Ministry for Primary Industries
Manatū Ahu Matua

Commercial catch composition of highly migratory elasmobranchs

New Zealand Fisheries Assessment Report 2013/68

M.P. Francis

ISSN 1179-5352 (online)
ISBN 978-0-478-42316-7 (online)

November 2013

New Zealand Government

Growing and Protecting New Zealand

Requests for further copies should be directed to:

Publications Logistics Officer
Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries websites at:
http://www.mpi.govt.nz/news-resources/publications.aspx
http://fs.fish.govt.nz go to Document library/Research reports

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Francis, M.P. Commercial catch composition of highly migratory elasmobranchs.

***New Zealand Fisheries Assessment Report 2013/68.* 79 p.**

This study focussed on blue, porbeagle and mako sharks, the main highly migratory elasmobranchs caught by New Zealand commercial fisheries. A fishery characterisation was carried out for the fishing years 2007–08 to 2010–11 as a basis for designing an at-sea observer sampling programme for the three sharks to estimate their catch composition, appropriate shark fin conversion factors and biological parameters such as size at maturity. Between 2007–08 and 2010–11, nearly all (98–99%) of the blue shark catch was taken by surface longline (SLL), most of it from FMAs 1 and 2. Most of the catch was finned, but an increasing proportion was discarded whole. Most porbeagle shark catch (74–84%) was taken by SLL, mainly in FMAs 1, 2 and 7, but a significant proportion (13–22%) came from midwater trawl. A high proportion of the porbeagle catch was finned. Most (92–95%) of the mako shark catch was taken by SLL from FMAs 1 and 2, and most was finned or discarded whole.

Intensive observer sampling of the three pelagic sharks was implemented in 2010–11 and 2011–12. Few samples were obtained from trawl vessels, with most vertebrae and data coming from SLL vessels. For blue sharks, maturity sampling by observers was reasonably representative during the peak period of May–August in both North and Southwest SLL fisheries, but vertebral and fin weight sampling was restricted to the Southwest SLL fishery and was therefore unrepresentative. Similar comments apply to the sampling of porbeagle and mako sharks, but very small samples sizes exacerbated the representativeness problems.

Analysis of long time series (1993−2012) of observer data showed an increase in the proportion of porbeagle and mako sharks (but not blue shark) discarded by SLL vessels since 1996. There was also a large decrease in the proportion of discarded sharks that were measured, and there was likely to be a bias in the measurements of discarded sharks towards small individuals. Consequently, declining trends noted in the percentages of mature blue, porbeagle and mako sharks are probably biased by changing fisher and observer practices associated with the introduction of these sharks into the Quota Management System in 2004.

There are strong spatial patterns in the size composition of pelagic sharks in New Zealand waters. Mature females of all three species are rare in all regions. Females caught in New Zealand waters are mainly juveniles and subadults. In the North, catches of female blue, porbeagle and mako sharks are dominated by juveniles whereas in the Southwest and Southeast regions, catches have a much higher proportion of subadults as well as juveniles. Mature male blue sharks were present in significant numbers in the North but absent from the Southwest and Southeast; catches in the latter two regions were dominated by juveniles and to a lesser extent, subadults. Male porbeagles showed similar size composition in the North and Southwest regions, being dominated by juveniles and subadults, but with a significant proportion of adults. Male mako sharks had a wide size range in the North region, from juveniles to adults, whereas the Southwest and Southeast regions produced mainly mature adults and subadults. Sex ratios were close to equality for all three species in the North region. In the Southwest and Southeast regions, blue shark catches were dominated by females, mako shark catches by males, and porbeagle shark catches had similar proportions of both sexes. In combination, the spatial variation in length composition and sex ratios indicate that blue and mako sharks segregate spatially by size and sex, whereas porbeagles are more uniformly distributed.

There were insufficient new data to estimate length at maturity except for male blue sharks. Median male blue shark maturity was estimated to be 163.3 ± 19 cm fork length, based on clasper size, calcification and mobility characters. This is considerably shorter than a previous estimate (190−195 cm) made using a broader suite of reproductive characters, suggesting that reliance on clasper length alone underestimates length at maturity.

A fin weight conversion factor of 20 was estimated for blue sharks caught by chartered Japanese SLL vessels that retain the entire tail as part of the fin set. Sparse data suggested that conversion factors were about 20−25 for porbeagle and mako sharks. These factors are well below the official conversion factors of 45−59 for wet fins, which were based on fin processing that involves discarding the upper lobe of the caudal fin, as practiced by New Zealand domestic vessels.

Trends in biological parameters may be valuable indicators of the health of a shark population. 'Indicator' analyses can involve monitoring trends in size composition, proportion of the population that is mature, sex ratio, distribution, and catch. Recommendations are made to improve the collection of data that could be used to carry out indicator analyses.

1. INTRODUCTION

Three species of highly migratory elasmobranchs (blue, porbeagle and mako sharks) are common bycatch in tuna longline fisheries around New Zealand (Francis et al. 2000, 2001, Ayers et al. 2004, Francis et al. 2004, Griggs et al. 2007, 2008). These three shark species have comprised 37% by number of the fish observed aboard tuna longline vessels since 1988–89, and they are numerically more important in the catches than the target tunas and swordfish (29% combined) (Griggs & Baird 2013). The sharks are generally processed for their fins and sometimes their meat, although a significant proportion are discarded (Francis et al. 2000, 2004, Griggs et al. 2006, 2007). Since these three species were introduced into the Quota Management System (QMS) in 2004, discard of live sharks has been permitted under Schedule 6 of the Fisheries Act 1996.

New Zealand tuna fisheries are managed under the umbrella of two Regional Fisheries Management Organizations: the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) is responsible for managing southern bluefin tuna (STN) and has an interest in ecologically related species taken in STN fisheries; and the Western and Central Pacific Fisheries Commission (WCPFC) is responsible for managing stocks of highly migratory species in the western and central Pacific Ocean. As a member of CCSBT and WCPFC, New Zealand has numerous obligations, including the provision of specific data and the submission of annual reports describing the fisheries and research activities. Within New Zealand fisheries waters, New Zealand implements the objectives of the WCPFC's conservation and management measure via catch limits for the main pelagic shark species.

Assessments for the stocks of the three pelagic sharks are done on a regional basis, with New Zealand being responsible of monitoring its fisheries and providing these data to the respective Commissions. In addition to the requirement for assessments, quantitative data on elasmobranch catches are also useful for monitoring the New Zealand component of these stocks, particularly as New Zealand fishes the extremes of the range for most of the HMS concerned. The National Plan Of Action-Sharks additionally requires that we fill some of the current data gaps in information on New Zealand shark fisheries.

Historically, most biological information for pelagic sharks has been collected by observers at sea in the tuna surface longline (SLL) fishery. These data have enabled the estimation of the size of catches and their fate (Francis et al. 2000, 2001, Ayers et al. 2004, Francis et al. 2004, Griggs et al. 2007, 2008, Griggs & Baird 2013), determination of length at maturity (Francis & Duffy 2005), and development of ageing techniques and estimation of growth rates (Manning & Francis 2005, Bishop et al. 2006, Francis et al. 2007) for all three species. Nevertheless, these studies and our overall knowledge of the three species have been constrained by the limited amount of data available, owing in part to the low levels of observer coverage, particularly in the domestic SLL fishery (coverage in the foreign charter vessel fleet has been much higher). This project aims to develop a dedicated observer-based sampling programme to address the historic shortcomings in sample collection.

At-sea sampling will overcome many of the problems associated with sampling in shore processing sheds, particularly the inability to determine the gender of processed sharks, difficulties determining the size of a shark from body parts (especially fins) and the non-availability of catches from charter vessels (because their catches are not landed in New Zealand) (Francis et al. 2006). The project aims to provide the first or improved estimates of a range of biological parameters, including: size, sex, and maturity composition of the catch; length at sexual maturity; and conversion factors for shark fins.

The objectives of this study were:
1. To characterise the fisheries for highly migratory elasmobranchs to inform observer deployment to collect catch-at-age information.
2. To manage the biological data collected by fishery observers for highly migratory elasmobranchs to the end of the 2011/12 fishing year.

3. To analyse the sex, maturity state, length and age structure of the commercial catch and collect conversion factor data from highly migratory elasmobranchs.

Analyses involving shark age structure were not possible in this project because the vertebrae collected by observers have not yet been aged.

2. METHODS

2.1 Fishery characterisation

A fishery characterisation was carried out as a basis for designing an at-sea observer sampling programme for estimating the catch composition of pelagic sharks, biological parameters such as size at maturity, and shark fin conversion factors. The characterisation covered the three fishing years immediately before observer sampling began (2007–08 to 2009–10) because the most recent fishery data provide the best guide to how the fishery is likely to operate during the catch sampling period. We also included fishery data for 2010–11 in the characterisation because they had been extracted by the time the characterisation analysis was finalised.

An extract was obtained from the Ministry for Primary Industries' (MPI) catch-effort database *warehou* on 1 February 2012 covering the four years from 2007–08 to 2010–11. Records containing the species codes BWS (blue shark), POS (porbeagle shark) and MAK (mako shark) were extracted from all estimated catch and landings form types. Fields extracted included date, fishing method, catch location (latitude, longitude, statistical area, Fisheries Management Area (FMA)), depth, processed state, destination and weight. For each shark species, a single Quota Management Area (QMA) encompasses the entire New Zealand Exclusive Economic Zone (BWS 1, POS 1, MAK 1), so Fishstock provides no useful information on catch location for these species.

Information on the processed state of the estimated catches was available only for Tuna Longlining Catch Effort Return (TLCER) forms. Estimated catches reported here from TLCERs include discards under Schedule 6 of the Fisheries Act (no attempt was made to separate retained from discarded catch as our intention was to sample both these catch components). To avoid double-counting of landings, records with landings codes B, D, M, P, Q, R, T and X were removed, as were records with secondary landed states (HDS, ROE, SHF, WSB, SKF, SWB, FIN, LIV). Simple grooming was carried out to remove obvious reporting errors. Five trips and 54 sets (0.1% and 0.2% of the total respectively) were removed from both estimated catches and landings because of highly implausible daily catch weights (including eight BWS catches of 19–38 t per SLL set, three POS catches of 8–24 t and one MAK catch of 7 t per SLL set).

MPI fishing return forms typically include estimated catches for only the top five or eight species caught (depending on the form type). Furthermore, estimated catches are meant to be whole (green) weight but some fishers incorrectly report processed weight. Characterisation studies frequently scale the estimated catches up to those of the reported landings in order to overcome these problems with reporting estimated catches. However in this study no scaling was carried out because (a) the three shark species are usually in the top five species caught by weight on tuna longlines (which take most of the catch of these species), and (b) estimated catches were always greater than the landings, probably because significant numbers of sharks are released under Schedule 6. Estimated catches were aggregated at the trip level before being compared with the landings from the same trip. Monthly Harvest Return (MHR) landings were obtained from the Plenary report (Ministry of Fisheries Science Group 2011).

Fishery data were stratified into North and South regions reflecting the geographic distribution of fishing effort (Francis et al. 2001, Griggs et al. 2008, Griggs & Baird 2013). The North region was defined as all sets made in FMAs 1, 2, 8 and 9, and the South region as all sets in FMAs 3–7. These regions are geographically similar to those used previously to define northern and southern tuna longline fisheries, except that earlier studies used fixed latitude boundaries at 39.5 ^{o}S on the west coast and 43.75 ^{o}S on the east coast (Griggs et al. 2008, Griggs & Baird 2013).

2.2 Managing biological data

A set of instructions was prepared for observers on sampling pelagic shark size, sex, maturity, vertebrae and fin weights (Appendix 1). Vertebrae were inventoried and archived in a freezer, and maturity and fin data were punched. Other observer data were punched and loaded using routine processes into the *COD* database managed by NIWA for MPI. The temporal and spatial coverage of the observer data and vertebral collections were assessed by comparing the distribution of data and sample collections by FMA and month with the distribution of estimated catches by FMA and month.

2.3 Analysis of observer data

Length-frequency distributions and sex ratios were calculated for each shark species using data collected by observers aboard SLL vessels. A total of 302 observer trips made between April 1993 and October 2012 were included. Observer data were stratified into regions because previous studies have identified spatial variation in pelagic shark length-frequency distributions (Francis et al. 2001). The North region was the same as defined above for fishery analysis (FMAs 1, 2, 8 and 9), but the South region was divided into a Southwest region (FMAs 5 and 7) and a Southeast region (FMAs 3 and 6) to explore differences between the eastern and western South Island. No SLL observer data were obtained from FMA 4.

For blue shark, 27 observer trips were omitted from length-frequency and proportion mature analyses because their length measurements showed a strong bias towards numbers ending in zero (more than 20% of lengths ending in zero compared with the expected 10%). This indicates that either that the sharks were not measured accurately, or that measurements were rounded to 10 cm intervals. Nineteen further trips by the same observers were also omitted because of uncertainty about the accuracy of their length measurements. Thus 46 observer trips (15.2%) were omitted from blue shark length-frequency analyses (but were included in other analyses such as sex ratio). Measurement bias was not apparent, or at least not detectable, for porbeagle and mako sharks, which were caught in much lower numbers and may therefore have been measured more accurately. Five additional trips (1.7%) were omitted from all analyses because of known species identification problems, or data quality issues.

Observers recorded the fate of sharks as follows:

- ‘Finned’ is the removal and retention of the fins from dead sharks, with the remainder of the shark being discarded at sea.
- ‘Retained’ is any other processing method that leads to retention of more than just the fins. For sharks this usually involves retention of the carcass (trunk).
- ‘Landed’ or ‘landing’ refers to sharks that are processed in some way such that products from them are kept and landed. ‘Landed’ is therefore the sum of sharks that are ‘retained’ and ‘finned’.
- ‘Discarded’ is any shark that is disposed of at sea. Before the introduction of blue, porbeagle and mako sharks into the QMS in October 2004, these species could be discarded at sea, dead or alive. Thereafter, Schedule 6 of the Fisheries Act allowed the release at sea of sharks that were alive and considered likely to survive; dead discards could also be authorised by an observer. Thus the ‘Discarded’ category used by observers (and followed in this report) can include both live and dead sharks, although since October 2004 most of the sharks would have been alive.
- ‘Lost’ refers to sharks that were seen by an observer but not brought aboard the vessel, either because they escaped or were released by the crew before the fishing gear was hauled.

For the analyses in this report the Retained and Finned categories (hereafter called Landed), and the Discarded and Lost categories (hereafter called Discarded) were combined. A more detailed analysis of the individual categories was provided by Clarke et al. (2013).

Observers measured sharks using one or both of two measurements: fork length (FL) and 'Length2'. Before 2002, most Length2 measurements were of precaudal length (PCL; tip of snout to the precaudal pit in front of the tail fin). After 2002, most Length2 measurements were of total length (TL). In 2002, some trips used PCL and others used TL. Fork length was adopted as the measurement standard in this study. For sharks having no FL measurement, FL was estimated from Length2 (if recorded) as follows. Time periods of consistent observer behaviour were identified. Plots of FL versus Length2 were generated for every individual trip by species. If Length2 was mostly less than FL, then Length2 was assumed to be PCL for the entire trip; if Length2 was mostly greater than FL, then Length2 was assumed to be TL for the entire trip. Generally it was obvious which measurement had been used, although some outliers existed within trips that were clearly errors, including occasional inadvertent swapping of FL and Length2 between datasheet columns. For blue and porbeagle sharks, trips 598–1633 (except 875) and 30601–31423 (1993– mid 2002) used Length2 = PCL and trips 1757 to 3551 (2003–2012) used Length2 = TL. Some intermediate trips in mid−late 2002 (1636–1686) were omitted because of uncertainty during the period of changeover from PCL to TL. For mako shark, individual trips during 1993−2002 used either PCL or TL with no clear temporal pattern, and after 2002, only two mako sharks with missing FL had Length2 (i.e. TL) recorded; consequently no length conversions were done for mako shark.

For blue and porbeagle shark, linear regressions of FL versus PCL and TL were generated and used to estimate FL where it was missing in the time periods described above. This procedure increased the number of FL measurements by 17.2% for blue shark and by 18.0% for porbeagle shark.

When large numbers of sharks (particularly blue sharks) are caught on a longline set, observers may not be able to record data from individual fish. In these cases, observers count ('tally') the sharks but do not measure and sex them or record other data such as the time of landing, fate, or processing method. Significant proportions of the sharks caught on some trips may be tallied, or important data may not be collected, leading to likely biases in length-frequency distributions, proportion of males, proportion mature, etc. These biases are considered in detail in the Results and Discussion sections below.

Most analyses of observer data were carried out separately for males and females. However, large numbers of tallied sharks were not sexed, so calculations of the proportions of sharks Discarded and measured were carried out for all sharks (males, females and unsexed sharks combined) so that the total sample size could be used.

For the historical time series (1993−2012), sharks were defined as mature if they exceeded the following median lengths at maturity for males and females respectively: 192.5 cm and 180 cm for blue sharks, 145 cm and 175 cm for porbeagle sharks, and 182.5 cm and 280 cm for mako sharks (Francis & Duffy 2005).

Maturity data collected by observers in 2010−11 and 2011−12 were based on a 3-stage elasmobranch maturity scale (immature, maturing and mature; see Appendix 1). Three additional stages (4−6) were used to classify mature females into reproductive stages (gravid I and II, post-partum). Immature and maturing sharks (classes 1 and 2) were combined as 'immature' and mature sharks (classes 3−6) were also combined as 'mature'. Maturity ogives were fitted to the proportions of sharks that were recorded as mature after grouping them into 5-cm length classes. Logistic regressions (binomial error structure with a logit link function) were fitted to the data using the GLM function in R statistical software (R Development Core Team 2008).

Observers were asked to weigh whole sharks and their associated shark fin sets in order to estimate conversion factors for raising fin weights to whole weight. None of the observer trips made during

2010−11 or 2011−12 had motion-compensated scales onboard, so small objects like shark fin sets were difficult to weigh accurately. If conditions did not permit weighing of individual fin sets, such as with small sharks, in rough weather conditions, or under other adverse circumstances, observers were asked to aggregate fin sets from all sharks of a given species caught on a longline set and weigh them together; these weights were then compared with the sum of the whole weights recorded for the same sharks. Owing to variations in finning practices among vessels, observers also recorded which fins were removed and comprised each fin set, and whether the entire tail was removed and kept, or just the valuable lower lobe of the tail. Fin data from two trips (3481 and 3495) were omitted because they represented an uncertain mix of finning practices, and included many improbably high ratios of whole weight to fin weight, suggesting the existence of weighing errors or the inclusion of dried fins.

For comparison with observer fin weight measurements, a small dataset of fin weights and whole weights for 29 mako sharks weighed on accurate, calibrated scales after landing at a number of North Island recreational fishing competitions in 2003−2005 was analysed (C. Duffy, Department of Conservation, unpubl. data). The fins were trimmed of excess meat, and only the first dorsal, two pectorals and lower caudal fin were included.

3. RESULTS

3.1 Fishery characterisation

Blue shark

Between 2007–08 and 2010–11, blue shark catches were about 900–1100 t per year compared with landings of about 700–800 t (MHR and catch-effort data) and a Total Allowable Commercial Catch (TACC) of 1860 t (Table 1, Figure 1). Catches increased during the four-year period, but landings were stable. The ratio of catches to landings increased from about 1.3 to 1.5 (Table 1, Figure 2). Nearly all (99%) of the catch was taken by SLL (Table 1, Figure 3). Much of the catch came from FMAs 1 and 2, with smaller amounts coming from FMAs 5, 7 and 9. Catches were strongly seasonal, with most being taken in April–August, peaking in May–July. Most of the catch was finned (wet fins, FIW), but an increasing proportion was reported as green (GRE); the latter represents whole sharks released under Schedule 6. A very small proportion of blue sharks were processed for their flesh (dressed, DRE).

The North SLL fishery caught blue sharks mainly in FMAs 1 and 2 during May–August, although the fishery operated year-round (Figures 4 and 5). The South SLL fishery took blue sharks in FMAs 5 and 7 during May–June. Small amounts of blue shark were caught by bottom longline (BLL) on the Chatham Rise and near the shelf edge around the mainland; by midwater trawl (MW) off the west coast of North and South Islands; and by set net (SN) in inshore waters of both islands (Figure 5).

Porbeagle shark

Porbeagle shark catches were about 40–80 t per year compared with landings of about 30–50 t (catch-effort data) or 40–70 t (MHR data) and a TACC of 215 t (Table 1, Figure 1). Catches and landings both increased during the four-year period, as did the ratio of catches to landings (1.4 to 1.6 for all methods and 1.8 to 2.1 for SLL) (Table 1, Figure 2). Most (74–84%) of the catch was taken by SLL, but a significant proportion (13–22%) came from MW (Table 1, Figure 6). Most of the catch came from FMAs 1, 2 and 7, with smaller amounts coming from FMAs 5 and 6. Catches were strongly seasonal, with most being taken in May–August, although porbeagles were also caught in small quantities in other months (Figure 7). A high proportion of the catch was finned, but an increasing proportion of released sharks was reported as green, and small amounts were processed for their flesh.

The North SLL fishery caught porbeagle shark mainly in FMAs 1 and 2 during most of the year, peaking in May–August (Figures 7 and 8). Catches in FMAs 5–7 were taken from May to September by SLL and MW. Midwater trawl catches were taken mainly by vessels targeting hoki and southern blue whiting. Small amounts of porbeagle shark were also caught by BLL on the Chatham Rise and along the south-east coast of North Island (Figure 8).

Mako shark

Mako shark catches were about 90–160 t per year compared with landings of about 70–90 t (MHR data) and a TACC of 406 t (Table 1, Figure 1). Catches increased during the four-year period but landings were fairly stable. The ratio of catches to landings increased sharply from about 1.4 to 2.2 for SLL (Table 1, Figure 2). Most (92–95%) of the catch was taken by SLL (Table 1, Figure 9). Most of the catch came from FMAs 1 and 2, with smaller amounts coming from FMAs 7 and 9 (Figures 10 and 11). Catches were strongly seasonal, with most being taken in March–August (Figures 9 and 10). Most of the catch was finned, or released green (in increasing quantities), although a significant amount was processed for its flesh.

The North SLL fishery caught most mako shark during March–August (Figure 10). Small amounts of mako shark were also caught in the South SLL fishery, by BLL on the north-east coast of North Island, and SN on the west coast of North Island (Figure 11).

3.2 Observer catch sampling

An observer sampling schedule for pelagic shark vertebrae was developed based on the fishery characterisation for the period 2007–08 to 2010–11. It was proposed to sample blue, porbeagle and mako sharks in the North SLL fishery, blue and porbeagle sharks in the South SLL fishery, and porbeagle sharks in the west coast South Island hoki fishery and Campbell Plateau southern blue whiting fishery, during specified periods. Nominal targets of 250 vertebrae per sex, species and fishery were set as reasonable sample sizes for developing stratified age-length keys. However, in some strata, these targets may have exceeded the number of sharks seen by observers, and perhaps even exceeded the numbers caught by the fishery. Our main aim was to use the nominal targets to apportion observer effort across time and space in order to sample the EEZ-wide catch of each species representatively.

All sets from all of the chartered Japanese SLL vessels were observed and sampled in both 2010−11 and 2011−12 (Table 2). However, few domestic trips and only 6−7% of the domestic sets were observed, and even smaller proportions were sampled for vertebrae, maturity data or fin weights on domestic trips (Tables 2 and 3).

Data and samples were collected from 20 observer trips, 18 of them aboard SLL vessels and two aboard trawlers (Table 3). Most vertebrae and data came from SLL vessels operating in FMAs 1, 2, 5 and 7 during April–July. A total of 745 sharks were sampled for vertebrae, 80% of them blue sharks. Maturity was determined for 2051 sharks, again mostly (90%) blue sharks, and individual fin weights were collected from 664 sharks (88% blues) (Table 3). Aggregated fin weights and associated whole weights (i.e. summed by species across entire SLL sets) were obtained from 128 fin sets.

For blue sharks, observer maturity sampling was reasonably representative during the peak period of May–August in both North and South SLL fisheries, but the smaller catches between October and April were poorly sampled (Figure 12). Vertebrae were proportionally over-sampled in the South SLL fishery and under-sampled or not sampled (depending on the month) in the North SLL fishery; sampling was therefore unrepresentative. Observers had difficulty storing vertebrae on the small North domestic longline vessels (because of lack of suitable freezer facilities). Samples and maturity data from the South fishery came from a concentrated patch of SLL sets straddling the border between FMAs 5 and 7 (Figures 13 and 14). Samples from the North fishery were widely spaced through FMAs 1 and 2 but came from only a small proportion of the total sets. Individual fin weights were only obtained from the South SLL fishery (Figure 12).

Similar comments apply to the sampling of porbeagle and mako sharks, but small samples sizes exacerbated the representativeness problems (Figures 15–20).

Comparison of the length-frequency distributions of sharks sampled for vertebrae and maturity with the distributions for all sharks measured by observers showed that samples were generally representative of the sharks measured (Figures 21–26). Male blue sharks sampled for maturity were slightly larger on average than all measured sharks, as were female blue sharks and male mako sharks sampled for vertebrae. These biases indicate slight over-sampling of larger sharks which is beneficial for estimating size at maturity and growth rates (adult sharks are relatively uncommon in the catches).

3.3 Analysis of SLL observer data

The rest of this report deals with observer data collected from SLL vessels, because negligible data were available from other fishing methods.

Length-frequency distributions and sex ratios

Estimation of fork length from Length2

Data used for the estimation of FL from Length2 are shown in Figure 27. Although some outliers are apparent, they were numerically insignificant given the large sample sizes, and did not affect the fitted linear regressions. Regression parameters are shown in Table 4, and were used to estimate FL from Length2 for blue and porbeagle sharks in the series of observer trips detailed in the Methods.

Measurement biases

Observers on SLL vessels were not always able to measure every shark, and this may introduce biases into the recorded length-frequency distributions. Potential biases include:

1. Observers may not be able to measure all the sharks that are caught because of other priorities, or because they may not observe an entire haul if it continues beyond the end of a 12-hour day. If large tallied catches represent schools of a particular size group of sharks (e.g. sub-adults[1]), failure to measure them will result in under-estimation of the numbers of that size group.
2. Some sharks may be cut or shaken off the line alongside the boat, and not brought aboard; others are lost during hauling. This issue may be more important on smaller domestic vessels which are less able to bring large sharks aboard, particularly in bad weather. These sharks are not usually measured or sexed.
3. Discarded sharks cannot always be measured. There are two issues here. First, fishers may selectively discard or release particular size classes; e.g. small sharks have less-valuable fins than large sharks and may be preferentially released. Second, if released sharks are large and lively, they may be difficult and dangerous to measure, leading to biased measurements

No data are available from which to assess the magnitude of the first two biases listed above, although anecdotal information from observers confirms that those issues exist, and that size-related biases are likely (L. Griggs, NIWA, pers. comm.). The third potential bias can be partially explored by comparing length-frequency distributions of Landed and Discarded sharks, and determining whether the proportions of Discarded sharks, and of measured sharks, have changed over time. Changes in fisher behaviour might be expected to have occurred at the time of the introduction of the sharks to the QMS. However there is no way to determine whether measured Discarded sharks differ in length composition from unmeasured sharks.

[1] Sharks often school by size and sex.

Trends in measuring and discarding sharks

Observers recorded the fate of most sharks that they observed on SLL vessels. For the period 1993−2012, fate was recorded for 72.0% of 187 662 blue sharks, 92.6% of 18 605 porbeagle sharks, and 98.8% of 6098 mako sharks. The proportion of blue, porbeagle and mako sharks Discarded varied considerably among species and through time (Figure 28). The first three years in the time series had high discard rates for blue and porbeagle sharks, but these declined to low values by 1996. Discard rates were low for mako sharks in this early period (about 15%). Since 1996, the discard rate for blue sharks has been stable at 33%, but the discard rates for porbeagle and mako sharks have increased through time; porbeagles increased from 7−22% in the late 1990s to 35−64% in the last five years (2008−2012), and makos increased from 8−29% to 34−75%.

The proportion of sharks measured by observers varied greatly among years, but was usually higher in the Southwest region than the North region (Figure 29). Given this variability, it is difficult to discern any temporal trends, although the proportion of porbeagle and mako sharks measured in the North region may have declined in recent years, and the proportion of mako sharks measured was low in the early part of the Southwest series (particularly 1995 and 1996). Overall, smaller proportions of blue sharks were measured than porbeagle or mako sharks, presumably reflecting the fact that blue sharks are the most abundant of the three species, and were frequently tallied by observers when catches were high.

For all three shark species pre- and post-QMS, high proportions of small juvenile sharks were Discarded, but few large sharks were (Figures 30−32). For blue sharks, the percentage of all observed sharks that were Discarded remained the same post-QMS as pre-QMS (33%), as did the percentage of Landed sharks that were measured (44−57%). However, the percentage of Discarded sharks that were measured decreased substantially (60−63% pre-QMS to 16−21% post-QMS). For porbeagle sharks, the percentage Discarded increased substantially from 25% pre-QMS to 47% post-QMS, presumably because of Schedule 6 live releases. The percentage of Landed sharks that were measured increased slightly (69−74% pre-QMS to 80−81% post-QMS) but the percentage of Discarded sharks that were measured declined by about two-thirds (from 67−71% to 21−24%). For mako sharks, the percentage Discarded increased substantially from 28% pre-QMS to 49% post-QMS, presumably because of Schedule 6 live releases. The percentage of Landed sharks that were measured was about the same pre- and post-QMS (77−86%) but the percentage of Discarded sharks that were measured declined by about half (from 40−45% to 19−20%).

The big declines in the percentages of Discarded sharks that were measured make it difficult to discern any size-related trends resulting from the introduction of the sharks into the QMS and the introduction of Schedule 6 releases. They may also have exacerbated any size-related bias in shark measurements; i.e. the reductions in shark measurements may have been greater for large sharks than for small sharks, although percentages measured declined across the whole size range (Figures 30−32).

Sex ratios

The proportion of males in the observed catch showed no clear temporal trends (Figure 33). For blue sharks in the North region, there was a slight overall bias towards males (53%) but the sex ratio varied markedly among years. In the Southwest and Southeast regions, blue shark catches were dominated by females, with only 24% and 28% males respectively in the two regions. North catches were skewed towards males because of the presence there of mature adults as well as juveniles, and southern catches were dominated by females because of the large number of sub-adults (see next section for length-frequency distributions).

The proportion of male porbeagle sharks in the North region was generally higher in the first half of the time series than in the second half, although the relationship was weak. Overall, there were slightly more males than females in North (56%), and about equal numbers of both sexes in

Southwest and Southeast (51% and 49% males respectively). The North catch was skewed towards males because of the presence there of mature adults as well as juveniles (see next section).

The mako shark sex ratio was relatively stable over time in the North and Southwest regions. There were equal numbers of males and females in the North region (50% males), but there was a strong bias towards males in the Southwest region (82% males). Too few mako sharks were observed to estimate the proportion of males for the Southeast region.

Length-Frequencies

Large numbers of blue sharks were measured and sexed by observers between 1993 and 2012 (Figure 34). For all regions combined, males covered a broader length range (mainly 60–250 cm FL) than females (mainly 60–190 cm FL). Males in the North region had a broad distribution similar to the overall New Zealand distribution (60–250 cm), but in the Southwest region adult males over 200 cm long were rare, resulting in most sharks having a length range of 60–180 cm. The length distributions of female blue sharks were quite different in the North and Southwest regions: North sharks were mainly juveniles 60−160 cm, whereas Southwest sharks had a bimodal distribution consisting mainly of juveniles (60−110 cm) and subadults (130–180 cm). Sample sizes were small for the Southeast region, but the length distributions were similar to those in the Southwest region for both sexes. Length-frequency distributions by FMA generally reflected those of the associated region, except that FMA 9 had a higher proportion of large males and females than the other FMAs in the North region (FMAs 1 and 2) (Figure 35). FMA 10 (Kermadec Fisheries Management Area) had few juveniles shorter than 150 cm although small sample sizes mean that this interpretation is provisional. Annual length-frequency distributions by year and region (North and Southwest) are shown in Appendices 2 and 3. Caution should be used when interpreting these plots because sample sizes were frequently small, and may not have represented the fishery, particularly in the North region where observer coverage was low and unrepresentative. Nevertheless, there is some evidence of inter-annual variation in modal structure, particularly the relative abundance of juvenile and subadult modes.

Overall porbeagle shark length-frequency distributions were similar for both males and females, with strong juvenile modes at 75–90 cm and a strong mode of sub-adults at 110–150 cm FL (Figure 36). Large males and females made up a small but identifiable mode at the right end of each distribution. The strong juvenile mode was present in both the North and Southwest regions, but was absent from the Southeast region. Subadult males were present in all three regions, but adult males were proportionally more common in the North region than elsewhere. Subadult females dominated the Southwest and Southeast regions, but were uncommon in the North region, and there were few adult females in the North. FMAs 1, 2 and 7 had distributions of both sexes dominated by juveniles, whereas FMA 5 had similar proportions of subadults and juveniles, and FMA 3 had few juveniles (Figure 37). Insufficient data were available from FMAs 6, 9 and 10 to interpret. Annual length-frequency distributions by year and region (North and Southwest) are shown in Appendices 4 and 5. Caution should be used when interpreting these plots because sample sizes were frequently small, and may not have represented the fishery, particularly in the North region where observer coverage was low and unrepresentative.

Female mako sharks covered a broader size range than males, although few sharks were longer than 250 cm for either sex (Figure 38). In the North region, the distributions of both sexes were dominated by two or three juvenile modes between 70 and 175 cm. There was also a mode of mature males centred on about 200 cm but few mature females. In the Southwest region, the juvenile modes were missing or reduced, with the distributions being dominated by subadult and adult males and subadult females of 160–240 cm. Very few mature females were caught in any region. Distributions by FMA show that there were few small juveniles in FMAs 5 and 7, and that the distributions of mako sharks in FMA 10 were similar to those in FMAs 1 and 9 (Figure 39). Annual length-frequency distributions by year and region (North and Southwest) are shown in Appendices 6 and 7. Sample sizes were too small and probably too unrepresentative to permit interpretation of inter-annual patterns.

Maturity

For male blue sharks, immature, maturing and mature sharks (stages 1–3) were all well represented, allowing the fitting of a well-defined logistic growth curve (Figure 40). The estimated logistic parameters were $\beta_0 = -13.06 \pm 1.19$ (SE) and $\beta_1 = 0.080 \pm 0.008$. The estimated median length at maturity was 163.3 ± 19 cm. Very few mature females were sampled and length at maturity could not be estimated (Figure 40).

For porbeagle and mako sharks, too few sharks were staged, and more importantly too few mature (stage 3) sharks of either sex were observed, to allow the estimation of median length at maturity (Figures 41 and 42).

For reasons discussed below, the above estimate of male blue shark median length at maturity is regarded as too low. Furthermore, this study has not produced estimates of median maturity for porbeagle and mako sharks or female blue sharks. Consequently, the estimates of median length at maturity for both sexes of all three species produced earlier by Francis & Duffy (2005) were adopted for this study. The percentages of sharks that were mature in the 1993−2012 observer time series were estimated by applying these lengths at maturity to the relevant length-frequency distributions (Figure 43). Few mature females were observed for any of the three species: over the whole time series, estimated percentages mature in the three regions were 5−8% for blue sharks, 2−5% for porbeagle sharks, and 1−2% for mako sharks.

Higher proportions of males were found to be mature (Figure 43). For North region male blue sharks, the annual percentage mature fluctuated between 8 and 51% (18% overall). The percentage mature was higher on average before 2004 (36%) than from 2004 onwards (16%). Since the distinct change in 2004 coincided with the introduction of Schedule 6 releases, and a large reduction in the proportion of discarded sharks that were measured (Figure 30), this may reflect changes in fisher and observer practices rather than a real decline in the percentage of mature sharks being caught. Few mature males were observed in the Southwest and Southeast regions (1% and 0% respectively).

Mature male porbeagles made up 21−27% overall of the sharks observed in the three regions (Figure 43). However, the percentages fluctuated markedly among years and again there appeared to be a step down for North region males in about 2004. A high percentage of Southwest male makos were mature (66% overall), but the North region had a lower, variable percentage mature that also showed a step down in 2005.

