(year)2005   0.70627    0.24782   2.850 0.004416 **
as.factor(year)2006   0.56261    0.24394   2.306 0.021188 *
as.factor(year)2007  -0.37008    0.31060  -1.192 0.233592
as.factor(year)2008  -0.33341    0.28122  -1.186 0.235925
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 18.68031)

    Null deviance: 79625  on 2142  degrees of freedom
Residual deviance: 39042  on 2090  degrees of freedom
AIC: 12409

Number of Fisher Scoring iterations: 11
```

RTV Data, Region 2, Mako Shark, Binomial Portion

```
Call:
glm(formula = x != 0 ~ as.factor(cell) + as.factor(month) + as.factor(vessel) +
    as.factor(year) + as.factor(Leader) + ns(log(Hooks), df = 10),
    family = binomial, data = RTVNo, na.action = na.omit)

Analysis of Deviance Table (Type II tests)

Response: x != 0
```

```
                  LR Chisq Df Pr(>Chisq)
as.factor(cell)          20.912 12  0.0516837 .
as.factor(month)         18.242  5  0.0026582 **
as.factor(vessel)        12.752  8  0.1206608
as.factor(year)          35.232 16  0.0036940 **
as.factor(Leader)        18.672  3  0.0003196 ***
ns(log(Hooks), df = 10)  13.023 10  0.2223802
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.6947  -0.9335  -0.7573   1.3284   2.2613

Coefficients:
                     Estimate Std. Error z value Pr(>|z|)
(Intercept)          -2.60041    2.30529  -1.128  0.25931
as.factor(year)1993  -0.79571    0.56679  -1.404  0.16035
as.factor(year)1994  -0.09928    0.53474  -0.186  0.85271
as.factor(year)1995  -0.15274    0.52460  -0.291  0.77094
as.factor(year)1996  -0.20471    0.51795  -0.395  0.69267
as.factor(year)1997   0.07613    0.53178   0.143  0.88616
as.factor(year)1998   0.22390    0.51583   0.434  0.66425
as.factor(year)1999  -0.12195    0.52584  -0.232  0.81660
as.factor(year)2000  -1.40931    0.64199  -2.195  0.02815 *
as.factor(year)2001  -1.44555    0.65792  -2.197  0.02801 *
as.factor(year)2002  -1.93221    0.65506  -2.950  0.00318 **
as.factor(year)2003  -1.34710    0.66181  -2.035  0.04180 *
as.factor(year)2004  -1.59343    0.66660  -2.390  0.01683 *
as.factor(year)2005  -1.38249    0.67378  -2.052  0.04019 *
as.factor(year)2006  -1.47806    0.66209  -2.232  0.02559 *
as.factor(year)2007  -1.70155    0.68122  -2.498  0.01250 *
as.factor(year)2008  -1.32605    0.66696  -1.988  0.04679 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 3213.1  on 2543  degrees of freedom
Residual deviance: 3080.8  on 2488  degrees of freedom
AIC: 3192.8

Number of Fisher Scoring iterations: 12
```

RTV Data, Region 2, Mako Shark, Log Normal Portion

```
Call:
glm(formula = posx ~ as.factor(month) + as.factor(vessel) + as.factor(year) +
    as.factor(cell) + ns(log(Hooks), df = 10), family = gaussian(link = "log"),
    data = posdat, na.action = na.omit)

Analysis of Deviance Table (Type II tests)

Response: posx
                  LR Chisq Df Pr(>Chisq)
as.factor(month)          2.6970  4    0.60975
as.factor(vessel)         8.2336  8    0.41099
as.factor(year)          23.8462 16    0.09292 .
as.factor(cell)           6.4162 11    0.84420
ns(log(Hooks), df = 10)  13.4353 10    0.20034
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-0.8855  -0.3490  -0.1984   0.0611   5.1339

Coefficients:
                      Estimate Std. Error t value Pr(>|t|)
(Intercept)          2.925e-01  5.466e-01   0.535    0.593
as.factor(year)1993  1.513e-01  2.575e-01   0.587    0.557
as.factor(year)1994  2.636e-01  2.387e-01   1.104    0.270
as.factor(year)1995  3.228e-01  2.393e-01   1.349    0.178
as.factor(year)1996  1.007e-01  2.371e-01   0.425    0.671
as.factor(year)1997  2.946e-01  2.399e-01   1.228    0.220
as.factor(year)1998  1.277e-01  2.340e-01   0.546    0.585
as.factor(year)1999  1.382e-01  2.398e-01   0.576    0.565
as.factor(year)2000  1.960e-01  2.376e-01   0.825    0.410
as.factor(year)2001  2.083e-01  2.396e-01   0.869    0.385
as.factor(year)2002  5.568e-02  2.526e-01   0.220    0.826
as.factor(year)2003  2.653e-01  2.460e-01   1.078    0.281
as.factor(year)2004  1.684e-01  2.372e-01   0.710    0.478
as.factor(year)2005 -1.192e-02  2.476e-01  -0.048    0.962
as.factor(year)2006  1.552e-01  2.389e-01   0.650    0.516
as.factor(year)2007  3.040e-02  2.503e-01   0.121    0.903
as.factor(year)2008 -6.244e-05  2.411e-01   0.000    1.000

 (Dispersion parameter for gaussian family taken to be 0.4373074)

    Null deviance: 369.42  on 829  degrees of freedom
Residual deviance: 340.65  on 779  degrees of freedom
AIC: 1720.3

Number of Fisher Scoring iterations: 7
```

RTV Data, Region 2, Oceanic Whitetip, Binomial Portion

```
Call:
glm(formula = x != 0 ~ as.factor(cell) + as.factor(month) + as.factor(vessel) +
    as.factor(year) + as.factor(Leader) + ns(log(Hooks), df = 10),
    family = binomial, data = RTVNo, na.action = na.omit)

Analysis of Deviance Table (Type II tests)

Response: x != 0
                        LR Chisq Df Pr(>Chisq)
as.factor(cell)           26.858 12  0.0080981 **
as.factor(month)           5.281  5  0.3825697
as.factor(vessel)         12.095  8  0.1470264
as.factor(year)           39.985 16  0.0007824 ***
as.factor(Leader)          2.425  3  0.4890059
ns(log(Hooks), df = 10)   24.928 10  0.0054829 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.4402  -0.2397  -0.1200  -0.0506   3.4271

Coefficients:
                      Estimate Std. Error z value Pr(>|z|)
(Intercept)         -5.397e+00  4.025e+00  -1.341   0.1800
```

```
as.factor(year)1993      -2.700e-01  1.302e+00  -0.207   0.8358
as.factor(year)1994       5.332e-01  1.268e+00   0.421   0.6740
as.factor(year)1995       3.090e-01  1.246e+00   0.248   0.8041
as.factor(year)1996      -7.731e-01  1.293e+00  -0.598   0.5500
as.factor(year)1997      -1.108e+00  1.425e+00  -0.778   0.4367
as.factor(year)1998      -5.074e-01  1.307e+00  -0.388   0.6979
as.factor(year)1999      -1.910e+00  1.436e+00  -1.330   0.1834
as.factor(year)2000      -8.166e-01  1.391e+00  -0.587   0.5573
as.factor(year)2001      -3.945e-02  1.469e+00  -0.027   0.9786
as.factor(year)2002      -1.777e+00  1.541e+00  -1.153   0.2488
as.factor(year)2003      -1.732e+00  1.559e+00  -1.110   0.2668
as.factor(year)2004      -2.309e+00  1.640e+00  -1.408   0.1591
as.factor(year)2005      -1.769e-01  1.531e+00  -0.116   0.9080
as.factor(year)2006      -1.670e+00  1.597e+00  -1.046   0.2956
as.factor(year)2007      -1.659e+01  8.109e+02  -0.020   0.9837
as.factor(year)2008      -1.699e+01  7.736e+02  -0.022   0.9825
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 758.34  on 2543  degrees of freedom
Residual deviance: 559.73  on 2488  degrees of freedom
AIC: 671.73

Number of Fisher Scoring iterations: 18
```

RTV Data, Region 2, Oceanic Whitetip, Log Normal Portion

```
Call:
glm(formula = posx ~ as.factor(month) + as.factor(vessel) + as.factor(year) +
    as.factor(cell) + ns(log(Hooks), df = 10), family = gaussian(link = "log"),
    data = posdat, na.action = na.omit)

Analysis of Deviance Table (Type II tests)

Response: posx
                        LR Chisq Df Pr(>Chisq)
as.factor(month)          13.933  3   0.002998 **
as.factor(vessel)          2.705  8   0.951465
as.factor(year)           32.247 14   0.003694 **
as.factor(cell)           32.171 10   0.000375 ***
ns(log(Hooks), df = 10)    5.361 10   0.865812
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.39198  -0.07693   0.00000   0.05717   0.82732

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)            0.707293   0.729745   0.969 0.338401
as.factor(year)1993    0.255389   0.468053   0.546 0.588420
as.factor(year)1994    0.230785   0.419021   0.551 0.584931
as.factor(year)1995    0.087642   0.393753   0.223 0.825023
as.factor(year)1996    0.821775   0.402691   2.041 0.048090 *
as.factor(year)1997    0.018546   0.510893   0.036 0.971228
as.factor(year)1998   -0.169441   0.451366  -0.375 0.709400
as.factor(year)1999    0.116858   0.505033   0.231 0.818224
as.factor(year)2000   -0.034293   0.466702  -0.073 0.941800
as.factor(year)2001   -0.659453   0.502738  -1.312 0.197283
```

```
as.factor(year)2002      -0.376083   0.651717  -0.577 0.567212
as.factor(year)2003      -0.100029   0.517546  -0.193 0.847746
as.factor(year)2004       0.143735   0.495517   0.290 0.773299
as.factor(year)2005      -0.313806   0.561560  -0.559 0.579485
as.factor(year)2006      -0.602508   0.622261  -0.968 0.338883
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 0.09654213)

    Null deviance: 9.2644  on 86  degrees of freedom
Residual deviance: 3.7651  on 39  degrees of freedom
AIC: 71.703

Number of Fisher Scoring iterations: 7
```

RTV Data, Region 2, Thresher, Binomial Portion

