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EXECUTIVE SUMMARY

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Data from the Ministry of Fisheries Observer Programme were used to quantify the extent of fish bycatch caught on tuna longlines in New Zealand waters during the 2000–01 and 2001–02 fishing years. These data provide information on which fish species appeared as bycatch, the catch per unit effort (CPUE) of the most common of these species, and estimates of total catch. Data were summarised according to geographical location (North and South regions), and by fleet (foreign and charter, or domestic). Biological data were analysed for some of the major bycatch species. The proportion of fish alive at recovery and the proportion that were discarded were estimated. The size, sex, maturity composition, and catch weight of blue shark, porbeagle shark, mako shark, and Ray's bream were also determined.

Total fishing effort continued to increase, with at least 9.3 million hooks set in 2000–01 and about 10.5 million in 2001–02. The increase was due to increased domestic effort.

Observer coverage (as a percentage of the total effort) was greatest on chartered Japanese vessels in southern waters (79–87%). Coverage of domestic vessels increased slightly over previous years, and increased in geographical range. Despite this, the observer coverage of domestic vessels is very low (2–3%), and may affect the veracity of some results.

The species most commonly recorded by observers in the tuna longline fishery were blue shark (*Prionace glauca*), albacore tuna (*Thunnus alalunga*), and Ray's bream (*Brama brama*). Catch per unit effort in 2000–01 and 2001–02 did not differ greatly from those of previous years, though there appears to be a decline in catch rates during recent years for most species. For all data from 1988–89 to 2001–02, catch rates for many species in the northern region were higher than in the southern region. Dealfish (*Trachipterus trachypterus*), deepwater dogfish species, and Ray's bream clearly showed the opposite trend. Catch rates for school shark (*Galeorhinus galeus*), mako shark (*Isurus oxyrinchus*), porbeagle shark (*Lamna nasus*), and blue shark were fairly consistent throughout both regions.

Total estimated catches for the three pelagic sharks were generally higher than previous estimates. Estimated catches of blue shark were 1478 t and 1969 t in 2000–01 and 2001–02, respectively. For porbeagle sharks, the estimated catch weights were 98 t and 76 t, and for makos, 694 t and 340 t for 2000–01 and 2001–02. Estimates of the total catch of Ray's bream were 9.5 t in 2000–01 and 31 t in 2001–02.

1. INTRODUCTION

It is well known that tuna longline fishing in New Zealand waters has an associated catch of non-targeted species (Francis et al. 2001, 2004). As an active member of the Ecologically Related Species Working Group under the Commission for the Conservation of Southern Bluefin Tuna, New Zealand has an obligation to produce estimates of the numbers of non-target fish species taken in the tuna longline fishery. A more general responsibility of the Ministry of Fisheries is to determine the effects of fishing on associated or dependent species taken as bycatch of normal fishing operations. To achieve these aims, analyses were undertaken on observer data and commercial fishing data from the tuna longline fishery. In addition, New Zealand is developing a National Plan of Action (NPOA) on sharks, as a result of an FAO initiative to improve the assessment and management of shark fisheries worldwide. Estimates of shark bycatch from tuna longline fisheries will be beneficial to the development of this NPOA.

Tuna longline fishing, while considered more environmentally sound than other fishing methods, often catches non-targeted species. Catch rates of these species tend to be low, though for some target species, areas, and seasons the catch rates can be high (Francis et al. 2000, 2001, 2004). Observers have recorded over 70 non-target fish species in the New Zealand Exclusive Economic Zone (EEZ), though only 12 species (or species groups) are commonly observed. Since 1988, the most commonly observed species has been blue shark (*Prionace glauca*). Albacore tuna (*Thunnus alalunga*), Ray's bream (*Brama brama*), southern bluefin tuna (*Thunnus maccoyii*), porbeagle shark (*Lamna nasus*), and dealfish (*Trachipterus trachypterus*) have been caught frequently as well. The other major species observed were (ordered by decreasing abundance) lancetfish (*Alepisaurus ferox* and *A. brevirostris*), moonfish (*Lampris guttatus*), oilfish (*Ruvettus pretiosus*), deepwater dogfish (several species of sharks of the order Squaliformes), swordfish (*Xiphias gladius*), butterfly tuna (*Gasterochisma melampus*), mako shark (*Isurus oxyrinchus*), rudderfish (*Centrolophus niger*), school shark (*Galeorhinus galeus*), bigeye tuna (*Thunnus obesus*), and yellowfin tuna (*Thunnus albacares*).

Some of the main bycatch species are oceanic sharks. Increased demand for shark fins has led to an increase in shark landings over the last few decades (Bonfil 1994, Hayes 1996, Stevens 2000). Oceanic sharks are vulnerable to overfishing, due to their generally low reproductive rates, long life spans and possibly slow growth, and their segregation by age and sex (Compagno 1990, Fogarty et al. 1989, Hoenig & Gruber 1990). This work should provide more information on the status of some of these shark populations.

Billfish species are commonly caught in longline fisheries targeting tuna. Bailey et al. (1996) reported that blue marlin was the most common bycatch species in the western tropical Pacific longline fishery, whereas short-billed spearfish predominate in Australia. In New Zealand, broadbill swordfish are caught commonly, and striped marlin are occasionally taken (Francis et al. 2004). Only swordfish can be retained by commercial fishers; the other billfish species must be returned to the water alive or dead. The policies pertaining to billfish species are of interest to both commercial and recreational fishers. Commercial fishers view the practice of dumping marlin as a waste of valuable resources, and have sought a change in regulation that allows them to keep dead marlin. Recreational fishers, however, are concerned about potential effects on the recreational striped marlin fishery, especially fishing effort that may target striped marlin. There is some support for their position, as a recent study showed that the commercial catch per unit effort (CPUE) is negatively correlated with the CPUE from the recreational fishery (Holdsworth et al. 2003). That study also suggested that a recent rise in recreational CPUE was directly attributable to the moratorium on the landing of marlin by commercial fishers.

The present study was carried out under Ministry of Fisheries research project ENV2002/01. The objective was to estimate the catch rates, quantity, and discards of non-target fish, particularly oceanic sharks, broadbill swordfish, and marlins, caught in the longline fisheries for tuna, using data from observers and commercial fishing returns for the 2000–01 and 2001–02 fishing years. This is the fourth study to examine this topic; the previous three were described by Francis et al. (1999, 2000, 2004). This study adds estimates for two additional years to the time series of catch rates and total catches for the major species of bycatch.

2. METHODS

2.1 Data sources

New Zealand tuna longline fishery data are available for 2000–01 and 2001–02 from two sources: commercial fishing data and observed fishing data. The commercial data are from the Tuna Longlining Catch Effort Returns (TLCER) and Catch Effort Landing Returns (CELR) that longline fishers are required to submit to the Ministry. These data are stored in a database (*tuna*) which is managed by NIWA for the Ministry of Fisheries. These returns underestimate bycatch because much of it is discarded at sea. Analyses and descriptions given here for the entire tuna longlining fleet are based on these data.

More reliable fish bycatch data are collected by Ministry of Fisheries observers and stored in the observer database (*l_line*), which is also managed by NIWA. These observed data represent a proportion of the total fishing effort. These data can be more comprehensive than the commercial data, as the observers sometimes record data on lengths, weights, and the sex of the bycatch. In addition, the accuracy of these data is often better than the commercial data, as the processed and discarded catches are recorded, as is the proportion of catch alive and dead on recovery.

2.2 Data treatment

Data from the observer database were obtained for the fishing years 2000–01 and 2001–2002. These data are the primary focus of the current analyses. Data for the fishing years 1988–89 to 1999–2000 were also extracted, for comparison and identification of long-term trends.

Three distinct fleets of vessels operated in New Zealand waters during this period: foreign licensed vessels (primarily Japanese), foreign vessels chartered by New Zealand companies, and domestic owner-operator vessels. The foreign licensed vessels fished the early part of this period, until the end of the 1994–95 fishing year. A New Zealand company began chartering foreign vessels in 1988–89, and this fleet has fished most years since. In 1988–89, domestic vessels became involved in the tuna longline fishery. These vessels had sporadic effort in the early part of the decade, but effort has increased steadily since then. In this study we use data from domestic vessels that fished since the 1994–95 fishing year.

In our analyses, the foreign and chartered vessels are grouped into a single fleet because they generally fished in similar areas with similar gear. Observer coverage of these fleets was low in early years, and combining them produces better coverage of the actual fishing effort. In addition, one large domestic vessel is included in this fleet for the analyses, because it fished with and used similar methods to the charter vessels. Throughout this report italics denote these specific groupings of vessels. Thus, the *foreign and charter* fleet is defined as the foreign and chartered vessels, plus one domestic vessel. The *domestic* fleet is defined as domestic vessels excluding the one that fished with the other group.

A geographical distinction is made in the analysis. Data were allocated to a north (N) region, a southwest (SW) region, or a southeast (SE) region (Figure 1). The north region was defined as being north of latitude 39° 30′ S on the west coast, and north of 43° 45′ S on the east coast. The southwest region was defined as being west of Cook Strait, south of 39° 30′ S, and west of 169° E at the southern end of the South Island. The southeast region definition follows. Of the different regional boundaries examined, this definition of region is the best when all years of data are included.

In 2000–01 and 2001–02, no *domestic* vessels were observed in either of the southern regions, and only three trips by *foreign and charter* vessels were observed in the north region (two of these consisted of only two sets at the end of a southern trip). This distribution of fishing effort is consistent with that in recent years, in which *foreign and charter* vessels have fished primarily in the south. The spread of the data in the most recent fishing years showed similar patterns to that in previous years, where most effort was expended in the southwest region. This indicated that we should continue to perform analyses on a single south region (i.e., southwest and southeast regions combined), but also examine any differences between the east and west effort.

This geographical distinction results in the data being partitioned into four strata, based on fleet and region, for use in the CPUE analyses. The use of these strata reduces within-stratum variances. Note, however, that some of these strata are necessarily small, and that the factors used in their construction are not independent.

It is also possible to stratify the data by season, as this could potentially affect the catch rates of certain species. Exploratory analyses suggested that the data are not distributed evenly enough for this to be of benefit, though general comments are made about seasonal effects.

One improvement in the current analysis over previous analyses is the inclusion of more accurate data on the number of observed hooks. Previously, analysis proceeded on the assumption that all hooks on an observed set were observed. More refined data have been obtained to allow estimation of the actual number of hooks observed on each set. Thus the number of hooks observed in each set is estimated from the proportion of the haul observed (based on the haul duration and time recorded as unobserved in the observer events logs) multiplied by the number of hooks set. The total catches and average catch rates (number of fish per 1000 hooks) are now estimated more accurately by the inclusion of this information. This correction has also been applied to the data from the fishing years 1988–89 to 1999–2000.

Exploratory analysis of the observer data for the two most recent fishing years indicated that there were problems with some length-weight data reported by one observer in 2001–02. The values recorded by this observer are considered unreliable. Thus, all the length-weight data reported by this observer from two *domestic* vessels (19 sets representing about 19 822 hooks) have been excluded from the length and weight analysis for 2001–02.

Identification of some species during the early years of the observer programme was unreliable (Francis et al. 2004). Species affected by this problem include mako and porbeagle sharks, and the two species of lancetfish. There do not appear to be any problems of this nature in the most recent two years' data. When data from earlier years are used, they are grouped according to the procedures identified in Francis et al. (2004).

2.3 Catch per unit effort analysis

Catch per unit effort was defined as the number of fish caught per 1000 hooks set. The basic unit of sampling was an individual set; a set i has information on the number of fish caught (c_i) and the amount of effort expended (where u_i is the number of hooks). As mentioned above, all hooks on a set may not be observed. In the calculation of CPUE we use the estimated number of observed hooks. For each of the major bycatch species, CPUE values were calculated for each fleet and geographical region in each fishing year. Some minor grooming of the data occurred before CPUE analyses were carried out. Observations were removed from the dataset if there were known problems associated with them.

Previous analyses have used a mean of ratios estimator (Equation 1), which defines a CPUE for each set, and then averages this over all observed sets to obtain a measure for the entire fishery. Following the suggestions of Bradford (2002), we now use a ratio of means estimator (Equation 2), which is commonly known as a ratio estimator. This defines CPUE as the average catch of the fishery per average effort of the fishery.

(1) $$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} c_i / u_i$$

(2) $$\hat{y} = \frac{\sum_{i=1}^{n} c_i / n}{\sum_{i=1}^{n} u_i / n} = \frac{\sum_{i=1}^{n} c_i}{\sum_{i=1}^{n} u_i}$$

The primary reason for this change is that the ratio of means estimator is less affected by large catch rates than the mean of ratios estimator. A more detailed discussion and comparison of these two estimators was presented by Bradford (2002).

Although the aim of this report is to summarise data from the most recent two fishing years, it was necessary to calculate the CPUE for the previous 12 years as well, because of the use of a different CPUE estimator. Therefore, values presented in this report are not identical with those published previously. The effect of this change is that the CPUE indices tend to be slightly smaller than those reported previously, though the trends remain the same.

The variance of the ratio estimator is not the same as the commonly used formula for the variance of a mean. The ratio estimator is not unbiased, but it is approximately so with large sample sizes. Its approximate variance is estimated by:

(3) $$\hat{\mathrm{var}}(\hat{y}) = \frac{1}{\mu_u^2}\left(\frac{N-n}{N}\right)\frac{s_{\hat{y}}^2}{n}$$

where

$$s_{\hat{y}}^2 = \frac{1}{n-1}\sum_{i=1}^{n}(c_i - \hat{y}u_i)^2$$

and μ_u is the population mean of the effort variable. There has been some indication that the estimator $\hat{\mathrm{var}}(\hat{y})$ is correlated with the mean of the effort variable ($\bar{u}$). An adjusted estimator,

(4) $$\tilde{\mathrm{var}}(\hat{y}) = \left(\frac{\mu_u}{\bar{u}}\right)^2 \hat{\mathrm{var}}(\hat{y})$$

has been suggested to alleviate this problem (Thompson 1992). If Equation 3 is used, it is necessary to obtain information on effort from all of the commercial fishery. This is obtained from the TLCER forms. Equation 4, however, requires only the effort from observed trips.

It is also possible to estimate the variance by bootstrap. Both the analytical and the bootstrap approaches have been taken in this analysis, and comments are made about the differences between them. Analytical estimates of confidence intervals and variances are presented unless otherwise noted.

2.4 Estimation of total catches

The standard estimator for total catch is $\hat{T} = N\hat{y}$, where N represents the total number of hooks set in the entire fishery. This value is calculated for each stratum separately, and then these are summed to give the total for the entire New Zealand EEZ.

The estimated variance of these totals is given by $\hat{\mathrm{var}}(\hat{T}) = N^2\,\hat{\mathrm{var}}(\hat{y})$, or alternatively by $\hat{\mathrm{var}}(\hat{T}) = N^2\,\tilde{\mathrm{var}}(\hat{y})$. In this analysis we examine both of these estimators and a third one using the bootstrap variance for $\mathrm{var}(\hat{y})$. Comments on the differences in the estimators are made where appropriate.