Shark fin conversion factors

The vast majority of fin weight data came from chartered Japanese vessels (Table 3) which typically kept the entire tail as part of their fin sets; i.e. they did not discard the upper lobe of the tail as was the common practice on New Zealand domestic vessels. Consequently, 97.3% of the fin sets from 664 individual sharks comprised two pectoral fins, the first dorsal fin, and the whole tail removed at the caudal peduncle (such fin sets were classified here as fin code "A"). Most aggregated fin sets (90.1% of 128) were also class A, with the few remaining fin sets also including pelvic and/or second dorsal fins. Only class A fin sets provided enough data for analysis, so other fin classes have been omitted from the following analyses.

For blue sharks there is evidence of bimodality in plots of fin weight versus FL and whole weight (Figure 44). This may have been due to variable treatment of fins (e.g. the amount of meat removed when cutting and trimming the fins), the inclusion of different fins or portions of the tail in the weights (i.e., some of the data may not actually qualify for fin code A), or difficulties measuring small weights at sea on moving vessels. As a result of these issues, the data were highly variable among shark fin sets. Nevertheless, there were strong linear relationships between fin weight and whole weight, with near identical regressions for males and females. After exclusion of sharks with fin weight ratios of 50 or more, an indication of measurement errors (see outliers in Figure 44, middle left panel), the following regressions were obtained:

Males:		Fin weight = 0.174 + 0.0491 Whole weight
Females:	Fin weight = 0.193 + 0.0453 Whole weight
Fin sets aggregated for two or more blue sharks showed a tighter relationship between fin weight and whole weight (Figure 44). The regression relationship was:
Both sexes:	Fin weight = 0.620 + 0.0512 Whole weight
Conversion factors based on the inverse of the three regression slopes are 20.4 and 22.1 for males and females respectively, and 19.5 for aggregated fins. Given the likely large errors when weighing individual fins on standard scales at sea, and the uncertainty about whether all fins sets complied with fin code A, a suggested reasonable conversion factor for blue shark wet fin sets that include the whole tail is 20. Baird (2009) reported a blue shark conversion factor of 14.53 based on 139 blue sharks (total weight 2680 kg) weighed by an observer on a chartered Japanese SLL vessel; this value falls within the cloud of aggregated fin weight data obtained in this study (Figure 44).

For porbeagle and mako sharks, there were insufficient data to estimate regression relationships between fin weight and whole weight (Figures 45 and 46). However visual inspection of the data for both species suggests that conversion factors in the range 20−25 may be appropriate for wet fin sets that include the whole tail.

The mako shark fin set data from recreational fishing competitions were collected onshore using accurate scales, and they included first dorsal, pectoral and lower caudal fins after removal of excess meat (C. Duffy, pers. comm.). These data therefore approximate the processing methods used by New Zealand domestic SLL vessels. Fin weights in this data set were clearly lower than those obtained by observers for sharks of the same length (Figure 46). They also show clear evidence of variation with mako shark size: the ratio of whole weight to fin weight declined from a mean of 70 in sharks shorter than 150 cm to a mean of 45 for sharks 250 cm or longer. The overall mean ratio for all sharks in the sample was 58.5.

4. DISCUSSION

This study focussed on blue, porbeagle and mako sharks, the main highly migratory elasmobranchs caught by New Zealand commercial fisheries. A fishery characterisation was carried out for the fishing years 2007–08 to 2010–11 as a basis for designing an at-sea observer sampling programme for the three sharks to estimate their catch composition, biological parameters such as size at maturity, and shark fin conversion factors. Between 2007–08 and 2010–11, nearly all (98–99%) of the blue shark catch was taken by SLL from FMAs 1 and 2. Most of the catch was finned, but an increasing proportion was discarded whole. Most porbeagle shark catch (74–84%) was taken by SLL in FMAs 1, 2 and 7, but a significant proportion (13–22%) came from midwater trawl. A high proportion of the porbeagle catch was finned. Most (92–95%) of the mako shark catch was taken by SLL from FMAs 1 and 2, and most was finned, or discarded whole, although a significant amount was processed for its flesh. These patterns are consistent with those identified in earlier studies of the bycatch of New Zealand SLL fisheries (Francis et al. 1999, 2001, 2004, Griggs et al. 2007, 2008, Griggs & Baird 2013).

Observers began sampling SLL catches of the three sharks in 1988, although consistently accurate identification of porbeagle and mako sharks was not achieved until 1993. Intensified sampling of the three pelagic sharks was implemented in 2010–11 and 2011–12. Few samples were obtained from trawl vessels, with most vertebrae and data coming from SLL vessels. For blue sharks, observer maturity sampling was reasonably representative during the peak period of May–August in both North and Southwest SLL fisheries, but vertebral and fin weight sampling was restricted to the Southwest SLL fishery and was therefore unrepresentative. Similar comments apply to the sampling of porbeagle and mako sharks, but very small samples sizes exacerbated the representativeness problems.

Analysis of long time series (1993−2012) of observer data revealed that there has been an increase in the proportion of porbeagle and mako sharks (but not blue shark) discarded by SLL vessels since

1996. Although the proportion of sharks measured by observers showed no long-term trends for blue sharks, and female porbeagle and mako sharks, the annual estimates were often highly variable and there may have been overall declines for male porbeagle and mako sharks. In conjunction with a large decrease in the proportion of discarded sharks that were measured, and a likely bias in measurements of discarded sharks towards small individuals, the declining trends noted in the percentages of mature blue, porbeagle and mako sharks should not be interpreted as real as they are probably biased by changing fisher and observer practices, particularly associated with the introduction of these sharks to the QMS in 2004 and the associated ability to release live sharks under Schedule 6.

The interpretation of porbeagle and mako shark length-frequency distributions obtained from observer data is unfortunately confounded by the trends in fisher and observer practices. This could be partly mitigated by scaling the annual length-frequency distributions for Landed and Discarded sharks by the inverse of the proportions of sharks classified within each of these classes; this will give increasing weight to the length distributions of discarded sharks, and decreasing weight to the distributions of Landed sharks, through time. Scaling length-frequency distributions should be done on data stratified by region and vessel nationality to account for spatial and fleet differences in the way sharks are handled. However, data scaling will not correct any bias caused by observers tending to measure more small sharks and fewer large sharks.

Although the interpretation of trends in length-frequency distributions through time may be compromised by data issues, there are strong spatial patterns in the size composition of pelagic sharks in New Zealand waters. The patterns shown here (Figures 34−39) are essentially the same as those illustrated using a small subset of the current data collected up to 1998 (Francis et al. 2000, 2001), indicating that spatial variation in size composition is real and robust. Mature females of all three species were rare in all regions, presumably reflecting their scarcity in the fished areas. Mature, pregnant female blue sharks are often reported by observers on vessels working in FMA 10 near the Kermadec Islands (MPI and NIWA unpubl. data) but are poorly represented in the current study because few observer trips have been there. Pregnant female porbeagle sharks are caught most often off the southwest South Island, suggesting that the centre of their distribution may be south of New Zealand (Francis & Stevens 2000). Pregnant female mako sharks are very rarely seen in New Zealand waters (Duffy & Francis 2001), although new-born young are common in the North region, suggesting that females give birth in waters around northern North Island. The low incidence of mature female pelagic sharks in SLL catches suggests that this demographic category may enjoy a refuge from fishing pressure, unless they are taken by other fishing fleets on the high seas.

Female pelagic sharks caught in New Zealand waters are mainly juveniles and subadults. In the North region, catches of female blue, porbeagle and mako sharks are dominated by juveniles whereas in the Southwest and Southeast regions, catches have a much higher proportion of subadults as well as juveniles (juvenile porbeagles appear to be rare in the Southeast region, and mako abundance is very low there). Mature male blue sharks were present in significant numbers in the North but absent from the Southwest and Southeast; catches in the latter two regions were dominated by juveniles and to a lesser extent subadults. Porbeagle males showed similar size composition in the North and Southwest regions, being dominated by juveniles and subadults, but with a significant proportion of adults. Male mako sharks had a wide size range in the North region, from juveniles to adults, whereas the Southwest and Southeast regions produced mainly mature adults and subadults.

Sex ratios were close to equality for all three species in the North region (albeit with high inter-annual variation for blue sharks). In the Southwest and Southeast regions, blue shark catches were dominated by females, mako shark catches by males, and porbeagle shark catches had similar proportions of both sexes. In combination, the spatial variation in length composition and sex ratios indicate that blue and mako sharks segregate spatially by size and sex, whereas porbeagles are more uniformly distributed but with a higher proportion of juveniles in the north and subadults in the south. Spatial and sexual segregation are common in sharks, and have been reported for pelagic sharks elsewhere (Nakano et al. 1985, Nakano 1994, Nakano & Nagasawa 1996, Mucientes et al. 2009).

The amount of new data collected on pelagic shark maturity status was insufficient for estimating length at maturity for all except blue shark males. Median male blue shark maturity was estimated to be 163.3 ± 19 cm FL, based on clasper size, calcification and mobility characters. This is considerably shorter than the median length at maturity (190−195 cm) estimated previously for New Zealand blue sharks using a suite of reproductive characters (including the clasper characters mentioned) (Francis & Duffy 2005). In blue sharks, unlike in most other shark species, clasper length increases continuously across most of the length range, coming to an asymptote only in very large sharks (Pratt 1979, Francis & Duffy 2005). This makes it difficult to ascertain maturity from clasper length alone. The smallest male blue shark found by Francis & Duffy (2005) with spermatozeugmata (visible packets of spermatozoa) in its seminal vesicles was 164 cm, and 50% of males contained spermatozeugmata by 194 cm. Thus although clasper characters may indicate that incipient mating potential is reached in sharks at around 163 cm, their ability to fertilise oocytes probably does not occur until considerably later. The 190−195 cm size at maturity estimated by Francis & Duffy (2005) remains the best estimate available. Similarly, that study also provides the best estimates of lengths at maturity for female blue sharks, and male and female porbeagle and mako sharks in New Zealand waters.

The current MPI conversion factors for wet shark fins are 48 for blue shark, 45 for porbeagle shark, and 59 for mako shark[2]. The legal definition of wet fins includes "pectoral fins, dorsal fin and the lower lobe of the caudal fin". Thus the current conversion factors were designed for vessels (such as most New Zealand domestic SLL vessels) that land only the lower lobe of the tail rather than the entire tail. Chartered Japanese SLL vessels retain the entire tail, resulting in actual conversion factors of about 20 for blue sharks and about 20−25 for porbeagle and mako sharks (this study). Consequently, when the fin weights of chartered Japanese vessels are scaled up to whole weight by applying a conversion factor, the landings will be overestimated by factors of about 2.4 for blue shark, 2.0 for porbeagle shark, and 2.6 for mako shark. The conversion factor estimated from recreationally caught mako sharks was 58.5 (averaged across a range of shark lengths), and is consistent with the official conversion factor of 59.

5. RECOMMENDATIONS

Trends in biological parameters may be valuable indicators of the health of a shark population. 'Indicator' analyses can involve monitoring trends in size composition, proportion of the population that is mature, sex ratio, distribution, and catch rates (Clarke et al. 2011, 2013). In this study, trends in SLL discarding and measurement practices resulted in the utility of the time series of length-frequency data, and consequently measures such as median length and percentage mature, being compromised. In order to restore the utility of such time series, improved data collection procedures are required. They include:

1. Use of motion-compensated scales to improve the accuracy of fin weights measured at sea.
2. Individual recording of all sharks landed, including noting the life status, fate, sex and size. Tallied sharks provide little useful data, and may bias the other data collected.
3. A higher proportion of Discarded sharks should be measured and sexed to avoid length bias.

Items 1 and 2 are already being implemented by the MPI Observer Programme, and should quickly produce higher quality data.

Clasper characters have proven insufficient to accurately estimate maturity of male blue sharks, and inspection of seminal vesicles for presence of spermatozeugmata is recommended as an additional maturity character in future, at least on subsamples of the sharks. Porbeagle and mako sharks show strong inflections in clasper length (Francis & Duffy 2005), indicating that maturity estimates based on clasper development are more reliable for them than for blue sharks (although the production of spermatophores lags complete clasper development in the former (Francis & Duffy 2005)). Importantly, clasper characters can be assessed on live sharks that are being released, so there is merit in continuing to collect these data in a consistent way, even if they underestimate length at maturity.

[2] Dried shark fins have separate conversion factors but they are virtually never reported by SLL vessels.

Spermatophore and spermatozeugmata data would enable the degree of underestimation to be determined and corrected.

6. ACKNOWLEDGMENTS

Thanks to Lynda Griggs and MPI for providing data extracts. Warrick Lyon inventoried the vertebral samples. Warrick Lyon and Jordan Housiaux punched and checked the observer vertebral, maturity and fin data. Clinton Duffy provided mako shark fin weight data from recreational fishing competitions. Helpful suggestions were received from members of the MPI Highly Migratory Species Working Group. The draft report was reviewed by Reyn Naylor and Stephen Brouwer. This work was completed under Objectives 1–3 of Ministry for Primary Industries project HMS201003.

7. REFERENCES

Ayers, D.; Francis, M.P.; Griggs, L.H.; Baird, S.J. (2004). Fish bycatch in New Zealand tuna longline fisheries, 2000–01 and 2001–02. *New Zealand Fisheries Assessment Report 2004/46*. 47 p.

Baird, S.J. (2009). Characterisation of pelagic fisheries using observer data. *New Zealand Fisheries Assessment Report 2009/6*. 58 p.

Bishop, S.D.H.; Francis, M.P.; Duffy, C.; Montgomery, J.C. (2006). Age, growth, maturity, longevity and natural mortality of the shortfin mako (*Isurus oxyrinchus*) in New Zealand waters. *Marine and Freshwater Research 57*: 143–154.

Clarke, S.; Harley, S.; Hoyle, S.; Rice, J. (2011). An indicator-based analysis of key shark species based on data held by SPC-OFP. *Western Central Pacific Fisheries Commission Scientific Committee seventh regular session SC7-EB-WP-01*. 88 p.

Clarke, S.C.; Francis, M.P.; Griggs, L.H. (2013). Review of shark meat markets, discard mortality and pelagic shark data availability, and a proposal for a shark indicator analysis. *New Zealand Fisheries Assessment Report 2013/65*. 74 p.

Duffy, C.; Francis, M.P. (2001). Evidence of summer parturition in shortfin mako (*Isurus oxyrinchus*) sharks from New Zealand waters. *New Zealand Journal of Marine and Freshwater Research 35*: 319–324.

Francis, M.P.; Campana, S.E.; Jones, C.M. (2007). Age under-estimation in New Zealand porbeagle sharks (*Lamna nasus*): is there an upper limit to ages that can be determined from shark vertebrae? *Marine and Freshwater Research 58*: 10–23.

Francis, M.P.; Davies, N.; Griggs, L.H. (2006). Methods for the application of a shore-based catch sampling programme for highly migratory species. Final Research Report for Ministry of Fisheries Research Project TUN2005–02, Objective 2. 36 p. (Unpublished report held by Ministry for Primary Industries, Wellington.)

Francis, M.P.; Duffy, C. (2005). Length at maturity in three pelagic sharks (*Lamna nasus*, *Isurus oxyrinchus*, and *Prionace glauca*) from New Zealand. *Fishery Bulletin 103*: 489–500.

Francis, M.P.; Griggs, L.H.; Baird, S.J. (2001). Pelagic shark bycatch in the New Zealand tuna longline fishery. *Marine and Freshwater Research 52*: 165–178.

Francis, M.P.; Griggs, L.H.; Baird, S.J. (2004). Fish bycatch in New Zealand tuna longline fisheries, 1998–99 to 1999–2000. *New Zealand Fisheries Assessment Report 2004/22*. 62 p.

Francis, M.P.; Griggs, L.H.; Baird, S.J.; Murray, T.E.; Dean, H.A. (1999). Fish bycatch in New Zealand tuna longline fisheries. *NIWA Technical Report 55*. 70 p.

Francis, M.P.; Griggs, L.H.; Baird, S.J.; Murray, T.E.; Dean, H.A. (2000). Fish bycatch in New Zealand tuna longline fisheries, 1988–89 to 1997–98. *NIWA Technical Report 76*. 79 p.

Francis, M.P.; Stevens, J.D. (2000). Reproduction, embryonic development and growth of the porbeagle shark, *Lamna nasus*, in the south-west Pacific Ocean. *Fishery Bulletin 98*: 41–63.

Griggs, L.; Francis, M.; Baird, S. (2006). Validation of TLCER longline catch data in 2004–05. Final Research Report for Ministry of Fisheries Research Project TUN2004–01 Objective 5. 32 p. (Unpublished report held by Ministry for Primary Industries, Wellington.)

Griggs, L.H.; Baird, S.J. (2013). Fish bycatch in New Zealand tuna longline fisheries 2006–07 to 2009–10. *New Zealand Fisheries Assessment Report 2013/13*. 73 p.

Griggs, L.H.; Baird, S.J.; Francis, M.P. (2007). Fish bycatch in New Zealand tuna longline fisheries 2002–03 to 2004–05. *New Zealand Fisheries Assessment Report 2007/18*. 58 p.

Griggs, L.H.; Baird, S.J.; Francis, M.P. (2008). Fish bycatch in New Zealand tuna longline fisheries in 2005–06. *New Zealand Fisheries Assessment Report 2008/27*. 47 p.

Manning, M.J.; Francis, M.P. (2005). Age and growth of blue shark (*Prionace glauca*) from the New Zealand Exclusive Economic Zone. *New Zealand Fisheries Assessment Report 2005/26*. 52 p.

Ministry of Fisheries Science Group (2011). Report from the mid-year Fisheries Assessment Plenary, November 2011: stock assessments and yield estimates. (Unpublished report held in NIWA library, Wellington.) 355 p.

Mucientes, G.R.; Queiroz, N.; Sousa, L.L.; Tarroso, P.; Sims, D.W. (2009). Sexual segregation of pelagic sharks and the potential threat from fisheries. *Biology Letters 5*: 156–159.

Nakano, H. (1994). Age, reproduction and migration of blue shark in the North Pacific Ocean. *Bulletin of the National Research Institute of Far Seas Fisheries 31*: 141–256.

Nakano, H.; Makihara, M.; Shimazaki, K. (1985). Distribution and biological characteristics of the blue shark in the central North Pacific. *Bulletin of the Faculty of Fisheries, Hokkaido University 36*: 99–113.

Nakano, H.; Nagasawa, K. (1996). Distribution of pelagic elasmobranchs caught by salmon research gillnets in the North Pacific. *Fisheries Science 62*: 860–865.

Pratt, H.L. (1979). Reproduction in the blue shark, *Prionace glauca*. *Fishery Bulletin 77*: 445–470.

R Development Core Team. (2008). R: A language and environment for statistical computing. http://www.R-project.org. R Foundation for Statistical Computing, Vienna, Austria.

8. TABLES

Table 1: Estimated catches, landings, catches by fishing method, and catch/landing ratios by species and fishing year. MHR, Monthly Harvest Returns; SLL, surface longline; MW, midwater trawl.

	Fishing	MHR	Estimated		Percent catch by method			Catch/Landing ratio	
Species	year	landings	catch	Landings	SLL	MW	Other	All methods	SLL
Blue shark	2007-08	687	883	675	99.0	0.1	0.9	1.31	1.32
	2008-09	804	993	759	98.9	0.1	1.0	1.31	1.31
	2009-10	696	1,025	661	99.3	0.1	0.6	1.55	1.56
	2010-11	770	1,133	741	99.2	0.1	0.7	1.53	1.54
	Total	2,957	4,033	2,836	99.1	0.1	0.8	1.42	1.43
Porbeagle shark	2007-08	41	42	31	74.1	22.3	3.6	1.36	1.83
	2008-09	61	69	45	77.7	19.6	2.6	1.53	1.83
	2009-10	65	75	46	84.0	12.6	3.4	1.64	1.97
	2010-11	73	84	52	82.3	13.4	4.3	1.63	2.12
	Total	240	269	173	80.3	16.2	3.5	1.56	1.96
Mako shark	2007-08	74	94	68	92.3	2.1	5.6	1.38	1.44
	2008-09	78	109	69	93.6	0.9	5.4	1.59	1.70
	2009-10	67	127	65	92.0	1.8	6.2	1.96	2.18
	2010-11	91	159	78	95.4	0.9	3.6	2.03	2.18
	Total	310	488	279	93.5	1.4	5.1	1.75	1.88

Table 2: Number of surface longline (SLL) vessels and sets, observer coverage, and number of vessels sampled for vertebrae, maturity data or fin weights during 2010–11 and 2011–12.

Fishery	Fishing year	Fleet	No. of trips	No. of sets	Observed trips	Observed Sets	% sets observed	Trips sampled
SLL	2010-11	Charter	4	151	4	151	100.0	4
SLL	2010-11	Domestic	568	2736	14	172	6.3	3
SLL	2011-12	Charter	4	164	4	164	100.0	4
SLL	2011-12	Domestic	560	2617	12	174	6.6	7

Table 3: Observer samples of vertebrae, maturity and individual fin weights collected in 2010–11 and 2011–12. SLL, surface longline; TWL, trawl; C, chartered; D, domestic; STN, southern bluefin tuna; BIG, bigeye tuna; SWO, swordfish; HOK, hoki; SBW, southern blue whiting; HAK, hake; BAR, barracouta; BWS, blue shark; POS, porbeagle shark; MAK, mako shark.

2010-11 fishing year							Vertebrae				Maturity				Individual fin weights			
Trip	Year	Months	Method	Fleet	FMAs	Target species	BWS	POS	MAK	Total	BWS	POS	MAK	Total	BWS	POS	MAK	Total
1	2011	Apr-Jun	SLL	C	5, 7	STN	67	11	0	78	492	12	2	506	221	9	2	232
2	2011	Apr-Jun	SLL	C	5, 7	STN	20	8	3	31	0	0	1	1	12	7	3	22
3	2011	Apr-Jun	SLL	C	1, 5, 7	STN/BIG	51	0	5	56	236	5	5	246	0	0	0	0
4	2011	Apr-Jun	SLL	C	5, 7	STN	41	14	2	57	66	5	2	73	149	22	2	173
5	2011	Jun-Aug	SLL	D	1, 2	STN/BIG/SWO	0	0	0	0	385	41	24	450	0	0	0	0
6	2011	Jun-Jul	SLL	D	1, 2	STN	0	0	0	0	23	3	1	27	0	0	0	0
7	2011	Jul-Aug	SLL	D	1	STN/SWO	0	0	0	0	6	15	7	28	0	0	0	0
8	2011	Aug-Sep	TWL	C	6, 7	HOK/SBW	0	5	0	5	0	0	0	0	0	0	0	0
9	2011	Aug-Sep	TWL	D	3, 7	HOK/HAK/BAR	0	3*	0	0	0	3	0	3	0	3	0	3
Total							179	38	10	227	1 208	84	42	1 334	382	41	7	430
2011-12 fishing year																		
10	2012	May-Jun	SLL	D	2	STN	0	0	0	0	229	0	9	238	0	0	0	0
11	2012	Apr-Jun	SLL	C	5,7	STN	125	6	5	136	223	6	4	233	146	6	5	157
12	2012	Apr-Jun	SLL	C	5,7	STN	34	8	7	49	0	0	0	0	0	0	0	0
13	2012	Apr-Jun	SLL	C	5,7	STN	80	1	2	83	63	0	0	63	0	1	0	1
14	2012	Apr-Jun	SLL	C	5,7,9	STN/BIG	150	17	6	173	0	0	0	0	57	10	5	72
15	2012	May,Jul-Aug	SLL	D	7,9,1	STN/SWO	0	0	0	0	79	0	7	86	0	1	3	4
16	2012	May-Jul	SLL	D	2	STN	8	13	9	30	8	12	9	29	0	0	0	0
17	2012	Jun	SLL	D	1,2	STN	0	0	0	0	13	0	6	19	0	0	0	0
18	2012	Jun-Jul	SLL	D	1	STN	19	6	2	27	19	6	2	27	0	0	0	0
19	2012	Jun-Jul	SLL	D	7	STN	0	0	0	0	1	0	0	1	0	0	0	0
20	2012	Aug-Oct	SLL	D	1,9	STN/BIG	3	6	11	20	4	6	11	21	0	0	0	0
Total							419	57	42	518	639	30	48	717	203	18	13	234
Grand total							598	95	52	745	1847	114	90	2051	585	59	20	664
* Three POS vertebrae from Trip 9 not found and not included in totals																		

Table 4: Linear regression parameters used for estimating fork length from precaudal length (PCL) and total length (TL). Sample sizes are shown in Figure 27. BWS, blue shark; POS, porbeagle shark; MAK, mako shark.

Species	Length2	Intercept	Slope
BWS	PCL	1.6091	1.0853
BWS	TL	0.1758	0.8387
POS	PCL	2.1096	1.1068
POS	TL	0.3369	0.8896
MAK	PCL	1.6902	1.0919
MAK	TL	0.8010	0.9119

9. FIGURES

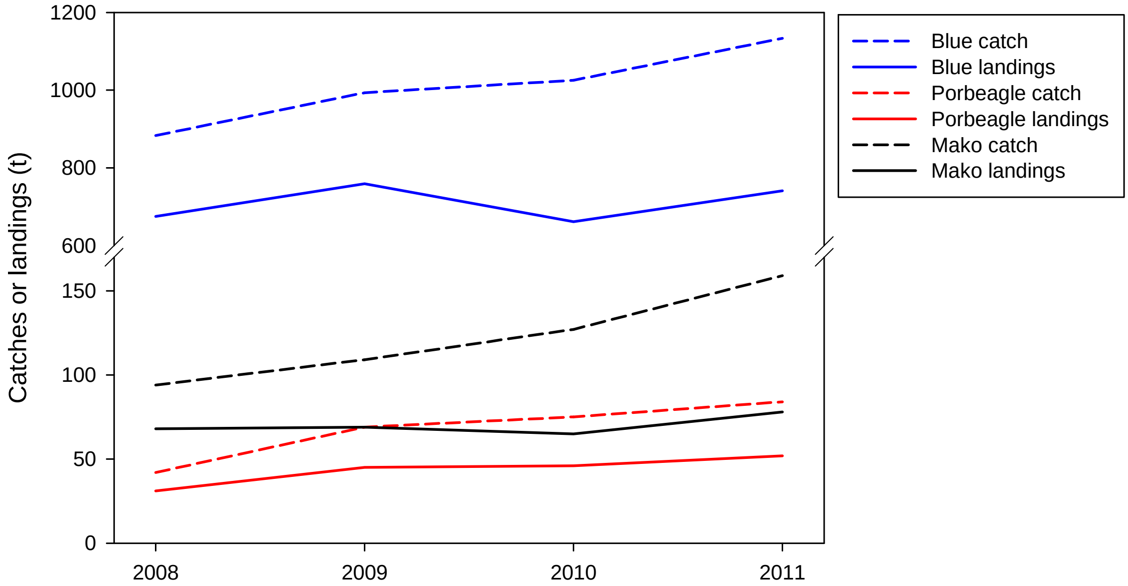


Figure 1: Estimated catches and landings of blue, porbeagle and mako sharks for fishing years 2007–08 to 2010–11.

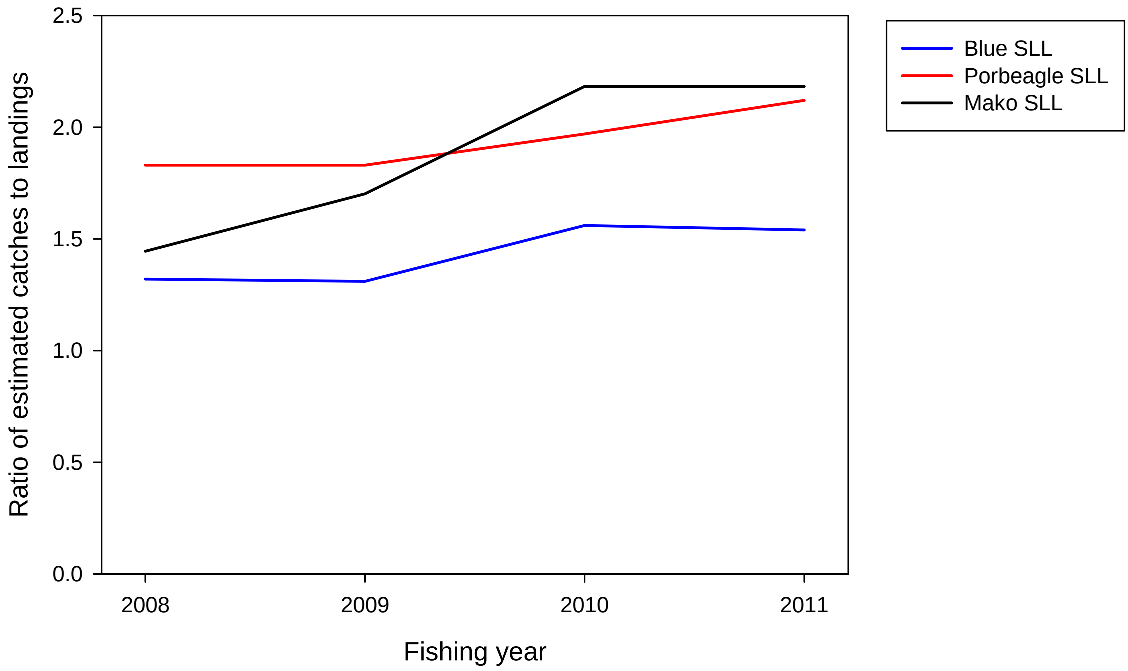


Figure 2: Ratio of estimated catches to landings of blue, porbeagle and mako sharks taken by surface longline for fishing years 2007–08 to 2010–11.

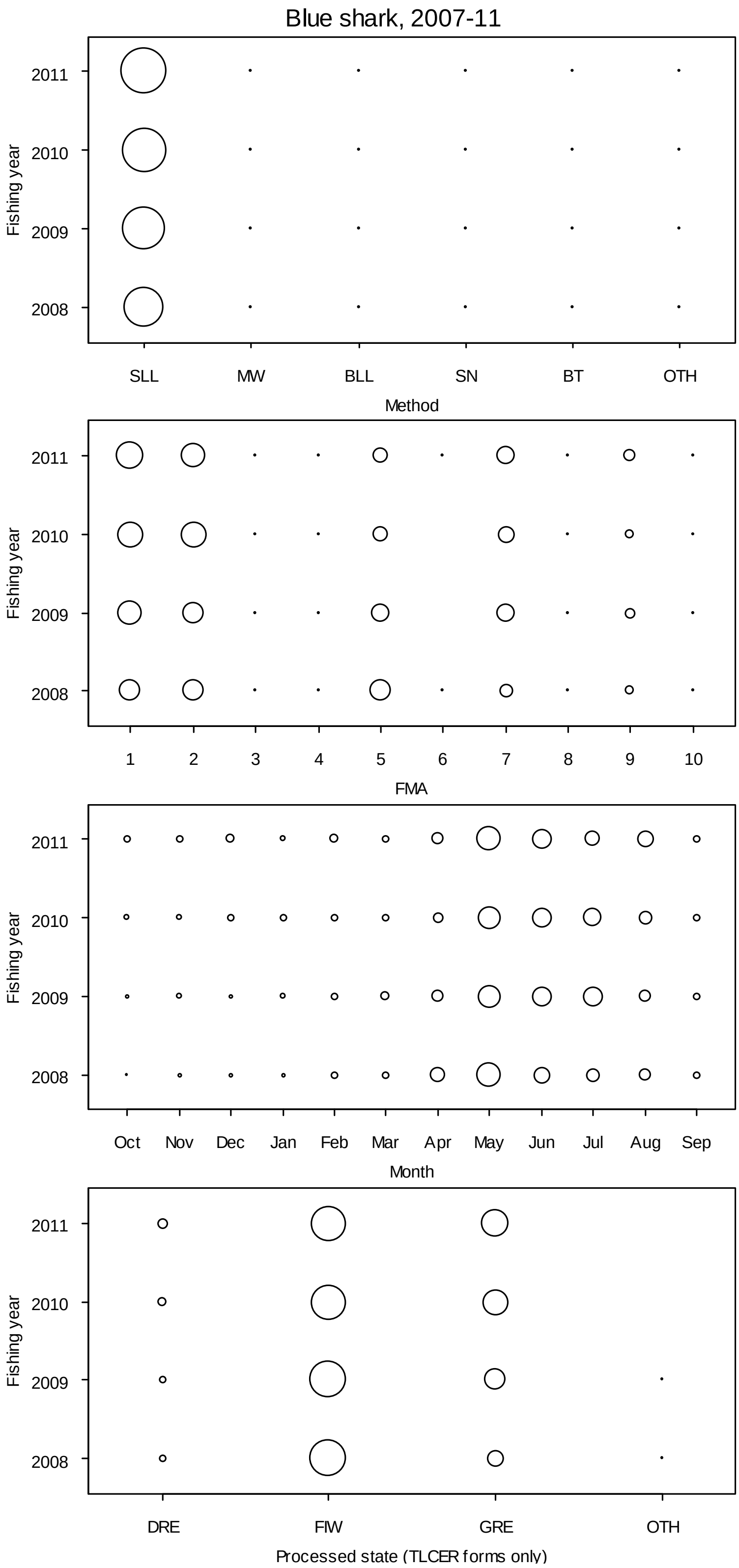


Figure 3: Proportional distribution of blue shark estimated catches by fishing method, FMA, month, and processed state for the fishing years 2007–08 to 2010–11. Fishing method codes: SLL, surface longline; MW, midwater trawl; BLL, bottom longline; SN, set net; BT, bottom trawl; OTH, other methods. Processed state codes: DRE, dressed; FIW, wet fins; GRE, green (whole); OTH, other states.

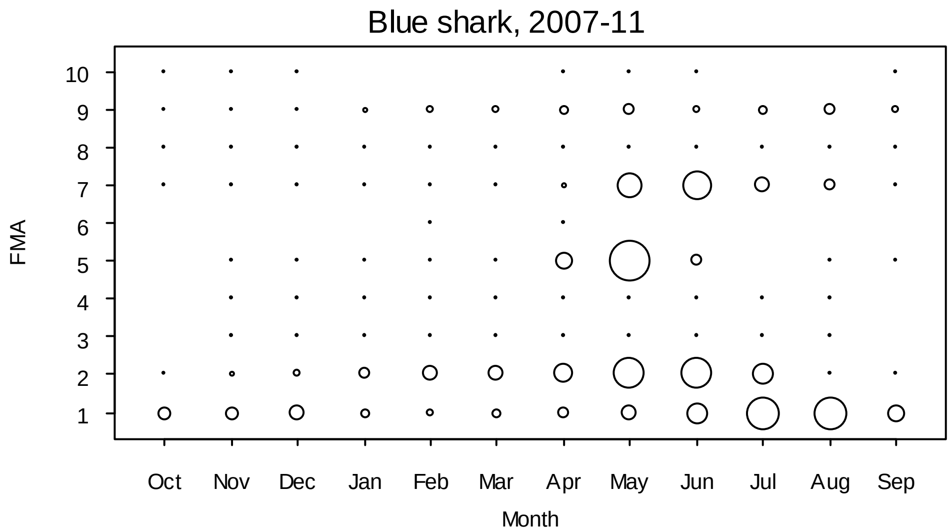


Figure 4: Proportional distribution of blue shark estimated catches by FMA and month for the fishing years 2007–08 to 2010–11 combined.

