Ministry for Primary Industries
Manatū Ahu Matua

Size, maturity and age composition of porbeagle sharks observed in New Zealand tuna longline fisheries

New Zealand Fisheries Assessment Report 2015/16

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ISSN 1179-5352 (online)
ISBN 978-0-477-10562-0 (online)

March 2015

New Zealand Government

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EXECUTIVE SUMMARY

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Pelagic sharks are routinely taken as bycatch in New Zealand's surface longline (SLL) fisheries, and to a lesser extent in midwater trawl fisheries. The porbeagle shark (*Lamna nasus*) is the third most-caught pelagic shark (after blue and mako sharks), with estimated catches of about 60−80 tonnes per year between 2008−09 and 2012−13, and a current Total Allowable Commercial Catch of 110 tonnes. Due to their migratory nature, management is done on a regional basis with New Zealand being responsible for monitoring its fisheries and providing these data to regional fisheries management organisations. This study assesses the catch composition of porbeagle sharks taken by SLL in New Zealand waters using data and samples collected by observers. Data were stratified by fleet (chartered Japanese or New Zealand domestic vessels) and region (North region = Fisheries Management Areas 1, 2, 8 and 9, and Southwest region = FMAs 5 and 7). Length-frequency distributions were scaled up to estimate the size composition of the commercial catch for the fishing years 2007 to 2013. Maturity and reproductive status were assessed from observer data collected between 2011 and 2014. Vertebrae were sectioned, and growth bands counted to estimate the age of a subsample of sharks. An ageing protocol was developed and growth curves were fitted to the length-at-age data. A scaled age-frequency distribution of the catch was generated by applying an age-length key to the scaled length-frequency distributions (by sex). The proportions of mature animals in the catch were estimated by applying the median length at maturity to the scaled length-frequency distributions (by sex).

Observer sampling of length data was compromised by their inability to measure every shark caught, and evidence that unmeasured, discarded sharks may have a different size composition from measured, discarded sharks. The proportion of porbeagles discarded or released alive under Schedule 6 of the Fisheries Act continues to increase, reaching two-thirds of the catch in 2013. In the North region, the proportion of porbeagles measured dropped to 16% in 2013, and observer coverage was low. High observer coverage of the Japanese charter fleet resulted in about 60% of porbeagles being measured each year in the Southwest region. The decline in numbers of porbeagle sharks measured by observers in the North region makes it difficult to assess recent patterns of size composition, sex ratio, maturity composition, and age composition.

The SLL porbeagle catch was dominated by juveniles, with about half of the males and two-thirds of the females being under 100 cm fork length. Only 21% of males and fewer than 2% of females were considered mature, but these proportions may have been under-estimated if significant numbers of large mature adults were being discarded unmeasured. Mature females are not considered vulnerable to the New Zealand SLL fishery, although they may be taken by other fleets in international waters. The catch of both sexes was dominated by one-year-old sharks and most of the rest of the catch was aged about 2−10 years. There remains a need to properly validate porbeagle ageing up to 20 years (age estimates beyond 20 years have been shown to seriously under-estimate true age). Such validation could be achieved by injection of oxytetracycline into tagged and released sharks to mark their vertebral centra with a time stamp. Males and females have significantly different growth curves but the curves only began diverging after 12−14 years, beyond which there were few aged sharks. Nevertheless, length at maturity differed between the two sexes, so their estimated ages at maturity also differed: about 6–8 years for males and 13–16 years for females.

Uncertainties and gaps in our knowledge of the biological parameters and catch composition of porbeagle sharks require that management is cautious, and that efforts are made to fill the gaps through appropriate research. In particular, a quantitative stock assessment is required to pull together New Zealand and overseas data into a coherent model in order to estimate the status of the stock.

1. INTRODUCTION

Pelagic sharks are routinely taken as bycatch in New Zealand's tuna longline fisheries, and to a lesser extent midwater trawl fisheries (Clarke et al. 2013; Francis 2013; Griggs & Baird 2013). The porbeagle shark (*Lamna nasus*) is the third ranked pelagic shark (after blue and mako sharks), with estimated catches of about 60−80 tonnes per year between 2008−09 and 2012−13, and a current Total Allowable Commercial Catch of 110 tonnes (Ministry for Primary Industries 2014a). Highly migratory species (HMS), including porbeagles, are managed by Regional Fisheries Management Organisations (RFMOs). Important RFMOs for porbeagles are the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) and the Western and Central Pacific Fisheries Commission (WCPFC). As a member of CCSBT and WCPFC, New Zealand has numerous obligations, including the provision of specific data and 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 measures via catch limits for the main HMS shark species.

Due to their HMS nature, assessments for these stocks are done on a regional basis with New Zealand being responsible for monitoring its fisheries and providing these data to the respective Commission. 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 (Ministry for Primary Industries 2014b) additionally requires that New Zealand fills some of the current data gaps in information on its shark fisheries.

Historically, most biological information for HMS species has been collected by observers at sea in the tuna longline fishery (Francis & Duffy 2005; Francis 2013). The low levels of domestic observer coverage result in low quantities of data being collected, and the need for multi-year sampling to answer key questions. Low observer coverage rates greatly reduce our ability to quantitatively monitor the components of the stock that migrate through or reside in New Zealand waters. Under a recent MPI research project (HMS2010-03), Francis (2013) characterised the fisheries for porbeagle sharks (and also blue and mako sharks), documented observer collections of vertebral samples and data on maturity and fin weights, analysed time series of length-frequency, maturity and sex ratio data from tuna longline catches, and made recommendations for improved data and sample collection. This study extends and builds on the previous project by ageing porbeagle vertebrae collected by observers in 2011–14, establishing a reference library of vertebral sections, estimating the length and age composition of tuna longline catches, and updating previous analyses of maturity composition and sex ratio. The results will be used as inputs to future stock assessments being undertaken by WCPFC and CCSBT.

The objectives of this study were:
1. To analyse the sex, maturity state, length and age structure of the commercial catch and review conversion factor data from porbeagle sharks
2. To age vertebrae collected by fishery observers
3. To develop an ageing library from the material used in this study

Results from an analysis of porbeagle shark conversion factor data (part of objective 1) were reported elsewhere (Francis 2014) and are not included here.

2. METHODS

2.1 Collecting biological data

A set of instructions was prepared for observers on sampling pelagic shark length, sex, maturity, vertebrae and fin weight (Appendix 1). Vertebrae were inventoried and archived in a freezer, and maturity and fin data were punched. In 2014, observers were also asked to record the presence or absence of spermatophores in the ampulla epididymis (seminal vesicle) of males (Pratt & Tanaka 1994). Spermatophore occurrence is a useful complement to clasper development when determining the maturity status of male porbeagles (Francis & Duffy 2005). Other observer data were punched and loaded using routine processes into the *COD* database managed by NIWA for MPI.

2.2 Analysis of observer data

The analyses in this report were based on data and specimens collected by observers. Most data and all specimens came from surface longline (SLL) vessels targeting tunas. A total of 316 SLL observer trips made between April 1993 and September 2013 were included[1]. Five of those trips (1.6%) were omitted from analyses because of known species identification problems, or data quality issues. Observer data were stratified into fleets (chartered Japanese or New Zealand domestic vessels) and regions because previous studies have identified spatial variation in pelagic shark length-frequency distributions (Francis et al. 2001; Francis 2013). The North region comprised Fisheries Management Areas (FMAs) 1, 2, 8 and 9, and the Southwest region comprised FMAs 5 and 7.

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. 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 porbeagle sharks, trips 598–1633 (except 875) and 30601–31423 (1993– mid 2002) used Length2 = PCL and trips 1757 to 3856 (2003–2013) 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. 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 (see Francis 2013 for regression equations). This procedure increased the number of FL measurements by 18.0% for porbeagle shark.

Hereafter, all references to years are for fishing years (1 October to 30 September) and each year is labelled after the second of the pair of calendar years (e.g. the 2012−13 fishing year is labelled as 2013). Data for 2014 were incomplete so annual summaries stop at 2013 whereas analyses of reproductive data include some data from 2014.

When large numbers of sharks (particularly blue sharks) are caught on SLL sets, 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. Tallies are not a major issue for porbeagles: between 1993 and 2013, only 2.3% of 19 370 observed

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[1] One trip that began in August 2013 continued into the 2013−14 fishing year, being completed on 2 December 2013.

porbeagles were tallied. However, many porbeagles that were individually recorded (44.4% of 18 916 sharks) were not measured.

Observer length-frequency distributions were scaled up to estimate the size composition of the commercial catch using NIWA's catch-at-length-and-age program CALA v2.0-2015-01-28 (rev. 371) (Francis et al. 2014b). Measured sharks were aggregated into four strata (Charter North, Charter South, Domestic North and Domestic South) and scaled up to the fishing year catch using the proportion of hooks observed in each stratum. Annual length-frequency distributions were then further scaled to the total catch for the years 2007−2013 using the ratio of the number of hooks set by the entire fleet in each year to the number of hooks set in 2008 (the year with the lowest fishing effort in the time series). Years before 2007 were not included because they had low observer coverage in the important Domestic North fishery (maximum 4.7% coverage but usually less than 3% and sometimes zero) (Griggs & Baird 2013). Coefficients of variation (CVs) for each length class, and mean weighted CVs across all length classes (MWCVs), were estimated by bootstrap re-sampling (N = 1000 samples) with replacement at the stratum level. No re-sampling was done at the year level.

Maturity and reproductive status were assessed from observer data collected between 2011 and 2014. Maturity was scored on a 3-stage elasmobranch 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).

2.3 Age, growth and age frequency of catch

The following description of methods used for ageing porbeagle shark in this study is also proposed as an age determination protocol for future ageing of this species. It follows the format and content of the Ministry of Fisheries document 'Guidelines for the development of fish age determination protocols' (Ministry of Fisheries Science Group 2011).

Vertebrae preparation

A block of 3−4 vertebrae was removed from beneath the first dorsal fin of each shark, trimmed of neural and haemal arches, muscle and connective tissue, and then frozen. Sex was recorded and FL was measured in a straight line from the tip of the snout to the fork in the tail, rounded down to the centimetre below actual length. A subsample of vertebrae for sectioning was selected to represent both sexes and the full length range (151 vertebrae were selected from 219 available samples). The vertebral blocks were defrosted, the largest visible vertebra was dissected, and it was physically trimmed of connective tissue and residual neural and haemal arches.

Vertebrae were sectioned with a Struers Secotom-10 diamond blade saw. For medium−large sharks (longer than about 120 cm with centrum length greater than about 8 mm), thawed, wet vertebrae were held in a clamp for sectioning. For small sharks having vertebrae too small to be clamped, vertebrae were briefly bleached (about 15 min), air dried overnight, and glued to small wooden blocks with epoxy resin. The wooden blocks were then placed in the saw's chuck for sectioning. Vertebrae were sectioned in the frontal plane (Wilson et al. 1987) by making two cuts with a single diamond-edged blade to produce a section about 0.6 mm thick. This produced 'bowtie' sections (Figure 1), although these frequently broke into two pieces at the focus. No grinding, polishing or staining was performed. Sections were stored in 70% isopropyl alcohol until they were aged.