2.5 Catch weights of oceanic sharks, Ray's bream, and striped marlin

The total estimated catch *weights* of blue, mako, and porbeagle sharks, Ray's bream, and striped marlin were calculated from the estimated numbers caught. Observers measured the weight and length (generally fork length) of many of the fish caught. We assume that the size composition and sex ratio of the observed samples is representative of the catch in each region. The length-frequencies were converted to proportions of the measured sample, and the number caught in each length class was calculated as the proportion multiplied by the estimated total number caught in each region. These numbers were converted to weights by multiplying by the mean weight for the length class (as determined from a length–weight regression calculated using all data in the observer database). Estimated weights were then summed over all length classes, sexes, and geographical regions to provide an estimate for the total weight caught during the fishing year. The length-weight regressions were as follows:

Blue sharks, males:	$\log_{10}\text{Weight} = -5.802 + 3.282\log_{10}\text{FL}$	$N = 1666$,	$R^2 = 0.942$
Blue sharks, females:	$\log_{10}\text{Weight} = -6.196 + 3.485\log_{10}\text{FL}$	$N = 3053$,	$R^2 = 0.948$
Porbeagle sharks, all:	$\log_{10}\text{Weight} = -4.669 + 2.924\log_{10}\text{FL}$	$N = 2457$,	$R^2 = 0.934$
Mako sharks, all:	$\log_{10}\text{Weight} = -4.622 + 2.847\log_{10}\text{FL}$	$N = 1016$,	$R^2 = 0.955$

Concern has been expressed over the quality of the observer data on Ray's bream (Francis et al. 2004). To circumvent those concerns, Francis et al. (2004) calculated the length–weight regression for this species from a sample of 122 fish caught in trawl surveys. Since that analysis was carried out, 12 other trawl surveys have collected length and weight data on an additional 810 fish. Data from these fish were used to calculate the length–weight relationship.

Ray's bream, all: $\log_{10}\text{Weight} = -2.224 + 3.288\log_{10}\text{FL}$ $N = 932$, $R^2 = 0.952$

We are also interested in the weight of striped marlin caught. Previous analyses have used only a mean weight for each fish, rather than a regression equation (Francis et al. 2000). We have calculated a length-weight relationship, though the data are sparse. This relationship agrees with the average values used previously.

Striped marlin, all: $\log_{10}\text{Weight} = -2.817 + 2.024\log_{10}\text{FL}$ $N = 15$, $R^2 = 0.902$

2.6 Status of fish on recovery and subsequent treatment

The status of fish at the time of recovery (retrieval to the side of the vessel), and the subsequent treatment of the catch, were recorded by the observers. The data from these observations were analysed for the 2000–01 and 2001–02 fishing years. Fish status was recorded as alive, dead, killed by crew, or unobserved. Fish recorded as killed by crew were treated as alive on recovery. Fish treatment was recorded as retained, finned, discarded, lost, or unobserved. Retained and finned fish were grouped to reflect the fish that were processed in some way, whereas the discarded and lost fish were categorised as not processed.

3. RESULTS

3.1 Fishing effort and observer coverage

Four chartered Japanese vessels and one large domestic vessel made up the *foreign and charter* fleet during 2000–01 and 2001–02. In 2000–01, these vessels set a total of 302 longlines (947 000 hooks). Of these, almost 819 000 hooks (about 87%) were observed on 272 sets. In 2001–02, these vessels set 322 longlines (983 000 hooks). Observer coverage was similar to the previous year, with 275 sets observed, accounting for over 773 000 hooks (about 79%). Table 1 shows the total numbers of hooks set and observed for all years from 1988–89 to 2001–02. The percentage of hooks observed for each fleet is presented in Table 2.

The *domestic* fleet operating in 2000–01 and 2001–02 consisted of 159 owner-operator vessels, of which 110 fished both fishing years. Over 7400 longlines were set in 2000–01, and 8133 were set in 2001–02. This equated to over 8.5 million and 9.5 million hooks being set in the two fishing years. These values are the greatest numbers of *domestic* hooks recorded, showing that the trend to increased *domestic* effort is continuing.

Observer coverage in the *domestic* fishery remained sparse, despite an effort to increase coverage. Twenty-four vessels from the *domestic* fleet were observed during these two fishing years. Only 202 sets (241 000 hooks) were observed in 2000–01. Coverage was even lower in 2001–02, with 123 sets observed (145 000 hooks). Total coverage of hooks for these two years is 2–3%.

The two fleets differed substantially in fishing practices (Murray et al. 1999, Francis et al. 2004). Historically, *foreign and charter* vessels mostly used a kuralon mainline with 2500–3600 hooks, while *domestic* vessels used shorter monofilament lines with 300–1700 hooks. The *foreign and charter* vessels have started to modify their behaviour, and are now fishing with gear that is more similar to that of the *domestic* vessels. The two fleets used different hook types.

Over 95% of the *foreign and charter* sets targeted southern bluefin tuna in the southern regions (the remainder targeted bigeye tuna in the north). The *domestic* vessels predominantly targeted bigeye tuna (74% of sets), and occasionally targeted southern bluefin tuna (15%) and albacore tuna (8%). Most *domestic* fishing effort was expended in the north. Figures 1 and 2 show the starting locations of all recorded sets in 2000–01 and 2001–02, respectively.

Since tunas and many bycatch species are highly migratory, it is important that observer coverage spans as large a geographical area as possible. Historically, however, observer coverage on *domestic* vessels has focussed on the Bay of Plenty and around East Cape. The most recent two years have seen an increase in geographical area covered by observers, and, as such, are probably more reflective of the entire fleet than data from previous years. Both years had observer coverage of vessels that fished far offshore, and 2000–01 had observations from the west coast of the North Island. The *foreign and charter* fleet has been observed almost in its entirety, and, as such, its geographical range is well represented. Locations of observed sets in 2000–01 are presented in Figures 3 and 4 respectively.

Most hooks on observed sets were themselves observed (Table 3). Of the 474 sets observed in the 2000–01 fishing year, all hooks were observed on 304 sets (64.1%). When all hooks per set were not observed, the average percentage of hooks observed was 94%. The average for all sets was 97.8% of hooks observed.

The 2001–02 fishing year was slightly less well observed. Of the 398 observed sets, only 180 had all the hooks observed (45.2%). The remaining sets averaged 89.0% of hooks observed. For all observed sets in 2001–02, the average was 94% hooks observed. In comparison with individual set data from previous years (1988–89 to 1999–2000), in which an average of 95.8% hooks in each set was observed, the coverage per set for 2000–01 was above average and that for 2001–02 was slightly below average.

Most of the southern region fishing effort (and observational effort) occurred in the SW region (see Figures 1–4). In the past two years, only 75 000 hooks were observed in the SE region, in comparison with 1.4 million observed in the SW region. The SE observations came from two observed trips, one in each year. In 2000–01, two *foreign and charter* vessels fished in the SE region, though only one was observed. A few domestic vessels also undertook short trips here. The 2001–02 fishing year was similar; one of the two *foreign and charter* vessels fishing in the SE area was observed. About five domestic vessels also made a few sets in this area.

Clearly, any trends observed in a combined southern region will be driven by the behaviour of the SW region. It is concluded that the analysis should retain only a single southern region, as trends observed in the SE may represent vessel or trip effects, rather than regional effects.

Foreign and charter vessels fished during the autumn–winter months only, whereas *domestic* vessels fished throughout the year (Figure 5). The observer coverage was not uniform throughout the year on *domestic* vessels; it was concentrated during summer. One new development is that the observations of *domestic* vessels included data from October and November of 2001. In previous fishing years, these months had no observer coverage. There were also observations in August, September, and December, for which historically there had been little coverage.

3.2 Species composition and CPUE of the observed catch

The main species observed as bycatch in the observed tuna longline sets in 2000–01 and 2001–02 were the same as those observed in previous years (Francis et al. 2004). The main species caught on observed vessels was blue shark (Table 4). Albacore tuna, Ray's bream, and southern bluefin tuna were caught frequently as well. Other major species observed were porbeagle shark, dealfish, lancetfish, moonfish, oilfish, deepwater dogfish, swordfish, butterfly tuna, mako shark, rudderfish, school shark, bigeye tuna, escolar, yellowfin tuna, and sunfish. The spatial distributions of the observed catches of these species were similar to those given by Francis et al. (1999).

For the main bycatch species, CPUE values were calculated for each fleet (*domestic* and *foreign and charter*) and geographical region (north and south). The numbers of observed hooks used in these calculations are given in Table 5. The CPUE indices are presented for the 14-year period from 1988–89 to 2001–02 in Figure 6. The indices for the first 12 years are not identical to those presented by Francis et al. (2004) because of the use of the ratio of means estimator, and the reduction in the numbers of observed hooks. Although the absolute values differ, the indices showed almost identical trends.

The CPUE results from the *domestic* fleet should be interpreted with caution because the observer coverage of this fleet is very low and it does not cover the full geographical or temporal range of the fishing effort. Contrasts between the total and observed effort can be seen in Figures 1–4. Species that inhabit the Bay of Plenty and East Cape regions will likely be well represented in the samples, but species that inhabit other regions may not be. The results of the CPUE analysis for the *foreign and charter* fleet are considered to be both reliable and indicative of the true CPUE for this fleet.

For most species, the data suggest a continuation of the trends observed in the last analysis (Francis et al. 2004). All shark species, except deepwater dogfish, had their maximum CPUEs in the 1994–95 or 1995–96 fishing years. Since then the values have dropped. For the north *foreign and charter* fleet, the CPUE increased in the final year for both blue sharks and mako sharks. Both blue and mako sharks have higher CPUEs in the north region. Catch rates for porbeagle and school sharks on *foreign and charter longlines* were slightly higher in the south region in 2000–01, but were similar in both north and south regions in the following year. The deepwater dogfish CPUE indices show that the species that form this group are caught primarily in the south region by the *foreign and charter* fleet. The most recent CPUE values for these species are substantially lower than the previous values (roughly 25–

33% of the size). The observed increase in CPUE between 2000–01 and 2001–02 for all shark species for the north *foreign and charter* vessels may be a result of the distribution of the observed fishing effort in those years (cf. Figures 3 and 4).

For bony fish bycatch, there were some exceptions to the general trend in recent years. A large increase was seen in the catch rate of Ray's bream by *foreign and charter* vessels in southern waters in 2001–02. This marks a return to the level observed in 1996–97. The catch rate for oilfish by northern *foreign and charter* effort in 2000–01 was the highest yet recorded, and more similar to that observed in 1996–97 and 1997–98, than in 1999–2000 and 2001–02. Similarly, a substantial increase in catch rate was observed in 2001–02 for lancetfish (both species combined) from the northern *domestic* fleet. However, generally the results given here for the most recent fishing years are consistent with previous analyses.

The CPUEs of tuna species in the last two years did not show any great departures from previous trends. The *domestic* fleet showed a decline in CPUE for albacore and yellowfin tuna and also for broadbill swordfish. These observations appear to be part of a longer decline, though the observer coverage of this fleet has been low in recent years and its distribution within the northern region has varied spatially and temporally among years.

CPUE trends for striped marlin were similar to those observed for the main shark and tuna species (Figure 7). There were no catches in the south region, and the north region shows an apparent decline in the last two years from a historic high in the mid to late 1990s. The *domestic* fleet caught marlin at a higher rate than the *foreign and charter* fleet.

3.3 Numbers of fish caught

Estimates of total numbers of fish caught in 2000–01 and 2001–02 are presented in Figure 8; the actual estimates are in Appendix 1. Comparison with the estimates from the 1998–99 and 1999–2000 fishing years is not advised, as those years did not use data from *domestic* vessels due to insufficient observer coverage (see Table 2). This is a problem, given that most effort in those years was from the *domestic* fleet.

Total catch estimates for most of the shark species were similar to those estimated in previous years. Blue shark, porbeagle shark, school shark, and deepwater dogfish had catch estimates that were within the ranges previously seen, though deepwater dogfish seem to be at the low end of their range. Mako sharks, however, showed a large increase in total catch. The values for 2000–01 and 2001–02 were double the highest previous yearly catch. Reported TLCER catches in these two years were also higher than those seen previously.

Bony fish bycatch species for which total catch estimates were calculated showed typical numbers in 2000–01 and 2002–02, except for lancetfish, moonfish, rudderfish, and Ray's bream, which all showed substantial increases in the 2001–02 fishing year. The large value for lancetfish is likely due to a substantial increase in CPUE from the *domestic* fleet in northern waters (the high value for the previous year seems to be due to a combination of high *domestic* and *foreign and charter* CPUEs). Reported catches paralleled the estimated catches.

In 2001–02 the southern *foreign and charter* fleet recorded an increase in CPUE for Ray's bream and rudderfish. The observed northern *foreign and charter* vessels showed increases in rudderfish and moonfish CPUE. Note, however, that the northern *foreign and charter* fleet consisted primarily of a single trip by one vessel, which is not typical behaviour for the *foreign and charter* fleet in general. Rudderfish and moonfish also showed an increase in *domestic* CPUE, which likely had more effect on the estimates of total catch.

Of the tuna species, only southern bluefin tuna and butterfly tuna showed similar estimated total catches to previous years. These estimates were similar to the 1998–99 and 1999–2000 estimates because these species were caught mainly by *foreign and charter* vessels.

The other tuna species all showed a large increase in estimated total catch in 2000–01, which persisted until 2001–02 for bigeye tuna and broadbill swordfish. The reported catches of these species also showed increases. The results for albacore tuna are interesting, in that there was a notable drop in the estimated catch in 2001–02, while the reported catch remained high.

Most marlins reported on TLCER forms were striped marlin, with only a few blue (*Makaira mazara*) and black (*M. indica*) marlins. The number of striped marlin reported by fishers has decreased in the last two years, after reaching a peak of 1651 in 1998–99. The number reported in 2000–01 was 507 and in 2001–02, 156 fish, and most of these were caught by *domestic* vessels.

Striped marlin were caught by observed vessels only in the northern region. Seven fish were recorded by observers in the *foreign and charter* fleet in 2000–01, and none was observed in this fleet in the following year. Observers of the *domestic* fleet recorded 74 striped marlin in 2000–01 and 11 in 2001–02. Observers reported that all marlins were discarded, with the exception of a few that were lost off the line.

Table 6 shows the number of marlin observed during each month of the most recent two fishing years, as well as the total numbers of hooks set and observed for those months. Most marlin were observed in February, though this also corresponds with the period of heaviest observer activity. The observer coverage for the 2001–02 fishing year was lower than for the previous year, which may partially explain the large difference in observed numbers of marlin. The total estimated marlin catch is presented in Figure 7.

3.4 Status of fish on recovery, and subsequent treatment

The percentages of each of the main non-target species recorded as alive or dead for the fishing years 2000–01 and 2001–02 are shown in Table 7. Data are presented by fleet and north and south regions, for stratum sample sizes greater than 50. Data for *domestic* vessels are confined to the north region due to lack of observer coverage in the south.

Most blue shark, mako shark, school shark, deepwater dogfish, Ray's bream, moonfish, oilfish, and rudderfish were alive when recovered. Most dealfish were dead in 2000–01, whereas nearly half were alive in 2001–02. About half of the porbeagle sharks and lancetfish and 25% of the butterfly tuna were alive when recovered. These figures are similar to those shown for observed data from 1992–93 to 1999–2000 (Francis et al. 2004). There were no obvious differences between regions and fleets in these two years for most species. In the 2000–01 and 2001–02 fishing years, more than half of the albacore caught were landed dead. The percentage of albacore dead was greater for the *domestic* vessels, where about two-thirds were dead, compared with about one-third for the *foreign and charter* vessels. About two-thirds of swordfish were recovered dead in 2000–01 and 2001–02, again higher in the *domestic* fleet (three-quarters) than the *foreign and charter* fleet (about half). Most striped marlin were recovered alive, 80% in 2000–01, and 73% overall from 1992–93 to 2001–02.

The treatment after capture for each of the main non-target species for the fishing years 2000–01 and 2001–02 is shown in Table 8. Data are presented by fleet and north and south regions, for sample sizes greater than 50.

Most blue, mako, porbeagle and school sharks, moonfish, butterfly tuna, albacore, and swordfish were processed in some way. All dealfish, almost all of the deepwater dogfish and lancetfish, and most of the rudderfish were discarded. About two-thirds of Ray's bream were discarded. Oilfish was mostly discarded by *foreign and charter* vessels, but was often retained by *domestic* vessels. Blue and porbeagle sharks that were processed were generally finned only, with the rest of the carcass discarded. School sharks were mainly processed for the flesh. Mako sharks were mainly retained for their flesh by the Japanese chartered vessels, whereas *domestic* owner-operator vessels mainly finned those processed, and discarded about 50% of their observed catch of mako sharks.

