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Preliminary time series for north Pacific blue and shortfin mako sharks from the U.S. West Coast drift gillnet fishery[1]

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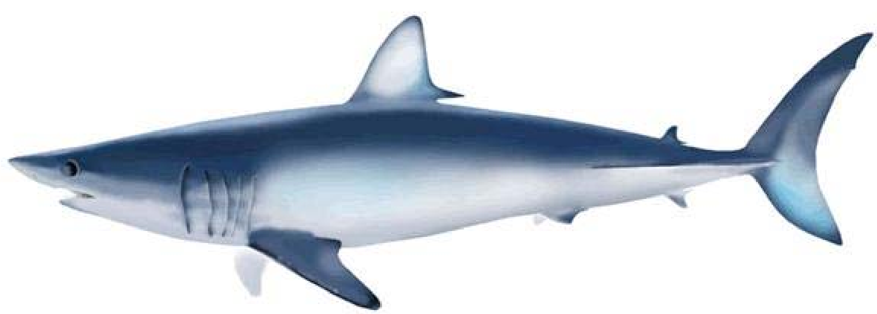

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ABSTRACT

Blue and mako sharks are not the primary target species of the U.S. West Coast drift gillnet fishery but are caught in non-negligible numbers. In this paper, we describe the data sources and methods used to develop preliminary time series (catch including retained catch and dead discards, size composition, and standardized abundance indices) spanning 1971-2010 for upcoming stock assessments. Commercial landings and logbook records of mako sharks are representative of the fishery impact on the stock but not for blue sharks, due to the large difference in economic value. Catch time series for mako sharks were therefore developed primarily from landing records but blue shark catch estimates were developed from several data sources using different algorithms for different periods. Catch estimates for blue sharks were reliable for 1990-2010 but earlier estimates were highly uncertain. Catch estimates for mako sharks were relatively reliable for the entire time series (1971-2010). Length compositions for both species were derived from observer (1990-2010) and market survey (1981-1990) data. Since blue shark is typically not landed by this fishery, market survey length composition data for blue shark were very sparse and not used. Standardized abundance indices for both species were developed from observer data (1990-2010). However, the small spatial scale of this fishery relative to the ranges of both stocks suggest that these two abundance indices are not likely to be representative of the population trends of the entire stocks. We therefore recommend that these abundance indices should not be used in the upcoming assessments but catch and length composition time series should be used for the assessments. It is also recommended that the units of catch for this fishery be thousands of fish and sensitivity runs be performed to account for the uncertainty in catch.

INTRODUCTION

Blue and mako sharks are not the primary target species for the U.S. West Coast drift gillnet fishery but this fishery does catch non-negligible numbers of these species. The objective of this document is to describe the data sources and methods used to develop preliminary time series from the U.S. West Coast pelagic drift gillnet fishery that are critical for the stock assessment of north Pacific blue and mako sharks conducted by the shark working group (SHARKWG) of the International Scientific Committee on Tuna and Tuna-like Species (ISC) in 2012 and 2013, respectively. These time series include retained catch as well as dead discards, size compositions, and standardized abundance indices. In addition, we developed these time series for the period 1971-2010 because the SHARKWG suggested an assessment period of 1971-2010 for the blue shark assessment.

The U.S. West Coast drift gillnet fishery primarily targets swordfish and thresher shark within the U.S. EEZ. Blue shark is considered a low value species and is generally discarded (both dead and alive). In contrast, mako shark is considered to be of higher economic value and is retained by the fishery. Since these shark species are not the targets of this fishery, the representativeness of commercial landings and logbook records for these species is mixed, depending on the species. Preliminary analysis comparing vessel logbooks with observer records indicated that commercial landings and logbook records of blue sharks were not representative of the fishery impact (Table 1). In contrast, commercial landings and logbook records of mako shark appeared to be representative for the drift gillnet fishery (Table 1).

Due to the differing reliability of data sources for these two species, catch time series for blue and mako sharks were developed from different data sources using different algorithms (see Materials and Methods for details). For both species, an annual abundance index and a length composition time series were developed.

MATERIALS AND METHODS

Data Sources

Five main sources of data are used to develop the time series for blue and mako sharks by the pelagic drift gillnet fishery: 1) commercial landings in the PacFIN database (1981 - 2010); 2) commercial landings in the California Department of Fish and Game (CDFG) database (1971-1980); 3) vessel logbooks (1981 - 2010); 4) onboard observers (1990 - 2010); and 5) length samples of landed fish ('market survey' data) from the CDFG database (1981-1990).

Commercial landings of blue and mako sharks on the U.S. West Coast are collected by individual states through a fish ticket system and compiled in the PacFIN database from 1981. Prior to 1981, the California commercial landings database maintained by the CDFG is used (Pearson et al. 2008). For the upcoming assessments, seasonal landings data for these two shark species and the target species (swordfish and common thresher shark) will be available from 1971. The gillnet fishery has generally landed negligible amounts of blue shark (generally 1 t or less in a single season) and small amounts of mako shark (up to 181 t in a single season). Logbooks, which include the time, location, catch by species, and net length (as well as other information) of each set, have been submitted by individual operators in the fishery since 1981. Onboard observers have been mandatory for this fishery since 1990 and observer coverage for this fishery ranges from 4.4% in 1990 to 22.9% in 2000. Observer data provide accurate records of time, location, catch by species, net length, and length of fish caught (as well as other information) of each observed set. The observer also records the status of the fish (kept, discarded alive, discarded dead, and discarded unknown). If a discarded fish was of unknown status, we assumed that the fish was a dead discard because this assumption is more conservative. In addition, it is mandatory for vessels to call in each trip before the start of the trip so that an observer may be assigned to the trip. Therefore the Southwest Regional Office of the National Marine Fisheries Service is able to provide estimates of the annual number of sets for the fishery from 1990.

Both observer and logbook databases include information from the drift gillnet and set net fisheries, so the data were filtered to extract data for only the drift gillnet fishery. For observer data, sets with a ≥14 inch mesh size and gear defined as 'D' (drift net) was assigned to the drift gillnet fishery. For logbook data, mesh size information was often missing so sets with gear defined as 'D' and target species of 'S' (swordfish or shark) were assigned to the drift gillnet fishery. Observer and logbook records with outlier or missing information on the date, area and/or length of the net used in the set were eliminated from the dataset prior to further analysis.

After filtering, the observer and logbook data were divided into strata based on year, season, and area. Each year was divided into quarters (Q1: Jan-Mar, Q2: Apr-Jun, Q3: Jul-Sep, Q4: Oct-Dec). Areas were defined differently for blue sharks (A1: <= 35 ºN latitude, A2: > 35 ºN latitude) and mako sharks (A1: <= 35 ºN latitude, A2: >35 & <=40 ºN, A3: > 40 ºN) because preliminary analysis showed that the residuals for the blue shark standardized abundance index adhered better to Gaussian assumptions when two areas were defined. 35 ºN is very close to Point Conception and 40 ºN to Cape Mendocino where oceanographic demarcations occur. No longitudinal boundaries were used because this fishery is highly coastal and limited to the U.S. EEZ (Fig. 1).

Onboard observers attempt to measure the length of fish caught in each observed set. These lengths were converted into weights using the following relationships, which were derived from sharks measured and weighed during NOAA juvenile shark surveys (blue sharks: *weight* (kg) = $5.00857 \times 10^{-6} \times$ *fork length* (cm) $^{3.0541}$, N=138, $R^2 = 0.8847$; mako sharks: *weight* (kg) = $1.1025 \times 10^{-5} \times$ *fork length* (cm) $^{3.0091}$, N=244, $R^2 = 0.9718$) (Teo et al. 2011). These length-weight relationships are highly similar to those found in a study on sharks from the western North Atlantic (Kohler et al. 1995). Length samples during 1981-1990 were also obtained from the CDFG database of market survey data from ports throughout California (Childers and Halko 1994). Most landings of sharks consisted of animal trunks (minus the head, fins and tail), so measurements of alternate lengths (from the origin of the first dorsal to the origin of the second dorsal) were made by port samplers in millimeters.

Catch

Due to the differing reliability of data sources for these two species, catch time series (including retained catch and dead discards) for blue and mako sharks were developed from different data sources using different algorithms. We validated the algorithms used to estimate blue shark catch by using these algorithms on mako sharks for the period 1990-2010 and comparing the estimated catches with actual landings.

<u>Blue shark</u>

Reliable catch estimates for blue shark are relatively difficult to develop because their commercial landings and logbook records were unrepresentative of actual catches (Table 1). In addition, no single data source covered the entire period (1971 - 2010). Therefore, three algorithms were developed for three periods, which were identified from differences in the available data: 1) Algorithm 1 - used for 1990-2010, when logbook and observer records were available for the fishery; 2) Algorithm 2 - used for 1981-1989, when logbook records were available but not observer data; and 3) Algorithm 3 - used for 1971-1980, when landings of target species were available but neither logbook nor observer records. Throughout these three periods, commercial landings records of blue shark were considered to be unreliable due to the high level of discards.

For the first period, 1990 to 2010, we used a modified version of the algorithm proposed in Teo et al. (2011). The catch and effort (in km of net) of each stratum (year x quarter x area) were extracted from the observer database and the CPUE (fish per km net) of each stratum was calculated. If no observer data were available for a particular stratum, the average CPUE for the particular year was used for that stratum. Total catch, C, for year t was then estimated as:

$$C_t = \sum_i \sum_j CPUE_{i,j,t} \times E_{i,j,t} \times \frac{1}{1-q_t} \times w_t$$

where $CPUE_{i,\,j,\,t}$ is the observed CPUE in area i, quarter j, and year t; $E_{i,\,j,\,t}$ is the logbook-recorded total effort (km of net) in the same stratum; q_t is the estimated proportion of sets that were not recorded, not submitted, or missing essential information (date, location, etc) in logbooks in year t; w_t is the estimated average weight of the species from observer records in year t.