In studies of shark age and growth, vertebral radius is typically measured between the focus of the 'bowtie' section and the vertebral margin along the corpus calcareum (Natanson et al. 2002). In this study, we instead measured centrum length (CL) as the maximum distance between the outer edges of the corpus calcareum in the anterio-posterior direction (Figure 1D). This was done for consistency with the only other study that has aged New Zealand porbeagles (Francis et al. 2007); in that study, the half-bowtie sections were frequently broken near the focus, rendering measurement of the vertebral radii impossible.

This preparation technique is very similar to that used in a validated age and growth study of North Atlantic porbeagles (Natanson et al. 2002). The only apparent differences are that the North Atlantic study collected vertebrae slightly further forward, above the gills; cut vertebral sections using a single cut with two blades separated by a spacer; and measured vertebral radius along the internal edge of the corpus calcareum (VR) instead of CL.

Vertebrae interpretation

Sections were drained and read wet using a Leica MZ12 stereomicroscope at 12.5× magnification. Illumination was by reflected white light (two fibre optic sources arranged at approximately 45° from the horizontal on either side of the specimen) against a black background.

Shark species often display a ‘birth band’, which is a prominent contrasting band in the centrum deposited about or soon after birth (Figure 1). Identification of this band is important in order to determine where subsequent band counts should begin. Natanson et al. (2002) confirmed the identity of the birth band in North Atlantic porbeagles by showing that its mean radius (BR = 5.4 mm, N = 578) was close to the VR of their two smallest new-born young (68−69 cm FL, VR = 5.3 mm) and was larger than the VR of three large New Zealand porbeagle embryos supplied by M. Francis (56−58 cm FL, VR = 4.3 mm). The birth band appears white under reflected light in porbeagles, and may be accompanied by a slight change in the angle of the centrum face (Natanson et al. 2002), although this latter feature was not reliably present in New Zealand porbeagle vertebrae. In the present study, if the location of the birth band was uncertain a 5 mm distance along the intermedialia from the focus was measured with an ocular micrometer to assist with its identification. However, this distance measure was not used as a primary criterion, as the distance of the birth band from the focus varies naturally among sharks (through variation in size or time of birth), and with the position along the vertebral column from which vertebrae were collected (vertebral size varies with position). Distinct bands are occasionally visible inside the birth band, but as their significance is unknown they were ignored. The precise timing of deposition of the birth band is unknown, although parturition is believed to occur in winter, peaking in June−July (Francis & Stevens 2000).

Counts were made of pairs of translucent (dark in reflected light) and opaque (white) bands beyond the birth band (Figure 1). Distinct bands usually traversed the corpus calcareum (the dense outer surface of the centrum) and the intermedialia (the more porous, triangular wedge between the corpora calcarea). Indistinct bands could often not be traced across both structures. Bands were generally easier to see and count in the corpus calcareum, but the full width of the section was examined where possible. Readers found it easier to count the translucent bands, but full band completion was judged to occur only when an opaque band had been deposited distal to the translucent band. Sections often displayed narrow pairs of light and dark bands within a larger band, particularly around 5−9 band pairs from the birth band. This sub-banding structure was usually apparent in both the corpus calcareum and the intermedialia. We interpreted these structures as split bands, and grouped them into a smaller number of wider bands when counting. Particular caution was required when ageing sharks in the age range 5−9 years, as split bands may occur near the margin of the section, and could easily be misinterpreted as full bands, leading to over-ageing. In larger sharks, band pairs rapidly became much narrower and difficult to resolve. Increased magnification and adjustment of lighting angle was often necessary to visualise and count these finer bands. Nevertheless, Francis et al. (2007) showed using radiocarbon dating that at least some of these narrow bands become unresolvable beyond an age of about 20 years, leading to substantial age underestimation. Because of this, and the small number of old porbeagles present in the commercial catch, we grouped all sharks aged 15 and older as a ‘15-plus’ group.

Vertebral bands were frequently indistinct, lacked contrast and were difficult to count. Sections were scored for their readability using a scale from 1 (excellent) to 5 (unreadable). The composition of the margin of the centrum was difficult to determine and was not recorded. Furthermore the timing of opaque band formation is uncertain, although a small sample (N = 6) of 3−5 year old North Atlantic porbeagles had translucent material at the growing edge of the centrum in spring and opaque material in autumn (Natanson et al. 2002). Estimated ages were recorded as the count of complete band pairs deposited outside the birth band. No age correction was made for the time of year of capture in relation to a theoretical birthdate, so all age estimates were integral values.

Vertebral band ageing was reported as validated for North Atlantic porbeagles by Natanson et al. (2002). Six tagged, known-age (0+) young that were recaptured after 3−5 years showed agreement between the number of band pairs on their vertebrae and their time at liberty. Two tagged, oxytetracycline-injected (OTC) sharks that were at liberty for 1.5 and 2.5 years had 1+ and 3 band pairs respectively beyond the OTC mark on their vertebrae at recapture. However the sample sizes were very small, and the oldest animal in the study (one of the OTC-injected sharks) was aged from its vertebrae as 11 years at recapture. Our attempts to validate age estimates of New Zealand porbeagles using bomb radiocarbon dating failed (Francis et al. 2007). We found that the ages of sharks older than 20 years were seriously under-estimated by band counts, sometimes by as much as 50%. Bomb radiocarbon ages of up to 65 years were obtained, whereas the maximum vertebral band count was 35. Age estimates up to about 20 years were consistent with their bomb radiocarbon ages, but were unreliable beyond that.

The age interpretation used in this study is similar to that used previously for porbeagles in New Zealand and the North Atlantic (Natanson et al. 2002; Francis et al. 2007). However, length-at-age estimates obtained here vary significantly from those found previously (see Results below), suggesting a shift in interpretation. This possibly resulted from treating more thin bands as split bands and grouping them.

Ageing procedures

Two readers were used, both of whom had previously aged porbeagle sharks: MPF (Reader 1) and Caoimhghin Ó Maolagáin (Reader 2). Both readers initially counted 30 sections, being a mixture of sections previously aged by Francis et al. (2007) and new sections from this study. This ‘familiarisation’ step is important because porbeagle vertebrae are difficult to count, and they are not aged regularly so there are expected to be large intervals between readings. This step should in future use sections assigned to the ageing library, and should cover a range of ages from 0+ to old sharks.

Both readers then counted all new sections independently (reading 1). Age estimates were compared, and their bias and precision assessed (see next section). There were large differences between readers for some sections, so examples of these were examined by both readers simultaneously by projecting them through a camera attached to the microscope on to a video monitor. The readers then agreed on an age interpretation protocol and re-counted all sections (reading 2). The second complete reading produced much closer results, but still contained some sections with significant discrepancies. Sections with discrepancies greater than one, or greater than zero for sharks less than 3 years old, were re-examined jointly. Where possible, the readers agreed on an age estimate, but otherwise their differing estimates were recorded (adjusted reading 2). The final age estimate for each section was taken as the mean of the adjusted second reading age estimates of the two readers.

Estimation of ageing precision

Age-estimation bias and precision between readings were explored using the NIWA R package *AgeCompare*. This produces a plot comparing the two readings, a frequency distribution of the age differences, an age-bias plot (Campana et al. 1995), and plots of the average percent error (APE) and the mean coefficient of variation (CV) (Campana et al. 1995; Campana 2001). CV is numerically $\sqrt{2}$ (= 1.414) times greater than APE.

Estimation of growth

Growth curves were fitted to the length-at-age data using the R package *FSA* (version 0.1.7) which fits non-linear curves using the R package *nlstools*. The von Bertalanffy growth model was used:

$$L_t = L_\infty\left(1 - e^{-K[t-t_0]}\right)$$

where L_t is the expected length at age t years, L_∞ is the asymptotic maximum length, K is the Brody growth coefficient, t is the fish age in years, and t_0 is the theoretical age at zero length. Growth models were fitted separately to males and females and these were then tested for significant differences. This was done by fitting eight models to the data: a 'general' model having three separate parameters for each sex; a 'common' model having the same three parameters for both sexes; and six intermediate models having different combinations of common and separate parameters. The best of the eight models was selected using Akaike's Information Criterion (AIC) (Akaike 1973). A similar approach was used for comparing growth models between the results from the present study and from the earlier study by Francis et al. (2007).

Reference collection

The recommended size for a reference collection for a species of medium longevity is 500 vertebral sections, with 200 being randomly drawn for reading prior to ageing a new sample. The present study aged only 150 porbeagle vertebral sections, so we propose to place all sections in the reference collection, and that the collection be augmented by new sections following any future studies.

The reference sections and band counts will be archived in the NIWA *Age* database. The precision for reading shark vertebrae in other studies is typically low, with CVs usually exceeding 10% (Campana 2001).

Scaled age composition

The length-at-age data derived above were used as an age-length-key (ALK) to convert the scaled observer length-frequency distributions to scaled age-frequency distributions. The procedure was carried out in CALA (Francis et al. 2014b) (see Section 2.2 for more details). CVs for each age class, and MWCVs across all age classes, were estimated by bootstrap re-sampling of the length-frequency distributions within strata, and bootstrap resampling of the data in the ALK with replacement (N = 1000 samples).

3. RESULTS

3.1 Observer sampling

All sets from all of the chartered Japanese SLL vessels were observed and sampled in 2011−14 (Table 1. Appendix 2). However, few domestic trips and only 4−7% of the domestic sets were observed, and even smaller proportions were sampled for vertebrae, maturity data or fin weights on domestic trips.

Data and samples were collected from 43 observer trips, 41 of them aboard SLL vessels and two aboard trawlers (Appendix 2). Most vertebrae and data came from SLL vessels operating in FMAs 1, 2, 5 and 7 during April–August. A total of 219 porbeagle sharks were sampled for vertebrae, 204 for maturity, and 121 for fin weights. Comparison of the length-frequency distributions of porbeagles sampled for vertebrae and maturity with the distributions for all porbeagles measured by observers showed that samples were generally representative of the sharks measured (Figures 2−3).

3.2 Length-frequency distributions and sex ratios

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[2]), 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.). Changes in fisher behaviour might be expected to have occurred at the time of the introduction of the sharks to the QMS (October 2004) and when shark finning was banned (October 2014). However there is no way to determine whether measured discarded sharks differ in length composition from unmeasured sharks.

The first three years in the time series had high discard rates for porbeagle sharks, but these declined to low values by 1996 (Figure 4). Since then, the discard rate has increased from 7−22% in the late 1990s to 62−67% in the last three years (2011−2013). In the North region, the proportion of porbeagle sharks measured by observers varied greatly among years up to 2006, but since then it has declined steadily from 59% in 2007 to only 16% in 2013 (Figure 5). In the Southwest region, the proportion measured has been relatively stable, averaging 61%.

The proportion of males in the observed catch showed no clear temporal trends (Figure 6). The proportion of males 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 the North (56%), and about equal numbers of both sexes in the Southwest (51% males). The North catch was skewed towards males because of the presence there of mature adult males as well as juveniles.

Scaled length-frequency distributions for the whole SLL fishery for the period 2007−2013 are shown in Figure 7. Both sexes had a strong mode at 75−85 cm. Males had further peaks at 110−155 cm but the individual length classes were variable and the CVs were high (20−50%), presumably because of the small sample sizes. Almost half of the males (46%) were shorter than 100 cm. Females did not show any prominent modes beyond 85 cm. MWCVs were moderate for both sexes (21−27%). Almost two-thirds of the females (63%) were shorter than 100 cm. For 2007−2013, the ratio of males to females in the scaled catch was 1.39:1 (58.2% males).