Shark bycatch can be either processed for both its flesh and fins, or just finned with the rest of the carcass being discarded. Table 9 provides a comparison of the percentage of sharks finned only versus those processed fully. School shark were almost all processed fully. Blue sharks showed the opposite extreme, with over 99% of all retained fish finned. Porbeagle sharks were predominantly finned (by both fleets), although about 20% are processed. There was a notable difference between the fleets for mako sharks. The *foreign and charter* fleet processed 96% of makos in 2000–01 and 84% in 2001–02. The *domestic* fleet, however, preferred to fin makos. Only 46% (in 2000–01), and 31% (in 2001–02) of makos were processed by this fleet.

A considerable number of school sharks (a quota species) were recorded as discarded or lost. Further breakdown of this category shows that many school sharks were actively discarded by both the *foreign and charter* and the *domestic* fleets (Table 10).

3.5 Length-frequency distributions and catch weights

3.5.1 Sharks

Length-frequency distributions of blue, porbeagle and mako sharks are shown in Figures 9–11. Data were pooled for 1992–93 to 2001–02, and separated by sex and geographic region. Differences in size composition between north and south regions were apparent for all three shark species. More large blue sharks were found in the north. Based on the length-frequency distributions and approximate mean lengths at maturity of 192.5 cm FL for males and 180 cm for females (Francis & Duffy in press), most blue sharks were immature (88.3% of males and 92.5% of females, overall). Greater numbers of mature blue sharks were found in northern New Zealand, with 26.5% of males and 8.1% of females mature. Based on length-frequencies and mean lengths at maturity of 145 cm FL for males and 175 cm FL for females (Francis & Duffy in press), most porbeagle sharks were immature, but 32.4% of males in the north were mature. With mean length of maturity of 182.5 cm FL for males and 280 cm FL for females (Francis & Duffy in press), most female mako sharks were immature, while many males were mature, particularly in the southern region where 68.9% were mature.

Total estimated catch weights of sharks were high. This is due to the increased estimated catch in numbers for most species. Estimated weights of blue sharks caught by all vessels in 2000–01 and 2001–02 were 1478 and 1969 t respectively. For porbeagle sharks, the estimated catch weights were 98 t and 76 t, and for makos, 694 t and 340 t for 2000–01 and 2001–02 respectively.

3.5.2 Ray's bream

Length-frequency distributions of Ray's bream are shown in Figure 12. Data were pooled for 1992–93 to 2001–02 and separated by sex and region. Most of the Ray's bream were caught in southern New Zealand and most were not sexed. Females mature at about 43 cm (Francis et al. 2004), and 90% of females in the south region were mature.

The estimated catch weights of Ray's bream were 9.5 t in 2000–01 and 31 t in 2001–02.

3.6 Properties of estimators

The estimation of average CPUE and total catch is relatively straightforward, but estimating the variances of these quantities can be more difficult. In this study we examined two analytical estimators and one bootstrap estimator of variance. The two analytical estimators are very similar: they differ only in the use of a population mean effort (from TLCER data) versus a sample mean effort (from observer data). Equations 3 and 4 show the precise difference. The bootstrap method generates a population of mean catch rates, and then uses the standard formula for a variance.

The difference between the two analytical variance estimators was negligible. This was due to the relative consistency in fishing methods. The mean number of hooks on observed vessels was almost identical to the mean number reported on TLCER forms. Because of the similarities, we used only the estimates of variance based on the sample means (Equation 4). Of the two, this estimator has the better statistical properties (Thompson 1992), and also requires less data, which is a desirable trait.

The bootstrap estimates were generally similar to the analytical variance estimates. Figure 13 shows the CPUE and estimated total catch for blue shark, with both analytical and bootstrap estimated variances. Other species had similar results. There was very little difference in the estimated variances for the total catches.

When the estimates and variances are calculated for each fleet separately (as they are for the CPUE results), a more noticeable difference arises. The *domestic* estimates of variance are similar for both the analytical and the bootstrap methods. However, there is a large difference between the estimates for the *foreign and charter* fleet. This is due to the high observer coverage for this fleet, and the presence of the finite population correction factor in the analytical estimate.

Formulae derived under standard sampling theory (for finite populations) incorporate the size of the sample relative to that of the population. As the sample size increases, we become more confident of our estimate of the parameter under investigation (in our case, the total number of fish). If we sample every member of the population we know, in theory, the exact total number of fish caught as bycatch. We are not unsure of our estimate at all, and hence there is no variance about our estimate. This is guaranteed by the presence of the finite population correction factor in the variance estimator. The bootstrap estimate does not have this guarantee built in to it, and, as such, does not get smaller as the sample size approaches the size of the population. If we explicitly add a finite population correction factor into the bootstrap estimate of the variance, it behaves more like the analytical estimate.

Differences between the two types of estimate also present themselves when the data are highly skewed. Most catch data are skewed, but the differences arise only in situations of extreme skewness. In these situations the bootstrap produces estimates that are smaller than those derived from the analytical formulae. These differences, however, are not large.

4. DISCUSSION

The results from these analyses suggest that although the CPUE of most bycatch species has been highly variable historically, most recent estimates of CPUE are within the historical levels, and show levels of variability that are also in line with previous results. There are, however, indications that shark CPUEs are low.

Estimated total catch (and also reported catch) tended to increase over the study period. This is generally related to the increase in domestic fishing effort. The large increases seen in lancetfish, Ray's bream, and rudderfish in 2001–02 cannot be explained solely by this increase in effort. The shark data tended to show smaller increases in estimated catch, in addition to decreases in the CPUE.

It is clear that the series of CPUE and total estimated catch do not necessarily reflect the actual abundance of these species in the New Zealand EEZ. Many other factors can potentially affect catch rates. Bradford (2003) examined factors that might influence the catch of some of the more common non-target fish species. She determined that striped marlin catch rates are affected by the sea temperature and the depth of the lines. Both these trends are corroborated by research on marlin species in other areas (Fonteneau & Richard 2003, Goodyear 2003).

Bradford (2003) also suggested that the month in which fishing occurs can affect the catch rate of non-target species. This should have little effect on the *foreign and charter* fleet, as it has a relatively well defined and short fishing season. The *domestic* fleet, however, fishes year round and the observer coverage is not proportional to effort.

If the observer coverage of the *domestic* vessels is increased it may be possible to improve estimates by stratifying on a temporal variable (month or perhaps season). This was examined briefly during the course of these analyses, but the small numbers of observations in most strata led to problems.

Exploratory analyses based on two southern regions do not show many strong trends. This is due to the small amount of fishing and observer coverage in the SE region. Only two *foreign and charter* vessels fished in this region between 2000 and 2002, and each of these made only one trip each year. Nine *domestic* vessels fished in the SE region during these two years, but they reported only a total of 18 sets over the entire two-year period, none of which was observed. The potential for these data to be affected by unmeasured factors is quite high. As such, it seems best to include these data in a single south region analysis.

Two species did show a difference in CPUE trends between the SW and the SE regions. These were porbeagle sharks and butterfly tuna, both of which showed higher CPUE in the SE region. Both of these seem to be persistent trends, having been observed in most years examined. Furthermore, both these species had catch rates that were much higher in the SE region than in the north region. Previous analyses indicated that CPUE differed between the SW and SE regions for many species (Francis et al. 2004).

The precision of the estimates of CPUE and catches can be determined in a number of ways. The examination of three different methods (two analytical formulae and one bootstrap estimate) here suggests that there is not much difference in the final results.

Many different methods may be used to estimate the mean catch rates and total catches. In this report we have used a ratio estimator, rather than averaging CPUE from individual sets. Sampling theory is sufficiently advanced to allow for many other approaches to be examined. We recommend the examination of regression estimators, as these may potentially improve the accuracy of the estimates by taking into account the effect of covariates. Furthermore, as we have taken a design-based approach to sampling theory in this report, we believe that developing a model-based approach may eliminate some problems with bias, and may also lead to better estimates. Thompson (1992) is a good reference for these issues. Also worthy of examination is the more advanced methodology which has been developed recently, such as the pseudo-empirical likelihood methods developed by Chen & Sitter (1999) and Chen et al. (2004).

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Table 1: Numbers of trips and sets in the New Zealand tuna longline fishery, 1988–89 to 2001–02.

Fishing year	Observed Trips	Observed Sets	Observed hooks Domestic	Observed hooks Foreign + charter	Observed hooks Total	Set hooks Domestic	Set hooks Foreign + charter	Set hooks Total	Set hooks % on CELRs
1988–89	5	86	0	234 826	234 826	400	9 618 860	9 619 260	0.0
1989–90	6	154	0	447 239	447 239	91 232	8 553 288	8 644 520	1.1
1990–91	3	150	0	421 808	421 808	195 645	13 129 251	13 324 896	1.4
1991–92	8	192	19 525	508 629	528 154	396 253	9 177 019	9 573 272	1.1
1992–93	17	373	0	1 057 985	1 057 985	869 013	4 589 581	5 458 594	0.5
1993–94	9	246	2 418	693 262	695 680	1 467 890	1 096 747	2 564 657	6.7
1994–95	12	339	65 694	815 807	881 501	2 197 548	1 685 821	3 883 369	12.1
1995–96	5	147	162 922	0	162 922	2 131 459	208 988	2 340 447	16.8
1996–97	15	424	79 991	882 763	962 754	1 709 417	1 465 302	3 174 719	3.1
1997–98	15	438	70 835	989 566	1 060 401	2 648 811	1 255 786	3 904 597	1.8
1998–99	9	402	35 264	1 052 721	1 087 985	5 191 438	1 515 915	6 707 353	3.1
1999–00	13	274	38 458	659 923	698 381	6 912 104	1 152 892	8 064 996	3.1
2000–01	23	474	240 979	818 744	1 059 723	8 535 364	946 818	9 482 182	1.3
2001–02	17	398	144 716	773 443	918 159	9 525 045	983 392	10 508 437	0.3

Table 2: Percentage of hooks observed by observers, based on the data in Table 1.

Fishing year	Domestic	Foreign + charter	Total
1988–89	0.0	2.4	2.4
1989–90	0.0	5.2	5.2
1990–91	0.0	3.2	3.2
1991–92	4.9	5.5	5.5
1992–93	0.0	23.1	19.4
1993–94	0.2	63.2	27.1
1994–95	3.0	48.4	22.7
1995–96	7.6	0.0	7.0
1996–97	4.7	60.2	30.3
1997–98	2.7	78.8	27.2
1998–99	0.7	69.4	16.2
1999–00	0.6	57.2	8.7
2000–01	2.8	86.5	11.2
2001–02	1.5	78.7	8.7

Table 3: Percentage of hooks observed on observed sets.

Fishing year	Percentage of hooks observed	Number of sets		
		Domestic	Foreign + charter	Total
2000–01	51–60	0	0	0
	61–70	1	0	1
	71–80	0	0	0
	81–90	1	3	4
	91–99	1	164	165
	100	199	105	304
	Total	**202**	**272**	**474**
2001–02	0–10	0	1	1
	11–20	0	0	0
	21–30	0	0	0
	31–40	0	0	0
	41–50	0	0	0
	51–60	0	1	1
	61–70	0	2	2
	71–80	0	18	18
	81–90	0	82	82
	91–99	0	114	114
	100	123	57	180
	Total	**123**	**275**	**398**

Table 4: Numbers of fish recorded by observers during 2000–01 and 2001–02, and the total observed catch since 1988–89. Totals for porbeagle and mako sharks are from 1992–1993, when these two species were accurately and consistently distinguished by observers.

Species	Scientific name	2000–01	2001–02	Total
Blue shark	*Prionace glauca*	8 509	5 901	109 915
Albacore tuna	*Thunnus alalunga*	8 549	1 874	49 256
Ray's bream	*Brama brama*	1 164	5 725	37 337
Southern bluefin tuna	*Thunnus maccoyii*	3 055	3 077	26 678
Porbeagle shark	*Lamna nasus*	648	306	14 987
Dealfish	*Trachipterus trachypterus*	1 075	650	11 744
Lancetfish	*Alepisaurus ferox & A. brevirostris*	1 877	1 775	7 010
Moonfish	*Lampris guttatus*	608	397	6 324
Oilfish	*Ruvettus pretiosus*	600	105	5 821
Deepwater dogfish	Squaliformes	133	254	4 754
Broadbill swordfish	*Xiphias gladius*	785	309	4 572
Butterfly tuna	*Gasterochisma melampus*	254	88	3 491
Mako shark	*Isurus oxyrinchus*	375	194	3 198
Rudderfish	*Centrolophus niger*	289	495	3 140
School shark	*Galeorhinus galeus*	127	124	2 504
Bigeye tuna	*Thunnus obesus*	309	114	1 979
Escolar	*Lepidocybium flavobrunneum*	120	206	1 828
Yellowfin tuna	*Thunnus albacares*	329	82	1 317
Sunfish	*Mola mola*	252	165	1 239
Hoki	*Macruronus novaezelandiae*	86	191	1 184
Big scale pomfret	*Taractichthys longipinnis*	81	257	1 135
Pelagic stingray	*Pteroplatytrygon violacea*	195	64	936
Thresher shark	*Alopias vulpinus*	135	132	832
Striped marlin	*Tetrapturus audax*	81	11	357
Barracouta	*Thyrsites atun*	4	2	336
Skipjack tuna	*Katsuwonus pelamis*	83	34	305
Black barracouta	*Nesiarchus nasutus*	30	23	285
Velvet dogfish	*Zameus squamulosus*	0	0	258
Dolphinfish	*Coryphaena hippurus*	137	86	254
Spiny dogfish	*Squalus acanthias*	8	5	174
Shark, unidentified	Selachii	5	18	173
Flathead pomfret	*Taractes asper*	29	40	158
Pacific bluefin tuna	*Thunnus orientalis*	16	4	154
Slender tuna	*Allothunnus fallai*	4	8	144
Hapuku and bass	*Polyprion oxygeneios & P. americanus*	17	13	89
Ray, unidentified	Torpediniformes	5	7	80
Kingfish	*Seriola lalandi*	9	5	67
Opah	*Lampris immaculatus*	13	0	58
Seal shark	*Dalatias licha*	6	1	56
Shortbill spearfish	*Tetrapturus angustirostris*	6	1	55
Bronze whaler shark	*Carcharhinus brachyurus*	10	3	50
Fanfish	*Pterycombus petersii*	0	0	48
Snipe eel	Nemichthyidae	0	11	45
Wingfish	*Pteraclis velifera*	2	4	25
Bigeye thresher	*Alopias superciliosus*	5	0	21
Hake	*Merluccius australis*	0	0	17

Table 4 (*continued*):

Species	Scientific name	2000–01	2001–02	Total
Gemfish	*Rexea solandri*	4	3	17
Skate	Rajidae	0	0	11
Hammerhead shark	*Sphyrna zygaena*	1	1	9
Oceanic whitetip shark	*Carcharhinus longimanus*	2	0	9
Pilotfish	*Naucrates ductor*	1	0	9
Barracudina	*Magnisudis prionosa*	0	0	8
Blue marlin	*Makaira mazara*	2	0	8
Barracuda	*Sphyraena novaehollandiae*	0	0	7
Ragfish	*Icichthys australis*	0	0	7
Frostfish	*Lepidopus caudatus*	1	0	6
Unicornfish	*Lophotus capellei*	1	0	6
Remora	Echeneidae	0	0	6
Sawtooth eel	*Serrivomer* spp.	0	0	6
Pelagic stargazer	*Pleuroscopus pseudodorsalis*	4	1	5
Ribaldo	*Mora moro*	0	0	5
Black marlin	*Makaira indica*	4	0	4
Bluenose	*Hyperoglyphe antarctica*	0	0	4
False frostfish	*Paradiplospinus gracilis*	0	0	4
Squid	Cephalopoda	0	0	4
Black mackerel	*Scombrolabrax heterolepis*	0	2	3
Manta ray	*Mobula japanica*	0	3	3
Great white shark	*Carcharodon carcharias*	0	0	3
Scalloped dealfish	*Zu elongatus*	0	0	3
Blue cod	*Parapercis colias*	0	0	2
Carpet shark	*Cephaloscyllium isabellum*	0	0	2
Cookie-cutter shark	*Isistius brasiliensis*	0	1	2
Marlin, unspecified	Istiophoridae	0	0	2
Octopus	Cephalopoda	0	0	2
Broadnose seven gill shark	*Notorynchus cepedianus*	0	0	2
Pelagic butterfish	*Schedophilus maculatus*	2	0	2
Large headed slickhead	*Rouleina* spp.	0	0	1
Bigeye scabbard fish	*Benthodesmus elongatus*	0	0	1
Brown stargazer	*Xenocephalus armatus*	1	0	1
Basking shark	*Cetorhinus maximus*	0	1	1
Cubehead	*Cubiceps baxteri*	0	0	1
Manefish	*Caristius* spp.	0	0	1
Blue mackerel	*Scomber australasicus*	0	0	1
Frigate tuna	*Auxis thazard*	0	0	1
Sharpnose seven gill shark	*Heptranchias perlo*	0	0	1
Pufferfish	*Sphoeroides pachygaster*	0	0	1
Red cod	*Pseudophycis bachus*	0	0	1
Salp	Thaliacea	0	0	1
Seahorse	*Hippocampus abdominalis*	0	0	1
Snapper	*Pagrus auratus*	1	0	1
Sprat	*Sprattus* spp.	0	0	1
Tiger shark	*Galeocerdo cuvier*	0	0	1
Tasmanian ruffe	*Tubbia tasmanica*	0	0	1
Wahoo	*Acanthocybium solandri*	0	0	1
White warehou	*Seriolella caerulea*	0	0	1

Table 5: Numbers of observed hooks used in the CPUE and estimated catch analyses, presented by geographical region (N, north; S, south).