```
Call:
glm(formula = x != 0 ~ as.factor(cell) + as.factor(month) + as.factor(vessel) +
    as.factor(year) + as.factor(Leader) + ns(log(Hooks), df = 10),
    family = binomial, data = RTVNo, na.action = na.omit)

Analysis of Deviance Table (Type II tests)

Response: x != 0
                        LR Chisq Df Pr(>Chisq)
as.factor(cell)           37.679 12  0.0001733 ***
as.factor(month)          23.116  5  0.0003208 ***
as.factor(vessel)         57.151  8  1.682e-09 ***
as.factor(year)           32.845 16  0.0077478 **
as.factor(Leader)         34.429  3  1.608e-07 ***
ns(log(Hooks), df = 10)   13.815 10  0.1816033
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.2759  -0.6485  -0.4960  -0.3139   2.6186

Coefficients:
                           Estimate Std. Error z value Pr(>|z|)
(Intercept)                -4.13229    2.52890  -1.634 0.102253
as.factor(year)1993         0.82187    0.86323   0.952 0.341051
as.factor(year)1994         1.11619    0.83822   1.332 0.182986
as.factor(year)1995         0.05653    0.84026   0.067 0.946358
as.factor(year)1996         0.74553    0.81924   0.910 0.362809
as.factor(year)1997         0.75090    0.82886   0.906 0.364969
as.factor(year)1998         0.95949    0.81689   1.175 0.240169
as.factor(year)1999         0.75225    0.82171   0.915 0.359947
as.factor(year)2000         0.64454    0.91200   0.707 0.479736
as.factor(year)2001         1.43543    0.92699   1.548 0.121507
as.factor(year)2002         0.89646    0.92158   0.973 0.330678
as.factor(year)2003         1.25190    0.92438   1.354 0.175639
as.factor(year)2004         0.81232    0.94117   0.863 0.388082
as.factor(year)2005         0.84274    0.95017   0.887 0.375117
as.factor(year)2006         1.33079    0.93077   1.430 0.152782
as.factor(year)2007         0.78673    0.95906   0.820 0.412042
as.factor(year)2008         1.78121    0.93381   1.907 0.056461 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

(Dispersion parameter for binomial family taken to be 1)

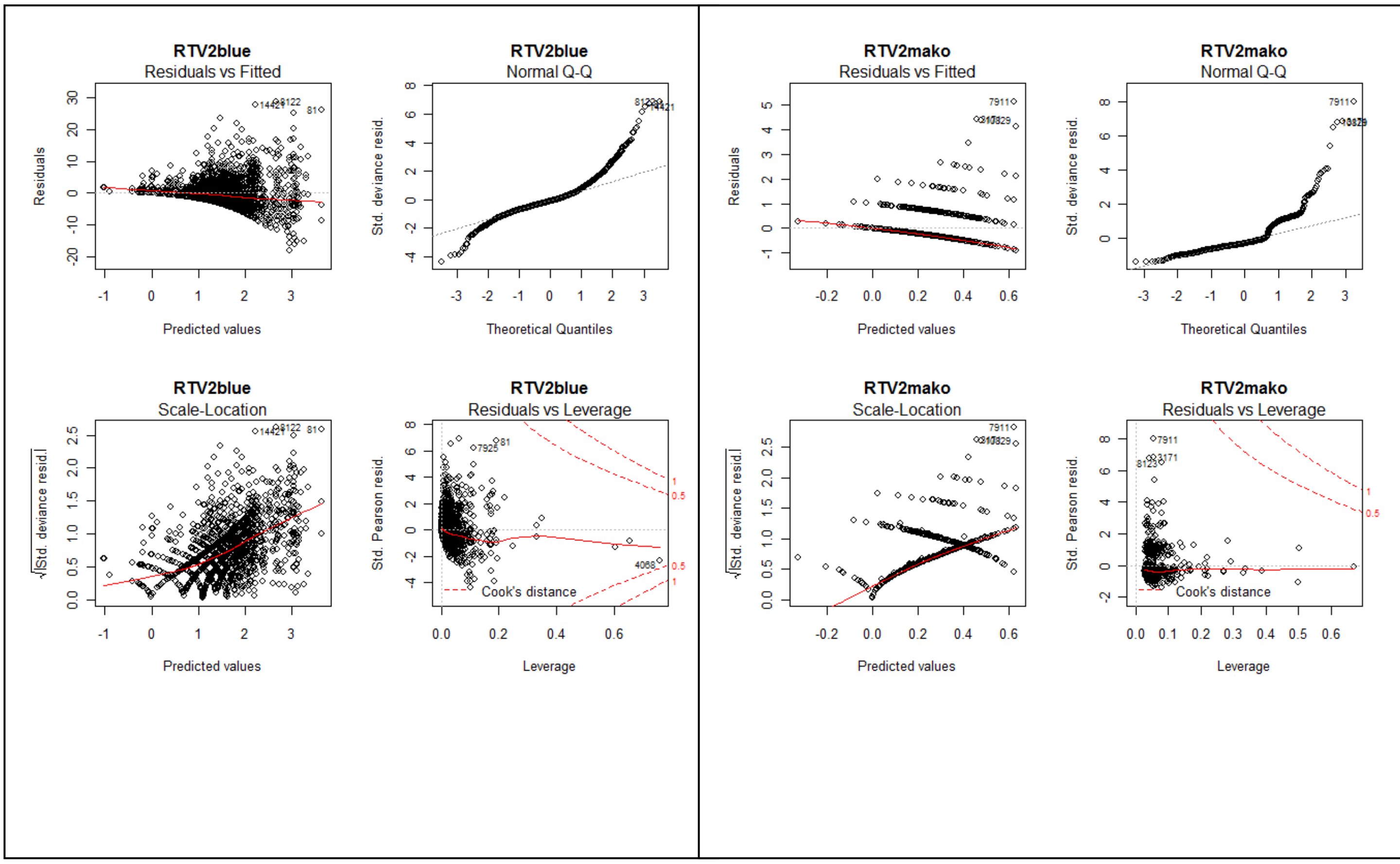
    Null deviance: 2458.3 on 2543 degrees of freedom
Residual deviance: 2146.8 on 2488 degrees of freedom
AIC: 2258.8