3.3 Maturity

Few porbeagle sharks were staged, and more importantly few mature sharks of either sex were sampled, leading to poorly defined maturity ogives with broad confidence intervals (Figure 8). Observers scored the occurrence of spermatophores for pelagic sharks (blue, mako and porbeagle sharks) on four trips in 2014. Only two of the trips scored porbeagle sharks, with a combined sample size of 53. However, none of the sharks was recorded as having spermatophores present, despite the

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[2] Sharks often school by size and sex.

fact that about half the sharks were large enough to have been mature. This suggests that observers were unable to detect spermatophores, since spermatophores have been found by other observers in a previous study (Francis & Duffy 2005). Consequently it was not possible to accurately estimate median length at maturity from the new observer data collected in the present study.

We therefore adopted the estimates of median length at maturity for both sexes produced earlier by Francis & Duffy (2005), i.e. 145 cm for males and 175 cm for females. The percentages of sharks that were mature in the 1993−2013 observer time series were estimated by applying these lengths at maturity to the relevant (unscaled) length-frequency distributions (Figure 9). Few mature females were observed: over the whole time series, estimated percentages mature in North and Southwest regions were 2−3%. Mature male porbeagles made up 21−27% overall of the sharks measured in the two regions. However, the percentages fluctuated markedly among years and there appeared to be a step down for North region males between 1999 and 2004. Based on the scaled length-frequency distributions for 2007−2013 (Figure 7), the percentages of mature porbeagles in the SLL catch were estimated to be 20.6% for males and 1.5% for females.

3.4 Age, growth and age frequency of catch

There was a linear relationship between CL and FL (Figure 10):
$CL = –0.111 + 0.067\ FL$ ($N = 150$, $R^2 = 0.91$).

Although vertebrae were difficult to read, only one was rejected as unreadable (readability score = 5), leaving 150 aged vertebrae. However, 98% were scored as readability 3 or 4 (moderate or poor respectively), and only 2% were scored as readability 2 (good). Difficulty was experienced in counting the narrow increments near the margin of the vertebrae from old sharks, and in interpreting the split ring pattern. A comparison between readers of the adjusted second readings is shown in Figure 10 and an analysis of the differences in Figure 11. One of the 150 aged sharks was unsexed, leading to a sample size of 149 (75 males and 74 females) for analyses by sex. Reader 1 showed a small but significant tendency to count more bands than reader 2 (paired t-test, $P = 0.012$) (Figure 11A, B). However there was no systematic pattern, with the slope of the age-bias regression being not significantly different from 1 ($P = 0.079$; Figure 11C). Overall, the CV between readers was 5.9%.

The final age estimates are shown in Figure 12. Most sharks were less than 10 years old, and few were more than 15 years old. The general Von Bertalanffy growth model, with different parameters for the two sexes, had the lowest AIC (1062.8). The next-best model, the common model with the same parameters for both sexes, had an AIC of 1063.7. Thus male and female porbeagle sharks had significantly different growth models. The parameters and 95% confidence limits of the general growth model are shown in Table 2, and the fitted growth curves in Figure 12. The growth curves showed rapid, near-linear growth up to an age of about 5 years, followed by reduced growth, and divergence of male and female curves at about 12−14 years. The oldest shark in our sample was a male, but this may reflect the paucity of mature females caught in the tuna longline fishery. The oldest male was estimated from vertebral bands to be 30.5 years old, and the oldest female was 25 years old. The growth curves intersected the length axis at 79.7 cm for males and 86.0 cm for females, which are both substantially greater than the reported length at birth of 58–67 cm FL (Francis & Stevens 2000). This discrepancy is at least partly due to use of integral ages rather than fractional ages corrected for the date of capture, but may also result from size-selectivity of the longline hooks or an absence of new-born young from the fishing grounds.

Ages at maturity were estimated by applying the sex-specific general Von Bertalanffy growth models to the estimated lengths at 50% maturity provided by Francis & Duffy (2005): 140–150 cm for males and 170–180 cm for females. The estimated ages at maturity were 6.3–8.2 years for males and 13.0–16.3 years for females.

For both sexes, the fitted Von Bertalanffy growth curves from the present study were significantly different from those generated by an earlier study of New Zealand porbeagles by Francis et al. (2007)

(Figure 13). For males, L_∞ differed significantly between periods and for females K differed significantly between periods. For both sexes, estimated length-at-age was higher for the present study than for the 2004 data. Consequently data from the two periods were not pooled.

Scaled age-frequency distributions were dominated by 0+ porbeagles: they contributed 35% of males and 58% of females (Figure 7). Sharks over 10 years old were rare in the samples. MWCVs were high (37% and 26% for males and females respectively), indicating that the age-composition of the observed catch was poorly estimated.

4. DISCUSSION

This study provides an updated and extended analysis of the composition of the catch of porbeagle sharks in the New Zealand tuna longline fishery. The previous analysis (Francis 2013) was updated by one year to include the 2013 fishing year, and extended by generating scaled length-frequency distributions of the total SLL catch for 2007−2013, ageing a subsample of sharks from their vertebrae and fitting new growth curves, and estimating the scaled age-frequency composition of the catch. The present study therefore provides improved information on porbeagle shark catch composition. It should be noted, however, that this study does not cover the midwater trawl fishery which accounted for 13−22% by weight of the New Zealand porbeagle catch in 2008−2011 (Francis 2013).

Furthermore, the quality of the data on which these analyses were based is limited in a number of respects. Observer sampling of length data was compromised by their inability to measure every shark caught, and evidence that unmeasured, discarded sharks may have a different size composition from measured, discarded sharks (Francis 2013). The proportion of porbeagles discarded or released alive under Schedule 6 of the Fisheries Act continues to increase, reaching two-thirds of the catch in 2013. This trend is expected to continue in future with the introduction of a ban on shark finning at the beginning of the 2014 fishing year. The issue is most acute in the North region, where the proportion of porbeagles measured dropped to 16% in 2013, and observer coverage was low (always less than 10% and often less than 5% (Griggs & Baird 2013)). High observer coverage of the Japanese charter fleet (usually more than 80% (Griggs & Baird 2013)) means the situation is much better in the Southwest region, where about 60% of porbeagles are measured each year. The decline in numbers of porbeagle sharks measured by observers in the North region makes it difficult to assess recent patterns of size composition, sex ratio, maturity composition and age composition. The analyses presented here must therefore be interpreted cautiously.

Scaled length-frequency distributions for 2007−2013 showed that the commercial SLL porbeagle catch was dominated by immature juveniles, a high proportion of them being under 100 cm long (about half of the males and two-thirds of the females). The scaled distributions differ from previous unscaled distributions (Francis 2013) in having a higher proportion of sharks shorter than 100 cm, and fewer subadults 100−150 cm. This change reflects the increased weight given to the North region catch, particularly by domestic vessels, in the scaled distributions. Only 21% of males and fewer than 2% of females were considered mature, but these proportions may have been under-estimated if significant numbers of large mature adults were being discarded unmeasured. That scenario is plausible for males because a higher proportion of mature males was recorded by observers when discard rates were low and the proportion of sharks measured was high during the mid−late 1990s (Figures 4, 5 and 9; Francis 2013 Appendices 4 and 5). However, it is not plausible for females, which have always been rare in the observer data.

Only unscaled observer-based estimates of the proportion mature are available before 2007. For males, the estimated proportions mature were highly variable among years and between regions (Figure 9), and they may be unreliable because of low observer coverage, particularly of the domestic fleet which mainly fishes in the North region. The proportion of mature females in the SLL catch has been consistently low in both regions and in all years. Mature females are therefore not considered vulnerable to the New Zealand SLL fishery, although they may be taken by other fleets in international waters.

Porbeagle sharks are born at a length of about 58−67 cm FL. Parturition peaks in June-July, and the theoretical birthdate has been defined as 1 June (Francis & Stevens 2000). Most (94%) of the porbeagles aged in this study were sampled in April−July, so they were approaching or near the theoretical birthdate. The sharks aged here in the 0+ age class measured 71−90 cm and averaged 80 cm (both sexes combined, N = 21). Most, and possibly all, of these sharks would have been almost one year old at capture, because porbeagles grow about 20 cm in their first year (based on length-frequency modal analysis (Francis & Stevens 2000)). No adjustment has been made to the ages reported here, so the growth curves and the age-frequency distributions (Figures 7, 12 and 13) are all shifted about one year to the left of their true positions. Thus the age-frequency distribution of the catch of both sexes was dominated by one-year-old sharks (the bars plotted at 0−1 year in Figure 7), and most of the rest of the catch was aged about 2−10 years. Sharks over 10 years old were rarely sampled, though they may have been caught in greater numbers than indicated and discarded unsampled.

The ageing technique used here, which is the recommended protocol for future porbeagle ageing, differs significantly from that used in an earlier study (Francis et al. 2007). The growth curves in the present study are shifted 1−2 years to the left of the earlier growth curves for sharks up to 10 years old (i.e. porbeagle sharks are estimated to grow faster than in the previous study). The difference resulted from interpreting some narrow bands as sub-annual bands, and grouping them into broader annual structures, in the present study. However, such interpretation is subjective and may be wrong. Francis et al. (2007) reported that their age estimates up to 20 years old were consistent with bomb radiocarbon ages. However, radiocarbon validation is a coarse method and it is not capable of distinguishing between age interpretations that differ by only a few years. Thus the new ageing procedure is also considered consistent with the bomb radiocarbon ages. Nevertheless, only four sharks of 20 years or less were tested for bomb radiocarbon, so there remains a need to properly validate porbeagle ageing up to 20 years (age estimates beyond 20 years have been shown to seriously under-estimate true age using bomb radiocarbon (Francis et al. 2007)). Such validation could be achieved by injection of oxytetracycline into tagged and released sharks to mark their vertebral centra with a time stamp.

Both the present and previous studies have found that males and females have significantly different growth curves. However, growth curves only began diverging after 12−14 years, beyond which there were few aged sharks in either study, and beyond 20 years the age estimates were unreliable. Thus the question of whether the sexes grow at different rates remains open. For practical purposes this is not important because juveniles under 10 years old dominated the SLL catch, and growth rates of the two sexes up to 10 years were practically identical. Nevertheless, length at maturity differed between the two sexes, so their estimated ages at maturity also differed: about 6–8 years for males and 13–16 years for females. These are younger than previous estimates of 8−11 and 15−18 years respectively (Francis et al. 2007), because of the faster growth reported here.

5. MANAGEMENT IMPLICATIONS

For the first time, this study provides scaled length-frequency and age-frequency estimates of the porbeagle shark catch composition in the SLL fishery, which accounts for most of the New Zealand catch. Subject to caveats about the representativeness of the observer sampling, the scaled distributions show that the catch is dominated by one-year-old juveniles, with older juveniles up to about 10 years comprising most of the rest of the catch. Few mature sharks are caught, especially mature females which make up a negligible part of the catch. The New Zealand porbeagle shark fishery is therefore mainly a juvenile fishery that provides an apparent refuge for mature breeding females. The whereabouts of mature females is unknown, though the few pregnant sharks caught tend to be found off the southwest South Island (Francis & Stevens 2000), suggesting that they may inhabit colder subantarctic waters. It is also possible that mature females are caught by SLL vessels working in international waters beyond New Zealand's EEZ, and efforts should be made to determine the catch composition of such vessels.