For the second period, 1981-1989, we developed a non year-specific delta lognormal model of blue shark CPUE using observer data from 1990-2010, and applied that to the logbook recorded effort from 1981-1989 to estimate catch. A binomial GLM with a logit link was used to model the probability of positive-catch while a lognormal GLM was used to model the CPUE of the positive-catch strata. The log-transformed CPUE of the positive-catch strata was related to the quarter (Q) and area (A) by:

$$\ln(CPUE_{i,j}) - X + A_i + Q_j + A_i * Q_j - \varepsilon_{i,j}$$

where $CPUE_{i,j}$ is the CPUE in area i and quarter j, and X is the intercept. The probability of positive catch given the area, quarter, and effort, $Pr(C_{i,j} > 0 \mid A_i, Q_j, E_{i,j})$, was related to the same factors using a binomial GLM with a logit link and an offset for effort. Note that year is not a factor because the model is used to estimate catch for a different time period. The expected catch for year t was then calculated as:

$$C_t = \sum_i \sum_j Pr(C_{i,j}>0 \mid A_i, Q_j, E_{i,j,t}) \times (CPUE_{i,j} \mid C_{i,j}>0) \times E_{i,j,t} \times \frac{1}{1-q_t} \times \overline{w}$$

where $(CPUE_{i,j} \mid C_{i,j}>0)$ is the expected CPUE in area i and quarter j given that catch in that strata is positive, which is calculated from the lognormal GLM; and $\overline{w}$ is the estimated average weight of the species from observer records during 1990-2010.

For the third period, 1971 to 1980, when only landings of target species were available, we used the average ratio of blue shark to target species catch (in numbers) recorded by observers from 1990-2010 and extrapolated that with the landings records of target species from 1971-1980. The expected catch for year t was then calculated as,

$$C_t = \overline{R} \times (w_b / w_x) \times K_t$$

where $\overline{R}$ is the average ratio of blue shark to target species catch (in numbers) recorded by observers from 1990-2010; $\overline{w}_b$ and $\overline{w}_x$ are the estimated average weights of blue sharks and target species respectively; and K_t is the catch of the target species for year t. The two main target species of this fishery are swordfish and common thresher shark. Preliminary analysis suggested that swordfish is a better candidate for this catch estimation method because $\overline{R}$ for thresher shark is substantially more uncertain and exhibits higher temporal variability than for swordfish (Table 2).

Mako shark

Reliable catch estimates were easier to develop for mako shark than blue shark because their commercial landings and logbook records were representative of actual catches due to high retention and market value (Table 1). Catch of mako shark was estimated from landings data and corrections made for the proportion of dead discards. The landings of mako shark (metric tons) were first extracted from the PacFIN and CDFG commercial landings databases from 1971 to 2010. We then corrected for the proportion of dead discards by multiplying the seasonal landings with $1+r_{dead}$, where r_{dead} is the average ratio of dead discards to retained catch derived from the observer data (0.0279). In addition, preliminary examination of the landings data from the CDFG versus PacFIN databases suggested that the landings from the CDFG database had to be inflated by approximately 30%. It should be noted that the landings data obtained from the CDFG database were not designated with specific gear codes and the estimated catches from 1971-1980 therefore included non-drift gillnet landings. This should not be a problem as long as estimated catches from other California fisheries are not extended to 1971-1980.

Size Compositions

Quarterly and annual size compositions were compiled from the CDFG market survey data (1981-1989) and observer data (1990-2010). Market survey and observer data consisted primarily of alternate (AL) and fork lengths (FL) respectively. It was agreed by the ISC Shark Working Group (28 Nov - 3 Dec 2011, La Jolla, CA) to use total length (TL) as the standard measure, and conversion equations for blue sharks (Wells and Kohin 2011) and mako sharks (Wells et al. 2011) are below:

Blue shark

$TL=(FL+1.122)/0.829$

$FL=2.746*(AL) + 11.803$

Mako shark

$TL=(FL+0.397)/0.913$

$FL=2.402*(AL) + 9.996$

Standardized Abundance Indices

Catch and effort data collected by observers in the US West Coast drift gillnet fishery were used to estimate standardized indices of abundance for blue and mako sharks from 1990-2010. For developing the standardized abundance indices, catch was defined as the sum of all kept and released fish. Effort was defined as the length of net (reported in fathoms and converted to kilometers) used in each set. Date and location (longitude and latitude) were recorded for each set.

The abundance indices for both species were estimated with delta-lognormal GLM models. The probability of positive catch was modeled with a binomial distribution with a logit link and the CPUE of positive catch sets (Catch > 0) was modeled with a log-normal distribution. The function delGLM() (delta_glm_1-7-2 for R, provided by Alec MacCall, SWSFC - Santa Cruz, CA) was used to estimate the index, using jackknifing of the first explanatory variable of the defined formula to estimate the coefficient of variation (C.V.). Below is the model formula:

$$CPUE \sim Year + Season + Area$$

where CPUE was a continuous variable and Year, Season and Area were factors.

RESULTS AND DISCUSSION

Catch

The majority of the blue (Fig. 2) and mako (Fig. 3) shark catches occurred in the Southern California Bight (Area 1) during Quarter 4. Based on observer data, the catches of blue shark were relatively high during 1992-2000 but have declined substantially since 2001 (Fig. 4). In contrast, catches of mako sharks have been relatively less variable. The ratio of blue shark to thresher shark catches is also substantially more uncertain and exhibits higher temporal variability than for swordfish (Fig. 4).

Validation tests of the blue shark catch algorithms indicated that Algorithm 1 provided highly representative estimates of catch but catches from Algorithms 2 and 3 were more uncertain. Mako shark catch estimates from Algorithm 1 were highly similar to (R^2 = 0.839) and significantly correlated (R = 0.929, p = 1.15E-9) with PacFIN landings of the gillnet fishery (Fig. 5). In contrast, Algorithm 2 resulted in catch estimates that were more uncertain (R^2 = 0.283) but remained significantly correlated (R = 0.661, p = 1.09E-3) with PacFIN landings (Fig. 5). An alternative to Algorithm 2, using a modified version of Algorithm 1 (non-year specific, area-quarter CPUE) was tested and performed even worse (R^2 = -0.346). Algorithm 3 provided catch estimates that were similarly uncertain (R^2 = 0.260) and significantly correlated (R = 0.733, p = 1.59E-4) with PacFIN landings, when using swordfish as the target species (Fig. 5). However, if we use thresher shark as the target species, the catch estimates were relatively poor (R^2 = -2.31). This large difference in the performance of Algorithm 3 is likely to the substantially higher variability in the ratio of non-target to thresher shark catch (Table 2). Therefore, we recommend that swordfish be used as the target species when using Algorithm 3.

Preliminary estimated catches for blue and mako are shown in Table 3. Blue shark catch estimates for 1971-1980 are not provided because we were unable to obtain reliable swordfish landings data for 1971-1980 in time for this workshop but these catch estimates will be available for the upcoming assessment. Overall, blue shark catch estimates for 1990-2010 can be considered to be relatively reliable but the estimates prior to that period should be considered highly uncertain. Due to the small size of this fishery, this uncertainty should not affect the assessment results substantially although we recommend that sensitivity runs be performed to account for this uncertainty. For the assessment, we also recommend that the units of catch for this fishery be thousands of fish rather than metric tons because the average weight of blue sharks caught is highly uncertain for the years prior to 1990 and using the overall average weight to estimate catch in weight will add unnecessary uncertainty to the catch estimates.

Size Compositions

Size compositions of mako sharks from CDFG market survey data (1981-1990) are shown in Figs. 6 (by year) & 7 (by sex). There was an insufficient number of blue shark samples from the CDFG market survey to be used in the upcoming assessment. Size compositions of mako sharks from observer data (1990-2010) are shown in Fig. 8 (by year) and Fig. 9 (by sex). Size compositions of blue sharks from observer data (1990-2010) are shown in Fig. 10 (by year) and Fig. 11 (by sex). Overall, the size compositions for both species show relatively stable distributions through time, indicating that selectivity of this fishery has likely been relatively stable. However, annual sample sizes since 2001 may be too small for use in the upcoming assessments directly. Instead, a combined super-year size composition may be required for those years, or perhaps sizes for those years should not be used in the assessment.

Sex-specific size compositions for both species indicate that both male and female sharks exhibit a similar size range for this fishery. However, sex was determined for very few of the sharks measured during the market survey. Thus we did not identify sex-specific size differences through time due to small sample sizes.

Since the total lengths were converted from alternate or fork lengths, the size compositions exhibit aliasing to various degrees (Fig. 7, 9, & 11). We therefore recommend using appropriate size bins for this fishery in the upcoming assessments to minimize the aliasing effect.

Standardized Abundance Indices

Total effort in the fishery has been in decline since the mid 1990s due in part to a number of regulatory changes (Teo et al. 2011). Observed effort increased rapidly from 1990-1994 as the observer program ramped up before declining steadily during the period of declining fishery effort until the end of the time-series (except 1997) (Fig. 12). Observed blue shark catch exhibited a steep drop around 2000-2001 followed by steady declines through 2010 (Fig. 12). Observed mako shark catch was generally stable from 1990-2004 and generally declining from 2005-2010 (Fig. 13).

The blue shark standardized abundance index showed an increasing trend from 1990-1999, and a decreasing trend from 2000-2010, although it was quite variable overall (Fig. 14). Residuals of the log-normal (positive catch) model were skewed slightly positive, but there were no major departures from normality assumptions (Fig. 15).

The mako shark standardized abundance index was highly variable and showed a slightly decreasing trend from beginning to end (Fig. 16). Residuals of the log-normal (positive catch) model were skewed slightly positive, but there were no major departures from normality assumptions (Fig. 17).

Although we developed these abundance indices for both species, the small spatial scale of this fishery relative to the ranges of both stocks suggest that these two abundance indices are not likely to be representative of the population trends of the entire stocks. Furthermore, the fishery effort since 2000 has been very low (Teo et al. 2011). We therefore recommend that these abundance indices should not be used in the upcoming assessments but that the catch and length composition time series should be used for the assessments.

Acknowledgements

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Table 1. Proportion of sets with positive catch and mean CPUE of positive catch sets of blue and mako sharks, using data from observers or logbooks between 1990 to 2009.

Species	Data source	Number of sets	Proportion of positive catch sets	Overall CPUE of positive catch sets (fish km^{-1})
Blue shark	Observer	8075	0.464	2.25
	Logbook	45389	0.040	1.27
Mako shark	Observer	8075	0.394	1.31
	Logbook	45389	0.389	1.53

Table 2. Average ratio of catch in numbers of non-target species (blue and mako sharks) to the catch of target species (thresher shark and swordfish), and range of annual ratios below that.

	blue	mako
thresher	4.29 *range: 0.27-17.74*	1.56 *range: 0.38-4.63*
swordfish	1.13 *range: 0.11-2.37*	0.55 *range: 0.16-1.56*

Table 3. Preliminary estimated annual catches (including dead discards) of blue and mako sharks by the US West Coast pelagic drift gillnet fishery from 1971 to 2010.

