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EXECUTIVE SUMMARY

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The Quota Management Areas (QMAs) for rig (*Mustelus lenticulatus*) and school shark (*Galeorhinus galeus*) were established in October 1986, when limited information was available on the stock relationships of these species. The five rig stocks around mainland New Zealand (excluding FMA 10) were established at a spatial scale consistent with tagging information, while the seven school shark stocks used Fisheries Management Area boundaries as a conservative measure. Elasmobranchs like rig and school shark have relatively slow growth rates, low reproductive capacity, and low productivity, and may be susceptible to over-fishing and local depletion. A mismatch between biological stocks and their management areas could result in sub-optimal management and overfishing. In this report we review biological and fishery data that have become available since 1986 to determine whether they provide any indication of such a mismatch.

The sources of information available for testing the validity of rig and school shark Fishstock boundaries are very limited. No significant differences in rig growth rate were found among SPO 1 East, 3, and 7 Fishstocks. Length and age at maturity were indistinguishable between SPO 3 and 7, but rig in SPO 1 East apparently matured at a smaller size than did South Island rig. There is no indication of a mismatch between the location of rig nursery grounds and the boundaries of rig Fishstocks – all Fishstocks contain at least one nursery ground. Length-weight regressions do not differ between SPO 3 and 7, and vertebral counts are similar throughout mainland New Zealand. Higher vertebral counts in SPO 10 are attributable to the existence there of a different undescribed species of *Mustelus*.

For school shark, no information is available for comparing morphology, growth rates, length and age at maturity, or weight-at-length among Fishstocks. School shark nursery areas appear to be restricted to mainland coastal waters between the Hauraki Gulf and Kaipara Harbour in the north and Oamaru and Jackson Bay in the south. Nursery areas are not known for SCH 4 and 5, or from Northland in SCH 1, despite considerable trawl survey effort in all three regions. This suggests that school shark populations in SCH 4 and 5 are maintained by recruits from central New Zealand (SCH 3 and 7 are the nearest Fishstocks that have nursery grounds).

Catch composition data and sex ratios obtained from commercial fisheries and trawl surveys provide little information on stock identity. For rig, there were no clear differences in size composition or sex ratio data that might indicate the existence of different stocks. For school shark, there may be a real difference in size composition between SCH 5 and elsewhere. However, this is not necessarily indicative of a distinct stock – an alternative explanation is that larger sharks migrate southwards from mainland New Zealand to the Stewart–Snares Islands shelf.

For rig, clear long-term differences were observed in two sets of catch per unit effort (CPUE) series from adjacent areas. The Manukau Harbour (SPO 1 West) index showed a long-term decline followed by stabilisation and slight recovery, whereas other adjacent SPO 1 subareas and SPO 8 showed relatively stable indices over the same time period. Similarly, contrasting trends were observed for west coast South Island (increasing) and Tasman and Golden bays (decreasing) in SPO 7. These patterns suggest that movement of rig may be insufficient to homogenise differences in population density and trajectory over relatively small spatial scales, but stock separation at the indicated spatial scale seems unlikely. The CPUE differences may result from processes acting below the stock level.

School shark CPUE trends also showed variability on a relatively small spatial scale. SCH 1 East showed a long-term increase whereas the adjacent SCH 1 West and 2 showed no trend. Again, the CPUE differences may result from processes acting below the stock level.

Overall, the information analysed for this report provides limited evidence for the existence of multiple stocks of rig and school shark in New Zealand waters. The only persuasive evidence for a mismatch between existing QMA boundaries and biological stocks for school shark is the apparent lack of juvenile and/or nursery areas in SCH 4 and SCH 5, suggesting these Fishstocks are not distinct, but are instead maintained by recruitment from other QMAs.

1. INTRODUCTION

Rig (*Mustelus lenticulatus*) is a small shark that occurs widely throughout New Zealand coastal waters. Rig commonly aggregate in near-inshore waters (to 50 m) to breed during spring and summer (Francis & Mace 1980), and these aggregations support locally important inshore fisheries. Most target rig fishing is by set netting, with important fisheries occurring off Ninety Mile Beach, Kaipara, Manukau and Raglan harbours, Hauraki Gulf, South Taranaki Bight, Tasman and Golden bays, Canterbury Bight, west coast South Island, and Kaikoura. Rig are also commonly taken as bycatch of bottom trawling and longline fishing in most areas (Ministry of Fisheries 2009).

Five putative biological stocks of rig were proposed in October 1986 at the start of the Quota Management System (QMS) (Francis 1985, 1988b, Ministry of Fisheries 2009): northeast coast North Island (NECNI), southeast coast North Island (SECNI), east coast South Island, Southland, and Fiordland (ECSI), west coast South Island (WCSI), and west coast North Island (WCNI). The ECSI and WCSI stocks were determined from a tagging programme carried out in the early 1980s (Francis 1988a, 1988b), NECNI and SECNI stocks were separated on the basis of different catch per unit effort (CPUE) trends before 1986 (Francis & Smith 1988), while the WCNI stock was arbitrarily defined to be similar in size to the South Island stocks.

Five Quota Management Areas (QMAs) for rig (excluding the Kermadec Islands) were established in October 1986. Fishstocks SPO 2, 3, and 7 closely correspond with the SECNI, ECSI, and WCSI biological stocks respectively. SPO 1 includes the northern part of the WCNI stock and the NECNI stock, while SPO 8 comprises the southern portion of the WCNI stock.

School shark (*Galeorhinus galeus*) is a small to medium sized shark that occurs widely over the shelf and upper slope, down to about 600 m depth. It is generally found in coastal inshore waters during summer, and in deeper waters during winter. School shark are considered to comprise one biological stock in New Zealand waters, based on tag return data. Although most tags have been recovered from within the QMA of release, many have moved large distances, including some that travelled 1700–5000 km to Australia (Coutin et al. 1992, Hurst et al. 1999).

In the absence of evidence for school shark (Paul 1988), seven QMAs were established in 1986 (excluding the Kermadec Islands) using FMA boundaries as a conservative measure. SCH 1 comprises the northwest coast North Island and northeast coast North Island, SCH 2 comprises the southeast coast North Island, SCH 3 comprises east coast South Island, SCH 4 includes the Chatham Rise and Chatham Islands, SCH 5 includes Southland, sub-antarctic waters and the Stewart-Snares shelf, SCH 7 includes the west coast South Island, and SCH 8 includes the southwest coast North Island (Ministry of Fisheries 2009).

In the 20 years since these QMA boundaries were established, a significant amount of new, pertinent information has been accumulated. Fishery managers are currently making decisions that may have important sustainability and cost implications on the basis of QMAs that may not be appropriate because they encompass multiple biological stocks, or only part of a biological stock. It is therefore timely to review the existing stock boundaries in order to determine whether they are appropriate.

Understanding fish stock ranges and boundaries is fundamental to accurate and sustainable fisheries management. A mismatch between the spatial range of biological stocks and management areas could lead to undesirable management consequences. In extreme cases, significant ‘leakage’ of fish across management boundaries could produce severe overfishing. For example if a management area straddles the boundary of two adjacent stocks A and B in which stock density is markedly different, Total Allowable Catches (TACs) set at levels appropriate for the higher density stock may be too high to be sustainable in the lower density stock.

Changes to management boundaries could lead to improvements in sustainability, increases in catch, improved catching efficiency for industry, simpler and cheaper quota trading, and reduced research, assessment, and management costs (especially if small QMAs are amalgamated into larger units). A fundamental principle is that QMAs should be matched to biological stock boundaries as closely as possible, unless other overriding considerations exist.

This report examines population-based measures, such as length and age at maturity, maximum size, and sex ratio, as indicators of stock identity. It also examines fishery-based indicators such as spatial variation in CPUE trends, which imply limited mixing of fish and may indicate the existence of different stocks. Trends in relative biomass as determined from trawl surveys have limited use, due to size related bias in catchability of rig and school shark. The larger, generally female, sharks are infrequently caught by trawling. However, trawl survey biomass estimates may provide reliable indices of recruitment, and different recruitment patterns may provide information on stock distribution.

2. LITERATURE REVIEW

Most rig is caught by target set net fishing (Blackwell et al. 2006), although it is also taken as a bycatch of inshore trawl, Danish seine, and line fisheries (Paul 2003, Manning et al. 2004, Watson et al. 2005). The exact composition of landings by method is unknown, as method data are available for only a portion of the rig catch in the Catch Effort and Landing Return (CELR) database (Ministry of Fisheries 2009).

Rig distribution has been analysed by Anderson et al. (1998) and Bagley et al. (2000). The locations of some nursery grounds were determined by Hendry (2004). Rig reproductive biology and age and growth have been analysed (Francis & Mace 1980, Massey & Francis 1989, Francis & Francis 1992, Francis & Ó Maolagáin 2000). Rig fisheries were considered to be overfished during the mid 1980s, and rig was introduced into the QMS in 1986 with Total Allowable Commercial Catches (TACCs) set low to allow stocks to rebuild (Francis & Smith 1988, Paul 2003). By the early 1990s anecdotal information suggested that rig stocks had recovered (Hartill 2002, Paul 2003), and all except SPO 10 were included in the Adaptive Management Programme (AMP) in 1991–92 with increased TACCs (Ministry of Fisheries 2009). Catch and unstandardised CPUE indices for SPO 1 and 8 subsequently declined (Vignaux 1997). SPO 1, 2, and 8 were removed from the AMP in 1997–98, and their TACCs reverted to the 1990–91 levels.

For rig and school shark, the reported landings are derived from processed catches using a conversion factor. In October 1992, the conversion factor for “headed and gutted” and “dressed” rig was reduced from 2.0 to 1.75, which resulted in an increase in removals of about 14% from the same nominal TACC. The conversion factor was further reduced to 1.55 from 2000–01 (Ministry of Fisheries 2009).

Initial analysis of trends in catch and unstandardised CPUE indices for rig using estimated catch data indicated a continuing decline in catch and relative abundance between 1996–97 and 2000–01 using estimated catch data (Hartill 2002, Paul 2003). Blackwell et al. (2006) found little trend in the standardised CPUE indices in SPO 1 and 8 from 1989–90 to 2003–04, based on recalculating landed whole weight using the most recent conversion factor (1.55). This method involved re-stratification, re-allocation, and merging of the available CELR data, generally following the methods of Paul (2003) and Starr (2003). The lack of trends in CPUE indicated that earlier reported declines were largely driven by changes in the conversion factor. Interpretation of early non-corrected CPUE data should take account of this bias. The revised method has been subsequently used to update the SPO 1 and 8 CPUE indices to 2006–07 (Manning unpublished results), SCH 1 and 2 CPUE (Manning et al. unpublished results), and all subsequent CPUE analyses of rig and school shark undertaken as part of the AMP (Starr et al. 2007a, b, c, d, e, 2008, Starr & Kendrick 2009).

Fishery descriptions, standardised CPUE analysis and description of several voluntary logbook programmes have been completed for rig stocks currently managed under the AMP (Lydon et al. 2006, 2007). Data are available for SPO 2 (Starr & Kendrick 2009), SPO 3 (Starr et al. 2008) and SPO 7 (Starr et al. 2006).

A characterisation and CPUE analysis of the commercial fisheries for school shark between 1989–90 and 1998–99 were completed by Paul & Sanders (2001) and Bradford (2001) respectively. Standardised CPUE indices were derived by Ayers et al. (2006) for several regional fisheries, and for SCH 1 and 2 by Manning et al. (unpublished results). Fishery descriptions, standardised CPUE analysis, and description of several voluntary logbook schemes have been completed for SCH 3, 5, 7, and 8 (Starr et al. 2007b, c, d, e).

School shark distribution has been described by Anderson et al. (1998), Bagley et al. (2000), and Hurst et al. (2000). Age and growth has been reviewed by Francis & Mulligan (1998).

3. METHODS

This review is based largely on published data, and involves no new analysis of fishery data (including length frequency and CPUE indices). Its purpose is to collate data from a variety of sources that may provide information on the stock structure of rig and school shark.

Published accounts of rig and school shark age, growth, and maturity were reviewed, with emphasis on identifying any parameters that vary among different parts of New Zealand. Information on nursery grounds for rig and school shark was summarised. Every biological stock must have at least one nursery ground within its boundaries to provide recruits.

Length-weight regression relationships may be useful for identifying among-stock variations in weight-at-length. Unfortunately, these regressions may be affected by weighing method (whether motion-compensating scales or hand-held spring balances were used), time of year (because of variations in body condition and reproductive state), stomach fullness, sex (mature female rig are heavier than mature males of the same length, especially if many of the former are pregnant (Francis 1979)), and sampling method (set net mesh size can bias samples by selectively catching more individuals within a particular girth range; trawl nets are not very efficient at catching longer sharks). Although a number of length-weight regressions have been published for different school shark and rig stocks (Ministry of Fisheries 2009), it was not possible to re-examine raw data sets to determine whether the samples were comparable. Consequently, we examined only length-weight regression relationships collected by MFish trawl surveys and stored on the MFish *trawl* database. These relationships were plotted and examined for differences among areas.

Precaudal vertebral counts were made by dissection for rig from around New Zealand during the 1980s (M. Francis, NIWA, unpublished data). Vertebral counts have been found useful for distinguishing species of *Mustelus* (Heemstra 1973), and they are also potentially useful for stock separation. Counts excluded the half centrum fused to the rear of the skull and caudal vertebrae which are small and difficult to count.

Two sources of fishery data were available. Fishery-dependent data were derived from catch sampling completed by fishers in several fishery-specific logbook programmes initiated and maintained as part of the AMP. Available data may include mean length, sex ratio, and length frequency data. The data provide information on predominant sex, size or maturity classes, and how these may differ among regions. These data are generally influenced by fishing method, and are separately presented for set net, trawl, and longline fisheries. For set nets, the length and sex ratio of rig or school shark may be strongly influenced by mesh size, and by the season and location of fishing. However, the available data are often summarised by fishing year for a Fishstock and separate information is largely unavailable. Data from commercial trawl fisheries are generally biased against larger fish, often larger female rig and school shark, as the catchability of these older size classes is low. Published data were kindly made available by SeaFIC for the rig and school shark stocks managed under the AMP.

Recently updated standardised CPUE indices are available for all rig and school shark QMAs that are currently within the AMP programme (SPO 3 and 7; SCH 3, 5, 7, and 8). Indices are available for several other stocks, including SPO 1 and 2 (Starr et al. 2009, Manning unpublished results) and SCH 1 and 2 (Manning et al. unpublished results). Examination of CPUE data has been restricted to series which use a standardised conversion factor in the analysis, and have been accepted by the relevant Working Group as likely to be representing changes in relative abundance (Ministry of Fisheries 2009).

Fishery-independent data from relevant trawl survey programmes were also examined. The rig and school shark length frequency data may have been affected by the mesh size used in different survey series, and larger rig and school shark have low catchability in trawl nets. Relative biomass estimates from these trawl surveys have been compared with trends in standardised CPUE analyses from commercial catch data where available and where the former meet criteria indicating that they may adequately index biomass (relative biomass not consistently below 200 t, c.v.s not consistently over 30% and length frequency distributions similar or displaying modal progression among surveys within a series).

4. RESULTS

4.1 Rig

4.1.1 Age, growth, maturity, and morphology

Information on age, growth and maturity is available for only three rig Fishstocks. The most comprehensive study was based on estimates of age derived from ring counts on vertebrae collected mainly from trawl surveys of ECSI (SPO 3) and WCSI (SPO 7) (Francis & Ó Maolagáin 2000). Sample sizes were relatively small (71 vertebrae from ECSI and 173 from WCSI) and ages were not validated. No significant difference in growth rates was found between males and females from WCSI so both sexes were pooled. No significant difference was found between the growth curves for ECSI and WCSI. However the authors noted that "we cannot discount the possibility that such differences exist, because in other species of *Mustelus*, differences only become apparent in older, mature sharks … and our WCSI samples contained few rig older than eight years. Furthermore, tagging data for WCSI and ECSI rig (combined) revealed significantly higher growth rates for female rig than male rig". The vertebral growth curve for WCSI and ECSI rig was virtually identical to a growth curve derived from a MULTIFAN analysis of length-frequency modes of Hauraki Gulf (SPO 1 East) rig (Francis & Ó Maolagáin 2000).

Rig from the ECSI and WCSI mature at about the same lengths (ca 85 cm for males and ca 100 cm for females) and ages (5–6 years for males and 7–8 year for females) (Francis & Francis 1992, Francis & Ó Maolagáin 2000). Rig from the Hauraki Gulf (SPO 1 East) apparently mature at smaller sizes (ca 72 cm for males and 82 cm for females) and younger ages (ca 4 years for males and 5 years for females) (Francis & Francis 1992), though the maturity sample sizes were small and the age at maturity estimates were based on MULTIFAN analysis of length-frequency modes rather than age data, so these estimates should be interpreted cautiously.

Rig produce live young which are born at a length of about 25–35 cm (Francis & Mace 1980, Francis & Francis 1992). In spring, pregnant females migrate into shallow coastal waters where they give birth. Young are either born in estuaries or large coastal harbours, or they make their way into these places after being born in coastal waters. The juveniles spend their first 6–8 months of life in estuaries and harbours before departing for deeper water in autumn–winter (Francis & Francis 1992). Estuaries and harbours in which new-born rig have been found include (Graham 1956, Webb 1973, Briggs 1980, Healy 1980, Francis 1985, 1988b, Jones & Hadfield 1985, Francis & Francis 1992, Hendry 2004, L. D. Ritchie unpublished data, M. P. Francis unpublished data):
SPO 1 East – Bay of Islands, Waitemata Harbour, Firth of Thames, Tauranga Harbour
SPO 1 West – Kaipara Harbour, Manukau Harbour, Raglan Harbour
SPO 2 – Poverty Bay
SPO 3 – Pegasus Bay, Avon-Heathcote Estuary, Lyttelton Harbour, Akaroa Harbour, Blueskin Bay
SPO 8 – Porirua Harbour, Pauatahanui Inlet

Coastal waters in which considerable numbers of small 0+ rig (less than 50 cm TL) have been caught in trawl surveys include (Hendry 2004):
SPO 1 East –Waitemata Harbour, Firth of Thames, eastern Bay of Plenty
SPO 1 West – west coast North Island
SPO 2 – Hawke Bay
SPO 3 – Pegasus Bay, Canterbury Bight
SPO 7 – Tasman and Golden bays, west coast South Island.