Fisheries on juvenile sharks can be sustainable if enough juveniles grow through the 'gauntlet' age range to replenish adults dying from natural causes (Simpfendorfer 1999). Currently, SLL fishing effort in New Zealand waters is near its lowest point in over 30 years: about 4 million hooks are set per year compared with over 25 million hooks in the early 1980s (Griggs & Baird 2013; Ministry for Primary Industries 2014a). A range of indicators suggest that the population size of porbeagles has either been stable or increased since 2005 (Francis et al. 2014a). Nevertheless, caution is required because:

- porbeagles mature at a moderately high age (despite the present estimates having been reduced slightly from earlier estimates)
- porbeagles have a high longevity of about 65 years (Francis et al. 2007)
- porbeagles have a very low fecundity of 3.85 pups per litter (Francis & Stevens 2000)
- the frequency of the reproductive cycle is unknown; if there is a resting period of one year between pregnancies, as occurs in a number of other shark species, the annual production of young would be half the litter size, or about 1.9 young per year
- there is no information on porbeagle stock structure in the Southern Hemisphere
- there are no historical and current porbeagle catch histories outside the New Zealand EEZ
- there is no information on the survival rate of sharks released alive under Schedule 6

These uncertainties require that management is cautious, and that efforts are made to fill the knowledge gaps through appropriate research. In particular, a quantitative stock assessment is required to pull together New Zealand and overseas data into a coherent model in order to estimate the status of the stock. As a preliminary to this, WCPFC is planning to convene a workshop to assemble the best set of biological parameters available for a range of Pacific shark species, including porbeagle shark. The revised or new estimates of growth rate, age at maturity, and length- and age-frequency of the SLL catch provided here will be important contributions to that process.

6. ACKNOWLEDGMENTS

Special thanks go to the MPI observers for collecting the data and specimens used in this study. Warrick Lyon organised and inventoried the observer biological data and vertebral specimens, and punched the data. Lynda Griggs extracted and summarised data from the *COD* database. Caoimhghin ÓMaolagáin prepared the vertebral sections and was one of the age readers. Dan Fu advised on the use of CALA software. Reyn Naylor reviewed the draft manuscript. This work was completed under Objectives 1−3 of Ministry for Primary Industries project HMS201302.

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8. TABLES

Table 1: Number of surface longline (SLL) vessels and sets, observer coverage, and number of vessels sampled for vertebrae, maturity data or fin weights during 2011−14. NA, not available.

Fishery	Fleet	Fishing year	No. of trips	No. of sets	Observed trips	Observed Sets	% sets observed	Trips sampled
SLL	Charter	2011	4	151	4	151	100.0	4
SLL	Charter	2012	4	164	4	164	100.0	4
SLL	Charter	2013	4	148	4	148	100.0	4
SLL	Charter	2014	4	186	4	186	100.0	4
SLL	Domestic	2011	568	2736	14	172	6.3	3
SLL	Domestic	2012	560	2617	12	174	6.6	7
SLL	Domestic	2013	510	2497	10	98	3.9	3
SLL	Domestic	2014	NA	NA	11	127	NA	7

Table 2: Von Bertalanffy growth model. The best fit model was the general model with separate parameters for the two sexes.

```
Formula: FL ~ Linf[sex] * (1 - exp(-K[sex] * (agreed.age - t0[sex])))

Parameters:
              Estimate    Std. Error  t value   Pr(>|t|)
Linf  male    185.77237   6.24131     29.765    < 2e-16 ***
Linf  female  210.86374   9.61980     21.920    < 2e-16 ***
K     male    0.13311     0.01497     8.892     2.38e-15 ***
K     female  0.08588     0.01186     7.239     2.56e-11 ***
t0    male    -4.21557    0.41794     -10.087   < 2e-16 ***
t0    female  -6.10057    0.66533     -9.169    4.73e-16 ***
---
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 8.339 on 143 degrees of freedom

95% confidence intervals for parameters:
                2.5%           97.5%
Linf  male      173.73056158   200.6548439
Linf  female    194.69704124   235.0972524
K     male      0.10368126     0.1688882
K     female    0.06307299     0.1106747
t0    male      -5.20637771    -3.4118856
t0    female    -7.65116072    -4.9410074
```

9. FIGURES

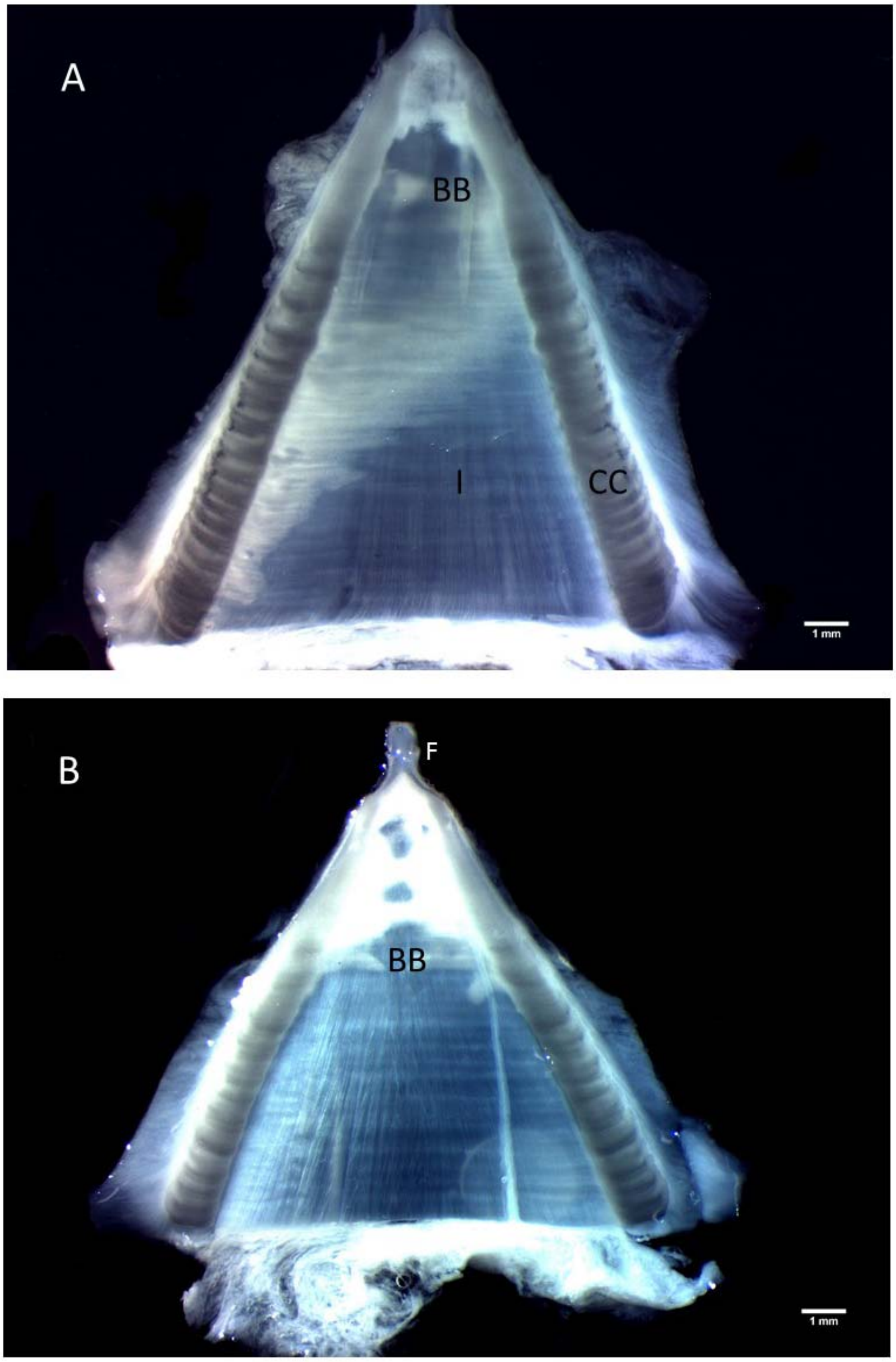
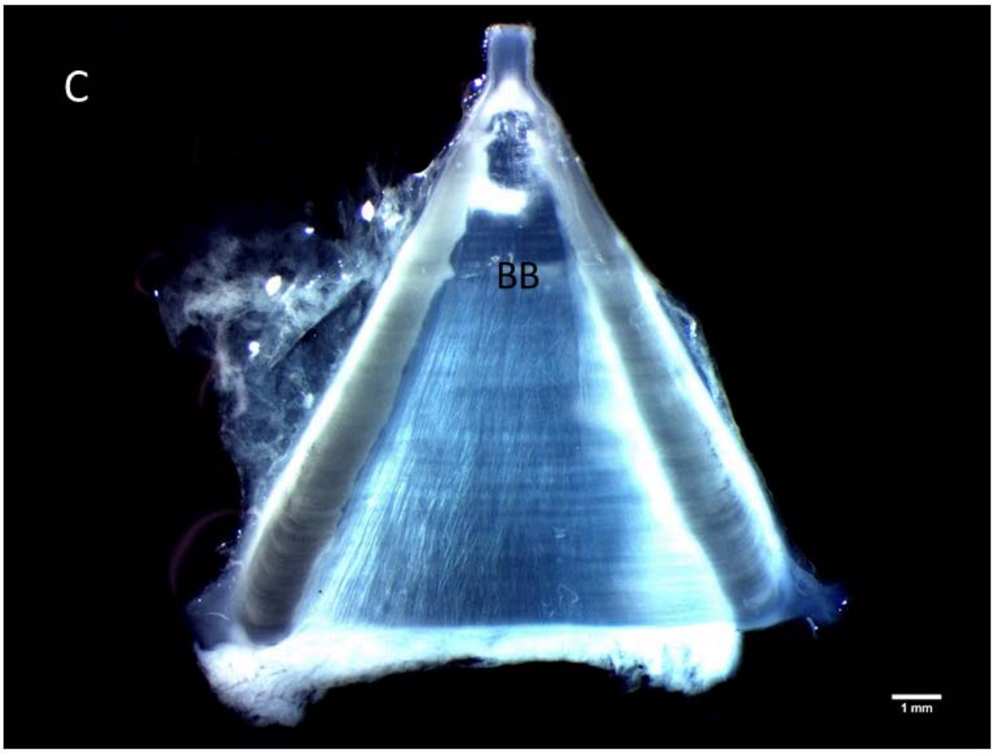


Figure 1: Half-bowtie thick sections of porbeagle shark vertebral centra. A – 184 cm female final age 20 years. B – 154 cm male final age 11.5 years. BB, birth band; CC, corpus calcareum; I, intermedialia; F, focus.