Fishing year	Domestic			Foreign and charter			
	N	S	Total	N	S	Total	Total
1988–89	0	0	0	120 823	114 003	234 826	234 826
1989–90	0	0	0	225 931	221 308	447 239	447 239
1990–91	0	0	0	339 693	82 115	421 808	421 808
1991–92	0	0	0	238 755	269 874	508 629	508 629
1992–93	0	0	0	329 597	728 388	1 057 985	1 057 985
1993–94	0	0	0	87 199	606 063	693 262	693 262
1994–95	65 694	0	65 694	27 451	788 356	815 807	881 501
1995–96	64 512	98 410	162 922	0	0	0	162 922
1996–97	79 991	0	79 991	118 131	764 632	882 763	962 754
1997–98	69 611	0	69 611	242 262	747 304	989 566	1 059 177
1998–99	35 264	0	35 264	83 329	969 392	1 052 721	1 087 985
1999–00	0	0	0	67 853	592 070	659 923	659 923
2000–01	238 984	0	238 984	77 940	740 804	818 744	1 057 728
2001–02	144 716	0	144 716	11 758	761 685	773 443	918 159
Total	698 772	98 410	797 182	1 970 722	7 385 994	9 356 716	10 153 898

Table 6: Numbers of hooks set and observed, and numbers of striped marlin observed by month for the 2000–01 and 2001–02 fishing years.

	Domestic			Foreign and charter		
Month	Number of hooks set	Number of hooks observed	Number of marlin observed	Number of hooks set	Number of hooks observed	Number of marlin observed
October 2000	594 160	0	–	0	0	–
November	427 005	0	–	0	0	–
December	438 850	9 287	0	0	0	–
January 2001	586 975	65 662	16	0	0	–
February	716 813	67 528	43	0	0	–
March	825 600	37 985	14	33 225	0	–
April	831 152	21 981	1	168 150	85 775	0
May	617 064	22 059	0	444 597	428 364	0
June	1 035 205	1 477	0	261 346	251 310	2
July	794 639	0	–	39 500	53 295	5
August	851 171	0	–	0	0	–
September	816 730	15 000	0	0	0	–
October	531 980	21 289	0	0	0	–
November	547 725	13 450	0	0	0	–
December	539 620	10 720	0	0	0	–
January 2002	813 420	28 057	4	0	0	–
February	715 826	36 142	5	0	0	–
March	860 554	5 701	2	47 184	15 030	0
April	1 215 995	9 257	0	220 507	130 191	0
May	1 187 863	7 600	0	411 400	351 706	0
June	948 100	1 400	0	304 301	276 516	0
July	787 337	0	–	0	0	–
August	847 090	4 420	0	0	0	–
September	529 535	6 680	0	0	0	–

Table 7: Percentage of main shark species that were alive or dead when observed, for the fishing years 2000–01 and 2001–02, by fleet and region.

Species	Fleet	Area	Year	% alive	% dead	No. observed
Blue shark	Domestic	North	2000–01	88.4	11.6	1 102
			2001–02	85.6	14.4	709
	Foreign + charter	North	2000–01	93.0	7.0	115
			2001–02	91.4	8.6	185
		South	2000–01	85.9	14.1	4 847
			2001–02	91.8	8.2	3 916
	Total		2000–01	86.5	13.5	6 064
			2001–02	90.9	9.1	4 810
Porbeagle shark	Domestic	North	2000–01	52.9	47.1	87
			2001–02	–	–	44
	Foreign + charter	North	2000–01	–	–	14
			2001–02	–	–	3
		South	2000–01	56.0	44.0	536
			2001–02	58.4	41.6	245
	Total		2000–01	55.1	44.9	637
			2001–02	60.6	39.4	292
Mako shark	Domestic	North	2000–01	64.4	35.6	264
			2001–02	66.1	33.9	112
	Foreign + charter	North	2000–01	–	–	34
			2001–02	–	–	10
		South	2000–01	78.9	21.1	76
			2001–02	81.4	18.6	70
	Total		2000–01	68.7	31.3	374
			2001–02	71.9	28.1	192
School shark	Domestic	North	2000–01	–	–	16
			2001–02	–	–	0
	Foreign + charter	North	2000–01	–	–	0
			2001–02	–	–	2
		South	2000–01	61.1	38.9	108
			2001–02	75.0	25.0	120
	Total		2000–01	62.1	37.9	124
			2001–02	74.6	25.4	122
Deepwater dogfish	Domestic	North	2000–01	–	–	1
			2001–02	–	–	1
	Foreign + charter	North	2000–01	–	–	0
			2001–02	–	–	0
		South	2000–01	78.4	21.6	125
			2001–02	83.0	17.0	247
	Total		2000–01	78.6	21.4	126
			2001–02	83.1	16.9	248

Table 7 (*continued*): **Percentages of main non-target teleost species that were alive or dead when observed, for the fishing years 2000–01 and 2001–02, by fleet and region.**

Species	Fleet	Area	Year	% alive	% dead	No. observed
Ray's bream	Domestic	North	2000–01	67.0	33.0	100
			2001–02	80.4	19.6	153
	Foreign + charter	North	2000–01	–	–	42
			2001–02	–	–	2
		South	2000–01	76.9	23.1	818
			2001–02	90.9	9.1	2 214
	Total		2000–01	76.1	23.9	960
			2001–02	90.2	9.8	2 369
Dealfish	Domestic	North	2000–01	–	–	26
			2001–02	–	–	2
	Foreign + charter	North	2000–01	–	–	0
			2001–02	–	–	0
		South	2000–01	5.6	94.4	338
			2001–02	40.6	59.4	503
	Total		2000–01	6.6	93.4	364
			2001–02	40.6	59.4	505
Moonfish	Domestic	North	2000–01	64.8	35.2	196
			2001–02	74.2	25.8	252
	Foreign + charter	North	2000–01	–	–	46
			2001–02	–	–	26
		South	2000–01	77.6	22.4	352
			2001–02	82.1	17.9	117
	Total		2000–01	72.7	27.3	594
			2001–02	77.5	22.5	395
Lancetfish	Domestic	North	2000–01	41.4	58.6	1 593
			2001–02	44.7	55.3	1 749
	Foreign + charter	North	2000–01	17.5	82.5	166
			2001–02	–	–	13
		South	2000–01	–	–	9
			2001–02	–	–	12
	Total		2000–01	39.0	61.0	1 767
			2001–02	44.7	55.3	1 773
Oilfish	Domestic	North	2000–01	84.4	15.6	180
			2001–02	75.6	24.4	90
	Foreign + charter	North	2000–01	86.1	13.9	287
			2001–02	–	–	14
		South	2000–01	–	–	1
			2001–02	–	–	1
	Total		2000–01	85.5	14.5	468
			2001–02	79.0	21.0	105
Rudderfish	Domestic	North	2000–01	–	–	42
			2001–02	96.0	4.0	50
	Foreign + charter	North	2000–01	–	–	4
			2001–02	–	–	7
		South	2000–01	70.4	29.6	230
			2001–02	92.5	7.5	398
	Total		2000–01	75.4	24.6	276
			2001–02	93.0	7.0	455

Table 7 (*continued*): Percentages of main non-target tuna and billfish species that were alive or dead when observed, for the fishing years 2000–01 and 2001–02, by fleet and region.

Species	Fleet	Area	Year	% alive	% dead	No. observed
Albacore	Domestic	North	2000–01	30.2	69.8	5 892
			2001–02	30.7	69.3	1 437
	Foreign + charter	North	2000–01	62.6	37.4	1 091
			2001–02	63.5	36.5	74
		South	2000–01	66.1	33.9	1 379
			2001–02	69.5	30.5	344
	Total		2000–01	40.3	59.7	8 362
			2001–02	39.2	60.8	1 855
Butterfly tuna	Domestic	North	2000–01	–	–	12
			2001–02	–	–	10
	Foreign + charter	North	2000–01	–	–	5
			2001–02	–	–	1
		South	2000–01	25.2	74.8	234
			2001–02	27.6	72.4	76
	Total		2000–01	23.9	76.1	251
			2001–02	24.1	75.9	87
Swordfish	Domestic	North	2000–01	24.8	75.2	528
			2001–02	25.1	74.9	203
	Foreign + charter	North	2000–01	42.6	57.4	136
			2001–02	–	–	33
		South	2000–01	55.3	44.7	114
			2001–02	54.9	45.1	71
	Total		2000–01	32.4	67.6	778
			2001–02	33.6	66.4	307

Table 8: Percentages of main shark species that were discarded or lost, and retained or finned, for the fishing years 2000–01 and 2001–02, by fleet and region.

Species	Fleet	Area	Year	% discarded or lost	% finned or retained	No. observed
Blue shark	Domestic	North	2000–01	39.9	60.1	1 102
			2001–02	44.4	55.6	708
	Foreign + charter	North	2000–01	43.5	56.5	115
			2001–02	24.7	75.3	186
		South	2000–01	22.6	77.4	4 869
			2001–02	25.3	74.7	3 919
	Total		2000–01	26.2	73.8	6 086
			2001–02	28.0	72.0	4 813
Porbeagle shark	Domestic	North	2000–01	70.1	29.9	87
			2001–02	–	–	44
	Foreign + charter	North	2000–01	–	–	14
			2001–02	–	–	3
		South	2000–01	10.4	89.6	546
			2001–02	9.6	90.4	251
	Total		2000–01	20.2	79.8	647
			2001–02	17.8	82.2	298
Mako shark	Domestic	North	2000–01	47.3	52.7	264
			2001–02	65.2	34.8	112
	Foreign + charter	North	2000–01	–	–	34
			2001–02	–	–	10
		South	2000–01	13.0	87.0	77
			2001–02	20.0	80.0	70
	Total		2000–01	38.1	61.9	375
			2001–02	46.4	53.6	192
School shark	Domestic	North	2000–01	–	–	16
			2001–02	–	–	0
	Foreign + charter	North	2000–01	–	–	0
			2001–02	–	–	2
		South	2000–01	32.1	67.9	109
			2001–02	20.0	80.0	120
	Total		2000–01	39.2	60.8	125
			2001–02	20.5	79.5	122
Deepwater dogfish	Domestic	North	2000–01	–	–	1
			2001–02	–	–	1
	Foreign + charter	North	2000–01	–	–	0
			2001–02	–	–	0
		South	2000–01	100.0	0.0	130
			2001–02	100.0	0.0	247
	Total		2000–01	100.0	0.0	131
			2001–02	100.0	0.0	248

Table 8 (*continued*): Percentages of main non-target teleost species that were discarded or lost, and retained, for the fishing years 2000–01 and 2001–02, by fleet and region.

Species	Fleet	Area	Year	% discarded or lost	% retained	No. observed
Rays bream	Domestic	North	2000–01	7.0	93.0	100
			2001–02	3.3	96.7	153
	Foreign + charter	North	2000–01	–	–	42
			2001–02	–	–	2
		South	2000–01	68.6	31.4	814
			2001–02	74.1	25.9	2 215
	Total		2000–01	63.4	36.6	956
			2001–02	69.5	30.5	2 370
Dealfish	Domestic	North	2000–01	–	–	26
			2001–02	–	–	2
	Foreign + charter	North	2000–01	–	–	0
			2001–02	–	–	0
		South	2000–01	100.0	0.0	392
			2001–02	100.0	0.0	508
	Total		2000–01	100.0	0.0	418
			2001–02	100.0	0.0	510
Moonfish	Domestic	North	2000–01	5.1	94.9	196
			2001–02	5.6	94.4	251
	Foreign + charter	North	2000–01	–	–	46
			2001–02	–	–	26
		South	2000–01	10.2	89.8	363
			2001–02	8.5	91.5	117
	Total		2000–01	8.4	91.6	605
			2001–02	7.1	92.9	394
Lancetfish	Domestic	North	2000–01	99.4	0.6	1 606
			2001–02	99.8	0.2	1 748
	Foreign + charter	North	2000–01	100.0	0.0	166
			2001–02	–	–	13
		South	2000–01	–	–	9
			2001–02	–	–	12
	Total		2000–01	99.5	0.5	1 781
			2001–02	99.8	0.2	1 773
Oilfish	Domestic	North	2000–01	48.6	51.4	179
			2001–02	35.6	64.4	90
	Foreign + charter	North	2000–01	100.0	0.0	287
			2001–02	–	–	14
		South	2000–01	–	–	1
			2001–02	–	–	1
	Total		2000–01	80.3	19.7	467
			2001–02	44.8	55.2	105
Rudderfish	Domestic	North	2000–01	–	–	42
			2001–02	26.0	74.0	50
	Foreign + charter	North	2000–01	–	–	4
			2001–02	–	–	7
		South	2000–01	99.6	0.4	243
			2001–02	99.8	0.2	412
	Total		2000–01	88.6	11.4	289
			2001–02	91.9	8.1	469

Table 8 (*continued*): Percentages of main non-target tuna and billfish species that were discarded or lost, and retained, for the fishing years 2000–01 and 2001–02, by fleet and region.

Species	Fleet	Area	Year	% discarded or lost	% retained	No. observed
Albacore	Domestic	North	2000–01	2.6	97.4	5 899
			2001–02	3.7	96.3	1 437
	Foreign + charter	North	2000–01	4.8	95.2	1 091
			2001–02	0.0	100.0	76
		South	2000–01	1.4	98.6	1 396
			2001–02	1.7	98.3	353
	Total		2000–01	2.7	97.3	8 386
			2001–02	3.2	96.8	1 866
Butterfly tuna	Domestic	North	2000–01	–	–	12
			2001–02	–	–	10
	Foreign + charter	North	2000–01	–	–	5
			2001–02	–	–	1
		South	2000–01	1.7	98.3	234
			2001–02	1.3	98.7	76
	Total		2000–01	2.4	97.6	251
			2001–02	1.1	98.9	87
Swordfish	Domestic	North	2000–01	17.6	82.4	528
			2001–02	14.3	85.7	203
	Foreign + charter	North	2000–01	37.5	62.5	136
			2001–02	–	–	34
		South	2000–01	2.6	97.4	114
			2001–02	1.4	98.6	71
	Total		2000–01	18.9	81.1	778
			2001–02	10.4	89.6	308

Table 9: Percentage of retained sharks that were finned only or processed for flesh and fins.