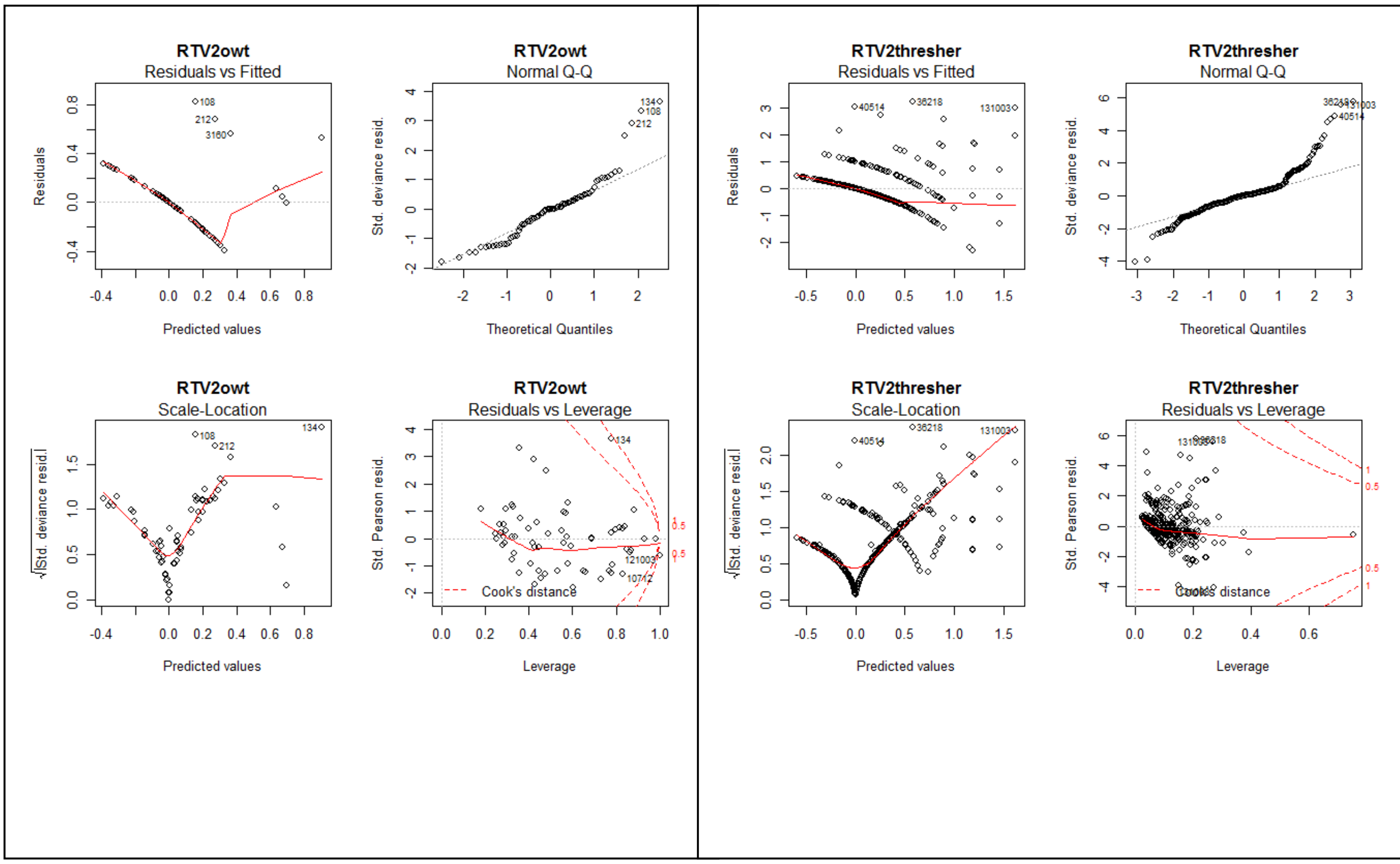
Number of Fisher Scoring iterations: 15

RTV Data, Region 2, Thresher, Log Normal Portion

```
Call:
glm(formula = posx ~ as.factor(month) + as.factor(vessel) + as.factor(year) +
    as.factor(cell) + ns(log(Hooks), df = 10), family = gaussian(link = "log"),
    data = posdat, na.action = na.omit)

Analysis of Deviance Table (Type II tests)
Response: posx
                        LR Chisq Df Pr(>Chisq)
as.factor(month)          25.758  4  3.541e-05 ***
as.factor(vessel)         20.375  8  0.009008 **
as.factor(year)          101.457 16  1.846e-14 ***
as.factor(cell)           19.115 11   0.059055 .
ns(log(Hooks), df = 10)   13.691 10   0.187568
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.2799  -0.2727   0.0046   0.2079   3.2128

Coefficients:
                     Estimate Std. Error t value Pr(>|t|)
(Intercept)         -0.677967   0.877882  -0.772 0.440379
as.factor(year)1993 -0.213468   0.511393  -0.417 0.676577
as.factor(year)1994  0.075052   0.493293   0.152 0.879144
as.factor(year)1995  0.066157   0.497586   0.133 0.894291
as.factor(year)1996  0.221842   0.486077   0.456 0.648339
as.factor(year)1997  0.243327   0.487952   0.499 0.618269
as.factor(year)1998  0.001482   0.488241   0.003 0.997579
as.factor(year)1999 -0.274626   0.488818  -0.562 0.574536
as.factor(year)2000 -0.164387   0.489924  -0.336 0.737385
as.factor(year)2001  0.241568   0.488402   0.495 0.621130
as.factor(year)2002  0.077527   0.491887   0.158 0.874837
as.factor(year)2003  0.663693   0.481048   1.380 0.168407
as.factor(year)2004  0.232908   0.485234   0.480 0.631479
as.factor(year)2005  0.616364   0.492243   1.252 0.211200
as.factor(year)2006  0.520999   0.483433   1.078 0.281773
as.factor(year)2007 -0.004044   0.496396  -0.008 0.993503
as.factor(year)2008  0.201502   0.483684   0.417 0.677181
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 0.3980986)
    Null deviance: 303.41  on 477  degrees of freedom
Residual deviance: 169.99  on 427  degrees of freedom
AIC: 966.3

Number of Fisher Scoring iterations: 9
```

PLOT DIAGNOSTICS FOR RTV REGION 2 MODELS





RTV Data, Region 4, Blue, Binomial Portion

Call:
glm(formula = x != 0 ~ as.factor(cell) + as.factor(tri) + as.factor(vessel) +
as.factor(year) + as.factor(Leader) + ns(log(Hooks), df = 10),
family = binomial, data = RTVNo, na.action = na.omit)

Analysis of Deviance Table (Type II tests)

Response: x != 0

	LR Chisq	Df	Pr(>Chisq)	
as.factor(cell)	99.275	33	1.479e-08	***
as.factor(tri)	12.303	2	0.002130	**
as.factor(vessel)	15.875	9	0.069534	.
as.factor(year)	46.811	16	7.287e-05	***
as.factor(Leader)	7.222	3	0.065138	.
ns(log(Hooks), df = 10)	4.308	10	0.932387	

Signif. codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 >**

Deviance Residuals:

Min	1Q	Median	3Q	Max
-3.4309	0.0000	0.0168	0.1115	0.9874

Coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	49.1924	34573.6864	0.001	0.9989
as.factor(year)1993	-15.3979	2958.9510	-0.005	0.9958
as.factor(year)1994	-13.6902	2958.9512	-0.005	0.9963
as.factor(year)1995	-15.8006	2958.9509	-0.005	0.9957

```
as.factor(year)1996         1.9465  3866.9229   0.001   0.9996
as.factor(year)1997         1.6499  3853.2249   0.000   0.9997
as.factor(year)1998         1.7102  4247.1281   0.000   0.9997
as.factor(year)1999       -14.2555  2958.9511  -0.005   0.9962
as.factor(year)2000       -14.6579  2958.9510  -0.005   0.9960
as.factor(year)2001       -12.5735  2958.9513  -0.004   0.9966
as.factor(year)2002       -12.6188  2958.9512  -0.004   0.9966
as.factor(year)2003       -14.9307  2958.9511  -0.005   0.9960
as.factor(year)2004       -14.1683  2958.9512  -0.005   0.9962
as.factor(year)2005       -15.7841  2958.9511  -0.005   0.9957
as.factor(year)2006       -16.2845  2958.9511  -0.006   0.9956
as.factor(year)2007       -14.7717  2958.9511  -0.005   0.9960
as.factor(year)2008       -16.4291  2958.9511  -0.006   0.9956
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 707.42  on 4869  degrees of freedom
Residual deviance: 459.79  on 4796  degrees of freedom
AIC: 607.8

Number of Fisher Scoring iterations: 21
```

RTV Data, Region 4, Blue, Log Normal Portion

```
Call:
glm(formula = posx ~ as.factor(tri) + as.factor(vessel) + as.factor(year) +
    as.factor(cell) + ns(log(Hooks), df = 10), family = gaussian(link = "log"),
    data = posdat, na.action = na.omit)

Analysis of Deviance Table (Type II tests)
Response: posx
                        LR Chisq Df Pr(>Chisq)
as.factor(tri)            167.62  2  < 2.2e-16 ***
as.factor(vessel)         276.26  9  < 2.2e-16 ***
as.factor(year)           804.67 16  < 2.2e-16 ***
as.factor(cell)          1434.46 32  < 2.2e-16 ***
ns(log(Hooks), df = 10)    49.81 10  2.896e-07 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-25.558   -4.226   -0.798    3.446  117.715

Coefficients:
                      Estimate Std. Error t value Pr(>|t|)
(Intercept)           0.509856   1.366463   0.373  0.70908
as.factor(year)1993  -0.046127   0.049235  -0.937  0.34887
as.factor(year)1994   0.059121   0.049136   1.203  0.22895
as.factor(year)1995  -0.103910   0.051131  -2.032  0.04218 *
as.factor(year)1996   0.092136   0.053383   1.726  0.08442 .
as.factor(year)1997   0.561712   0.047124  11.920  < 2e-16 ***
as.factor(year)1998   0.359515   0.055173   6.516 7.97e-11 ***
as.factor(year)1999   0.310992   0.052385   5.937 3.12e-09 ***
as.factor(year)2000   0.370111   0.050378   7.347 2.38e-13 ***
as.factor(year)2001   0.338189   0.053630   6.306 3.12e-10 ***
as.factor(year)2002   0.420372   0.054518   7.711 1.52e-14 ***
as.factor(year)2003   0.186295   0.057193   3.257  0.00113 **
as.factor(year)2004   0.001958   0.060948   0.032  0.97438
as.factor(year)2005  -0.200275   0.071900  -2.785  0.00537 **
```

```
as.factor(year)2006      -0.437617   0.080950  -5.406 6.76e-08 ***
as.factor(year)2007      -0.389042   0.081006  -4.803 1.61e-06 ***
as.factor(year)2008      -0.359279   0.083636  -4.296 1.78e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 55.84186)

    Null deviance: 413949  on 4802  degrees of freedom
Residual deviance: 264297  on 4733  degrees of freedom
AIC: 33022

Number of Fisher Scoring iterations: 8
```

RTV Data, Region 4, Mako, Binomial Portion

```
Call:
glm(formula = x != 0 ~ as.factor(cell) + as.factor(tri) + as.factor(vessel) +
    as.factor(year) + as.factor(Leader) + ns(log(Hooks), df = 10),
    family = binomial, data = RTVNo, na.action = na.omit)

Analysis of Deviance Table (Type II tests)
Response: x != 0
                     LR Chisq Df Pr(>Chisq)
as.factor(cell)         119.193 33  1.111e-11 ***
as.factor(tri)           30.632  2  2.230e-07 ***
as.factor(vessel)        34.915  9  6.168e-05 ***
as.factor(year)          43.763 16  0.0002143 ***
as.factor(Leader)         1.714  3  0.6338159
ns(log(Hooks), df = 10)   25.084 10  0.0051889 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.4375  -0.6829  -0.5106  -0.3440   2.7194

Coefficients:
                      Estimate Std. Error z value Pr(>|z|)
(Intercept)          -1.621e+01  1.029e+03  -0.016  0.98743
as.factor(year)1993    2.802e-01  3.779e-01   0.741  0.45842
as.factor(year)1994    4.889e-01  3.824e-01   1.278  0.20112
as.factor(year)1995    6.506e-01  3.736e-01   1.741  0.08160 .
as.factor(year)1996   -9.387e-02  3.998e-01  -0.235  0.81439
as.factor(year)1997    3.102e-01  3.857e-01   0.804  0.42118
as.factor(year)1998    1.123e+00  3.940e-01   2.850  0.00438 **
as.factor(year)1999    4.551e-01  3.829e-01   1.189  0.23460
as.factor(year)2000    8.775e-01  3.831e-01   2.290  0.02200 *
as.factor(year)2001    7.012e-01  4.611e-01   1.521  0.12829
as.factor(year)2002    8.172e-01  4.605e-01   1.774  0.07598 .
as.factor(year)2003    3.722e-01  4.666e-01   0.798  0.42502
as.factor(year)2004    3.424e-01  4.796e-01   0.714  0.47533
as.factor(year)2005    6.940e-01  4.772e-01   1.454  0.14590
as.factor(year)2006    4.708e-01  4.817e-01   0.977  0.32839
as.factor(year)2007    7.421e-01  4.730e-01   1.569  0.11669
as.factor(year)2008    9.262e-01  4.779e-01   1.938  0.05262 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 4746.5  on 4869  degrees of freedom
```

Residual deviance: 4323.7 on 4796 degrees of freedom
AIC: 4471.7

Number of Fisher Scoring iterations: 14

RTV Data, Region 4, Mako, Log Normal Portion

Call:
glm(formula = posx ~ as.factor(tri) + as.factor(vessel) + as.factor(year) +
as.factor(cell) + ns(log(Hooks), df = 10), family = gaussian(link = "log"),
data = posdat, na.action = na.omit)