Thus estuaries, harbours and shallow coastal waters throughout much of mainland New Zealand act as nursery grounds for 0+ rig, and all Fishstocks contain such nurseries within their boundaries.

Length-weight relationships for rig sampled during South Island trawl surveys are shown in Figure 1. The curves generated from ECSI and WCSI trawl surveys essentially overlie each other, indicating no differences between SPO 3 and SPO 7.

Precaudal vertebral counts from rig caught in SPO 1 East, 2, 3, 7, and 10 are shown in Figure 2 (M. Francis, unpublished data). All mainland rig stocks (SPO 1 East, 2, 3, and 7) had similar distributions of vertebral numbers, with mean counts of 95–97. The two South Island stocks had slightly higher means than the two North Island stocks, but this may simply be an artifact of small sample size. A very small sample of Kermadec Islands (SPO 10) rig showed significantly higher vertebral counts than the mainland Fishstocks, and the Kermadec specimens are now known to represent a different undescribed species (C. Duffy and M. Francis, unpublished results). Whether true rig (*Mustelus lenticulatus*) occurs in SPO 10 is unknown, and further samples from the Kermadecs are required to determine this.

4.1.2 Length frequencies and sex ratios

Rig undergo seasonal migrations related to reproductive activity, and the sex ratio varies among seasons. Catch samples from SPO 3 (Kaikoura, Pegasus Bay, and Otago) and SPO 7 (Tasman and Golden bays) in the late 1970s and early 1980s showed strong trends in sex ratio in some locations (Figure 3). These patterns sometimes reflected small scale spatial variation, but they also had a seasonal variation component.

Length frequency data from trawl surveys around New Zealand were largely uninformative. Sample sizes were usually too small to represent population length distributions adequately: 69% of the survey-year-sex strata had sample sizes less than 50 and 90% had sample sizes less than 100. Furthermore, large rig are rarely caught by trawl nets, and so samples were biased towards small individuals (mainly shorter than 100 cm total length [TL]) and males (because females grow larger than males). Inter-annual variability in the length-frequency distributions confirmed that they were not providing a reliable estimate of the size composition of the rig population. Consequently trawl survey length frequencies are not generally presented here. However, the length frequency distributions from SPO 7 trawl surveys are shown (Figure 4) to illustrate the size composition of rig for which relative biomass estimates are present (Section 4.1.3).

Data from the SPO 3 AMP set net logbook scheme have been collected mainly in Canterbury Bight, off Puysegur Point, and Stewart Island from 1995–96 to 2006–07 (Figure 5). Length-frequency distributions were generally consistent among years, although it is not known whether the mesh sizes used in the fishery varied spatially or inter-annually, so interpretation of the data needs to be cautious. Males had a single narrow length mode peaking at about 85–100 cm TL, whereas females had a broader and more variable mode between 80 and 120 cm TL. Ignoring years with sample sizes less than 100 rig, the percentage of males varied between 50 and 76% (mean 61%) (see Appendix Table A1).

Data from the SPO 7 set and bottom trawl logbook programmes are available from 2001–02 to 2004–05 (Starr et al. 2006). Only set net data are presented here because bottom trawl samples are biased towards small rig, and because there are no commercial trawl samples from other rig stocks to compare them with. Set net sample sizes were large, exceeding 2000 rig measured per year (Appendix Table A2). Length frequency distributions are presented separately for the west coast South Island and Tasman and Golden bays in Figures 6 and 7 respectively. On the west coast, male distributions were variable among years, having broad modes (70–100 cm TL) in some years and narrow modes (85–100 cm TL) in others. Similarly, females had broad modes (90–120 cm TL) or narrow modes (120–140 cm TL). In Tasman and Golden bays, male rig displayed a consistent narrow–medium mode at 75–95 cm, and females had broad modes at 95–135 cm. It is not known whether the mesh sizes used in the fishery varied spatially or inter-annually over this period, so interpretation of the data needs to be cautious. The percentage of males in SPO 7 (both sub-areas combined) varied between 45 and 63% (mean 51%) (see Appendix Table A2).

4.1.3 Trends in CPUE and relative biomass

SPO 1
Standardised CPUE indices (Figure 8) for four out of five subareas in SPO 1 between 1989–90 and 2006–07 have been relatively stable over the long term (Manning unpublished results). However, in the last five years, the indices for SPO 1 East (Thames) and SPO 1 East (Coast) show inverse patterns in (the former increasing and the latter decreasing) that might indicate local spatial variations in rig distribution. The indices for SPO 1 West have remained relatively stable for the Kaipara and west coast subareas, but the Manukau subarea declined steeply to 2005 followed by a stabilisation and slight recovery.

SPO 2
Between 1986–87 and 2006–07, over 70% of the rig in SPO 2 was taken as bycatch in the bottom trawl fisheries for red gurnard and tarakihi. A further 25% was taken by set net fishing for flatfish, blue warehou, rig, and blue moki (Starr & Kendrick 2009). Standardised CPUE indices for rig from the red gurnard and tarakihi target bottom trawl fisheries increased gradually between 1989–90 and 2003–04 and then showed a slight decline (Figure 9). While fewer data were available from the combined set net fisheries, CPUE followed a similar, but more variable trend. A strong decline was apparent after 2004–05 (Starr & Kendrick 2009).

SPO 3
Three standardised CPUE indices for SPO 3 developed from: (1) the general shark set net fishery; (2) the mixed target bottom trawl fishery; and (3) the bottom trawl flatfish fishery (Figure 10) showed no overall change between 1989–90 and 2006–07 (Starr et al. 2007a, 2008). However, the AMP Working Group concluded (in 2005) that declines in annual landings and in the mean size of males and females over the six years between 1999–2000 and 2004–05 were consistent with a decline in the abundance of SPO 3 (Starr et al. 2008).

Relative abundance indices from the winter and summer inshore trawl survey series completed in SPO 3 provide little useful data on trends in pre-recruit biomass.

SPO 7
The standardised CPUE indices for the set net fishery showed different trends between the west coast South Island subarea and the Tasman and Golden bays subarea (area 038) between 1989–90 and 2004–05 (Starr et al. 2006). An increasing trend is indicated for the west coast South Island set net fishery, while a declining trend is apparent for Tasman and Golden bays (Figure 11).

Relative biomass indices from the 1992 to 2009 autumn WCSI survey series (Figure 12, combined surveys) were considered to monitor pre-recruit abundance for rig (Stevenson & Hanchet 2000, 2007). They indicate a decline between 1995 and 2003. Separate indices for the west coast South

Island and Tasman and Golden bays subareas appear to follow generally similar trends, though the c.v.s were high and biomass estimates low in the latter subarea (Figure 12).

SPO 8

A standardised CPUE index (Figure 8) was stable between 1989–90 and to 2001–02, increased slightly in 2002–03, but subsequently declined (Manning unpublished results).

4.2 School shark

4.2.1 Age, growth, maturity, and morphology

There has been only one study on New Zealand school shark age and growth. Francis & Mulligan (1998) developed growth curves from age estimates derived from vertebral sections and from MULTIFAN modal analysis of length-frequency data. Most of the vertebral samples (73% of 264 sections) came from WCSI trawl surveys (SCH 7) with small amounts from SCH 1 West, 3, 5, and 8 added to boost the number of older sharks in the sample. No attempt was made to estimate separate growth curves by QMA, and because of small sample sizes this would not be feasible. Thus no information is available for comparing growth rates among Fishstocks. The same is true for length and age at maturity. No suitable stock-specific morphological data exist for school shark.

School shark produce live young which are born at a length of about 30–35 cm. In spring, pregnant females migrate into coastal waters where they give birth. Little is known about the habitat requirements of newborn school shark, and well defined nurseries either do not exist or they have not yet been identified. 0+ juveniles less than 50 cm TL are known from inshore coastal waters in the following regions (Francis & Mulligan 1998, Hurst et al. 2000, S. Hernandez, VUW, unpublished data):

SCH 1 East – Hauraki Gulf, Bay of Plenty

SCH 1 West – Manukau Harbour, Kaipara Harbour, west coast North Island between Manukau Harbour and Raglan Harbour

SCH 2 – Hawke Bay to East Cape, Wellington Harbour

SCH 3 – Pegasus Bay, Canterbury Bight

SCH 7 – Tasman and Golden bays, west coast South Island.

SCH 8 – Kapiti coast

No records of 0+ juveniles are known from SCH 4 and 5, or from Northland in SCH 1. Similarly, there are no trawl survey records of 1+ school shark (50–61 cm TL) from these regions (Hurst et al. 2000). Thus nursery areas for school shark appear to be restricted to mainland coastal waters between the Hauraki Gulf and Kaipara Harbour in the north and Oamaru and Jackson Bay in the south.

Length-weight relationships for school shark sampled around the South Island are shown in Figure 13. Three different curves from SCH 7 and one from SCH 5 coincided almost exactly, indicating no difference between these two stocks.

4.2.2 Length frequencies and sex ratios

Sample sizes of school shark measured from trawl surveys around New Zealand were often too small to represent population length distributions adequately: 43% of the survey-year-sex strata had sample sizes less than 50 and 67% had sample sizes less than 100. Furthermore, large school shark are rarely caught by trawl nets, and so samples were biased towards small individuals (mainly shorter than 100 cm TL). Trawl survey length frequencies are presented here for the ECSI summer and winter survey series (Figures 14 & 15), the WCSI autumn survey series (Figure 16), and the Chatham Rise summer survey series (Figure 17) to illustrate the size composition of the catches for which relative biomass estimates have been made (see Section 4.2.3). The Chatham Rise surveys caught larger school sharks (most over 120 cm TL with a mode at 140–155 cm) than the ECSI and WCSI surveys (most less than 120 cm).

Length frequencies from catch sampling in the Cook Strait set net fishery (SCH 2) during 1995–1999 (Paul & Sanders 2001) showed catches dominated by a broad mode of females at 70–170 cm TL in three of the four years, with a narrow mode at 130–150 cm in 1997–98 (Figure 18). Males made up a small proportion of the catches in all years.

Length frequencies from catch sampling in the east coast South Island (SCH 3) set net fishery during 1995–2006 (Starr et al. 2007b) showed a strong and consistent mode of both sexes at 70–100 cm TL, and a smaller mode of large sharks, most notably for females, at 130–150 cm (Figure 19). There appeared to be strong recruitment of young fish in 2002–03. The sex ratio has been close to 50:50 since 1999–2000, but was variable before that (Appendix Table A3).

In the Southland (SCH 5) set net fishery (Starr et al. 2007c), the length frequency distributions were very different from the east coast South Island, being dominated by large modes of both sexes at 100–140 cm TL (Figure 20). The mean sex ratio was 57% male, though it has been closer to 50% in recent years (Appendix Table A4).

The logbook programmes in SCH 7 (Starr et al. 2007d) covered set net, bottom trawl, and longline fisheries for only two years (2004–05 and 2005–06). The number of school sharks measured was high in the bottom trawl fishery but low in the other two fisheries (Appendix Table A5). Cautious interpretation is required because of small sample sizes, limited temporal span of the data, and biased sampling by both set net and trawl nets. Most school sharks caught by set net and trawl fisheries were 70–120 cm TL, though set nets tended to catch larger females than did trawl nets (Figure 21). Longlines caught larger school sharks of both sexes (mainly 90–160 cm). The overall sex ratio was similar in all three fisheries: 58% male in set nets, 52% male in bottom trawl, and 56% male in bottom longline (Appendix Table A5).

Length frequency distributions for SCH 8 set net, bottom trawl, and longline fisheries in 2004–05 and 2005–06 (Starr et al. 2007e) were similar to those in SCH 7 except that females caught in set nets and bottom trawls were smaller (mainly 70–90 cm TL) (Figure 22). Sex ratios were similar to those in SCH 7 (54% male in the set net fishery, 50% male in the bottom trawl fishery, and 57% male in the bottom longline fishery (Appendix Table A6).

4.2.3 Trends in CPUE and relative biomass

Fishery-dependent CPUE indices have been accepted by the Inshore Working Group as monitoring relative abundance of the school shark substocks, except for SCH 5 (Ministry of Fisheries 2009). CPUE indices for SCH 1 West, 2, 3, 7, and 8 showed no trend over the full time series, though SCH 8 showed some variability (possibly a decline followed by a recovery) (Figure 23). CPUE increased in SCH 1 East. The Inshore Working Group suggested that a reciprocal relationship between SCH 7 and 8 may be a result of migration patterns between these adjacent QMAs (Ministry of Fisheries 2009).

Few trawl survey time series of school shark relative abundance meet the criteria for consideration in this study. The indices for SCH 3, 4, and 7 from the ECSI, Chatham Rise, and WCSI trawl surveys respectively showed no long-term trends, although the SCH 7 relative biomass may have increased during the early to mid 1990s and then declined again to a stable level (Figure 24).

5. DISCUSSION

The sources of information available for testing the validity of rig and school shark Fishstock boundaries are very limited. Comparable morphometric data, and age, growth, maturity, and weight biological parameters, are not available for all stocks. Even when estimates of these parameters are available, comparisons are often constrained by small sample sizes and/or confounded by biased sampling methods or different sampling techniques among Fishstocks.

No significant differences in rig growth rate were found among SPO 1 East, 3, and 7 Fishstocks. Length and age at maturity were indistinguishable between SPO 3 and 7, but rig in SPO 1 East apparently matured at a smaller size than did South Island rig. However, this last conclusion needs verification with more robust data and analysis. There is no indication of a mismatch between the location of rig nursery grounds and the boundaries of rig Fishstocks – all Fishstocks contain at least one nursery ground. Length-weight regressions did not differ between SPO 3 and 7, and vertebral counts were similar throughout mainland New Zealand. Higher vertebral counts in SPO 10 are attributable to the existence there of a different, undescribed species of *Mustelus*.

For school shark, no information is available for comparing morphology, growth rates, length and age at maturity, or weight-at-length among Fishstocks. School shark nursery areas appear to be restricted to mainland coastal waters between the Hauraki Gulf and Kaipara Harbour in the north and Oamaru and Jackson Bay in the south. Nursery areas are not known for SCH 4 and 5, or from Northland in SCH 1, despite considerable trawl survey effort in all three regions. This suggests that school shark populations in SCH 4 and 5 are maintained by recruits from central New Zealand (SCH 3 and 7 are the nearest Fishstocks that have nursery grounds).

Information on size composition and sex ratio of commercial and trawl survey catches provided little information on stock identity. There are many problems with the interpretation of these data, even when logbook or survey coverage is representative, sample sizes are adequate, and a number of years have been sampled. The data are often biased by gear selectivity (particularly caused by variations in mesh size of set nets and trawl nets, and escapement of large sharks from slow moving trawl nets), and confounded by the common behaviour of shark species to school by size and sex, thus introducing high temporal and spatial variability into the data. An observation of different size composition or sex ratio in adjacent Fishstocks or subareas could be interpreted in several ways: it may represent a real population difference among distinct stocks; it may reflect different selectivity or availability in fisheries using different fishing gear or fishing in different months, seasons, depths or locations; or it may result from different habitat usage by different population components (e.g., mature females may be spatially segregated from immature fish of both sexes). Consequently, assigning a stock interpretation to these data is problematic, even when a large difference is detected among areas.

For rig, good size composition and sex ratio data sets were available for SPO 3 and 7 (including west coast and Tasman and Golden bays subareas of the latter). In both Fishstocks, females tended to be considerably larger than males, but no clear patterns existed between areas or subareas – there was strong overlap of modes among areas within sex, and variability among years. Thus no clear differences are apparent that might indicate the existence of different stocks.

Longlines caught larger school sharks in SCH 7 than did set nets or bottom trawls. This was likely an effect of gear selectivity, but spatial distribution of fishing effort may also have been important: since 1989–90, more than half of the longline catch in SCH 7 has come from Cook Strait (statistical areas 16–18), whereas bottom trawl catches were more widely distributed through SCH 7 (mainly Cook Strait and west coast South Island) and set net catches came mainly from the west coast South Island (Starr et al. 2007d). This confirms that comparison of length composition among areas must be cautious. For set nets, SCH 2, 3, 7, and 8 all had similar length composition, whereas SCH 5 (Southland) had considerably larger sharks. The SCH 5 fishery has historically used larger mesh set nets than in other QMAs. Although mesh size probably has a direct effect on the size composition of the shark catch, fishers presumably use larger mesh only in areas that have a high proportion of large sharks. Thus there may be a real difference in size composition between SCH 5 and elsewhere. However, this should not necessarily be interpreted as indicative of a distinct stock – an alternative explanation is that larger sharks migrate southwards from mainland New Zealand to the Stewart–Snares Islands shelf.

Trends in CPUE and trawl survey relative biomass may be more informative than catch composition data, although catchability biases again cause interpretation problems. Trawl survey estimates only provided indices of rig or school shark juveniles and possibly sub-adults because of escapement of large sharks, and CPUE indices may track only part of the population. Comparisons among areas may be confounded by differences in methods, mesh sizes, or seasonality. Short-term fluctuations (e.g., 2–5 years) in CPUE or trawl survey biomass may reflect inter-annual variation in migration patterns. Therefore we consider these indices to be only useful if consistent long-term differences are apparent among areas.