Species	Fleet	Fishing year	Percent finned	Percent processed	Number observed
Blue shark	Foreign + charter	2000–01	99.6	0.4	3 832
	Domestic		99.7	0.3	662
	Total		99.6	0.4	4 494
	Foreign + charter	2001–02	99.8	0.2	3 069
	Domestic		99.0	1.0	394
	Total		99.7	0.3	3 463
Mako shark	Foreign + charter	2000–01	4.3	95.7	93
	Domestic		54.0	46.0	139
	Total		34.1	65.9	232
	Foreign + charter	2001–02	15.6	84.4	64
	Domestic		69.2	30.8	39
	Total		35.9	64.1	103
Porbeagle shark	Foreign + charter	2000–01	82.9	17.1	490
	Domestic		80.8	19.2	26
	Total		82.8	17.2	516
	Foreign + charter	2001–02	80.4	19.6	230
	Domestic		73.3	26.7	15
	Total		80.0	20.0	245
School shark	Foreign + charter	2000–01	1.4	98.6	74
	Domestic		0.0	100.0	2
	Total		1.3	98.7	76
	Foreign + charter	2001–02	1.0	99.0	97
	Domestic		–	–	0
	Total		1.0	99.0	97

Table 10: Distribution of lost and discarded school sharks.

Fleet	Fishing year	Number discarded	Number lost	Total
Domestic	2000–01	12	2	14
	2001–02	–	–	0
Foreign + charter	2000–01	14	21	35
	2001–02	20	5	25
Total	2000–01	26	23	49
	2001–02	20	5	25

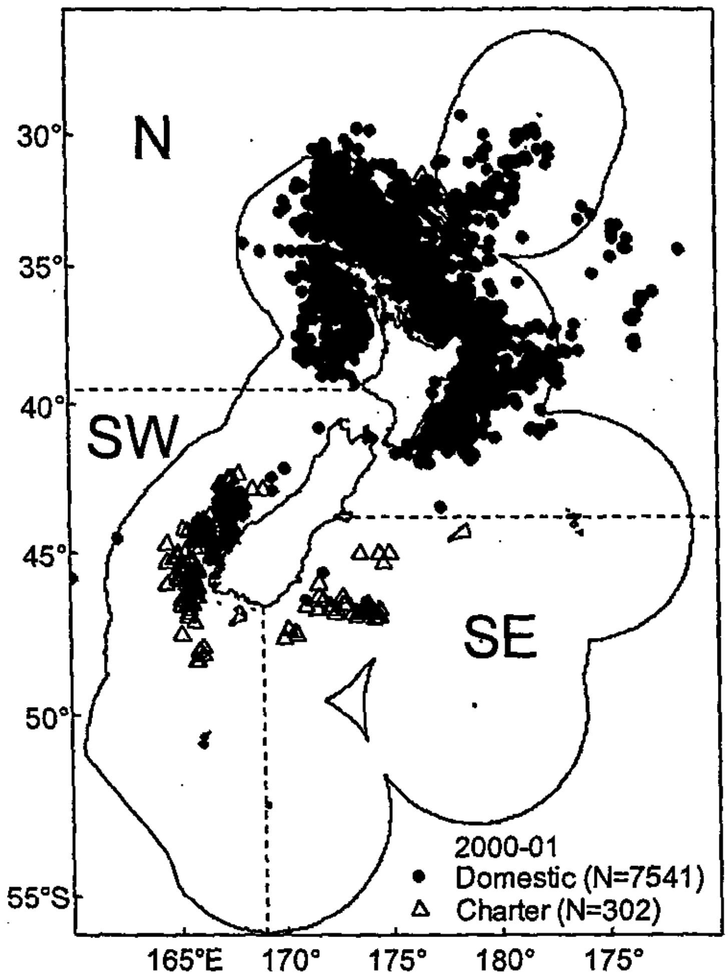


Figure 1: Start positions for tuna longline sets reported on TLCERs and CELRs in 2000–01. The easternmost points are possibly errors where longitude was reported as west rather than east.

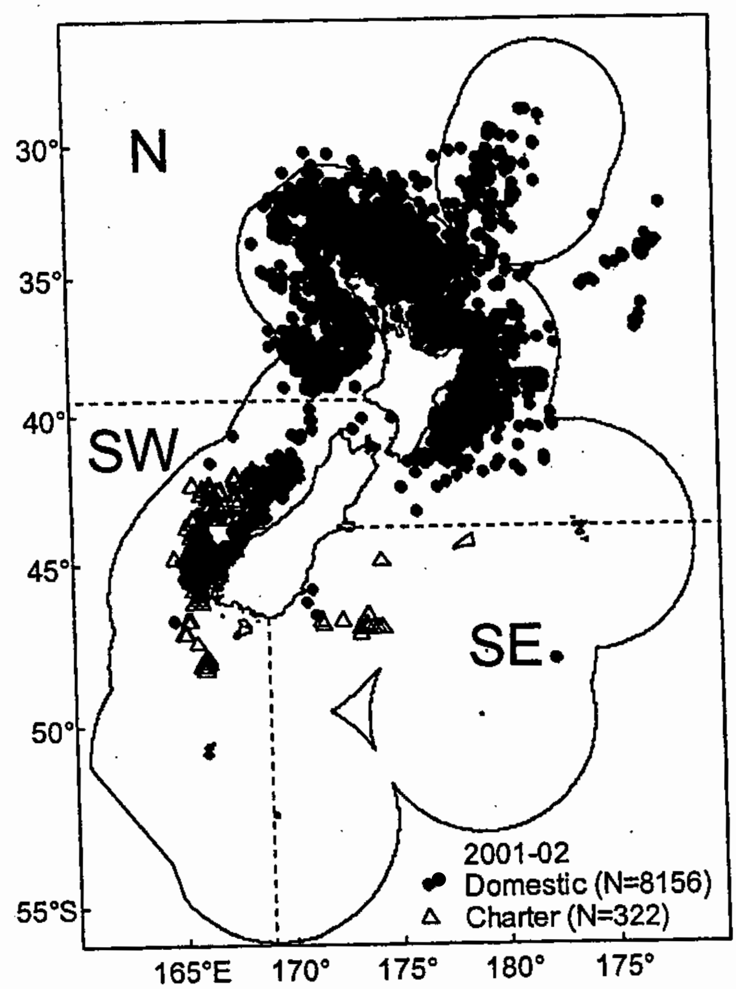


Figure 2: Start positions for tuna longline sets reported on TLCERs and CELRs in 2001–02. The easternmost points are possibly errors where longitude was reported as west rather than east.

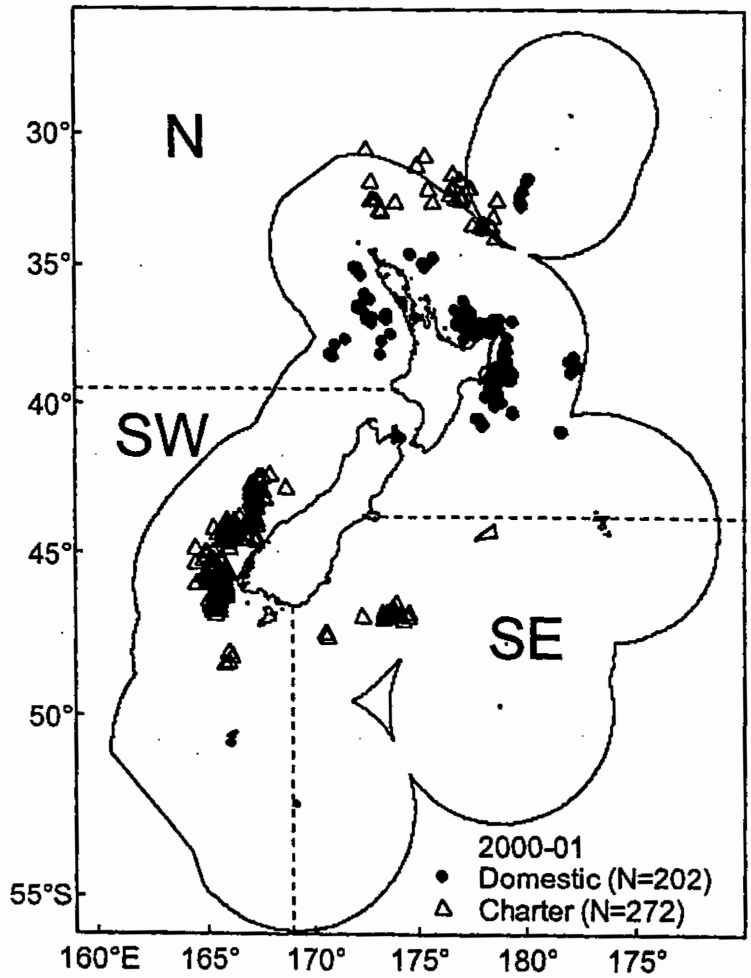


Figure 3: Start positions of observed tuna longline sets in 2000–01.

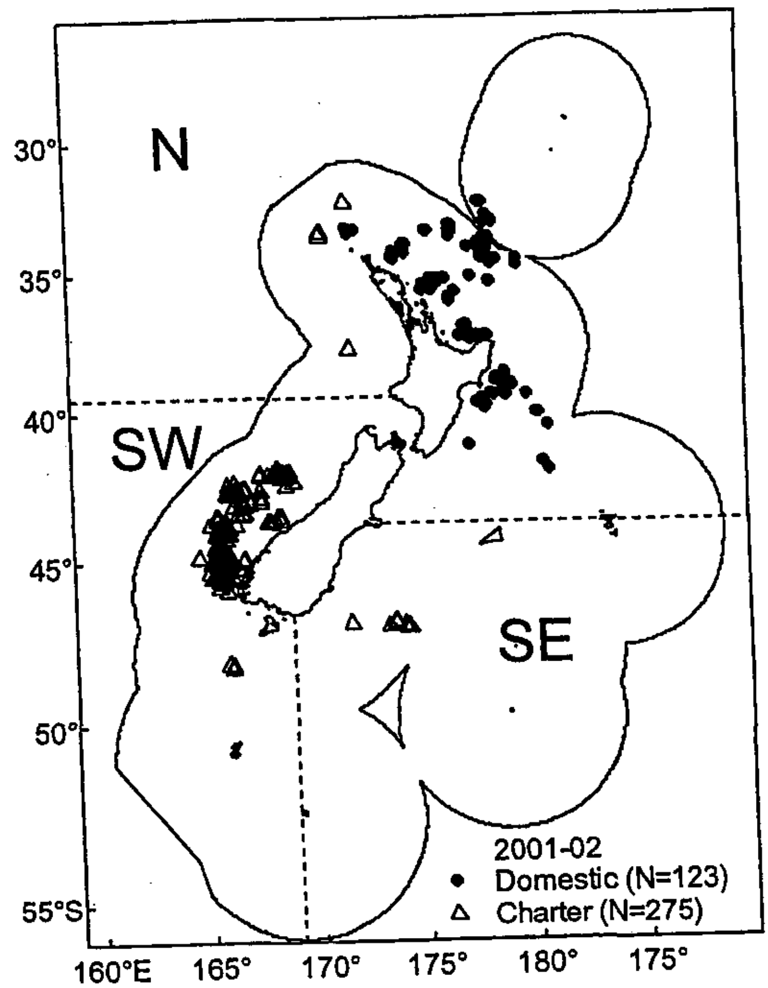


Figure 4: Start positions of observed tuna longline sets in 2001–02.

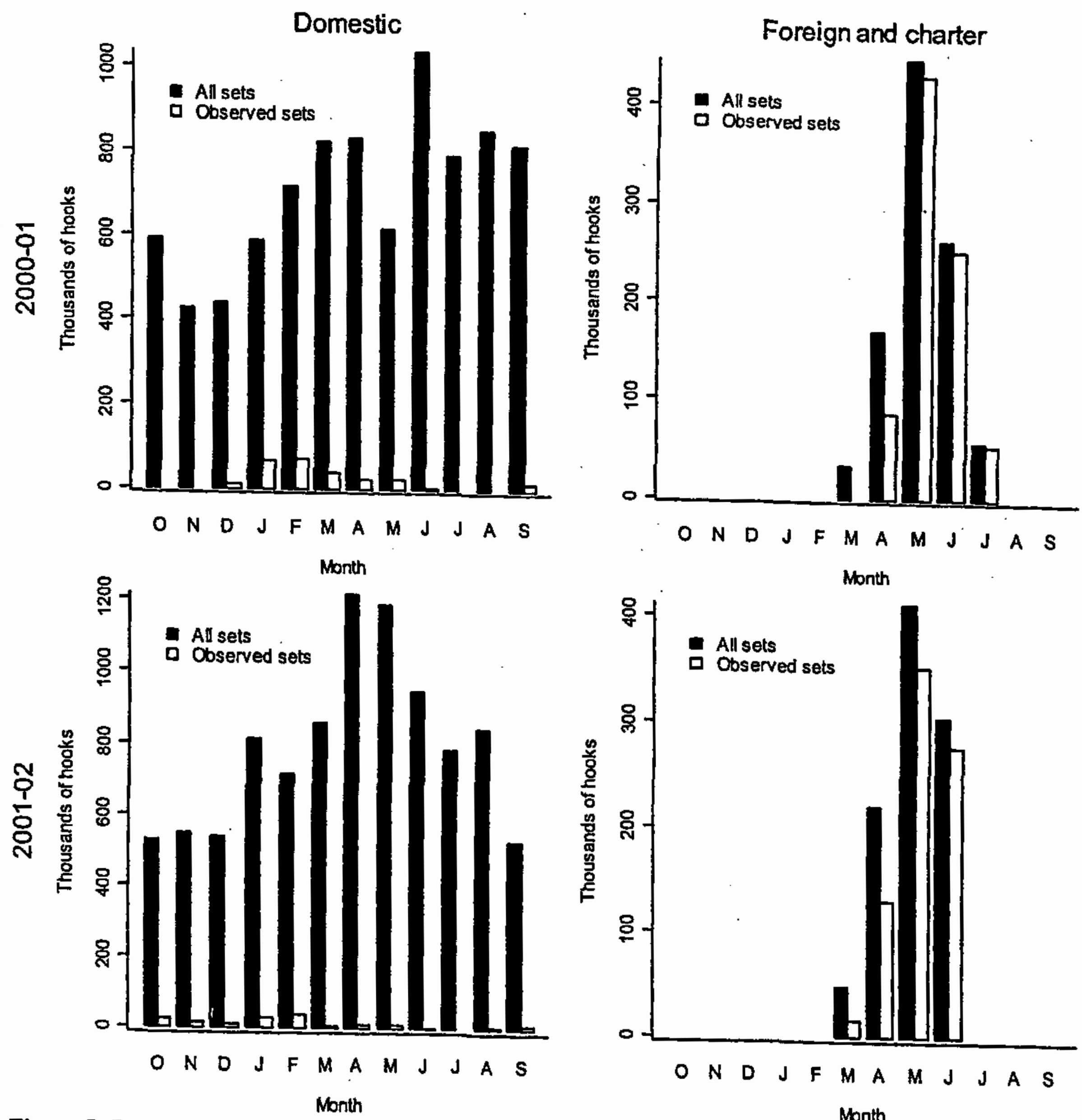


Figure 5: Seasonal distribution of total and observed sets by fleet and fishing year.

