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Trawl survey of middle depth species in the Southland and Sub-Antarctic areas, November–December 2003 (TAN0317)

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EXECUTIVE SUMMARY

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This report presents results from the summer 2003 trawl survey of the Southland and Sub-Antarctic areas. The 2003 survey, the seventh in the summer time series, was carried out from 11 November to 11 December. A total of 81 trawls was successfully completed in 20 strata. All contracted objectives were met, despite some survey time being lost.

Biomass estimates (and c.v.s) were 14 700 t (12.6%) for hoki, 22 200 t (10.2%) for ling, and 1900 t (20.6%) for hake. Estimated hoki biomass in 2003 was less than 20% of the hoki biomass observed in trawl surveys of the Southland and Sub-Antarctic areas in the early 1990s and only 36–37% of the estimates from the two previous summer surveys in 2001 and 2002. Biomass estimates for hake and ling from all strata in 2003 were also lower than equivalent estimates from the previous summer survey in November–December 2002, but the decline in biomass for these species was much smaller than that observed for hoki. Gear performance was similar to that in other surveys in the time series and there was no evidence for a decrease in trawl catchability in 2003 that would bias trawl survey results.

The hoki catch was still dominated by fish from the strong 1991–94 year-classes, seen in 2003 as 9–12 year-olds. Recent recruitment of hoki to the Sub-Antarctic has been weak, but some very small (30–43 cm) hoki from the 2002 year-class were caught at Puysegur during the 2003 survey. The 2000 year-class, which was relatively abundant on the Southern Plateau at age 2 in 2002, was less abundant at age 3 and much weaker than the strong 1992 and 1994 year classes were at the equivalent age. Hoki condition indices in 2003 were similar to those recorded in 2001 and 2002. Most ling were between 50 and 100 cm and aged 4–10. The length and age distributions for hake were broad with no clear modes.

Acoustic data were also collected during the trawl survey. Bad weather conditions with rough seas for most of the voyage meant that the quality of acoustic recordings was poor. There was a weak positive correlation between acoustic density close to the bottom and trawl catch rates.

1. INTRODUCTION

Trawl surveys of the Southland and Sub-Antarctic region provide fishery-independent abundance indices for hoki, hake, and ling. Hoki supports New Zealand's largest fishery with a TACC in 2003–04 of 180 000 t. The Southland and Sub-Antarctic region is believed to be the principal residence area for the hoki that spawn off the west coast of the South Island in winter (Annala et al. 2004). Catches of western hoki from adult spawning and residence areas combined made up about 54% of the total hoki catch in 2002–03, with about 26 000 t taken in the southern region (including Puysegur) (O'Driscoll et al. 2004). Hake and ling are also important commercial species in the Southland and Sub-Antarctic, with catches of 2500 t of hake and 8700 t of ling in 2001–02 (Annala et al. 2004).

Two time series of trawl surveys have been carried out from *Tangaroa* in the Southland and Sub-Antarctic region (collectively referred to as the Southern Plateau): a summer series in November–December 1991, 1992, 1993, 2000, 2001, and 2002; and an autumn series in March–June 1992, 1993, 1996 and 1998 (see review by O'Driscoll & Bagley 2001). The main focus of the early surveys (1991–1993) was to estimate the abundance of hoki. The surveys in 1996 and 1998 were developed primarily to estimate the abundance of hake and ling. Autumn was chosen for these species as the biomass estimates were generally higher and more precise at this time of year. Autumn surveys also allowed the proportion of hoki maturing to spawn to be estimated (Livingston et al. 1997, Livingston & Bull 2000).

In 2000, the timing of the trawl survey was moved back to November–December for two reasons. First, the Hoki Working Group wanted to obtain an estimate of total adult hoki biomass at a time when abundance should be maximal in Southland and the Sub-Antarctic. Interpretation of trends in the autumn trawl survey series was complicated by the possibility that different proportions of the hoki adult biomass may have already left the survey area to spawn. Second, there was concern that hake age structure was not well represented by the small number of otolith samples collected in autumn surveys. The longer daylight hours in December allow more stations to be occupied than in April, so more hake samples are likely to be taken.

Hoki biomass estimates from the last three Southern Plateau surveys were the lowest in the summer time series, and only 40–60% of the biomass observed in surveys in the early 1990s (O'Driscoll et al. 2002, O'Driscoll & Bagley 2003a, 2003b). Biomass estimates for hoki, hake, and ling all decreased by 24–30% from 2000 to 2001 (O'Driscoll & Bagley 2003a). This decline was confirmed in 2002, when estimates for hoki and ling were similar to those in 2001 (O'Driscoll & Bagley 2003b). Hake biomass continued to decrease from 2001 to 2002, and the 2002 estimate was the lowest in the summer series (O'Driscoll & Bagley 2003b).

The stock status for western hoki stock from the 2003 assessment suggested that current biomass was 25–35% B_0 and that recent recruitment (1995–2001) has been poor (Annala et al. 2003). The 2003 trawl survey, carried out from 11 November to 11 December 2003 (TAN0317) provided a seventh summer estimate of western hoki biomass in time for the 2004 assessment.

2. METHODS

2.1 Survey design

As in previous years, the survey was a two-phase stratified random design (after Francis 1984). The survey area was divided into 21 strata by depth (300–600, 600–800, and 800–1000 m) and area (Figure 1). There were 15 core 300–800 m strata (Strata 1 to 15) which have been surveyed in all previous summer and autumn surveys. Strata 3 and 5 have been subdivided since 2000 to increase sampling in the region where hake and ling aggregations were thought to occur (Bull et al. 2000). Deeper 800–1000 m strata (Strata 25–28) have been surveyed since 1996. There is no 800–1000 m stratum along the eastern side of the survey area as catches of hake, hoki, and ling from adjacent strata are small. Known areas of foul ground were excluded from the survey.

The allocation of stations in Phase 1 was based on a statistical analysis of catch rate data from the most recent surveys in 2000–02 using the procedure of Bull et al. (2000). A minimum of three stations per stratum was used. Conservative target c.v.s of 17% for hake and 12% for hoki and ling were used in the statistical analysis to increase the chance that the usual Ministry of Fisheries target c.v.s of 20% for hake and 15% for hoki and ling would be met. Additional stations were added to some strata outside the statistical framework because of the need to focus effort on covering the full distributional range of hake age classes. A total of 92 stations was originally planned for Phase 1 (Table 1), with Phase 2 stations to be allocated at sea to improve c.v.s for hoki, hake, and ling, and to increase the number of hake sampled.

About 63 h of survey time were lost on 17–20 November because *Tangaroa* had to assist in a search and rescue operation. This meant that the 92 phase 1 stations proposed for the survey (Table 1) could not be completed. A revised station allocation of 80 phase 1 stations was discussed and agreed with MFish following the operation (Table 1). The key components of the revised allocation were to drop Stratum 26, where very few hoki, hake, or ling were caught in the last three years, and to remove the additional stations (primarily round the Stewart-Snares area) which were added to boost the number of hake sampled. The revised allocation should not affect the relative abundance indices for hoki, hake, and ling as only core strata are currently used in the stock assessment.

2.2 Vessel and gear specifications

Tangaroa is a purpose-built research stern trawler of 70 m overall length, a beam of 14 m, 3000 kW (4000 hp) of power, and a gross tonnage of 2282 t.

The trawl was the same as that used on previous surveys of middle depth species by *Tangaroa*. The net is an eight-seam hoki bottom trawl with 100 m sweeps, 50 m bridles, 12 m backstrops, 58.8 m groundrope, 45 m headline, and 60 mm codend mesh (see Chatterton & Hanchet (1994) for net plan and rigging details). The trawl doors were Super Vee type with an area of 6.1 m^2. Measurements of doorspread (from a Scanmar 400 system) and headline height (from a Furuno net monitor) were recorded every 5 min during each tow and average values calculated.

2.3 Trawling procedure

Trawling followed the standardised procedures described by Hurst et al. (1992). Station positions were selected randomly before the voyage using the Random Stations Generation Program (Version 1.6) developed at NIWA, Wellington. A minimum distance between stations of 3 n. miles was used. If a station was found to be on foul ground, a search was made for suitable ground within 3 n. miles of the station position. If no suitable ground could be found, the station was abandoned and another random position was substituted. Tows were carried out during daylight hours (as defined by Hurst et al. 1992), with all trawling between 0441 h and 2030 h NZST, except for two tows which were carried out at night in Stratum 25 to increase the numbers of hake otoliths collected. These two night tows were not used for biomass estimation. At each station the trawl was towed for 3 n. miles at a speed over the ground of 3.5 knots. If foul ground was encountered, or the tow hauled early due to reducing daylight, the tow was included as valid only if at least 2 n. miles had been covered. If time ran short at the end of the day and it was not possible to reach the last station, the vessel headed towards the next station and the trawl was shot on that course before 1900 h NZST, if at least 50% of the steaming distance to the next station was covered.

Towing speed and gear configuration were maintained as constant as possible during the survey, following the guidelines given by Hurst et al. (1992). The average speed over the ground was calculated from readings taken every 5 min during the tow.

2.4 Acoustic data collection

Acoustic data were collected during trawling and while steaming between trawl stations (both day and night) using a custom-built *CREST* system (Coombs et al. 2003) with hull-mounted Simrad single-beam 12 kHz and 38 kHz transducers. *CREST* is a computer-based 'software echo-sounder' which supports multiple channels. The transmitter was a switching type with a nominal power output of 2 kW rms. Transmitted pulse length was 1 ms with 3 s between transmits. The *CREST* receiver has a broadband, wide dynamic range pre-amplifier and serial analog-to-digital converters (ADCs), which feed a digital signal processor (DSP56002). Data from the ADCs were complex demodulated, filtered, and a 20 log *R* time-varied gain was applied. The results were then shifted to give 16-bit resolution in both the real and imaginary terms and the complex data stored for later processing. The 38 kHz transducer was calibrated before the survey following standard procedures (Foote et al. 1987). The 12 kHz transducer was not calibrated. Data collected on 12 kHz were used only to make visual comparisons with 38 kHz data and were not analysed quantitatively.

2.5 Hydrology

Temperature and salinity data were collected using a calibrated Seabird SM-37 Microcat CTD datalogger (serial number 2958) mounted on the headline of the trawl. Data were collected at 5 s intervals throughout the trawl, providing vertical profiles. Surface values were read off the vertical profile at the beginning of each tow at a depth of about 5 m, which corresponded to the depth of the hull temperature sensor used in previous surveys. Bottom values were about 7.0 m above the sea-bed (i.e., the height of the headline).

2.6 Catch and biological sampling

At each station all items in the catch were sorted into species and weighed on Seaway motion-compensating electronic scales accurate to about 0.3 kg. Where possible, finfish, squid, and crustaceans were identified to species and other benthic fauna to species or family. Unidentified organisms were collected and frozen at sea. Specimens and digital photographs are being stored at NIWA for subsequent identification.

An approximately random sample of up to 200 individuals of each commercial, and some common non-commercial, species from every successful tow was measured and sex determined. More detailed biological data were also collected on a subset of species and included fish weight, sex, gonad stage, gonad weight, and occasional observations on stomach fullness, and contents and prey condition. Otoliths were taken from hake, hoki, and ling for age determination. A description of the macroscopic gonad stages used for the three main species is given in Appendix 1.

The summer survey series does not currently provide any information on the annual proportion of hoki spawning. In 2001 and 2002, O'Driscoll & Bagley (2003a, 2003b) observed that hoki that were classified macroscopically as spent or partially spent appeared to have lower liver condition than fish of other macroscopic stages. Liver and gutted weights were recorded from 20 hoki per station to determine condition indices. Female gonads from the subset of hoki with recorded organ weights were preserved in formalin and are available for future microscopic examination.

2.7 Estimation of biomass and length frequencies

Doorspread biomass was estimated by the swept area method of Francis (1981, 1989) using the formulae in Vignaux (1994). Biomass and coefficient of variation (c.v.) were calculated by stratum for major species. The group of 'major' species was defined by O'Driscoll & Bagley (2001), and includes 11 commercial species (hoki, hake, ling, southern blue whiting, pale ghost shark, dark ghost shark, spiny dogfish, black oreo, lookdown dory, ribaldo, white warehou) and one non-commercial species (javelinfish).

The catchability coefficient (an estimate of the proportion of fish in the path of the net which is caught) is the product of vulnerability, vertical availability, and areal availability. These factors were set at 1 for the analysis, the assumptions being that fish were randomly distributed over the bottom, that no fish were present above the height of the headline, and that all fish within the path of the doors were caught.

Scaled length frequencies were calculated for the major species with the Trawlsurvey Analysis Program, version 3.2 (Vignaux 1994), using length-weight data from this survey.

Data from all daytime stations where the gear performance was satisfactory (codes 1 or 2) were included for estimating biomass and calculating length frequencies.

2.8 Estimation of numbers at age

Hoki, hake, and ling otoliths were prepared and aged using validated ageing methods (hoki, Horn & Sullivan (1996) as modified by Cordue et al. (2000); hake, Horn (1997); ling, Horn (1993)).

Subsamples of 750 hoki otoliths and 600 ling otoliths were selected from those collected during the trawl survey. Subsamples were obtained by randomly selecting otoliths from 5 cm length bins covering the bulk of the catch and then systematically selecting additional otoliths to ensure the tails of the length distributions were represented. The numbers aged approximated the sample size necessary to produce mean weighted c.v.s of less than 20% across all age classes. All hake otoliths were read.

Numbers at age were calculated from observed length frequencies and age-length keys using customised NIWA catch-at-age software (Bull & Dunn 2002). For hoki, this software also applied the 'consistency scoring' method of Francis (2001), which uses otolith ring radii measurents to improve the consistency of age estimation.