For rig, clear long-term differences were observed in two sets of CPUE series from adjacent areas. The Manukau Harbour index showed a long-term decline followed by stabilisation and slight recovery, whereas other adjacent SPO 1 subareas and SPO 8 showed relatively stable indices over the same time period. Similarly, contrasting trends were observed for west coast South Island (increasing) and Tasman and Golden bays (decreasing) in SPO 7. These patterns suggest that movement of rig may be insufficient to homogenise differences in population density and trajectory over relatively small spatial scales, but stock separation at the indicated spatial scale seems unlikely. The CPUE differences may result from processes acting below the stock level (e.g., differential spatial distribution of males and females, philopatric homing by females to natal pupping and nursery grounds).

School shark CPUE trends also showed relatively small spatial scale variability. SCH 1 East showed a long-term increase whereas the adjacent SCH 1 West and 2 showed no trends. Again, it is not clear whether these differences are sufficient or robust enough to be taken as evidence of distinct stocks.

Overall, the information analysed for this report provides limited evidence for the existence of multiple stocks of rig and school shark in New Zealand waters. *Mustelus* specimens collected from the Kermadec Islands are an undescribed species different from New Zealand rig, although the presence of the latter at the Kermadecs cannot yet be ruled out. Length at maturity data suggest that rig in SPO 1 East are a distinct stock from those on east and west coasts of the South Island (SPO 3 and SPO 7), although better sampling and data analysis are required to confirm this. An apparent lack of school shark nursery grounds in SCH 4 and 5 suggests that these Fishstocks are not biologically distinct from the adjacent SCH 3 and/or 7. Different trends in CPUE for both species over a small spatial scale seem unlikely to result from stock differences, and may instead reflect within-stock size- and sex-segregation behaviour, or age-related migration patterns.

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7. REFERENCES

Anderson, O.F.; Bagley, N.W.; Hurst, R.J.; Francis, M.P.; Clark, M.R.; McMillan, P.J. (1998). Atlas of New Zealand fish and squid distributions from research bottom trawls. *NIWA Technical Report 42*. 303 p.

Ayers, D.; Paul, L.J.; Sanders, B.M. (2006). Estimation of catch per unit effort analyses for school shark (*Galeorhinus galeus*) from bycatch and target fisheries in New Zealand, 1989–90 to 2001–02. *New Zealand Fisheries Assessment Report 2006/26.* 121 p.

Bagley, N.W.; Anderson, O.F.; Hurst, R.J.; Francis, M.P.; Taylor, P.R.; Clark, M.R.; Paul, L.J. (2000). Atlas of New Zealand fish and squid distributions from midwater trawls, tuna longline sets, and aerial sightings. *NIWA Technical Report 72*. 171 p.

Beentjes, M.P.; Stevenson, M.L. (2000). Review of the east coast South Island winter trawl survey time series, 1991–96. *NIWA Technical Report 86*. 64 p.

Beentjes, M.P.; Stevenson, M.L. (2001). Review of the east coast South Island trawl survey time series, 1996–97 to 1999–2000. *NIWA Technical Report 108*. 92 p.

Beentjes, M.P.; Stevenson, M.L. (2008). Inshore trawl survey of Canterbury Bight and Pegasus Bay, May–June 2007 (KAH0705). *New Zealand Fisheries Assessment Report 2008/38*. 95 p.

Blackwell, R.G.; Manning, M.J.; Gilbert, D.G.; Baird, S.J. (2006). Standardised CPUE analysis of the target rig (*Mustelus lenticulatus*) setnet fishery in northern New Zealand (SPO 1 and 8). *New Zealand Fisheries Assessment Report 2006/32*. 56 p.

Briggs, I. (1980). Upper Waitemata Harbour – interim fish survey. *Upper Waitemata Harbour Catchment Study Working Report No.* 17. 28 p.

Bradford E. (2001). Standardised catch rate indices for New Zealand school shark, *Galeorhinus galeus,* in New Zealand, 1989–90 to 1998–99. *New Zealand Fisheries Assessment Report 2001/33.* 75 p.

Coutin, P.; Bruce, B.; Paul, L.J. (1992). New Zealand school sharks cross the Tasman Sea. *Australian Fisheries 51(3)*: 24–25.

Francis, M.P. (1979). A biological basis for the management of New Zealand moki (*Latridopsis ciliaris*) and smoothound (*Mustelus lenticulatus*) fisheries. Unpubl. M.Sc. thesis, University of Canterbury, Christchurch. 208 p.

Francis, M.P. (1985). Rig. *In*: Colman, J.A.; McKoy, J.L.; Baird, G.G. (eds). Background papers for the 1985 Total Allowable Catch recommendations, pp. 145–169. (Unpublished report held in NIWA library, Wellington).

Francis M.P. (1988a). Movement patterns of rig (*Mustelus lenticulatus*) tagged in southern New Zealand. *New Zealand Journal of Marine and Freshwater Research 22*: 259–272.

Francis M.P. (1988b). Rig. New Zealand Fisheries Assessment Research Document 88/24. 19 p. (Unpublished report held in NIWA library, Wellington).

Francis M.P.; Francis R.I.C.C. (1992). Growth rate estimates for New Zealand rig (*Mustelus lenticulatus*). *Australian Journal of Marine and Freshwater Research 43*: 1157–1176.

Francis M.P.; Mace J.T. (1980). Reproductive biology of *Mustelus lenticulatus* from Kaikoura and Nelson. *New Zealand Journal of Marine and Freshwater Research 14:* 303–311.

Francis, M.P.; Mulligan, K.P. (1998). Age and growth of New Zealand school shark, *Galeorhinus galeus*. *New Zealand Journal of Marine and Freshwater Research 32*: 427–440.

Francis M.P.; Ó Maolagáin, C. (2000). Age, growth and maturity of a New Zealand endemic shark (*Mustelus lenticulatus*) estimated from vertebral bands. *Marine and Freshwater Research 51*: 35–42.

Francis M.P.; Smith D.W. (1988). The New Zealand rig fishery: Catch statistics and composition, 1974–85. *New Zealand Fisheries Technical Report No. 7*. 30 p.

Graham, D.H. (1956). A treasury of New Zealand fishes. Second edition. Reed, Wellington. 424 p.

Hartill, B. (2002). Characterisation of the commercial FLA, GMU and SPO fisheries in the Kaipara Harbour. Final Research Report for Ministry of Fisheries Research project MOF2002/03C, Objective 1. 18 p. (Unpublished report held by MFish, Wellington.)

Healy, W.B. (1980). Pauatahanui Inlet – an environmental study. *DSIR Information Series No. 141*. 198 p.

Heemstra, P.C. (1973). A revision of the shark genus *Mustelus* (Squaliformes: Carcharhinidae). Unpubl. Ph.D. thesis, University of Miami, Miami. 187 p.

Hendry, R.T. (2004). An assessment of the spatial extent and relative importance of nurseries, and of the genetic structure among nurseries of rig (*Mustelus lenticulatus*), an endemic New Zealand shark. Unpubl. M.Sc. thesis, Victoria University of Wellington, Wellington. 210 p.

Hurst., R.J.; Bagley, N.W.; McGregor, G.A.; Francis, M.P. (1999). Movements of the New Zealand school shark, *Galeorhinus galeus*, from tag returns. *New Zealand Journal of Marine and Freshwater Research 33*: 29–48.

Hurst, R.J.; Bagley, N.W.; Anderson, O.F.; Francis, M.P.; Griggs, L.H.; Clark, M.R.; Paul, L.J.; Taylor, P.R. (2000). Atlas of juvenile and adult fish and squid distributions from bottom and midwater trawls and tuna longlines in New Zealand waters. *NIWA Technical Report No.* 84. 162 p.

Jones, J.B.; Hadfield, J.D. (1985). Fishes from Porirua and Pauatahanui Inlets: occurrence in gill nets. *New Zealand Journal of Marine and Freshwater Research 19*: 477–484.

Livingston, M.E; Clark, M.R.; Baird, S.J. (2003). Trends in incidental bycatch of major fisheries on the Chatham Rise for fishing years 1989–90 to 1998–99. *New Zealand Fisheries Assessment Report 2003/52*. 74 p.

Livingston, M.E ; Stevens, D.W. (2005). Trawl survey of hoki and middle depths species on the Chatham Rise, January 2004 (TAN0401). *New Zealand Fisheries Assessment Report 2005/21*. 62 p.

Lydon G.J.; Middleton D.A.J.; Starr P.J. (2006). Performance of the SPO 3 Logbook Programme. AMP-WG-06/23. (Unpublished manuscript available from the New Zealand Seafood Industry Council, Wellington).

Lydon, G; Banks, D.; Starr, P. (2007). The design and evolution of SeaFIC managed adaptive management logbook programmes. AMPWG07/05. 48 p. (Unpublished document available at: http://cs.fish.govt.nz/forums/195/PostAttachment.aspx)

Manning, M.J.; Hanchet, S.M.; Stevenson, M.J. (2004) A description and analysis of New Zealand's spiny dogfish (*Squalus acanthias*) fisheries and recommendations on appropriate methods to monitor the status of the stocks. *New Zealand Fisheries Assessment Report 2004/61*. 135 p.

Massey, B.R.; Francis, M.P. (1989). Commercial catch composition and reproductive biology of rig (*Mustelus lenticulatus*) from Pegasus Bay, Canterbury, New Zealand. *New Zealand Journal of Marine and Freshwater Research 23:* 113–20.

Ministry of Fisheries (2009). Report from the Fishery Assessment Plenary, May 2009: stock assessments and yield estimates. Ministry of Fisheries. 1036p. (Unpublished report held in NIWA library, Wellington.)

Paul, L.J. (1988). School shark. New Zealand Fisheries Assessment Research Document 88/27. 32 p. (Unpublished report held in NIWA library, Wellington.)

Paul, L.J. (2003). Characterisation of the commercial and recreational fisheries for rig (*Mustelus lenticulatus*) in northern New Zealand (SPO 1 and SPO 8), and unstandardised CPUE analyses of the targeted set net fisheries. *New Zealand Fisheries Assessment Report 2003/22* . 69 p.

Paul L J.; Sanders B. (2001). A description of the commercial fishery for school shark, *Galeorhinus galeus,* in New Zealand, 1945 to 1999. *New Zealand Fisheries Assessment Report 2001/32*. 63 p.

Starr, P.J. (2003). Procedure for merging MFish landing and effort data. Version 1.0. 13 p. (Unpublished report available from the author: paul@starrfish.net)

Starr, P.J.; Kendrick T.H.; Lydon, G J. (2006). Full Term Review of the SPO 7 Adaptive Management Programme. AMP WG 2006/04 90p. (Unpublished manuscript available from the New Zealand Seafood Industry Council, Wellington).

Starr, P.J.; Kendrick, T.H.; Lydon, G.J.; Bentley, N.(2007a). Report to the Adaptive Management Programme Fishery Assessment Working Group: Review of the SPO 3 Adaptive Management Programme. AMP-WG-2007/06. 87 p. (Unpublished manuscript available from the New Zealand Seafood Industry Council, Wellington).

Starr, P.J.; Kendrick, T.H.; Lydon, G.J.; Bentley N. (2007b.) Report to the Adaptive Management Programme Fishery Assessment Working Group: Two year review of the SCH 3 Adaptive Management Programme. AMP-WG-07-08. (Unpublished manuscript available from the New Zealand Seafood Industry Council, Wellington).

Starr, P.J.; Kendrick, T.H.; Lydon G.J.; Bentley, N. (2007c). Report to the Adaptive Management Programme Fishery Assessment Working Group: Two year review of the SCH 5 Adaptive Management Programme. AMP-WG-07-09. (Unpublished manuscript available from the New Zealand Seafood Industry Council, Wellington).

Starr, P.J.; Kendrick T.H.; Lydon G.J.; Bentley N. (2007d). Report to the Adaptive Management Programme Fishery Assessment Working Group: Two year review of the SCH 7 Adaptive Management Programme. AMP-WG-07-15. (Unpublished manuscript available from the New Zealand Seafood Industry Council, Wellington).

Starr P.J.; Kendrick T.H.; Lydon G.J.; Bentley N. (2007e). Report to the Adaptive Management Programme Fishery Assessment Working Group: Two year review of the SCH 8 Adaptive Management Programme. AMP-WG-07-16. (Unpublished manuscript available from the New Zealand Seafood Industry Council, Wellington.

Starr, P.J.; Kendrick, T.H.; Bentley, N.; Lydon, G.J. (2008). Report to the Adaptive Management Programme Fishery Assessment Working Group: Review of the SPO 3 Adaptive Management Programme. AMP WG 08/05 (Revision 2). 102 p. (Unpublished report held by Ministry of Fisheries, Wellington).

Starr, P.J.; Kendrick, T.H. (2009). SPO 2 catch/effort analysis. Report to the Northern Inshore Fisheries Working Group. NINS WG 2009/27-v2. (Unpublished report held by Ministry of Fisheries, Wellington).

Stevens, D.W.; Livingston, M.E.; Bagley, N.W. (2001). Trawl survey of hoki and middle depths species on the Chatham Rise, January 2000 (TAN0001). *NIWA Technical Report 104*. 55 p.

Stevens, D.W.; Livingston, M.E.; Bagley, N.W. (2002). Trawl survey of hoki and middle depths species on the Chatham Rise, January 2001 (TAN0101). *NIWA Technical Report 116*. 61 p.

Stevens, D.W.; Livingston, M.E. (2003). Trawl survey of hoki and middle depths species on the Chatham Rise, January 2002 (TAN0201). *New Zealand Fisheries Assessment Report 2003/19*. 57 p.

Stevens, D.W.; O'Driscoll, R.L.(2006). Trawl survey of hoki and middle depths species on the Chatham Rise, January 2005 (TAN0501). *New Zealand Fisheries Assessment Report 2006/13*. 73 p.

Stevens, D.W.; O'Driscoll, R.L.(2007). Trawl survey of hoki and middle depths species on the Chatham Rise, January 2006 (TAN0601). *New Zealand Fisheries Assessment Report 2007/5*. 73 p.

Stevens, D.W.; O'Driscoll, R.L.; Gauthier, S. (2008). Trawl survey of hoki and middle depths species on the Chatham Rise, January 2007 (TAN0701). *New Zealand Fisheries Assessment Report 2008/52*. 81 p.

Stevens, D.W.; O'Driscoll, R.L.; Horn, P.L. (2009). Trawl survey of hoki and middle depths species on the Chatham Rise, January 2008 (TAN0801). *New Zealand Fisheries Assessment Report 2009/18*. 86 p.

Stevenson, M.L. (2007). Inshore trawl survey of the west coast of the South Island and Tasman and Golden Bays, March–April 2007 (KAH0704). *New Zealand Fisheries Assessment Report 2007/41*. 64 p.

Stevenson, M.L.; Beentjes, M.P. (2002). Inshore trawl survey of the Canterbury Bight and Pegasus Bay, December 2000–January 2001. *NIWA Technical Report 112*. 97 p.

Stevenson, M.L.; Hanchet, S.M. (2000). Review of the inshore trawl survey series off the west coast South Island, and Tasman and Golden Bays, 1992–97. *NIWA Technical Report 82*. 79 p.

Stevenson, M.L.; Hanchet, S.M. (2007). Inshore trawl survey of the west coast of the South Island and Tasman and Golden Bays, March–April 2007 (KAH0704). *New Zealand Fisheries Assessment Report 2007/41*. 64 p.

Vignaux M. (1997). CPUE analyses for stocks in the Adaptive Management Programme. New Zealand Fisheries Assessment Research Document 1997/24: 68 p. (Unpublished report held in NIWA library, Wellington)

Watson, T.; McKenzie, I.; Hartill, B. (2005).Catch per unit effort analysis of the northern (GMU 1) grey mullet *(Mugil cephalus)* setnet fishery, 1989–2002. *New Zealand Fisheries Assessment Report 2009/22*. 36 p.

Webb, B.F. (1973). Fish populations of the Avon-Heathcote Estuary. 5. Records of less common species. *New Zealand Journal of Marine and Freshwater Research 7*: 307–321.

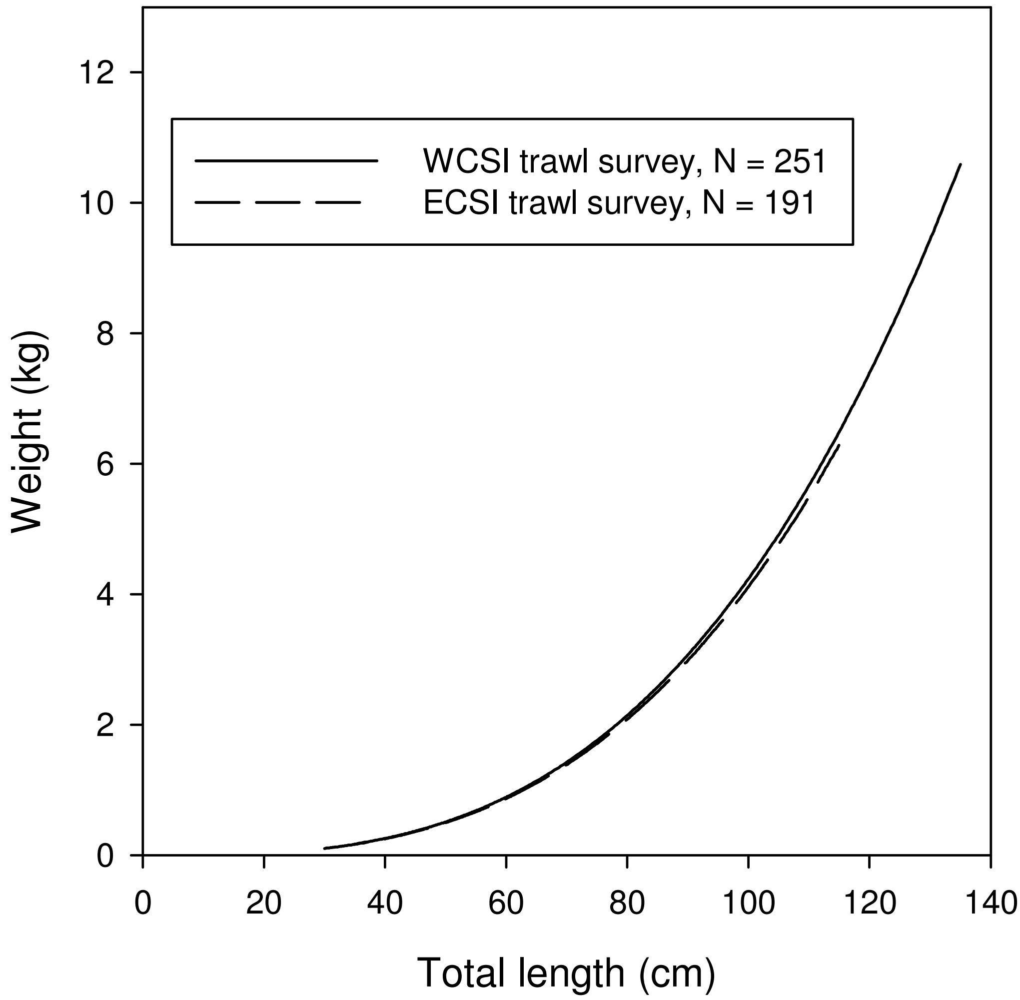

Figure 1: Length-weight regression relationships for rig sampled from SPO 3 (ECSI trawl survey) and SPO 7 (WCSI trawl survey). Source: MFish *trawl* database.