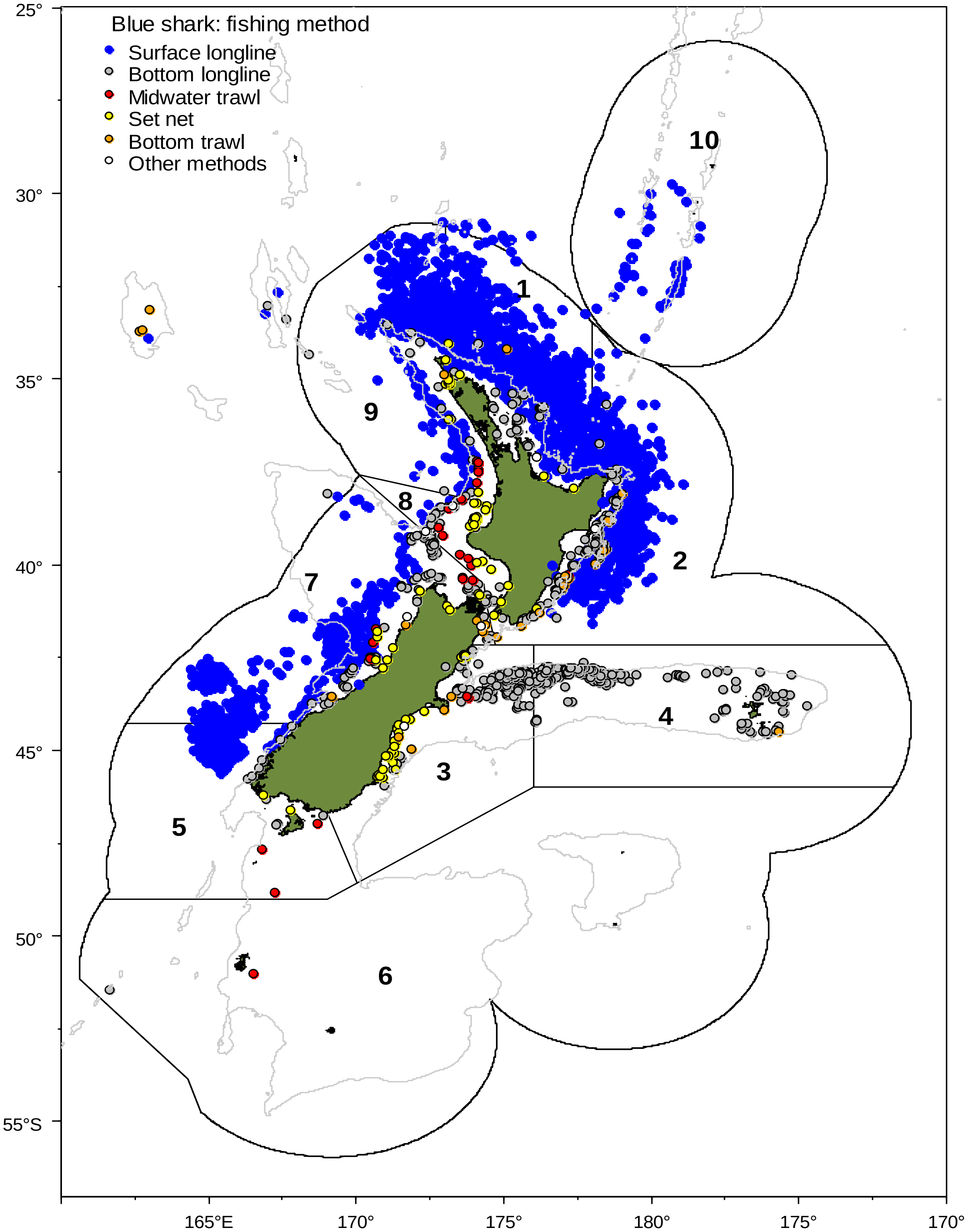


Figure 5: Start-of-set or start-of-tow positions for fishing events from 2007–08 to 2010–11 reporting estimated catches of blue shark. Black lines indicate boundaries of the EEZ and FMAs (numbered) and the grey line is the 1000 m depth contour.

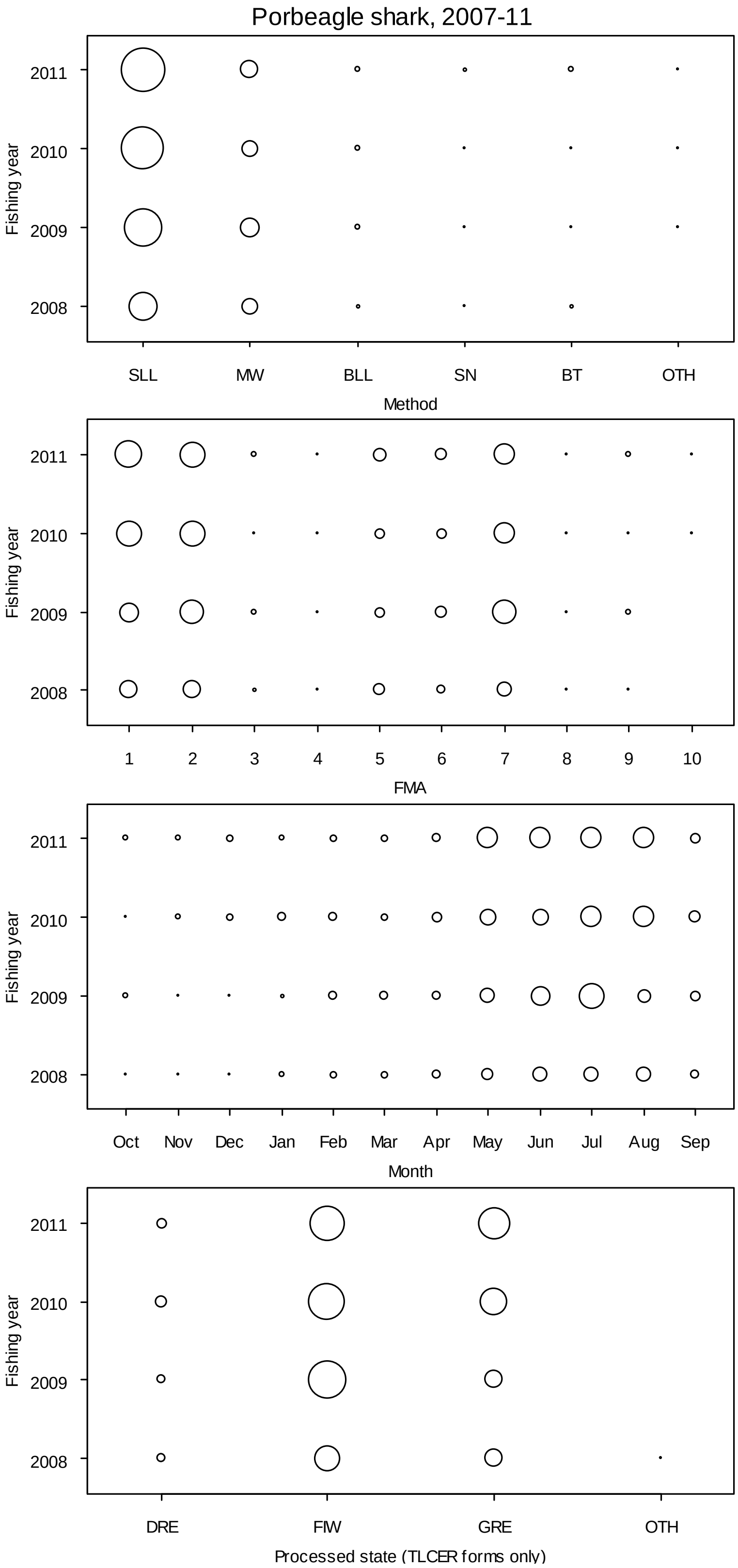


Figure 6: Proportional distribution of porbeagle shark estimated catches by fishing method, FMA, month, and processed state for the fishing years 2007–08 to 2010–11. Fishing method codes: SLL, surface longline; MW, midwater trawl; BLL, bottom longline; SN, set net; BT, bottom trawl; OTH, other methods. Processed state codes: DRE, dressed; FIW, wet fins; GRE, green (whole); OTH, other states.

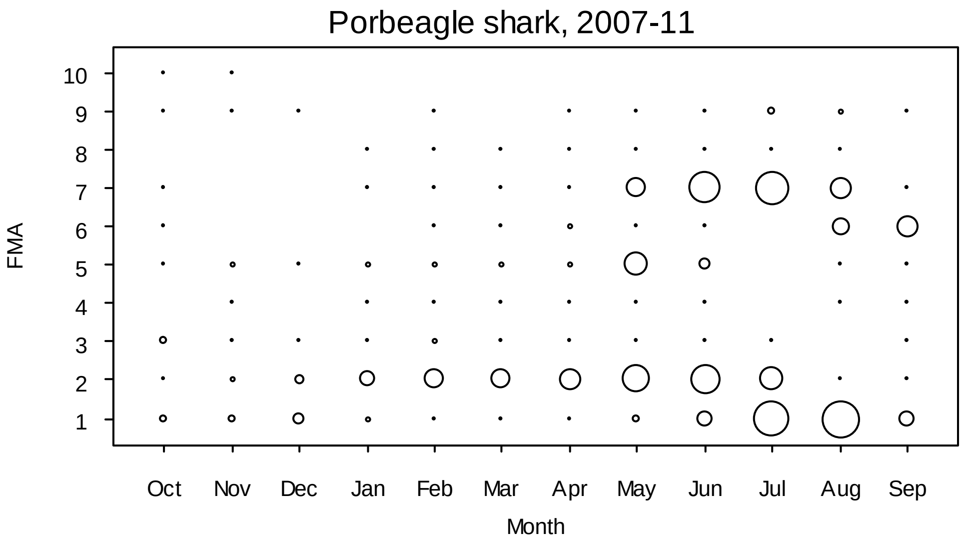


Figure 7: Proportional distribution of porbeagle shark estimated catches by FMA and month for the fishing years 2007–08 to 2010–11 combined.

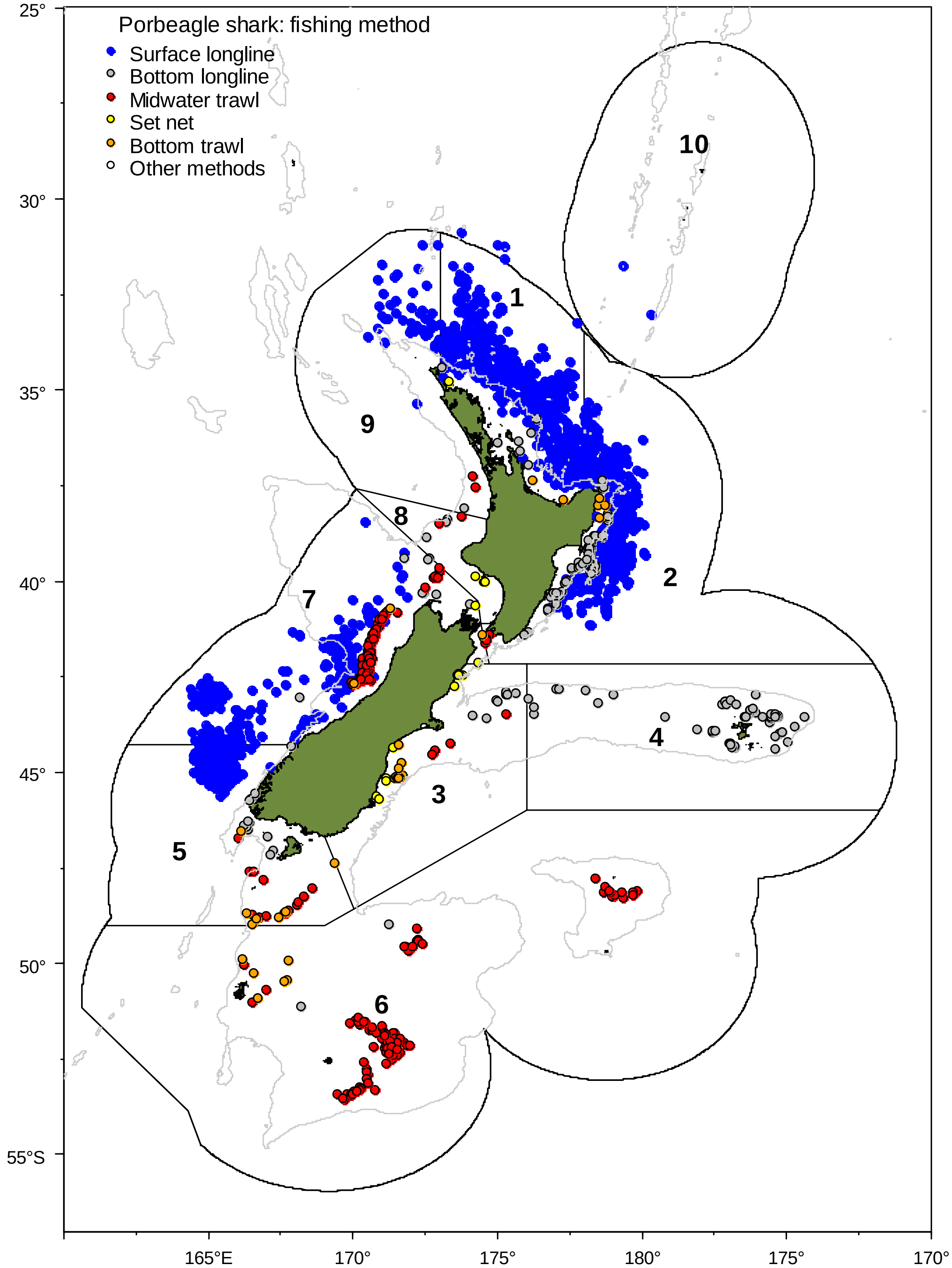


Figure 8: Start-of-set or start-of-tow positions for fishing events from 2007–08 to 2010–11 reporting estimated catches of porbeagle shark. Black lines indicate boundaries of the EEZ and FMAs (numbered) and the grey line is the 1000 m depth contour.

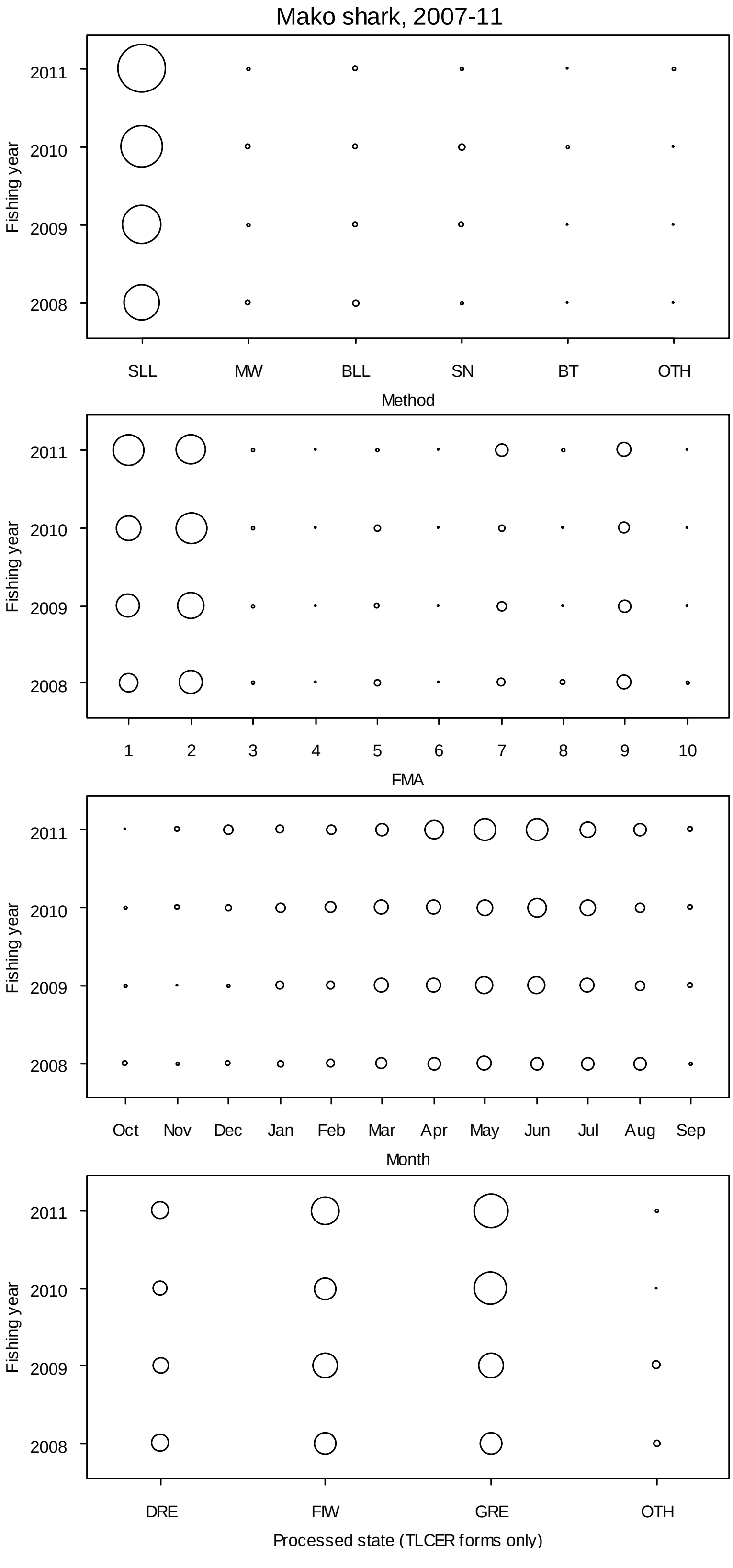


Figure 9: Proportional distribution of mako shark estimated catches by fishing method, FMA, month, and processed state for the fishing years 2007–08 to 2010–11. Fishing method codes: SLL, surface longline; MW, midwater trawl; BLL, bottom longline; SN, set net; BT, bottom trawl; OTH, other methods. Processed state codes: DRE, dressed; FIW, wet fins; GRE, green (whole); OTH, other states.

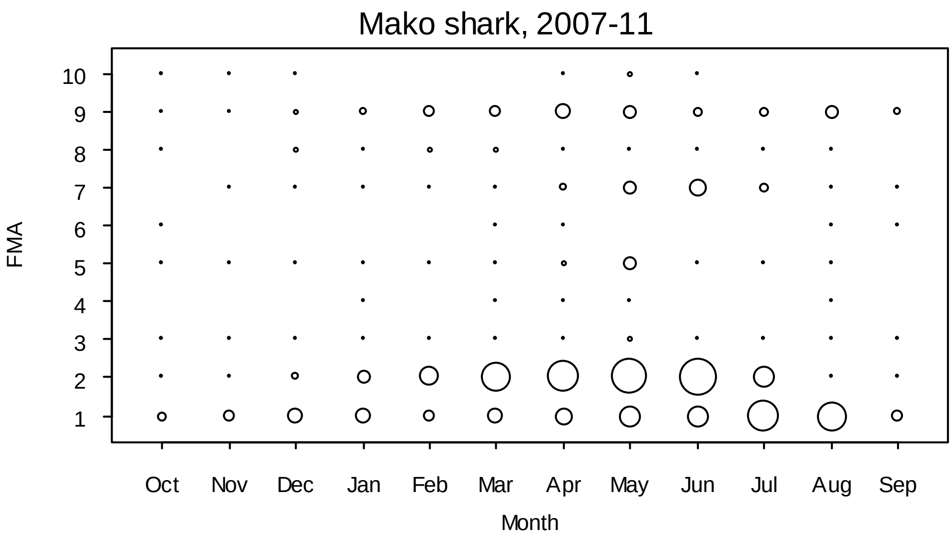


Figure 10: Proportional distribution of mako shark estimated catches by FMA and month for the fishing years 2007–08 to 2010–11 combined.

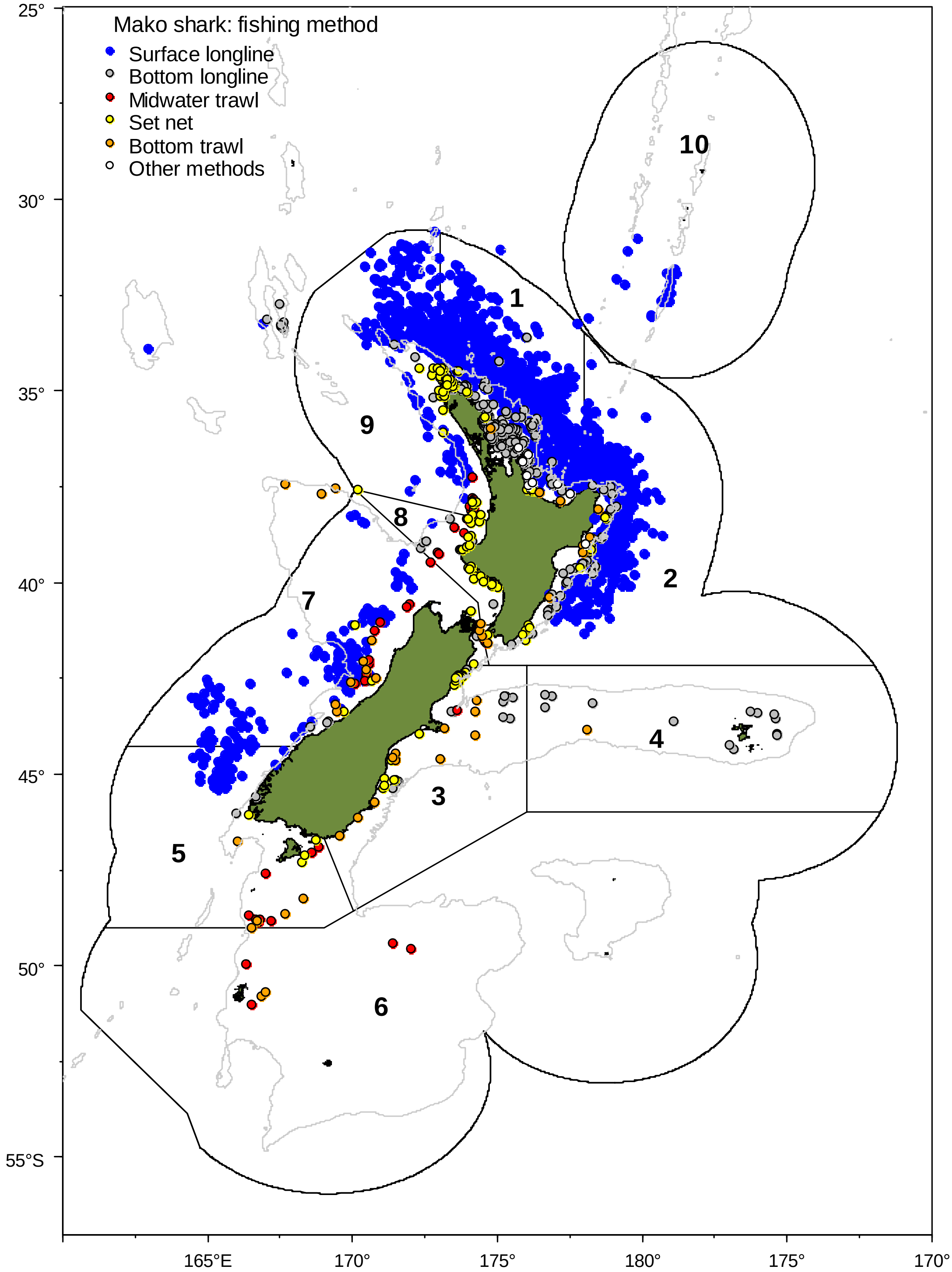


Figure 11: Start-of-set or start-of-tow positions for fishing events from 2007–08 to 2010–11 reporting estimated catches of mako shark. Black lines indicate boundaries of the EEZ and FMAs (numbered) and the grey line is the 1000 m depth contour.

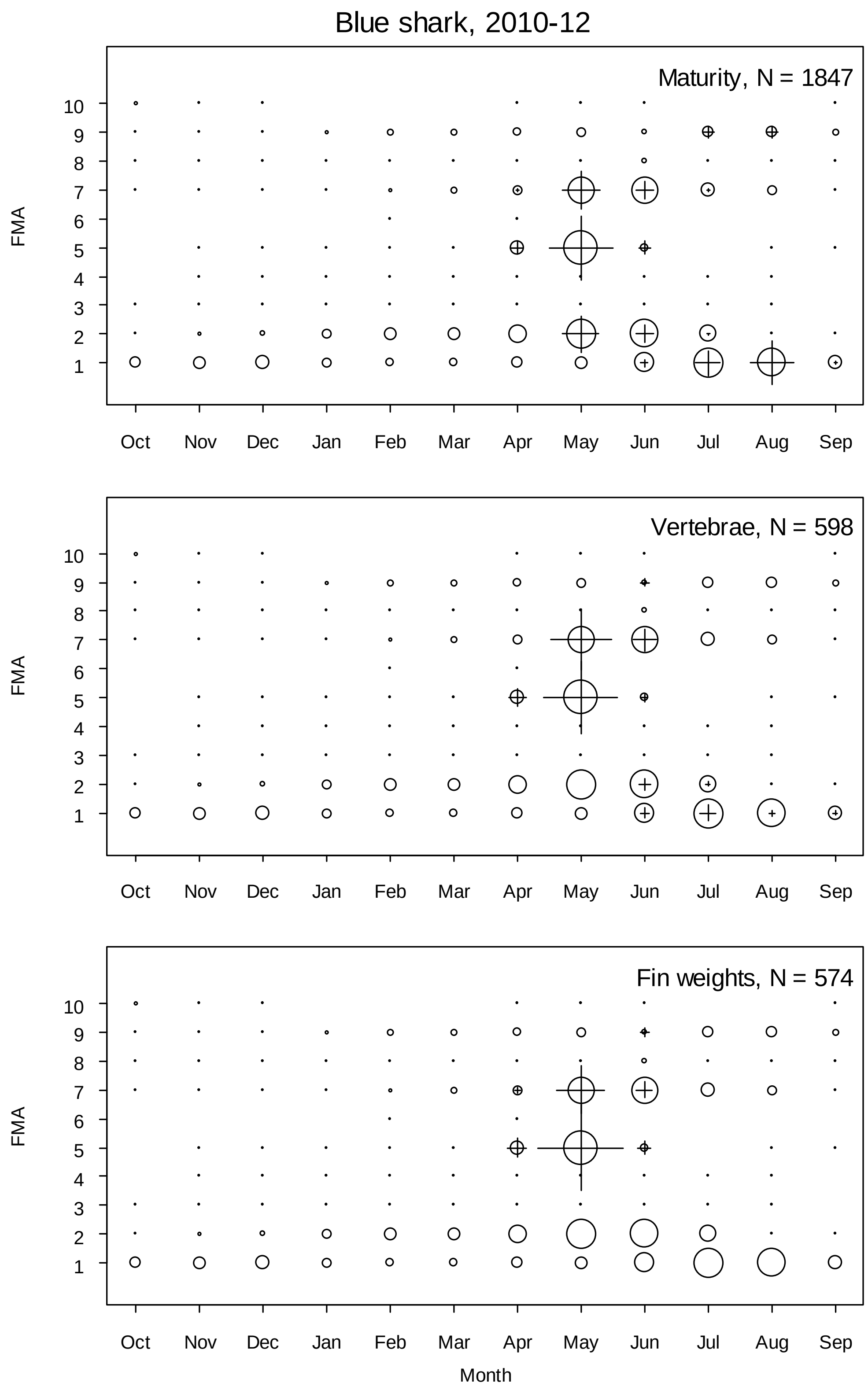


Figure 12: Comparison of proportional distributions of blue shark estimated catches (circles) and observer-collected data and samples (crosses) for (top) reproductive maturity data, (middle) vertebral samples, and (bottom) fin weights for the 2010–12 fishing years. N, sample size.

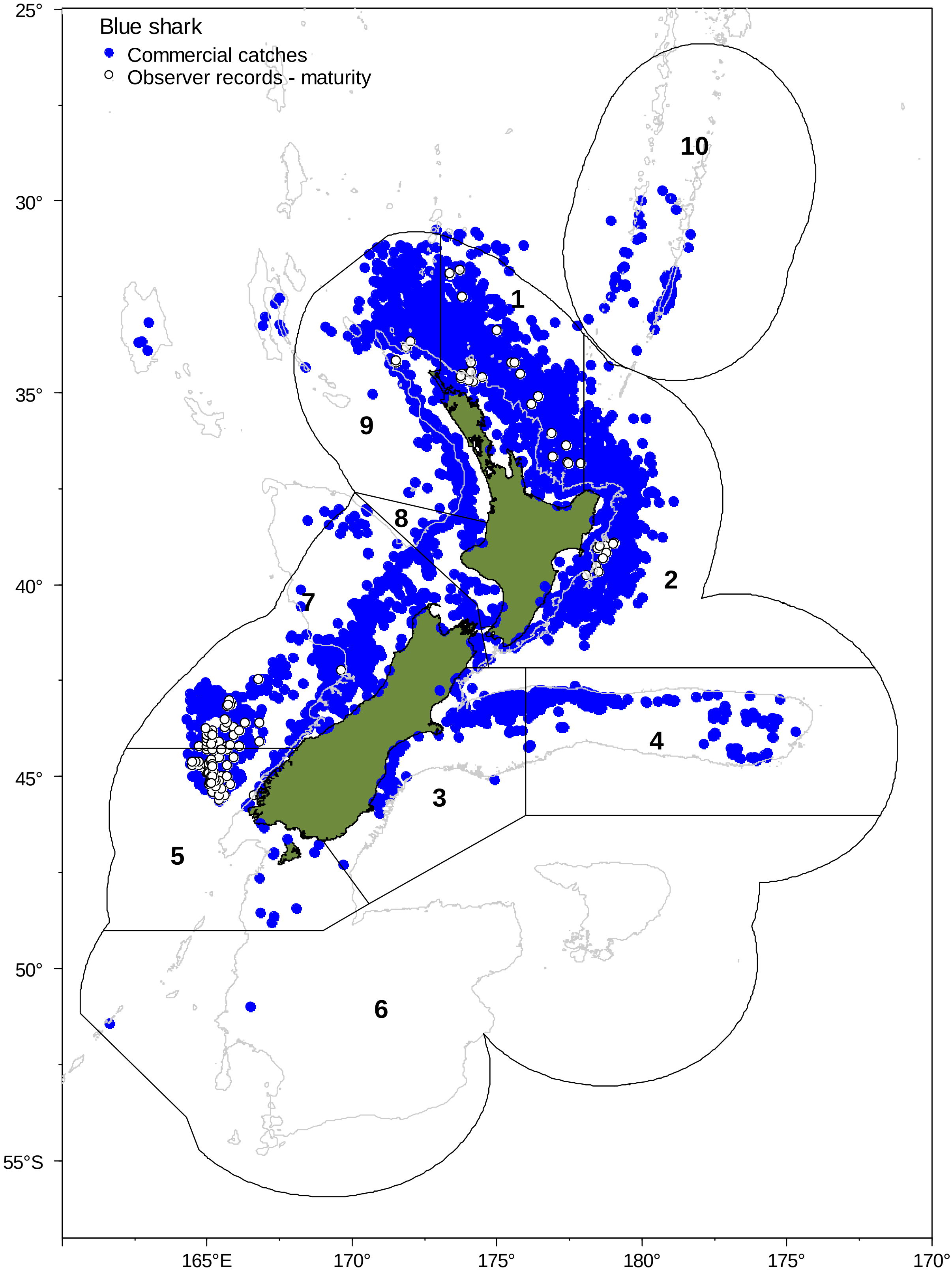


Figure 13: Start-of-set or start-of-tow positions for fishing events (all methods combined) reporting estimated catches of blue shark and observer collections of reproductive maturity data in 2010–12. Black lines indicate boundaries of the EEZ and FMAs (numbered) and the grey line is the 1000 m depth contour.

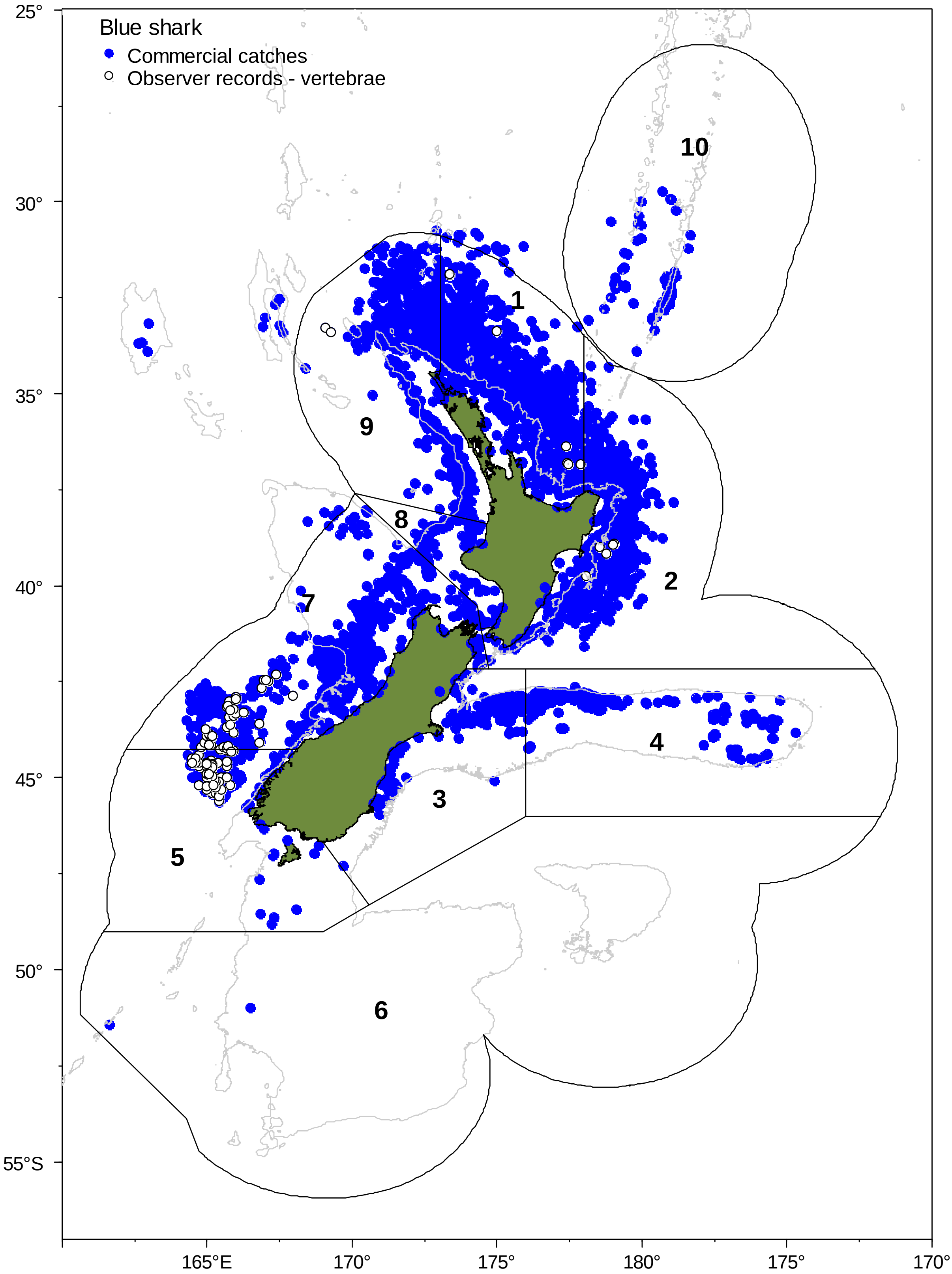


Figure 14: Start-of-set or start-of-tow positions for fishing events (all methods combined) reporting estimated catches of blue shark and observer collections of vertebrae in 2010–12. Black lines indicate boundaries of the EEZ and FMAs (numbered) and the grey line is the 1000 m depth contour.