2.9 Acoustic data analysis

Acoustic recordings made during the trawl survey (both during trawls and while steaming between stations) were visually examined. Marks were classified based on the relative depth of the mark in the water column, mark orientation (surface- or bottom-referenced), mark structure (layers, schools, or single targets), and the relative strength of the mark on 38 kHz and 12 kHz (see O'Driscoll (2001) for details). Descriptive statistics were produced on the frequency of occurrence of different mark types. As part of the qualitative description, the quality of acoustic data recordings was subjectively classified as 'good', 'marginal', or 'poor' (Appendix 2). Only good or marginal quality recordings were considered suitable for quantitative analysis.

A quantitative analysis was carried out to compare acoustic backscatter from bottom-referenced marks with previous surveys. Acoustic data collected on 38 kHz during each trawl were integrated using custom Echo Sounder Package (ESP2) software (McNeill 2001) to calculate the mean acoustic backscatter per square kilometre from bottom-referenced marks. Two values of acoustic backscatter were calculated for each trawl. The first estimate was based an integration height of 10 m above the acoustic bottom, which was similar to the measured headline height of the trawl (average 7.0 m). The second acoustic estimate integrated all backscatter from the bottom up to the maximum height of the bottom referenced mark or 100 m, but excluded all other mark types.

3. RESULTS

3.1 Survey coverage

The trawl survey and acoustic work contracted for this voyage were successfully completed. Some survey time was lost due to bad weather and responding to the search and rescue call-out. The search and rescue operation took 63 h (see Section 2.1) and there were about 94 h when it was too rough to trawl. High winds and large swells also slowed the vessel down when steaming, reducing the number of stations able to be completed in a day.

A total of 81 successful trawl survey stations was completed in 20 strata (Figure 2, Table 1). The revised station allocation was achieved with the exception of one station in Stratum 6, which was dropped due to time constraints and weather (Table 1). No Phase 2 stations were completed. The total survey area covered was 288 417 km^2 (excluding Stratum 26) with an average station density of 1:3561 km^2. A further five stations were excluded from the biomass estimation. Three tows (Stations 38, 55, 59) did not meet standard trawl criteria due to incorrect depth, foul ground or net damage. The other two trawls (65, 71) were carried out at night in Stratum 25 to increase numbers of hake otoliths collected.

3.2 Gear performance

Gear parameters by depth and for all observations are summarised in Table 2. The headline height was obtained on 80 of the 81 successful tows, but the doorspread sensors failed early in the survey resulting in doorspread readings for just 13 tows. In previous surveys, missing doorspread values were estimated from data collected in the same depth range during that voyage (e.g., O'Driscoll & Bagley 2003b). However, in 2003 there were too few measured values to accurately estimate average values in each depth range (Table 2). Instead, we carried out a regression analysis using doorspread measurements from all previous Sub-Antarctic surveys. Missing doorspreads in 2003 were predicted from a linear model which related doorspread to warp length, vessel speed, headline height, swell height (3-stage categorical variable: swells 0–2 m, 2–4 m, over 4 m), sea state (10-stage categorical variable analogous to the Beaufort scale), and water depth (Table 3). Headline height, swell height, and vessel speed were found to be significant predictive variables (Table 3) and the regression model explained 41% of the variance in doorspread. This analysis assumed that the relationship between doorspread and the other variables was not survey dependent.

Measured gear parameters in 2003 were similar to those obtained on other voyages of *Tangaroa* in this area when the same gear was used (Table 4).

3.3 Catch

A total catch of 35.8 t was recorded from all successful trawl stations (Table 5). Of the 162 species or species groups caught, 84 were teleosts, 22 elasmobranchs, 13 cephalopods, 18 crustaceans, and 14 echinoderms (Appendix 3). The main species by weight in the catch were ling (17.1%), hoki (14.2%), *Pyrosoma* salps (14.2%), black oreo (13.4%), javelinfish (4.7%), longnose velvet dogfish (4.4%), pale ghost shark (4.2%), hake (3.6%), and spiny dogfish (3.5%) (Table 5).

3.4 Biomass estimates

Total survey biomass estimates for commercial species and the most abundant non-commercial species are given in Table 5, and biomass estimates are presented by stratum for the 12 major species in Table 6. Subtotals are given for the core 300–800 m depth range (Strata 1–15) and core + Puysegur 800–1000 m (Strata 1–25) in Table 6 to allow comparison with results of previous surveys where not all deep (800–1000 m) strata were surveyed (O'Driscoll & Bagley 2001).

The core biomass estimate for hoki in 2003 was only 36–37% of the estimates from the two previous summer surveys in 2001 and 2002, and was by far the lowest observed in both the summer and autumn trawl time-series (Figure 3, Table 7). Estimated hoki biomass in 2003 was less than 20% of the hoki biomass observed in trawl surveys of the Southland and Sub-Antarctic areas in the early 1990s (Table 7).

The biomass estimate for ling in 2003 was also lower than that from 2002, but the 13% drop in ling biomass was much smaller than the 64% decline observed for hoki (Table 7). Ling biomass in 2003 was the second lowest estimate in the summer trawl series (after 1992) and was lower than in all autumn surveys (Figure 3).

Biomass of hake in the core 300–800 m strata in 2003 was slightly higher than that in 2002, but there was a small (7%) decline in biomass over all strata due to lower densities of hake in Strata 25 and 28 (see Table 6). The exclusion of Stratum 26 in the 2003 survey did not affect the overall hake biomass estimate as no hake were caught in this stratum in 2001 or 2002 (O'Driscoll & Bagley 2003a, 2003b).

Biomass estimates in core strata for five of the nine other major species increased from 2002 to 2003 (Figure 3), suggesting that there was not a major decline in trawl catchability in 2003. Biomass estimates for species which were relatively well estimated by the trawl survey (low c.v.s), like javelinfish (up 1%), ribaldo (no change), and pale ghost shark (up 13%), were similar in 2002 and 2003 (Figure 3).

3.5 Species distribution

The distribution and catch rates at each station for hoki, hake, and ling are given in Figures 4–6. Hoki were widespread throughout the core 300–800 m survey area, occurring in 77 of the 81 trawl stations. As in previous surveys (see review by O'Driscoll & Bagley 2001), hoki catch rates were generally higher in the west, on the Stewart-Snares shelf, on the western side of the Campbell Rise, and at Puysegur (Figure 4a). Large catches (more 300 kg) of small (1 year-old) hoki were made at the four stations in Stratum 1 (300–600 m) at Puysegur (Figure 4b). Hake were concentrated in deeper water (more than 600 m) at Puysegur and on the western part of the Stewart-Snares shelf (Figure 5). About 30% of the hake biomass was from the 800–1000 m depth range (see Table 5). Ling were widely distributed over most of the survey area between 300–800 m, with highest catch rates at Puysegur and on the Stewart-Snares shelf (Figure 6). Both hoki and ling were seldom caught deeper than 800 m.

3.6 Biological data

The numbers of fish of each species measured or selected for biological analysis are shown in Table 8. Pairs of otoliths were removed from 1197 hoki, 1085 ling, and 424 hake. Length-weight relationships used to scale length frequency data are given in Table 9. Length frequency histograms by sex for hoki, hake, and ling are compared to those observed in previous surveys in Figures 7–9. Length frequencies for the other major species are shown in Figure 10.

Hoki length frequencies in 2003 (see Figure 7) showed an adult mode centred on about 87 cm for males and about 91 cm for females. Ageing shows that these are mostly fish from the strong year classes in 1991–94 seen in 2003 as 9–12 year olds (Figure 11). There were few hoki from the 2000 year-class (Figure 11). Although this year-class was relatively abundant on the Southern Plateau at age 2 in 2002, the numbers at age 3 were very much lower than for the strong 1992 and 1994 year classes in autumn 1996 and 1998 respectively (Figure 11). Relatively high numbers of small (less than 43 cm) 1+ hoki from the 2002 year-class were caught during the survey, but these came from only one stratum at Puysegur. Although these small hoki were the most abundant year-class by number in the 2003 survey (Figure 11) they contributed little to the biomass.

The length frequency distribution of hake was broad with no clear modes (see Figure 8). As in previous surveys, small hake (50–70 cm) tended to occur outside the core strata in 800–1000 m depth. Most hake caught in 2003 were younger than age 10 (Figure 12).

The length frequency distribution of ling was similar to that observed in the three previous surveys, with modal lengths of 50–90 cm for males and 50–100 cm for females (see Figure 9). Most ling were ages 4–10 (Figure 13). The number of large ling older than age 16 appears to have decreased since surveys in the 1990s.

The length frequency distribution of southern blue whiting in 2003 was bimodal (see Figure 10) with modes at 30 cm (both sexes) and 40 cm (males) or 42 cm (females). Southern blue whiting were smaller than in the 2002 survey, when the modal length was 44 cm for males and 48 cm for females (O'Driscoll & Bagley 2003b), and there was a higher proportion of young (less than 35 cm) fish in 2003 which may indicate an incoming year-class. The size of black oreo was similar to that observed in the three previous surveys, with modal lengths of 34 cm for males and 29 cm for females (see Figure 10). Other points of interest in Figure 10 were the bimodal distribution of female spiny dogfish and the apparent modes in the length distributions of female ribaldo and male lookdown dory. Similar patterns were observed in the length distributions for these species in 2001 (O'Driscoll & Bagley 2003a) and 2002 (O'Driscoll & Bagley 2003b).

Gonad stages for hoki, hake, and ling are summarised in Table 10. Most (59%) hoki were in the resting phase, with a significant proportion of immature fish (30%), many of which were from the 2002 year-class. About 3% of female hoki were macroscopically staged as spent, and 20% of male hoki still exuded milt and were classified as partially spent. About 11% of female ling and 52% of male ling were observed in spawning condition (ripe and running ripe), suggesting that some spawning was occurring at the time of the trawl survey. A third of the male hake sampled were ripe or running ripe, but the majority of females were immature (44%), resting (22%), or ripening (30%).

3.7 Hoki condition indices

Liver and gutted weights were recorded from 945 hoki. Hoki liver condition index (LCI = liver weight divided by gutted weight) and somatic condition factor (CF = gutted weight divided by length cubed) were similar to 2001 and 2002 (Table 11). There was no evidence that hoki were in poor condition during the 2003 survey.

As in 2001 and 2002, female hoki that were macroscopically staged as spent (stage 7) tended to have lower LCI (average LCI = 2.4%, n = 29) than resting (stage 2) females (average LCI = 2.9%, n = 597, t-test $p < 0.05$), suggesting that fish that have recently spawned may have lower condition than fish that either spawned earlier or did not spawn. Objective 6 of MFish project MDT2003/01 will microscopically examine gonad tissue samples from female hoki collected in Sub-Antarctic trawl surveys from 2001–03 and by fisheries observers in 2003–04 to further investigate whether condition indices can be used to indicate the annual proportion spawning.

3.8 Acoustic results

A total of 169 acoustic data files (83 'trawl' files and 86 'steam' files) was recorded during the trawl survey. Bad weather conditions with rough seas for most of the voyage meant that the quality of acoustic recordings was lower than in previous surveys (Table 12). In surveys from 2000 to 2002, between 57 and 78% of recordings were good quality and 10–22% were poor. In 2003, only 37% of the acoustic files were good, and 38% were considered too poor to be analysed quantitatively.

Mark types were generally similar to those described by O'Driscoll (2001) and O'Driscoll & Bagley (2003a, 2003b). The frequency of occurrence in 2003 of each of the eight mark categories described by O'Driscoll (2001) is given in Table 13. The most noticeable change in 2003 was a lower occurrence of pelagic schools and layers in daytime (day steam and trawl) recordings. Pelagic schools and layers probably contain mesopelagic fish species such as pearlsides (*Maurolicus australis*) and myctophids, which are important prey of hoki. The apparent decline in the occurrence of pelagic marks did not appear to have a major influence on hoki feeding as the proportion of hoki with empty stomachs in 2003 (54%) was only slightly higher than the proportion observed in the three previous summer surveys (43–51%). There was also a decrease in the occurrence of single targets close to the bottom in 2003 (Table 13). This was likely an artefact due to poor data quality in 2003 making it more difficult to recognise low densities of demersal fish.

The frequency of occurrence of other mark types was similar to that in previous surveys (Table 13). Surface layers shallower than 100 m were observed in almost all (90%) echograms from 2003. The identity of organisms in these surface layers is unknown because no tows were targeted at the surface. Acoustic scattering is probably contributed by a number of pelagic zooplankton (including gelatinous organisms such as salps) and fish. Bottom layers were observed in 67% of day steam files and 46% of trawl files in 2003. Bottom layers were usually associated with a mix of demersal fish species, but may also contain mesopelagic species when these occur close to the bottom (O'Driscoll 2002). There was a strong bottom layer present in trawl recordings from Puysegur (Stratum 1) where large catches of 1 year-old hoki were taken, but the quality of recordings was poor (Figure 14). Pelagic and bottom layers tended to disperse at night, to form pelagic and bottom clouds respectively. Most bottom-referenced schools were observed during the day in 300–600 m water depth. Bottom schools are sometimes associated with catches of southern blue whiting in the bottom trawl (O'Driscoll 2001).