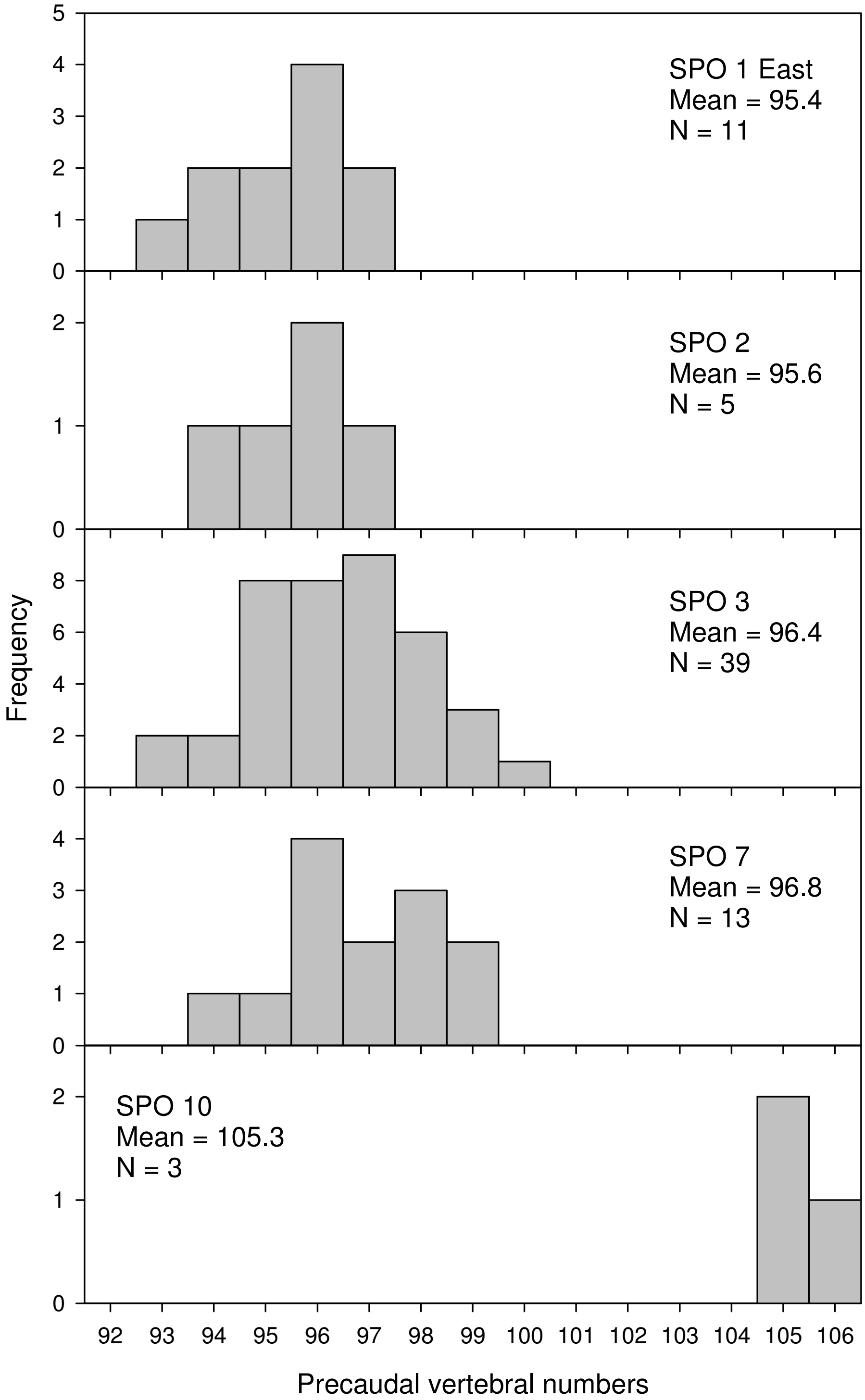

Figure 2: Precaudal vertebral counts for rig sampled from various QMAs around New Zealand.

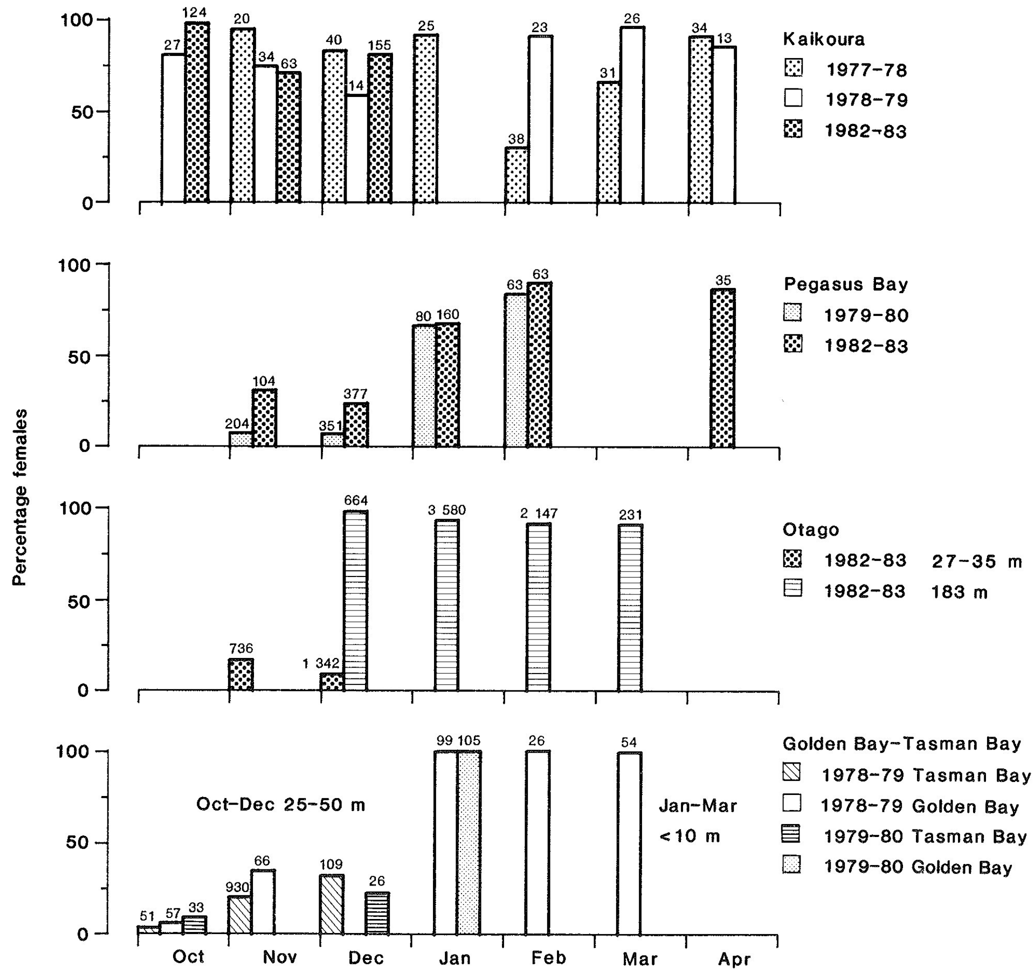

Figure 3: Seasonal and spatial trends in the sex ratio of rig from set net catch samples (160–180 mm mesh set nets combined). After Francis & Smith (1988).

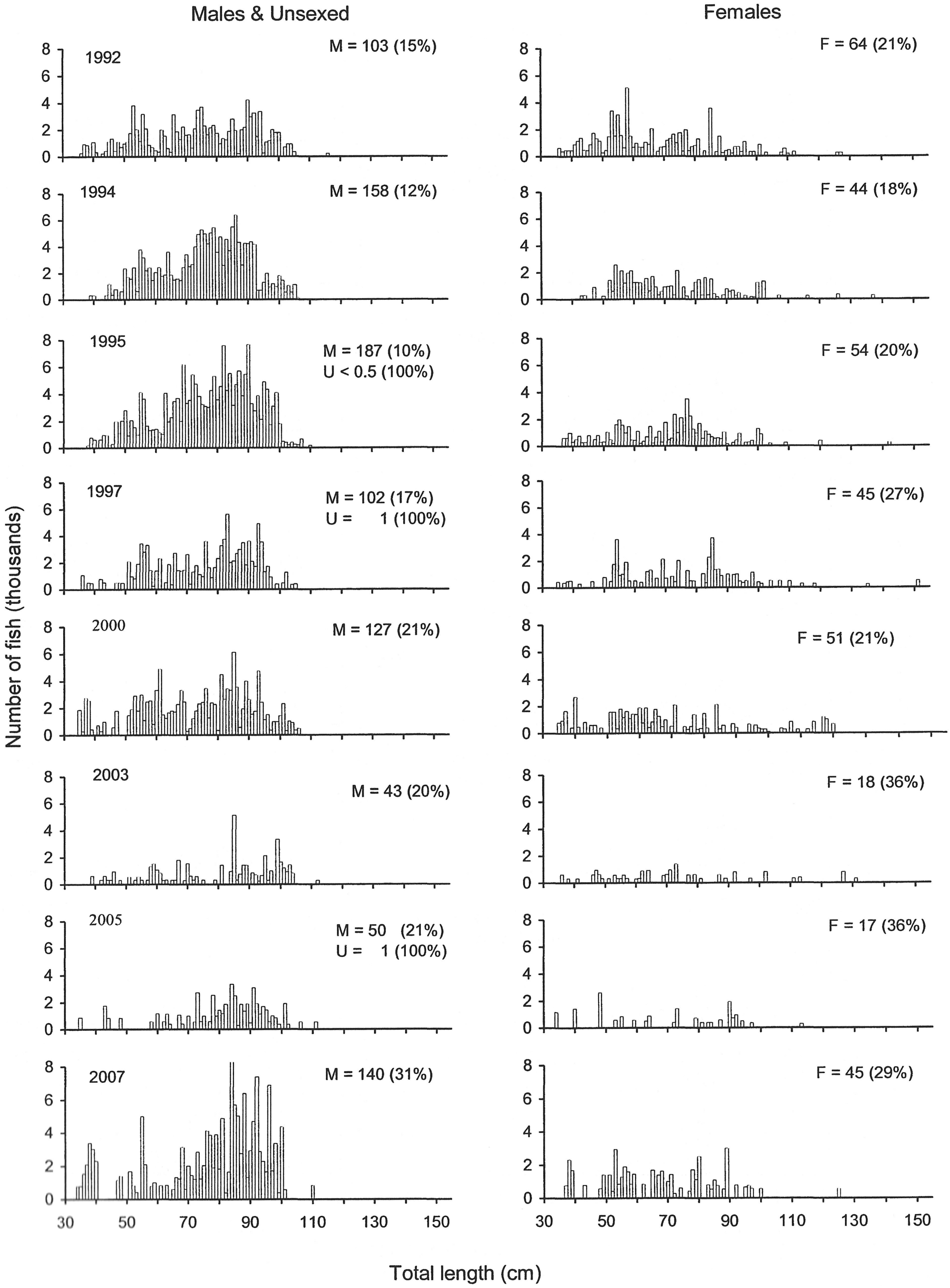

Figure 4: Scaled length frequency distributions for rig from the 1992–2007 WCSI trawl survey series. Population estimates are in thousands of fish. M, number of males; F, number of females; U, unsexed; ( ), c.v. After Stevenson (2007).

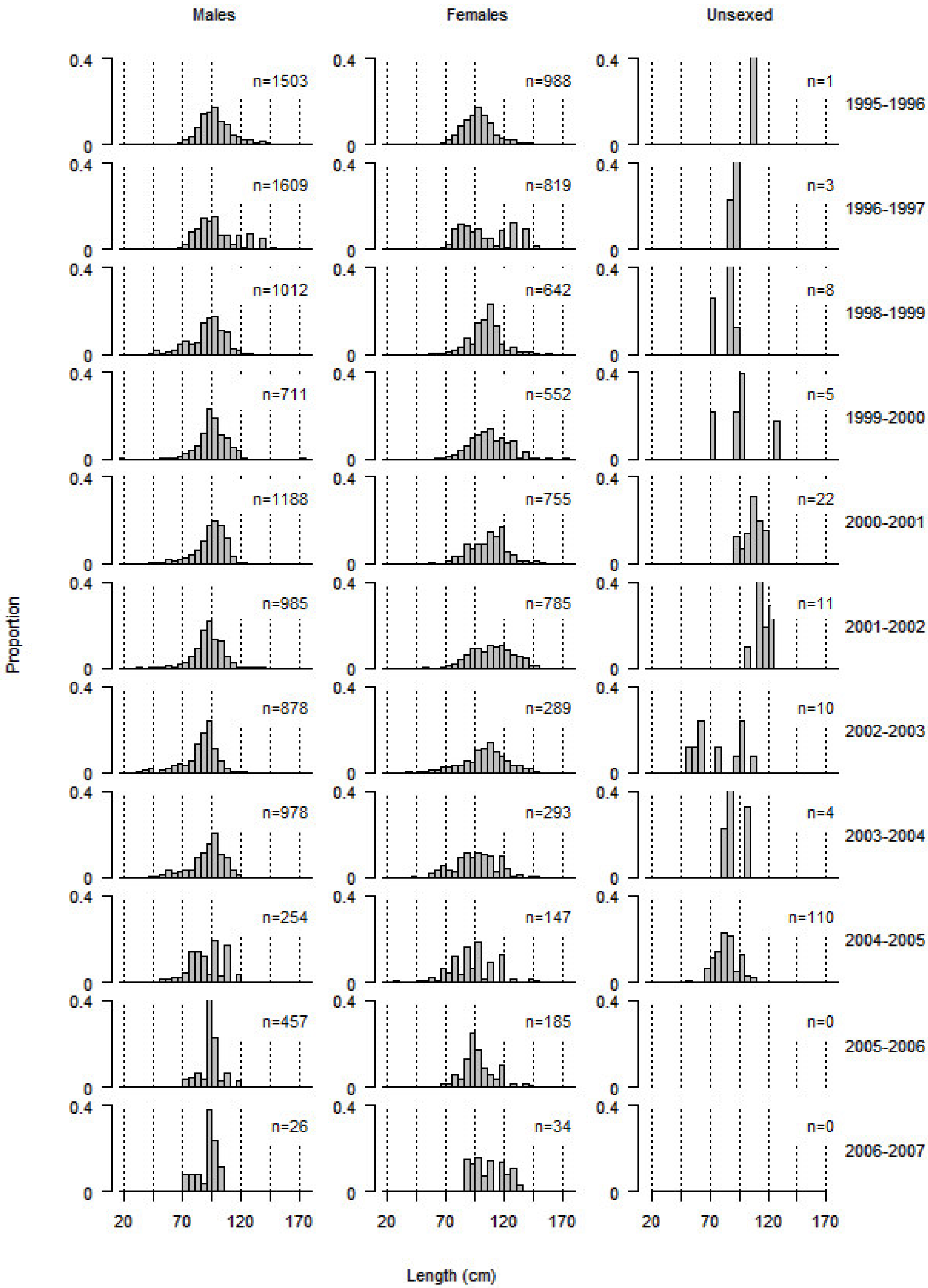

Figure 5: Scaled length frequency distributions for male and female rig sampled from the SPO 3 shark set net fishery. Length data have been binned into 5 cm length classes. Sample sizes by sex are provided and sampled fish have been scaled relative to the MFish estimated catch by month and statistical area. The combined male and female distributions sum to one. After Starr et al. (2008).