Year	Blue shark (metric tons)	Mako shark (metric tons)
1971		3.6
1972		0.1
1973		0.5
1974		4.3
1975		6.0
1976		1.4
1977		12.1
1978		16.6
1979		21.4
1980		94.1
1981	55.1	158.0
1982	84.2	333.9
1983	124.8	206.8
1984	135.3	135.6
1985	118.7	132.2
1986	376.1	256.6
1987	152.2	213.7
1988	125.1	108.6
1989	128.1	120.4
1990	299.0	235.8
1991	93.6	128.3

Table 3. Continued.

Year	Blue shark (metric tons)	Mako shark (metric tons)
1992	135.0	120.8
1993	104.8	89.0
1994	36.6	82.1
1995	160.4	80.8
1996	85.2	87.1
1997	64.1	122.0
1998	103.5	90.0
1999	52.1	53.7
2000	26.9	66.1
2001	18.0	31.5
2002	12.2	70.8
2003	15.0	58.5
2004	10.0	38.8
2005	2.5	25.7
2006	3.3	39.0
2007	27.1	38.0
2008	13.7	27.4
2009	4.9	25.6
2010	3.2	17.4

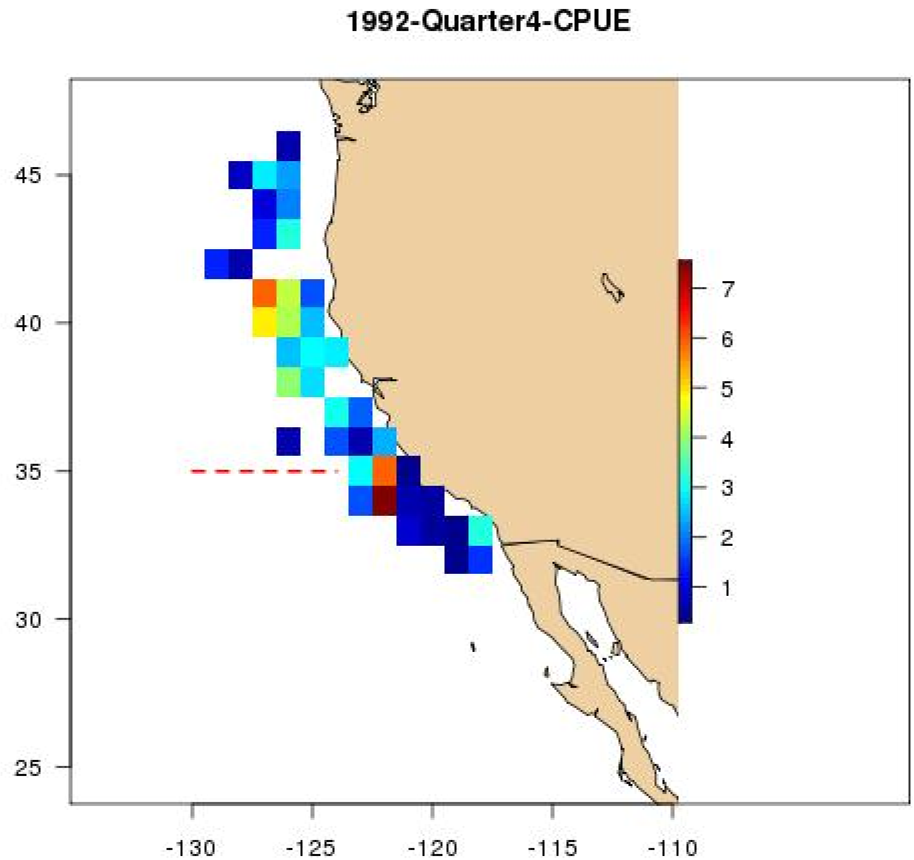
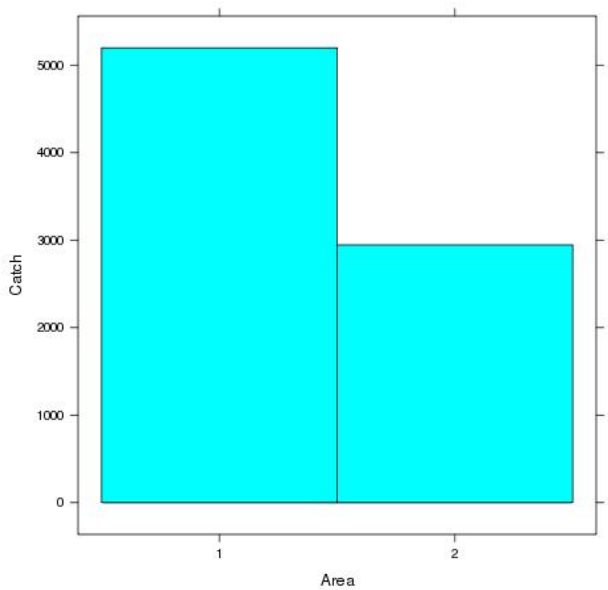


Figure 1. Blue shark quarterly CPUE spatial distribution for Quarter 4 of 1992. This is generally representative of the coastal extent of the U.S. West Coast drift gillnet fishery. The dotted red line delineates the latitudinal boundary of areas defined for blue shark abundance indices.

A



B

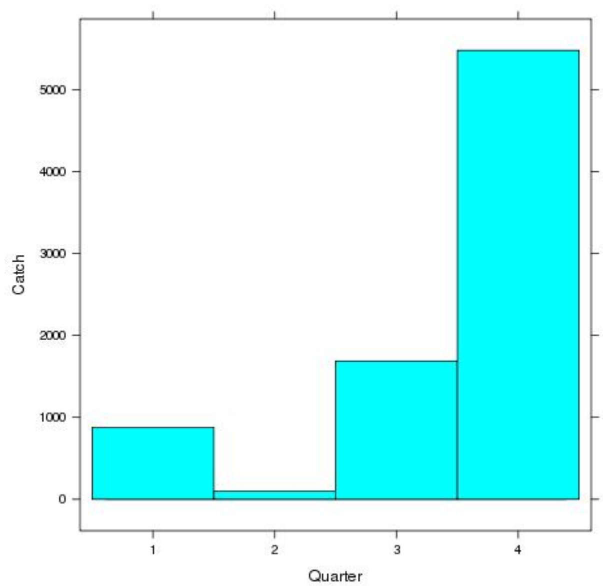
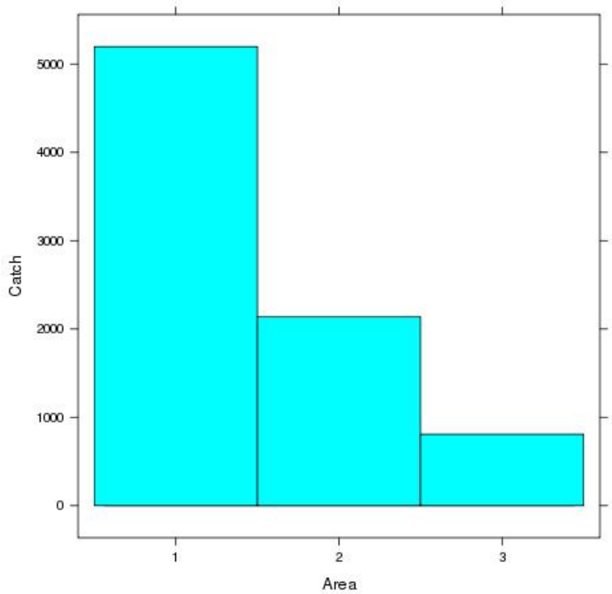


Figure 2. Blue shark catch in numbers of fish by (A) area and (B) quarter.

A



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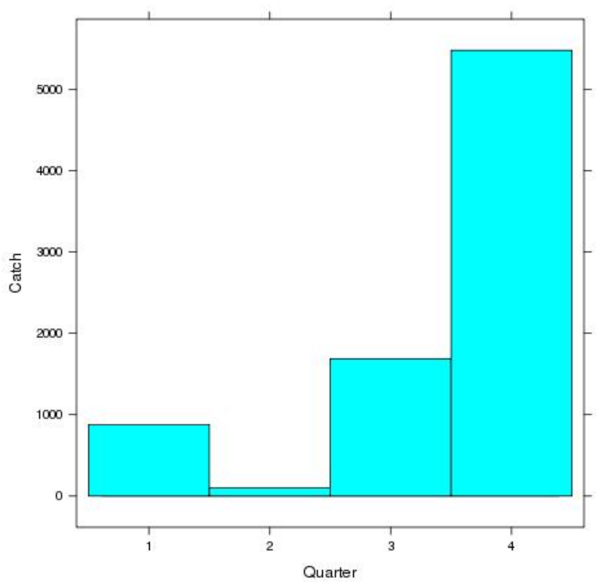

Figure 3. Mako shark catch in numbers of fish by (A) area and (B) quarter.