Acoustic data from 48 'trawl' files were integrated. Data from the other 35 trawl recordings were not included in the quantitative analysis because the acoustic data were too noisy (see Appendix 2). Average acoustic backscatter from bottom-referenced regions was lower in 2003 than in 2000–02 (Table 14). This decrease in acoustic backscatter was consistent with the lower average trawl catch rates in the equivalent tows. Acoustic backscatter in the bottom 10 m in 2003 was in the range of previous surveys (Table 14). There was a weak positive correlation between acoustic backscatter and trawl catch rates (Figure 15). Trawl catch rates were more strongly correlated with total acoustic backscatter from bottom-referenced marks than with backscatter from the bottom 10 m only (Figure 15). This suggests that the trawl may be herding fish from more than 10 m above the bottom. Significant positive correlations were also observed between trawl and acoustic data in 2000 and 2001 (O'Driscoll 2002), but not in 2002, when O'Driscoll & Bagley (2003b) hypothesised that there may have been an increased proportion of mesopelagic species close to the bottom.

3.9 Hydrological data

Surface (5 m depth) temperatures ranged between 7.1 and 12.1 °C (Figure 16), while bottom temperatures were between 4.8 and 9.7 °C (Figure 17). Bottom temperature decreased with depth, with lowest bottom temperatures recorded from water deeper than 900 m on the northern and eastern margins of the Campbell Plateau. Highest surface and bottom temperatures were at Puysegur. There was a general trend of increasing water temperatures towards the north and west (Figures 16–17).

The average surface temperature in 2003 (8.8 °C) was 1.5° cooler than the average surface temperature in 2002 (10.3 °C). Vertical profiles of temperature (e.g., Figure 18) indicated that there was a deeper mixed layer in 2003 and 2002, probably due to surface mixing by the rough sea conditions. Average bottom temperatures were similar in 2003 (6.9 °C) and 2002 (6.7 °C). In both 2002 and 2003, temperatures were measuring using a calibrated CTD. It is difficult to compare temperatures with previous summer Sub-Antarctic surveys because temperature sensors were uncalibrated before 2002.

4. CONCLUSIONS

The 2003 survey met target c.v.s of 15% for hoki and ling and nearly achieved the target c.v. of 20% for hake. The biomass estimate for hoki in 2003 was the lowest observed in either the summer or autumn Sub-Antarctic trawl time-series and only 36–37% of the estimates from the two previous summer surveys in 2001 and 2002. Overall biomass estimates for hake and ling in 2003 were also lower than those from the 2002 survey, but the decline in biomass for these species was much smaller than that observed for hoki. The weather during the 2003 survey was poor, but there was no evidence for a decrease in trawl catchability, a change of gear performance, or unusual environmental conditions which could have biased trawl survey results. Commercial vessels in the survey area also reported very low catch rates.

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Table 1: Stratum areas, depths, and number of successful biomass stations from the 2003 Southern Plateau trawl survey. No Phase 2 stations were carried out.

Stratum	Name	Depth (m)	Area (km²)	Phase 1 stations: Original allocation	Phase 1 stations: Revised allocation	Phase 1 stations: Completed stations	Station density (km²)
1	Puysegur Bank	300–600	2 150	4	4	4	1 : 538
2	Puysegur Bank	600–800	1 318	4	4	4	1 : 330
3a	Stewart-Snares	300–600	4 548	4	3	3	1 : 1 516
3b	Stewart-Snares	300 -600	1 556	4	3	3	1 : 519
4	Stewart-Snares	600–800	21 018	5	3	3	1 : 7 006
5a	Snares-Auckland	600–800	2 981	4	3	3	1 : 994
5b	Snares-Auckland	600–800	3 281	3	3	3	1 : 1 093
6	Auckland Is.	300–600	16 682	5	5	4	1 : 4 171
7	South Auckland	600–800	8 497	3	3	3	1 : 2 832
8	N.E. Auckland	600–800	17 294	4	3	3	1 : 5 765
9	N. Campbell Is.	300–600	27 398	9	9	9	1 : 3 044
10	S. Campbell Is.	600–800	11 288	3	3	3	1 : 3 763
11	N.E. Pukaki Rise	600–800	23 008	4	4	4	1 : 5 752
12	Pukaki	300–600	45 259	8	8	8	1 : 5 657
13	N.E. Camp. Plateau	300–600	36 051	5	5	5	1 : 7 210
14	E. Campbell Plateau	300–600	27 659	4	4	4	1 : 6 915
15	E. Campbell Plateau	600–800	15 179	3	3	3	1 : 5 060
25	Puysegur Bank	800–1 000	1 928	5	4	4	1 : 482
26	S.W. Campbell Is.	800–1 000	31 778	3	0	0	–
27	N.E. Pukaki Rise	800–1 000	12 986	5	3	5*	1 : 2 597
28	E. Stewart Is.	800–1 000	8 336	3	3	3	1 : 2 779
Total•			288 417	92	80	81	1 : 3 561

* completed before Phase 1 stations were revised.
• excluding Stratum 26

Table 2: Survey tow and gear parameters (recorded values only). Values are number of tows (n), and the mean, standard deviation (s.d.), and range of observations for each parameter.

	n	Mean	s.d	Range
Tow parameters				
Tow length (n.miles)	81	2.98	0.10	2.46–3.06
Tow speed (knots)	81	3.5	0.09	3.1–3.6
Gear parameters (m)				
300–600 m				
Headline height	40	7.0	0.23	6.7–7.8
Doorspread	5	125.3	2.9	122.6–129.7
600–800 m				
Headline height	29	7.0	0.21	6.5–7.4
Doorspread	3	122.1	2.1	119.8–123.8
800–1000 m				
Headline height	11	7.1	0.14	6.9–7.3
Doorspread	5	121.6	4.8	117.3–128.2
All stations 300–1000 m				
Headline height	80	7.0	0.22	6.5–7.8
Doorspread	13	123.1	3.8	117.3–129.7

Table 3: Summary of regression model used to predict doorspreads for tows with missing values. Statistically significant predictive variables are shown in bold.

Predictive variable	Estimate	Standard error	t value	Significance (p value)
(Intercept)	189.800	10.130	18.739	<0.0001
warp length	-0.001	0.004	-0.150	0.881
vessel speed	**-5.386**	**2.005**	**-2.686**	**0.007**
headline height	**-8.703**	**0.556**	**-15.647**	**<0.0001**
factor(swell height)2	**1.691**	**0.461**	**3.669**	**<0.0001**
factor(swell height)3	**3.483**	**0.675**	**5.160**	**<0.0001**
factor(sea state)1	2.319	5.421	0.428	0.669
factor(sea state)2	1.816	5.314	0.342	0.733
factor(sea state)3	3.292	5.295	0.622	0.534
factor(sea state)4	4.434	5.303	0.836	0.403
factor(sea state)5	6.773	5.321	1.273	0.203
factor(sea state)6	4.581	5.420	0.845	0.398
factor(sea state)7	4.126	6.483	0.636	0.525
average bottom depth	0.012	0.007	1.573	0.116

Table 4: Comparison of doorspread and headline measurements from all surveys in the summer *Tangaroa* time-series. Values are the mean and standard deviation (s.d.). The number of tows with measurements (n) and range of observations is also given for doorspread.

	Doorspread (m)					Headline height (m)	
Survey	*n*	mean	s.d.	min	max	mean	s.d.
1991	152	126.5	7.05	106.5	145.5	6.6	0.31
1992	127	121.4	6.03	105.0	138.4	7.4	0.38
1993	138	120.7	7.14	99.9	133.9	7.1	0.33
2000	68	121.4	5.22	106.0	132.4	7.0	0.20
2001	95	117.5	5.19	103.5	127.6	7.1	0.25
2002	97	120.3	5.92	107.0	134.5	6.8	0.14
2003	13	123.1	3.80	117.3	129.7	7.0	0.22

Table 5: Biomass estimates, coefficients of variation, and catch of all commercial species and abundant (defined as catch over 100 kg) non-commercial species in the 2003 Sub-Antarctic trawl survey. Estimates are for all strata combined. Biomass estimates from 2002 (from O'Driscoll & Bagley 2003b) are shown for comparison.

		2003 (TAN0317)			2002 (TAN0219)		
Commercial species	Species code	Catch (kg)	Biomass (t)	c.v. (%)	Catch (kg)	Biomass (t)	c.v. (%)
Ling	LIN	6 107	22 192	10.2	10 271	25 635	10.1
Hoki	HOK	5 095	14 724	12.6	10 589	40 503	13.6
Black oreo	BOE	4 797	21 525	71.1	4 804	19 719	95.7
Pale ghost shark	GSP	1 497	10 360	8.7	1 723	9 297	9.3
Hake	HAK	1 297	1 898	20.6	2 354	2 037	16.3
Southern spiny dogfish	SPD	1 256	2 317	16.8	1 884	3 505	18.9
Smooth oreo	SSO	903	3 563	65.1	675	2 784	57.7
Southern blue whiting	SBW	361	3 058	28.8	686	6 517	38.2
Arrow squid	NOS	357	325	40.3	334	303	29.7
Ribaldo	RIB	221	696	17.9	404	722	16.2
Giant stargazer	STA	156	252	43.2	524	409	24.6
Orange roughy	ORH	150	153	56.5	122	292	52.7
Dark ghost shark	GSH	150	382	48.9	159	175	37.7
White warehou	WWA	139	709	58.4	919	863	23.9
Lookdown dory	LDO	127	636	23.7	128	446	22.1
Smooth skate	SSK	96	475	60.3	127	299	65.3
Red cod	RCO	71	140	49.3	47	60	35.5
Common warehou	WAR	71	56	91.7	0	0	–
Bluenose	BNS	44	28	72.9	13	8	100.0
Seal shark	BSH	43	21	85.9	81	26	60.0
Silver warehou	SWA	23	23	71.8	227	141	62.1
Rough skate	RSK	22	78	42.9	32	83	44.8
Southern Ray's bream	SRB	20	45	96.4	5	57	73.4
Hapuka	HAP	13	31	100.0	21	17	100.0
Sea perch	SPE	13	11	54.3	27	16	61.4
Gemfish	SKI	8	6	61.0	8	5	68.6
Cardinalfish	EPT	2	1	82.6	22	10	43.7
Non commercial species over 100 kg catch							
Pyrosoma salps	PYR	5 075	5 262	92.2	380	*	*
Javelinfish	JAV	1 676	7 713	10.1	2 915	7 525	10.7
Longnose velvet dogfish	CYP	1 590	2 112	28.3	864	2 293	13.4
Shovelnosed dogfish	SND	429	263	21.0	1 006	*	*
Baxter's dogfish	ETB	378	1 665	25.3	539	2 334	15.8
Ridge-scaled rattail	MCA	402	1 511	25.6	1 998	12 892	11.5
Oliver's rattail	COL	294	1 407	24.8	197	556	22.4
Warty squid	MIQ	287	1 629	12.8	285	1 414	10.6
Small-scaled slickhead	SSM	232	416	68.8	1 163	5 524	9.6
Leafscale gulper shark	CSQ	175	375	45.5	434	*	*
Oblique-banded rattail	CAS	169	905	25.1	541	1 418	34.2
Silverside	SSI	153	1 252	11.0	179	1 407	17.8
Banded rattail	CFA	150	826	16.1	176	696	23.9
Longnose chimaera	LCH	124	751	29.2	203	1 242	12.6
Spineback eel	SBK	113	655	56.0	138	*	*
Four rayed rattail	CSU	101	168	24.5	329	631	25.8
Total catch		35 769			50 423		

* Biomass not calculated by O'Driscoll & Bagley (2003b)

Table 6: Estimated biomass (t) and coefficients of variation (%, below in parentheses) of the twelve major species by stratum. Species codes are given in Table 5. Subtotals are provided for core strata (1–15) and core + Puysegur 800–1000 m (Strata 1–25).

Stratum	HOK	LIN	HAK	BOE	GSH	GSP
1	1 977	1 362	2	0	0.3	0
	(25)	(51)	(100)		(70)	
2	105	109	37	0	5	8
	(40)	(21)	(32)		(80)	(37)
3a	560	2 616	24	0	28	163
	(68)	(43)	(100)		(100)	(52
3b	112	171	75	0	78	0
	(41)	(37)	(100)		(83)	
4	1 265	1 453	62	0	0	971
	(61)	(14)	(100)			(22)
5a	203	251	535	0	0	28
	(30)	(16)	(43)			(67)
5b	116	242	36	0	0	194
	(55)	(29)	(75)			(35)
6	1 371	1 028	65	0	193	58
	(60)	(32)	(37)		(85)	(73)
7	389	322	210	0	0	88
	(64)	(10)	(81)			(46)
8	960	1 783	45	0	0	1 052
	(14)	(59)	(100)			(14)
9	1 756	3 898	66	0	39	1 079
	(27)	(24)	(51)		(100)	(18)
10	246	723	35	0	0	146
	(56)	(57)	(57)			(5)
11	1 085	778	0	4 634	0	404
	(40)	(60)		(100)		(48)
12	1 756	2 872	37	0	0	3 299
	(33)	(14)	(100)			(16)
13	1 061	2 615	0	0	0	1 697
	(41)	(24)				(30)
14	261	1 570	61	0	38	858
	(24)	(31)	(100)		(100)	(37)
15	1 096	382	46	6	0	128
	(75)	(69)	(100)	(100)		(55)
Subtotal (strata 1–15)	**14 318**	**22 174**	**1 335**	**4 642**	**382**	**10 172**
	(12.9)	**(10.2)**	**(24.1)**	**(99.8)**	**(48.9)**	**(8.9)**
25	72	4	337	0	0	3
	(64)	(69)	(61)			(52)
Subtotal (strata 1–25)	**14 390**	**22 178**	**1 672**	**4 642**	**382**	**10 175**
	(12.7)	**(10.2)**	**(22.9)**	**(99.8)**	**(48.9)**	**(8.9)**
26	-	-	-	-	0	0
27	199	0	127	16 826	0	62
	(49)		(64)	(87)		(49)
28	134	14	101	57	0	124
	(93)	(100)	(19)	(35)		(41)
Total (All strata)	**14 724**	**22 192**	**1 898**	**21 525**	**382**	**10 360**
	(12.6)	**(10.2)**	**(20.6)**	**(71.1**	**(48.9)**	**(8.7)**

Table 6 (cont): Estimated biomass (t) and coefficients of variation (%, below in parentheses) of the twelve major species by stratum. Species codes are given in Table 5. Subtotals are provided for core strata (1–15) and core + Puysegur 800–1000 m (Strata 1–25).