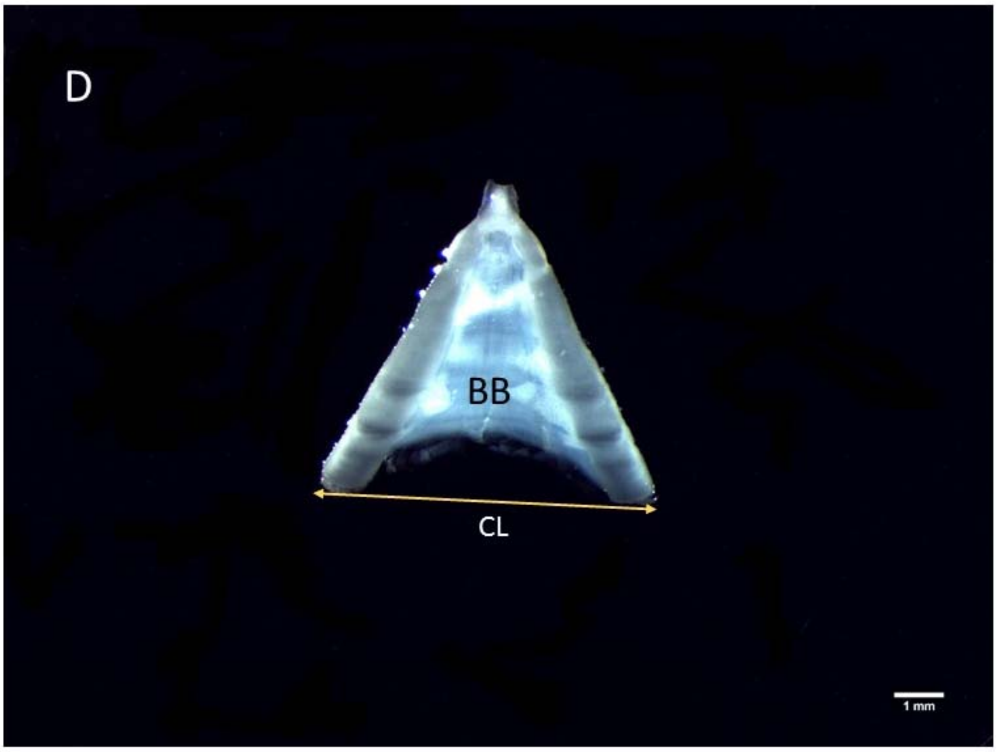


Figure 1 (continued): Half-bowtie thick sections of porbeagle shark vertebral centra. C – 169 cm female final age 13 years. D – 95 cm female final age 2 years. BB, birth band; CC, corpus calcareum; I, intermedialia; F, focus; CL, centrum length measurement.

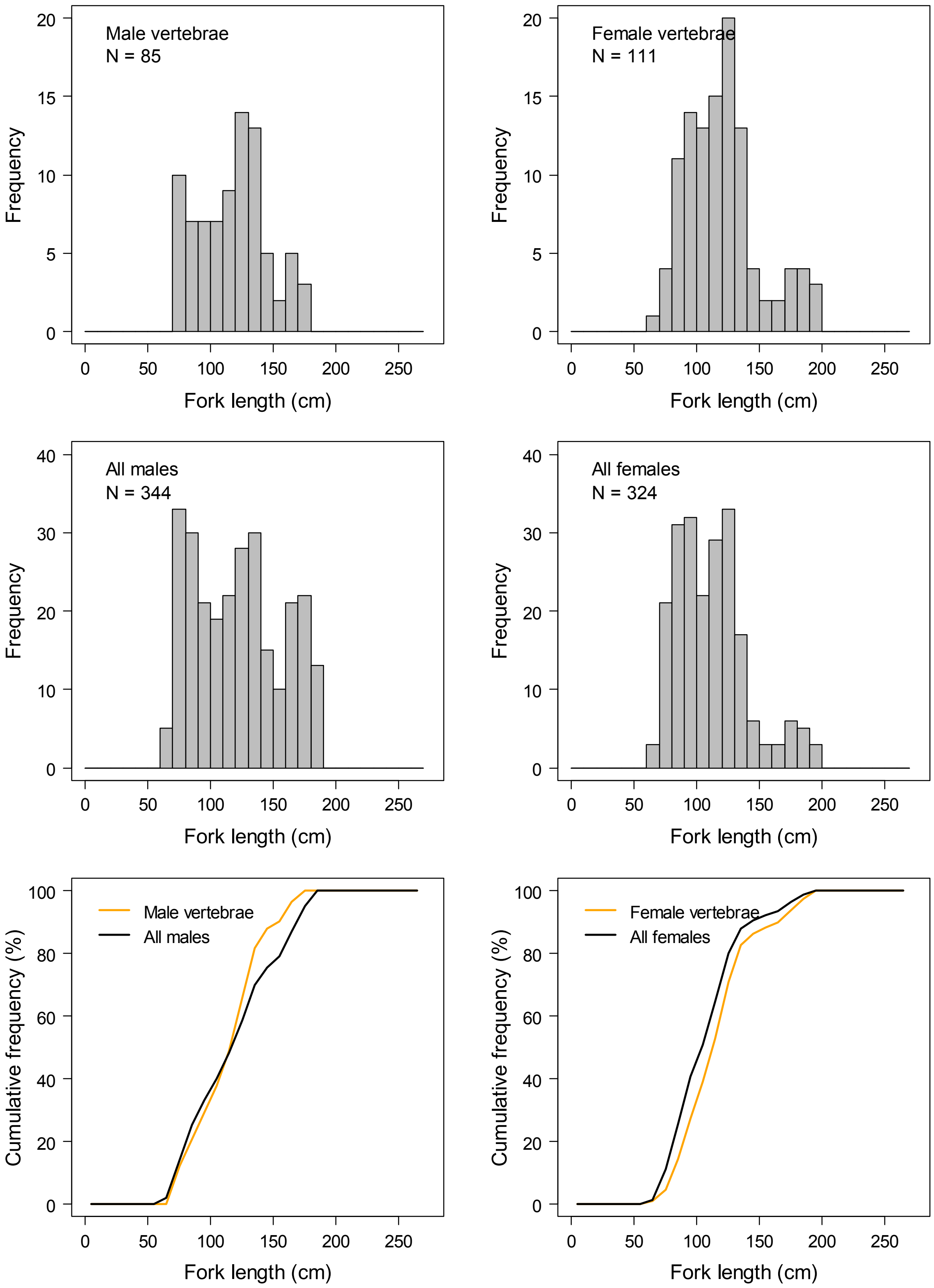


Figure 2: Length-frequency distributions of male and female porbeagle sharks sampled in 2011–14 for vertebrae (top panels) compared with the distributions of all porbeagle sharks measured during the same period (middle panels). The bottom panels show cumulative distribution curves for the data in the top and middle panels.

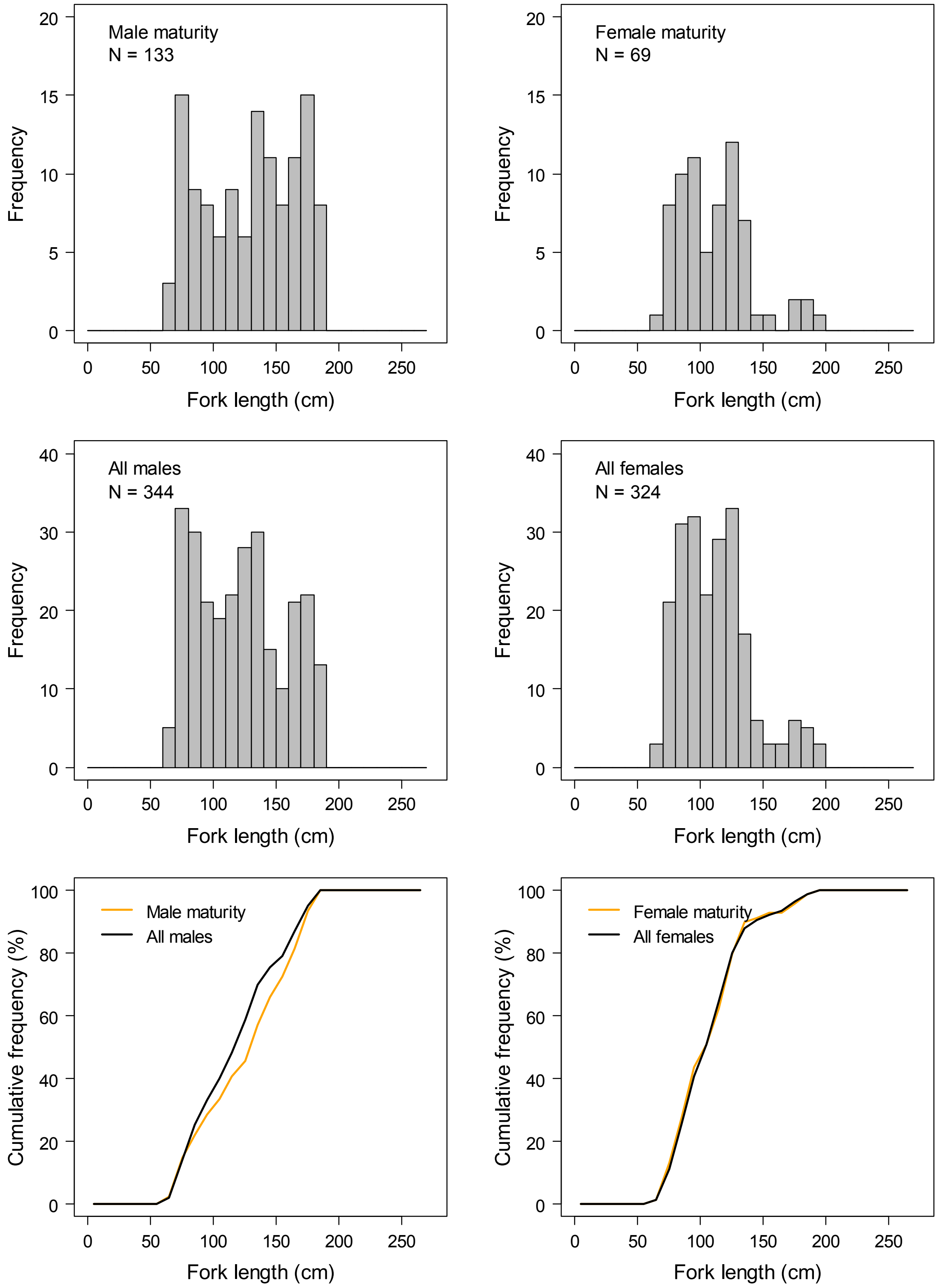


Figure 3: Length-frequency distributions of male and female porbeagle sharks sampled in 2011–14 for maturity (top panels) compared with the distributions of all porbeagle sharks measured during the same period (middle panels). The bottom panels show cumulative distribution curves for the data in the top and middle panels.