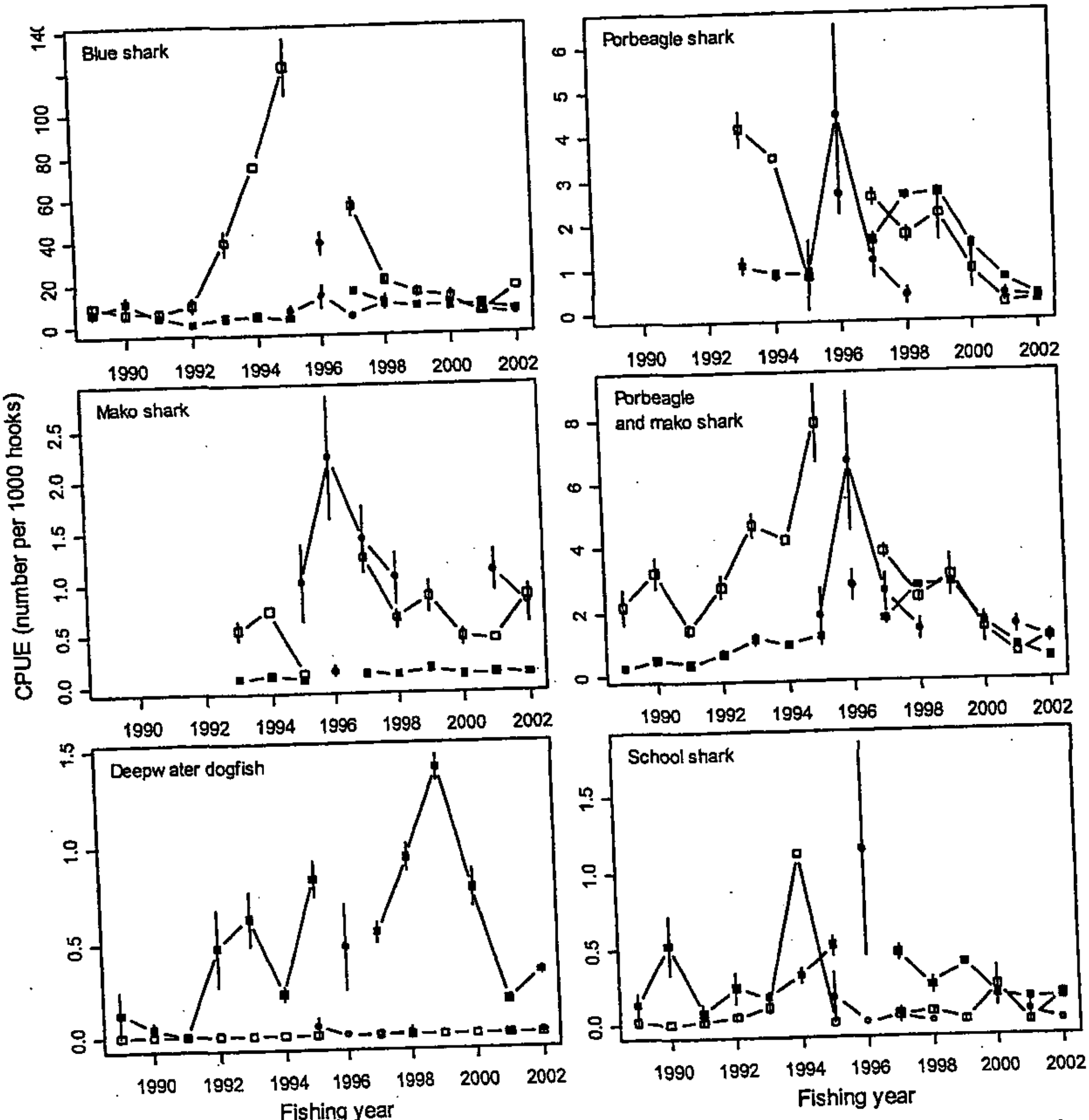


Figure 6: CPUE indices for the *foreign and charter* fleet and the *domestic* fleet for shark species. Confidence intervals (95%) are from analytical formulae (Equation 4). Fishing year is identified by the most recent calendar year (1996 = 1995–96 fishing year). -■- *foreign and charter* south; -□- *foreign and charter* north; -●- *domestic* south; -○- *domestic* north.

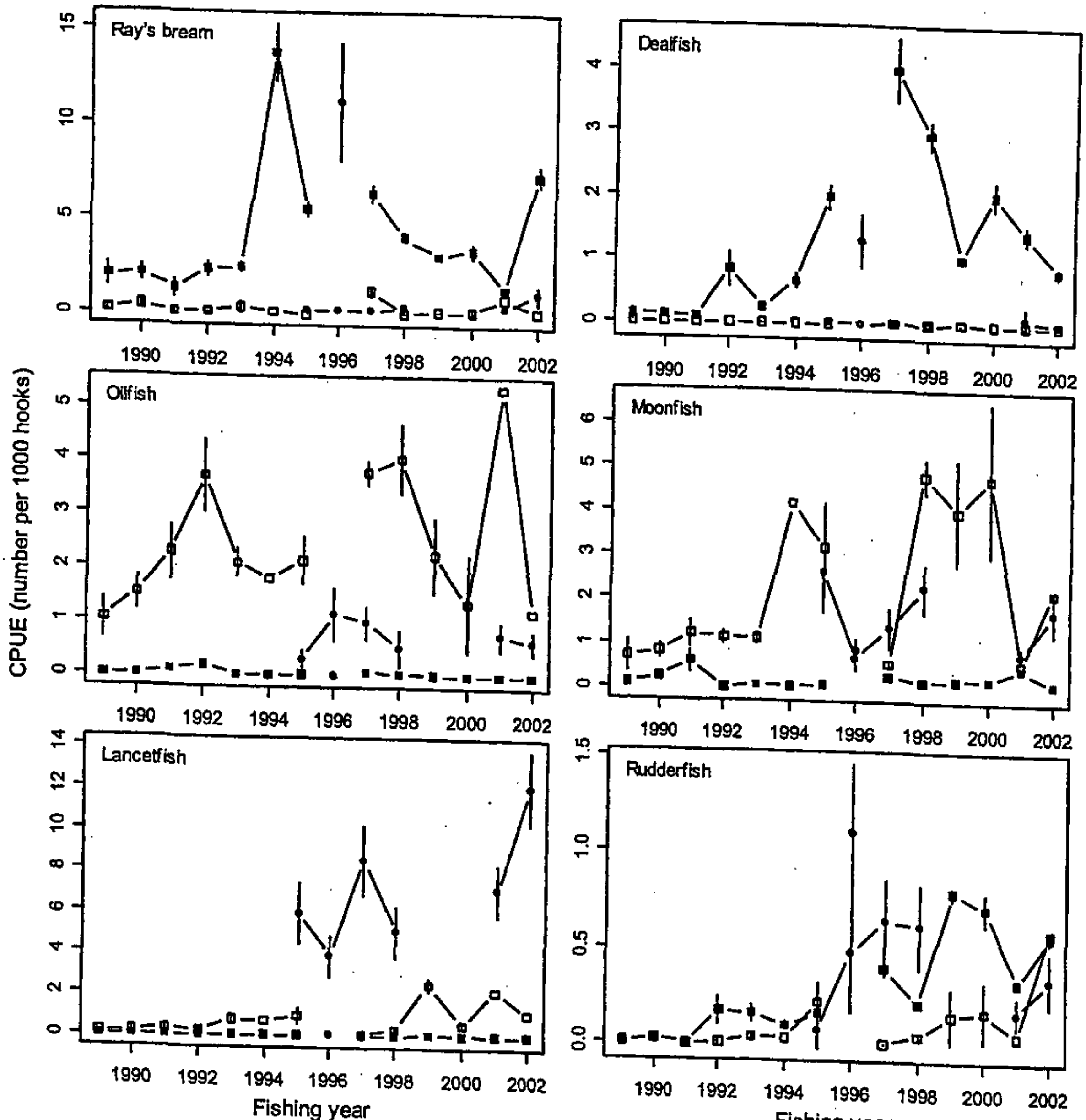


Figure 6 (*continued*): CPUE indices for bony fish bycatch species. Fishing year is identified by the most recent calendar year (1996 = 1995–96 fishing year). -■- *foreign and charter* south; -□- *foreign and charter* north; -●- *domestic* south; -○- *domestic* north.

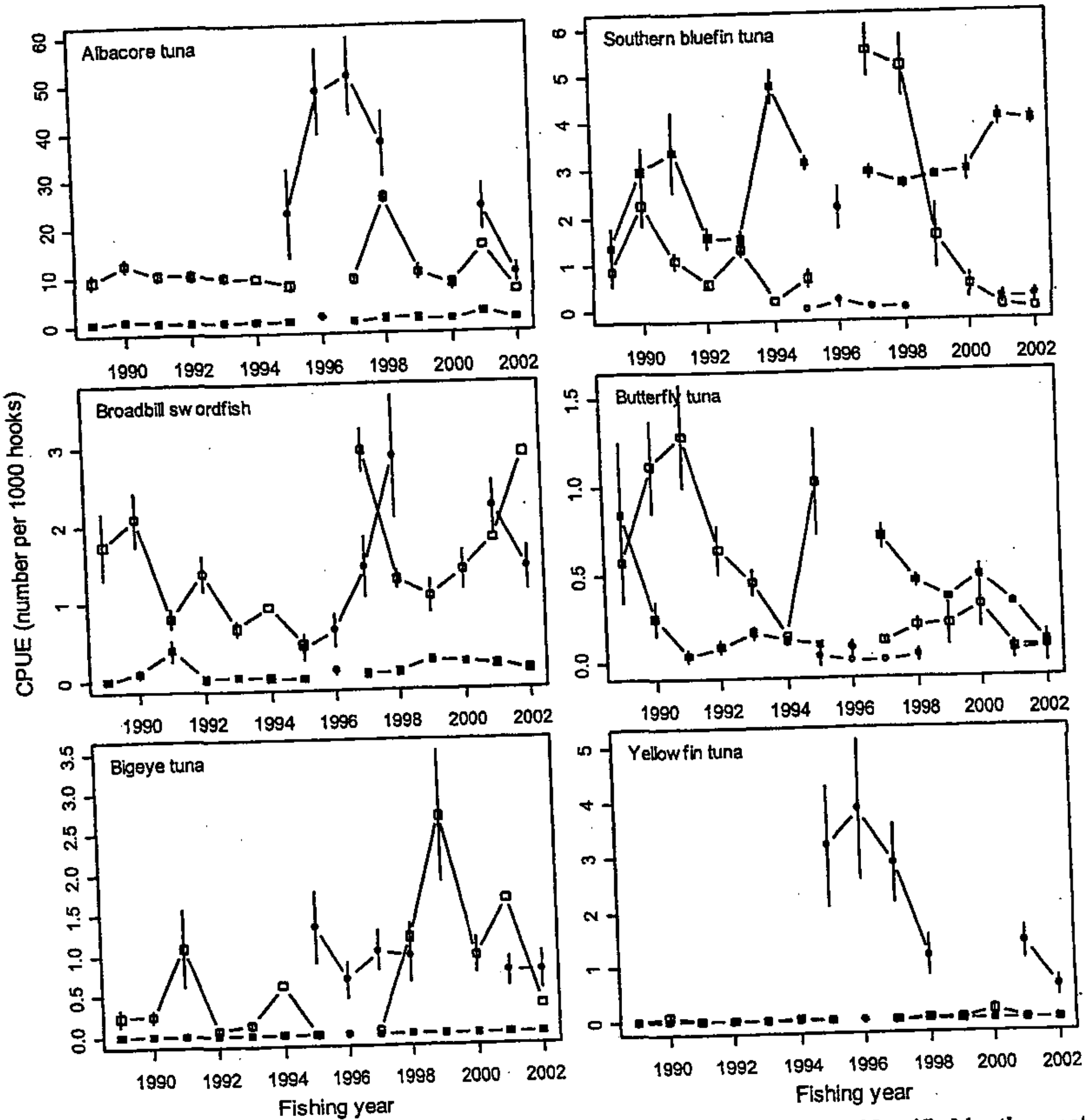


Figure 6 (*continued*): CPUE indices for tuna species and swordfish. Fishing year is identified by the most recent calendar year (1996 = 1995–96 fishing year). -■- *foreign and charter* south; -□- *foreign and charter* north; -●- *domestic* south; -○- *domestic* north.

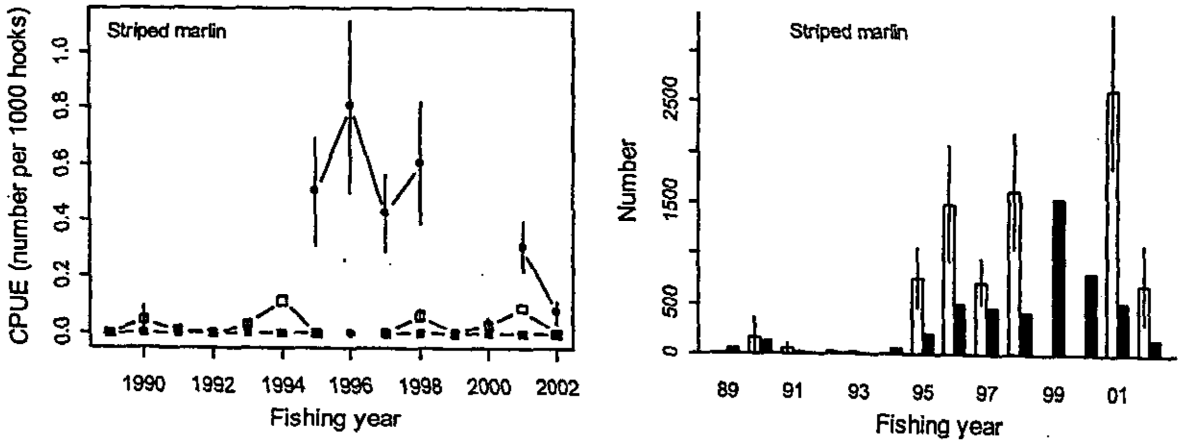


Figure 7: Catch per unit effort and total catch estimates for striped marlin. -■- foreign and charter south; -□- foreign and charter north; -●- domestic south; -o- domestic north. Empty bars are estimated catch, black bars are reported catch.