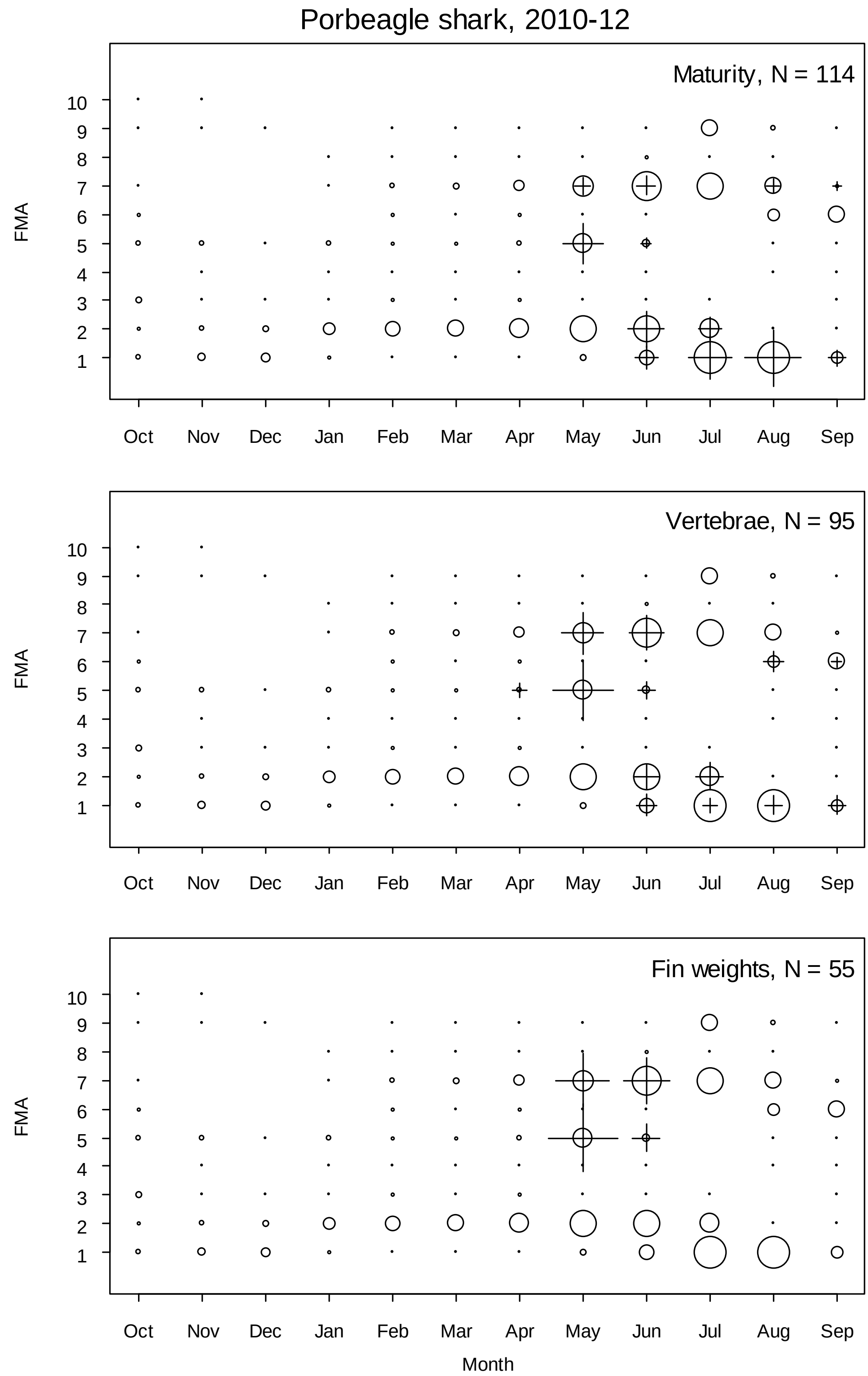


Figure 15: Comparison of proportional distributions of porbeagle shark estimated catches (circles) and observer-collected data and samples (crosses) for (top) reproductive maturity data, (middle) vertebral samples, and (bottom) fin weights for the 2010–12 fishing years. N, sample size.

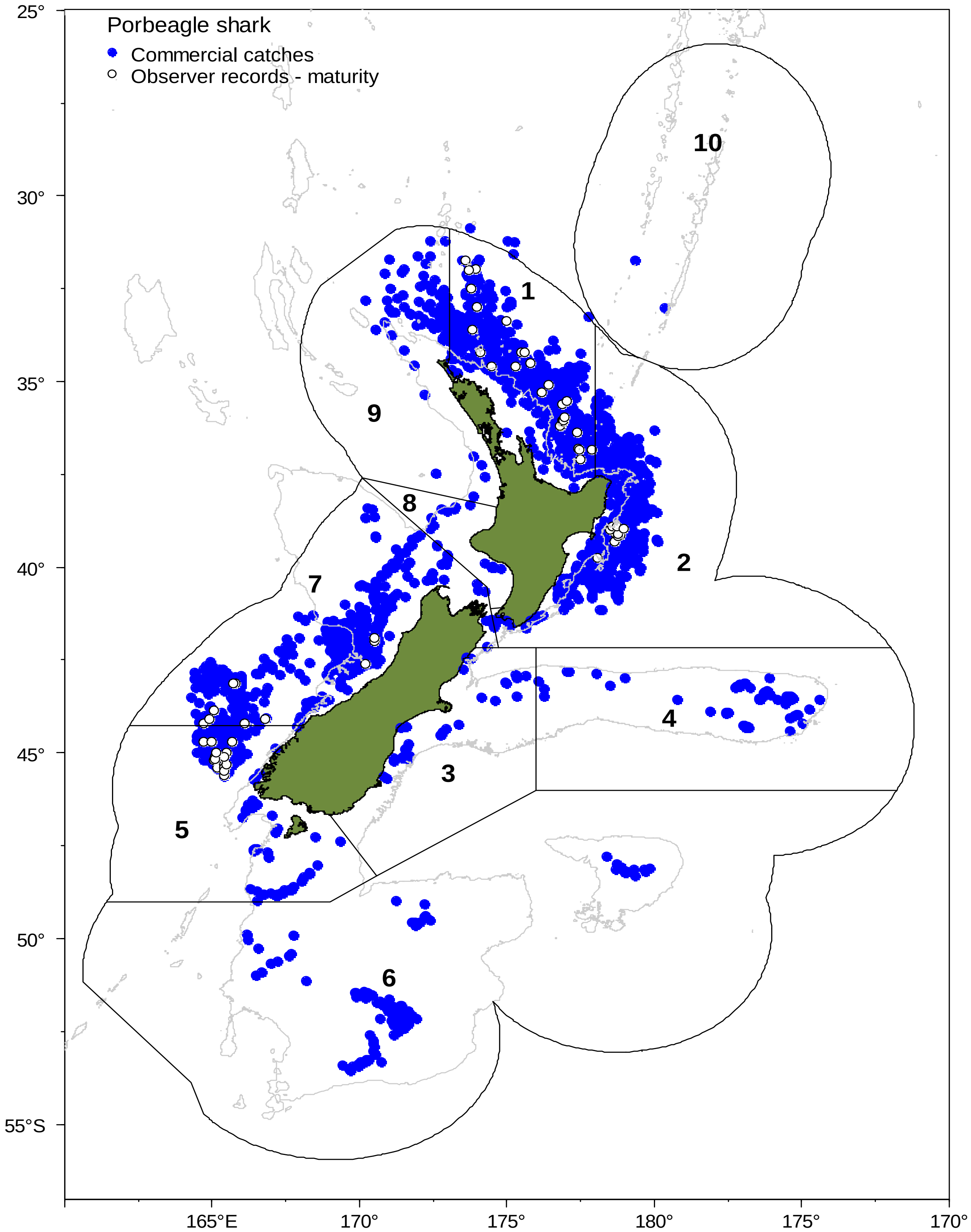


Figure 16: Start-of-set or start-of-tow positions for fishing events (all methods combined) reporting estimated catches of porbeagle shark and observer collections of reproductive maturity data in 2010–12. Black lines indicate boundaries of the EEZ and FMAs (numbered) and the grey line is the 1000 m depth contour.

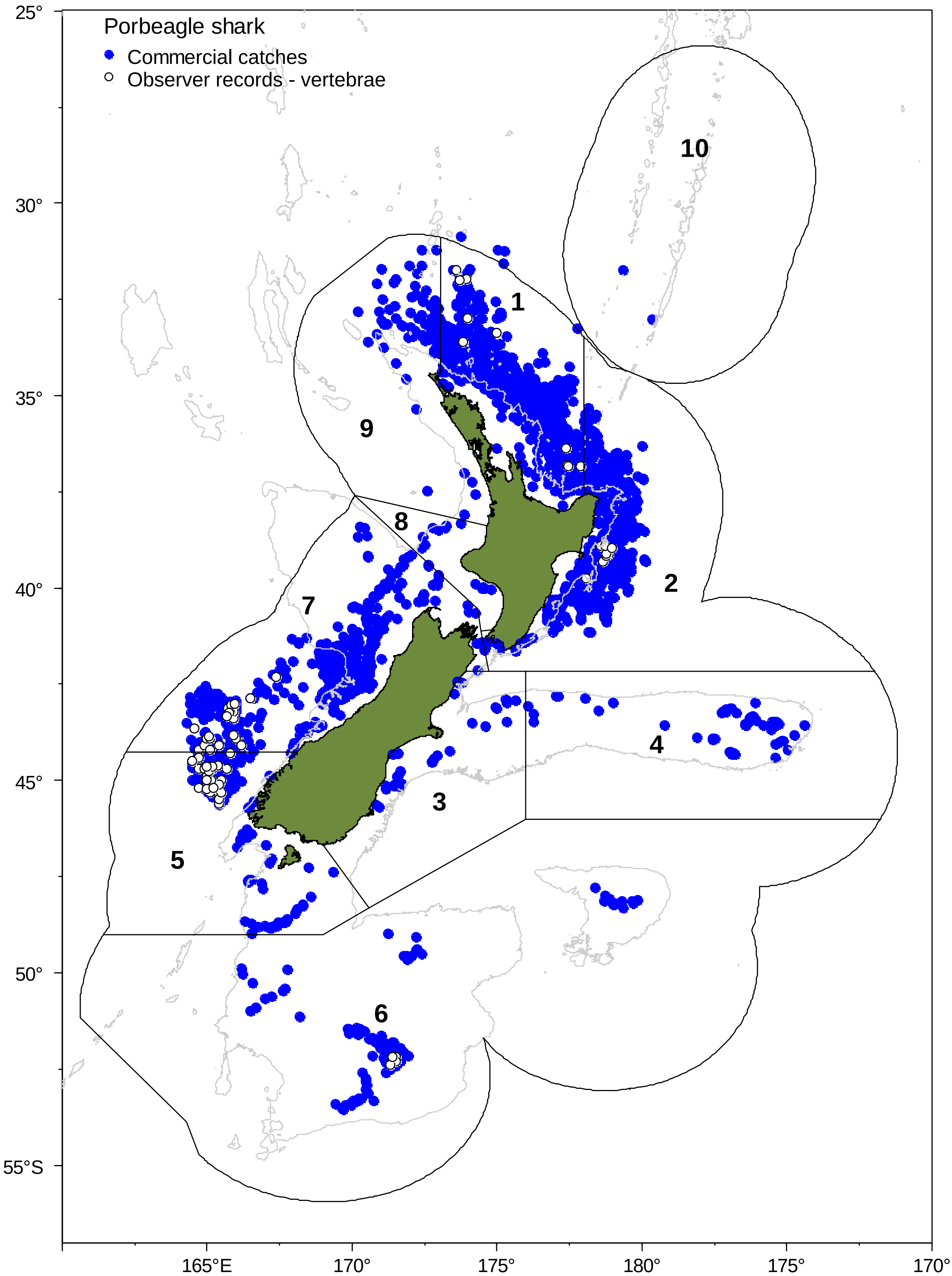


Figure 17: Start-of-set or start-of-tow positions for fishing events (all methods combined) reporting estimated catches of porbeagle shark and observer collections of vertebrae in 2010–12. Black lines indicate boundaries of the EEZ and FMAs (numbered) and the grey line is the 1000 m depth contour.

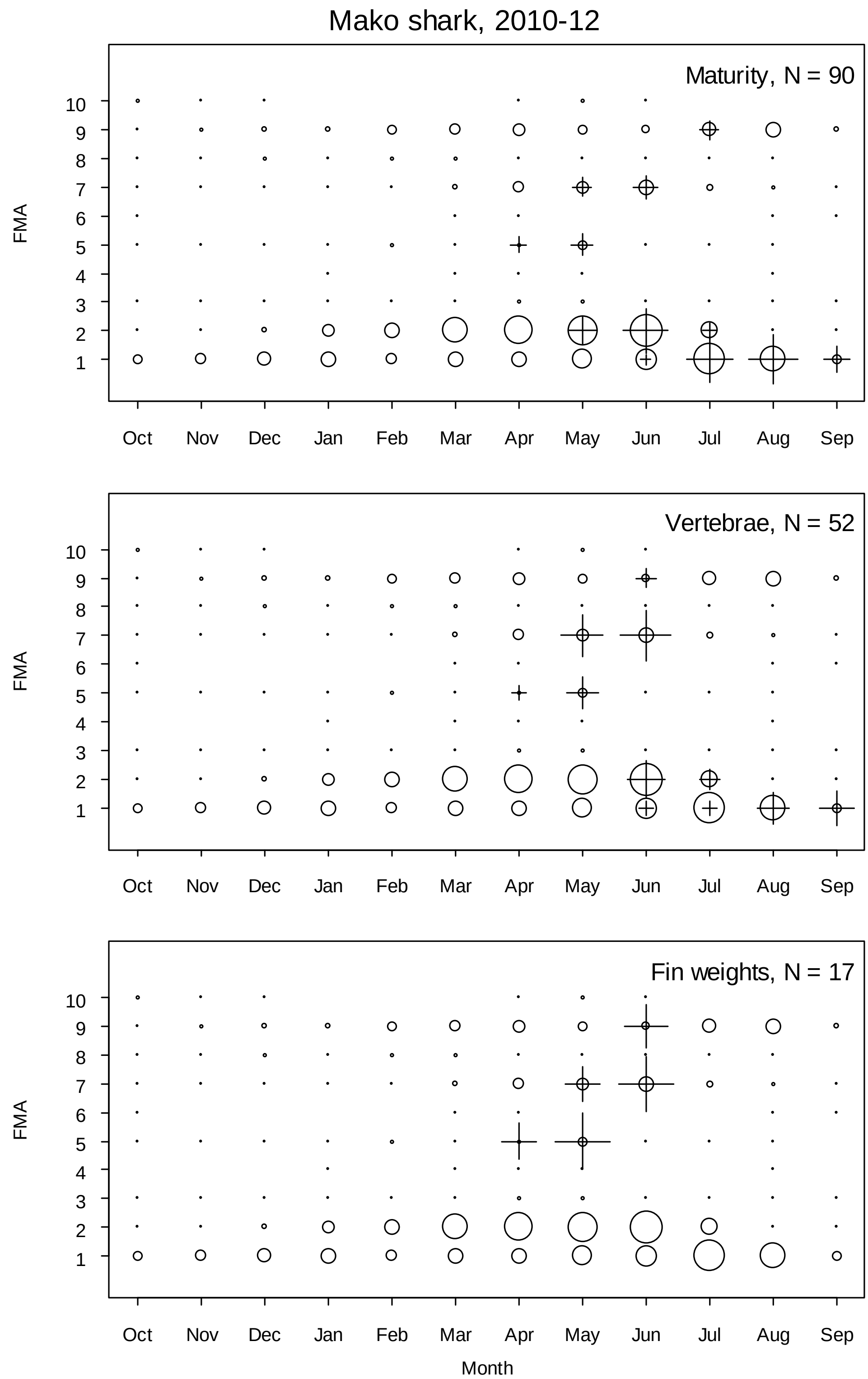


Figure 18: Comparison of proportional distributions of mako shark estimated catches (circles) and observer-collected data and samples (crosses) for (top) reproductive maturity data, (middle) vertebral samples, and (bottom) fin weights for the 2010–12 fishing years. N, sample size.

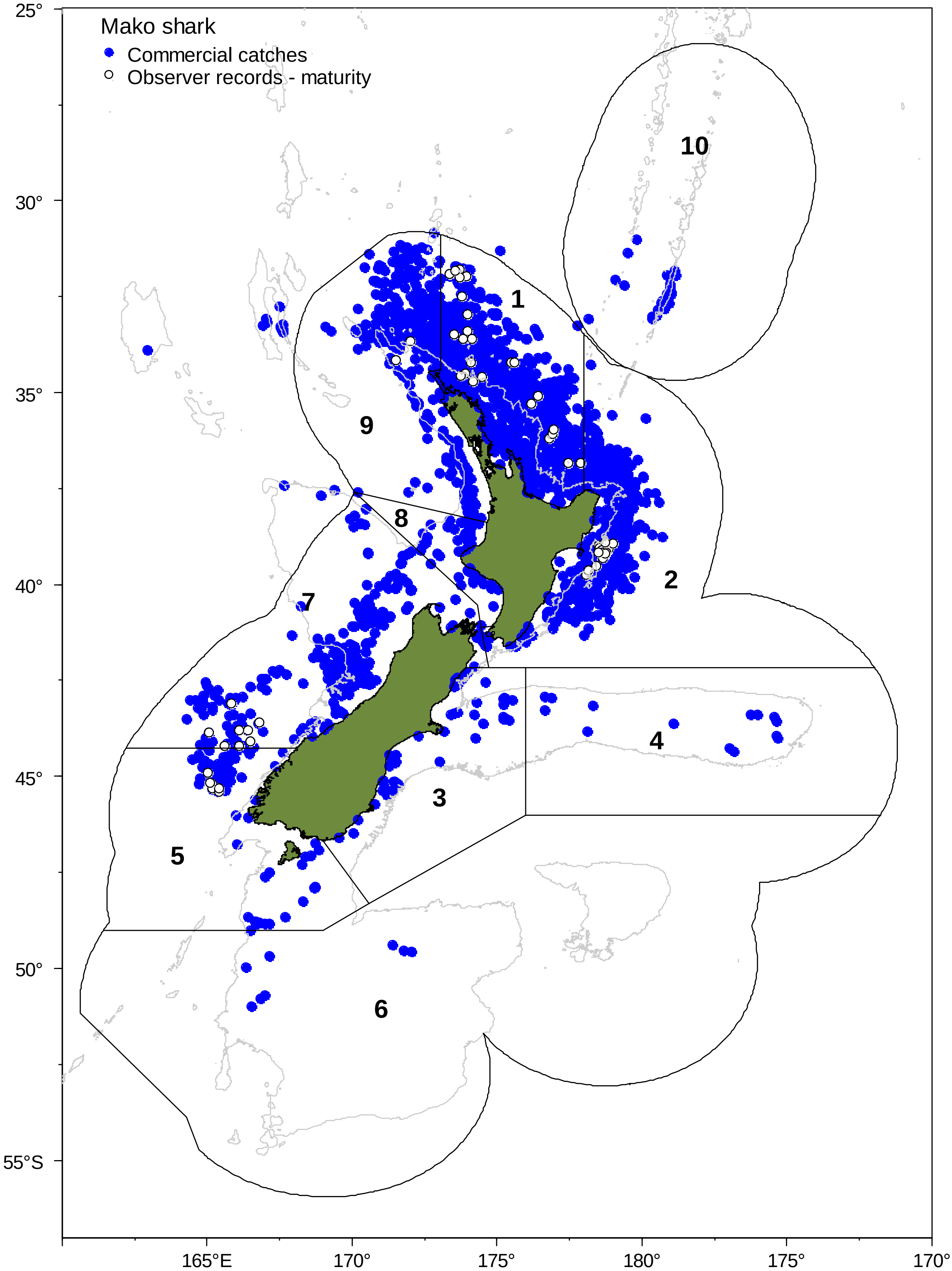


Figure 19: Start-of-set or start-of-tow positions for fishing events (all methods combined) reporting estimated catches of mako shark and observer collections of reproductive maturity data in 2010–12. Black lines indicate boundaries of the EEZ and FMAs (numbered) and the grey line is the 1000 m depth contour.

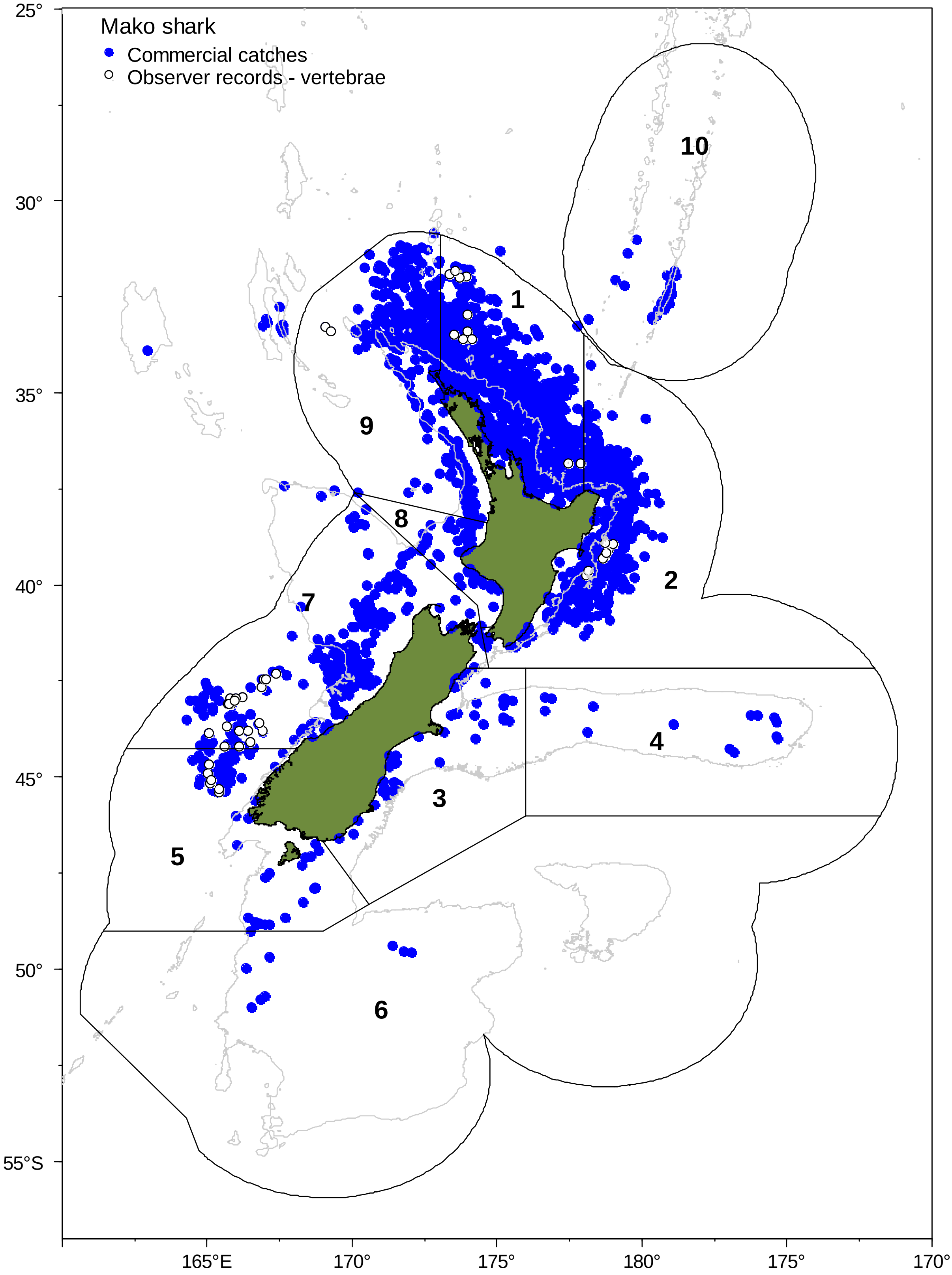


Figure 20: Start-of-set or start-of-tow positions for fishing events (all methods combined) reporting estimated catches of mako shark and observer collections of vertebrae in 2010–12. Black lines indicate boundaries of the EEZ and FMAs (numbered) and the grey line is the 1000 m depth contour.

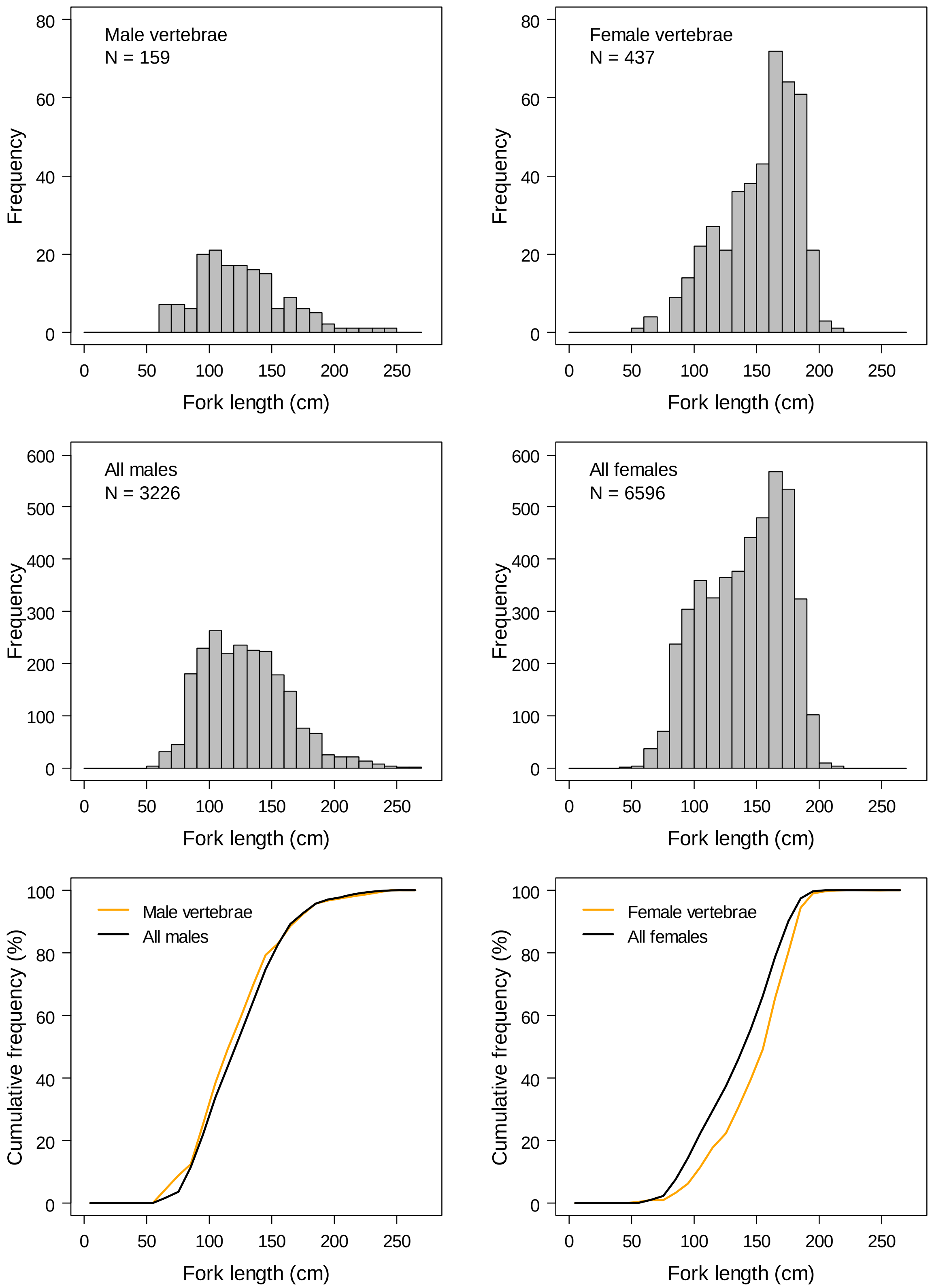


Figure 21: Length-frequency distributions of male and female blue sharks sampled in 2010–12 for vertebrae (top panels) compared with the distributions of all blue sharks measured during the same period (middle panels). The bottom panels show cumulative distribution curves for the data in the top and middle panels.

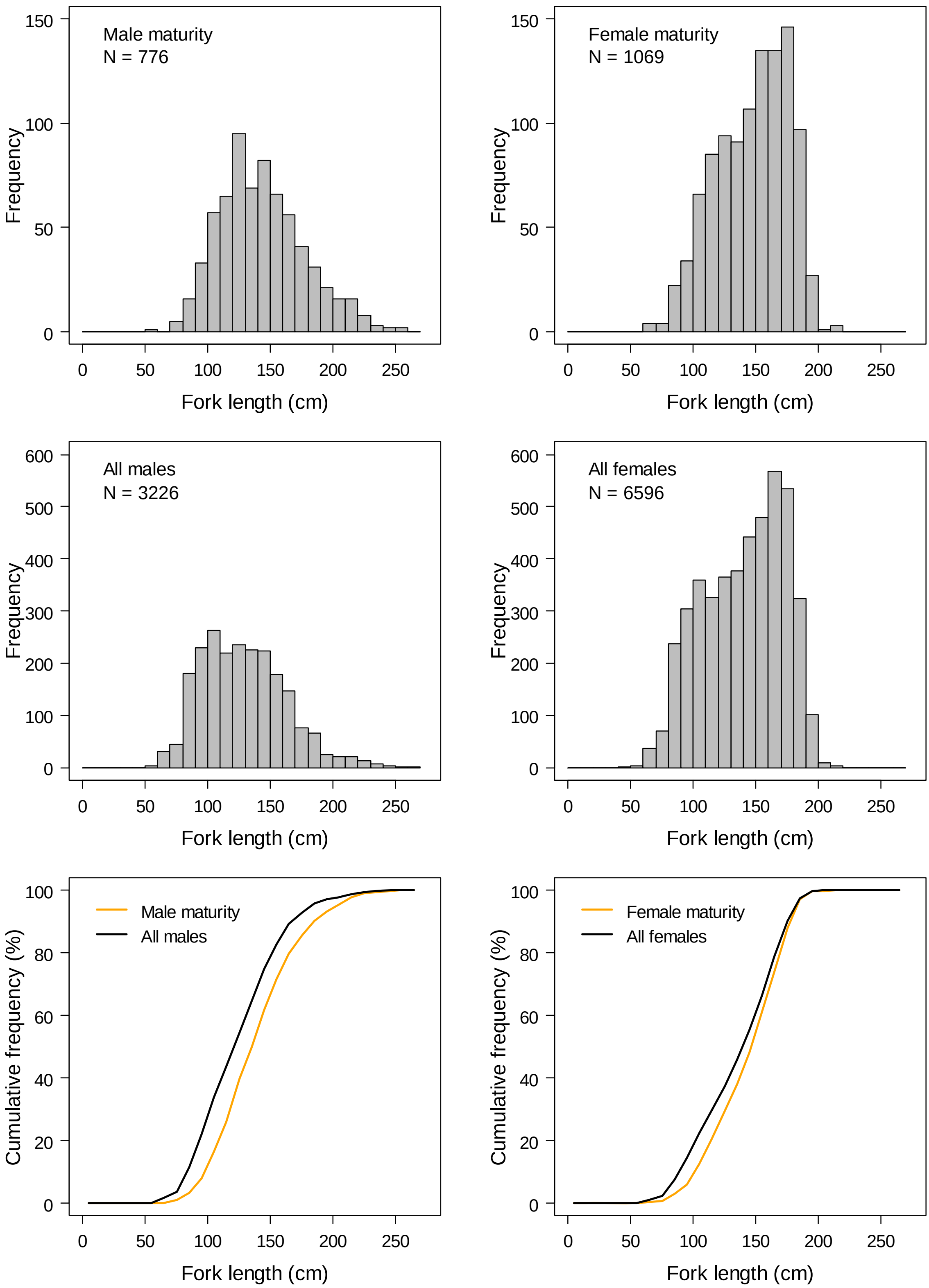


Figure 22: Length-frequency distributions of male and female blue sharks sampled in 2010–12 for maturity (top panels) compared with the distributions of all blue sharks measured during the same period (middle panels). The bottom panels show cumulative distribution curves for the data in the top and middle panels.

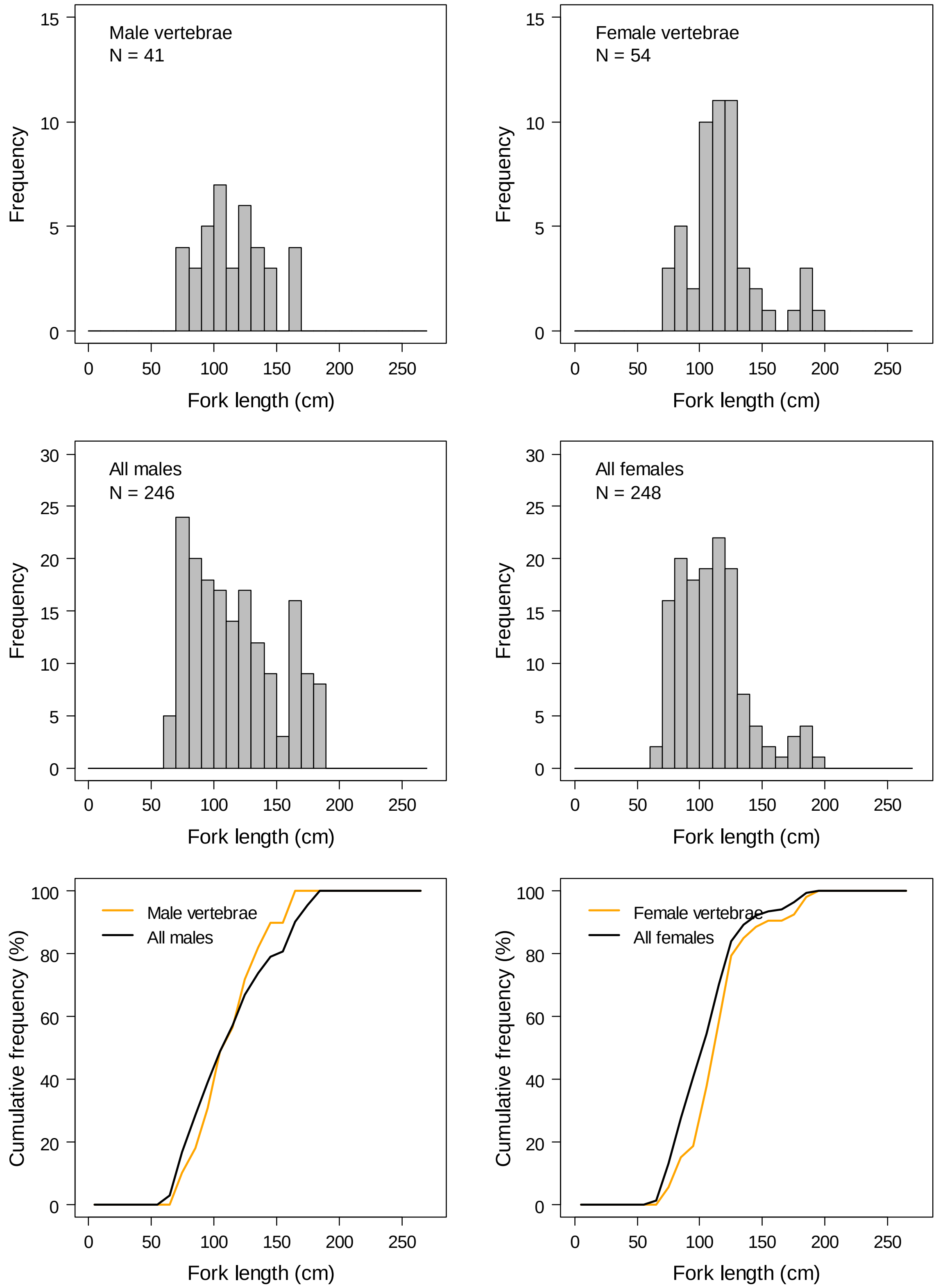


Figure 23: Length-frequency distributions of male and female porbeagle sharks sampled in 2010–12 for vertebrae (top panels) compared with the distributions of all porbeagle sharks measured during the same period (middle panels). The bottom panels show cumulative distribution curves for the data in the top and middle panels.