Stratum	JAV	LDO	RIB	SBW	SPD	WWA
1	13	9	0	0	460	1
	(43)	(39)			(23)	(100)
2	64	5	27	0	0	0.9
	(8)	(49)	(23)			(100)
3a	180	19	0	0	444	131
	(51)	(41)			(64)	(100)
3b	9	14	0.2	0	220	5
	(55)	(39)	(100)		(30)	(100)
4	648	8	76	0	31	0
	(59)	(100)	(53)		(52)	
5a	103	6	29	0	0	4
	(12)	(58)	(53)			(100)
5b	100	0	16	0	143	0
	(45)		(69)		(54)	
6	226	138	24	250	9	27
	(34)	(57)	(100)	(95)	(100)	(78)
7	445	28	100	0	0	0
	(45)	(100)	(26)			
8	570	0	80	0	298	0
	(31)		(33)		(54)	
9	631	0	70	82	145	0
	(37)		(52)	(40)	(42)	
10	624	14	92	0	0	0
	(31)	(73)	(68)			
11	977	137	112	0	80	0
	(21)	(73)	(66)		(61)	
12	1 198	182	4	1 731	411	503
	(34)	(35)	(100)	(35)	(30)	(78)
13	536	44	0	192	36	30
	(33)	(70)		(45)	(65)	(100)
14	192	17	0	802	41	8
	(37)	(100)		(72)	(100)	(100)
15	649	16	24	0	0	0
	(11)	(100)	(100)			
Subtotal (strata 1–15)	**7 165**	**636**	**653**	**3 058**	**2 317**	**709**
	(10.6)	**(23.7)**	**(18.9)**	**(28.8)**	**(16.8)**	**(58.4)**
25	194	0	28	0	0	0
	(60)		(39)			
Subtotal (strata 1–25)	**7 358**	**636**	**681**	**3 058**	**2 317**	**709**
	(10.5)	**(23.7)**	**(18.2)**	**(28.8)**	**(16.8)**	**(58.4)**
26	-	-	-	-	-	-
27	304	0	15	0	0	0
	(39)		(70)			
28	51	0	0	0	0	0
	(81)					
Total (All strata)	**7 713**	**636**	**696**	**3 058**	**2 317**	**709**
	(10.1)	**(23.7)**	**(17.9)**	**(28.8)**	**(16.8)**	**(58.4)**

Table 7: **Biomass estimates of hoki, hake, and ling for all surveyed strata and for core 300–800 m strata. Estimates from previous Sub-Antarctic surveys are provided for comparison.**

	Core strata (300–800 m)		All strata (300–1000 m)	
HOKI	Biomass	c.v. (%)	Biomass	c.v. (%)
Summer series				
1991	80 285	7		
1992	87 359	6		
1993	99 695	9		
2000	55 663	13	56 407	13
2001	38 145	16	39 396	15
2002	39 890	14	40 503	14
2003	14 318	13	14 724	13
Autumn series				
1992	67 831	8		
1993	53 466	10		
1996	89 029	9	92 650	9
1998	67 709	11	71 738	10
HAKE				
Summer series				
1991	5 553	44		
1992	1 822	12		
1993	2 286	12		
2000	2 194	17	3 103	14
2001	1 831	24	2 360	19
2002	1 293	20	2 037	16
2003	1 335	24	1 898	21
Autumn series				
1992	5 028	15		
1993	3 221	13		
1996	2 026	12	2 825	12
1998	2 506	18	3 898	16
LING				
Summer series				
1991	24 085	7		
1992	21 368	6		
1993	29 747	12		
2000	33 023	7	33 033	7
2001	25 059	7	25 167	6
2002	25 628	10	25 635	10
2003	22 174	10	22 192	10
Autumn series				
1992	42 334	6		
1993	33 553	5		
1996	32 133	8	32 363	8
1998	30 776	9	30 893	9

Table 8: Numbers of fish for which length, sex, and biological data were collected, - no data.

	Length frequency data				Length-weight data	
		No. of fish measured		No. of	No. of	No. of
Species	Total †	Male	Female	samples	fish	samples
Arrow squid	295	141	109	17	-	-
Banded rattail	1 552	11	17	48	390	9
Basketwork eel	26	1	1	3	2	1
Baxter's lantern dogfish	319	130	89	26	204	18
Black javelinfish	8	0	0	2	-	-
Black oreo	637	318	319	10	257	9
Bluenose	2	0	2	2	2	2
Blue warehou	16	4	12	2	16	2
Bollons's rattail	74	9	17	12	52	10
Brown ghost shark	1	0	1	1	-	-
Catshark	8	5	3	2	3	1
Dark ghost shark	176	112	64	13	176	13
Deepsea cardinalfish	21	1	2	3	-	-
Deepwater spiny dogfish	28	12	16	11	15	8
Four-rayed rattail	572	0	0	9	41	2
Gemfish	7	4	3	3	7	3
Giant stargazer	43	13	30	10	43	10
Hake	424	194	230	39	424	39
Hapuku	1	0	1	1	1	1
Hoki	2 323	896	1 425	78	1 330	77
Javelinfish	5 599	4	74	73	498	9
Johnson's cod	61	23	17	2	-	-
Kermadec rattail	16	0	0	4	10	2
Ling	2 463	1 292	1 170	72	1 325	72
Longnose velvet dogfish	454	208	246	15	234	10
Longnosed chimaera	19	8	11	5	7	3
Lookdown dory	128	60	67	34	126	33
Lucifer dogfish	24	14	11	8	19	4
Notable rattail	42	0	0	4	1	1
Oblique banded rattail	549	1	19	26	193	8
Oliver's rattail	2 045	5	1	38	173	6
Orange roughy	229	118	111	7	89	6
Pale ghost shark	861	420	439	67	644	52
Plunket's shark	11	3	8	6	10	6
Red cod	68	42	26	9	41	7
Ribaldo	144	32	112	35	130	33
Ridge-scaled rattail	244	83	154	22	118	17
Rough skate	9	4	5	7	9	7
Sea perch	11	3	8	2	11	2
Seal shark	15	3	12	4	10	3
Serrulate rattail	27	0	0	4	1	1
Shovelnosed dogfish	201	121	77	9	87	6
Silver warehou	20	8	12	3	20	3
Silverside	1 081	6	8	43	406	13
Small-scaled slickhead	179	78	101	5	43	3
Smooth oreo	644	340	304	9	294	8
Smooth skate	11	5	6	10	10	9
Smooth skin dogfish	31	12	19	5	19	3
Southern blue whiting	855	425	430	22	525	17
Southern rays bream	11	6	5	2	-	-
Spineback eel	17	1	13	4	14	2

Table 8 (cont): Numbers of fish for which length, sex, and biological data were collected, - no data.

Spiny dogfish	573	132	441	39	536	36
Two saddle rattail	1	0	1	1	1	1
Warty squid (*Moroteuthis ingens*)	99	13	65	32	91	31
Warty squid (*M. robsoni*)	4	1	3	4	4	4
White rattail	12	1	1	2	10	1
White warehou	104	71	33	14	101	12
Widenosed chimaera	1	0	1	1	1	1

† Total is sometimes greater than the sum of male and female fish due to the sex of some fish not recorded.

Table 9: Length-weight regression parameters* used to scale length frequencies for the twelve major species.

	Regression parameters				Length	
Species	*a*	*b*	r^2	*n*	range (cm)	Data source
Black oreo	0.009943	3.221040	0.89	257	23.4 – 38.9	TAN0317
Dark ghost shark	0.001205	3.399527	0.99	176	25.8 – 73.2	TAN0317
Javelinfish	0.000840	3.260928	0.97	481	18.5 – 54.3	TAN0317
Hake	0.002086	3.284013	0.97	422	47.8 – 128.3	TAN0317
Hoki	0.003975	2.922135	0.98	1 325	30.5 – 107.4	TAN0317
Ling	0.001789	3.220908	0.97	1 323	38.2 – 137.0	TAN0317
Lookdown dory	0.026336	2.974992	0.97	125	14.3 – 51.1	TAN0317
Pale ghost shark	0.009366	2.885588	0.97	643	31.1 – 86.4	TAN0317
Ribaldo	0.004590	3.218200	0.99	128	27.9 – 68.3	TAN0317
Southern blue whiting	0.002378	3.265098	0.98	525	25.3 – 53.0	TAN0317
Spiny dogfish	0.002135	3.163118	0.95	535	49.4 – 101.5	TAN0317
White warehou	0.014200	3.120743	0.98	101	29.8 – 58.7	TAN0317

* $W = aL^b$ where W is weight (g) and L is length (cm); r^2 is the correlation coefficient, *n* is the number of samples.

Table 10: Numbers of hoki, hake, and ling at each reproductive stage*.

Reproductive stage	Hoki		Hake		Ling	
	Male	Female	Male	Female	Male	Female
1	352	329	59	102	180	273
2	311	1 014	53	51	246	642
3	4	7	13	70	130	29
4	1	0	16	0	560	106
5	1	0	53	0	68	6
6	175	2	0	2	13	1
7	15	43	0	5	1	0
Total staged	859	1 395	194	230	1 198	1 057

*See Appendix 1 for description of gonad stages.

Table 11: Average liver condition index (LCI) and somatic condition factor (CF) for hoki sampled during Sub-Antarctic trawl surveys 2001–03.

Year	LCI		CF	
	Male	Female	Male	Female
2001	2.58	3.12	2.61	2.57
2002	2.37	2.74	2.63	2.60
2003	2.36	2.93	2.62	2.60

LCI = liver weight (g) / gutted weight (g) x 100
CF = gutted weight (g) / (length (cm))^3 x 1000

Table 12. Quality of acoustic data collected during trawl surveys in the Sub-Antarctic in 2000–03. The quality of each recording was subjectively categorised as "good", "marginal" or "poor" based on the appearance of the 38 kHz echograms (see Appendix 2).

Survey	Number of recordings	% of recordings Good	Marginal	Poor
2000 (TAN0012)	234	57	21	22
2001 (TAN0118)	221	65	20	15
2002 (TAN0219)	202	78	12	10
2003 (TAN0317)	169	37	25	38

Table 13: Percentage occurrence of the eight acoustic mark types classified by O'Driscoll (2001). Several mark types were usually present in the same echogram. n is the number of acoustic files examined.

				Pelagic marks				Bottom marks			
Acoustic file	Survey	*n*	Surface Layer	School	Layer	Cloud		Layer	Cloud	School	Single target
Day steam	2000	90	93	71	63	6		58	17	11	96
	2001	85	91	71	72	41		54	26	12	91
	2002	72	92	72	75	19		79	19	14	94
	2003	64	94	56	53	47		67	30	13	77
Night steam	2000	36	97	22	14	33		17	67	3	92
	2001	26	100	23	19	85		38	85	8	88
	2002	23	100	13	13	96		39	91	0	87
	2003	22	95	14	14	86		32	73	0	55
Trawl	2000	108	90	50	52	23		37	20	10	91
	2001	110	81	60	62	32		35	26	15	89
	2002	108	91	60	59	32		41	31	15	56
	2003	83	86	37	53	28		46	25	4	65

Table 14. Average trawl catch and acoustic backscatter from bottom-referenced marks during tows where acoustic data quality was suitable for echo integration in the Sub-Antarctic in 2000–03. All tows were conducted during daylight. Data for 2000–02 are from O'Driscoll & Bagley (2003).