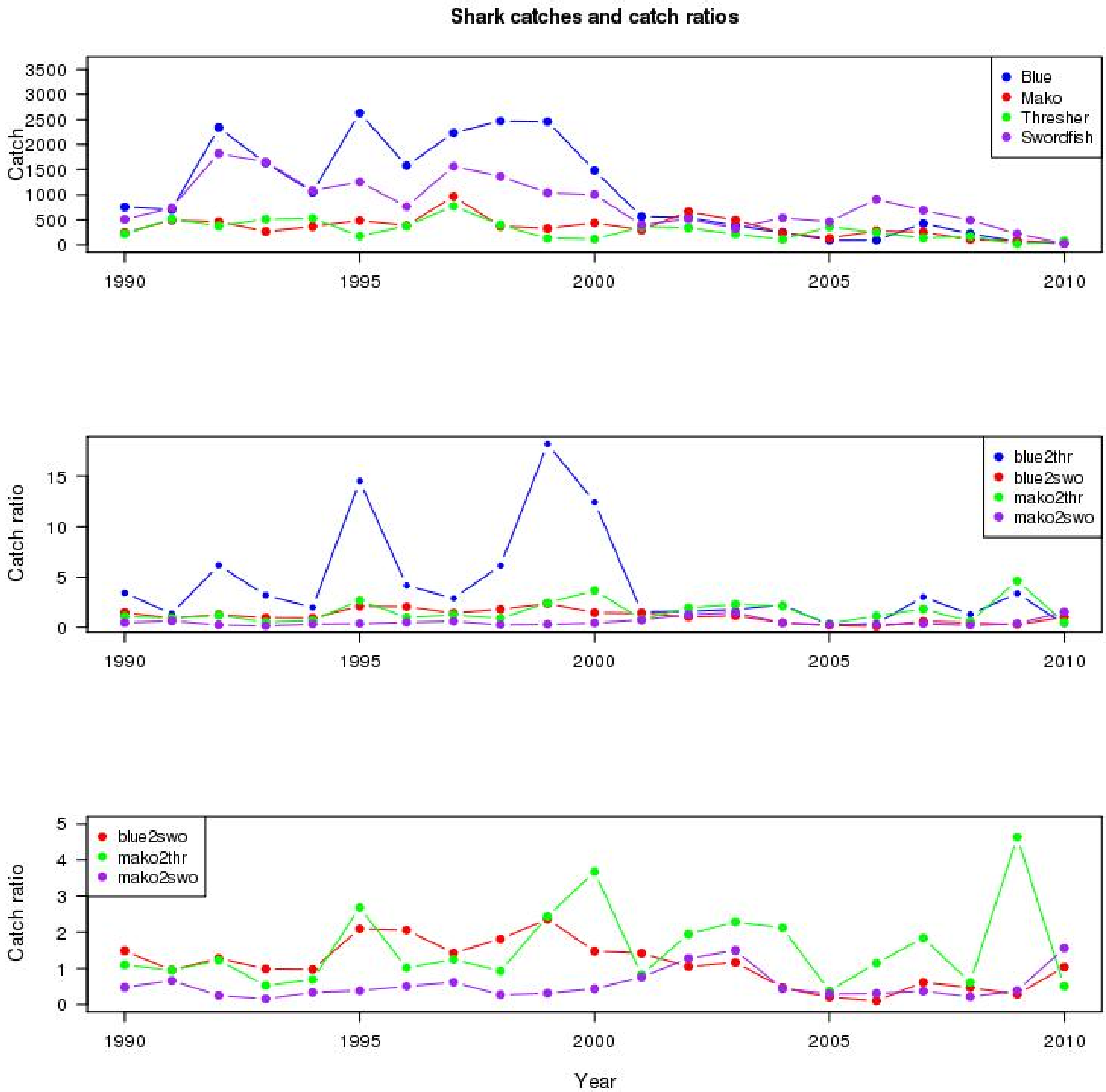

Figure 4. Top: Catches of swordfish, blue, mako, and thresher sharks in numbers of fish from 1990-2010. Middle: Catch ratios of blue and mako sharks to thresher and swordfish. Bottom: Catch ratios from middle panel enlarged to show better detail.

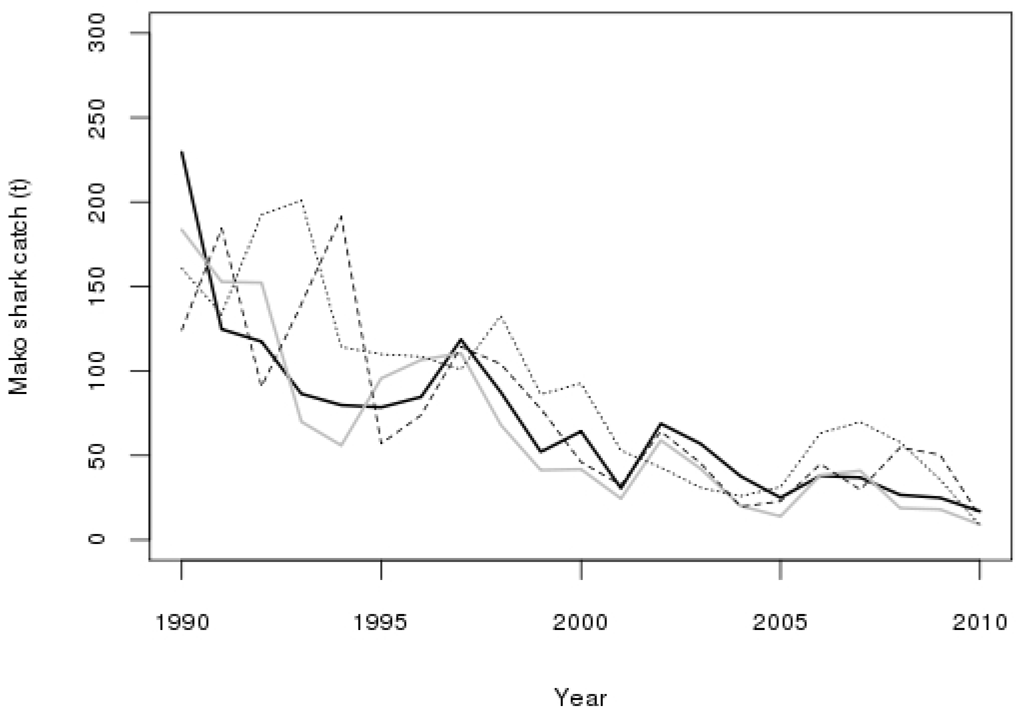

Figure 5. Comparison of mako shark landings from PacFIN (black) to the catch estimates using Algorithm 1 (gray), Algorithm 2 (dashed), and Algorithm 3 (dotted).

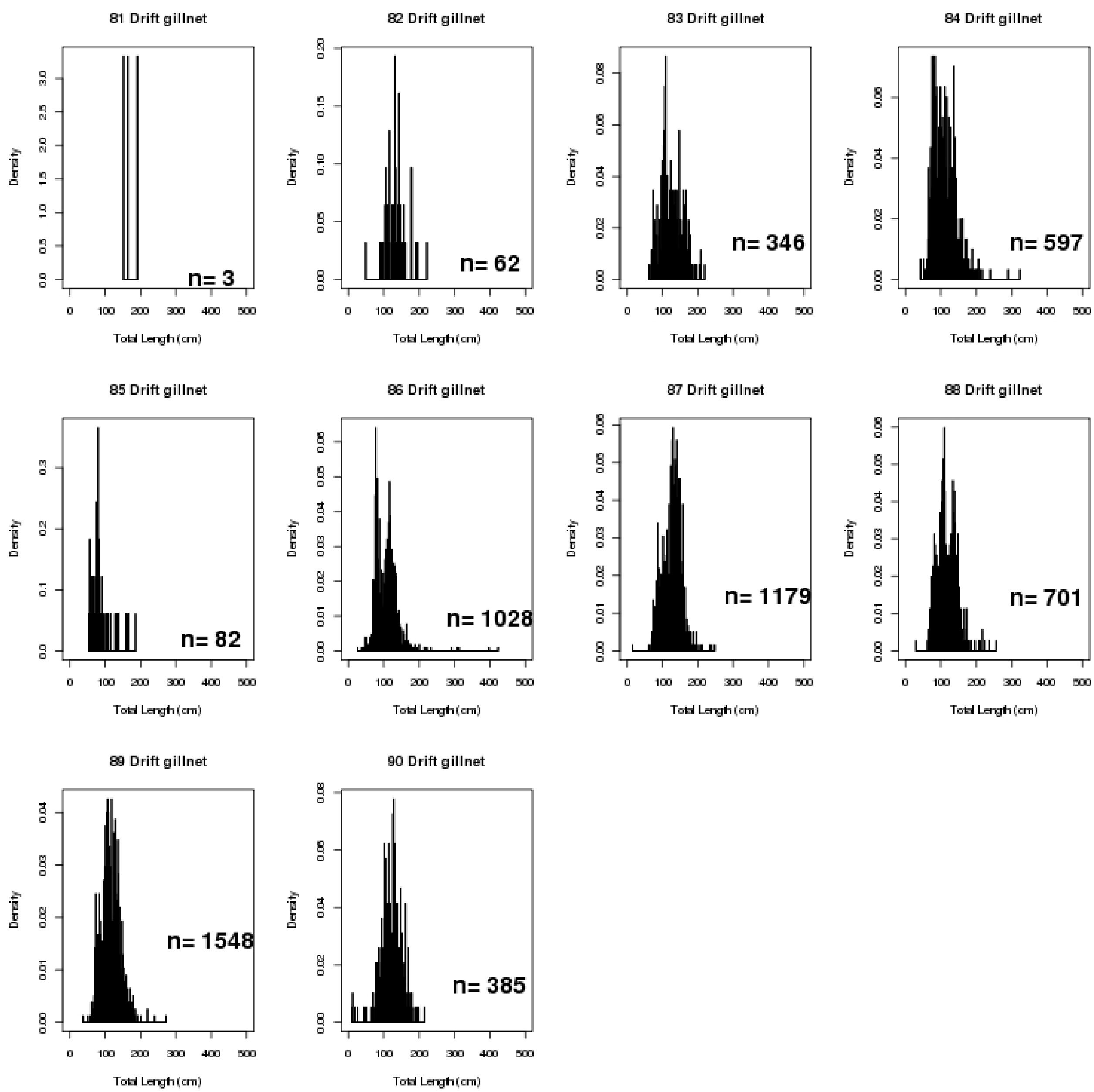

Figure 6. Mako shark total lengths (cm) from 1981-1990 market samples by year.