Analysis of Deviance Table (Type II tests)
Response: posx

	LR Chisq	Df	Pr(>Chisq)	
as.factor(tri)	1.467	2	0.4802	
as.factor(vessel)	14.578	9	0.1032	
as.factor(year)	21.915	16	0.1460	
as.factor(cell)	130.198	26	7.891e-16	***
ns(log(Hooks), df = 10)	8.594	9	0.4756	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Deviance Residuals:

Min	1Q	Median	3Q	Max
-1.2073	-0.2757	-0.1291	0.0225	4.3522

Coefficients: (1 not defined because of singularities)

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	0.147156	0.499356	0.295	0.76830
as.factor(year)1993	0.026121	0.185087	0.141	0.88780
as.factor(year)1994	0.031301	0.186807	0.168	0.86697
as.factor(year)1995	-0.072210	0.190683	-0.379	0.70501
as.factor(year)1996	-0.116871	0.201665	-0.580	0.56238
as.factor(year)1997	-0.026268	0.193738	-0.136	0.89218
as.factor(year)1998	0.061129	0.190802	0.320	0.74876
as.factor(year)1999	-0.046508	0.186483	-0.249	0.80311
as.factor(year)2000	0.086642	0.181226	0.478	0.63271
as.factor(year)2001	0.221250	0.184520	1.199	0.23083
as.factor(year)2002	0.099301	0.189236	0.525	0.59989
as.factor(year)2003	0.087493	0.191518	0.457	0.64790
as.factor(year)2004	0.010617	0.192088	0.055	0.95593
as.factor(year)2005	0.025091	0.187861	0.134	0.89378
as.factor(year)2006	0.101772	0.188735	0.539	0.58986
as.factor(year)2007	-0.008268	0.187599	-0.044	0.96486
as.factor(year)2008	0.004067	0.187317	0.022	0.98268

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 0.3250728)

Null deviance: 348.48 on 928 degrees of freedom
Residual deviance: 281.51 on 866 degrees of freedom
AIC: 1655.2

Number of Fisher Scoring iterations: 7

RTV Data, Region 4, Oceanic Whitetip, Binomial Portion

Call:
glm(formula = x != 0 ~ as.factor(cell) + as.factor(tri) + as.factor(vessel) +

```
   as.factor(year) + as.factor(Leader) + ns(log(Hooks), df = 10),
   family = binomial, data = RTVNo, na.action = na.omit)

Analysis of Deviance Table (Type II tests)
Response: x != 0
                  LR Chisq Df Pr(>Chisq)
as.factor(cell)        134.125 33  3.820e-14 ***
as.factor(tri)          29.382  2  4.166e-07 ***
as.factor(vessel)       48.827  9  1.788e-07 ***
as.factor(year)        164.512 16  < 2.2e-16 ***
as.factor(Leader)        9.440  3    0.02397 *
ns(log(Hooks), df = 10)   57.061 10  1.298e-08 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.9582  -0.8143  -0.4612   0.9721   2.8275

Coefficients:
                     Estimate Std. Error z value Pr(>|z|)
(Intercept)          10.64215  378.59903   0.028 0.977575
as.factor(year)1993    0.10968    0.19881   0.552 0.581156
as.factor(year)1994   -0.57402    0.20754  -2.766 0.005678 **
as.factor(year)1995    0.22062    0.19859   1.111 0.266598
as.factor(year)1996    0.05151    0.20938   0.246 0.805664
as.factor(year)1997    0.74516    0.21057   3.539 0.000402 ***
as.factor(year)1998   -0.29223    0.24190  -1.208 0.227030
as.factor(year)1999    0.07262    0.21684   0.335 0.737684
as.factor(year)2000   -0.49084    0.23391  -2.098 0.035874 *
as.factor(year)2001   -0.65483    0.30814  -2.125 0.033575 *
as.factor(year)2002   -1.17966    0.32559  -3.623 0.000291 ***
as.factor(year)2003   -1.26596    0.31197  -4.058 4.95e-05 ***
as.factor(year)2004   -1.48060    0.33669  -4.398 1.09e-05 ***
as.factor(year)2005   -1.96792    0.36810  -5.346 8.99e-08 ***
as.factor(year)2006   -2.58522    0.40397  -6.399 1.56e-10 ***
as.factor(year)2007   -2.45274    0.37896  -6.472 9.66e-11 ***
as.factor(year)2008   -1.74205    0.35871  -4.856 1.19e-06 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 6049.6  on 4869  degrees of freedom
Residual deviance: 4978.6  on 4796  degrees of freedom
AIC: 5126.6

Number of Fisher Scoring iterations: 12
```

RTV Data, Region 4, Oceanic Whitetip, Log Normal Portion

```
Call:
glm(formula = posx ~ as.factor(tri) + as.factor(vessel) + as.factor(year) +
   as.factor(cell) + ns(log(Hooks), df = 10), family = gaussian(link = "log"),
   data = posdat, na.action = na.omit)

Analysis of Deviance Table (Type II tests)
Response: posx
                  LR Chisq Df Pr(>Chisq)
as.factor(tri)          28.946  2  5.181e-07 ***
as.factor(vessel)       30.038  9  0.0004323 ***
as.factor(year)         60.364 16  4.544e-07 ***
```

```
as.factor(cell)         164.199 31  < 2.2e-16 ***
ns(log(Hooks), df = 10)   26.126 10  0.0035749 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-5.1076  -0.6091  -0.1752   0.3670  28.9741

Coefficients:
                    Estimate Std. Error t value Pr(>|t|)
(Intercept)          1.21004    0.94706   1.278 0.201569
as.factor(year)1993     -0.20386    0.08550  -2.384 0.017240 *
as.factor(year)1994     -0.36753    0.10515  -3.495 0.000488 ***
as.factor(year)1995     -0.49180    0.09462  -5.198 2.30e-07 ***
as.factor(year)1996     -0.24109    0.09052  -2.663 0.007824 **
as.factor(year)1997     -0.28350    0.09235  -3.070 0.002182 **
as.factor(year)1998     -0.26511    0.11790  -2.249 0.024684 *
as.factor(year)1999     -0.42172    0.11116  -3.794 0.000155 ***
as.factor(year)2000     -0.36762    0.10861  -3.385 0.000731 ***
as.factor(year)2001     -0.63254    0.14862  -4.256 2.21e-05 ***
as.factor(year)2002     -0.71264    0.19968  -3.569 0.000370 ***
as.factor(year)2003     -0.47047    0.19738  -2.384 0.017272 *
as.factor(year)2004     -0.58771    0.19539  -3.008 0.002676 **
as.factor(year)2005     -0.67246    0.30251  -2.223 0.026374 *
as.factor(year)2006     -0.71537    0.39740  -1.800 0.072051 .
as.factor(year)2007     -0.79943    0.29166  -2.741 0.006201 **
as.factor(year)2008     -1.19580    0.31097  -3.845 0.000126 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 1.998765)

    Null deviance: 3705.3  on 1521  degrees of freedom
Residual deviance: 2904.1  on 1453  degrees of freedom
AIC: 5442.6

Number of Fisher Scoring iterations: 10
```

RTV Data, Region 4, Silky, Binomial Portion

```
Call:
glm(formula = x != 0 ~ as.factor(cell) + as.factor(tri) + as.factor(vessel) +
    as.factor(year) + as.factor(Leader) + ns(log(Hooks), df = 10),
    family = binomial, data = RTVNo, na.action = na.omit)

Analysis of Deviance Table (Type II tests)
Response: x != 0
                        LR Chisq Df Pr(>Chisq)
as.factor(cell)          142.430 33  1.499e-15 ***
as.factor(tri)            44.035  2  2.741e-10 ***
as.factor(vessel)         59.507  9  1.668e-09 ***
as.factor(year)          189.598 16  < 2.2e-16 ***
as.factor(Leader)          3.088  3   0.378300
ns(log(Hooks), df = 10)   25.487 10   0.004496 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.9505  -0.5982  -0.3990  -0.2266   3.0401
```

```
Coefficients:
                    Estimate Std. Error z value Pr(>|z|)
(Intercept)          1.346e+01  1.029e+03   0.013 0.989563
as.factor(year)1993    1.538e+00  2.713e-01   5.670 1.43e-08 ***
as.factor(year)1994    1.044e-01  3.157e-01   0.331 0.740763
as.factor(year)1995    1.606e+00  2.697e-01   5.954 2.62e-09 ***
as.factor(year)1996    5.970e-01  3.078e-01   1.940 0.052425 .
as.factor(year)1997    1.317e+00  2.879e-01   4.574 4.78e-06 ***
as.factor(year)1998    4.499e-01  3.565e-01   1.262 0.206956
as.factor(year)1999    1.519e+00  2.952e-01   5.145 2.68e-07 ***
as.factor(year)2000    1.180e+00  3.231e-01   3.653 0.000260 ***
as.factor(year)2001    2.036e+00  3.906e-01   5.214 1.85e-07 ***
as.factor(year)2002    5.419e-01  4.441e-01   1.220 0.222443
as.factor(year)2003    1.417e+00  3.940e-01   3.597 0.000322 ***
as.factor(year)2004   -1.968e-01  4.983e-01  -0.395 0.692867
as.factor(year)2005    1.248e+00  4.288e-01   2.911 0.003605 **
as.factor(year)2006   -2.078e-01  5.120e-01  -0.406 0.684846
as.factor(year)2007    9.005e-02  4.725e-01   0.191 0.848859
as.factor(year)2008    9.182e-01  4.444e-01   2.066 0.038793 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 4167.2  on 4869  degrees of freedom
Residual deviance: 3517.2  on 4796  degrees of freedom
AIC: 3665.2

Number of Fisher Scoring iterations: 14
```