Survey	Number of recordings	Average trawl catch (kg km^{-2})	Average acoustic backscatter (m^2 km^{-2})	
			Bottom 10 m	Entire layer
2000 (TAN0012)	100	697	0.502	3.37
2001 (TAN0118)	101	779	0.506	2.90
2002 (TAN0219)	96	726	0.657	4.08
2003 (TAN0317)	48	568	0.622	2.50

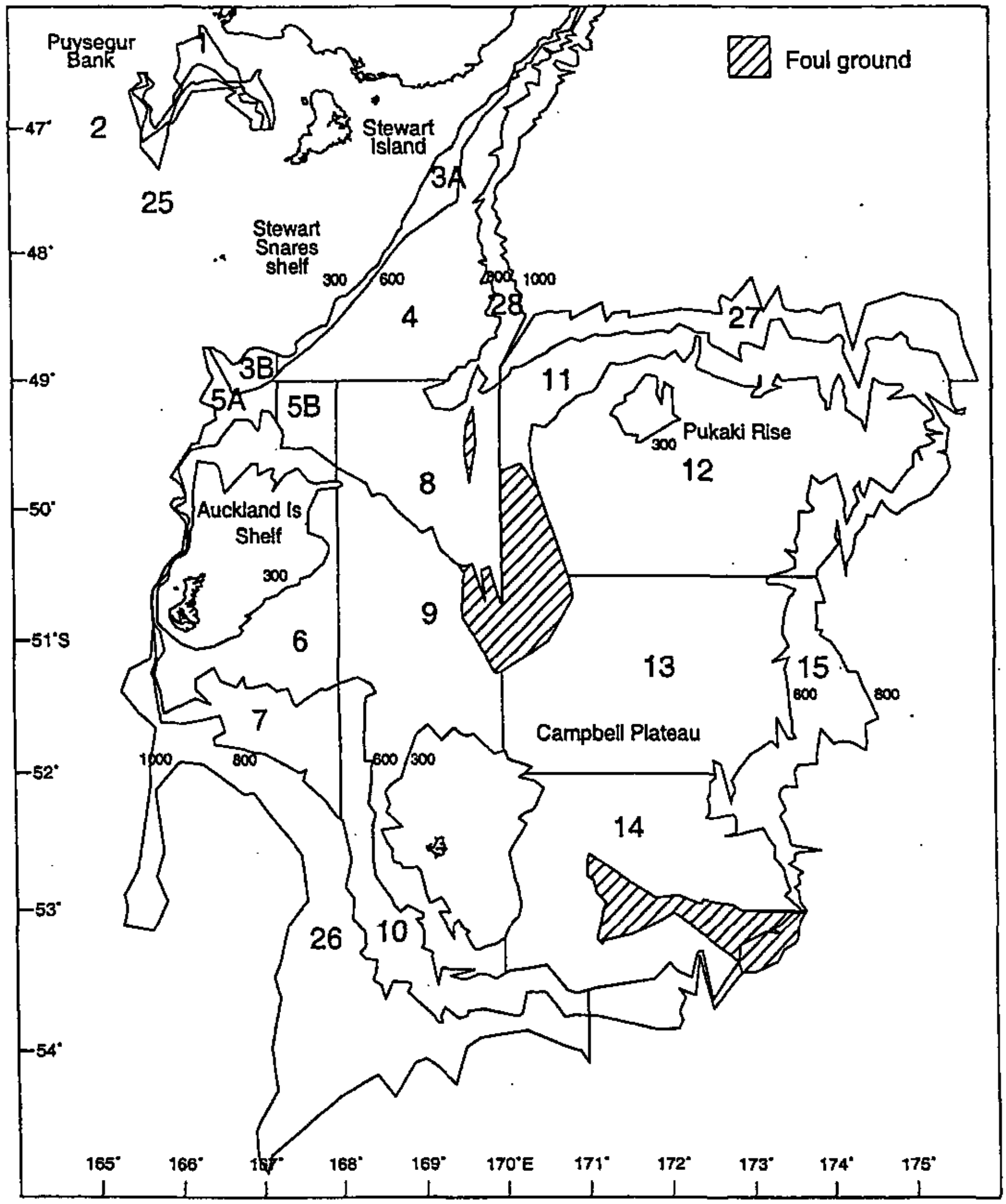


Figure 1: Survey area and stratum boundaries and numbers for the November–December 2003 Sub-Antarctic trawl survey.

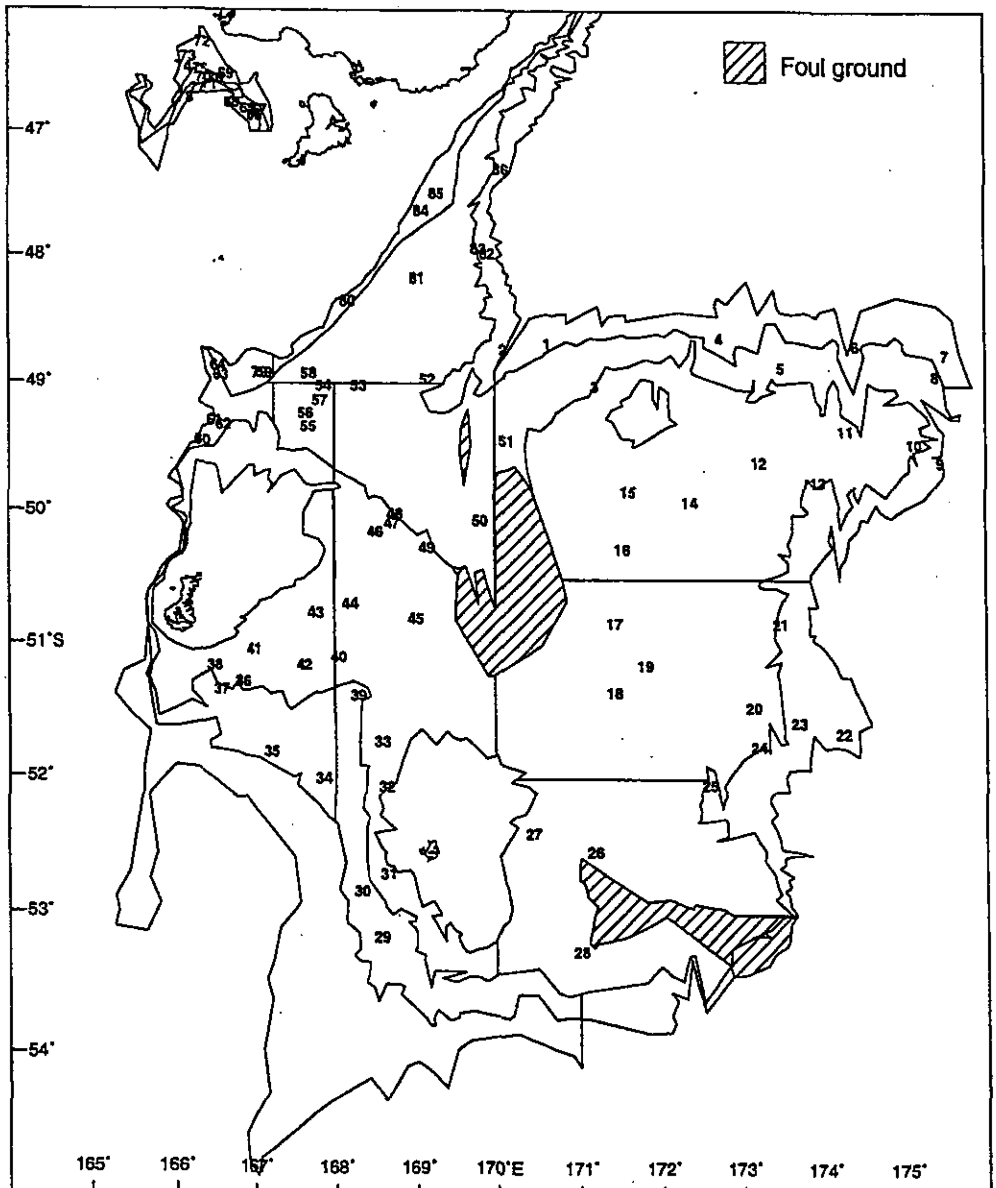


Figure 2: Bottom trawl station positions.

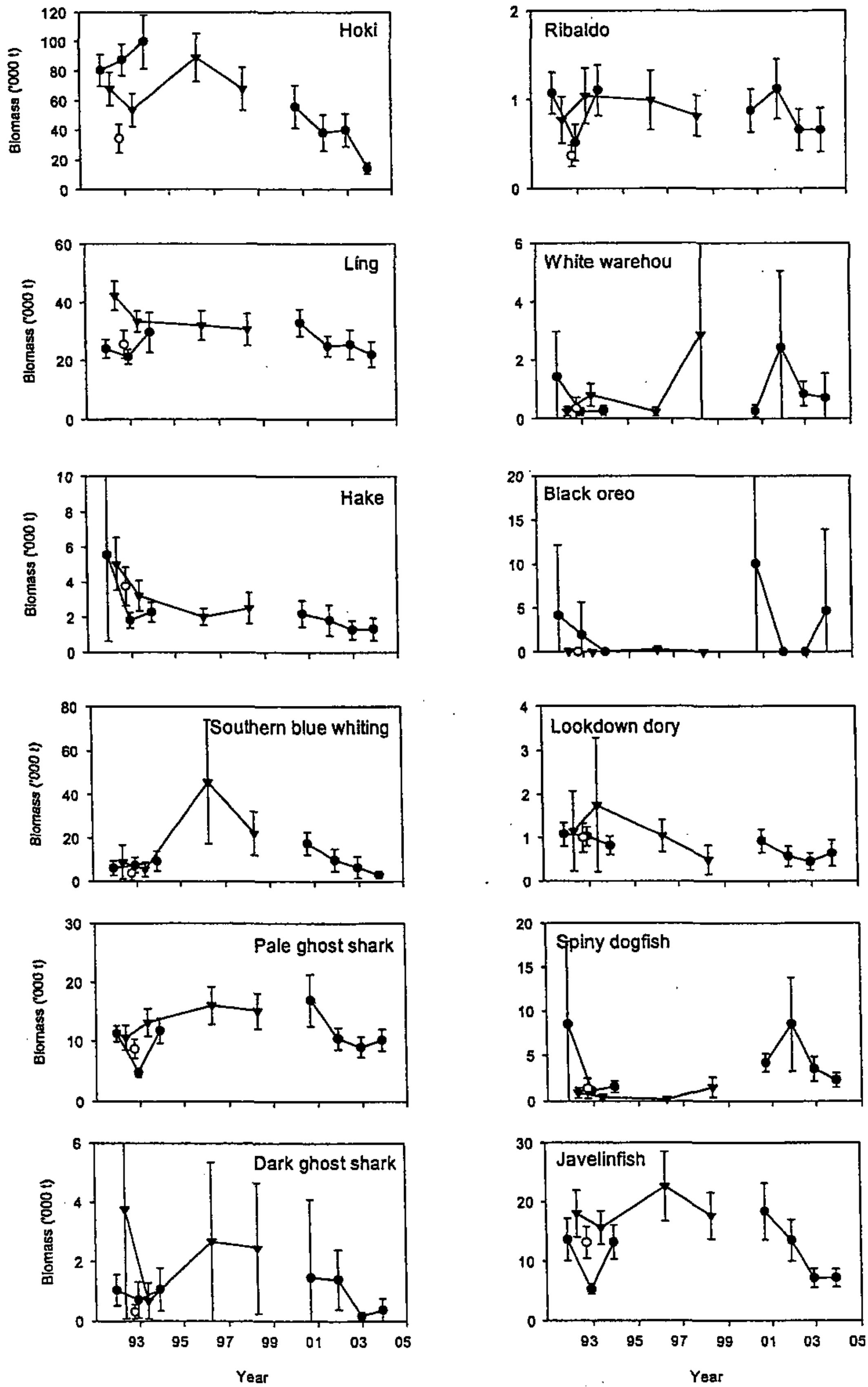


Figure 3: Trends in biomass (± 2 standard errors) of major species in the core 300–800 m strata in all Sub-Antarctic trawl surveys from *Tangaroa*. Solid circles show the summer time series and solid triangles the autumn time series. The open circle shows biomass from a survey of the same area in September–October 1992.

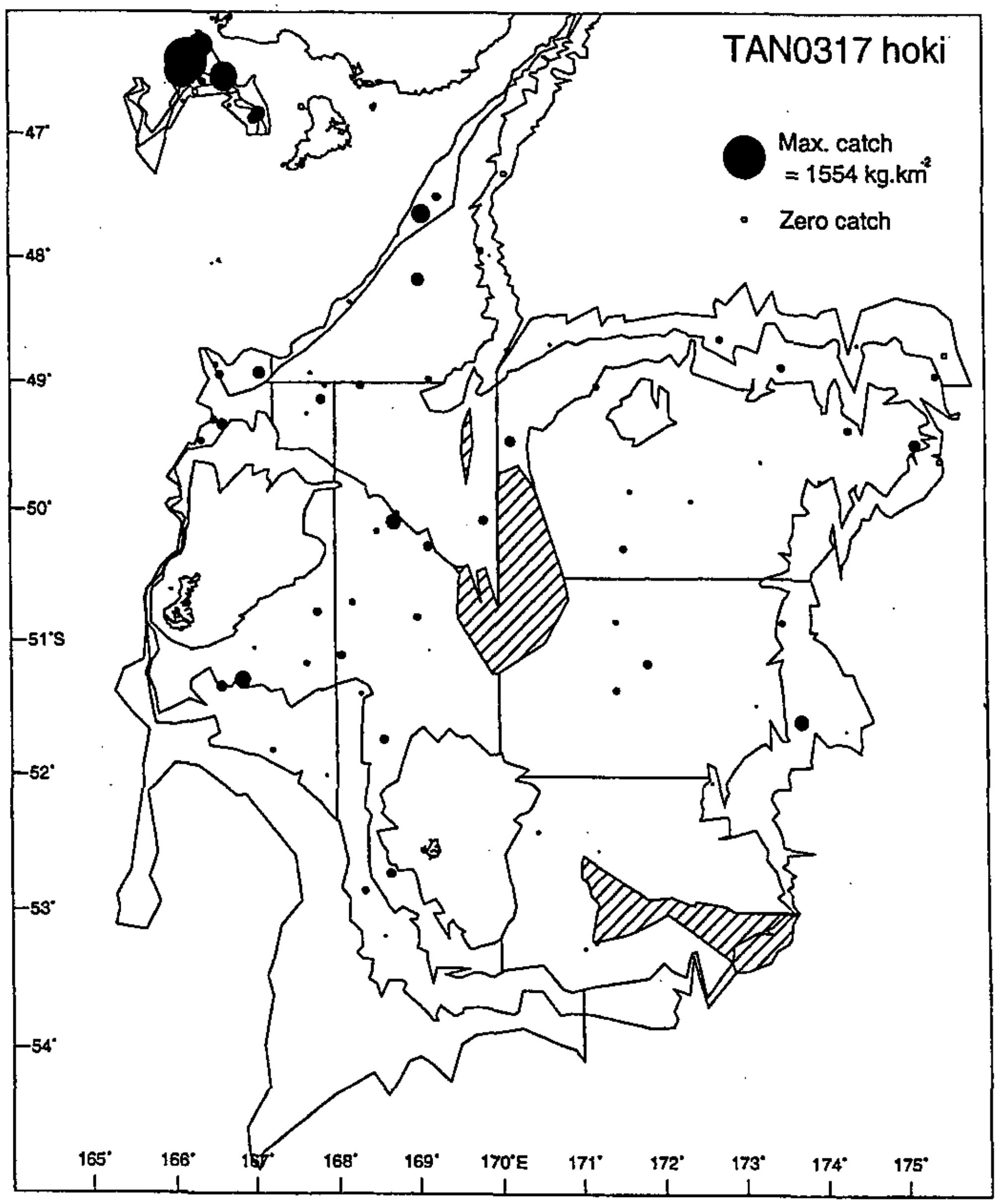


Figure 4a: Distribution and catch rates of all hoki in the summer 2003 trawl survey. Circle area is proportional to catch rate.