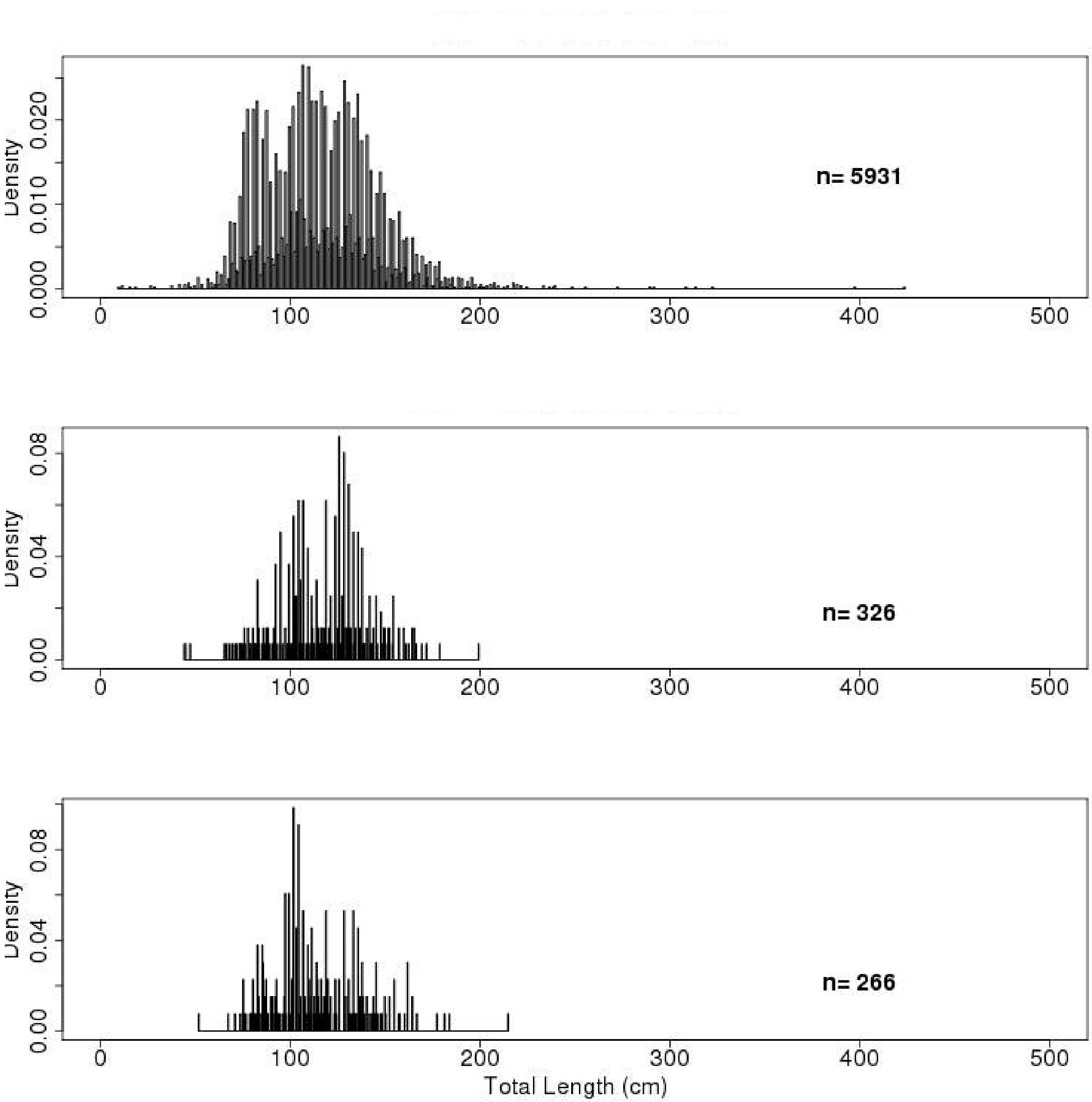

Figure 7. Mako shark size total lengths (cm) from 1981-1990 market survey data for all measured sharks (top), males (middle), and females (bottom).

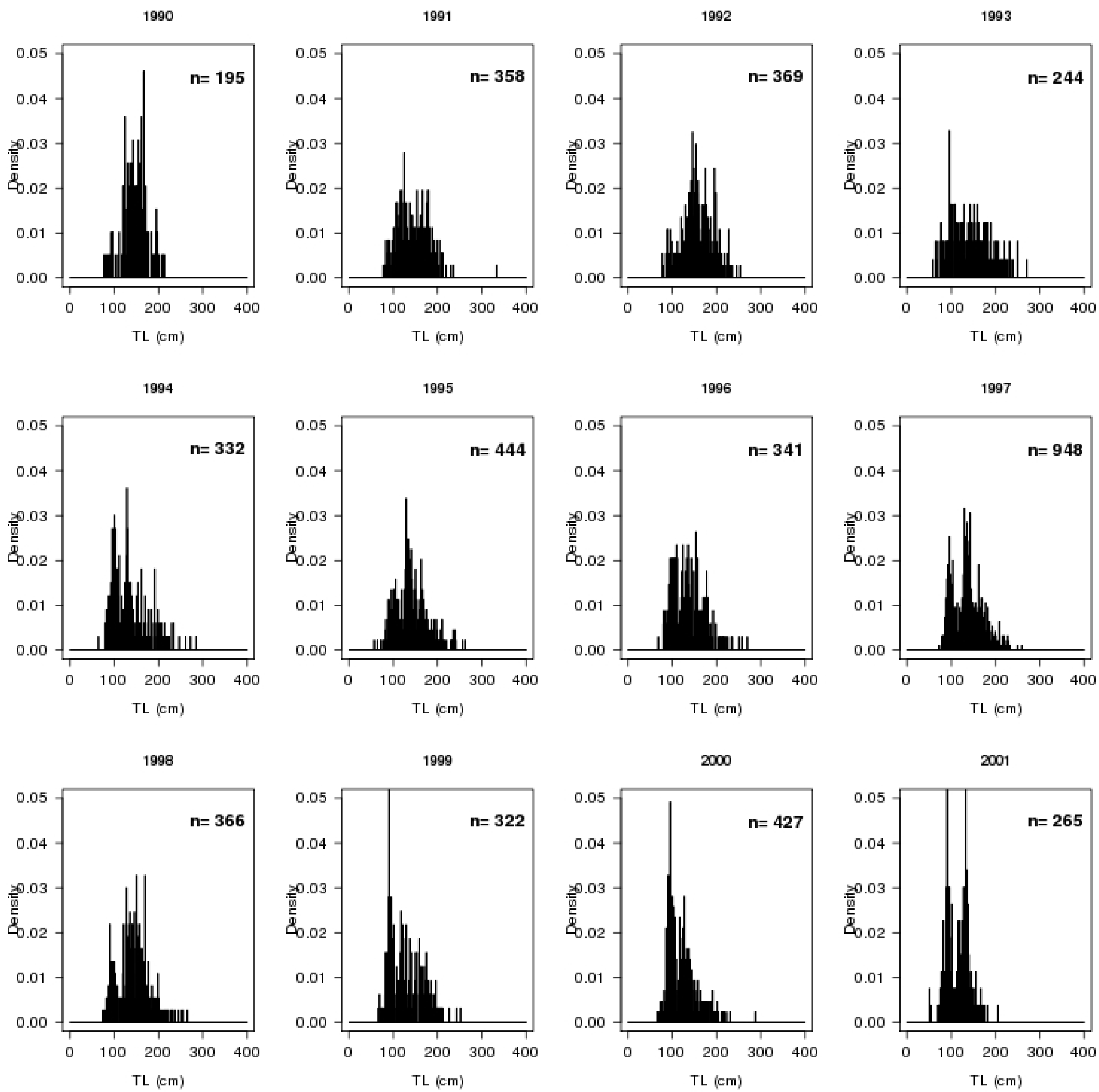

Figure 8. Mako shark size total lengths (cm) from 1990-2010 from observers. Sample sizes indicate number of fish measured, including measured TL and TL converted from FL or AL. Continued on next page.

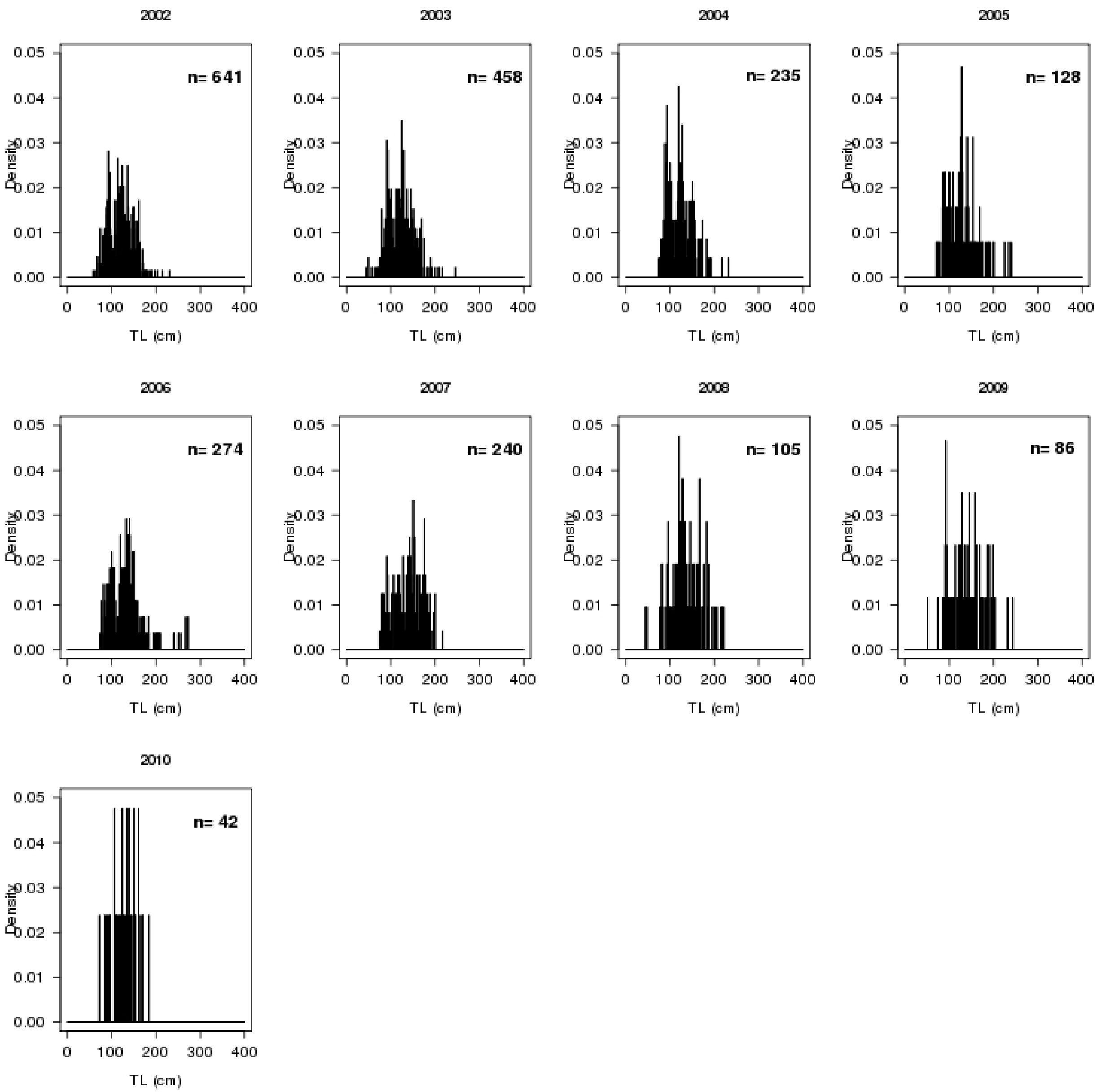

Figure 8. continued.