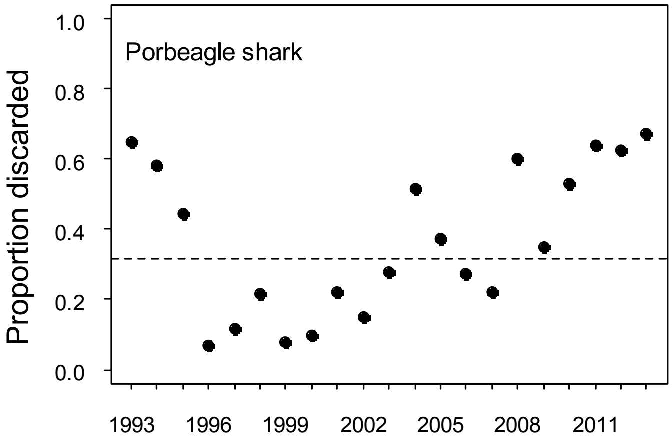


Figure 4: Proportion of porbeagle sharks discarded from surface longline vessels, 1993−2013. The horizontal dashed line indicates the overall discard rate for the whole time series.

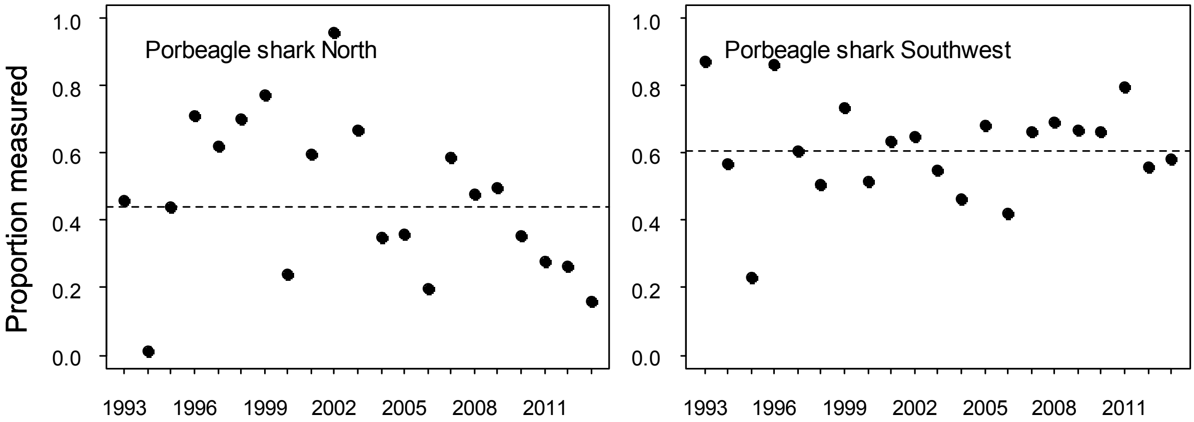


Figure 5: Proportion of porbeagle sharks measured from surface longline vessels in North and Southwest regions, 1993−2013. The horizontal dashed lines indicate the proportion measured for the whole time series.

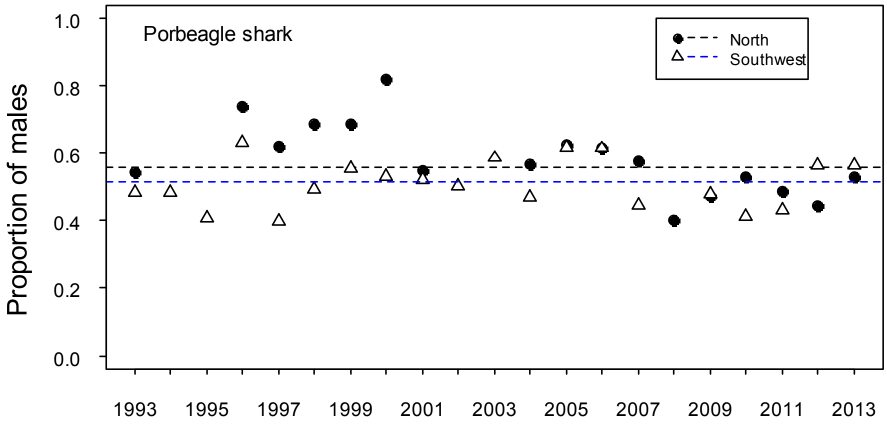


Figure 6: Proportion of male porbeagle sharks by region from surface longlines, 1993−2013. The horizontal dashed lines indicate the proportions of males for the whole time series in each region. Only sample sizes greater than 50 are shown.

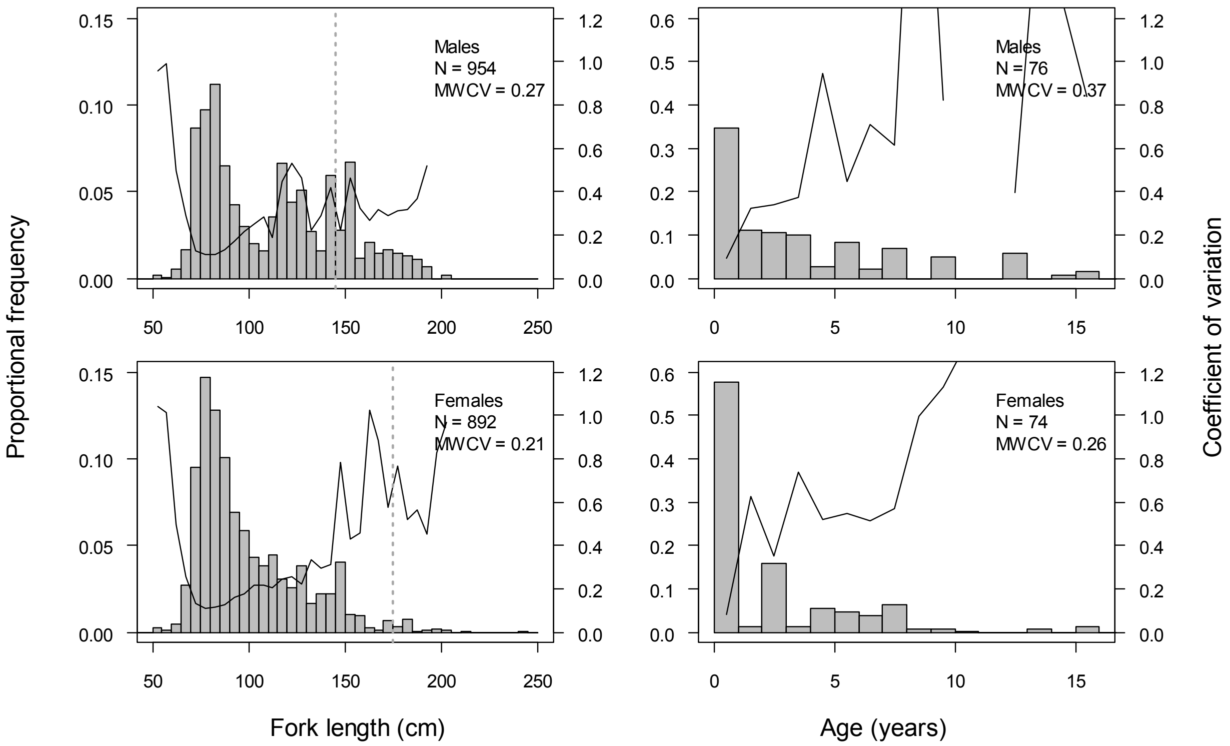


Figure 7: Porbeagle shark scaled length-frequency (left) and age-frequency (right) distributions by sex with bootstrapped coefficients of variation (CV, solid lines) and mean weighted CVs (MWCV). Sample sizes for length distributions are the number of sharks measured, and for age distributions are the number of sharks aged and used for the age-length key.

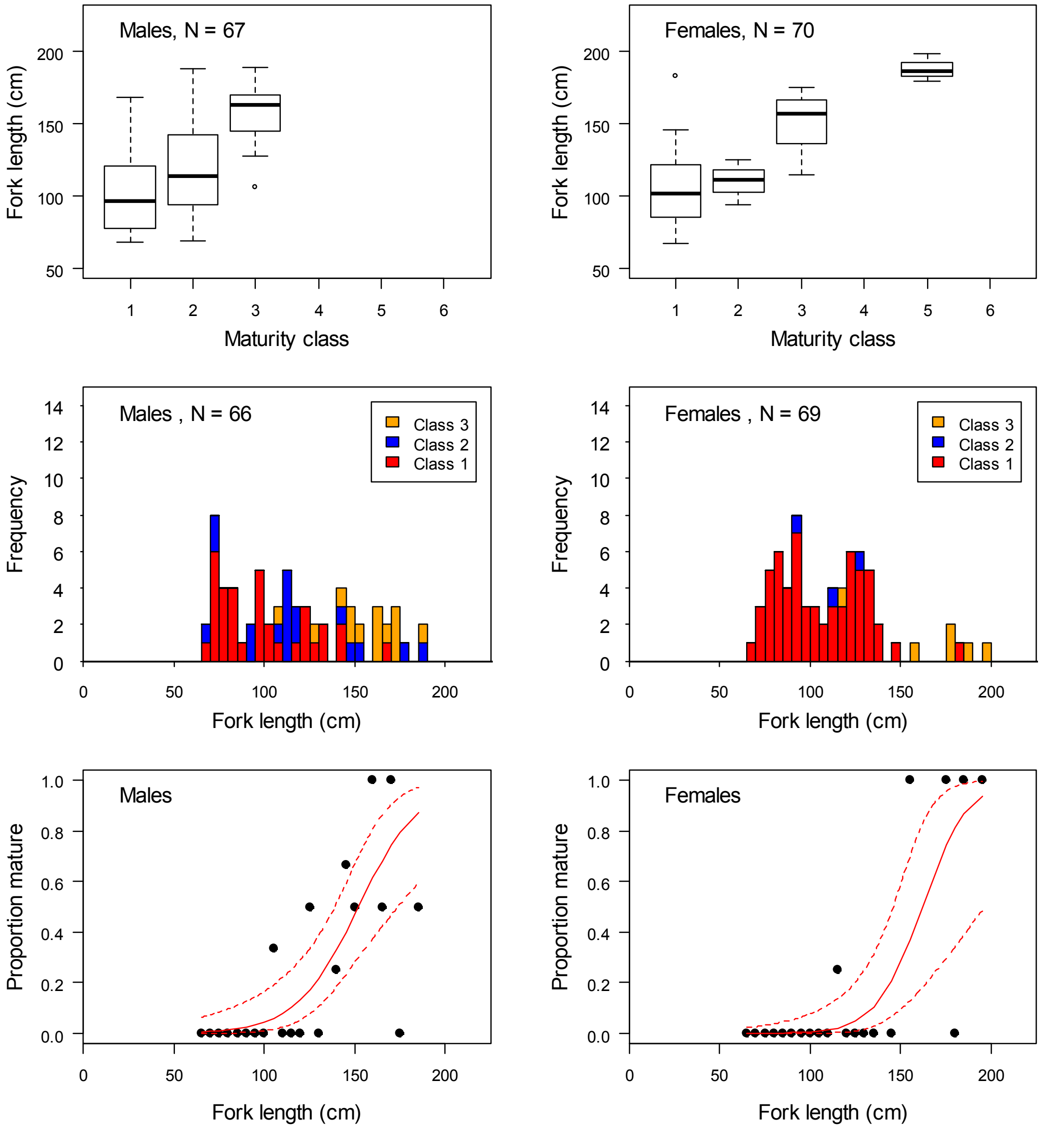


Figure 8: Maturity data collected from male and female porbeagle sharks, 2011–14. Top panels: Box plots of fork length classified by maturity stage (see Appendix 1 for stages). The central black bar is the median, the box spans the first to third quartiles, and the whiskers extend to the most extreme 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.