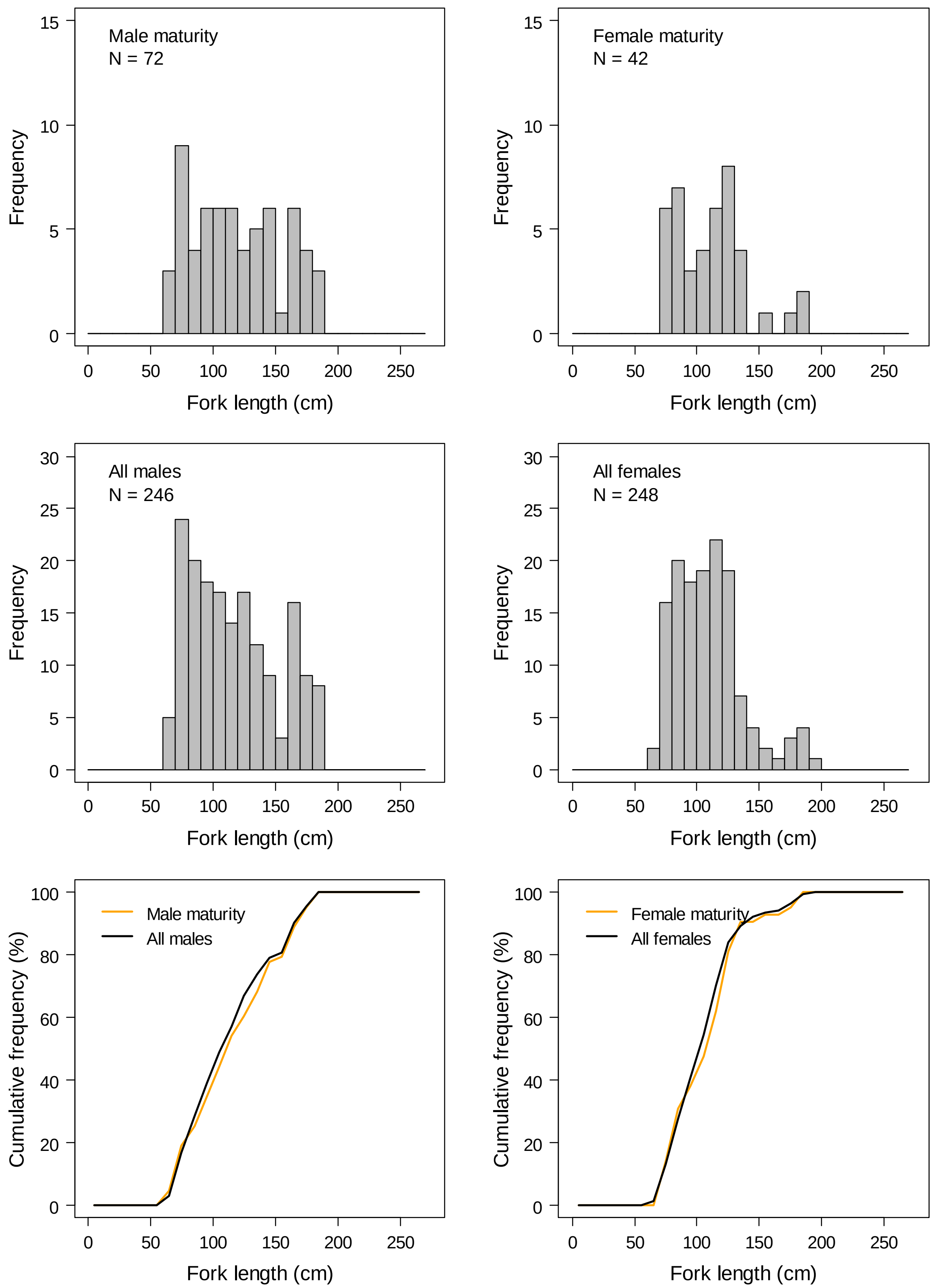


Figure 24: Length-frequency distributions of male and female porbeagle sharks sampled in 2010–12 for maturity (top panels) compared with the distributions of all porbeagle sharks measured during the same period (middle panels). The bottom panels show cumulative distribution curves for the data in the top and middle panels.

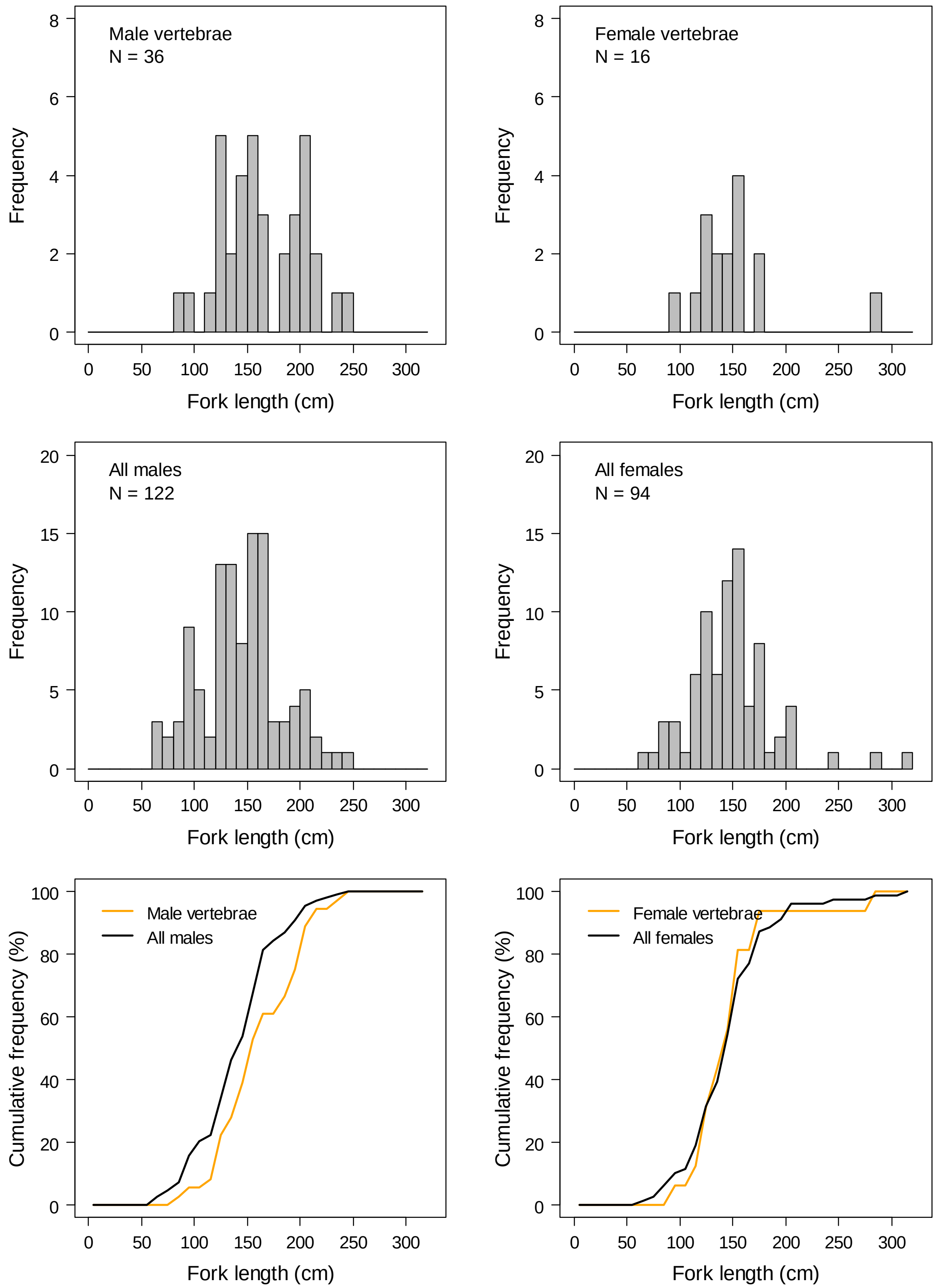


Figure 25: Length-frequency distributions of male and female mako sharks sampled in 2010–12 for vertebrae (top panels) compared with the distributions of all mako sharks measured during the same period (middle panels). The bottom panels show cumulative distribution curves for the data in the top and middle panels.

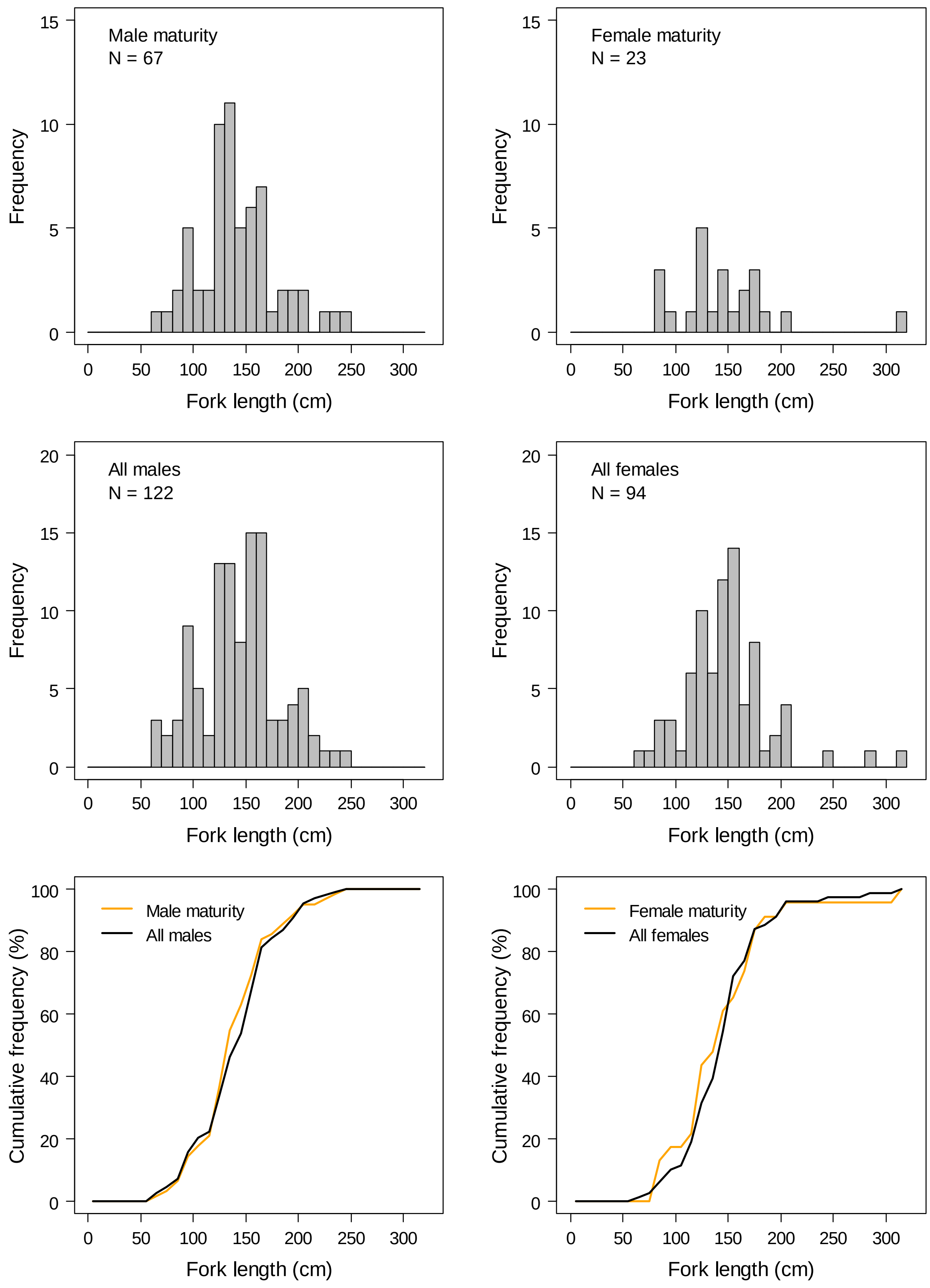


Figure 26: Length-frequency distributions of male and female mako sharks sampled in 2010–12 for maturity (top panels) compared with the distributions of all mako sharks measured during the same period (middle panels). The bottom panels show cumulative distribution curves for the data in the top and middle panels.

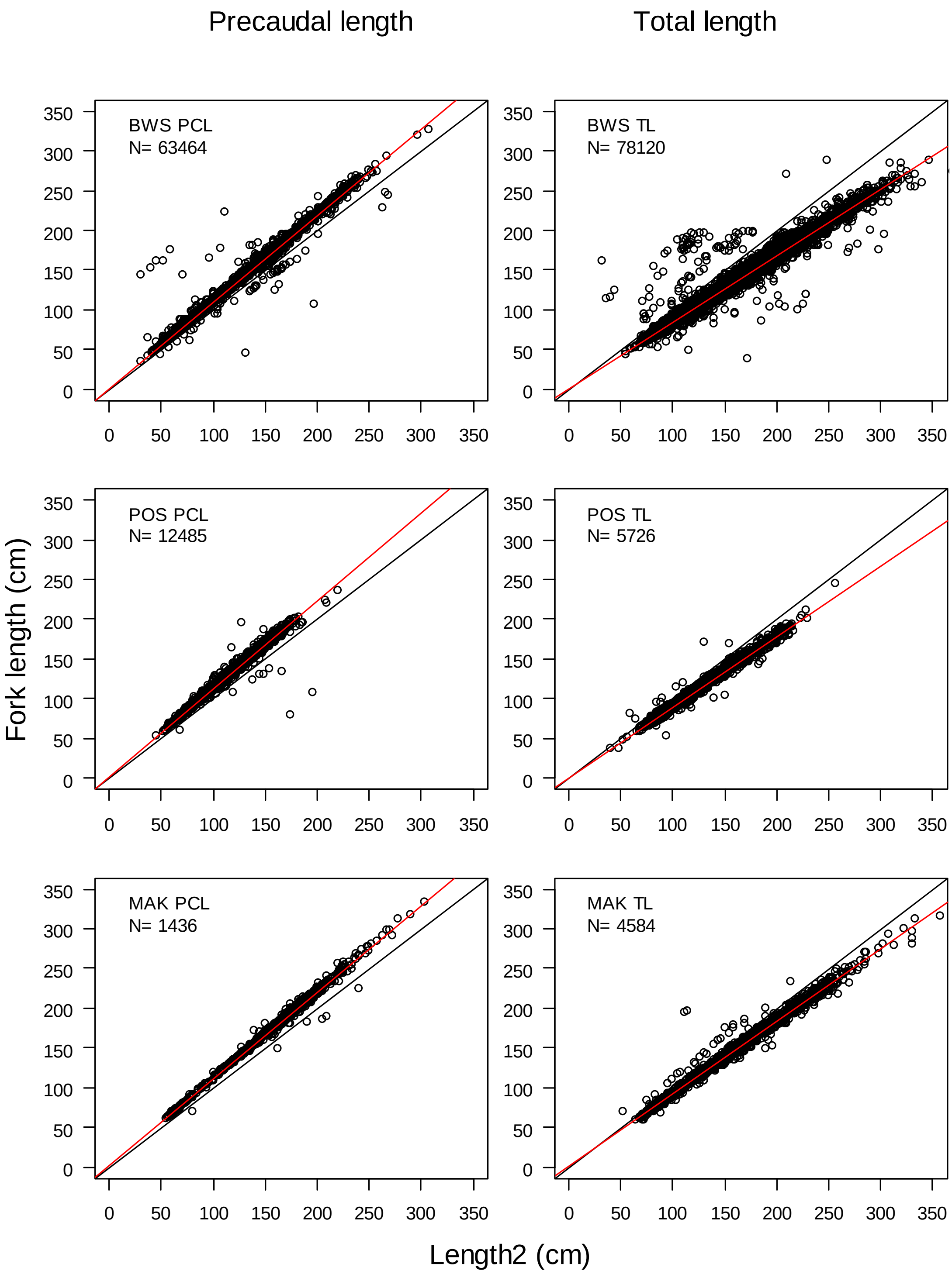


Figure 27: Relationship between fork length and precaudal (PCL) and total length (TL) for blue, porbeagle and mako sharks. BWS, blue shark; POS, porbeagle shark; MAK, mako shark. The black diagonal line is the 1:1 line, and the red line is the fitted linear regression.

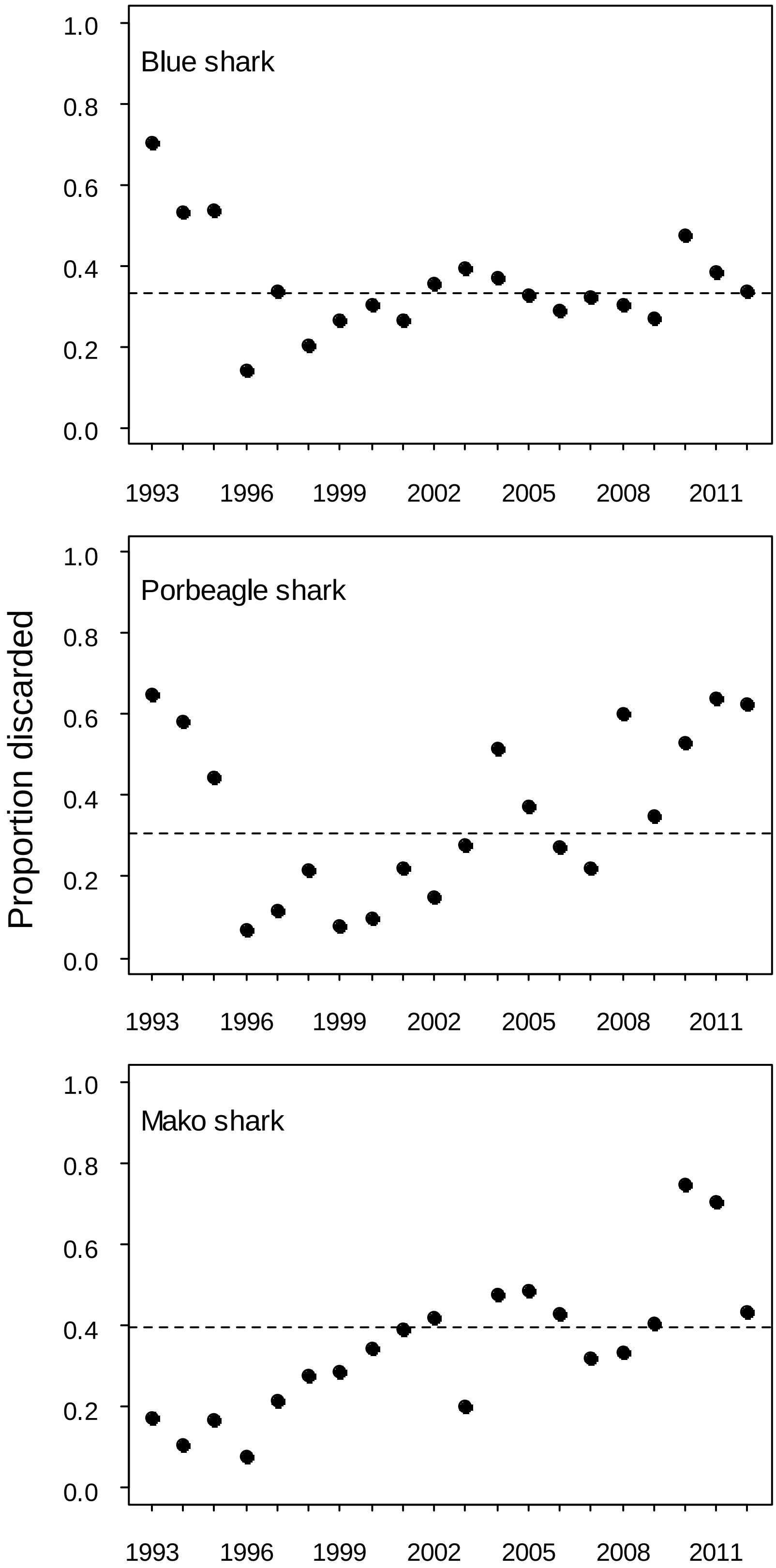


Figure 28: Proportions of blue, porbeagle and mako sharks Discarded from surface longline vessels, 1993–2012. The horizontal dashed lines indicate the overall discard rate for the whole time series.

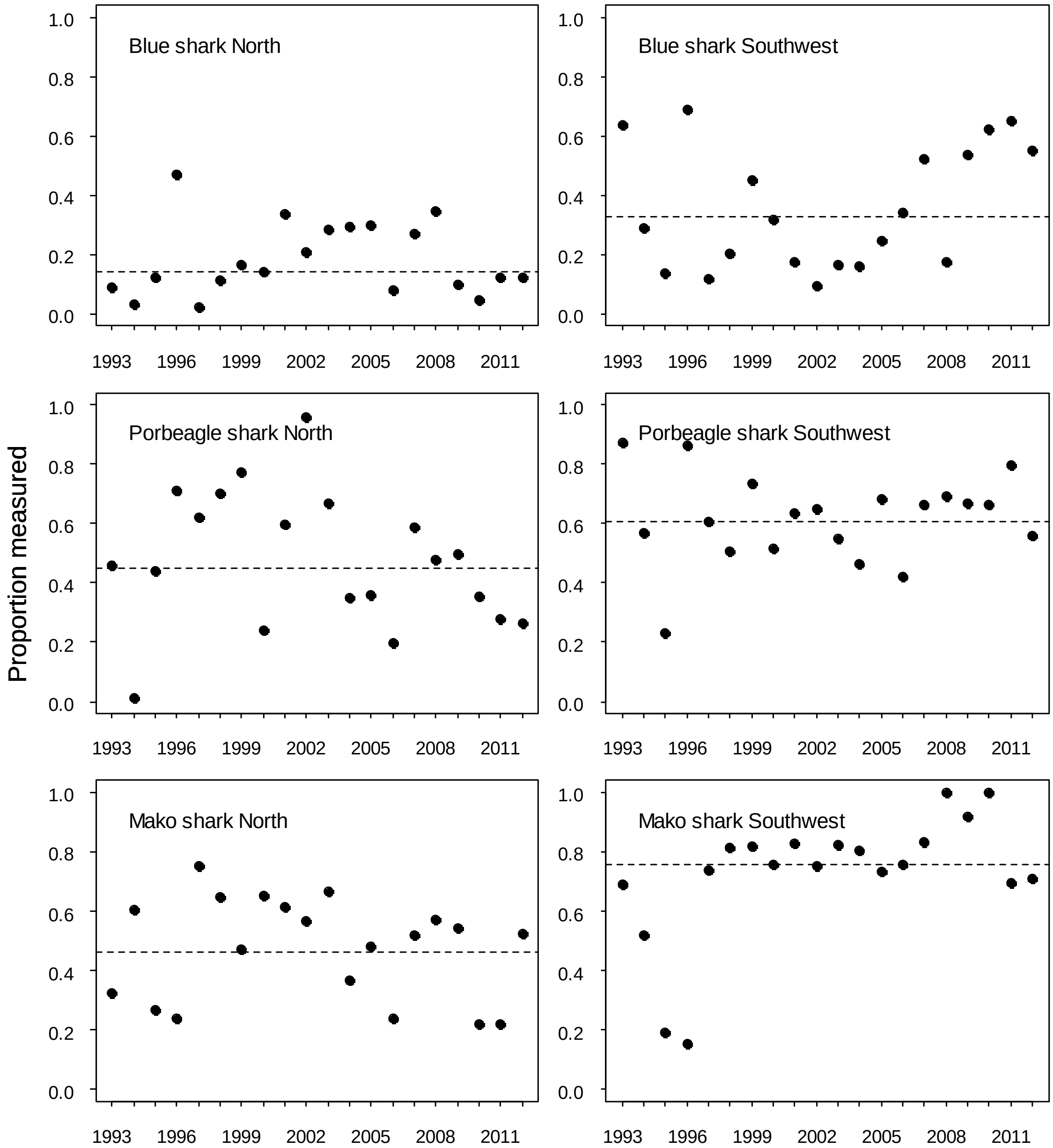


Figure 29: Proportions of blue, porbeagle and mako sharks measured from surface longline vessels in North and Southwest regions, 1993−2012. The horizontal dashed lines indicate the proportion measured for the whole time series.

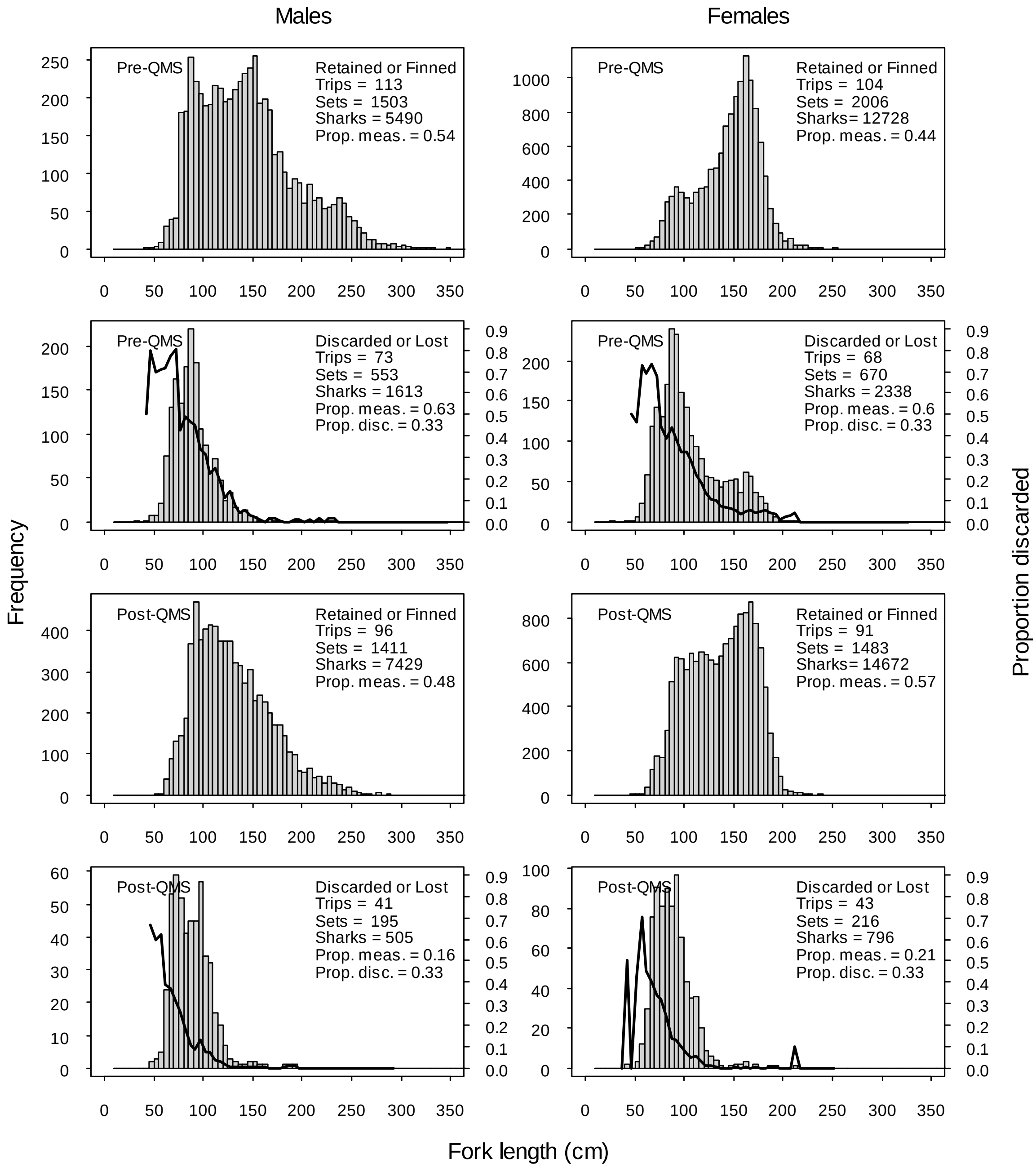


Figure 30: Length-frequency distributions for male and female blue sharks pre- and post-QMS, classified by observer processed state codes: Landed (Retained or Finned) and Discarded (Discarded or Lost). Also shown (black lines) are the proportions of measured sharks that were Discarded. The legend boxes indicate the proportion of sharks that were measured and therefore contributed to the distributions, and the overall proportions Discarded (the latter was calculated for both sexes combined so the value reported is the same in both the male and female panels).

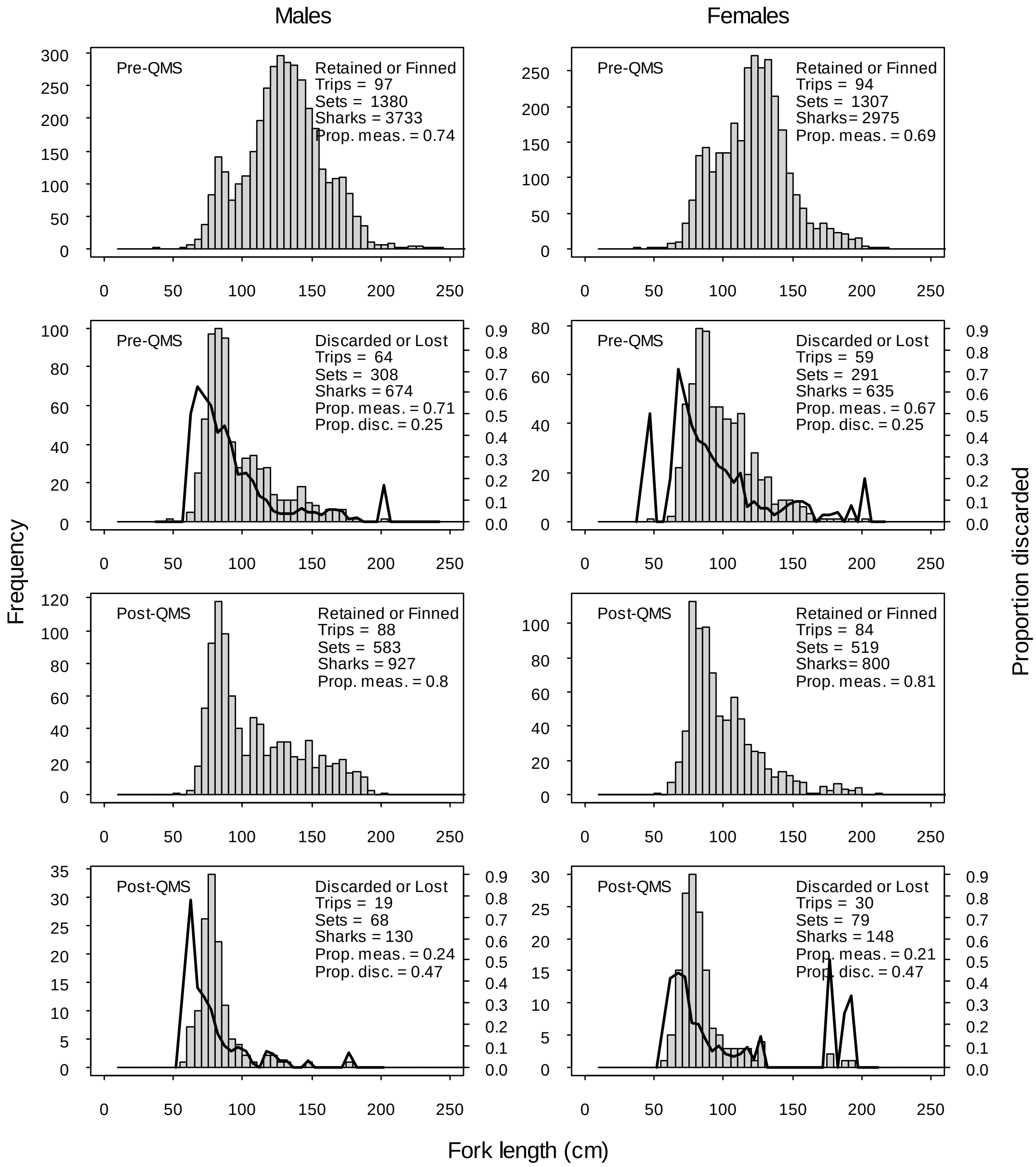


Figure 31: Length-frequency distributions for male and female porbeagle sharks pre- and post-QMS, classified by observer processed state codes: Landed (Retained or Finned) and Discarded (Discarded or Lost). Also shown (black lines) are the proportions of measured sharks that were Discarded. The legend boxes indicate the proportion of sharks that were measured and therefore contributed to the distributions, and the overall proportions Discarded (the latter was calculated for both sexes combined so the value reported is the same in both the male and female panels).

F

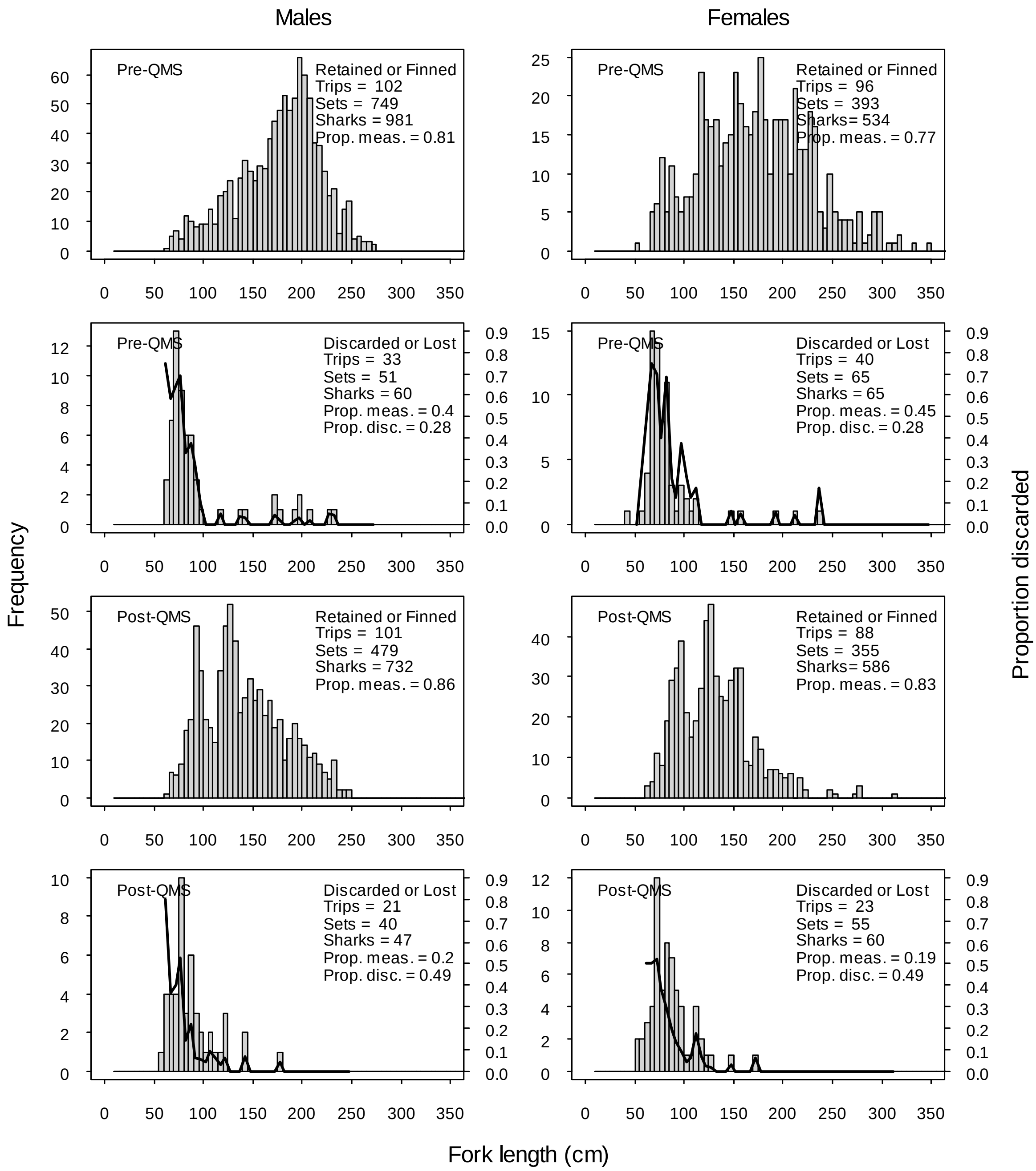


Figure 32: Length-frequency distributions for male and female mako sharks pre- and post-QMS, classified by observer processed state codes: Landed (Retained or Finned) and Discarded (Discarded or Lost). Also shown (black lines) are the proportions of measured sharks that were Discarded. The legend boxes indicate the proportion of sharks that were measured and therefore contributed to the distributions, and the overall proportions Discarded (the latter was calculated for both sexes combined so the value reported is the same in both the male and female panels).