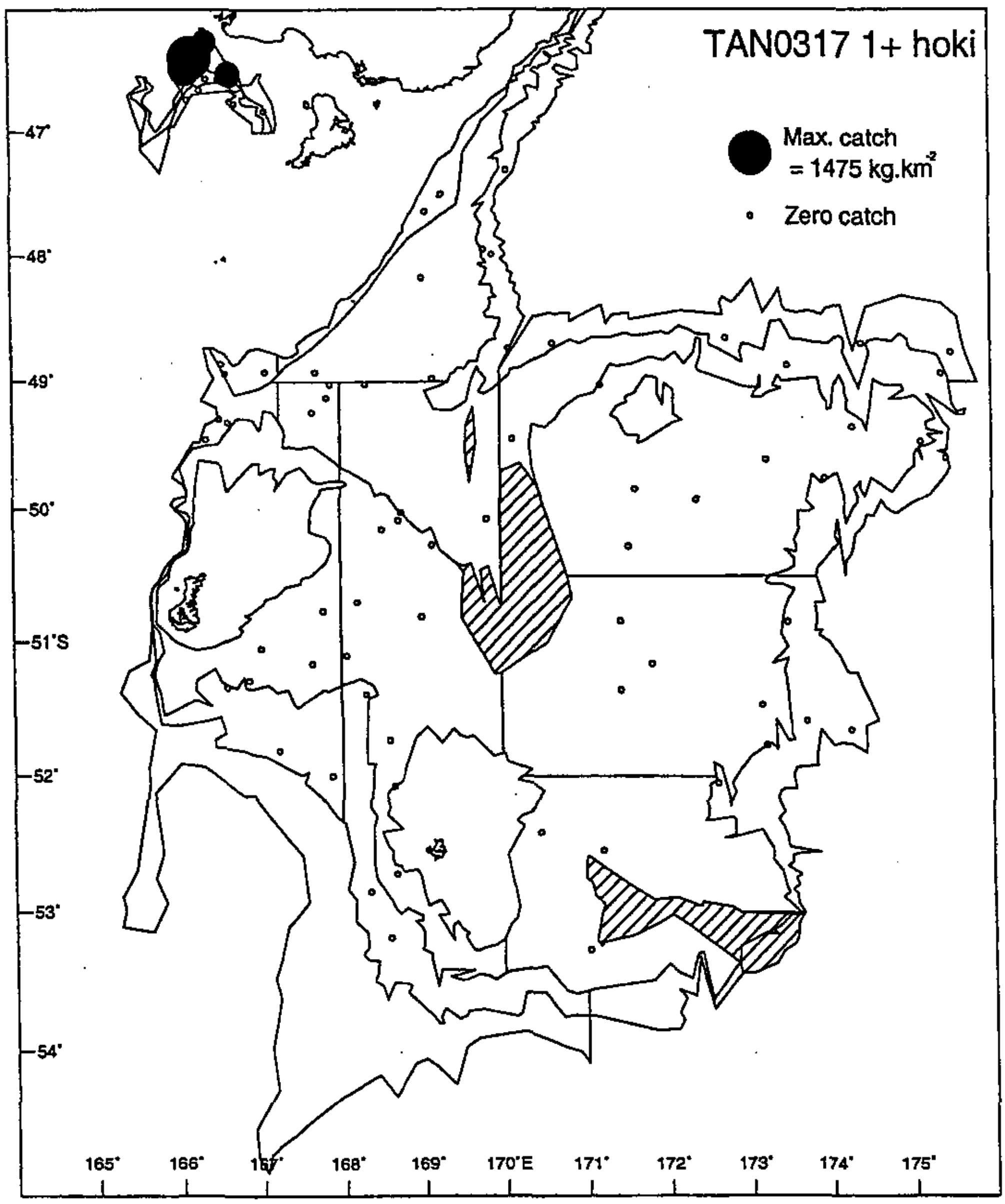


Figure 4b: Distribution and catch rates of 1+ (30–45 cm) hoki in the summer 2003 trawl survey. Circle area is proportional to catch rate.

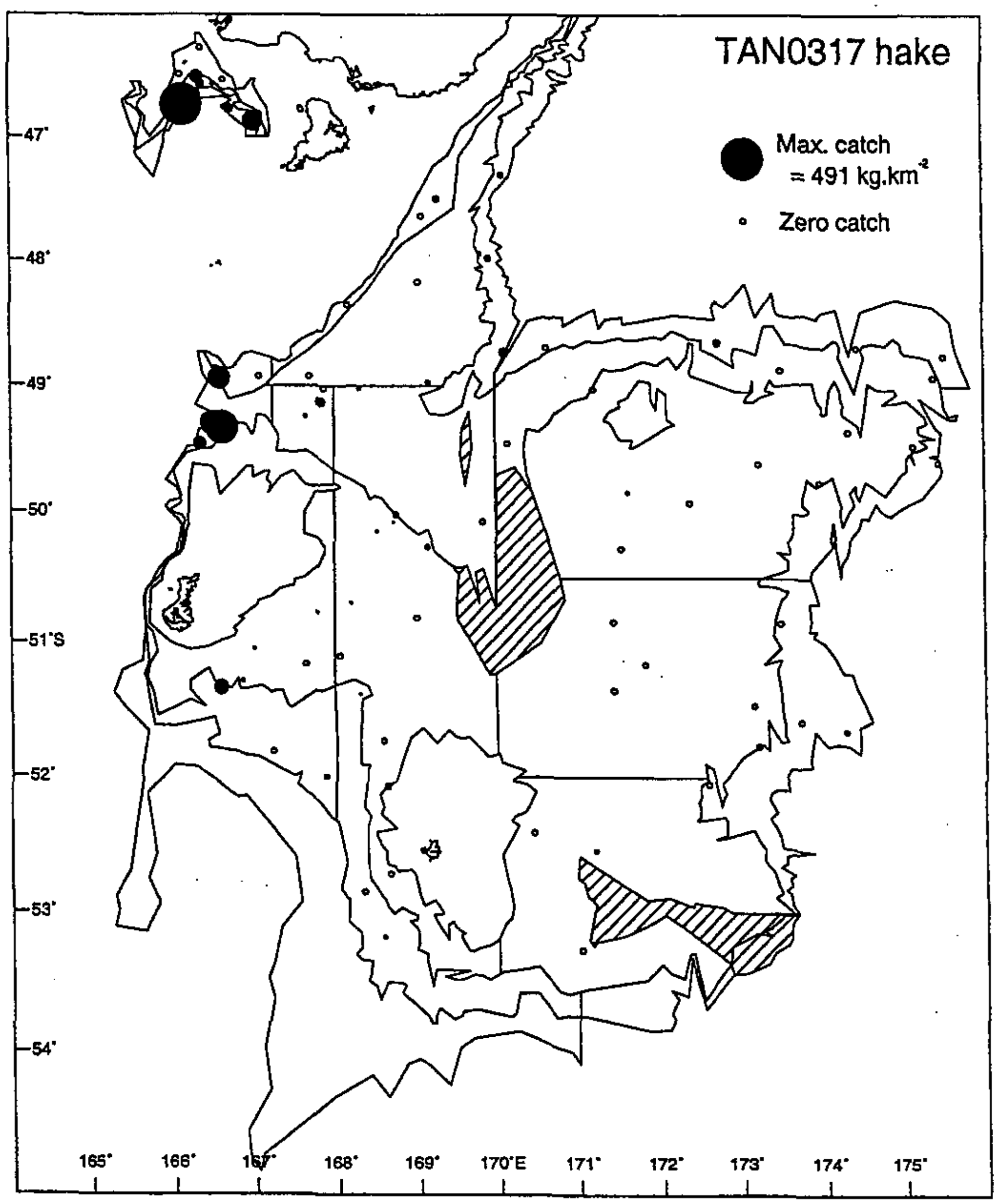


Figure 5: Distribution and catch rates of hake in the summer 2003 trawl survey. Circle area is proportional to catch rate.

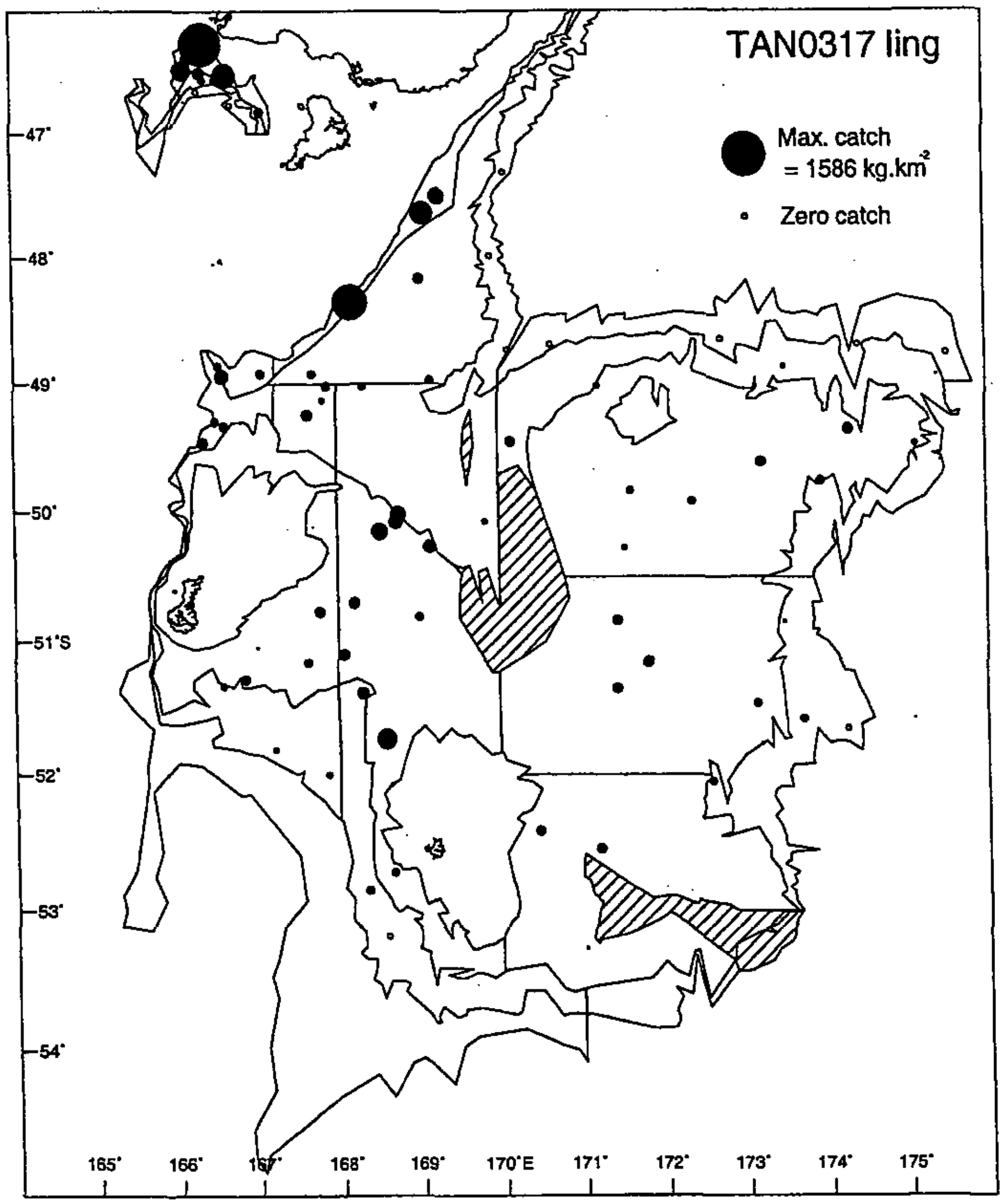


Figure 6: Distribution and catch rates of ling in the summer 2003 trawl survey. Circle area is proportional to catch rate.