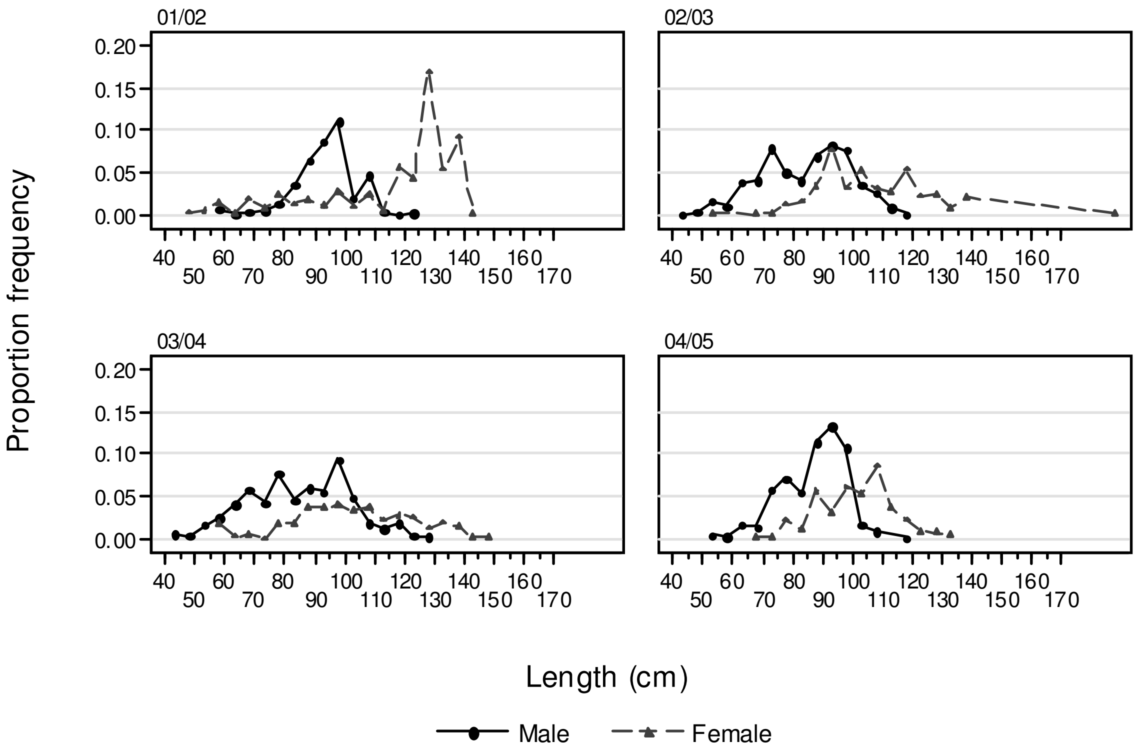

Figure 6: Scaled length frequency plots by sex for rig (SPO 7) in the west coast South Island set net fishery for 2001–02 to 2004–05. The logbook data have been scaled to the sample weights. Length frequencies have been binned in 5 cm length classes. After Starr et al. (2006).

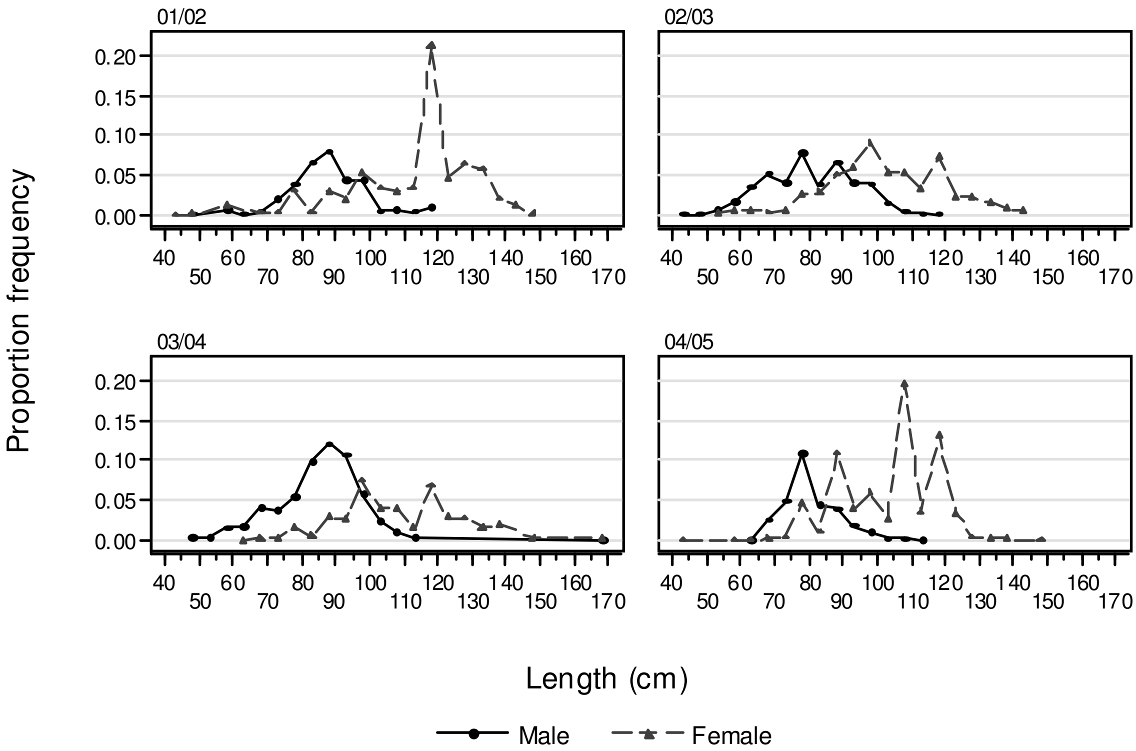

Figure 7: Scaled length frequency plots by sex for rig (SPO 7) in the Area 038 (Tasman and Golden bays) set net fishery for 2001–02 to 2004–05. The logbook data have been scaled to the sample weights. Length frequencies have been binned in 5 cm length classes. After Starr et al. (2006).

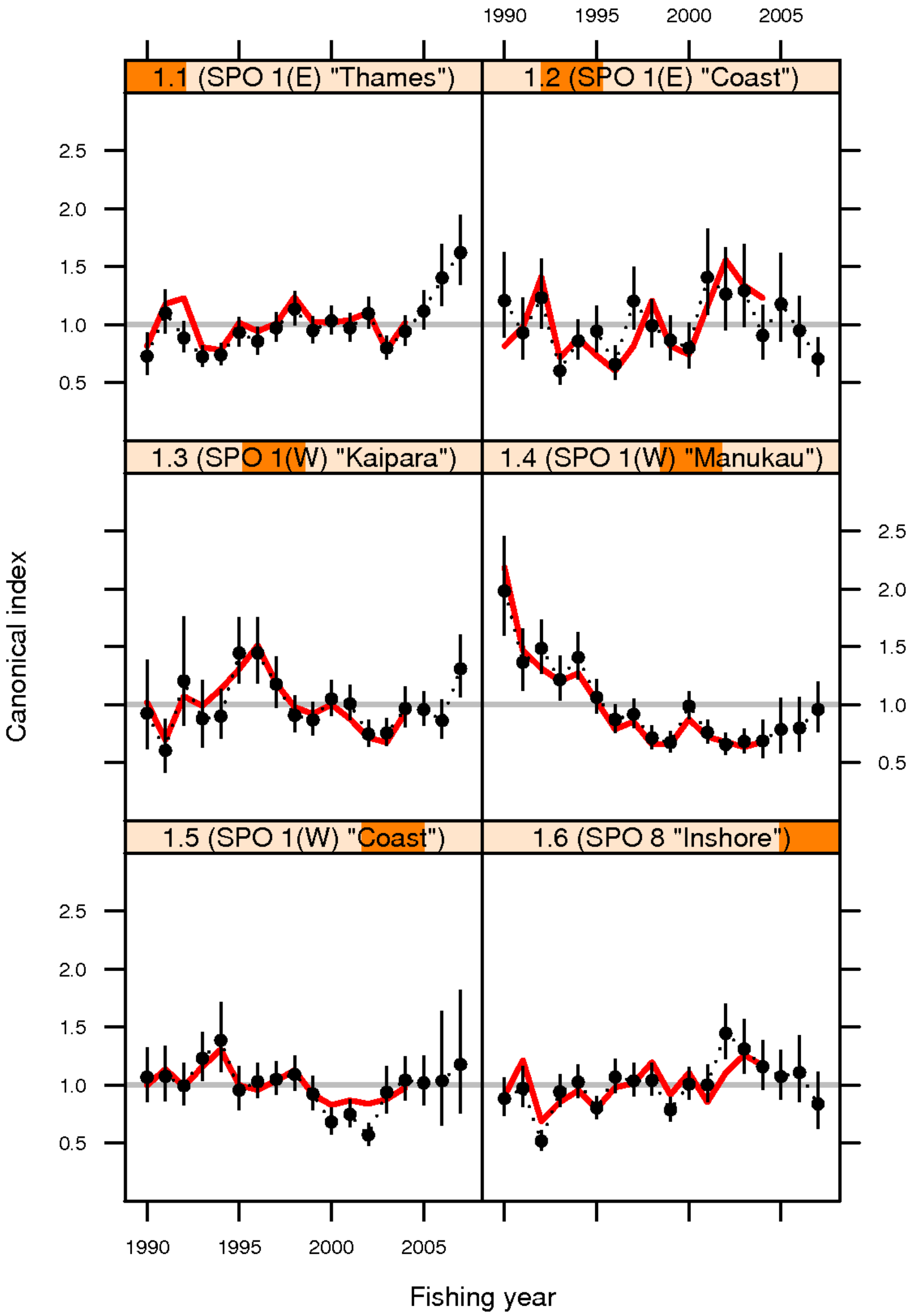

Figure 8: Standardised CPUE indices, based on non-zero, core-vessel set net catches (calculated green weight) for SPO 1 and 8 (Manning unpublished results). Error bars represent 95% confidence intervals and the solid line represents the previous indices from Blackwell et al. (2006).

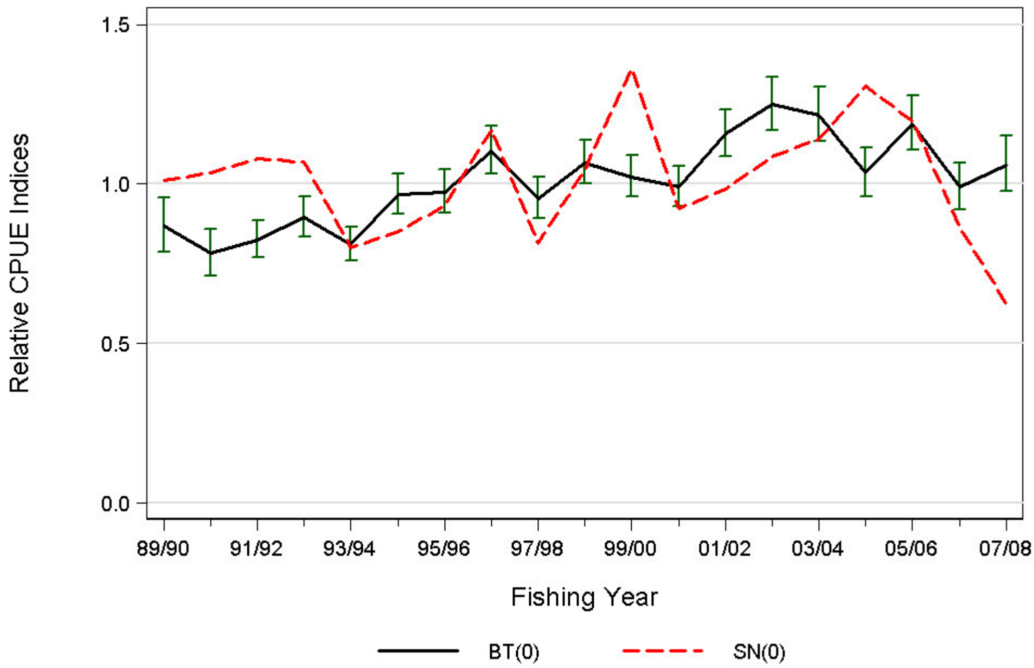

Figure 9: Plot of standardised CPUE models for SPO 2 for rig bycatch in bottom trawl fishing (solid line), and rig target and bycatch in set nets (dashed line). Each series is scaled so that the geometric mean = 1. After Starr & Kendrick (2009).

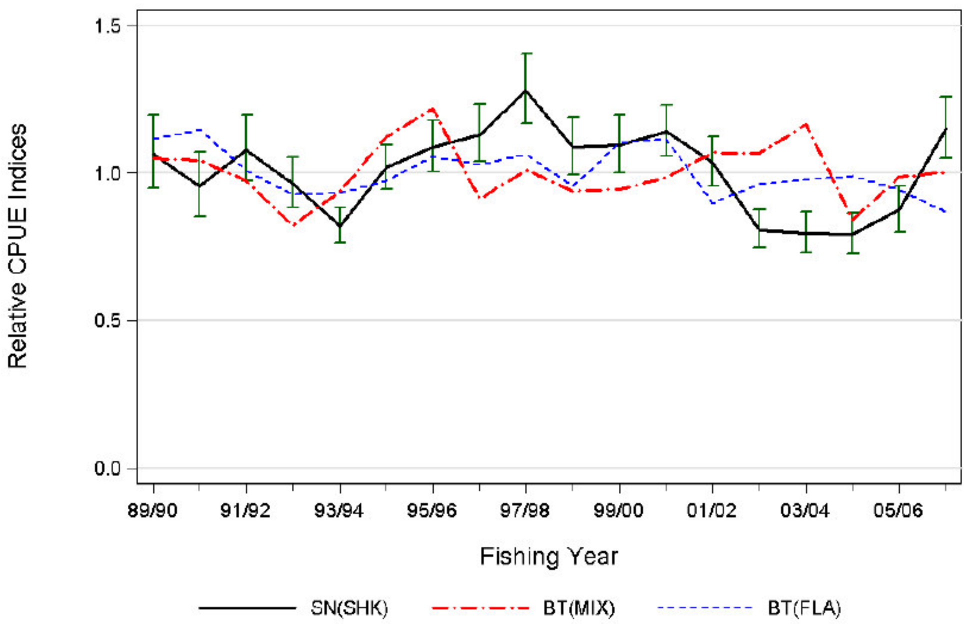

Figure 10: Lognormal standardisation of non-zero set net catches in SPO 3. Each series is scaled so that the geometric mean = 1. SN[SHK]: target shark species setnet fishery; BT[MIX]: mixed target species bottom trawl fishery; BT[FLA]: target flatfish bottom trawl fishery. Source Starr et al. (2008).

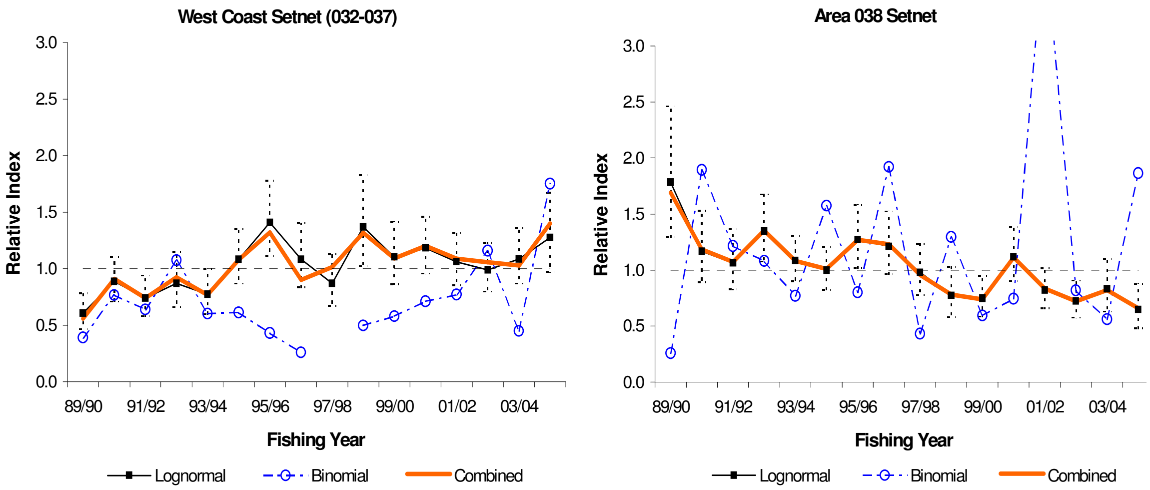

Figure 11: Plot of two standardised CPUE models for SPO 7: [left panel] the west coast South Island set net fishery and [right panel] the Area 038 (Tasman and Golden bays) set net fishery showing a lognormal model using non-zero landings as the dependent variable (with associated 95% lognormal error bars); a binomial (logistic) model using a binary variable indicating a successful or zero catch of rig; and a combined model which summarises the two sets of indices into a single trajectory. Source Starr et al. (2006).

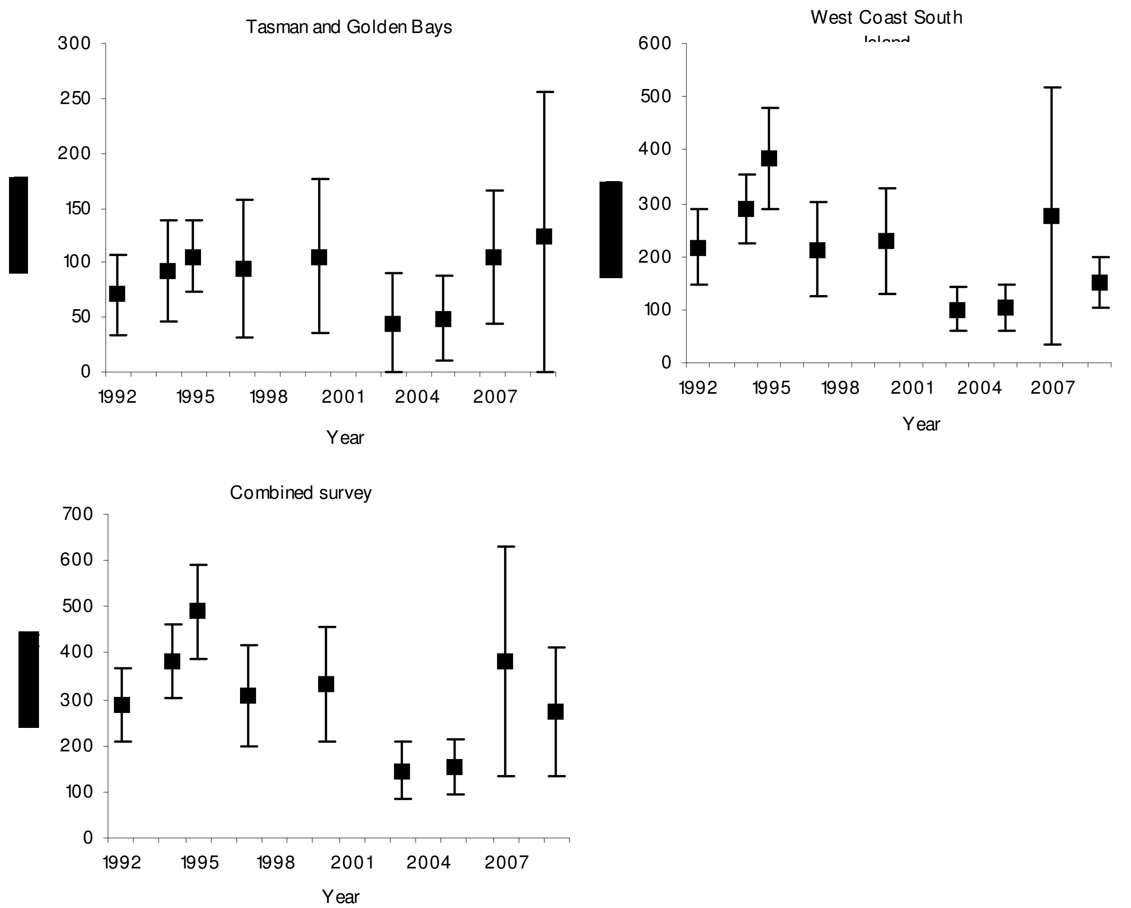

Figure 12: Plots of SPO 7 biomass estimates (t) for rig from Tasman and Golden bays strata (area 038), west coast South Island strata, and the combined WCSI survey by year. Error bars are approximated from the c.v.s assuming a lognormal distribution. After Starr et al. (2006), M.L. Stevenson (NIWA), unpublished data.