RTV Data, Region 4, Silky, Log Normal Portion

```
Call:
glm(formula = posx ~ as.factor(tri) + as.factor(vessel) + as.factor(year) +
    as.factor(cell) + ns(log(Hooks), df = 10), family = gaussian(link = "log"),
    data = posdat, na.action = na.omit)

Analysis of Deviance Table (Type II tests)
Response: posx
                  LR Chisq Df Pr(>Chisq)
as.factor(tri)           3.365  2   0.185896
as.factor(vessel)       11.275  9   0.257333
as.factor(year)         45.842 16   0.000103 ***
as.factor(cell)        173.549 29  < 2.2e-16 ***
ns(log(Hooks), df = 10)   27.666 10   0.002041 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Deviance Residuals:
    Min      1Q   Median      3Q      Max
-8.5000  -0.5843  -0.1907   0.2843   9.6428

Coefficients:
                    Estimate Std. Error t value Pr(>|t|)
(Intercept)          1.941047   0.590082   3.289 0.001056 **
as.factor(year)1993    0.561013   0.200980   2.791 0.005396 **
as.factor(year)1994    0.053555   0.267418   0.200 0.841333
as.factor(year)1995    0.163413   0.204293   0.800 0.424050
as.factor(year)1996    0.092960   0.263920   0.352 0.724776
as.factor(year)1997    0.088451   0.221664   0.399 0.689994
as.factor(year)1998    0.150677   0.283242   0.532 0.594919
as.factor(year)1999    0.444086   0.228808   1.941 0.052689 .
```

```
as.factor(year)2000       0.415636   0.232383   1.789 0.074129 .
as.factor(year)2001       0.107308   0.238159   0.451 0.652441
as.factor(year)2002       0.109384   0.312742   0.350 0.726629
as.factor(year)2003       0.005583   0.285822   0.020 0.984423
as.factor(year)2004       0.753861   0.269646   2.796 0.005325 **
as.factor(year)2005      -0.136242   0.309154  -0.441 0.659576
as.factor(year)2006      -0.444552   0.573027  -0.776 0.438140
as.factor(year)2007      -0.134918   0.410584  -0.329 0.742559
as.factor(year)2008      -0.224644   0.333795  -0.673 0.501176
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 1.788392)

    Null deviance: 1719.7  on 744  degrees of freedom
Residual deviance: 1212.5  on 678  degrees of freedom
AIC: 2613.1

Number of Fisher Scoring iterations: 9
```

RTV Data, Region 4, Thresher, Binomial Portion

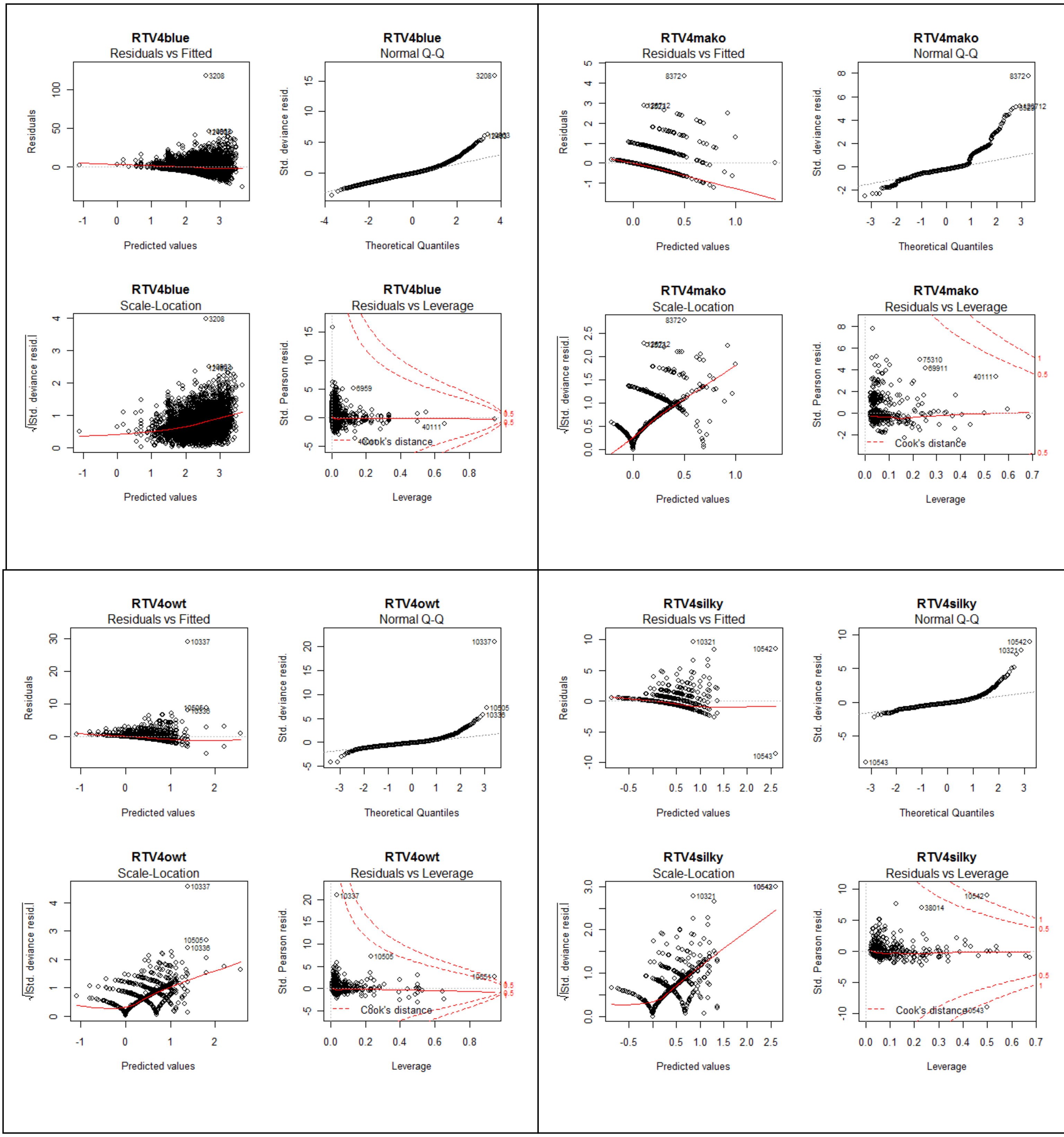
```
Call:
glm(formula = x != 0 ~ as.factor(cell) + as.factor(tri) + as.factor(vessel) +
    as.factor(year) + as.factor(Leader) + ns(log(Hooks), df = 10),
    family = binomial, data = RTVNo, na.action = na.omit)

Analysis of Deviance Table (Type II tests)

Response: x != 0
                        LR Chisq Df Pr(>Chisq)
as.factor(cell)          147.342 33  < 2.2e-16 ***
as.factor(tri)            34.790  2  2.788e-08 ***
as.factor(vessel)        119.790  9  < 2.2e-16 ***
as.factor(year)          116.827 16  < 2.2e-16 ***
as.factor(Leader)         36.660  3  5.430e-08 ***
ns(log(Hooks), df = 10)   38.325 10  3.332e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.2046  -1.1559   0.6675   0.9793   2.3485

Coefficients:
                    Estimate Std. Error z value Pr(>|z|)
(Intercept)         -0.58192    2.08274  -0.279 0.779936
as.factor(year)1993 -0.74741    0.21107  -3.541 0.000399 ***
as.factor(year)1994  0.19547    0.22276   0.877 0.380226
as.factor(year)1995 -0.32881    0.21095  -1.559 0.119066
as.factor(year)1996  0.69166    0.23088   2.996 0.002737 **
as.factor(year)1997  0.14349    0.22627   0.634 0.525972
as.factor(year)1998  0.09582    0.25025   0.383 0.701787
as.factor(year)1999  0.43200    0.23234   1.859 0.062976 .
as.factor(year)2000  0.27198    0.23288   1.168 0.242855
as.factor(year)2001  0.68769    0.30015   2.291 0.021955 *
as.factor(year)2002  0.88609    0.30447   2.910 0.003611 **
as.factor(year)2003  0.37412    0.29206   1.281 0.200197
as.factor(year)2004  0.73987    0.31439   2.353 0.018604 *
as.factor(year)2005  1.15150    0.32189   3.577 0.000347 ***
as.factor(year)2006  0.32557    0.31724   1.026 0.304764
as.factor(year)2007  0.61758    0.31095   1.986 0.047018 *
```

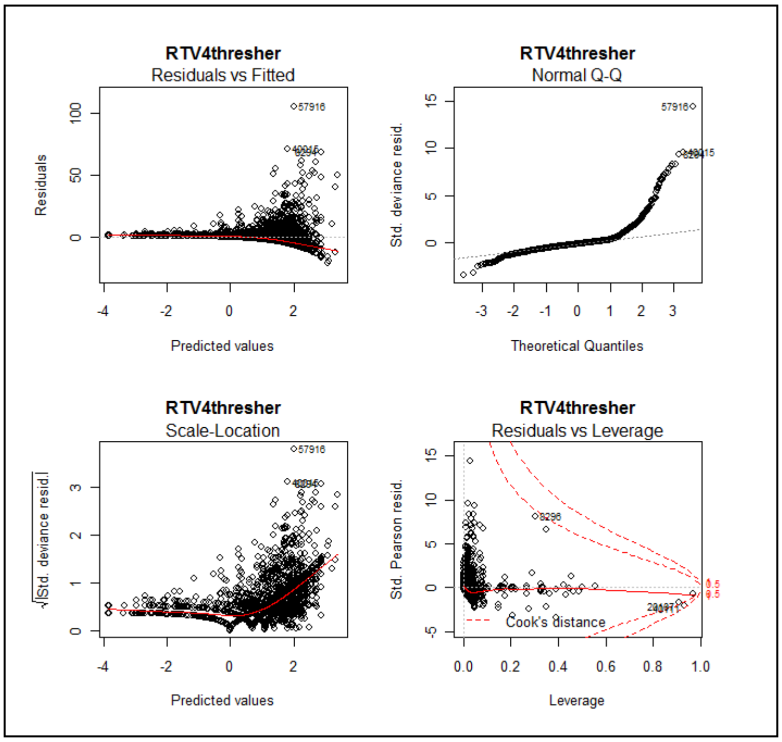
```
as.factor(year)2008        0.76624    0.32197   2.380 0.017321 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 6514.2  on 4869  degrees of freedom
Residual deviance: 5927.1  on 4796  degrees of freedom
AIC: 6075.1

Number of Fisher Scoring iterations: 13
```