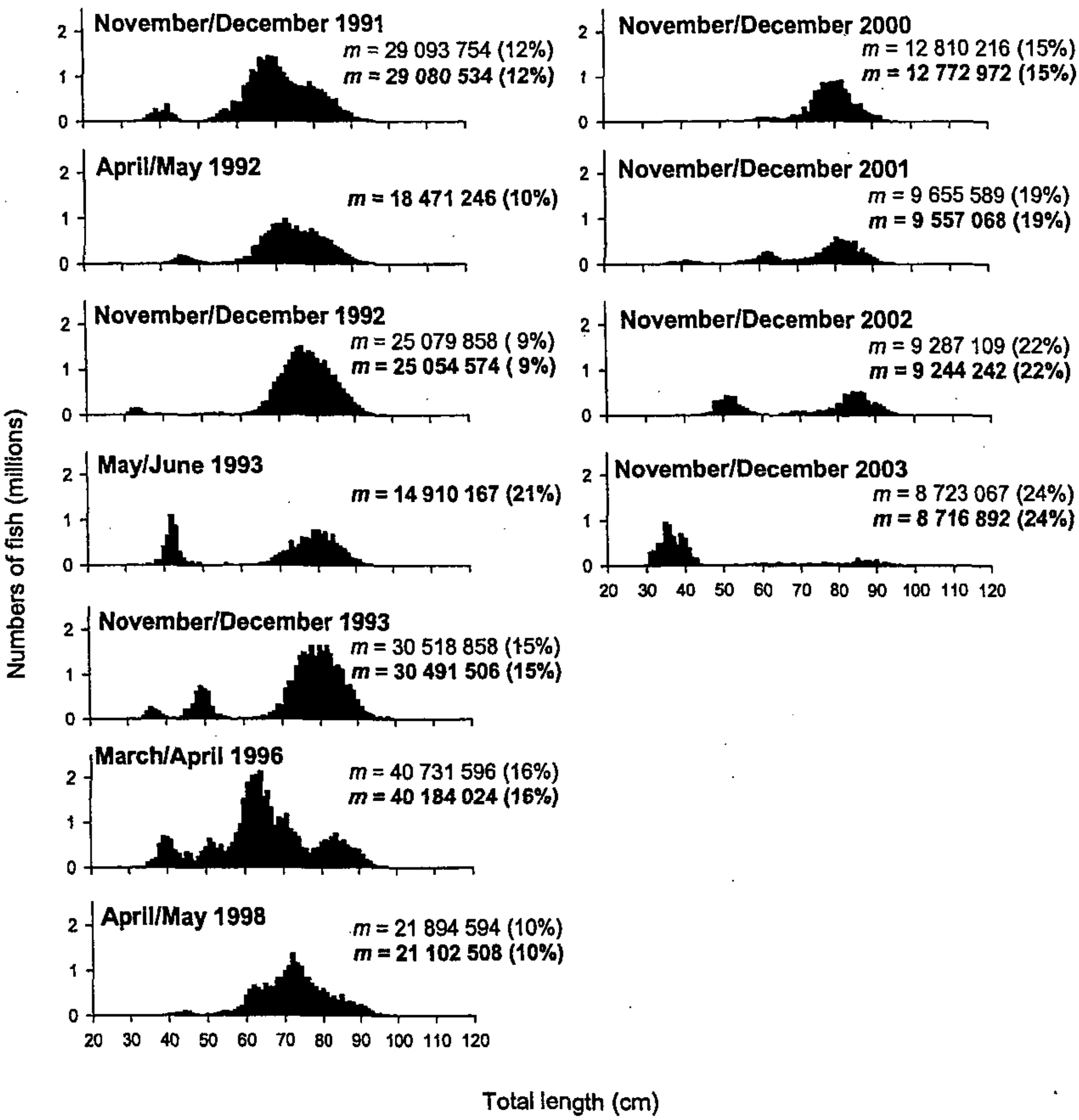


Figure 7a: Scaled length frequency for male hoki from all Sub-Antarctic *Tangaroa* trawl surveys. Population numbers for core strata are presented as black bars and for all strata as grey bars. Numbers (*m* values) above are for all strata and below (in bold) for core strata with c.v.s in parentheses.

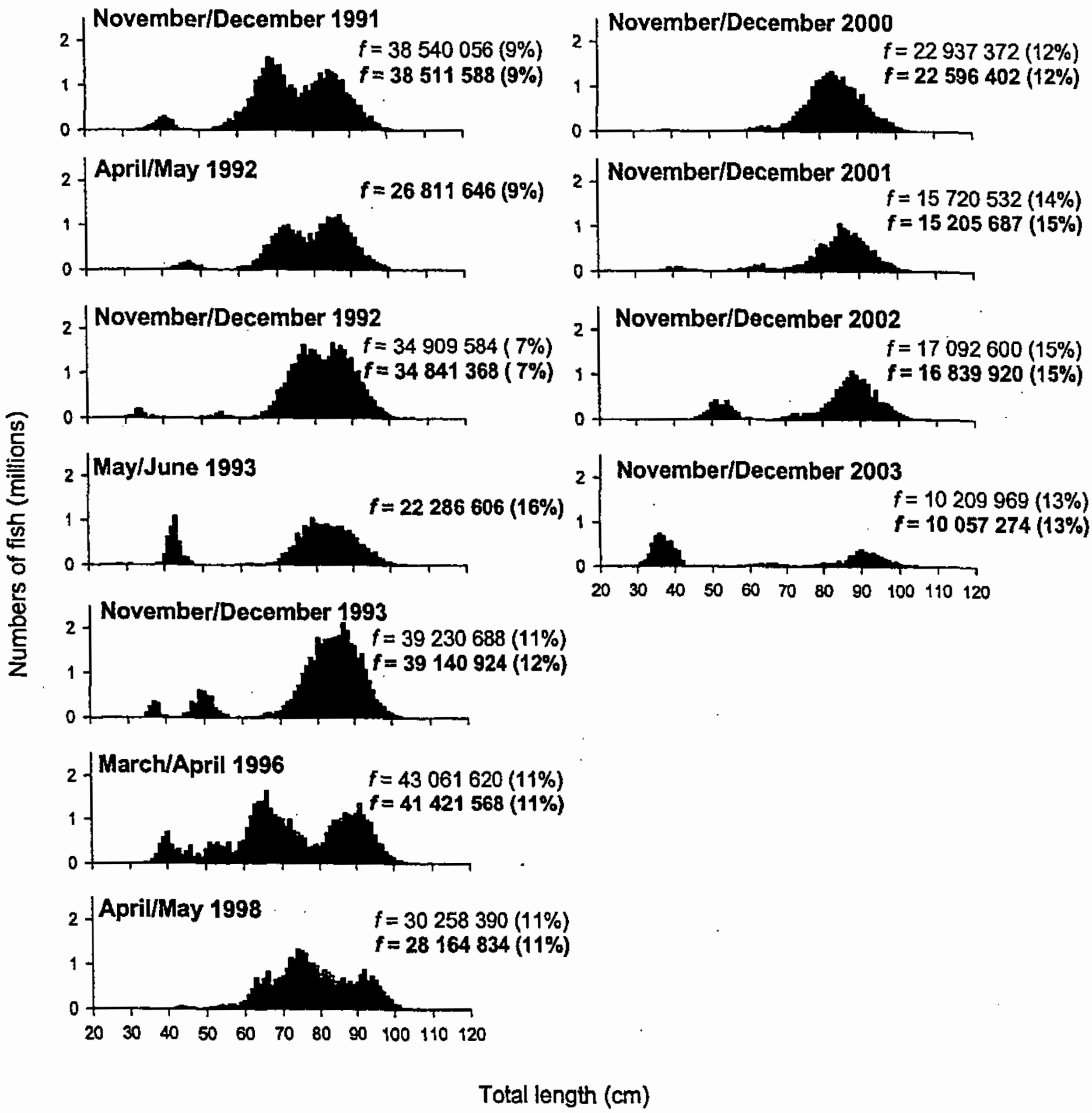


Figure 7b: Scaled length frequency for female hoki from all Sub-Antarctic *Tangaroa* trawl surveys. Population numbers for core strata are presented as black bars and for all strata as grey bars. Numbers (*f* values) above are for all strata and below (in bold) for core strata with c.v.s in parentheses.

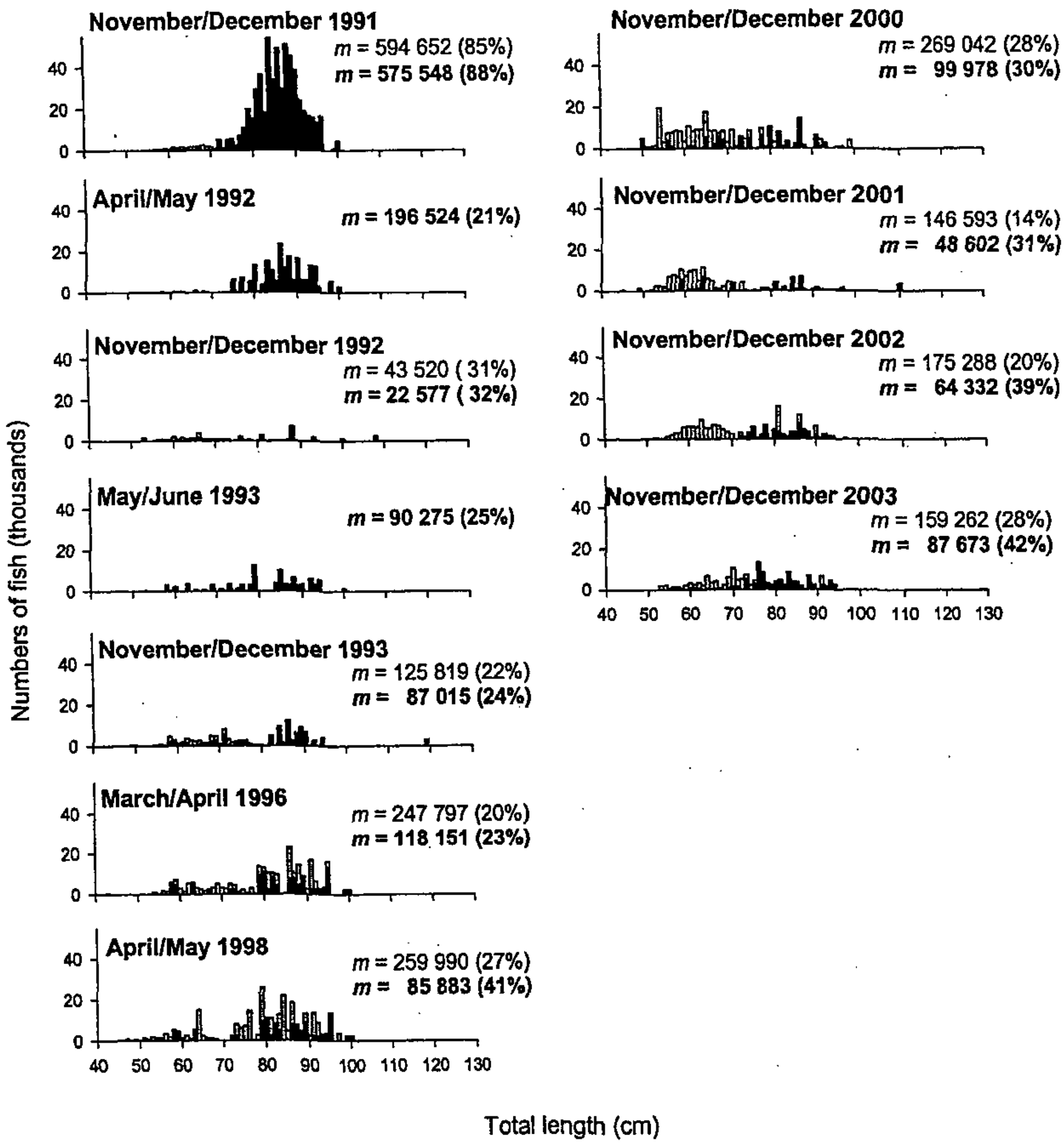


Figure 8a: Scaled length frequency for male hake from all Sub-Antarctic *Tangaroa* trawl surveys. Population numbers for core strata are presented as black bars and for all strata as grey bars. Numbers (*m* values) above are for all strata and below (in bold) for core strata with c.v.s in parentheses.

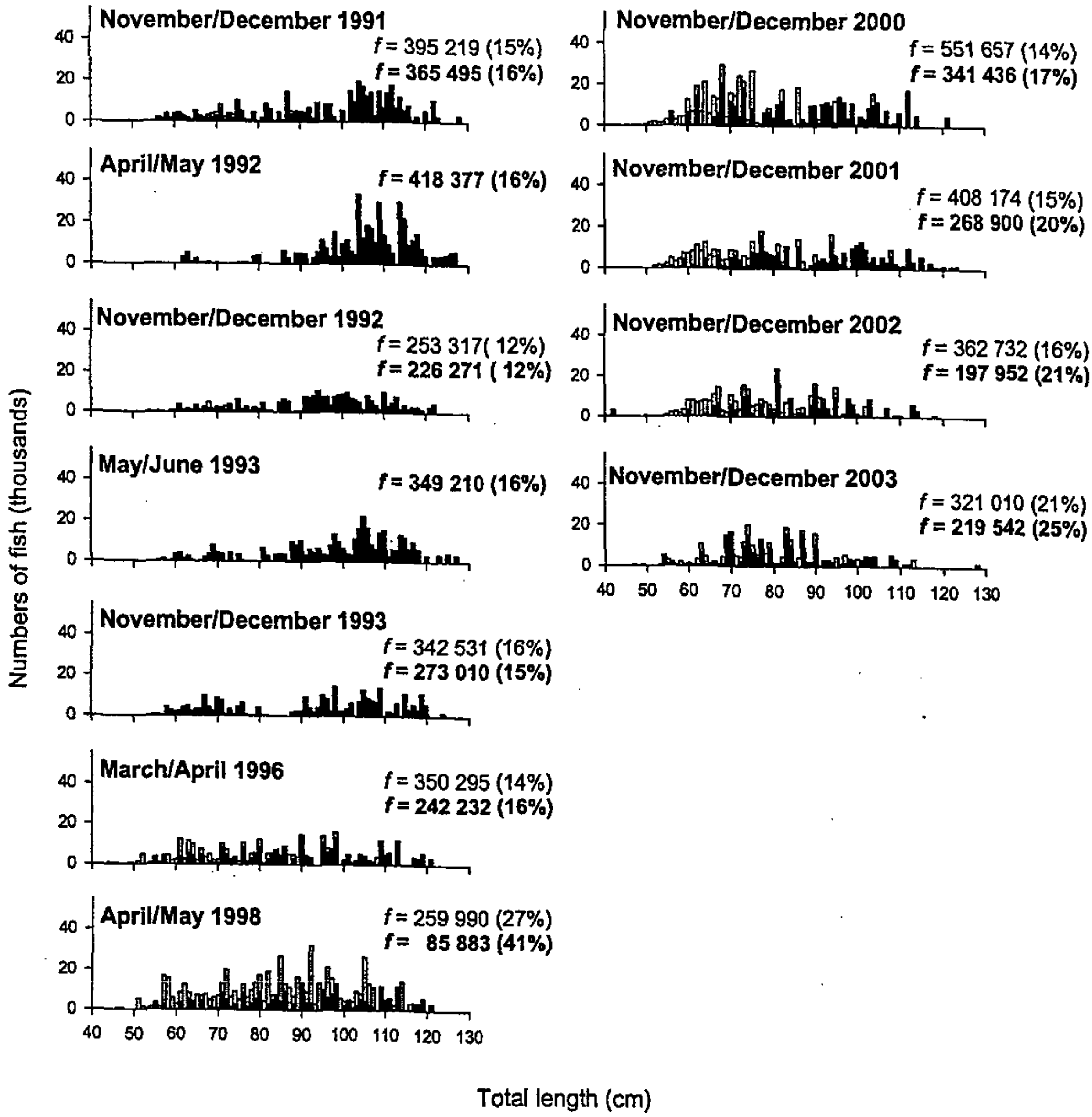


Figure 8b: Scaled length frequency for female hake from all Sub-Antarctic *Tangaroa* trawl surveys. Population numbers for core strata are presented as black bars and for all strata as grey bars. Numbers (*f* values) above are for all strata and below (in bold) for core strata with c.v.s in parentheses.