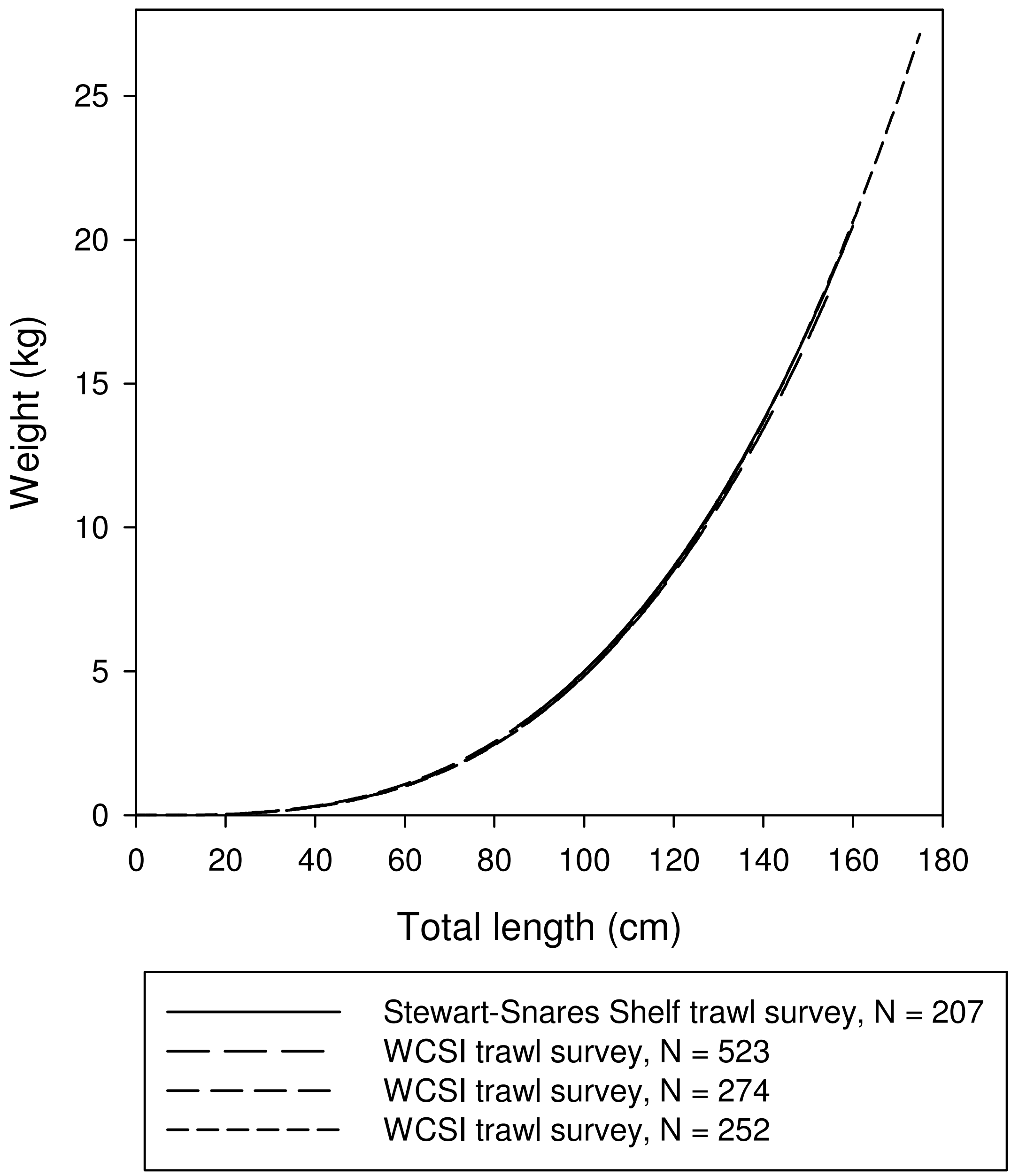

Figure 13: Length-weight regression relationships for school shark sampled from SCH 5 (Stewart–Snares Shelf trawl survey) and SCH 7 (WCSI trawl survey). Source: MFish *trawl* database.

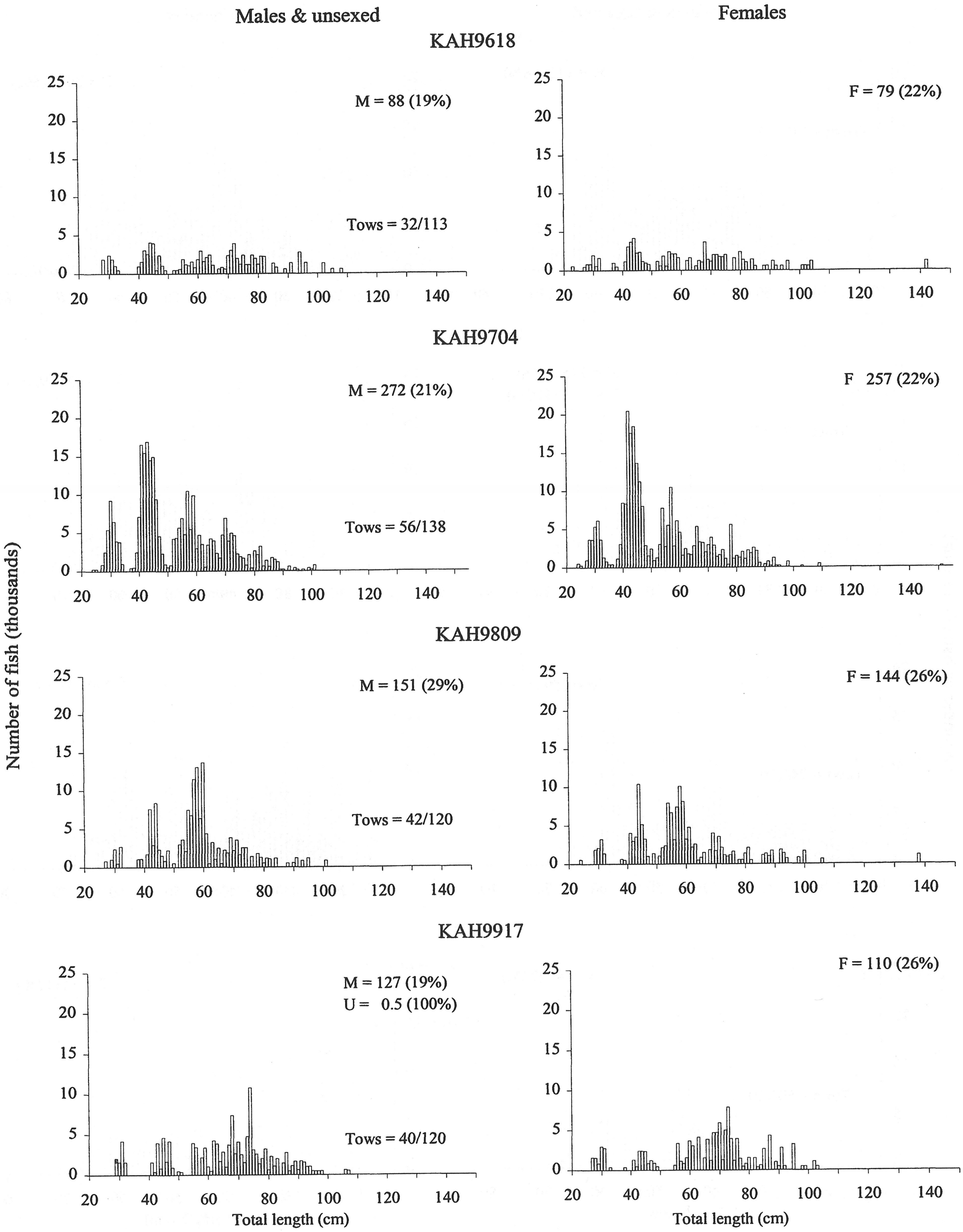

Figure 14: Scaled length frequency distributions for school shark from the 1996–99 ECSI summer trawl survey series. Population estimates are in thousands of fish. M, number of males; F, number of females; U, unsexed; ( ), c.v. After Beentjes & Stevenson (2001).

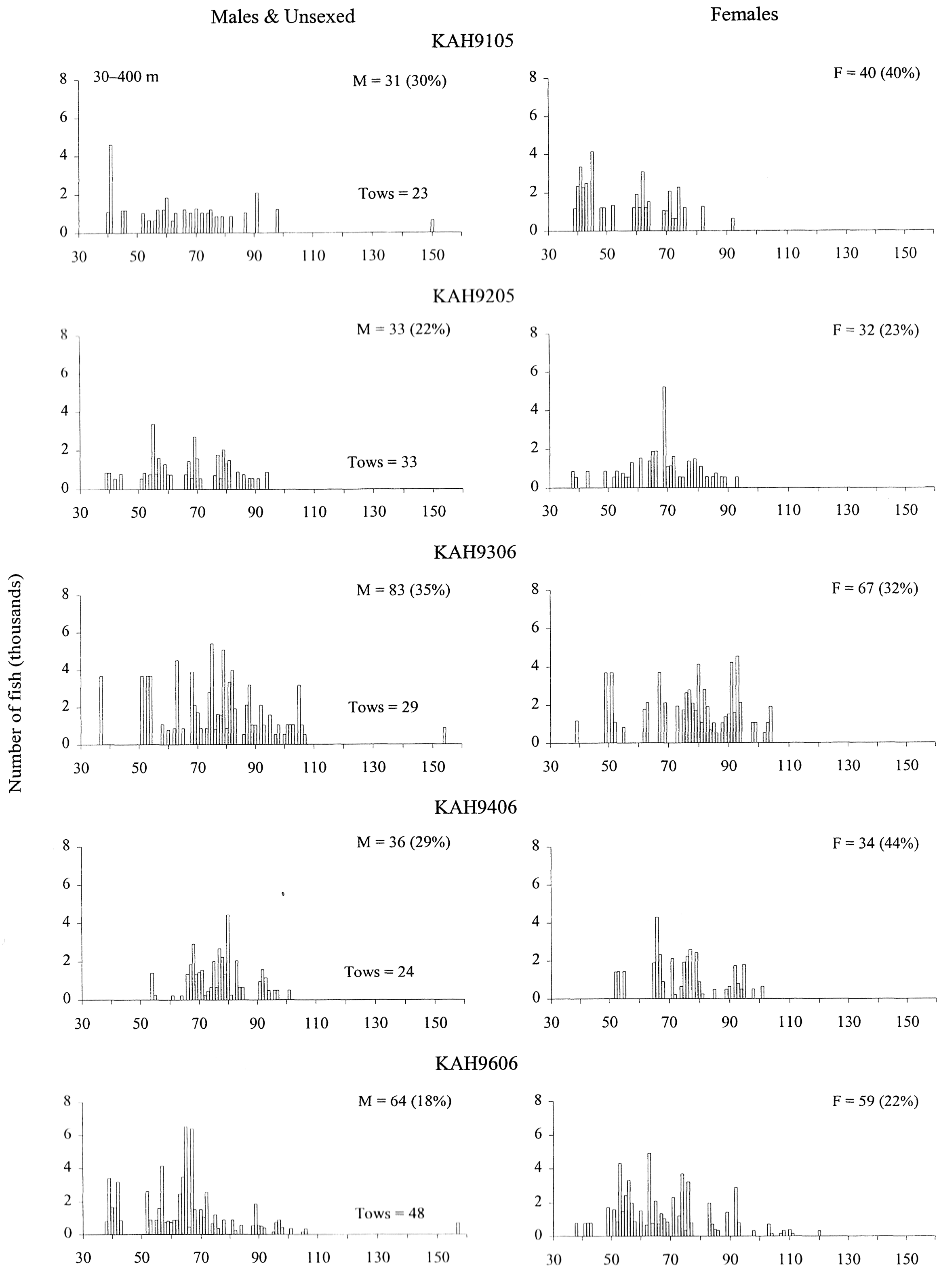

Figure 15: Scaled length frequency distributions for school shark from the 1991–96 ECSI winter trawl survey series. Population estimates are in thousands of fish. M, number of males; F, number of females; U, unsexed; ( ), c.v. After Beentjes & Stevenson (2000).

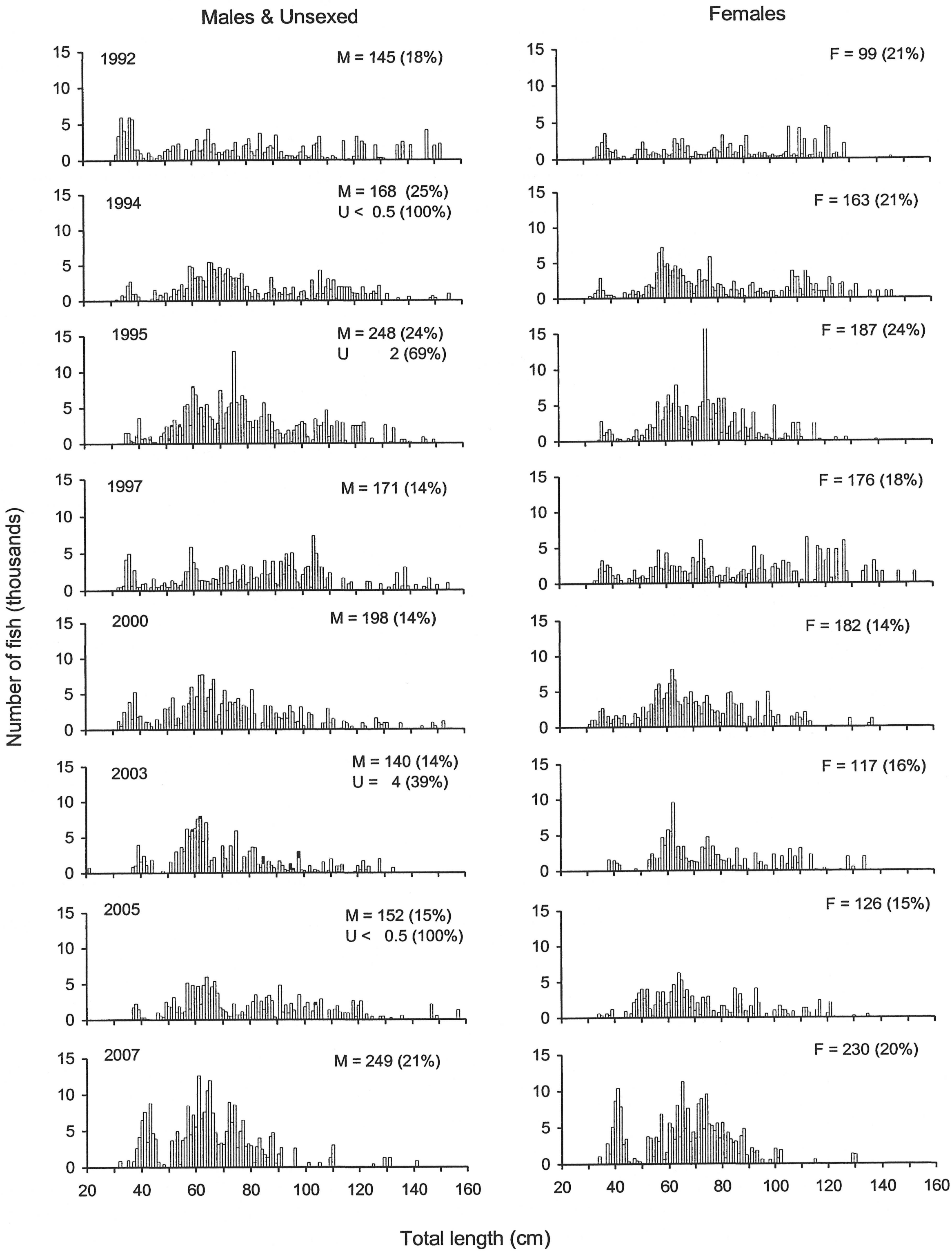

Figure 16: Scaled length frequencies for school shark from the WCSI summer trawl survey series 1992–2007. Estimated population in thousands and c.v.%. (M, males; F, females; U, unsexed). After Stevenson (2007).