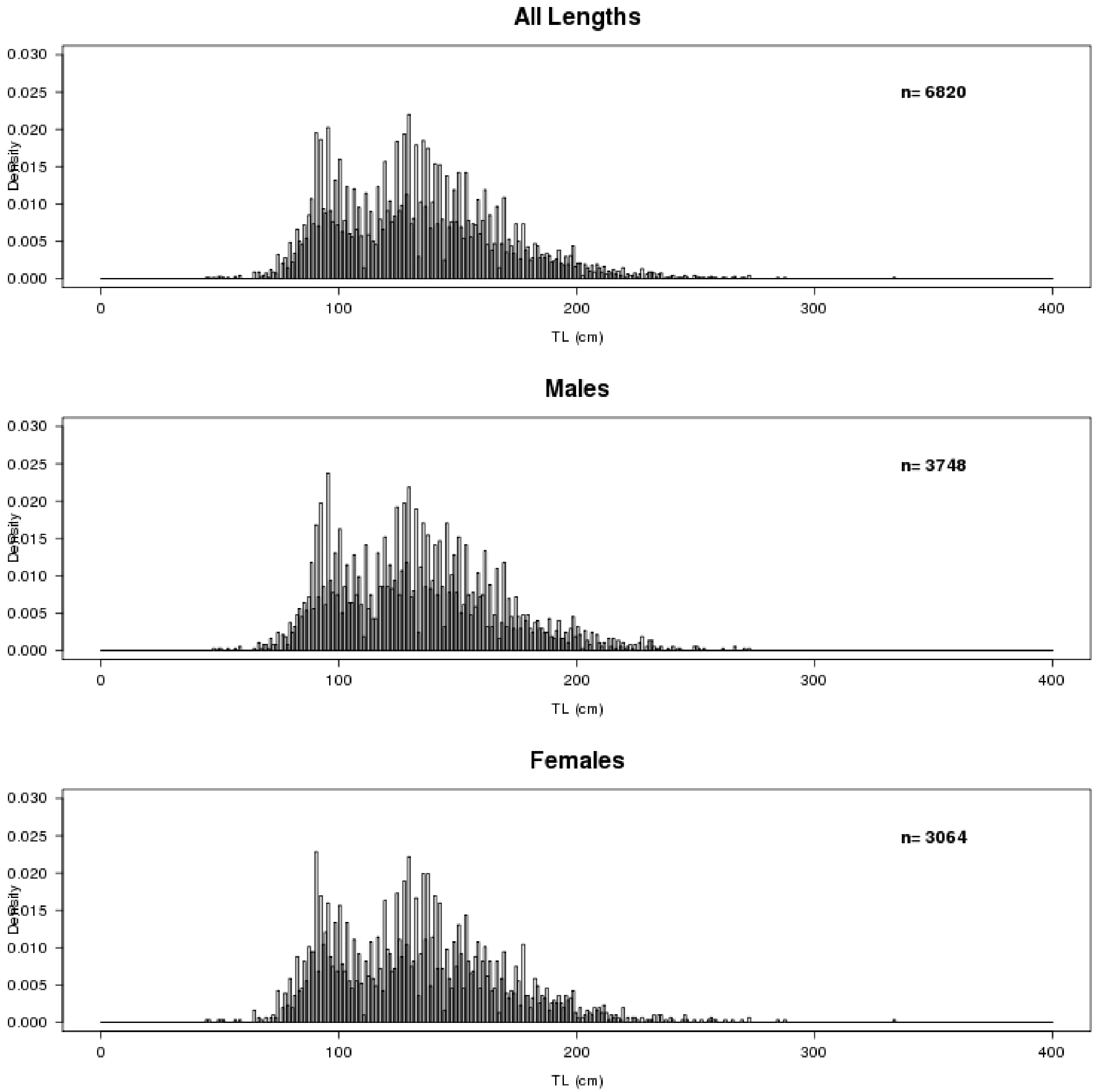

Figure 9. Mako shark size total lengths (cm) from 1990-2010 observer data, including measured TL and TL converted from FL or AL of all measured sharks (top), males (middle), and females (bottom).

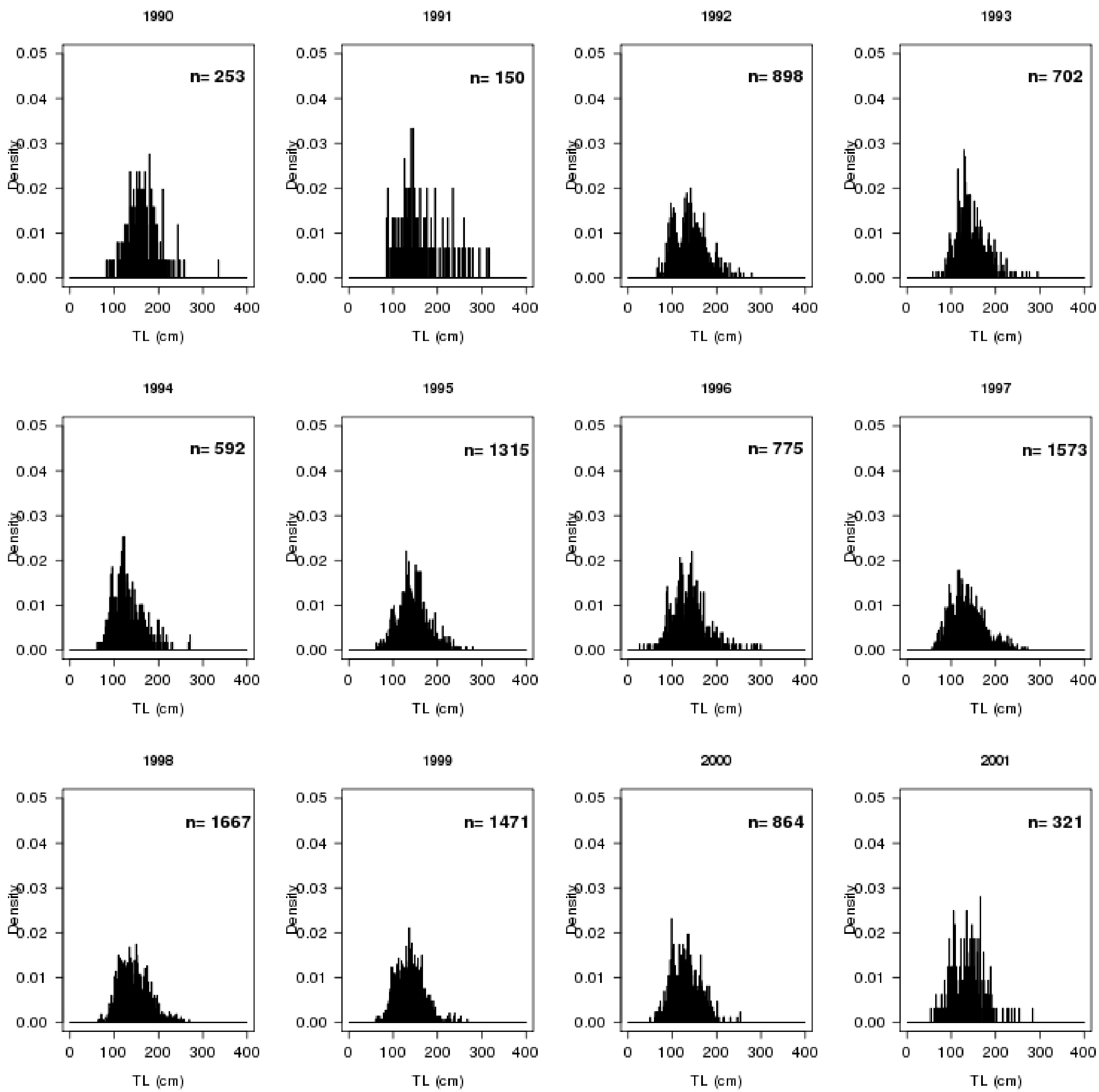

Figure 10. Blue shark total lengths (cm) from 1990-2010 from observers. Sample sizes indicate number of fish measured, including measured TL and TL converted from FL or AL. Continued on next page.

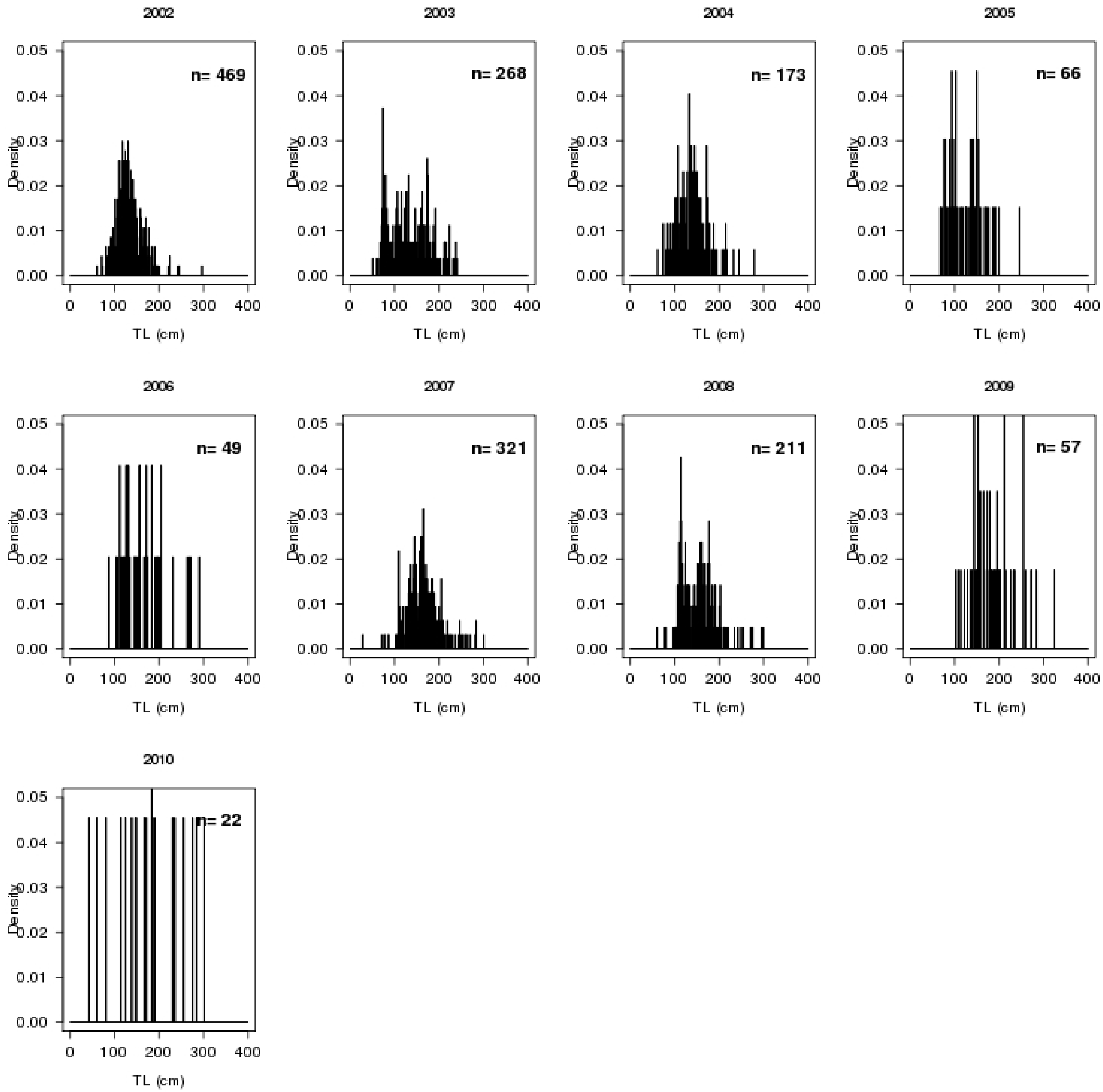

Figure 10. Continued.