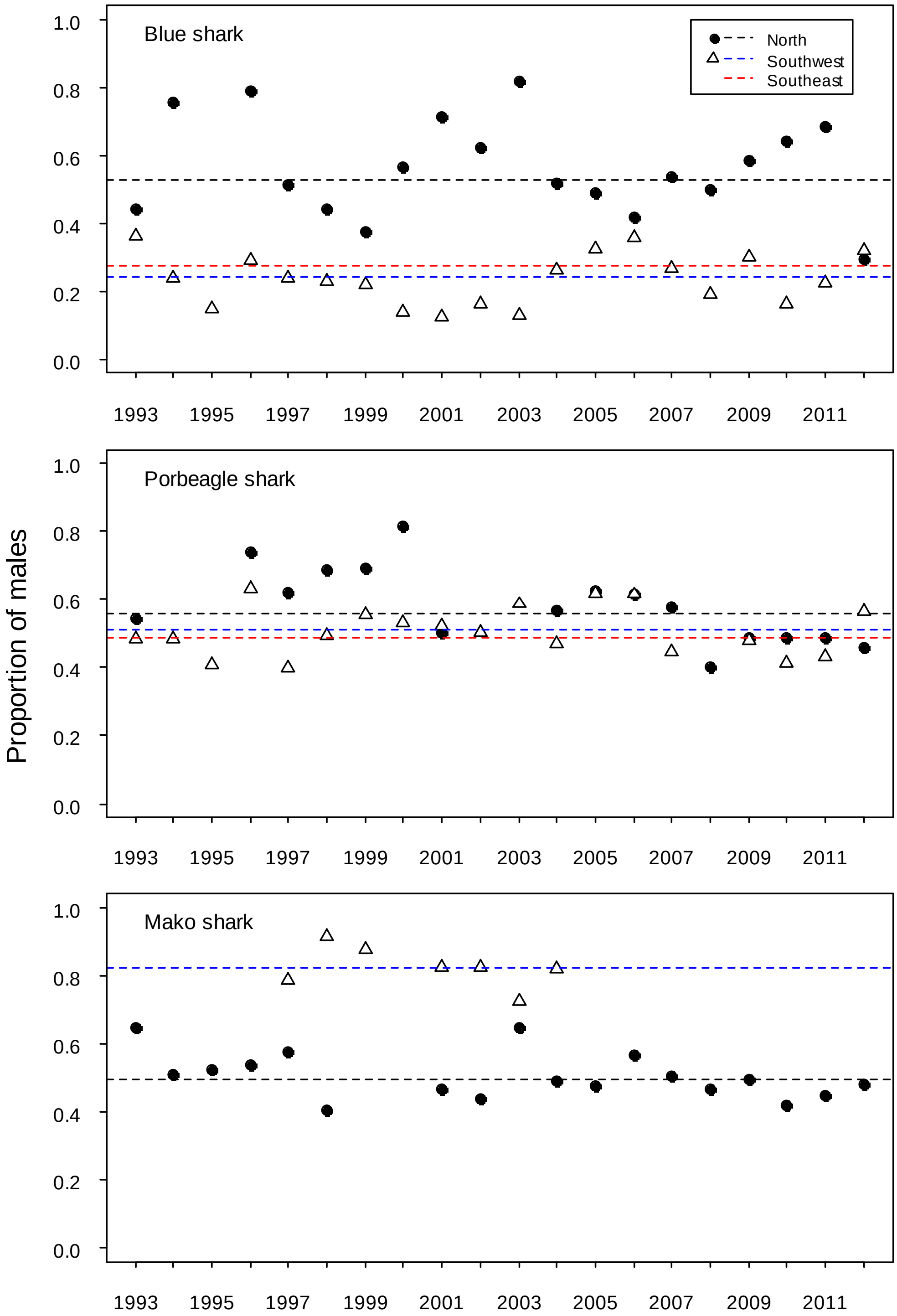


Figure 33: Proportions of male blue, porbeagle and mako sharks by region from surface longlines, 1993−2012. The horizontal dashed lines indicate the proportions of males for the whole time series in each region. Only sample sizes greater than 50 are shown for North and Southwest regions. Data for individual years are not shown for the Southeast region because too few years and sharks were sampled. Southeast region data are not plotted for mako sharks because only 29 sharks were observed.

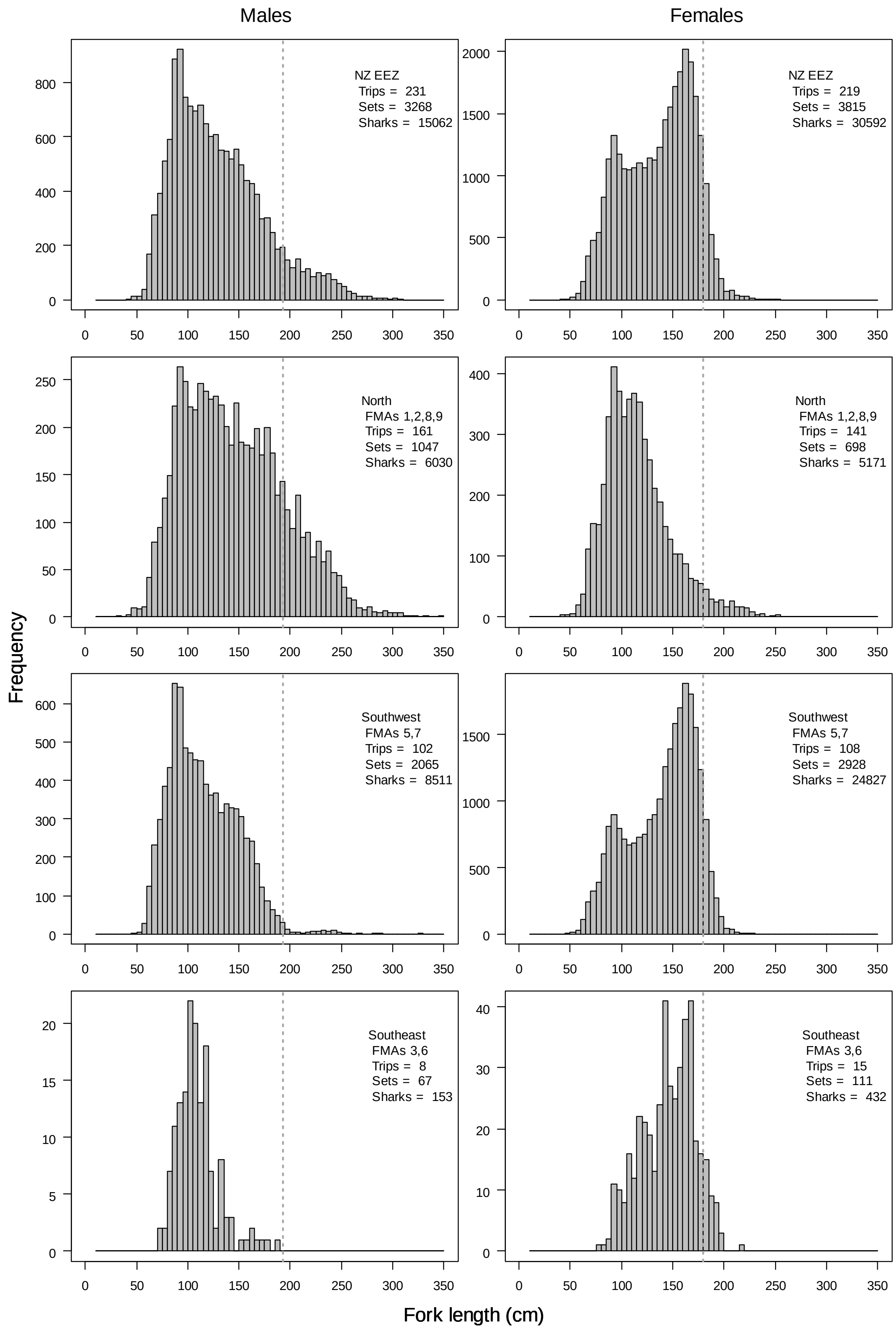


Figure 34: Length-frequency distributions of male and female blue sharks measured by observers aboard surface longline vessels between 1993 and 2012 for the New Zealand EEZ, and North, Southwest and Southeast regions. The dashed vertical lines indicate the median length at maturity.

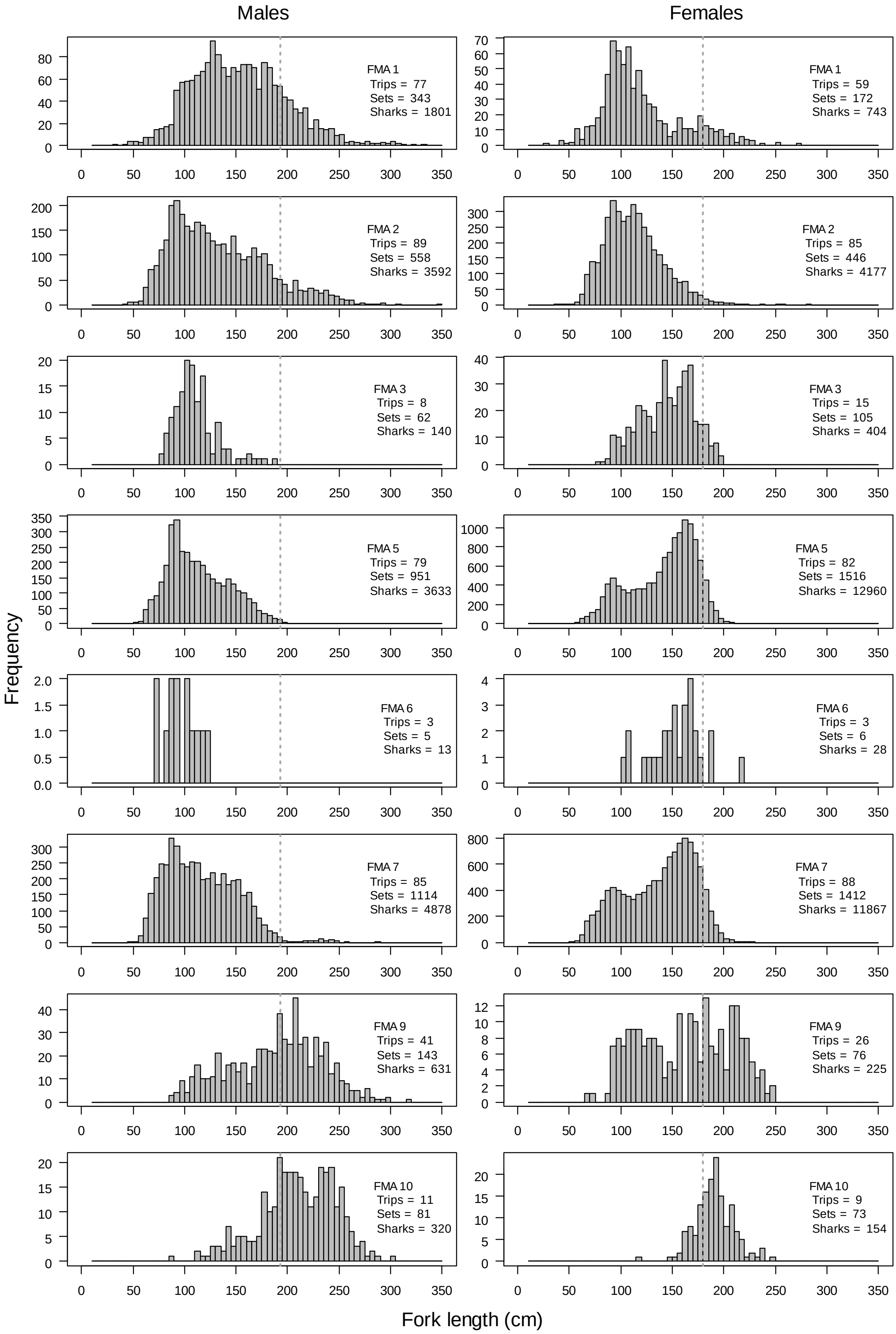


Figure 35: Length-frequency distributions of male and female blue sharks measured by observers aboard surface longline vessels between 1993 and 2012 by Fisheries Management Area (FMA). There were no data from FMA 4, and too few data from FMA 8 to warrant plotting. The dashed vertical lines indicate the median length at maturity.

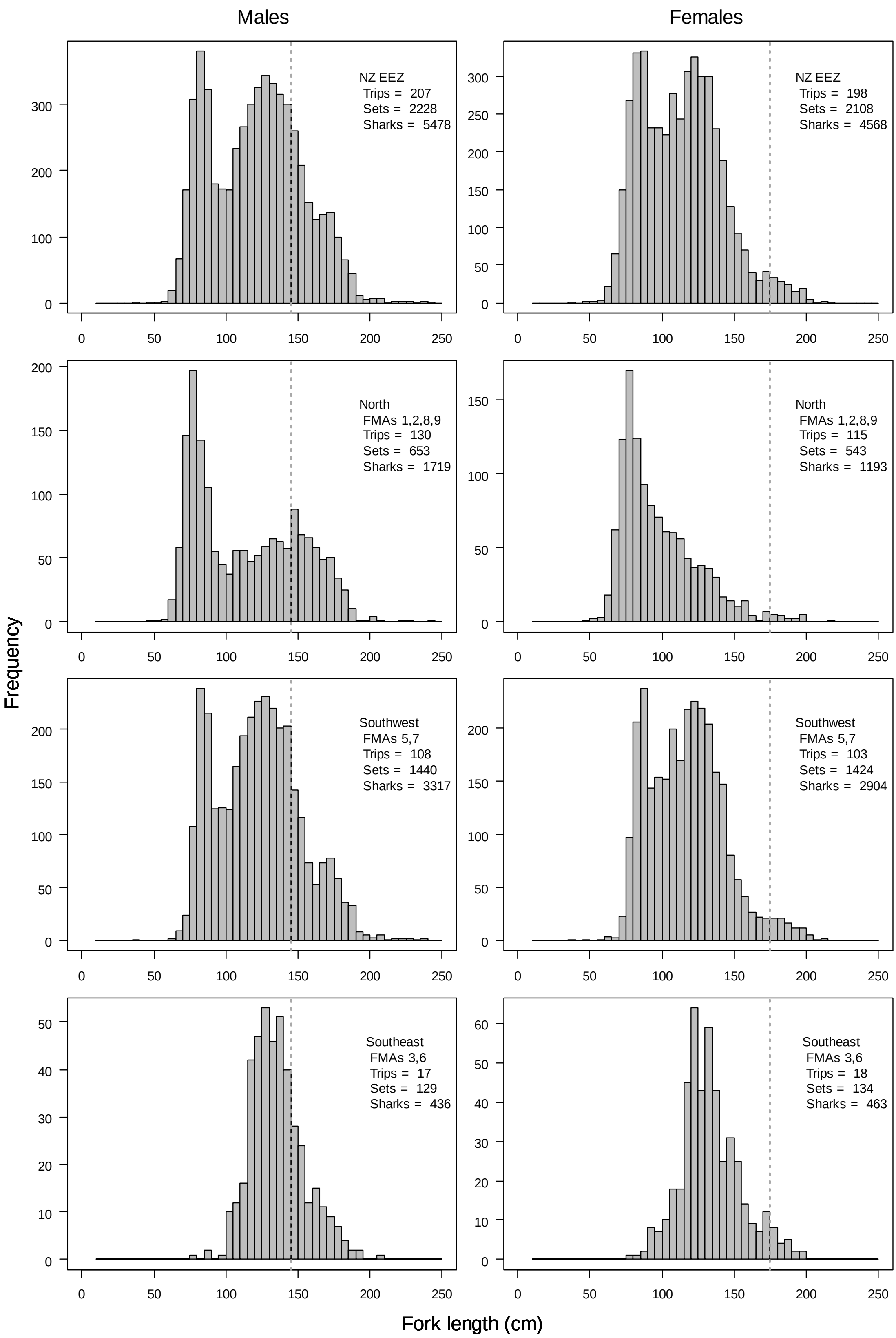


Figure 36: Length-frequency distributions of male and female porbeagle sharks measured by observers aboard surface longline vessels between 1993 and 2012 for the New Zealand EEZ, and North, Southwest and Southeast regions. The dashed vertical lines indicate the median length at maturity.

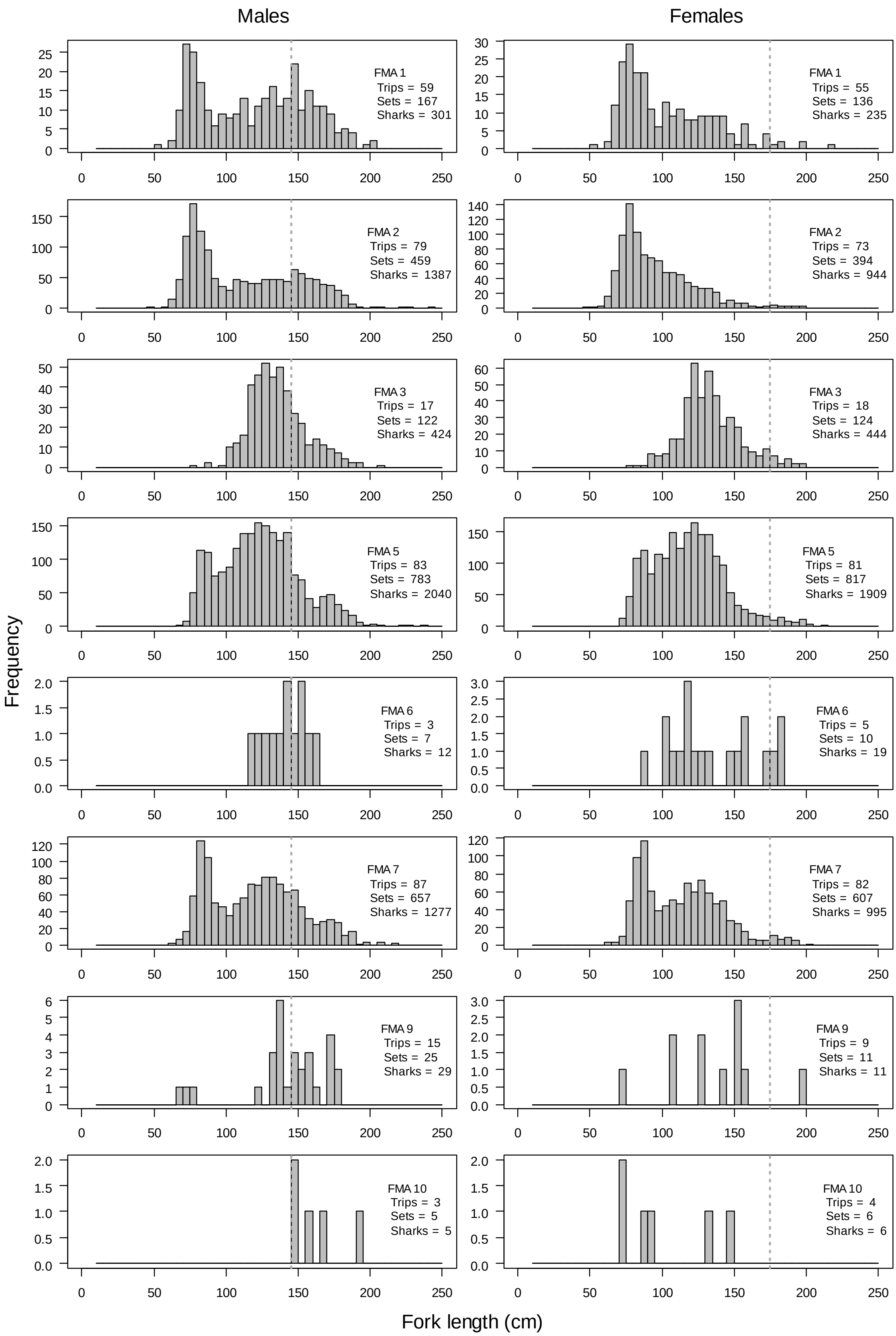


Figure 37: Length-frequency distributions of male and female porbeagle sharks measured by observers aboard surface longline vessels between 1993 and 2012 by Fisheries Management Area (FMA). There were no data from FMA 4, and too few data from FMA 8 to warrant plotting. The dashed vertical lines indicate the median length at maturity.

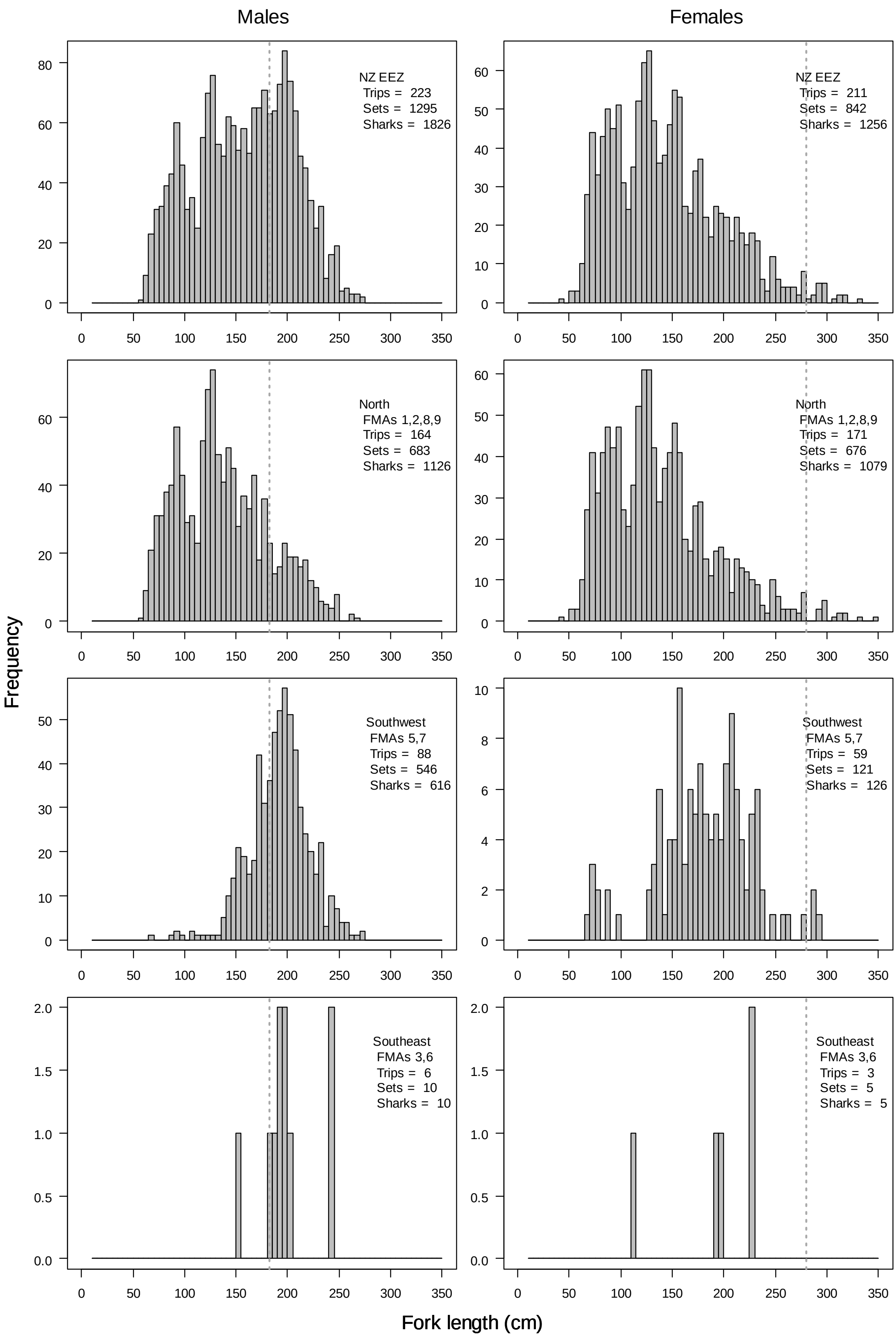


Figure 38: Length-frequency distributions of male and female mako sharks measured by observers aboard surface longline vessels between 1993 and 2012 for the New Zealand EEZ, and North, Southwest and Southeast regions. The dashed vertical lines indicate the median length at maturity.

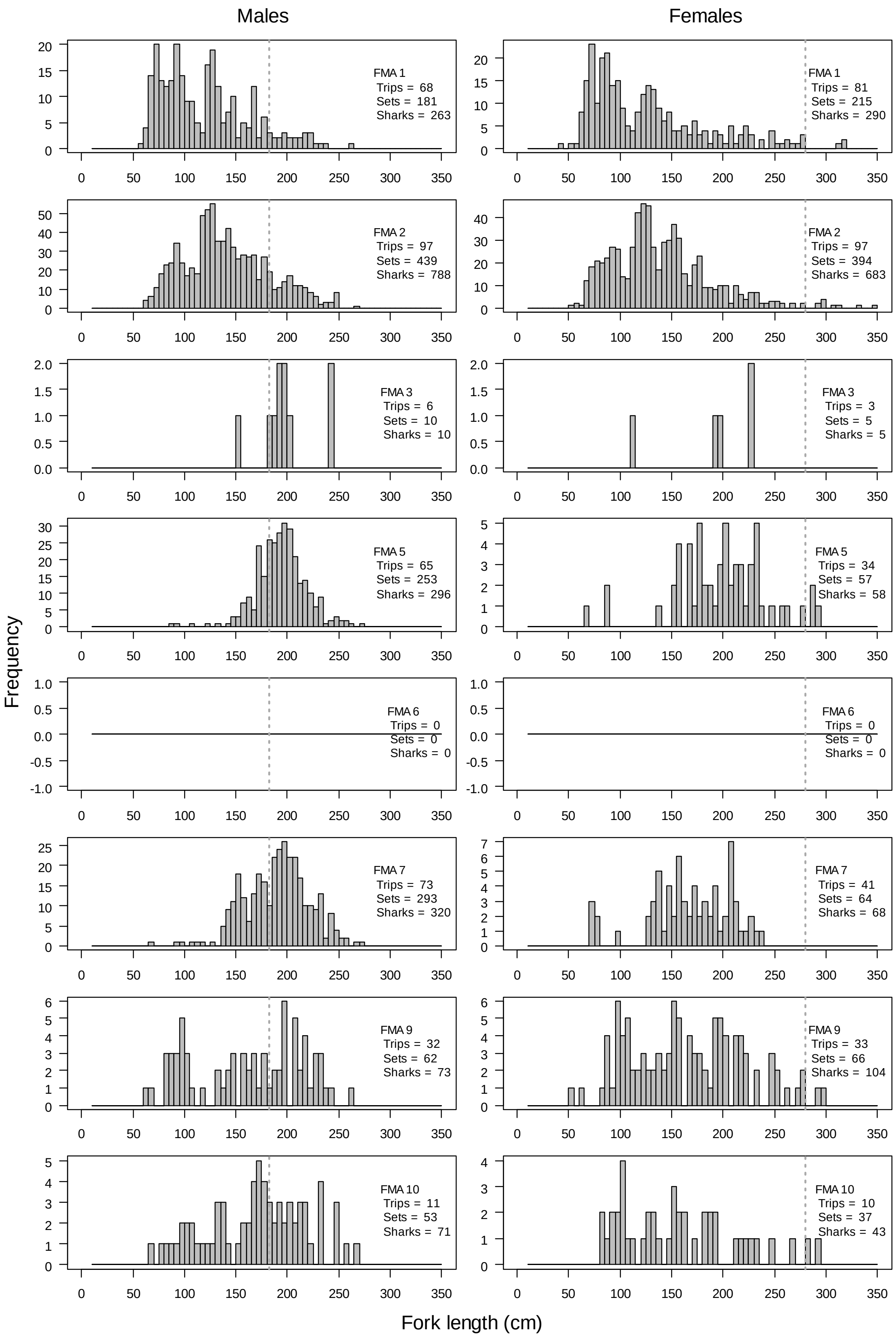


Figure 39: Length-frequency distributions of male and female mako sharks measured by observers aboard surface longline vessels between 1993 and 2012 by Fisheries Management Area (FMA). There were no data from FMA 4, and too few data from FMA 8 to warrant plotting. The dashed vertical lines indicate the median length at maturity.

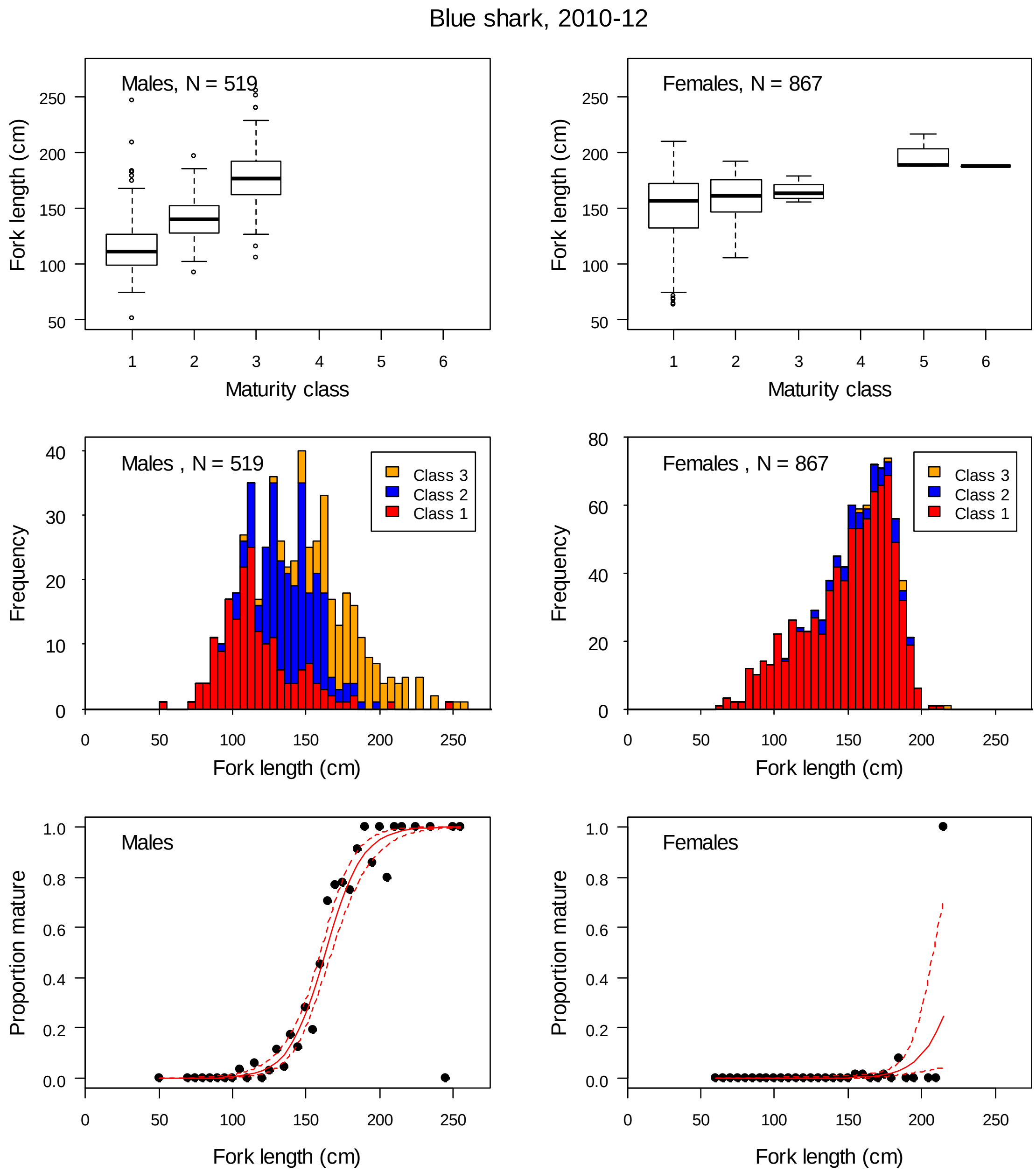


Figure 40: Maturity data collected from male and female blue sharks, 2010–12. Top panels: Box plots of fork length classified by maturity stage (see Appendix 1 for stages). The central black bar is the median, the box spans the first to third quartiles, and the whiskers extend to the most extreme data point which is no more than 1.5 times the interquartile range from the box. Middle panels: Length-frequency distributions classified by maturity class (female classes 4–6 were combined with class 3). Bottom panels: Proportion of sharks that were mature (in 5 cm length intervals) with fitted logistic regressions. Dashed lines are 95% confidence intervals.

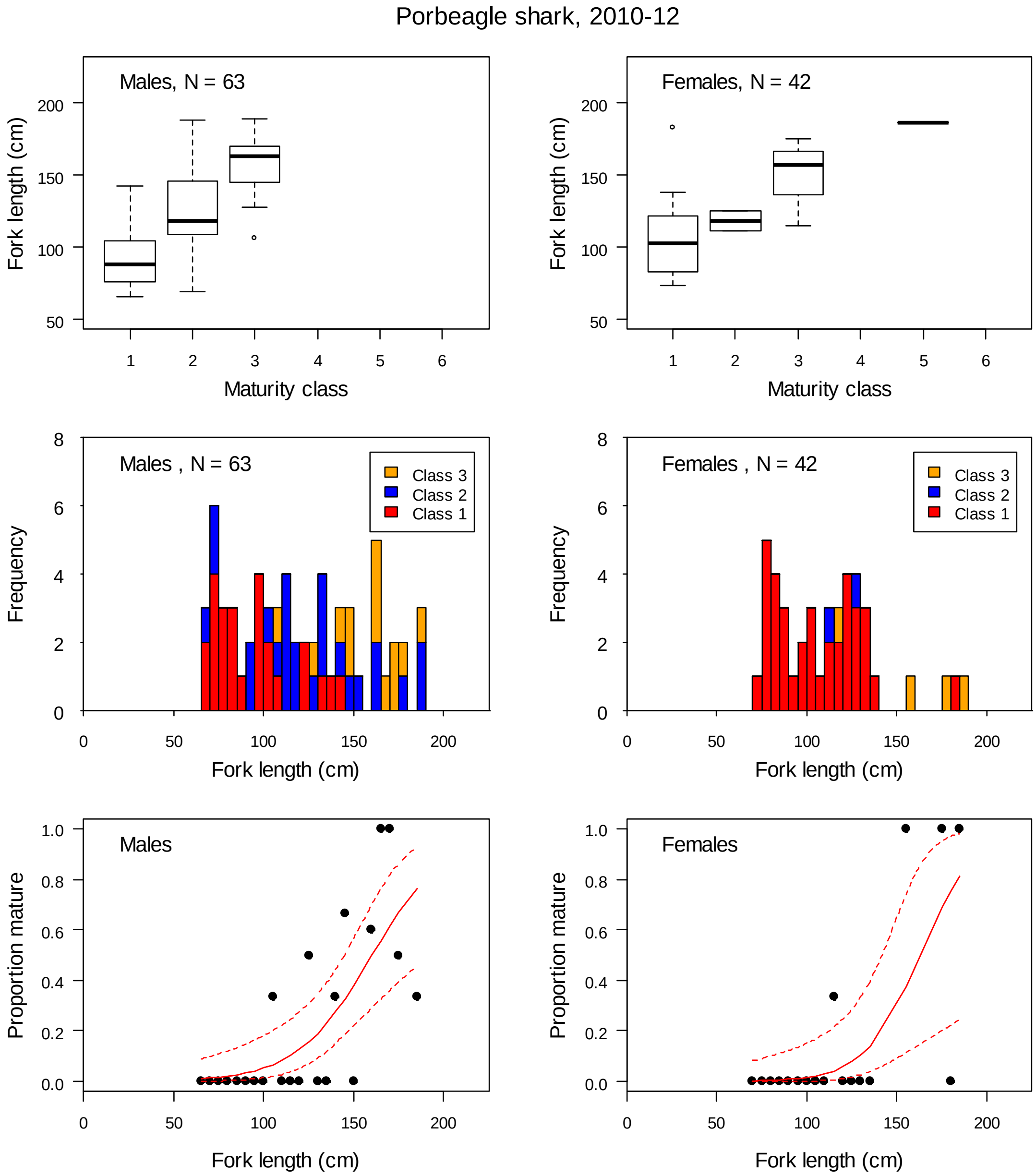


Figure 41: Maturity data collected from male and female porbeagle sharks, 2010–12. Top panels: Box plots of fork length classified by maturity stage (see Appendix 1 for stages). The central black bar is the median, the box spans the first to third quartiles, and the whiskers extend to the most extreme data point which is no more than 1.5 times the interquartile range from the box. Middle panels: Length-frequency distributions classified by maturity class (female classes 4–6 were combined with class 3). Bottom panels: Proportion of sharks that were mature (in 5 cm length intervals) with fitted logistic regressions. Dashed lines are 95% confidence intervals.