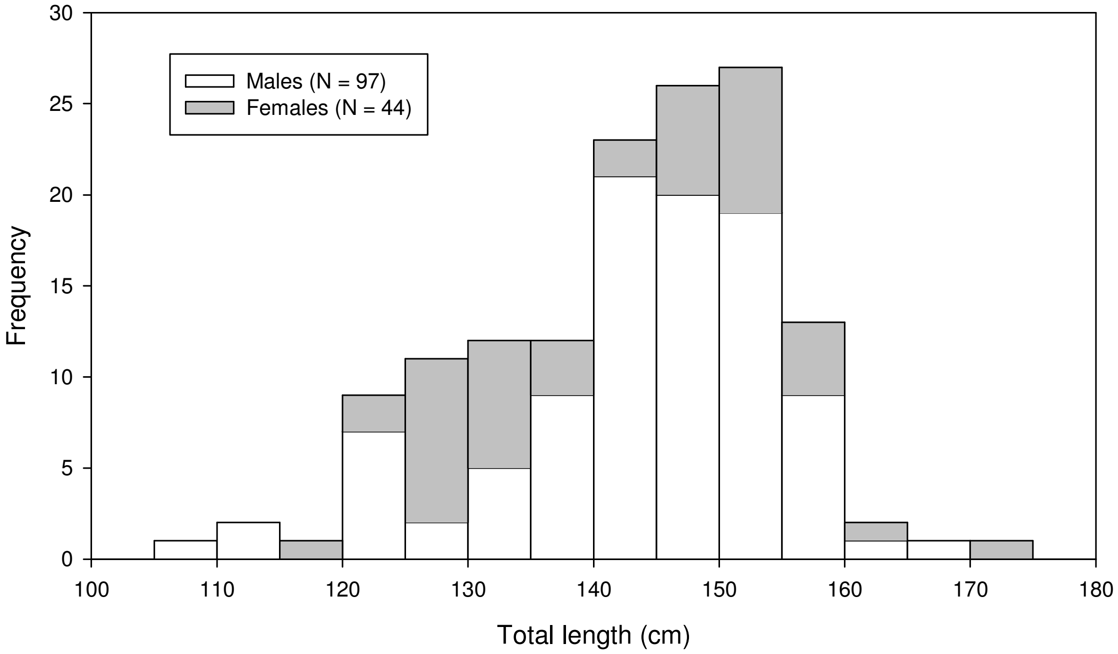

Figure 17: Unscaled length frequency distributions for school shark from the 1998–2009 Chatham Rise trawl survey series. Data from MFish *trawl* database.

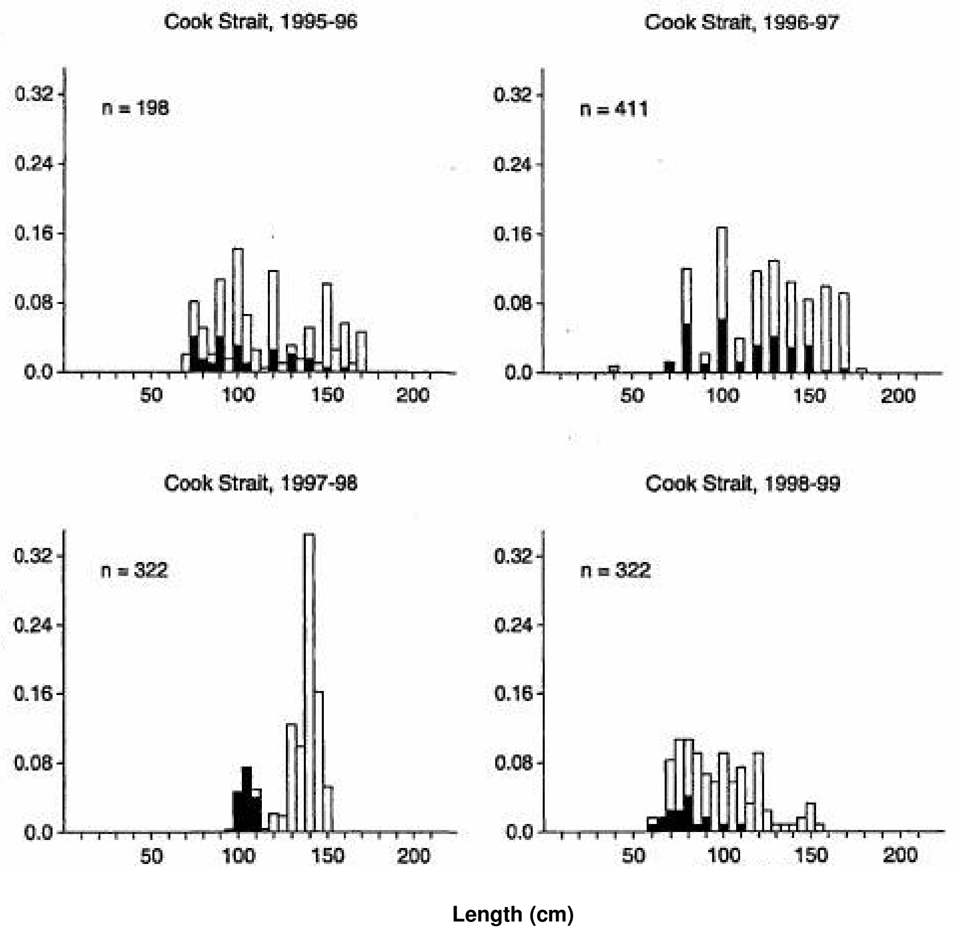

Figure 18: Length frequency of school shark measured in the set net logbook programme in the Cook Strait region (SCH 2) defined by Paul & Sanders (2001). n, numbers of fish; black bars, males; white bars females.

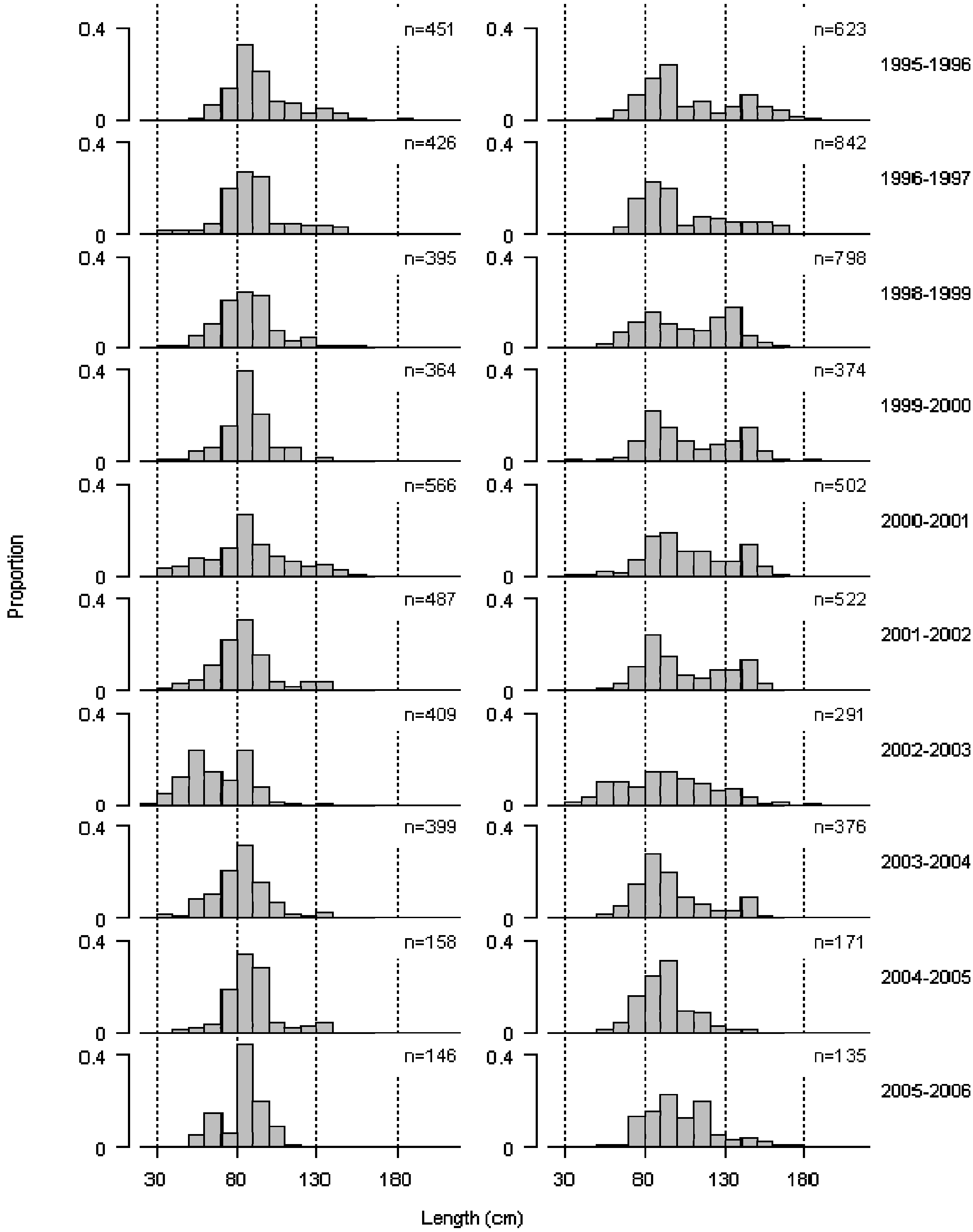

Figure 19: Scaled frequency distributions for male and female school shark sampled from the target shark SCH 3 set net fishery. Length data have been binned into 5 cm length classes. Sample sizes by sex are provided and sampled fish have been scaled relative to the MFish estimated catch by month and statistical area. The combined male and female distributions sum to one. After Starr et al. (2007b).

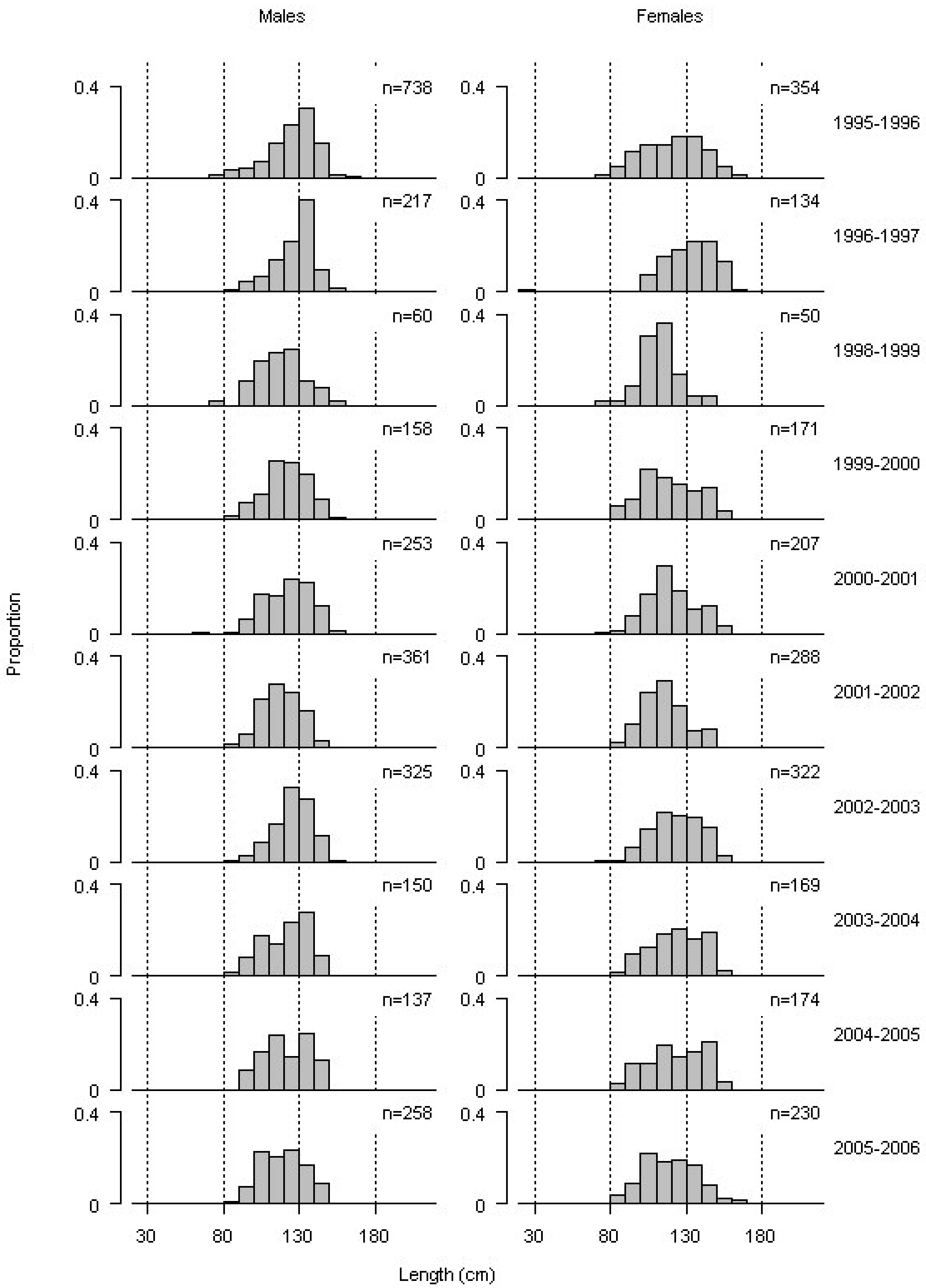

Figure 20: Scaled frequency distributions for male and female school shark sampled from the target shark SCH 5 set net fishery. Length data have been binned into 5 cm length classes. Sample sizes by sex are provided and sampled fish have been scaled relative to the MFish estimated catch by month and statistical area. The combined male and female distributions sum to one. After Starr et al. (2007c).

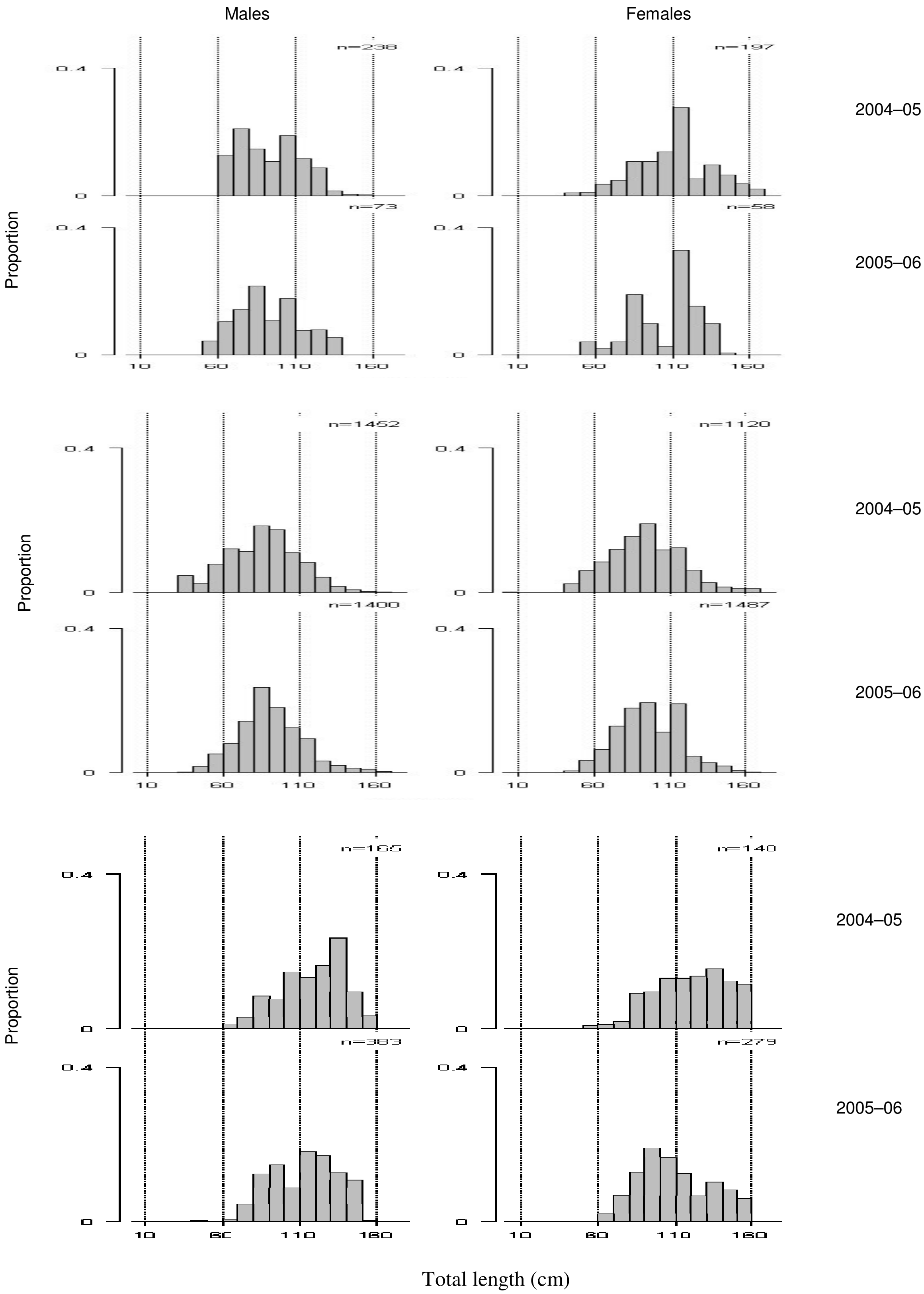

Figure 21: Scaled frequency distributions for male and female school shark sampled from (upper), the SCH 7 set net fishery, (mid) bottom trawl fishery, (lower), longline fishery. Length data have been binned into 5 cm length classes. Sample sizes by sex are provided and sampled fish have been scaled relative to the MFish estimated catch by month and statistical area. The combined male and female distributions sum to one. After Starr et al. (2007d).