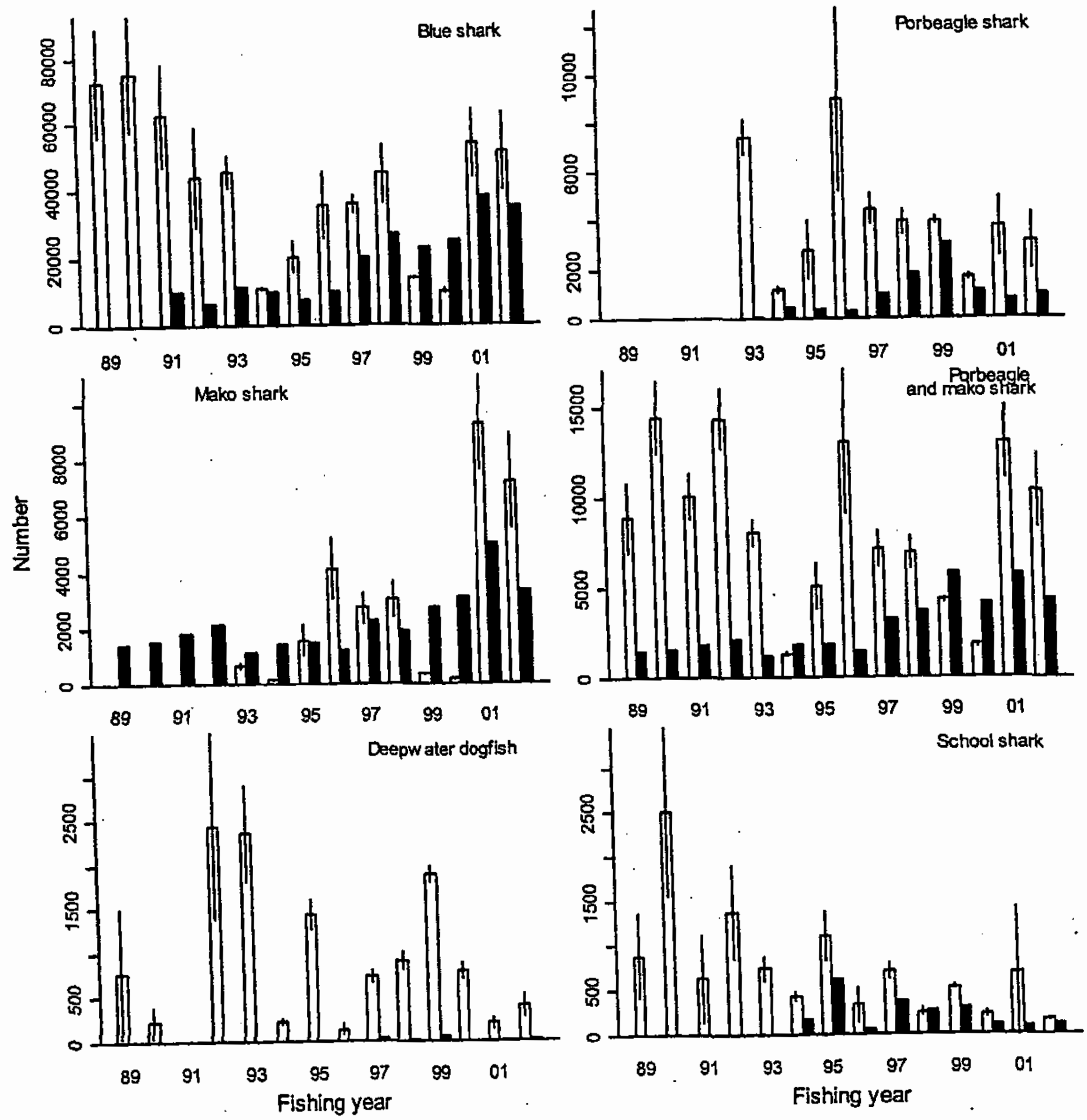


Figure 8: Estimates of total catch of shark species by year (white bars, with 95% confidence intervals calculated by analytical formulae (Equation 4)). Black bars are total catch reported on TLCERs. Fishing year is identified by the most recent calendar year (99 = 1998–99 fishing year). Estimates for the 1998–99 and 1999–2000 fishing years are based only on *foreign and charter* data because of low *domestic* coverage. Catches will therefore be underestimated if the species is caught primarily by *domestic* vessels.

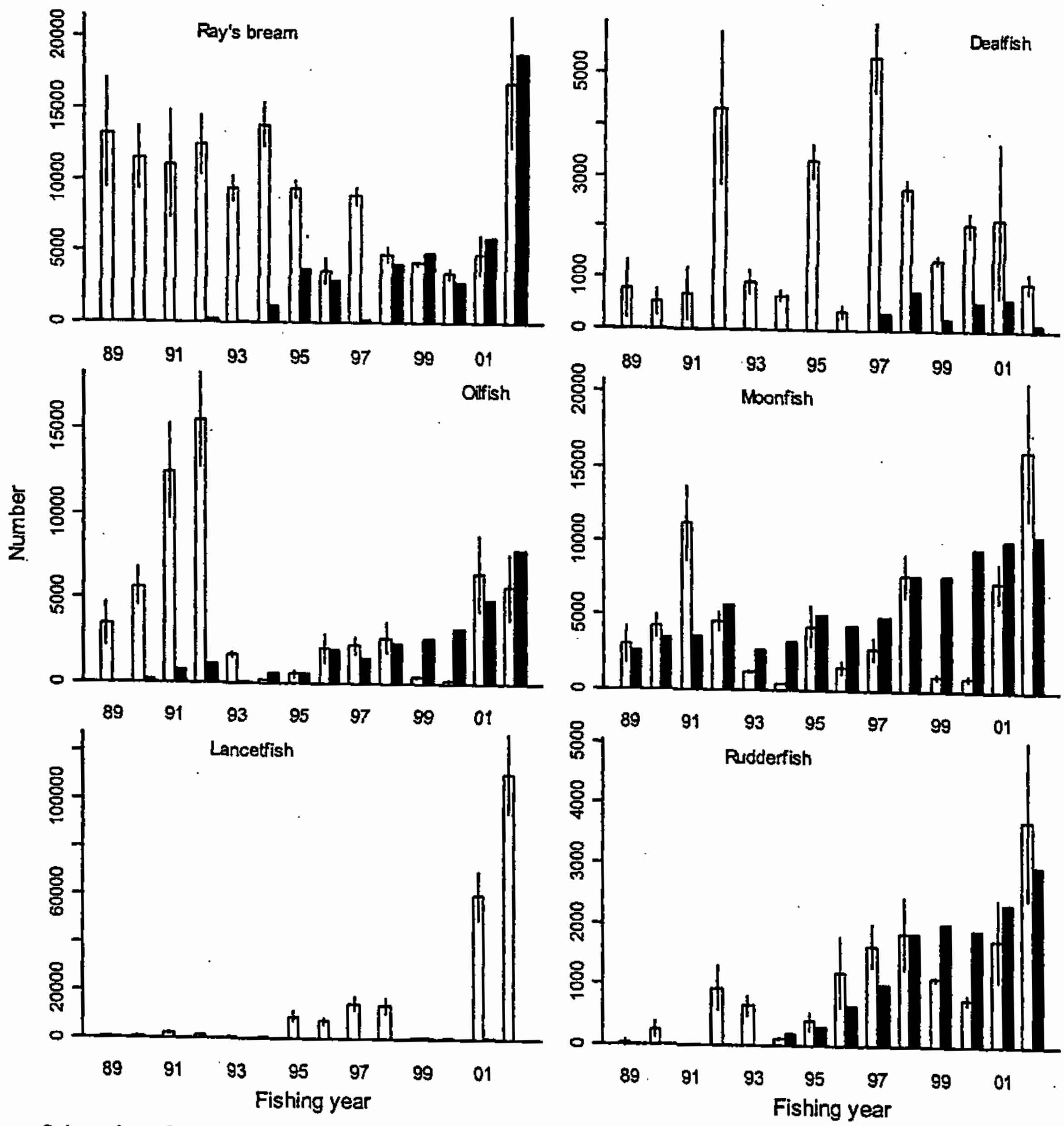


Figure 8 (*continued*): Estimated catch for bony fish bycatch species. Fishing year is identified by the most recent calendar year (*99* = *1998–99* fishing year).

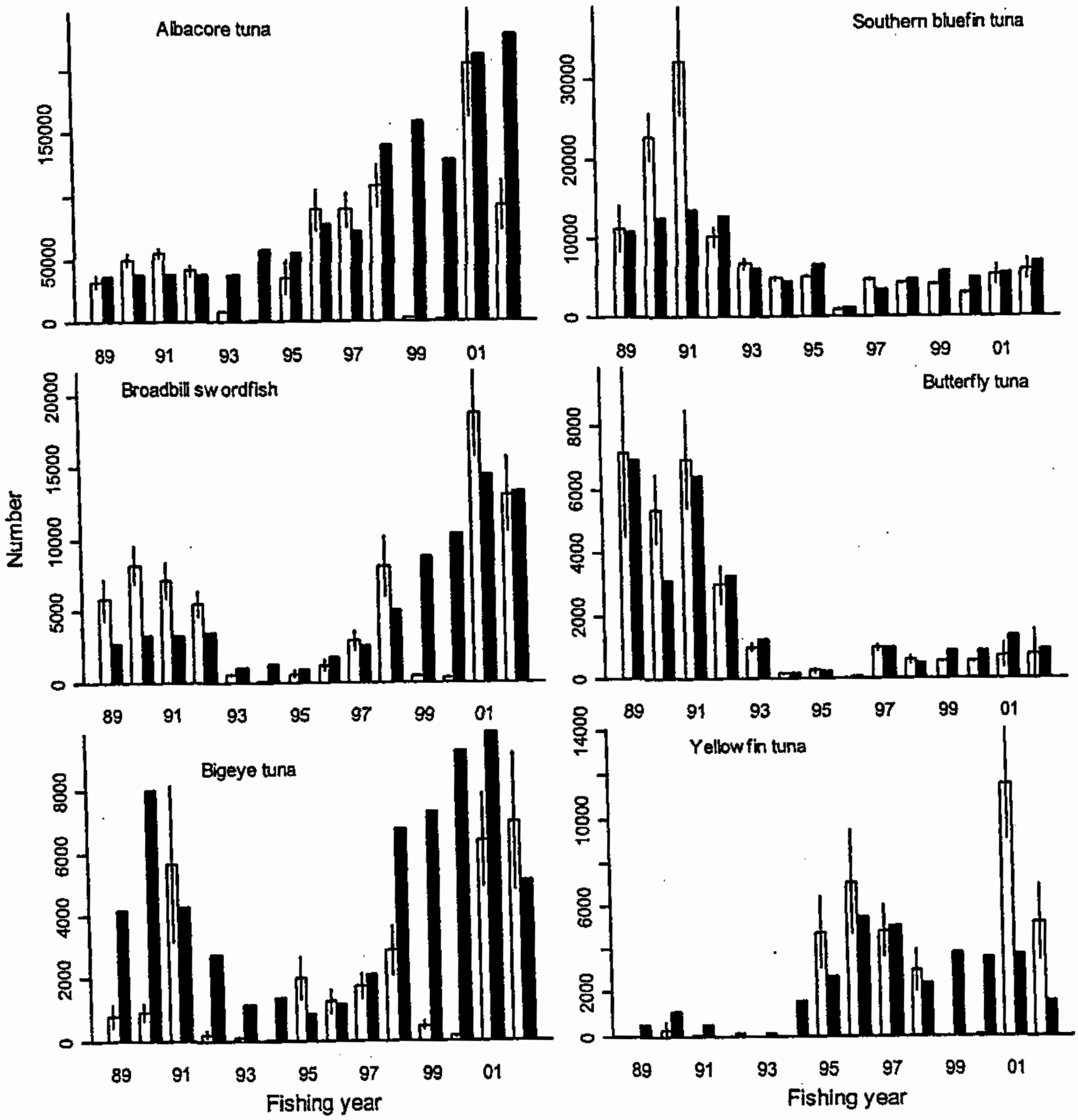


Figure 8 (*continued*): Estimated catch for tuna species and swordfish. Fishing year is identified by the most recent calendar year (99 = 1998–99 fishing year).

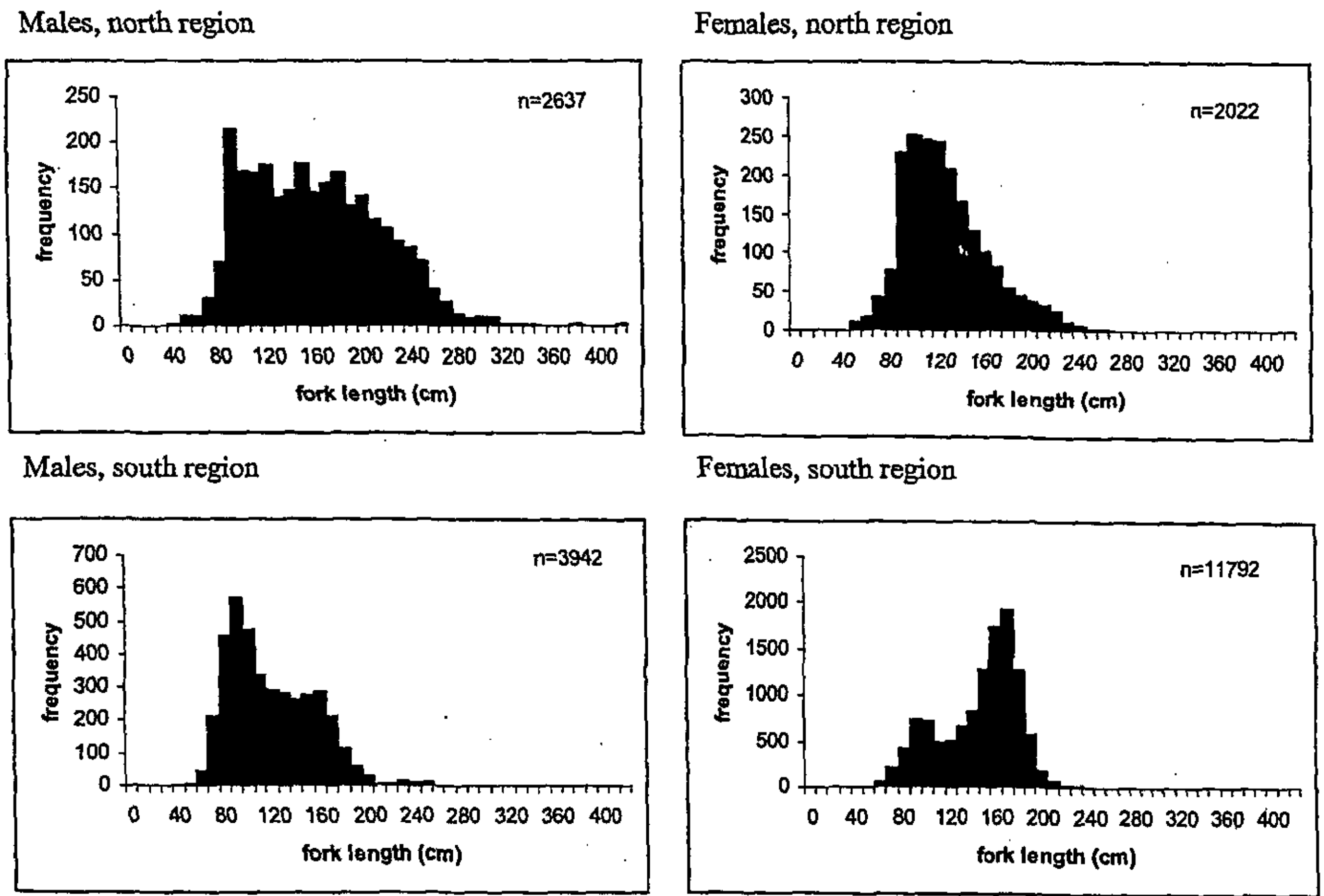
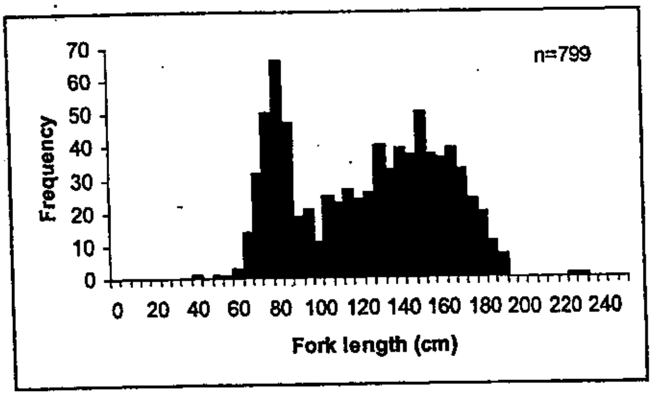
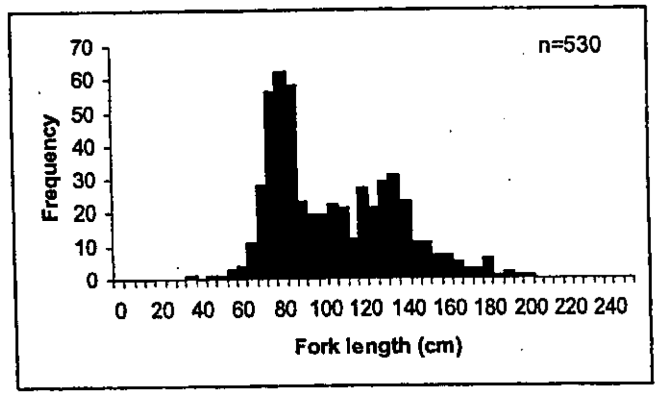


Figure 9: Length-frequency distributions of blue shark by sex and region. Pooled data from 1992–93 to 2001–02. n= sample size.