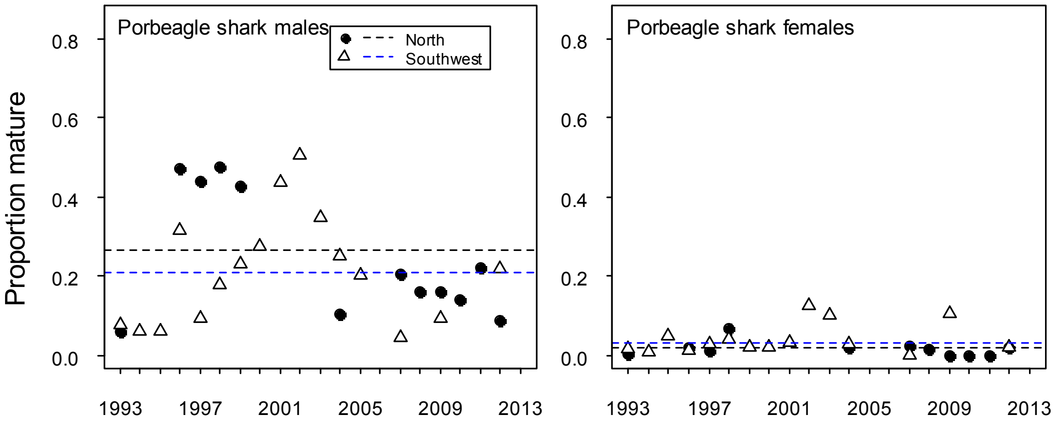


Figure 9: Proportions of observed porbeagle sharks that were estimated to be mature based on length-frequency distributions and median lengths at maturity.

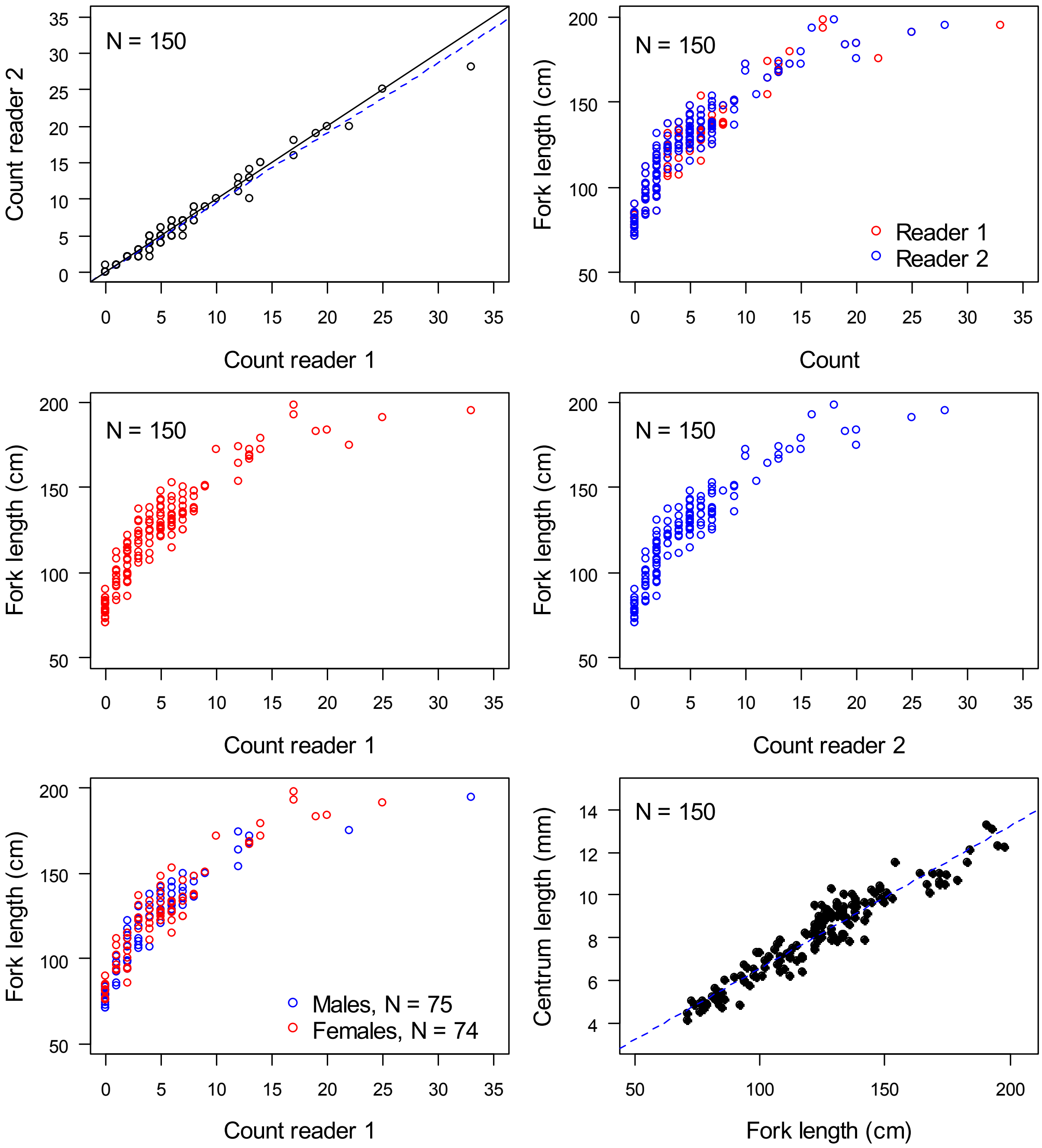


Figure 10: Comparison of vertebral band counts of readers 1 and 2. Diagonal black line is the 1:1 line; dashed blue lines are fitted linear regressions. The bottom right panel shows the relationship between centrum length and fork length.

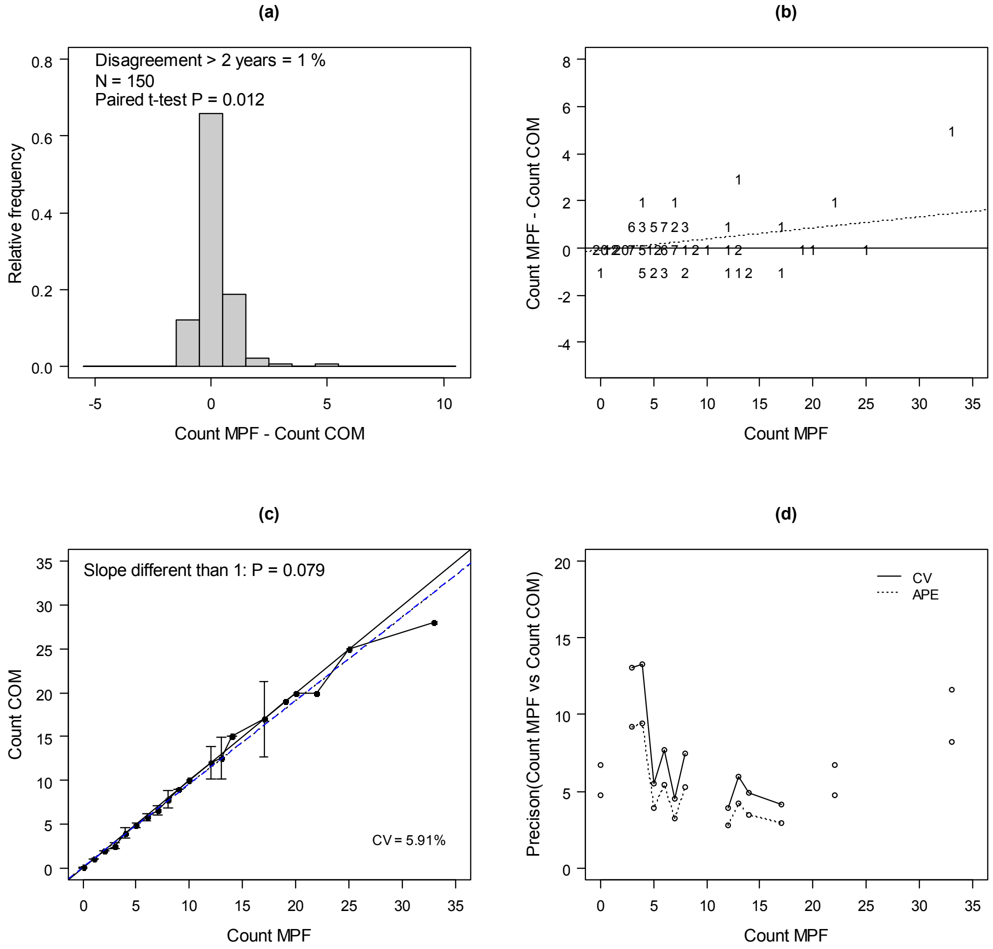


Figure 11: Analysis of vertebral band count differences between reader 1 (MPF) and reader 2 (COM). Dotted and dashed lines are fitted linear regressions. CV, coefficient of variation; APE, average percentage error.

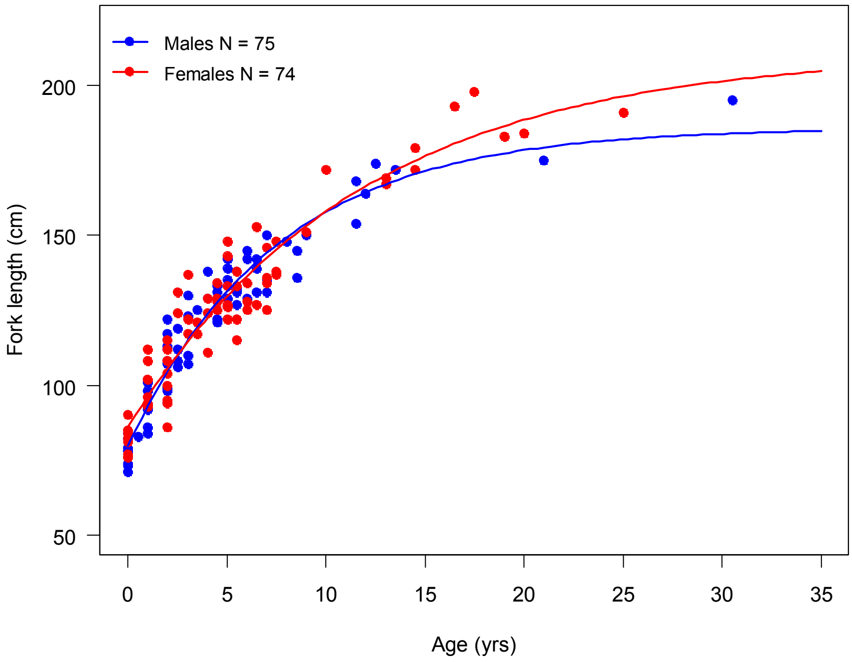


Figure 12: Von Bertalanffy growth curves generated from final age estimates for porbeagle sharks.