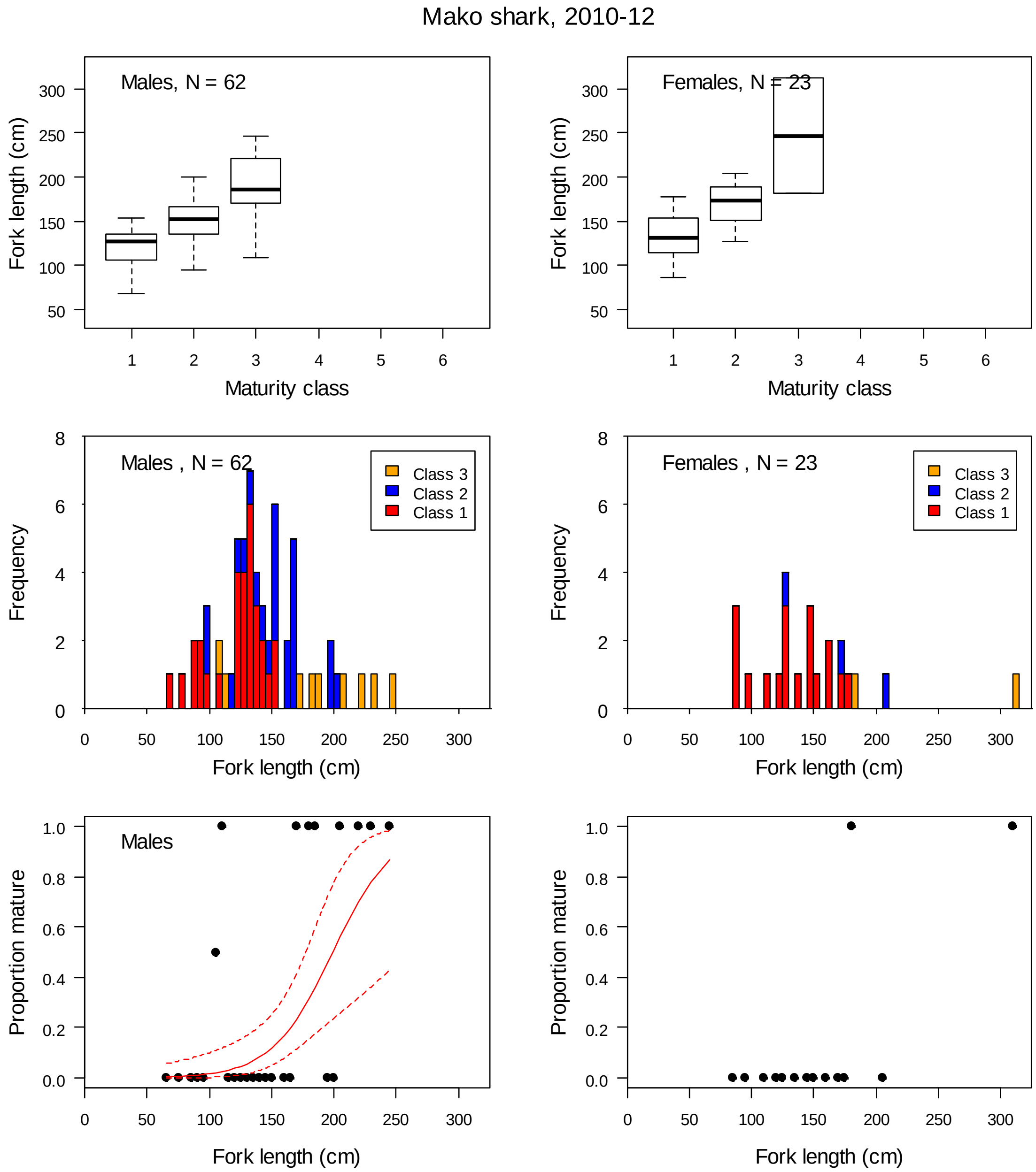


Figure 42: Maturity data collected from male and female mako sharks, 2010–12. Top panels: Box plots of fork length classified by maturity stage (see Appendix 1 for stages). The central black bar is the median, the box spans the first to third quartiles, and the whiskers extend to the most extreme data point which is no more than 1.5 times the interquartile range from the box. Middle panels: Length-frequency distributions classified by maturity class (female classes 4–6 were combined with class 3). Bottom panels: Proportion of sharks that were mature (in 5 cm length intervals) with fitted logistic regressions. Dashed lines are 95% confidence intervals.

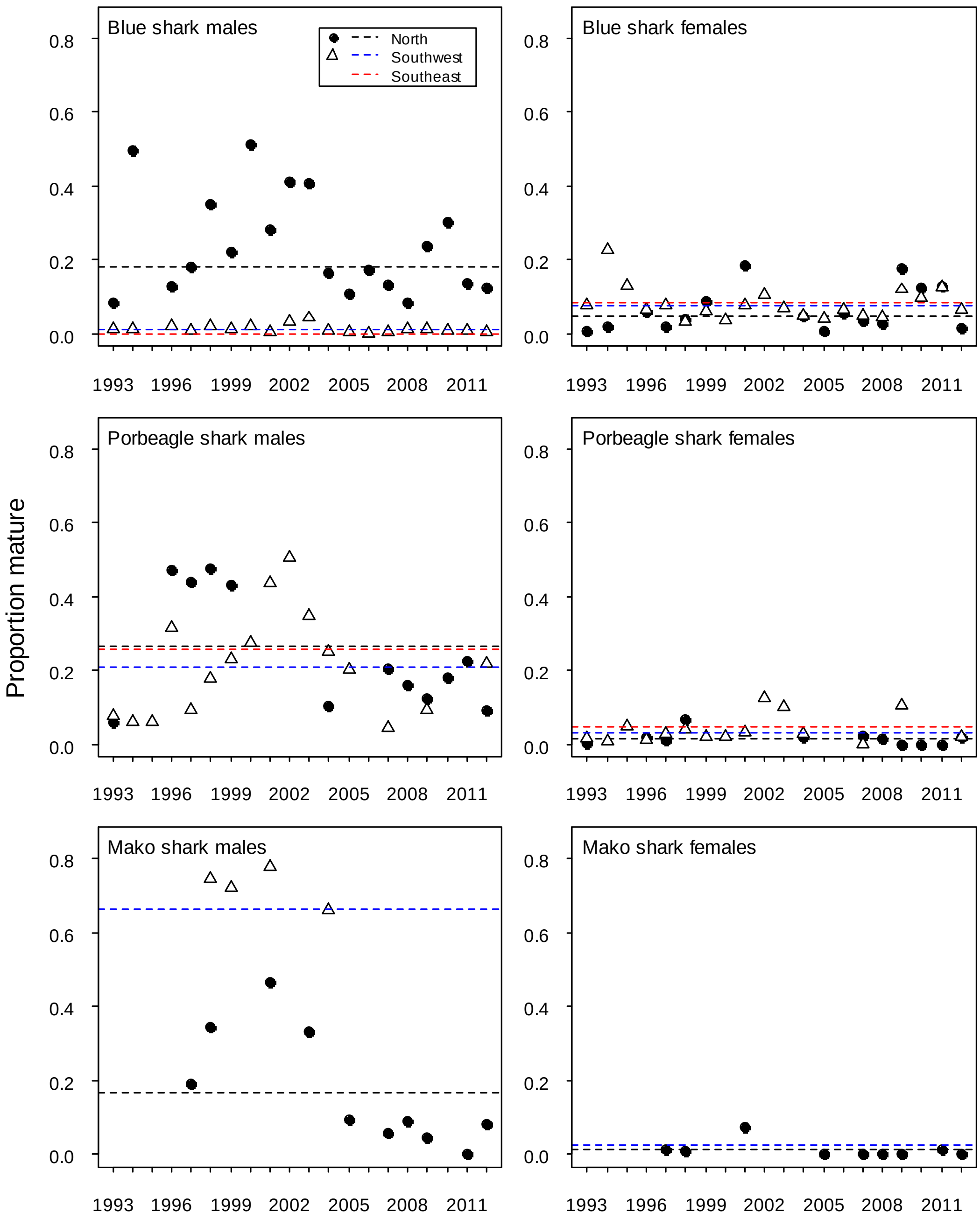


Figure 43: Proportions of observed blue, porbeagle and mako sharks that were estimated to be mature based on length-frequency distributions and median lengths at maturity. For porbeagle males, North and Southeast regions had the same overall proportion mature (0.26).

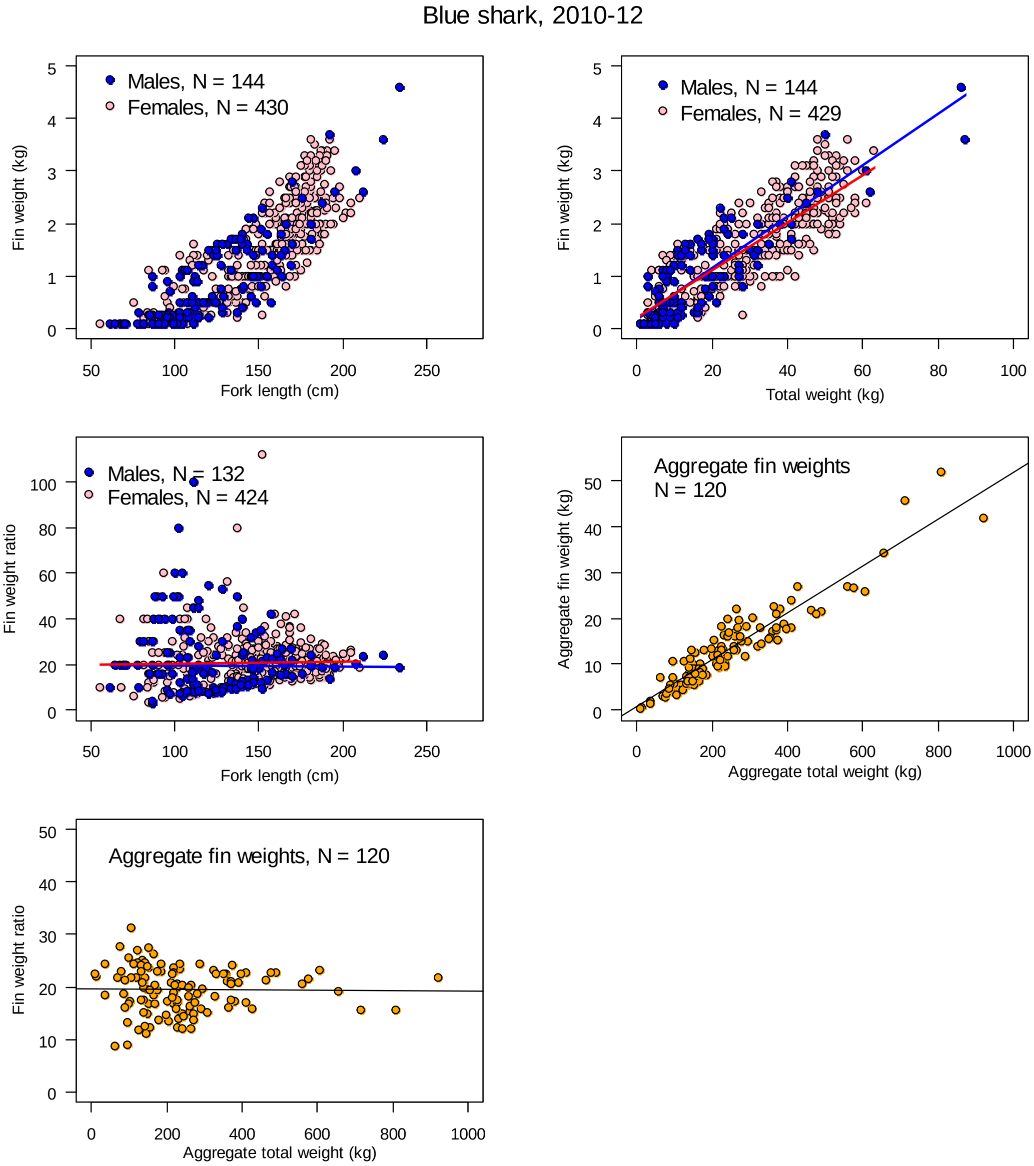


Figure 44: Fin weight data collected from male and female blue sharks in 2010–12. Panels 1–3 (numbered from left to right, top to bottom) show data for fin sets from individual sharks, and panels 4–5 show data aggregated from two or more sharks. Solid lines are fitted linear regressions. Sharks having fin weight ratios 50 or over were omitted from the linear regressions in the top right and middle left panels.

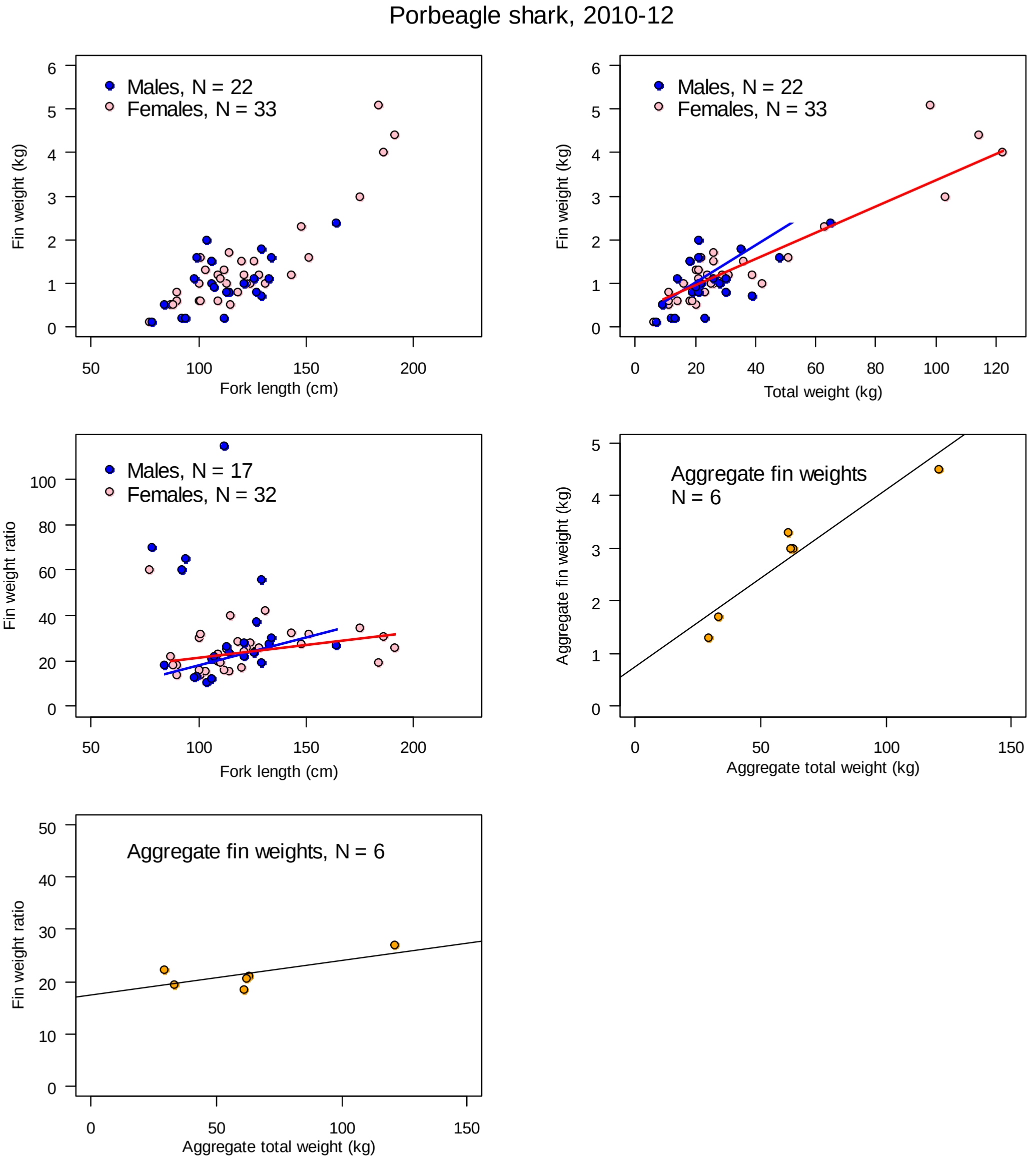


Figure 45: Fin weight data collected from male and female porbeagle sharks in 2010–12. Panels 1–3 (numbered from left to right, top to bottom) show data for fin sets from individual sharks, and panels 4–5 show data aggregated from two or more sharks. Solid lines are fitted linear regressions. Sharks having fin weight ratios 50 or over were omitted from the linear regressions in the top right and middle left panels.

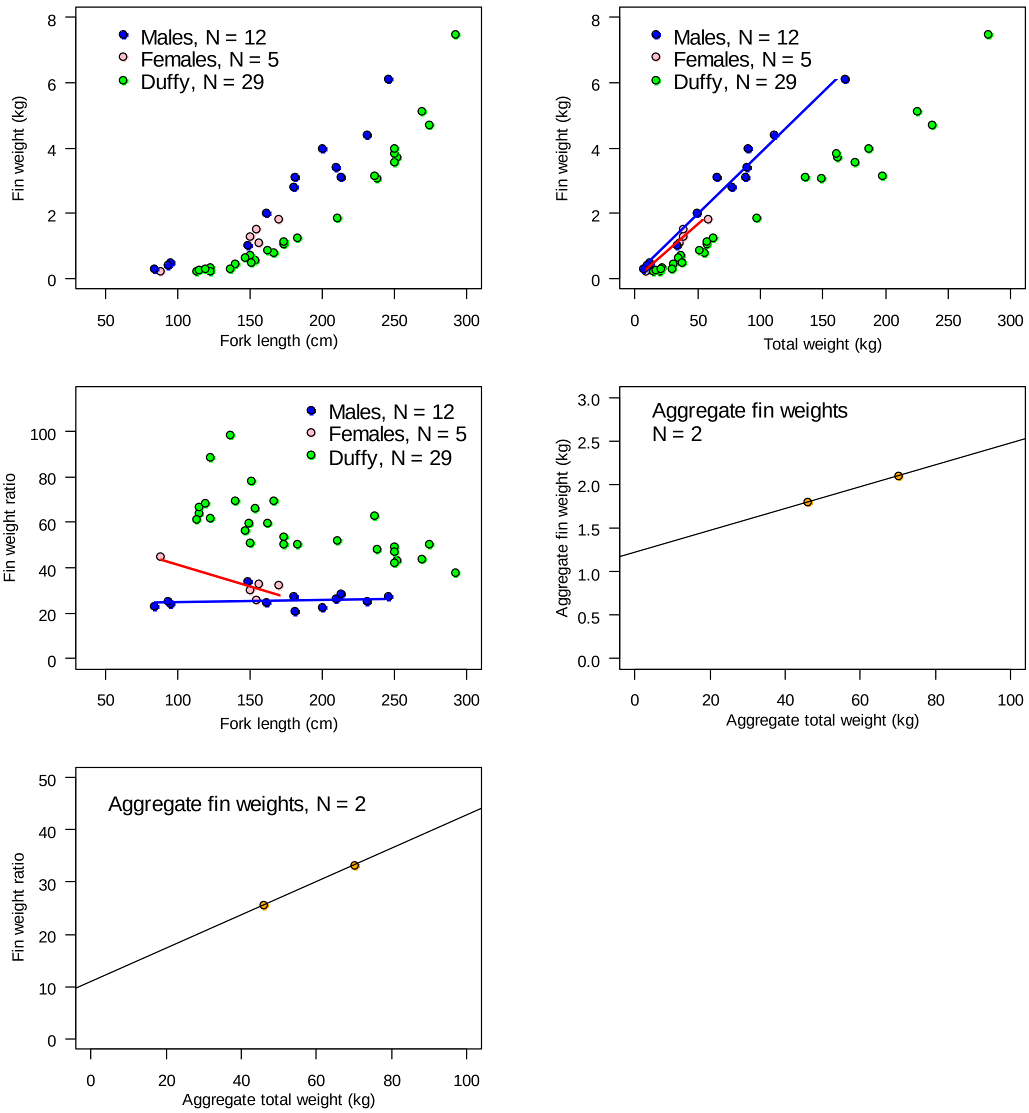


Figure 46: Fin weight data collected from male and female mako sharks in 2010–12. Panels 1–3 (numbered from left to right, top to bottom) show data for fin sets from individual sharks, and panels 4–5 show data aggregated from two or more sharks. Solid lines are fitted linear regressions. Sharks having fin weight ratios 50 or over were omitted from the linear regressions in the top right and middle left panels. Data from North Island fishing competitions for mako shark fin sets that included only the lower tail lobe are also shown in green (C. Duffy, unpubl. data).

Appendix 1: Observer instructions for sampling pelagic sharks

Collection of pelagic shark vertebrae and maturity and fin weight data

Pelagic sharks (blue, porbeagle and mako sharks) are caught mainly in tuna longline and midwater trawl fisheries around New Zealand. A sampling programme has been initiated to obtain information on the catch composition of these sharks in commercial catches, and to develop improved shark fin conversion factors. Size, sex, and maturity data will be collected, along with vertebrae to enable the sharks to be aged. Fins will be weighed at sea and related to shark green weight to obtain fin weight ratios.

Size and sex composition

For each shark caught, measure fork length and determine sex. Where possible, weigh green weight.

Maturity

For as many sharks as possible, determine maturity status (see shark staging guide below; note that males have a 3-stage maturity scale and females have a 6-stage scale). **Males of all three species can be staged by examining the state of clasper development**.

Females have to be opened up to examine the reproductive tract**.**

BWS
For blue sharks use the ovarian egg diameter as indicated in the staging guide to determine female maturity.

MAK and POS
Please record uterus width and check for pregnancy for:
MAK longer than 250 cm fork length
POS longer than 150 cm fork length

For mako and porbeagle sharks (MAK and POS), the ovarian egg size is not a good indicator of maturity. Instead, measurements are required of uterus widths to estimate female maturity. **Measure uterus width about three-quarters of the way along the body cavity.** There are two uteri, one on either side of the backbone, and they are suspended from the roof of the body cavity by a translucent mesentery. **Only measure one uterus, and don't include the mesentery in the measurement (see figures)**. The width of the uterus in natural position (flattened, but not squashed) should be measured with a small ruler to the nearest millimetre. For female MAK and POS, record uterus width in the column provided, and try and determine maturity stage from the guide below (staging should be easy for small females (stage 1), and large pregnant or recently-pupped females (stages 4-6), but may be difficult to determine for other females (stages 2-3), hence the need for uterine width measurements). **Check out a few large females first and be sure you know what the uteri look like, before routinely recording widths.** Check for pregnancy in all three species. **If the uteri appear to have objects inside, open the uteri and record pup or uterine egg numbers, and average size of pups, in the 'Comments' field.**

Ageing

Remove a section of 3-4 vertebrae. For makos, vertebrae should be taken from the front of the fish just behind the head, to avoid damaging the carcass; for blue and porbeagle sharks the vertebrae should be taken from beneath the first dorsal fin. If blue and porbeagle shark carcasses are being retained by the vessel, take vertebrae from the front of the column as described for makos, and record this in the 'Comments' field. Put a label in with each specimen giving trip, set/tow number, fork length and sex (or sample number). The vertebrae should then be bagged and frozen. Please ensure that all bags are tightly sealed to reduce desiccation in the freezer.

The numbers of sharks to be sampled has been determined according to a monthly sampling schedule and will be advised by the Observer Programme.

Fin weights

If the vessel is finning sharks, fin and green weights should be obtained for as many BWS, POS and MAK as possible, ensuring that a wide range of shark sizes are included. For each shark, record the basic information (trip, set/tow number, fork length and sex (or sample number)) and green weight. GW is essential for determining fin weight ratios. Where possible, record the individual weights (using motion-compensated scales) for each fin that is removed (except for the two pelvic fins which should be combined). Two options are available for the tail fin, depending on how the crew handle these: whole tail fin (cut off the carcass at the tail stock) or tail fin lower lobe (where only the lower fin lobe is retained). Note in the ‘Comment’ field whether further trimming of fins occurred after the weights were recorded.

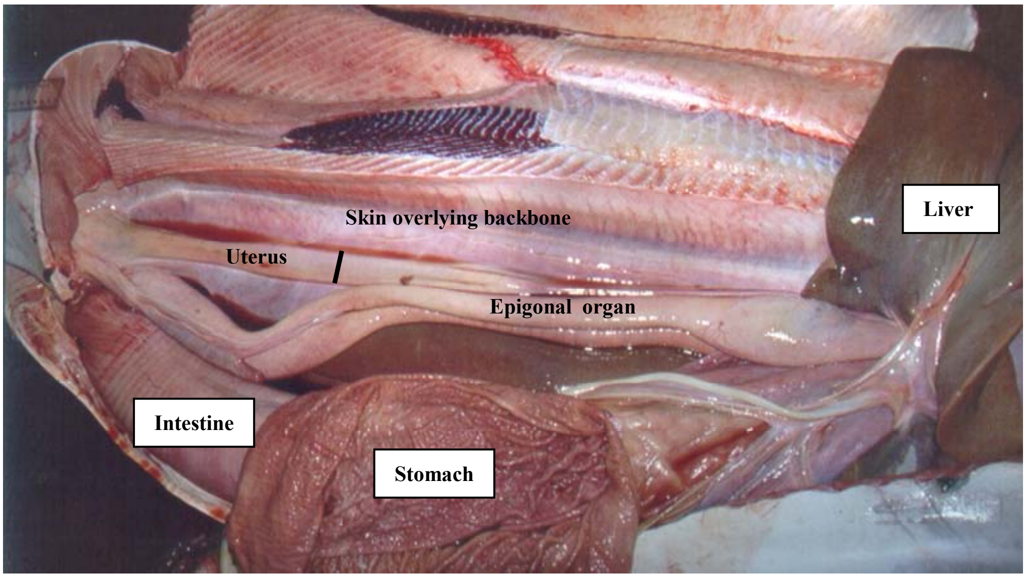
If it is not possible to weigh fins from individual sharks, an aggregated total for a group of sharks (e.g. all sharks of a single species caught in one longline set or one trawl tow) is still useful for calculating conversion factors. In this situation, please record the number of sharks in the group, and the total green weight and fin weight for all sharks in the group. In the ‘Comments’ field, please note which fins were included in the fin weights.

In some circumstances, it may be possible to access sacks of fins after they have been frozen for a while. It would be useful to estimate any loss of weight due to freezing and desiccation. However, it is essential that such weights can be related back to the original wet weights or green weights, so please record them on the same line of the form used for the corresponding wet fin weights or green weights.

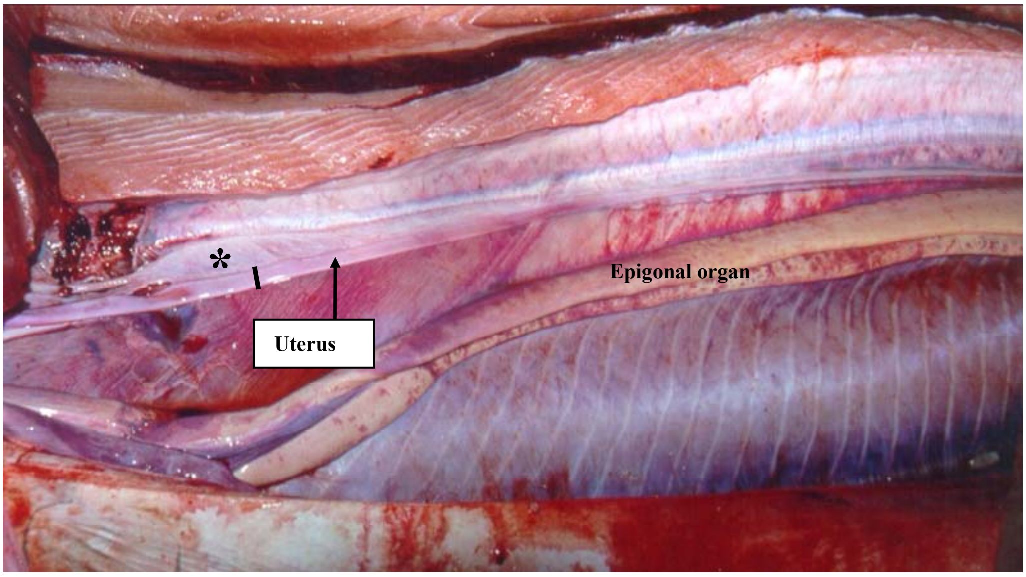
Reproductive staging guide for sharks and skates

Stage	Name	Males	Females
1	Immature	Claspers shorter than pelvic fins, soft and uncalcified, unable or difficult to splay open	BWS: Ovaries small and undeveloped. Ova not visible, or small (pin-head sized) and translucent whitish POS: Uterine width about 4-7 mm MAK: Uterine width about 4-15 mm
2	Maturing	Claspers longer than pelvic fins, soft and uncalcified, unable or difficult to splay open or rotate forwards	BWS: Some ova enlarged, up to about pea-sized or larger, and white to cream. POS: Uterine width about 8-10 mm MAK: Uterine width about 16-30 mm
3	Mature	Claspers longer than pelvic fins, hard and calcified, able to splay open and rotate forwards to expose clasper spine	BWS: Some ova large (greater than pea-sized) and yolky (bright yellow) POS: Uterine width > 10 mm MAK: Uterine width > 30 mm
4	Gravid I	*Not applicable*	Uteri contain eggs or egg cases but no embryos are visible
5	Gravid II	*Not applicable*	Uteri contain visible embryos.
6	Post-partum	*Not applicable*	Uteri flaccid and vascularised indicating recent birth

Uterine width measurements for POS and MAK

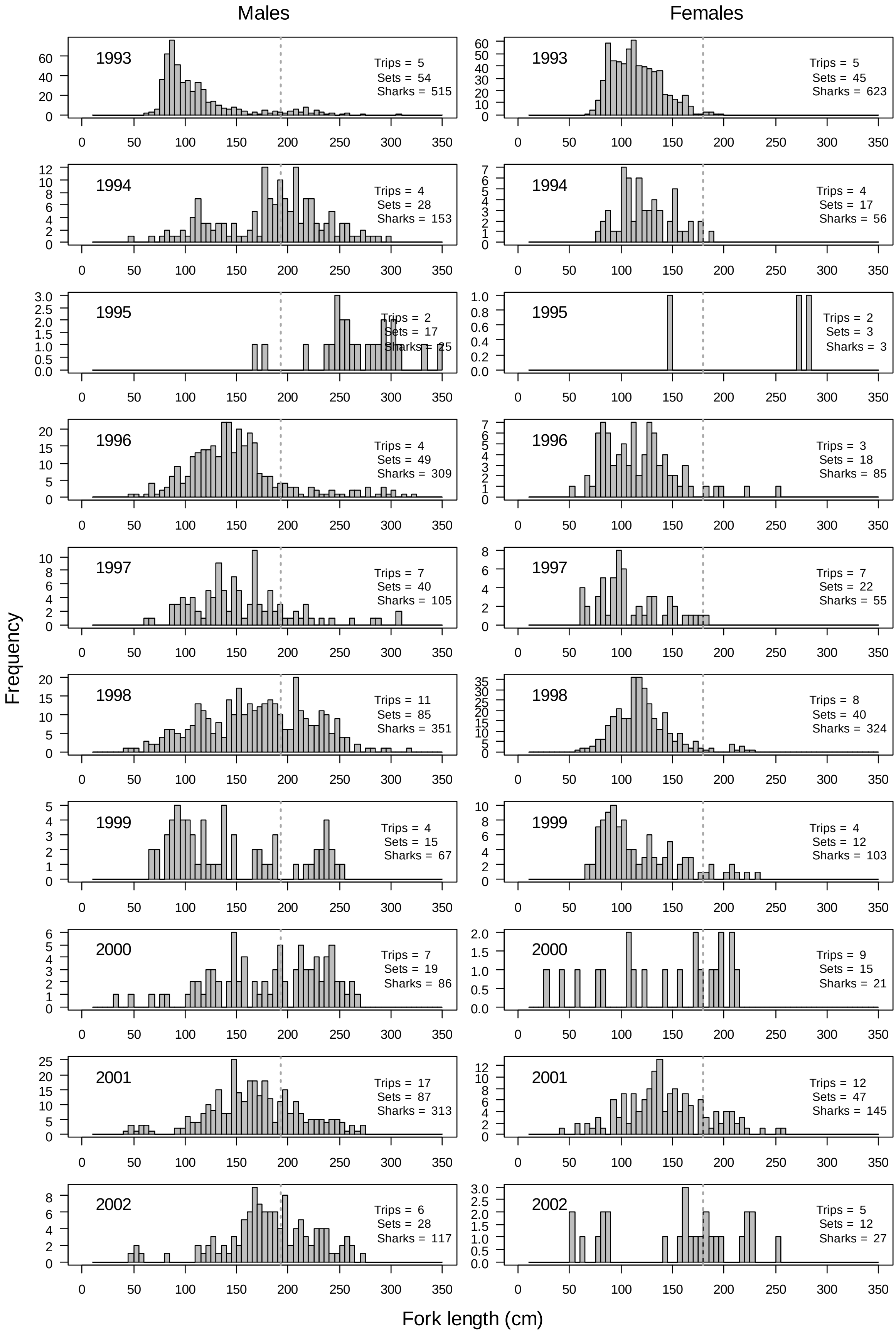


Dissection of maturing female mako shark (stage 2) with liver folded back towards head, (right) and stomach (opened) and intestine displaced downwards. The uterus is moderately well developed and of intermediate width; only the right uterus is visible. Black bar shows location of width measurement. Note the paired epigonal organ running the full length of the body cavity – do not confuse this with the uterus. The epigonal organ is soft, mushy, and easily damaged (like the liver but even softer), and usually yellowish and reddened by blood vessels. The uterus is usually cream or white, has fewer blood vessels (except in pregnant and recently pupped females), is tougher (more muscular), and is suspended closer to the backbone than the epigonal organ.

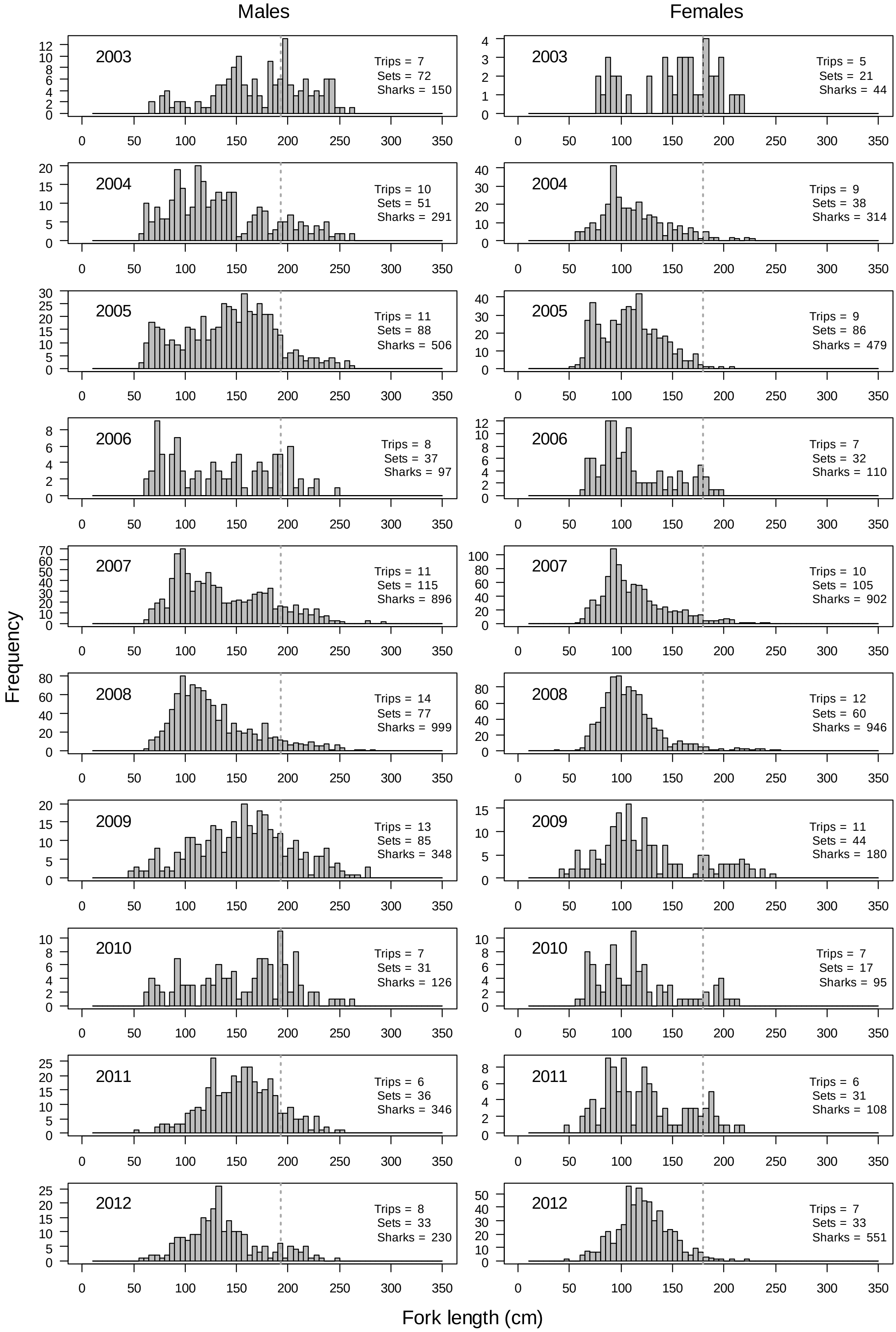


Immature female mako shark with liver, stomach and intestine removed. The uterus is narrow and undeveloped. Black bar shows location of width measurement. Asterisk indicates mesentery supporting uterus – do not include mesentery in width measurement. In both photos the head is to the right and tail to the left.