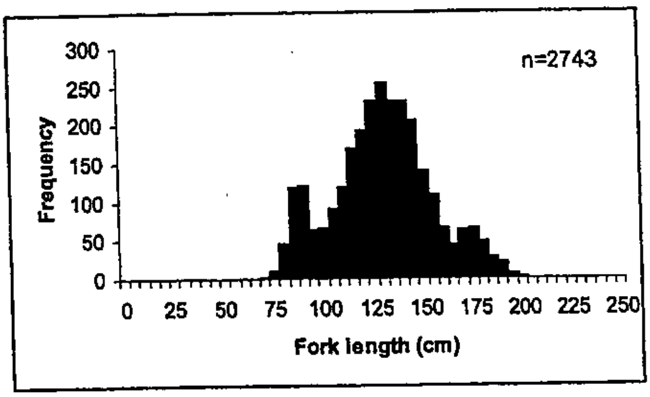
Males, North region



Females, North region



Males, South region



Females, South region

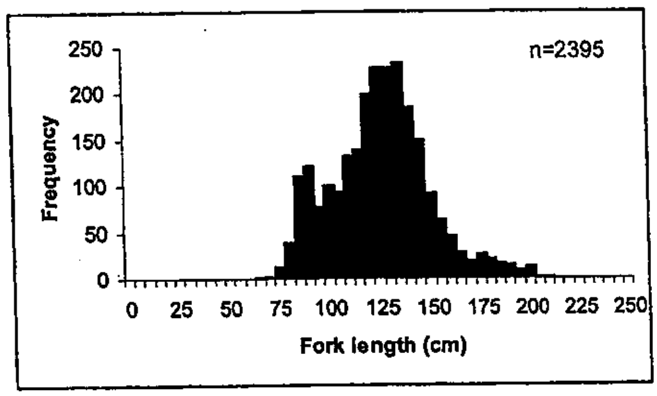


Figure 10: Length-frequency distributions of porbeagle sharks by sex and region. Pooled data from 1992–93 to 2001–02. n=sample size.

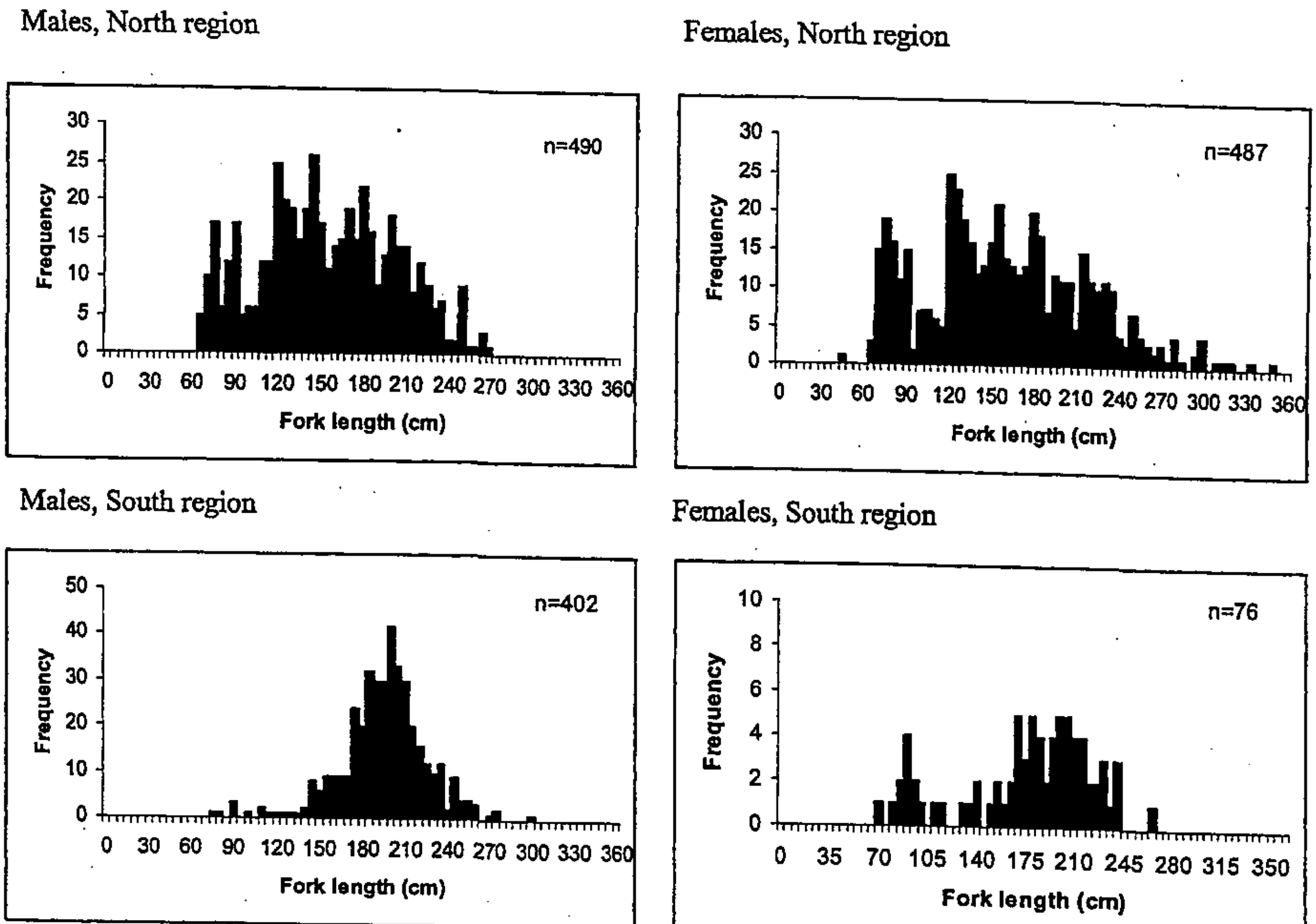
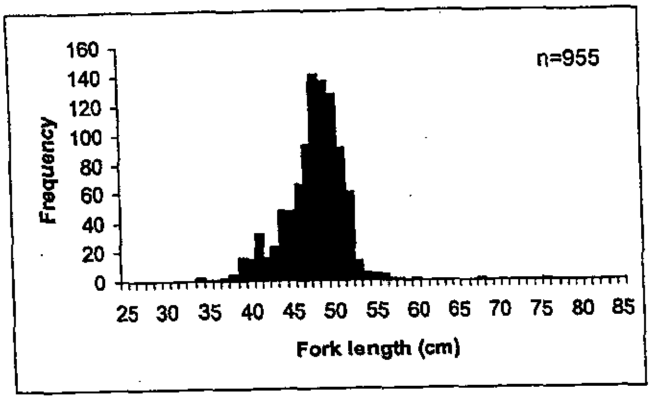
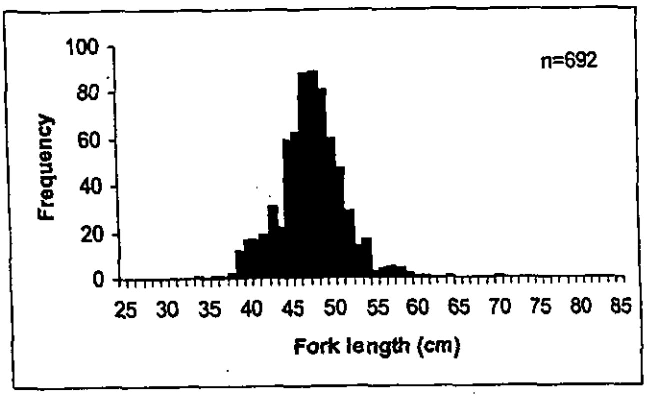


Figure 11: Length-frequency distributions of mako sharks by sex and region. Pooled data from 1992–93 to 2001–02. n= sample size.

Ray's bream
Males, south region



Females, south region



All, north region

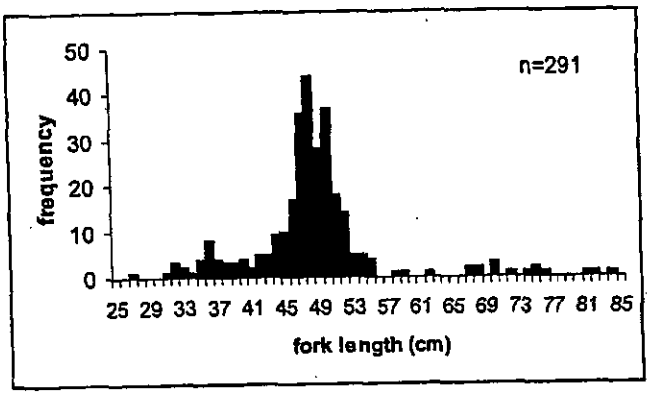


Figure 12: Length-frequency distributions of Ray's bream by sex and region. Pooled data from 1992–93 to 2001–02. n= sample size.

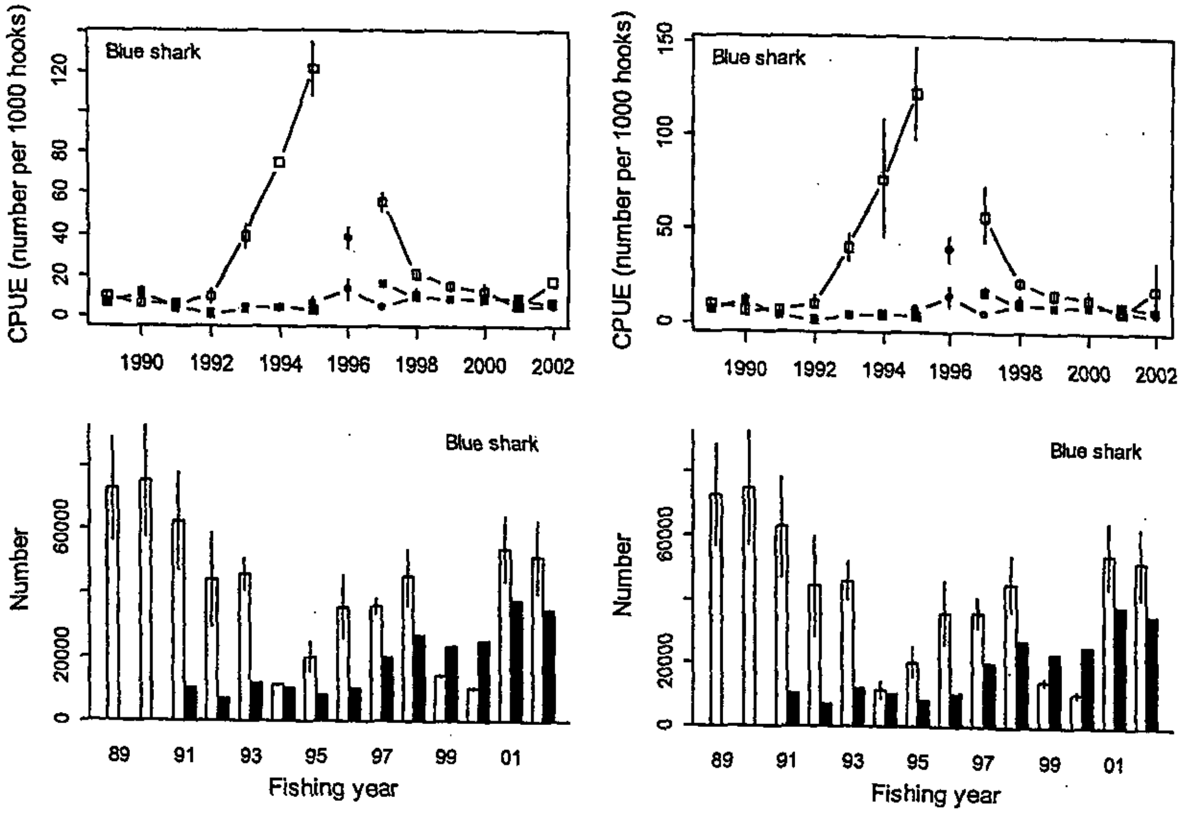


Figure 13: Comparison of analytical (left panels) and bootstrap (right panels) estimates of variance for CPUE and total catch of blue shark. Analytical variances are calculated with Equation 4. -■- *foreign and charter* south; -□- *foreign and charter* north; -●- *domestic* south; -○- *domestic* north. Empty bars are estimated catch, black bars are reported catch.

Appendix 1: Estimated catch of bycatch species (in thousands of fish). ***Domestic*** **data were not used in 1998–99 and 1999–2000; results for these years are not complete.**

Fishing year	Blue shark	Porbeagle shark	Mako shark	Mako & porbeagle sharks	Deepwater dogfish	School shark
1988–89	72.74	0.00	0.00	8.85	0.77	0.88
1989–90	75.14	0.00	0.00	14.48	0.22	2.51
1990–91	62.66	0.00	0.00	10.13	0.00	0.62
1991–92	44.68	0.00	0.00	14.51	2.41	1.36
1992–93	46.23	7.46	0.65	8.11	2.34	0.73
1993–94	11.16	1.18	0.15	1.33	0.22	0.42
1994–95	20.25	2.79	1.57	5.10	1.43	1.10
1995–96	35.73	8.97	4.13	13.10	0.13	0.33
1996–97	35.94	4.44	2.71	7.15	0.73	0.71
1997–98	45.03	3.91	3.03	6.95	0.91	0.25
1998–99	14.29	3.98	0.35	4.32	1.88	0.53
1999–00	10.23	1.66	0.15	1.81	0.78	0.21
2000–01	53.95	3.72	9.30	13.03	0.19	0.70
2001–02	51.49	3.12	7.20	10.32	0.39	0.16

	Albacore tuna	Southern bluefin tuna	Broadbill swordfish	Butterfly tuna	Bigeye tuna	Yellowfin tuna
1988–89	31.85	11.29	5.84	7.19	0.78	0.00
1989–90	49.22	22.68	8.25	5.37	0.90	0.27
1990–91	54.85	32.24	7.12	6.97	5.67	0.02
1991–92	41.69	10.09	5.55	2.99	0.22	0.00
1992–93	8.65	6.76	0.59	0.98	0.10	0.00
1993–94	1.07	4.80	0.09	0.13	0.06	0.00
1994–95	35.29	5.16	0.62	0.25	2.00	4.81
1995–96	89.20	0.93	1.17	0.02	1.23	7.10
1996–97	88.93	4.67	2.91	0.95	1.75	4.87
1997–98	107.99	4.20	8.05	0.56	2.90	3.05
1998–99	2.83	4.09	0.48	0.51	0.47	0.00
1999–00	1.65	3.07	0.38	0.52	0.13	0.02
2000–01	203.36	5.37	18.69	0.71	6.41	11.58
2001–02	91.57	6.03	12.99	0.73	6.97	5.19

	Ray's bream	Dealfish	Oilfish	Moonfish	Lancetfish	Rudderfish	Striped marlin
1988–89	13.24	0.77	3.45	3.02	0.50	0.03	0.00
1989–90	11.47	0.52	5.66	4.23	0.73	0.23	0.17
1990–91	11.05	0.67	12.49	11.19	1.69	0.00	0.06
1991–92	12.28	4.27	15.68	4.71	0.83	0.92	0.00
1992–93	9.37	0.92	1.70	1.23	0.62	0.64	0.02
1993–94	13.86	0.67	0.17	0.43	0.07	0.10	0.01
1994–95	9.35	3.30	0.55	4.28	9.02	0.39	0.76
1995–96	3.61	0.37	2.06	1.54	7.17	1.20	1.49
1996–97	8.94	5.32	2.23	2.81	14.51	1.64	0.72
1997–98	4.77	2.76	2.67	7.74	13.52	1.85	1.62
1998–99	4.15	1.38	0.40	0.99	0.50	1.10	0.00
1999–00	3.46	2.06	0.18	0.87	0.10	0.75	0.00
2000–01	4.79	2.16	6.51	7.34	59.76	1.74	2.61
2001–02	16.80	0.95	5.72	16.14	110.83	3.73	0.70