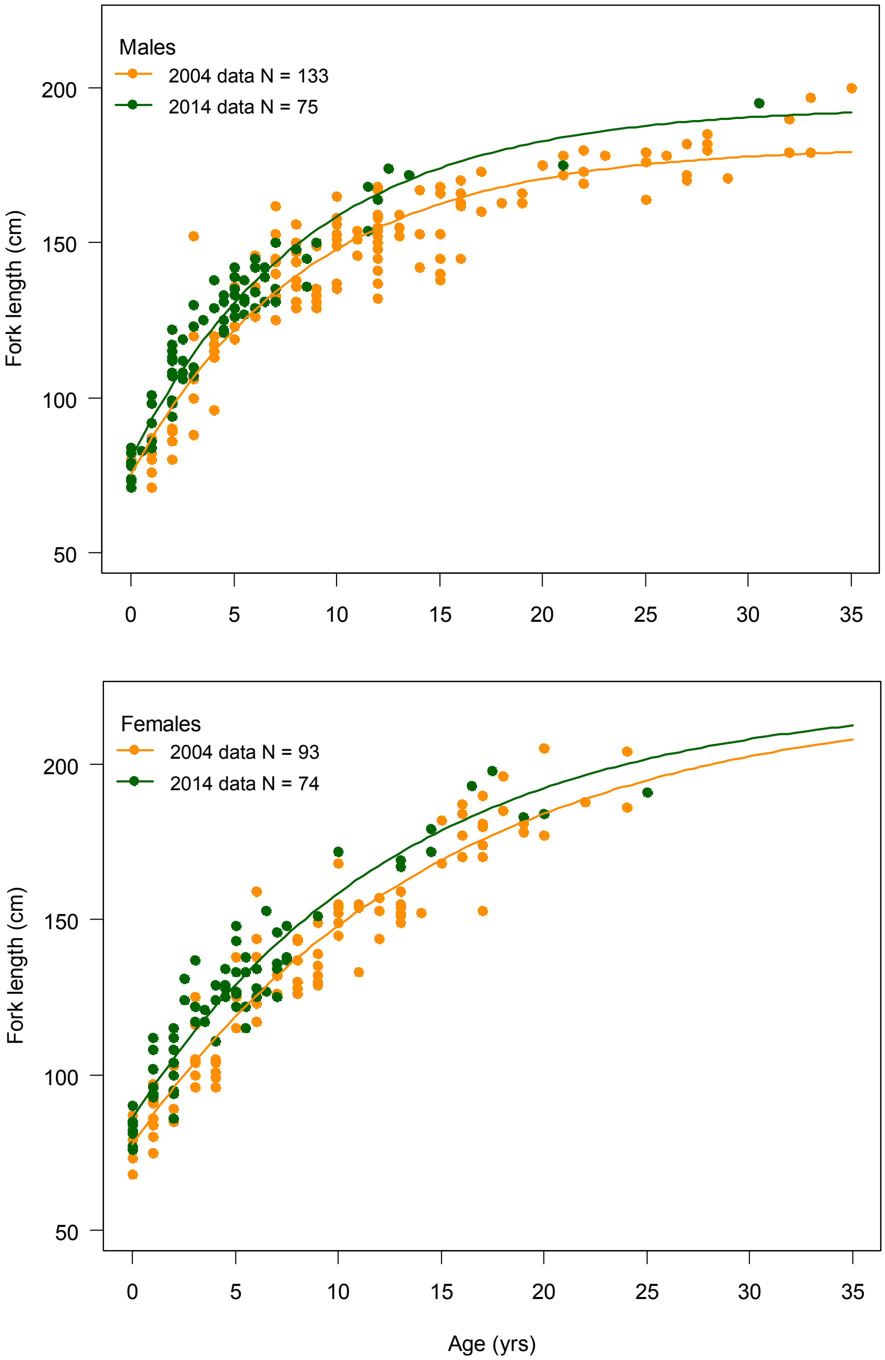


Figure 13: Comparison of Von Bertalanffy growth curves between the present study (2014 data, green) and the earlier study by Francis et al. (2007) (2004 data, orange) for males (top) and females (bottom).

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.

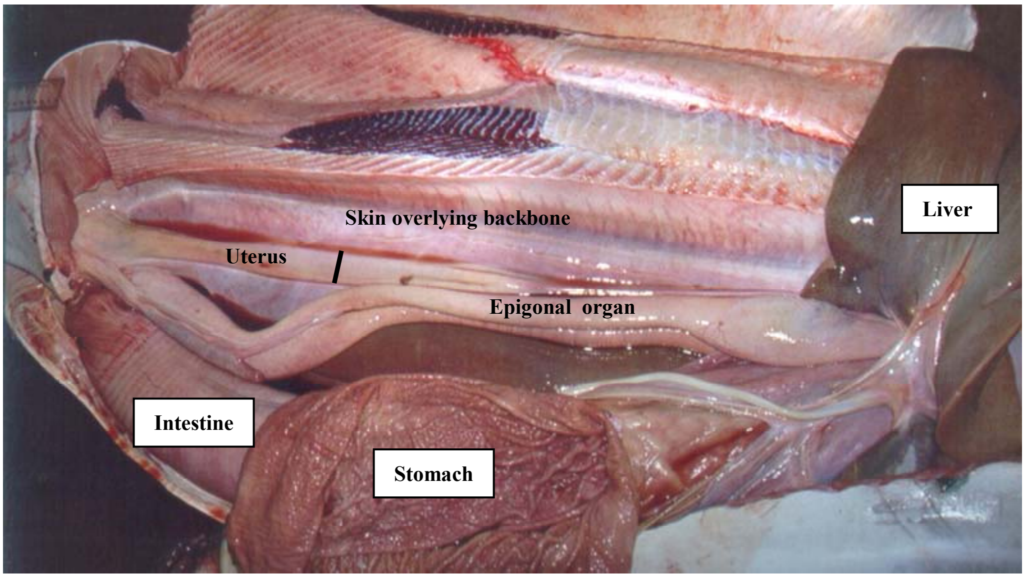
If it is not possible to weigh fins from individual sharks, an aggregated total for a group of sharks (e.g. all sharks of a single species caught in one longline set or one trawl tow) is still useful for calculating conversion factors. In this situation, please record the number of sharks in the group, 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.

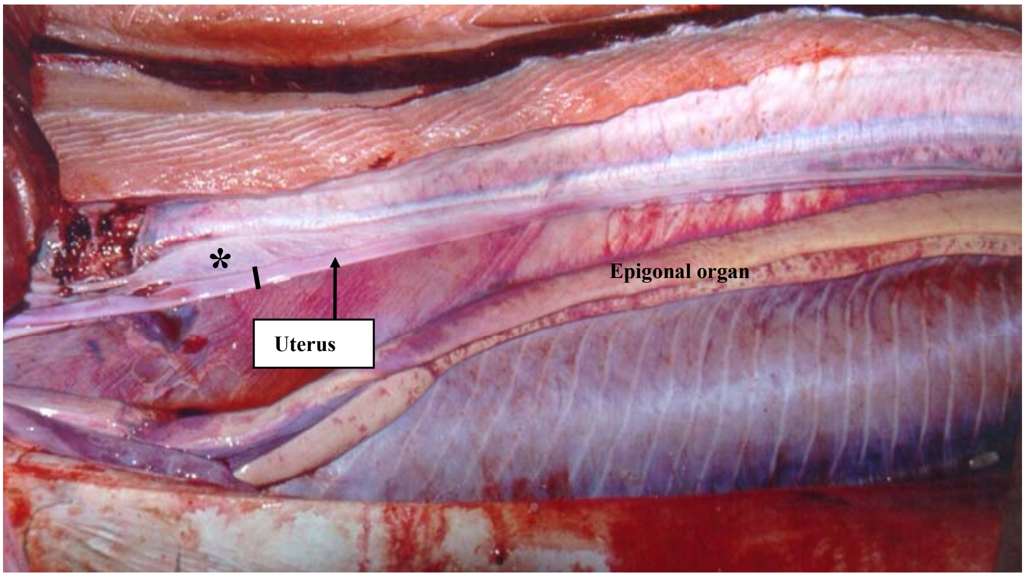
Reproductive staging guide for sharks and skates

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

Inventory of vertebral samples, and maturity and fin weight records, collected by observers for blue, porbeagle and mako sharks in the 2011 to 2014 fishing years (2014 not complete).

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	1208	84	42	1334	382	41	7	430
2011-12 fishing year							Vertebrae				Maturity				Individual fin weights			
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
2012-13 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
21	2013	May-Jun	SLL	C	1,5,7,9	STN/BIG	81	5	11	97	79	4	11	94	0	0	0	0
22	2013	May-Jun	SLL	C	5,7,9	STN	113	26	6	145	0	0	0	0	0	0	0	0
23	2013	May-Jun	SLL	C	5,7	STN	20	10	3	33	0	0	0	0	96	9	5	110
24	2013	May-Jun	SLL	C	5,7	STN	90	11	13	114	88	8	10	106	88	8	10	106
25	2013	May-Jun	SLL	D	1	BIG	4	0	1	5	14	0	4	18	0	0	0	0
26	2013	May-Sep	SLL	D	1,9	STN/SWO	23	0	0	23	61	1	0	62	0	0	0	0
27	2013	Jun	SLL	D	7	STN	1	3	2	6	1	3	2	6	0	0	0	0
28	2013	Jul-Aug	SLL	D	1,2	STN	34	10	4	48	33	7	3	43	0	0	0	0
29	2013	Jul-Aug	SLL	D	1	STN	11	2	0	13	0	0	0	0	0	0	0	0
30	2013	Aug-Dec	SLL	D	1,9	BIG/STN	0	0	1	1	0	0	0	0	0	0	0	0
31	2013	Aug	SLL	D	9	BIG	0	0	0	0	38	0	4	42	0	0	0	0
Total							377	67	41	485	314	23	34	371	184	17	15	216
2013-14 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
32	2013	Nov-Dec	SLL	D	1	BIG	0	0	0	0	2	4	0	6	0	0	0	0
33	2014	Jan-Mar	SLL	D	1,9	BIG	1	0	18	19	1	0	23	24	0	0	22	22
34	2014	Apr-Jun	SLL	D	7	STN	0	3*	2*	0	0	42	12	54	0	0	0	0
35	2014	May-Jul	SLL	C	5,7	STN	21	16	5	42	0	1	0	1	112	22	5	139
36	2014	May-Jun	SLL	C	5,7	STN	34	9	4	47	33	8	4	45	0	0	0	0
37	2014	May-Jun	SLL	C	5,7	STN	61	19	5	85	0	1	0	1	77	20	5	102
38	2014	May-Jun	SLL	C	5,7	STN	7	1	2	10	0	0	0	0	203	3	2	208
39	2014	May	SLL	D	7	STN	1*	0	0	0	1	0	0	1	0	0	0	0
40	2014	May-Jun	SLL	D	7	STN	0	0	0	0	34	1	1	36	0	0	0	0
41	2014	Jul-Aug	SLL	D	1,2	STN	21	5	1	27	17	10	1	28	0	0	0	0
42	2014	Aug	SLL	D	1	STN	3	0	0	3	0	0	0	0	0	0	0	0
43	2014	Jul-Aug	SLL	D	2	STN/BIG	1	7	1	9								
Total							149	57	36	242	88	67	41	196	392	45	34	471
Grand total							1124	219	129	1472	2249	204	165	2618	1161	121	69	1351
* Vertebrae not received																		