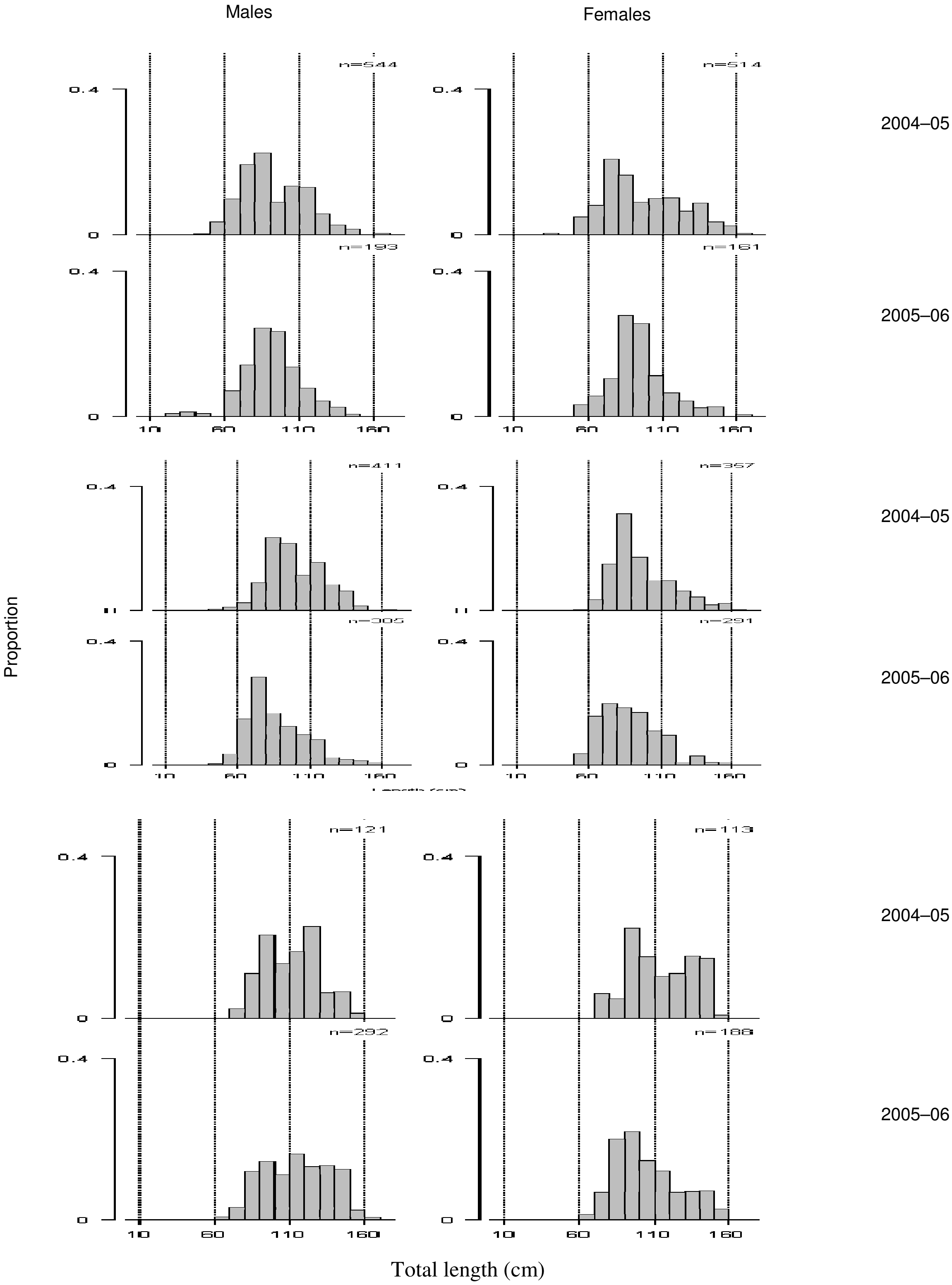

Figure 22: Scaled frequency distributions for male and female school shark sampled from the upper) SCH 8 set net fishery, (mid) bottom trawl fishery, (lower) bottom longline fishery. Length data have been binned into 5 cm length classes. Sample sizes by sex are provided and sampled fish have been scaled relative to the MFish estimated catch by month and statistical area. The combined male and female distributions sum to one. After Starr et al. (2007e).

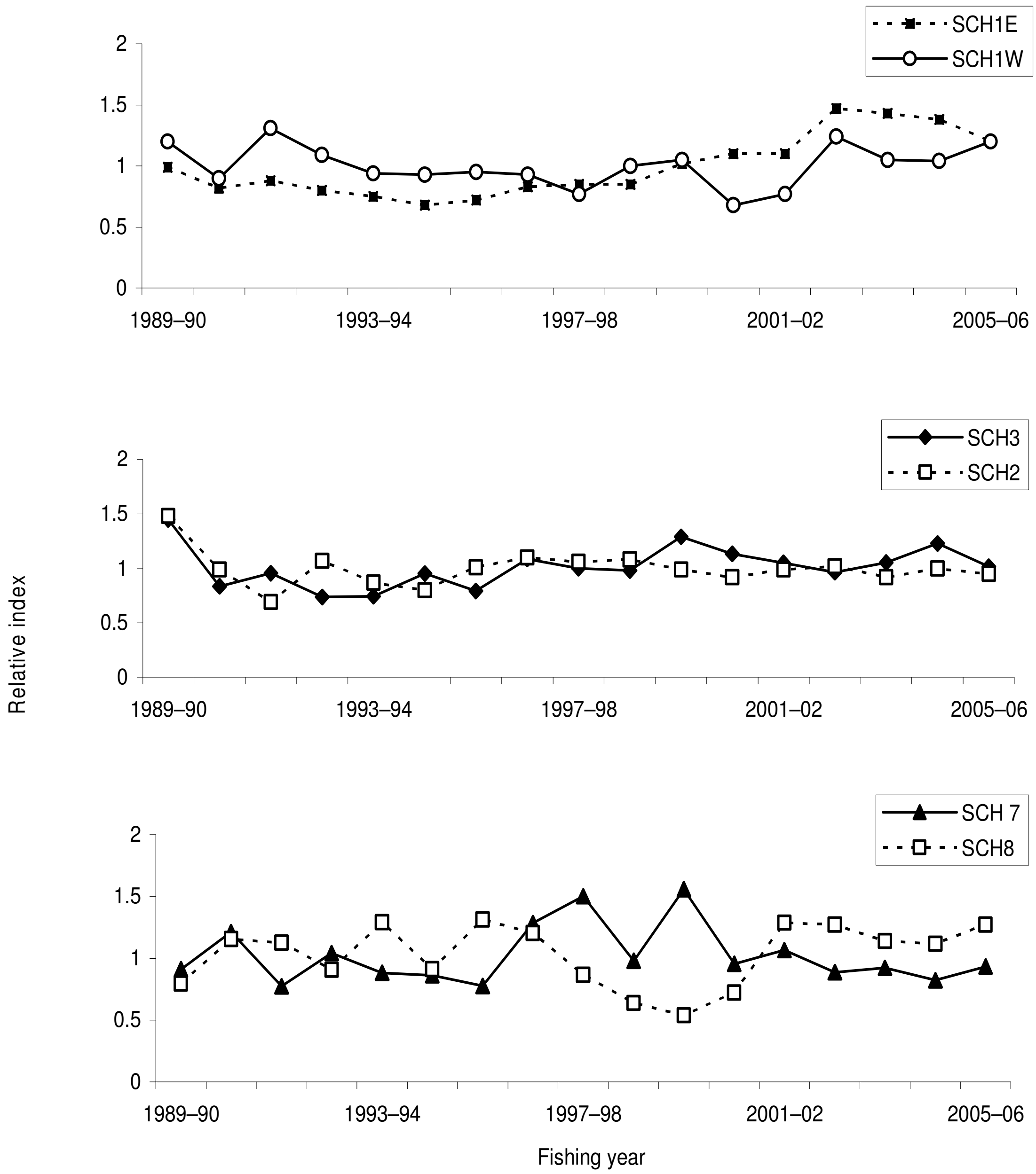

Figure 23: Standardised CPUE indices for selected school shark stocks, 1989–90 to 2005–06. After Starr et al. (2007b, d, e) and Manning et al. (unpublished results).

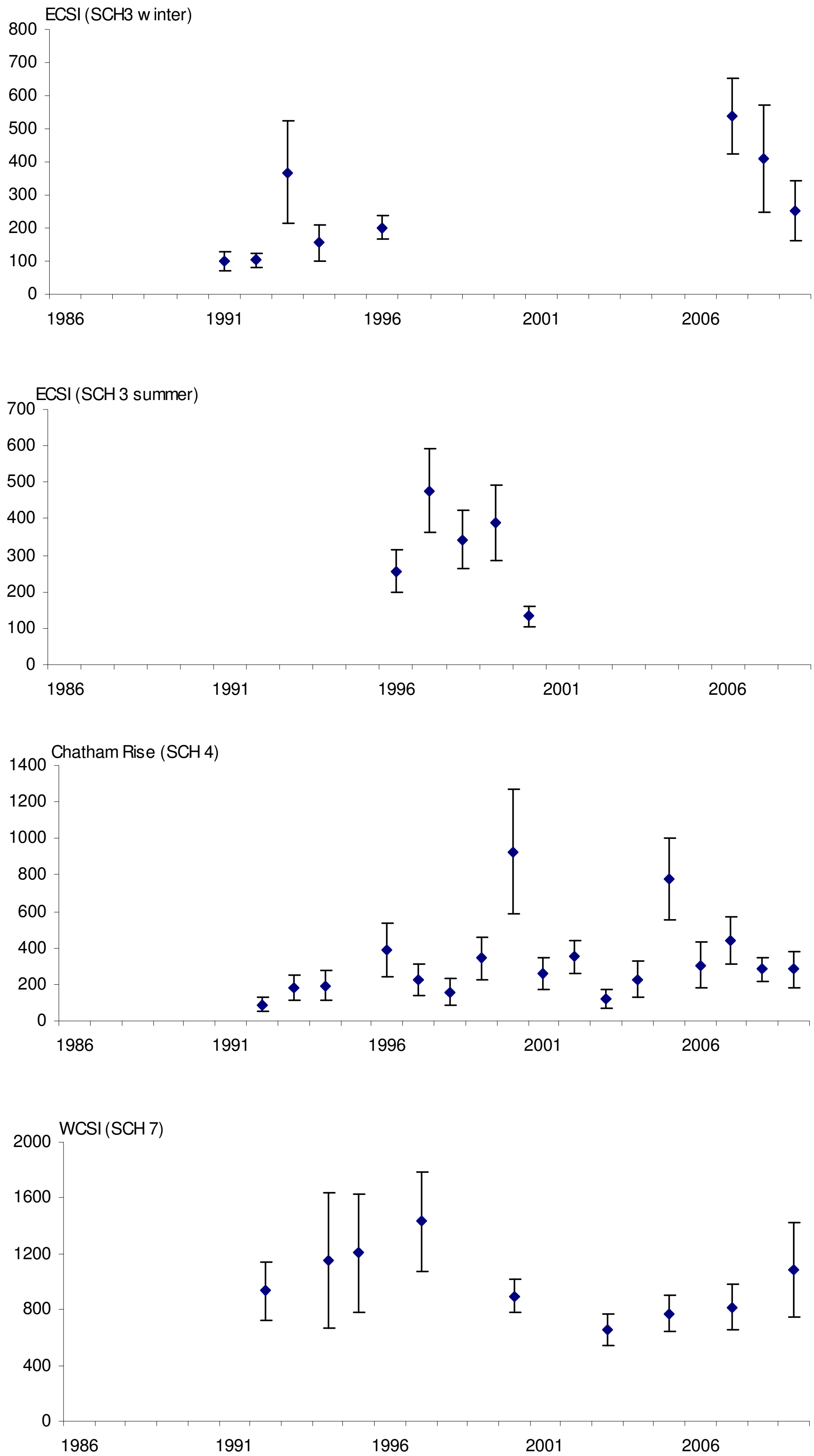

Figure 24: Trawl survey relative biomass estimates (t) and c.v.s of for school shark. After Beentjes & Stevenson (2000, 2001, 2008), Stevenson & Beentjes (2002), Stevenson & Hanchet (2000, 2007), Livingston et al. (2003), Stevens et al. (2001, 2002, 2008, 2009), Stevens & Livingston (2003), Livingston & Stevens (2005), Stevens & O'Driscoll (2006, 2007), NIWA unpublished data.

Appendix

Table A1: Number of length frequencies by sex and fishing year for rig from the set net logbook programme in SPO 3. The percentage male and the mean length by sex have been scaled relative to the MFish QMR catch by month and statistical area. After Starr et al. (2007a).

Fishing Year	Number Male	Number Female	Number Unsexed	Total Sampled	Male Percent	Male Mean (cm)	Female Mean (cm)
94/95	49	29	0	78	60	90.6	91.8
95/96	1503	988	1	2492	57	102.5	103.0
96/97	1609	819	3	2431	64	102.9	106.4
97/98	55	28	0	83	66	101.4	103.9
98/99	1012	642	8	1662	56	95.3	107.8
99/00	711	552	5	1268	50	99.4	110.6
00/01	1188	755	22	1965	53	97.8	110.6
01/02	985	785	11	1781	50	95.1	112.8
02/03	878	289	10	1177	71	90.0	107.0
03/04	978	293	4	1275	76	94.8	98.9
04/05	254	147	110	511	60	93.0	95.9
05/06	457	185	0	642	71	97.3	100.8
06/07	26	34	0	60	42	95.3	110.0
All years	9705	5546	174	15425	60	97.6	107.0

Table A2: Number of rig measured, proportion males and scaled median length (cm) of rig in SPO 7 obtained by the set net logbook programme from 2001–02 to 2004–05. Logbook data have been scaled to the sample weights. After Starr et al. (2006).

Fishing year	Number of lengths			Male percent	Median length (cm)		
	M	F	Total		M	F	Total
01/02	1 215	1 505	2 720	45	91	120	101
02/03	1 074	998	2 072	52	84	103	93
03/04	1 290	748	2 038	63	87	105	92
04/05	1 341	1 414	2 755	49	85	108	94
Total	4 920	4 665	9 585	51	87	110	95

Table A3: Number of length frequencies by sex and fishing year for school shark from the set net logbook programme in SCH 3. The percentage male and the mean length by sex have been scaled relative to the MFish QMR catch by month and statistical area. After Starr et al. 2007b.

Fishing Year	Number Male	Number Female	Total Sampled	Male Percent	Male Mean (cm)	Female Mean (cm)
94/95	22	14	36	59	91.1	96.1
95/96	451	623	1074	42	102.2	114.9
96/97	426	842	1268	36	98.6	110.6
97/98	5	3	8	62	103.6	95.0
98/99	395	798	1193	32	95.0	115.4
99/00	364	374	738	50	96.0	116.8
00/01	566	502	1068	54	96.7	116.2
01/02	487	522	1009	49	93.4	114.3
02/03	409	291	700	59	77.1	102.6
03/04	399	376	775	51	91.1	104.8
04/05	158	171	329	48	95.2	98.5
05/06	146	135	281	51	92.2	109.0
All years	3828	4651	8479	46	93.4	112.0

Table A4: Number of length frequencies by sex and fishing year for school shark from the set net logbook programme in SCH 5. The percentage male and the mean length by sex have been scaled relative to the MFish QMR catch by month and statistical area. After Starr et al. 2007c.

Fishing Year	Number Male	Number Female	Total Sampled	Male Percent	Male Mean (cm)	Female Mean (cm)
95/96	738	354	1092	67	134.4	129.7
96/97	217	134	351	63	136.4	140.5
98/99	60	50	110	56	127.7	122.3
99/00	158	171	329	50	130.4	128.4
00/01	253	207	460	55	131.2	128.7
01/02	361	288	649	58	127.3	125.1
02/03	325	322	647	53	135.0	132.4
03/04	150	169	319	49	131.1	132.4
04/05	137	174	311	46	131.9	132.2
05/06	258	230	488	56	129.2	128.4
All years	2657	2099	4756	57	132.0	130.0

Table A5: Number of length frequencies by sex and fishing year for school shark from the logbook programmes for three fishing methods in SCH 7. The percentage male and the mean length by sex have been scaled relative to the MFish QMR catch by month and statistical area. After Starr et al. (2007d).

Fishing Year	Number Male	Number Female	Total Sampled	Male Percent	Male Mean (cm)	Female Mean (cm)
Set net						
04/05	238	197	435	59	100.8	118.0
05/06	73	58	131	54	102.3	115.6
All years	311	255	566	58	101.2	117.0
Bottom trawl						
04/05	1452	1120	2572	56	93.1	101.5
05/06	1400	1487	2887	48	97.8	102.8
All years	2852	2607	5459	52	95.1	102.0
Longline						
04/05	165	140	305	54	127.1	129.0
05/06	383	279	662	57	121.1	117.8
All years	548	419	967	56	123.3	122.0

Table A6: Number of length frequencies by sex and fishing year for school shark from the logbook programmes for three fishing methods in SCH 8. The percentage male and the mean length by sex have been scaled relative to the MFish QMR catch by month and statistical area. (After Starr et al. 2007e).

Fishing Year	Number Male	Number Female	Total Sampled	Male Percent	Male Mean (cm)	Female Mean (cm)
Set net						
04/05	544	514	1058	53	101.0	105.4
05/06	193	161	354	55	100.9	102.5
All years	737	675	1412	54	100.9	105.0
Bottom trawl						
04/05	411	357	768	52	107.2	104.4
05/06	305	291	596	49	94.7	95.8
All years	716	648	1364	50	101.1	100.0
Longline						
04/05	121	113	234	48	120.6	122.8
05/06	292	188	480	61	122.9	113.0
All years	413	301	714	57	122.3	117.0