RTV Data, Region 4, Thresher, Log Normal Portion

```
Call:
glm(formula = posx ~ as.factor(tri) + as.factor(vessel) + as.factor(year) +
    as.factor(cell) + ns(log(Hooks), df = 10), family = gaussian(link = "log"),
    data = posdat, na.action = na.omit)

Analysis of Deviance Table (Type II tests)
Response: posx
                        LR Chisq Df Pr(>Chisq)
as.factor(tri)            55.594  2  8.471e-13 ***
as.factor(vessel)        109.378  9  < 2.2e-16 ***
as.factor(year)          126.320 16  < 2.2e-16 ***
as.factor(cell)          201.800 30  < 2.2e-16 ***
ns(log(Hooks), df = 10)   19.352 10    0.03602 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-20.849   -2.924   -0.728    1.111  105.480

Coefficients:
                     Estimate Std. Error t value Pr(>|t|)
(Intercept)         -1.112e+00  7.658e+00  -0.145 0.884536
as.factor(year)1993  2.538e-01  3.475e-01   0.730 0.465200
as.factor(year)1994  7.023e-01  2.826e-01   2.485 0.013008 *
as.factor(year)1995  4.278e-01  3.132e-01   1.366 0.172122
as.factor(year)1996  1.227e+00  2.728e-01   4.498 7.12e-06 ***
as.factor(year)1997  1.197e+00  2.757e-01   4.341 1.47e-05 ***
as.factor(year)1998  8.607e-01  2.974e-01   2.894 0.003831 **
as.factor(year)1999  1.389e+00  2.735e-01   5.080 4.01e-07 ***
as.factor(year)2000  1.277e+00  2.801e-01   4.558 5.38e-06 ***
as.factor(year)2001  1.050e+00  2.881e-01   3.645 0.000272 ***
as.factor(year)2002  1.484e+00  2.820e-01   5.262 1.53e-07 ***
as.factor(year)2003  8.699e-01  3.485e-01   2.496 0.012617 *
as.factor(year)2004  1.099e+00  2.945e-01   3.731 0.000195 ***
as.factor(year)2005  1.054e+00  2.941e-01   3.584 0.000344 ***
as.factor(year)2006  1.115e+00  3.040e-01   3.667 0.000250 ***
as.factor(year)2007  1.476e+00  2.894e-01   5.101 3.60e-07 ***
as.factor(year)2008  1.463e+00  2.945e-01   4.970 7.09e-07 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 55.64316)
    Null deviance: 187387  on 2969  degrees of freedom
Residual deviance: 161467  on 2902  degrees of freedom
AIC: 20434
Number of Fisher Scoring iterations: 15
```

PLOT DIAGNOSTICS FOR RTV REGION 4 MODELS





RTV4thresher
Residuals vs Fitted
Residuals
Predicted values
RTV4thresher
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
RTV4thresher
Scale-Location
√|Std. deviance resid.|
Predicted values
RTV4thresher
Residuals vs Leverage
Std. Pearson resid.
Cook's distance
Leverage
57916

LLL Data, Region 1, Blue, Binomial Portion

```
Call:
glm(formula = x != 0 ~ as.factor(BranchLine) + as.factor(tri) +
   as.factor(cell) + as.factor(HPB) + as.factor(CallSign) +
   as.factor(Year) + ns(log(Hooks), df = 10), family = binomial,
   data = subS, na.action = na.omit)

Analysis of Deviance Table (Type II tests)
Response: x != 0
                  LR Chisq Df Pr(>Chisq)
as.factor(BranchLine)      0.89  2     0.641
as.factor(tri)           85.90  2  < 2.2e-16 ***
as.factor(cell)         431.65 44  < 2.2e-16 ***
as.factor(HPB)           76.34 18  3.719e-09 ***
as.factor(CallSign)      761.13 87  < 2.2e-16 ***
as.factor(Year)         317.95 15  < 2.2e-16 ***
ns(log(Hooks), df = 10)   130.08 10  < 2.2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Deviance Residuals:
   Min      1Q   Median      3Q      Max
-4.1249   0.0659   0.1112   0.1850   1.2685

Coefficients:
                     Estimate Std. Error z value Pr(>|z|)
(Intercept)             37.19859 6632.70237   0.006 0.995525
as.factor(Year)1994        -0.01575    0.10652  -0.148 0.882465
as.factor(Year)1995         0.20343    0.11596   1.754 0.079382 .
as.factor(Year)1996         0.29895    0.12109   2.469 0.013556 *
as.factor(Year)1997         0.59920    0.13336   4.493 7.02e-06 ***
as.factor(Year)1998         0.81520    0.14936   5.458 4.82e-08 ***
as.factor(Year)1999         1.62704    0.18713   8.695  < 2e-16 ***
as.factor(Year)2000         1.44438    0.17771   8.128 4.37e-16 ***
as.factor(Year)2001         1.00919    0.15268   6.610 3.85e-11 ***
as.factor(Year)2002         1.67817    0.19612   8.557  < 2e-16 ***
as.factor(Year)2003         1.79028    0.23182   7.723 1.14e-14 ***
as.factor(Year)2004         0.32615    0.17381   1.876 0.060591 .
as.factor(Year)2005         1.54312    0.26068   5.920 3.23e-09 ***
as.factor(Year)2006         1.74688    0.28532   6.123 9.21e-10 ***
as.factor(Year)2007         2.08060    0.29094   7.151 8.60e-13 ***
as.factor(Year)2008         1.07136    0.23301   4.598 4.27e-06 ***
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

   Null deviance: 13945  on 84203  degrees of freedom
Residual deviance: 11680  on 84025  degrees of freedom
AIC: 12038

Number of Fisher Scoring iterations: 17
```

LLL Data, Region 1, Blue, Log Normal Portion

```
Call:
glm(formula = posx ~ as.factor(BranchLine) + as.factor(tri) +
   as.factor(cell) + as.factor(CallSign) + as.factor(Year) +
   ns(log(Hooks), df = 10), family = gaussian(link = "log"),
   data = posdat, na.action = na.omit)

Analysis of Deviance Table (Type II tests)
```

```
Response: posx
                   LR Chisq Df Pr(>Chisq)
as.factor(BranchLine)      25.2  2  3.297e-06 ***
as.factor(tri)           9676.4  2  < 2.2e-16 ***
as.factor(cell)         15938.1 42  < 2.2e-16 ***
as.factor(CallSign)      2652.9 87  < 2.2e-16 ***
as.factor(Year)          3599.1 15  < 2.2e-16 ***
ns(log(Hooks), df = 10)   553.3 10  < 2.2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-689.10   -39.16    -9.59    21.03  1323.49

Coefficients:
                     Estimate Std. Error t value Pr(>|t|)
(Intercept)          3.390171   1.780535   1.904 0.056911 .
as.factor(Year)1994 -0.106672   0.037792  -2.823 0.004765 **
as.factor(Year)1995 -0.069889   0.040183  -1.739 0.081992 .
as.factor(Year)1996  0.081078   0.035503   2.284 0.022392 *
as.factor(Year)1997  0.524291   0.030917  16.958  < 2e-16 ***
as.factor(Year)1998  0.468586   0.031534  14.860  < 2e-16 ***
as.factor(Year)1999  0.570844   0.030395  18.781  < 2e-16 ***
as.factor(Year)2000  0.340067   0.030475  11.159  < 2e-16 ***
as.factor(Year)2001  0.526276   0.029554  17.807  < 2e-16 ***
as.factor(Year)2002  0.644707   0.029564  21.807  < 2e-16 ***
as.factor(Year)2003  0.575572   0.029976  19.201  < 2e-16 ***
as.factor(Year)2004  0.601414   0.030120  19.967  < 2e-16 ***
as.factor(Year)2005  0.878450   0.029112  30.175  < 2e-16 ***
as.factor(Year)2006  0.580692   0.029947  19.391  < 2e-16 ***
as.factor(Year)2007  0.404320   0.030947  13.065  < 2e-16 ***
as.factor(Year)2008  0.279742   0.031261   8.949  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 9318.267)

    Null deviance: 1131726258  on 82840  degrees of freedom
Residual deviance:  770434128  on 82682  degrees of freedom
AIC: 992396

Number of Fisher Scoring iterations: 9
```

LLL Data, Region 1, Mako, Binomial Portion

```
Call:
glm(formula = x != 0 ~ as.factor(BranchLine) + as.factor(tri) +
    as.factor(cell) + as.factor(HPB) + as.factor(CallSign) +
    as.factor(Year) + ns(log(Hooks), df = 10), family = binomial,
    data = subS, na.action = na.omit)

Analysis of Deviance Table (Type II tests)

Response: x != 0
                   LR Chisq Df Pr(>Chisq)
as.factor(BranchLine)      59.0  2  1.518e-13 ***
as.factor(tri)            119.7  2  < 2.2e-16 ***
as.factor(cell)          1224.4 44  < 2.2e-16 ***
as.factor(HPB)            869.4 18  < 2.2e-16 ***
as.factor(CallSign)     17190.1 87  < 2.2e-16 ***
as.factor(Year)          3595.8 15  < 2.2e-16 ***
```

```
ns(log(Hooks), df = 10)    190.4 10  < 2.2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.7482  -0.8247  -0.2039   0.8917   2.8840

Coefficients:
                     Estimate Std. Error z value Pr(>|z|)
(Intercept)         -1.653e+01  3.980e+03  -0.004 0.996687
as.factor(Year)1994  -1.140e-02  4.913e-02  -0.232 0.816575
as.factor(Year)1995  -8.124e-04  5.031e-02  -0.016 0.987115
as.factor(Year)1996   4.689e-01  4.955e-02   9.464  < 2e-16 ***
as.factor(Year)1997   4.554e-01  5.173e-02   8.804  < 2e-16 ***
as.factor(Year)1998   7.432e-01  5.253e-02  14.147  < 2e-16 ***
as.factor(Year)1999   1.145e+00  5.271e-02  21.716  < 2e-16 ***
as.factor(Year)2000   1.223e+00  5.185e-02  23.597  < 2e-16 ***
as.factor(Year)2001   1.137e+00  5.121e-02  22.198  < 2e-16 ***
as.factor(Year)2002   1.166e+00  5.262e-02  22.154  < 2e-16 ***
as.factor(Year)2003   1.140e+00  5.582e-02  20.416  < 2e-16 ***
as.factor(Year)2004   1.048e+00  5.820e-02  18.004  < 2e-16 ***
as.factor(Year)2005   1.594e+00  5.839e-02  27.291  < 2e-16 ***
as.factor(Year)2006   1.865e+00  5.900e-02  31.610  < 2e-16 ***
as.factor(Year)2007   1.964e+00  5.597e-02  35.088  < 2e-16 ***
as.factor(Year)2008   2.242e+00  6.216e-02  36.067  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 113652  on 84203  degrees of freedom
Residual deviance:  83830  on 84025  degrees of freedom
AIC: 84188

Number of Fisher Scoring iterations: 16
```