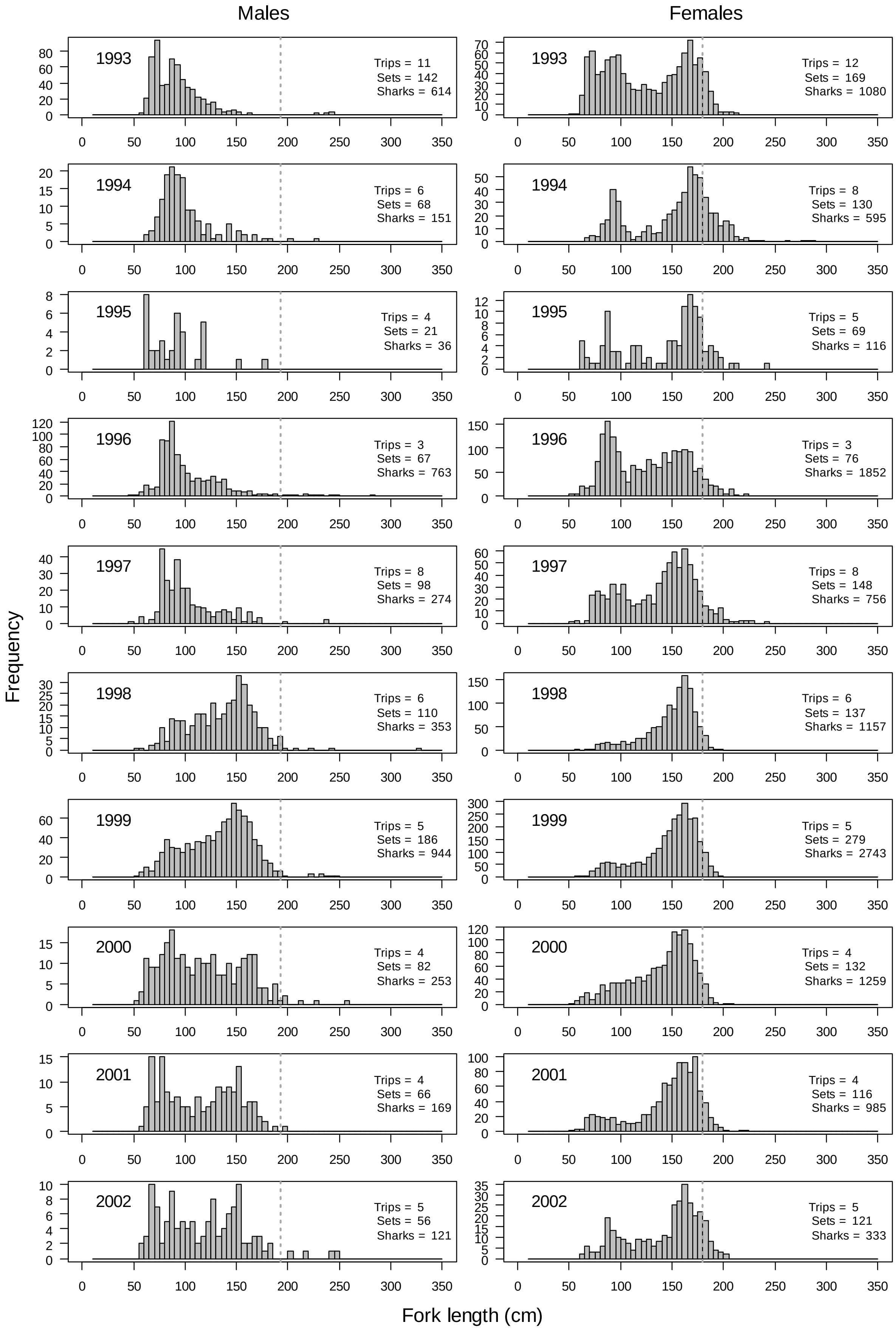
Appendix 2: Length-frequency distributions of blue sharks from the North region by year.



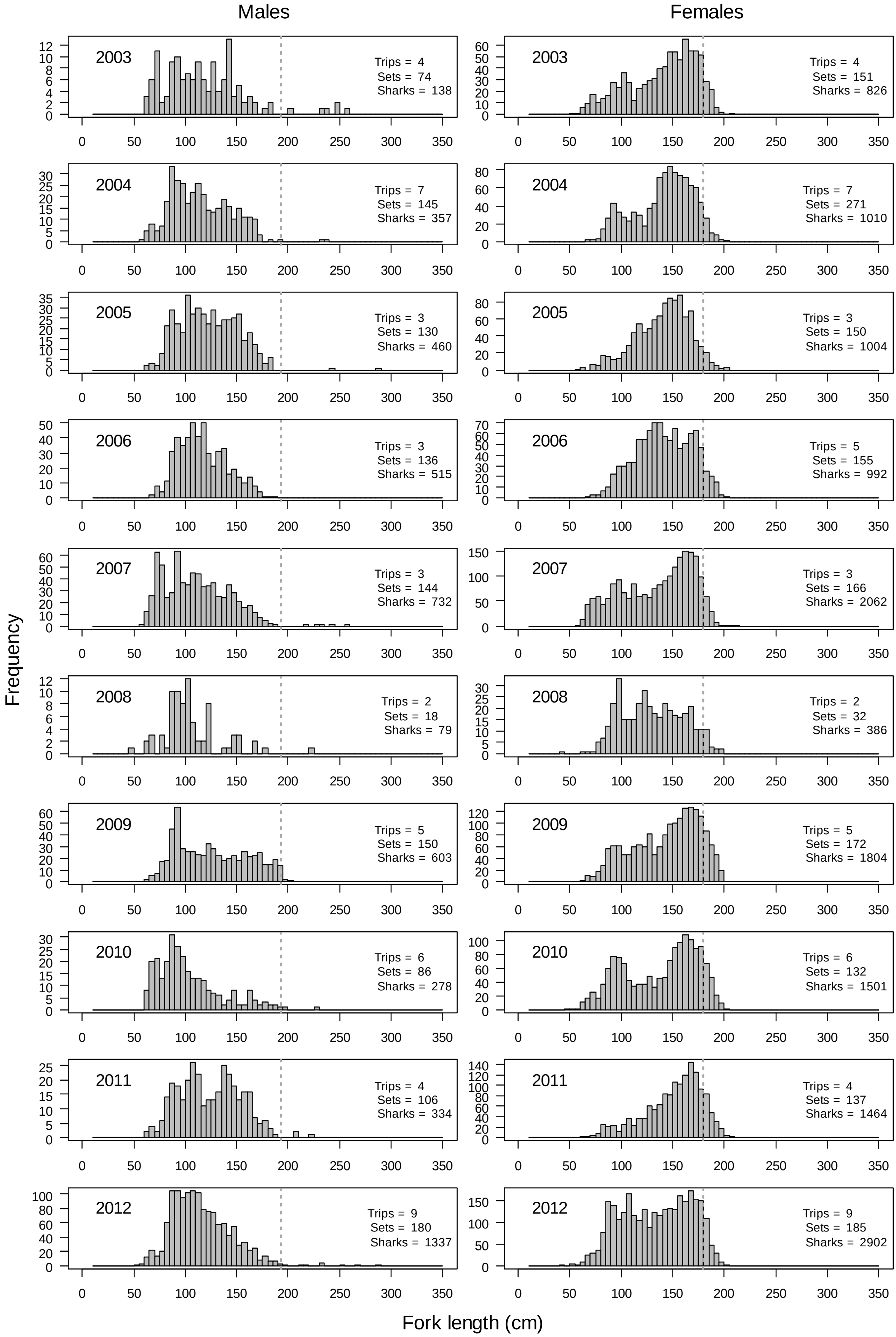
Appendix 2 (cont.): Length-frequency distributions of blue sharks from the North region by year.



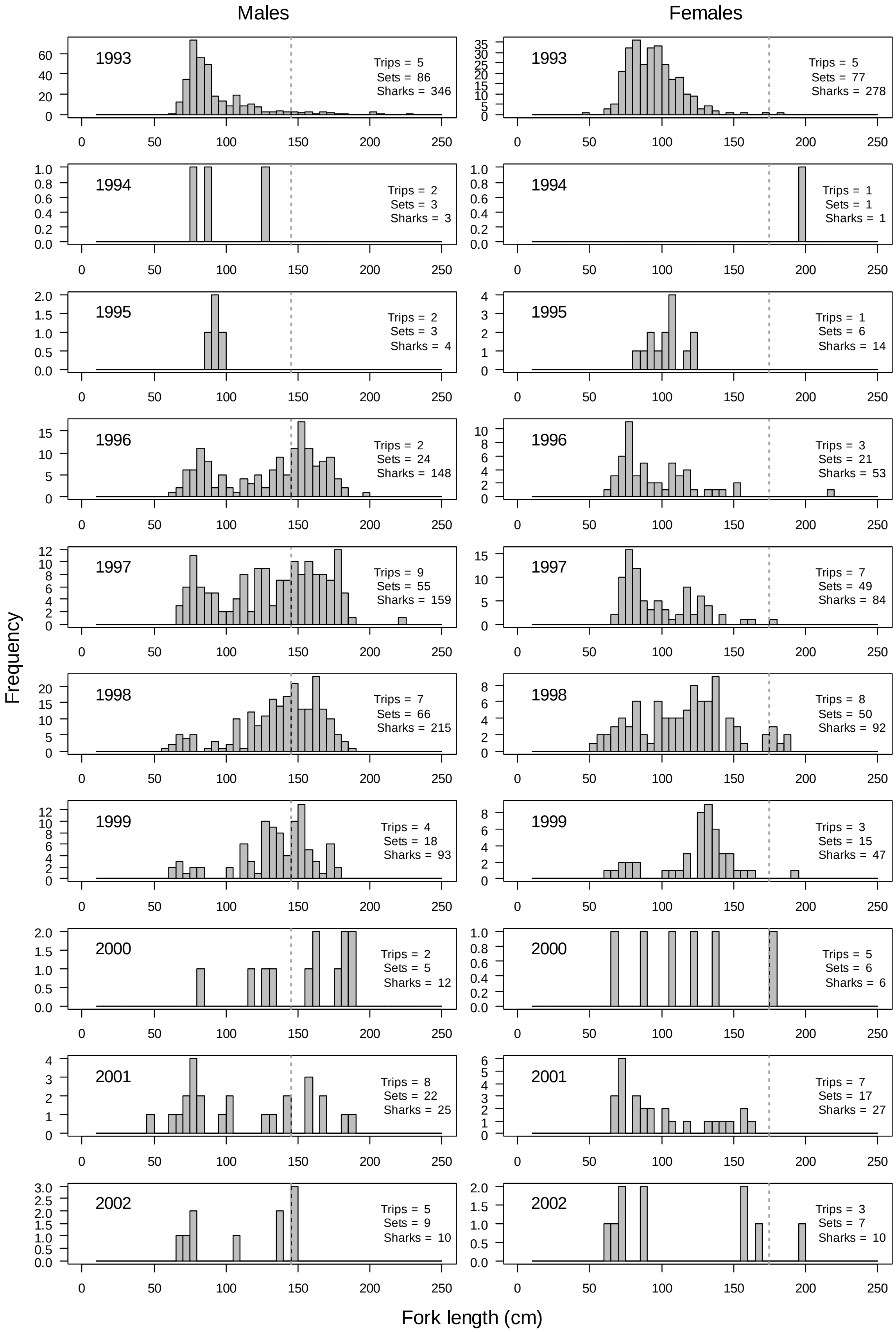
Appendix 3: Length-frequency distributions of blue sharks from the Southwest region by year.



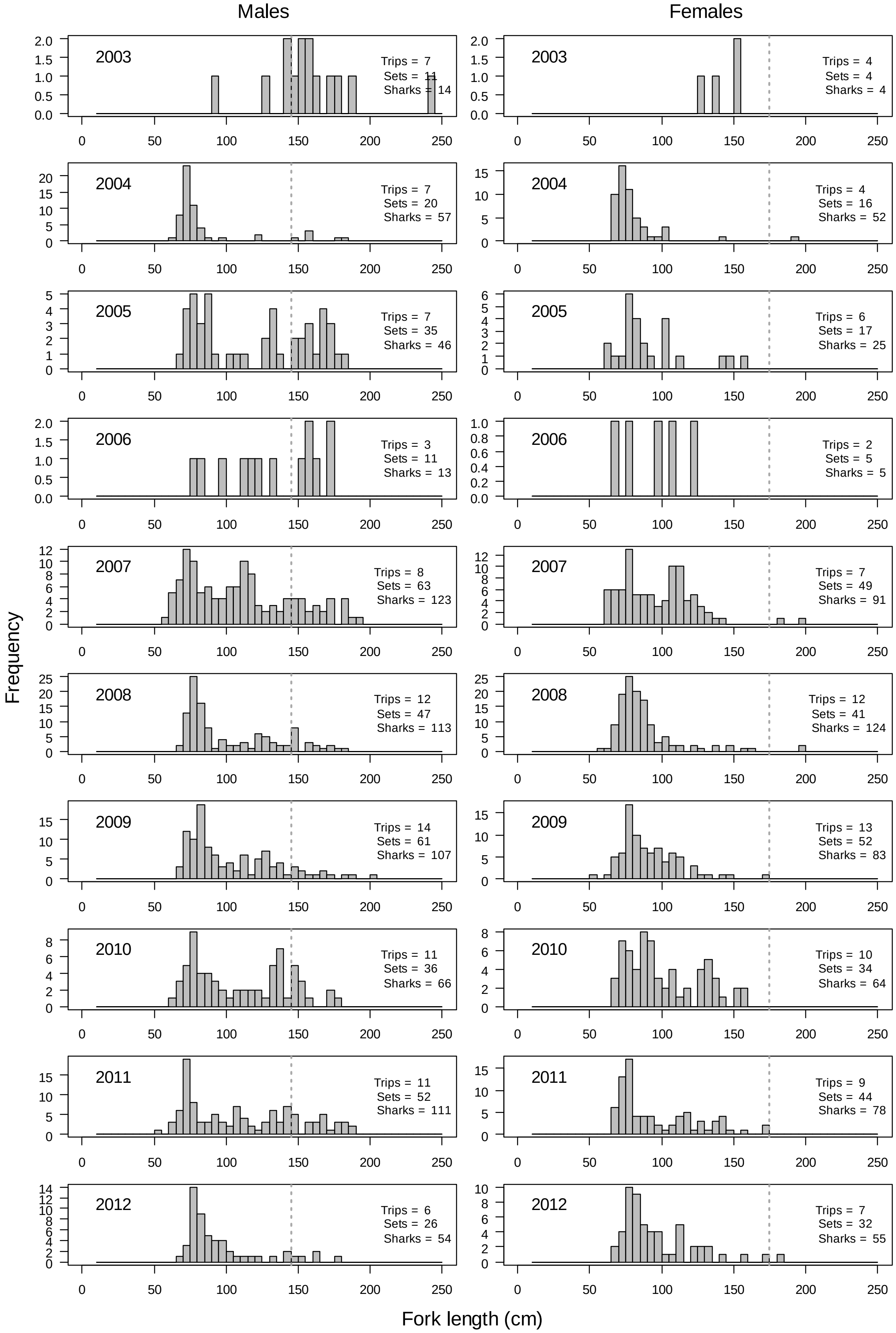
Appendix 3 (cont.): Length-frequency distributions of blue sharks from the Southwest region by year.



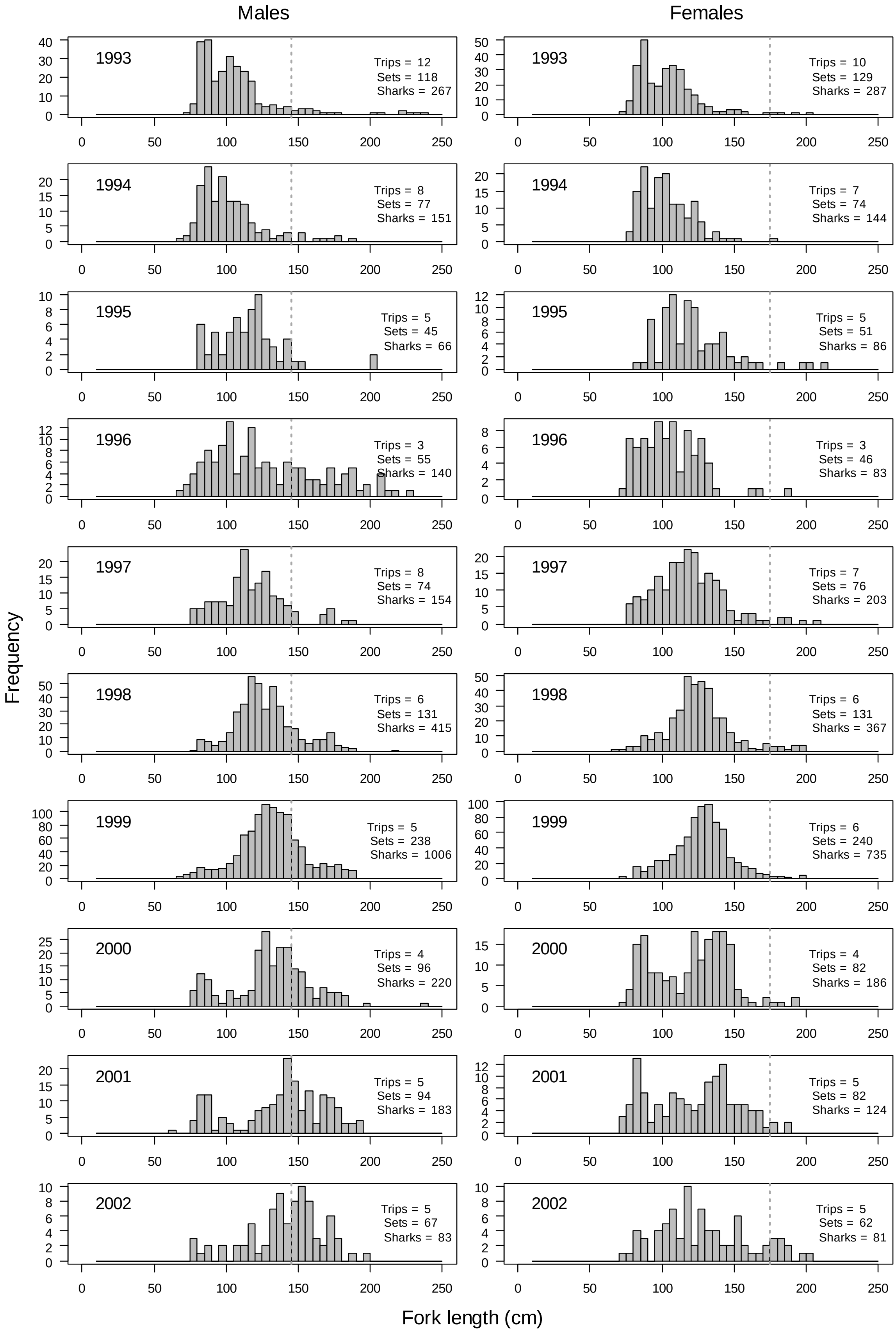
Appendix 4: Length-frequency distributions of porbeagle sharks from the North region by year.



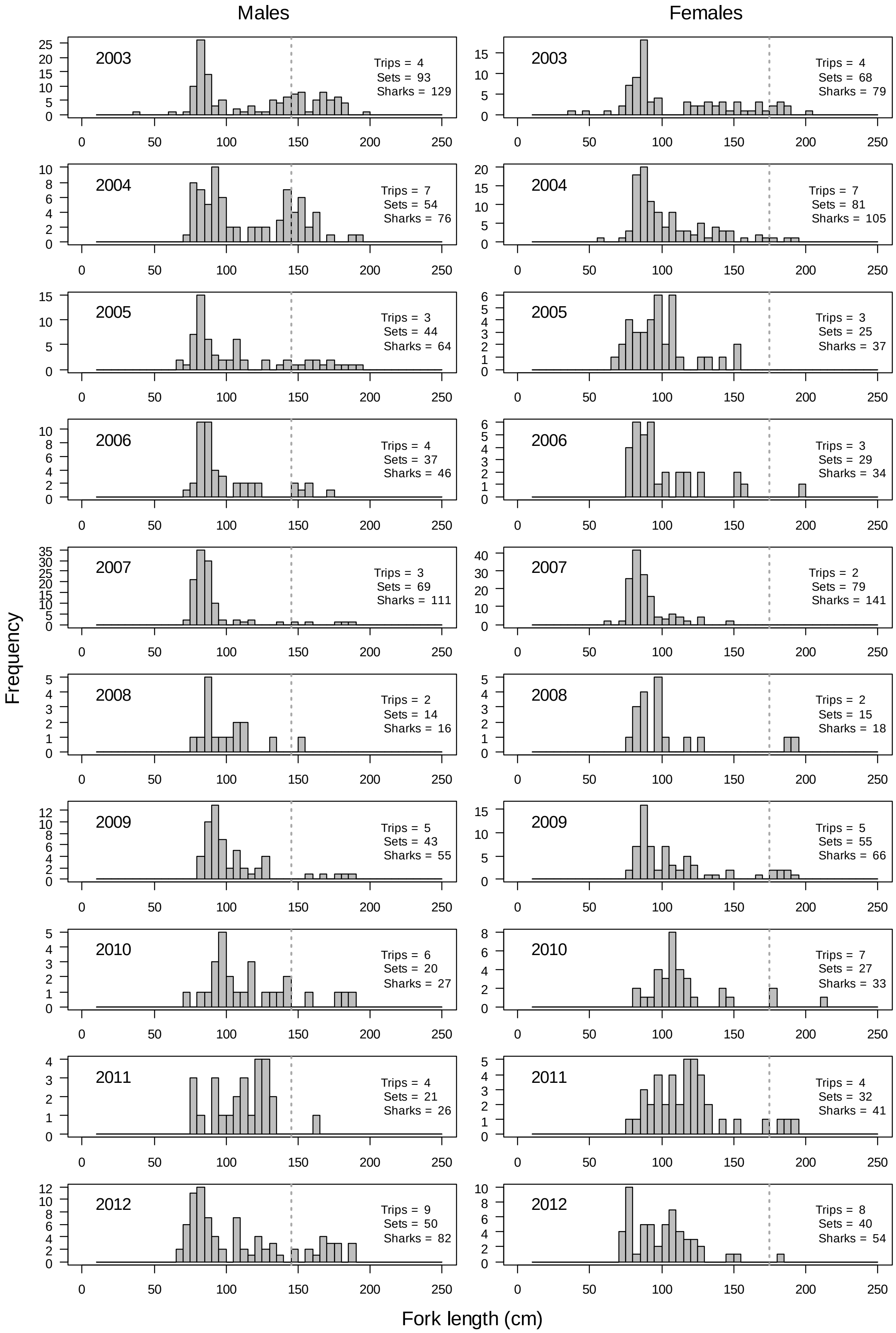
Appendix 4 (cont.): Length-frequency distributions of porbeagle sharks from the North region by year.



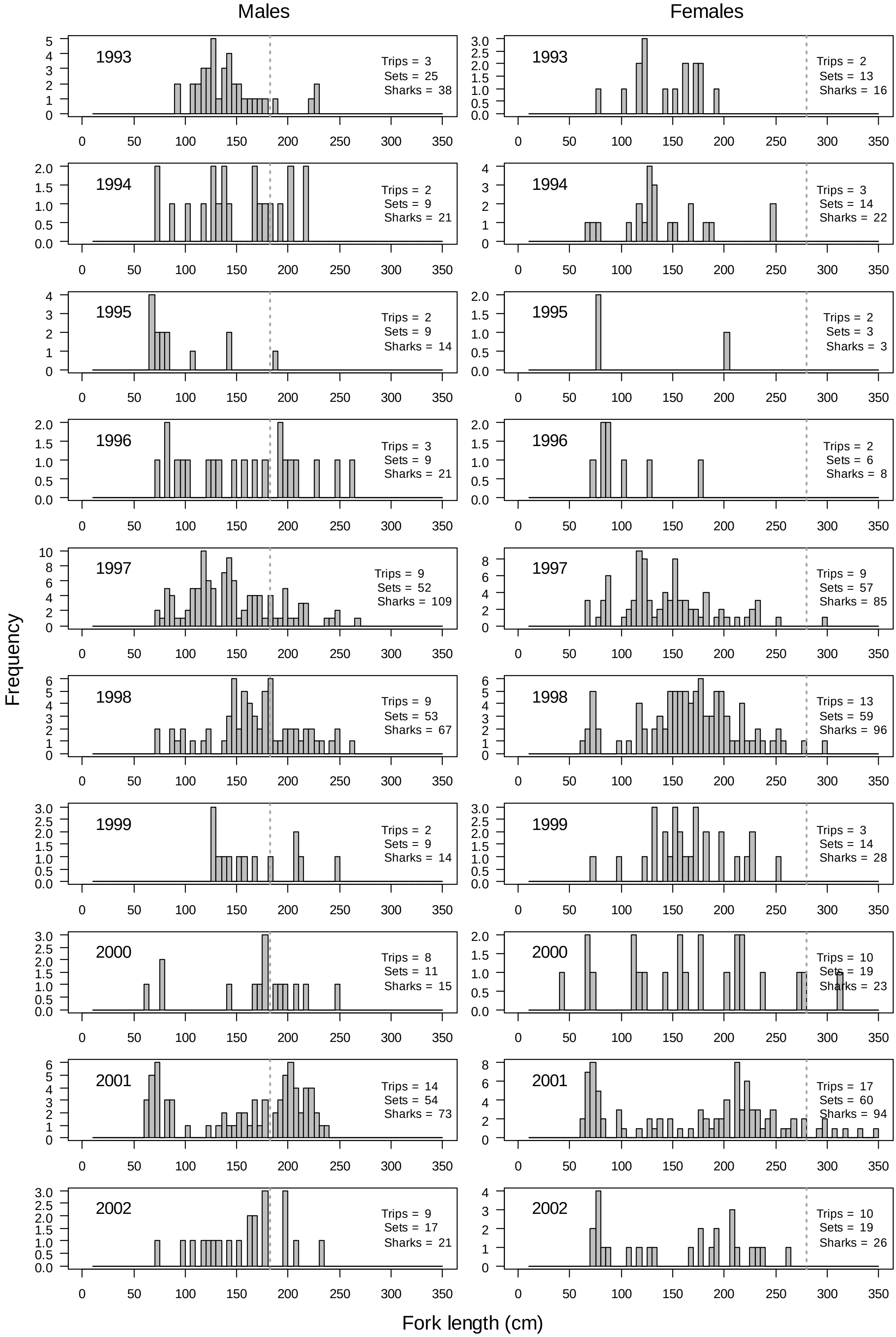
Appendix 5: Length-frequency distributions of porbeagle sharks from the Southwest region by year.



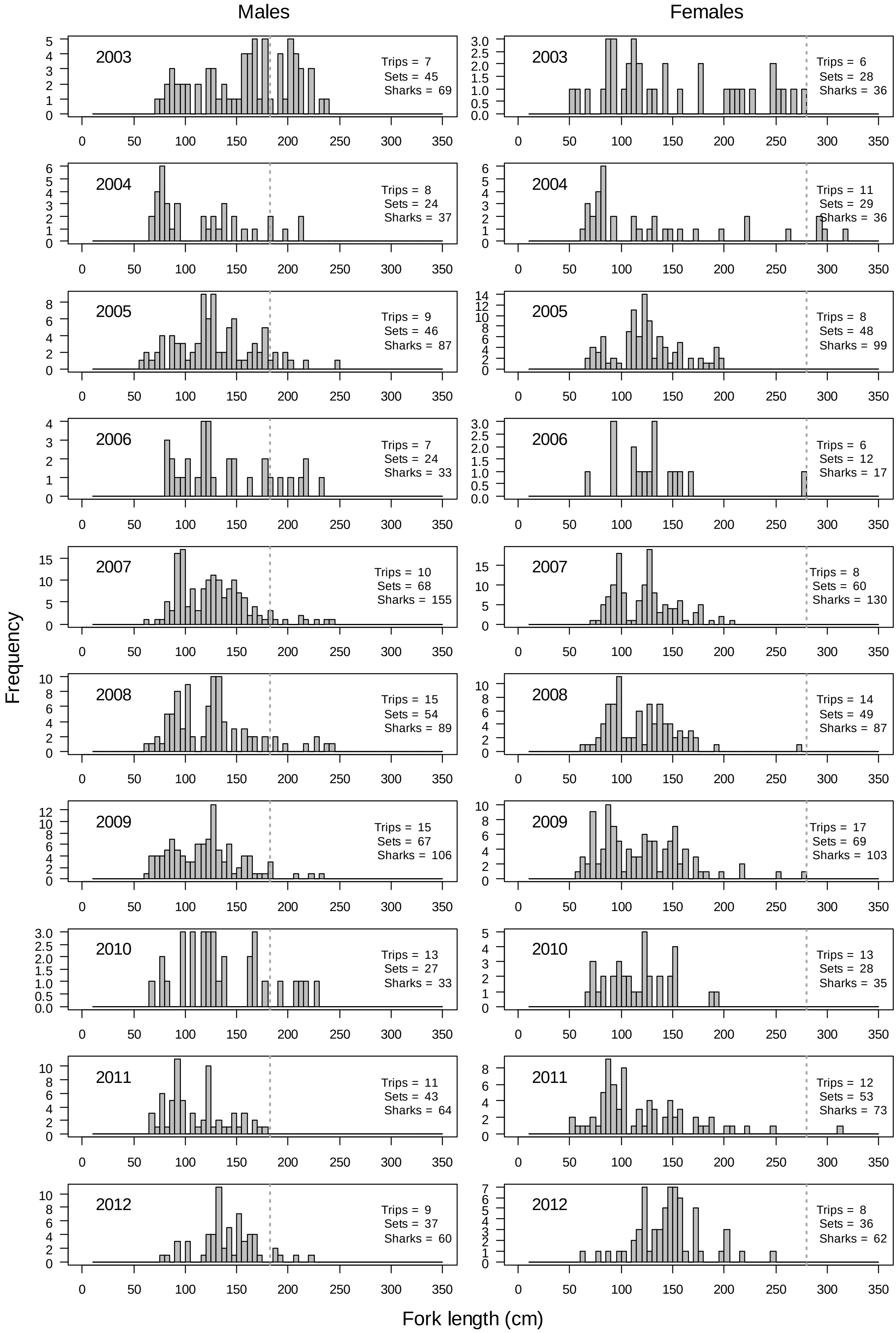
Appendix 5 (cont.): Length-frequency distributions of porbeagle sharks from the Southwest region by year.



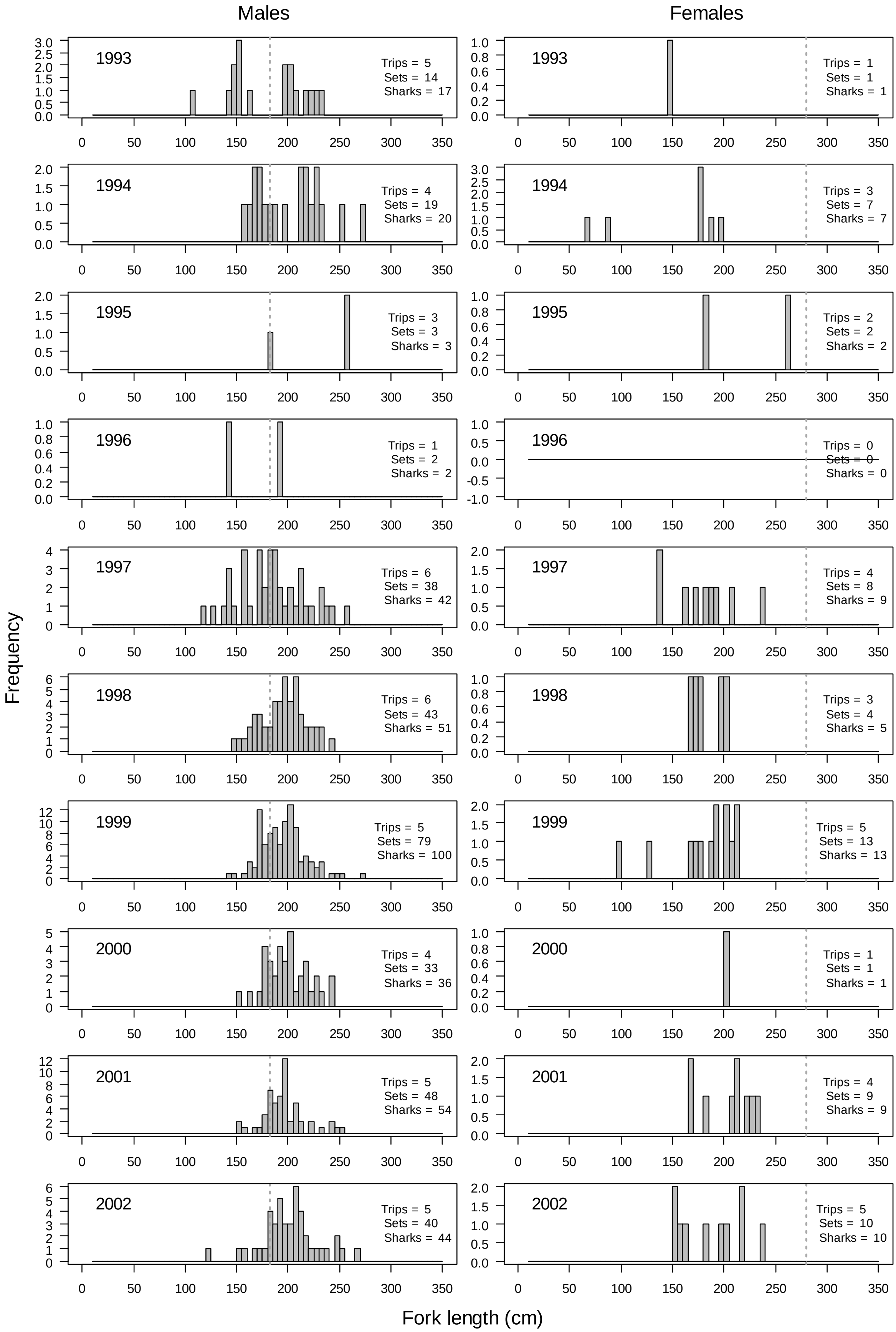
Appendix 6: Length-frequency distributions of mako sharks from the North region by year.



Appendix 6 (cont.): Length-frequency distributions of mako sharks from the North region by year.



Appendix 7: Length-frequency distributions of mako sharks from the Southwest region by year.



Appendix 7 (cont.): Length-frequency distributions of mako sharks from the Southwest region by year.