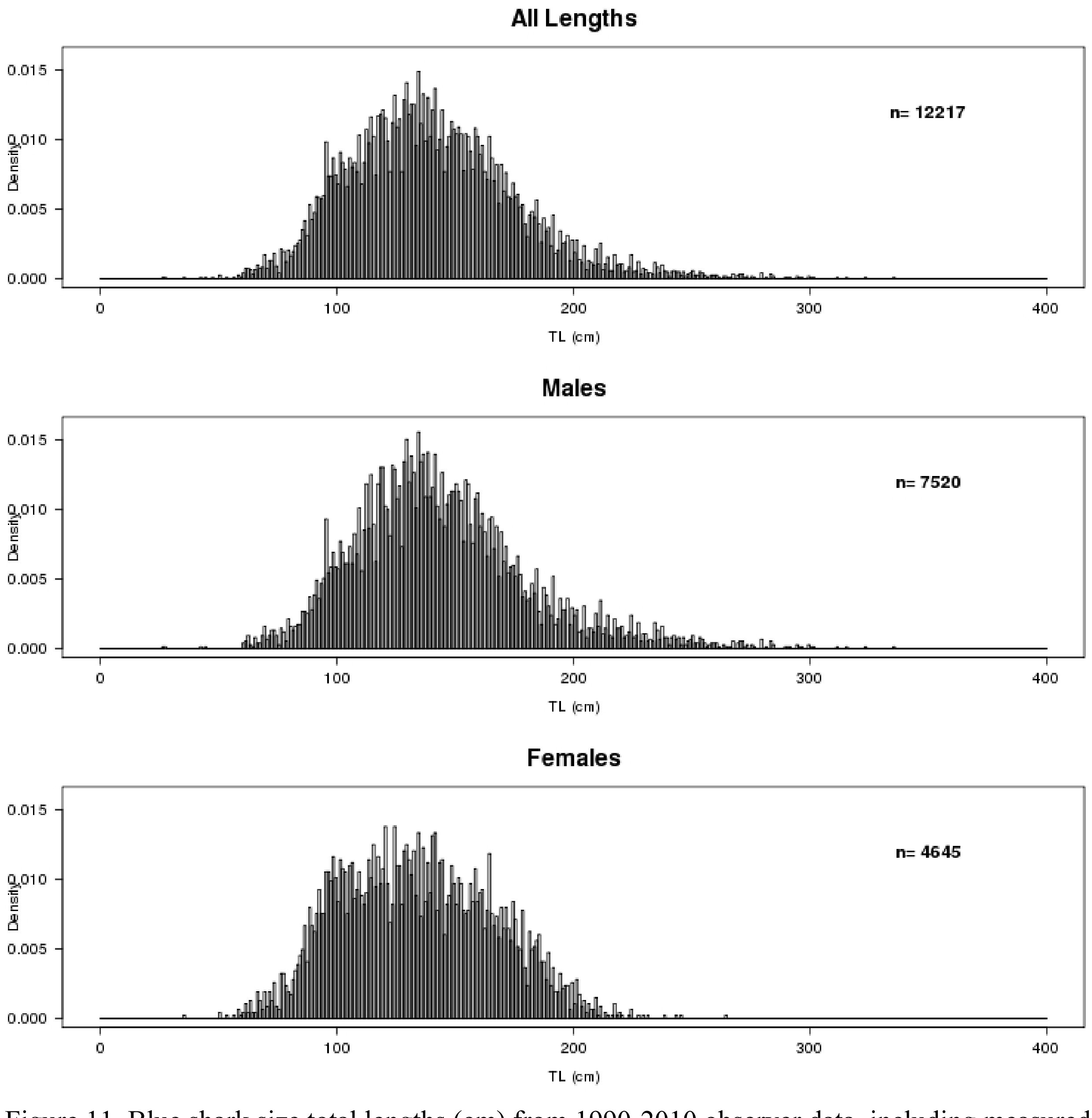

Figure 11. Blue shark size total lengths (cm) from 1990-2010 observer data, including measured TL and TL converted from FL or AL for all measured sharks (top), males (middle), and females (bottom).

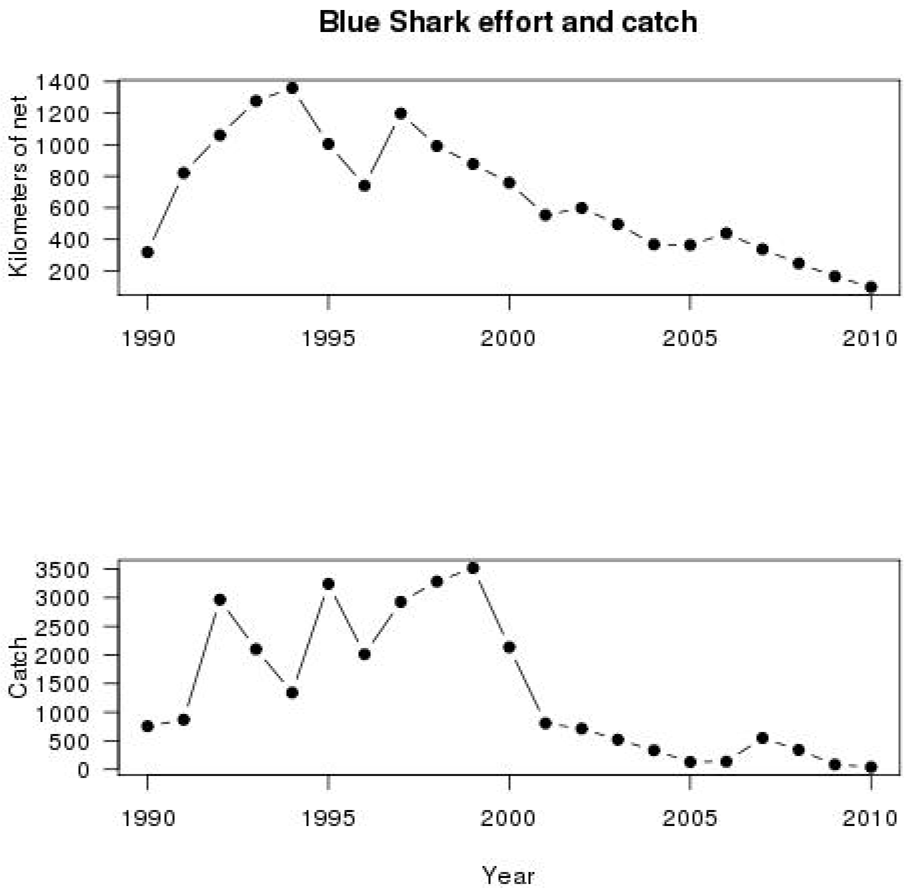

Figure 12. Observed blue shark effort (top panel) and catch in numbers of fish (bottom panel).

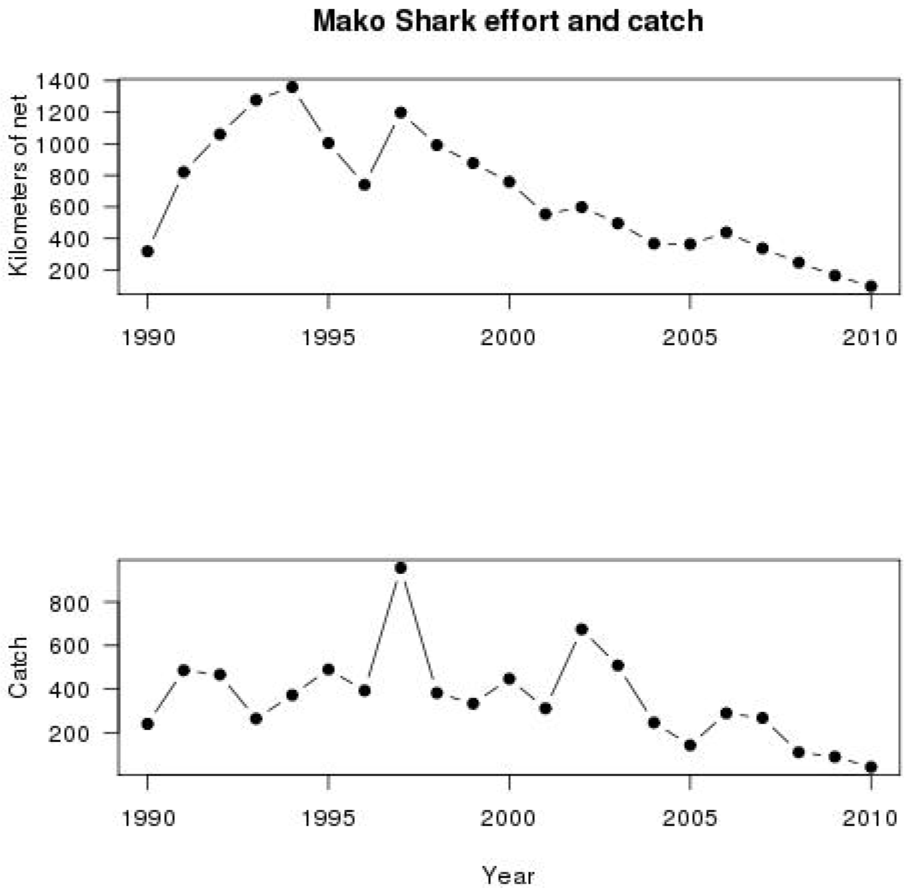

Figure 13. Observed mako shark effort (top panel) and catch in numbers of fish (bottom panel).