LLL Data, Region 1, Mako, Log Normal Portion

```
Call:
glm(formula = posx ~ as.factor(BranchLine) + as.factor(tri) +
    as.factor(cell) + as.factor(CallSign) + as.factor(Year) +
    ns(log(Hooks), df = 10), family = gaussian(link = "log"),
    data = posdat, na.action = na.omit)

Analysis of Deviance Table (Type II tests)
Response: posx
                      LR Chisq Df Pr(>Chisq)
as.factor(BranchLine)     0.20  2     0.9061
as.factor(tri)           19.46  2  5.951e-05 ***
as.factor(cell)        2790.96 41  < 2.2e-16 ***
as.factor(CallSign)     729.99 64  < 2.2e-16 ***
as.factor(Year)        1045.28 15  < 2.2e-16 ***
ns(log(Hooks), df = 10)  126.47 10  < 2.2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-14.390   -1.738   -0.636    0.797  240.748

Coefficients:
                     Estimate Std. Error t value Pr(>|t|)
```

```
(Intercept)             0.049679   0.836503   0.059 0.952643
as.factor(Year)1994      -0.193453   0.069401  -2.787 0.005315 **
as.factor(Year)1995      -0.114647   0.068685  -1.669 0.095093 .
as.factor(Year)1996      -0.066687   0.062847  -1.061 0.288652
as.factor(Year)1997       0.197700   0.057665   3.428 0.000608 ***
as.factor(Year)1998       0.095510   0.059223   1.613 0.106816
as.factor(Year)1999       0.177297   0.056931   3.114 0.001846 **
as.factor(Year)2000       0.253367   0.054295   4.667 3.07e-06 ***
as.factor(Year)2001       0.115978   0.055650   2.084 0.037162 *
as.factor(Year)2002       0.204028   0.056471   3.613 0.000303 ***
as.factor(Year)2003       0.529586   0.054993   9.630  < 2e-16 ***
as.factor(Year)2004       0.513726   0.056084   9.160  < 2e-16 ***
as.factor(Year)2005       0.687277   0.053313  12.891  < 2e-16 ***
as.factor(Year)2006       0.689052   0.053202  12.952  < 2e-16 ***
as.factor(Year)2007       0.597051   0.052803  11.307  < 2e-16 ***
as.factor(Year)2008       0.322066   0.055384   5.815 6.11e-09 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 17.75829)

    Null deviance: 694170  on 34074  degrees of freedom
Residual deviance: 602686  on 33940  degrees of freedom
AIC: 194864

Number of Fisher Scoring iterations: 10
```

LLL Data, Region 1, Oceanic Whitetip, Binomial Portion

```
Call:
glm(formula = x != 0 ~ as.factor(BranchLine) + as.factor(tri) +
    as.factor(cell) + as.factor(HPB) + as.factor(CallSign) +
    as.factor(Year) + ns(log(Hooks), df = 10), family = binomial,
    data = subS, na.action = na.omit)

Analysis of Deviance Table (Type II tests)

Response: x != 0
                  LR Chisq Df Pr(>Chisq)
as.factor(BranchLine)      1.66  1    0.19800
as.factor(tri)           78.03  2  < 2.2e-16 ***
as.factor(cell)         342.41 40  < 2.2e-16 ***
as.factor(HPB)           11.49 12    0.48770
as.factor(CallSign)     192.41 48  < 2.2e-16 ***
as.factor(Year)          40.94  8  2.143e-06 ***
ns(log(Hooks), df = 10)   19.29 10    0.03677 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.6651  -0.0937  -0.0494  -0.0113   4.2773

Coefficients:
                      Estimate Std. Error z value Pr(>|z|)
(Intercept)            -1.647e+01  5.319e+03  -0.003 0.997529
as.factor(Year)2001       4.055e-02  2.218e-01   0.183 0.854903
as.factor(Year)2002       2.161e-01  2.246e-01   0.962 0.335965
as.factor(Year)2003      -6.310e-01  2.996e-01  -2.106 0.035196 *
as.factor(Year)2004      -1.903e-01  2.961e-01  -0.643 0.520528
as.factor(Year)2005      -1.425e+00  4.024e-01  -3.541 0.000398 ***
as.factor(Year)2006      -6.394e-01  3.507e-01  -1.824 0.068220 .
```

```
as.factor(Year)2007      -1.126e+00  3.503e-01  -3.215 0.001307 **
as.factor(Year)2008      -9.589e-01  4.058e-01  -2.363 0.018124 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 3194.8  on 39080  degrees of freedom
Residual deviance: 2332.9  on 38959  degrees of freedom
AIC: 2576.9

Number of Fisher Scoring iterations: 20
```

LLL Data, Region 1, Oceanic Whitetip, Log Normal Portion

```
Call:
glm(formula = posx ~ as.factor(BranchLine) + as.factor(tri) +
    as.factor(cell) + as.factor(CallSign) + as.factor(Year) +
    ns(log(Hooks), df = 10), family = gaussian(link = "log"),
    data = posdat, na.action = na.omit)

Analysis of Deviance Table (Type II tests)

Response: posx
                        LR Chisq Df Pr(>Chisq)
as.factor(BranchLine)      0.484  1  0.4864192
as.factor(tri)             3.279  2  0.1940600
as.factor(cell)           24.836 31  0.7749878
as.factor(CallSign)       48.914 28  0.0085259 **
as.factor(Year)           26.908  8  0.0007332 ***
ns(log(Hooks), df = 10)   31.911 10  0.0004143 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-4.2786  -0.4599   0.0000   0.5089  14.7214

Coefficients:
                     Estimate Std. Error t value Pr(>|t|)
(Intercept)            3.8345     3.2891   1.166   0.2452
as.factor(Year)2001   -0.5794     0.3572  -1.622   0.1065
as.factor(Year)2002    0.1651     0.3387   0.487   0.6266
as.factor(Year)2003   -0.7797     0.4441  -1.756   0.0808 .
as.factor(Year)2004   -0.6625     0.4479  -1.479   0.1408
as.factor(Year)2005   -0.8965     0.9640  -0.930   0.3536
as.factor(Year)2006   -1.4312     0.8717  -1.642   0.1023
as.factor(Year)2007    0.3097     0.7330   0.422   0.6732
as.factor(Year)2008   -1.1788     0.7534  -1.565   0.1194
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 3.023690)

    Null deviance: 983.4  on 266  degrees of freedom
Residual deviance: 559.3  on 185  degrees of freedom
AIC: 1121.1

Number of Fisher Scoring iterations: 25
```

LLL Data, Region 1, Thresher, Binomial Portion

```
Call:
glm(formula = x != 0 ~ as.factor(BranchLine) + as.factor(tri) +
    as.factor(cell) + as.factor(HPB) + as.factor(CallSign) +
    as.factor(Year) + ns(log(Hooks), df = 10), family = binomial,
    data = subS, na.action = na.omit)

Analysis of Deviance Table (Type II tests)

Response: x != 0
                      LR Chisq Df Pr(>Chisq)
as.factor(BranchLine)      2.91  1      0.088 .
as.factor(tri)            47.03  2  6.137e-11 ***
as.factor(cell)         1132.23 40  < 2.2e-16 ***
as.factor(HPB)            45.10 12  9.908e-06 ***
as.factor(CallSign)     1514.89 48  < 2.2e-16 ***
as.factor(Year)          294.82  8  < 2.2e-16 ***
ns(log(Hooks), df = 10)   75.35 10  4.072e-12 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

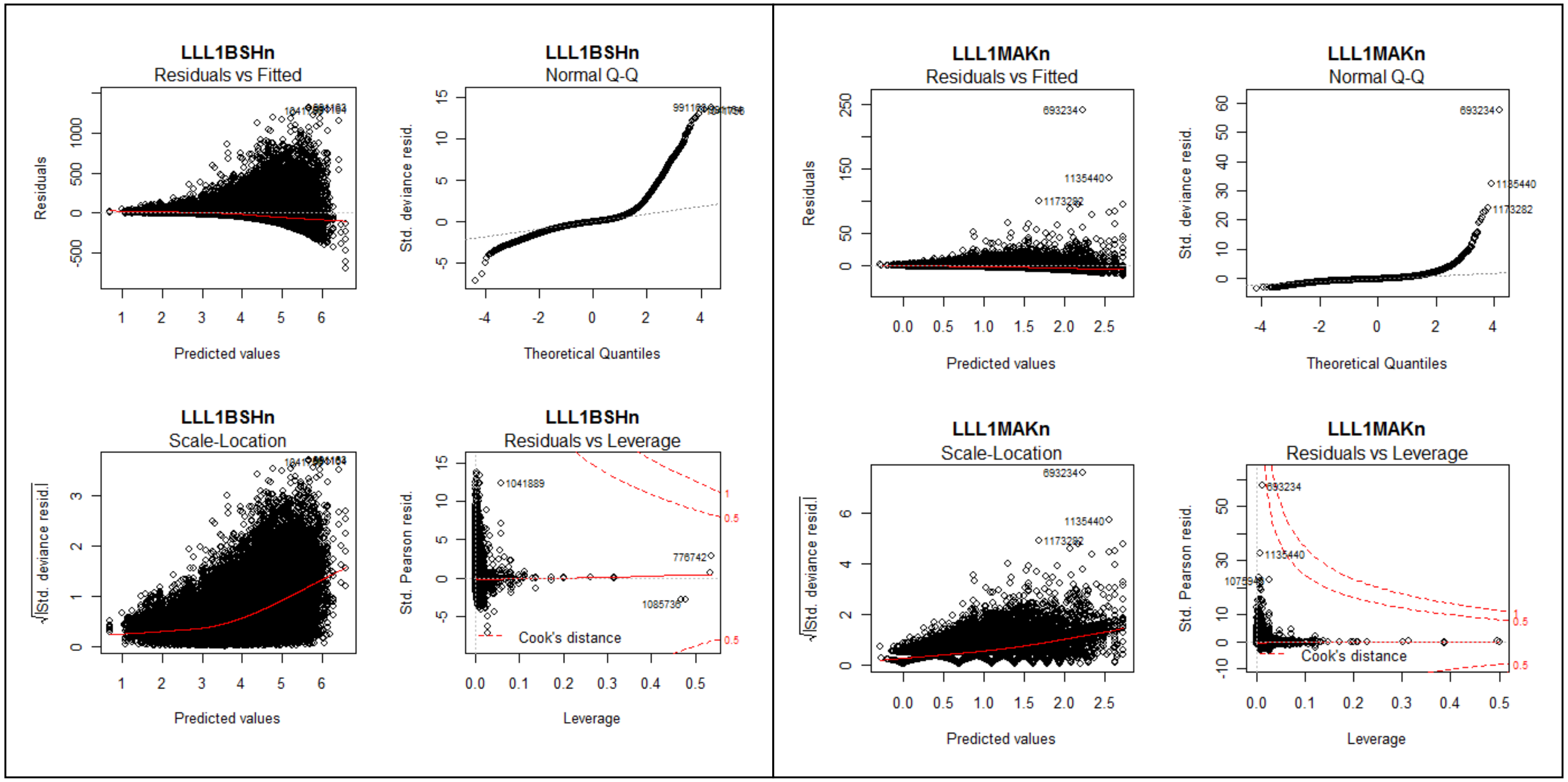

```
Analysis of Deviance Table (Type II tests)

Response: x != 0
                      LR Chisq Df Pr(>Chisq)
as.factor(BranchLine)      2.91  1      0.088 .
as.factor(tri)            47.03  2  6.137e-11 ***
as.factor(cell)         1132.23 40  < 2.2e-16 ***
as.factor(HPB)            45.10 12  9.908e-06 ***
as.factor(CallSign)     1514.89 48  < 2.2e-16 ***
as.factor(Year)          294.82  8  < 2.2e-16 ***
ns(log(Hooks), df = 10)   75.35 10  4.072e-12 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

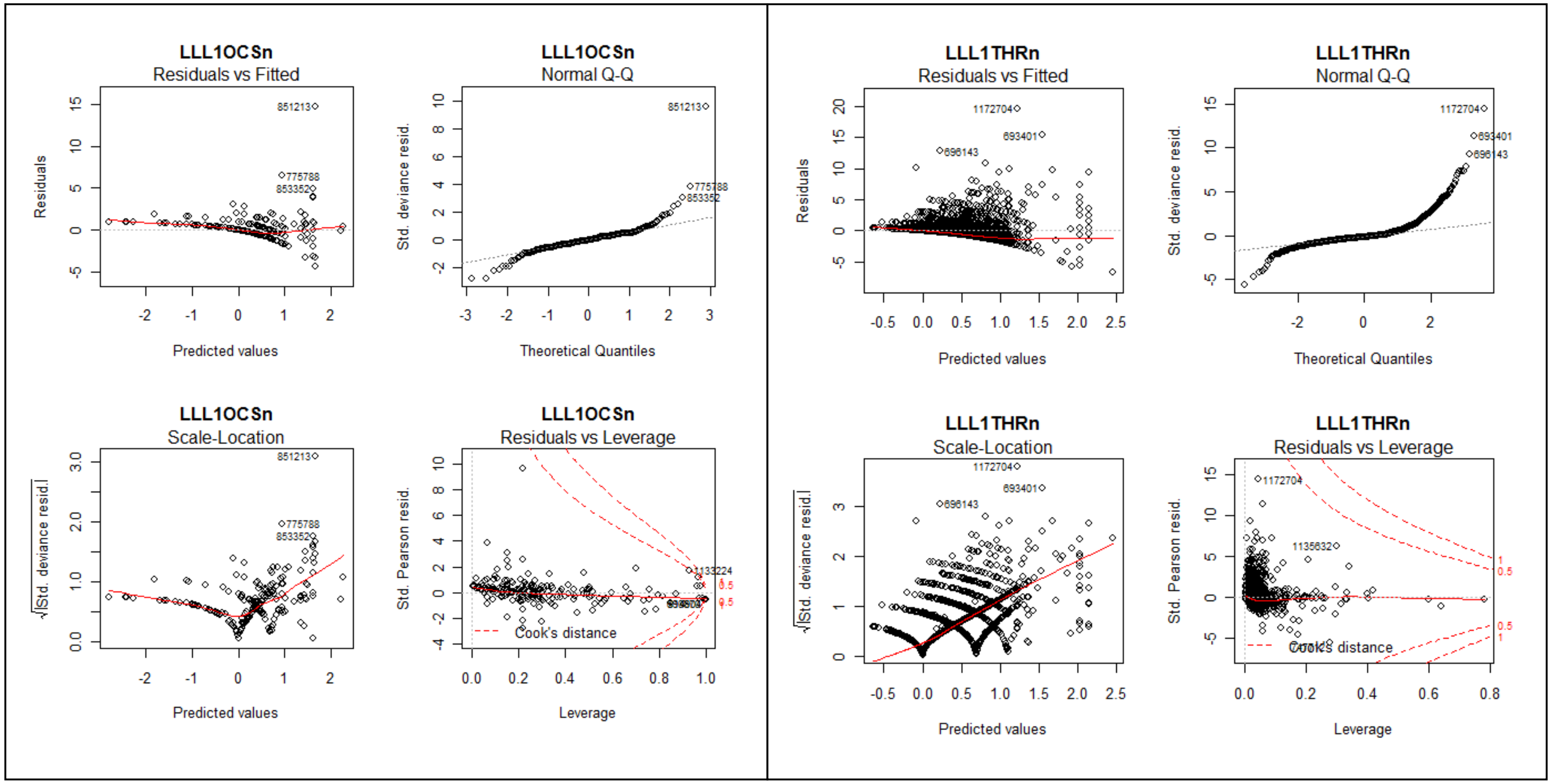

```
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.6651  -0.4535  -0.2675  -0.0931   3.9252

Coefficients:
                      Estimate Std. Error z value Pr(>|z|)
(Intercept)          -18.29921 1280.70645  -0.014 0.988600
as.factor(Year)2001   -0.35879    0.06634  -5.409 6.35e-08 ***
as.factor(Year)2002   -0.36408    0.07212  -5.048 4.46e-07 ***
as.factor(Year)2003   -0.67355    0.08374  -8.043 8.76e-16 ***
as.factor(Year)2004   -1.18013    0.09980 -11.825  < 2e-16 ***
as.factor(Year)2005   -1.42910    0.11201 -12.759  < 2e-16 ***
as.factor(Year)2006   -1.17516    0.10547 -11.142  < 2e-16 ***
as.factor(Year)2007   -0.72353    0.08423  -8.590  < 2e-16 ***
as.factor(Year)2008   -0.73051    0.09510  -7.682 1.57e-14 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 21928  on 39080  degrees of freedom
Residual deviance: 17973  on 38959  degrees of freedom
AIC: 18217

Number of Fisher Scoring iterations: 17
```

LLL Data, Region 1, Thresher, Log Normal Portion

```
Call:
glm(formula = posx ~ as.factor(BranchLine) + as.factor(tri) +
    as.factor(cell) + as.factor(CallSign) + as.factor(Year) +
    ns(log(Hooks), df = 10), family = gaussian(link = "log"),
    data = posdat, na.action = na.omit)

Analysis of Deviance Table (Type II tests)

Response: posx
                      LR Chisq Df Pr(>Chisq)
as.factor(BranchLine)    16.68  1  4.436e-05 ***
as.factor(tri)           83.44  2  < 2.2e-16 ***
as.factor(cell)         220.90 36  < 2.2e-16 ***
as.factor(CallSign)     543.60 38  < 2.2e-16 ***
as.factor(Year)          31.32  8  0.0001234 ***
ns(log(Hooks), df = 10)  18.29 10  0.0502838 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-6.6264  -0.5717  -0.2108   0.2184  19.5935

Coefficients:
                      Estimate Std. Error t value Pr(>|t|)
(Intercept)          1.4432014  0.4823250   2.992 0.002792 **
as.factor(Year)2001  0.1182020  0.0465125   2.541 0.011093 *
as.factor(Year)2002 -0.0716183  0.0587879  -1.218 0.223223
as.factor(Year)2003  0.0798006  0.0645367   1.237 0.216362
as.factor(Year)2004  0.0928310  0.0848630   1.094 0.274088
as.factor(Year)2005 -0.3123979  0.1225141  -2.550 0.010824 *
as.factor(Year)2006  0.0854455  0.0768595   1.112 0.266350
as.factor(Year)2007 -0.0707409  0.0652073  -1.085 0.278068
as.factor(Year)2008 -0.0844229  0.0740254  -1.140 0.254184
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 1.931357)

    Null deviance: 8120.3  on 3154  degrees of freedom
Residual deviance: 5907.7  on 3059  degrees of freedom
AIC: 11127

Number of Fisher Scoring iterations: 9
```

PLOT DIAGNOSTICS FOR LLL REGION 1 MODELS





LLL1OCSn
Residuals vs Fitted
Residuals
Predicted values
851213
775788
853352
LLL1OCSn
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
LLL1OCSn
Scale-Location
√|Std. deviance resid.|
Predicted values
LLL1OCSn
Residuals vs Leverage
Std. Pearson resid.
Leverage
Cook's distance
LLL1THRn
Residuals vs Fitted
Residuals
Predicted values
1172704
693401
696143
LLL1THRn
Normal Q-Q
Std. deviance resid.
Theoretical Quantiles
LLL1THRn
Scale-Location
√|Std. deviance resid.|
Predicted values
LLL1THRn
Residuals vs Leverage
Std. Pearson resid.
Leverage
1135632
Cook's distance