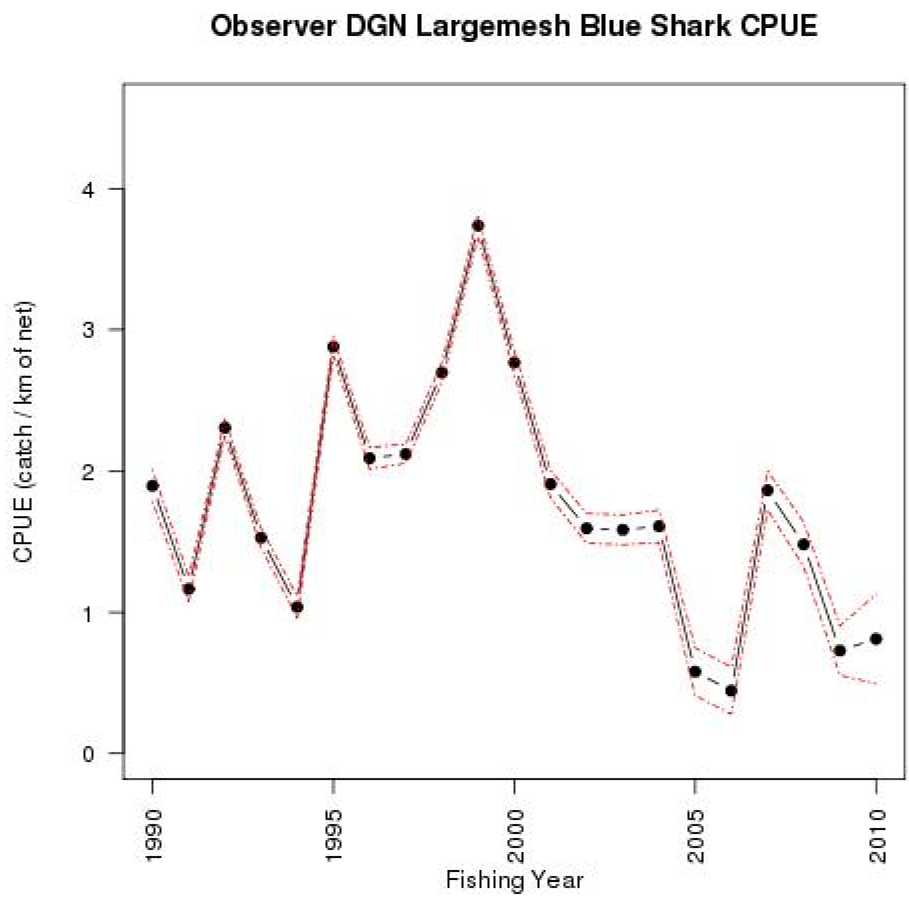

Figure 14. Blue shark standardized abundance index with C.V. (red lines).

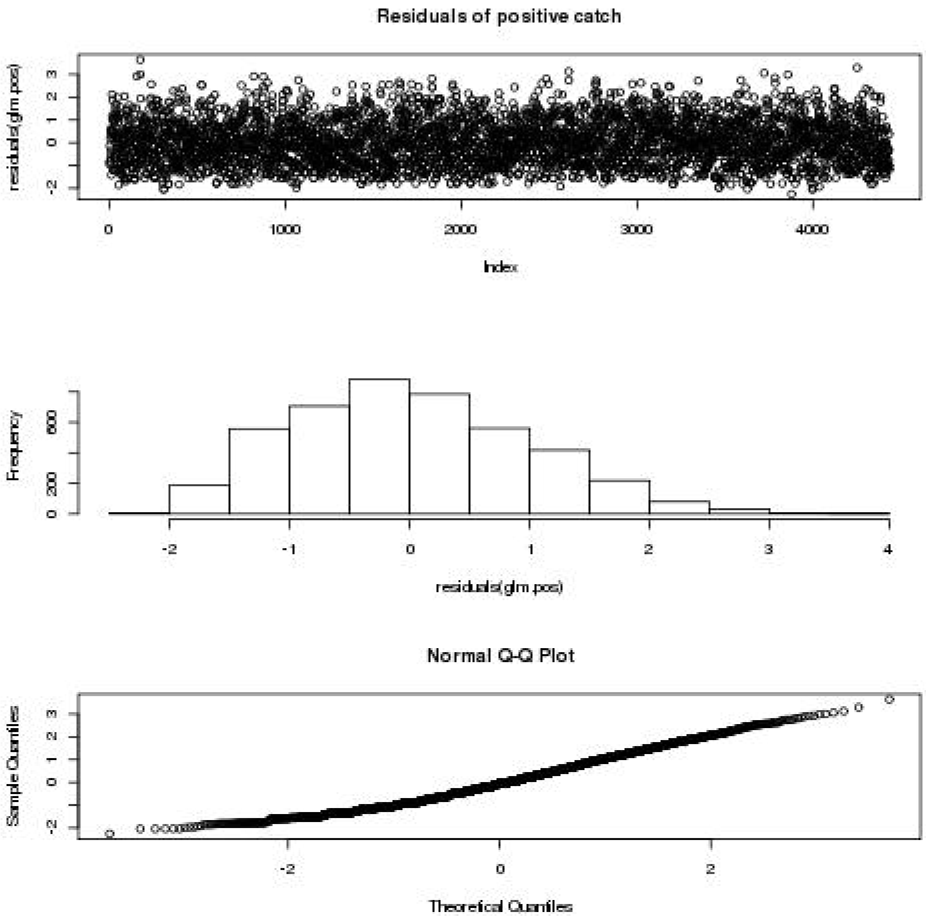

Figure 15. Diagnostics of the lognormal model component of the blue shark standardized abundance index.

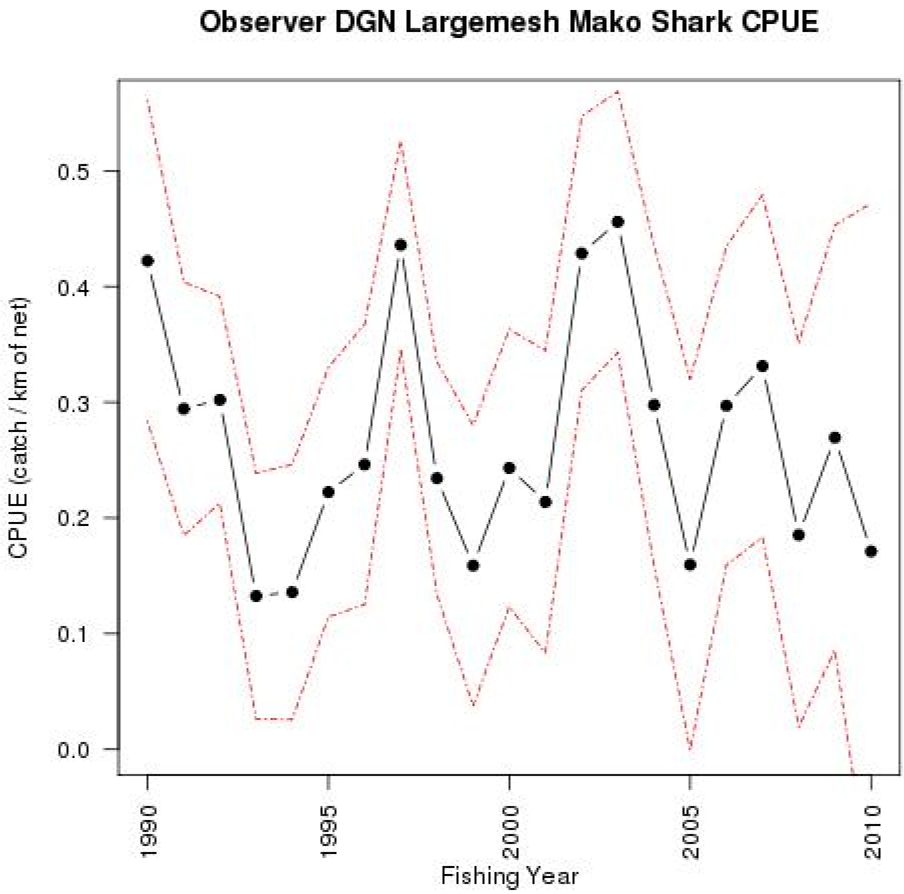

Figure 16. Mako shark standardized abundance index with CV (red lines).

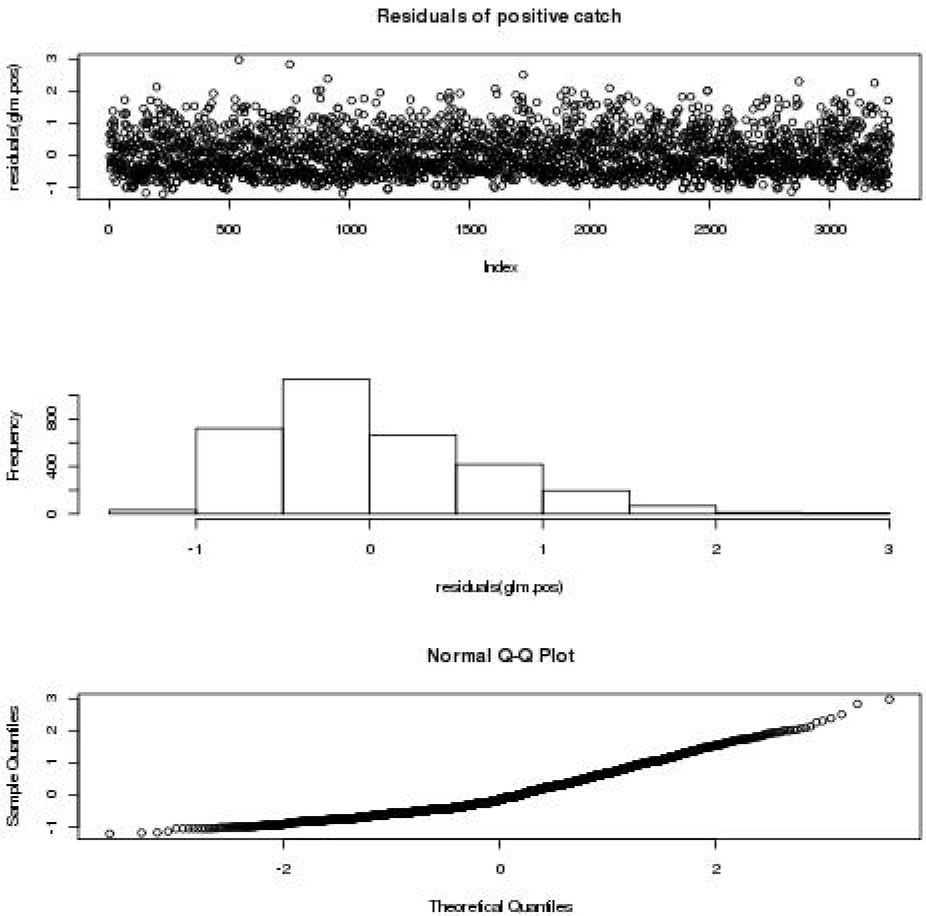

Figure 17. Diagnostics of the lognormal model component of the mako shark standardized abundance index.