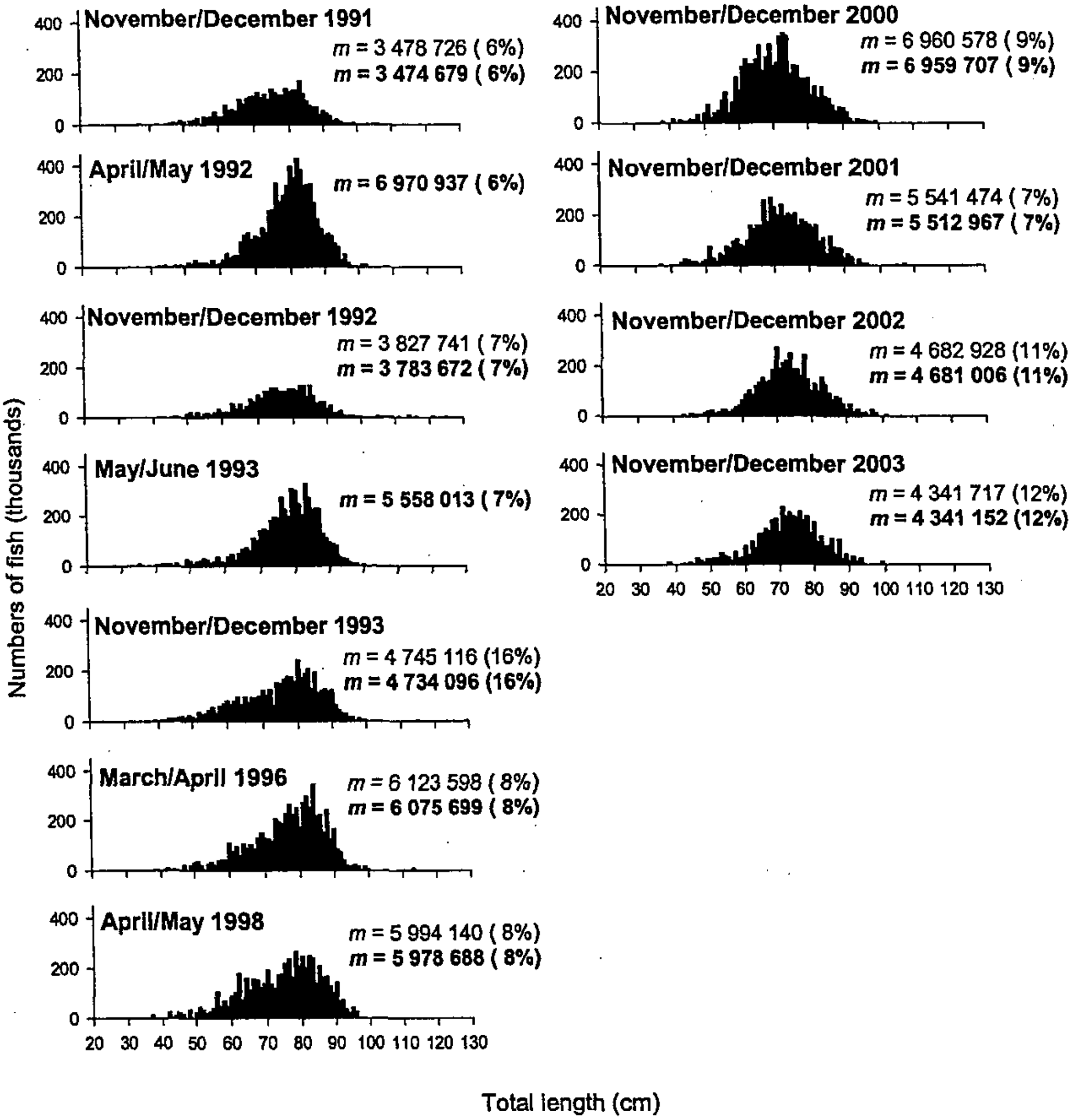


Figure 9a: Scaled length frequency for male ling from all Sub-Antarctic *Tangaroa* trawl surveys. Population numbers for core strata are presented as black bars and for all strata as grey bars. Numbers (*m* values) above are for all strata and below (in bold) for core strata with c.v.s in parentheses.

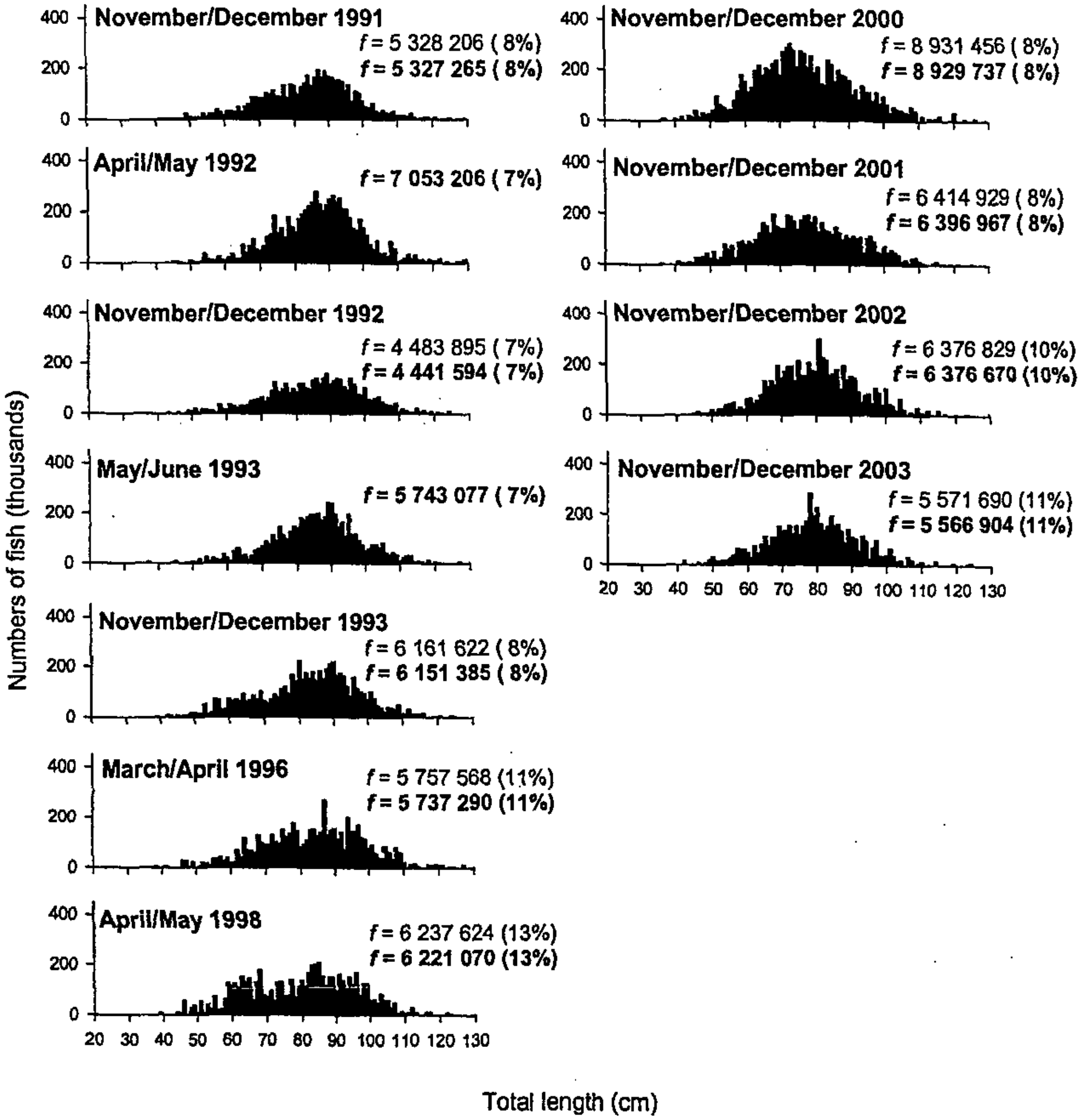


Figure 9b: Scaled length frequency for female ling from all Sub-Antarctic *Tangaroa* trawl surveys. Population numbers for core strata are presented as black bars and for all strata as grey bars. Numbers (*f* values) above are for all strata and below (in bold) for core strata with c.v.s in parentheses.

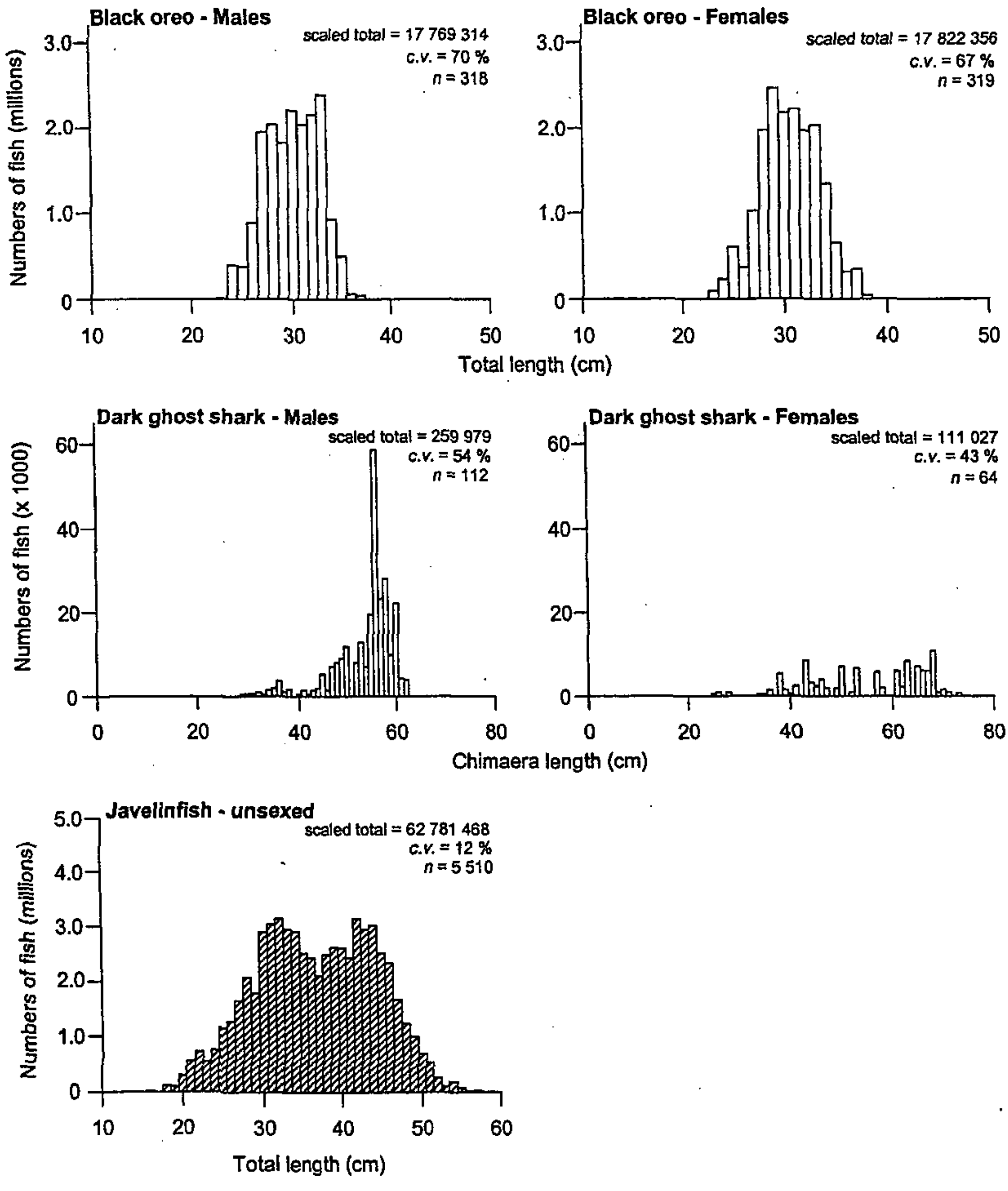


Figure 10: Length frequency by sex of other major species in the November–December 2003 survey. Scaled total is the estimated total number of fish in the surveyed area, c.v. is the coefficient of variation, *n* is the number of fish measured. Hatched bars indicate unsexed fish.

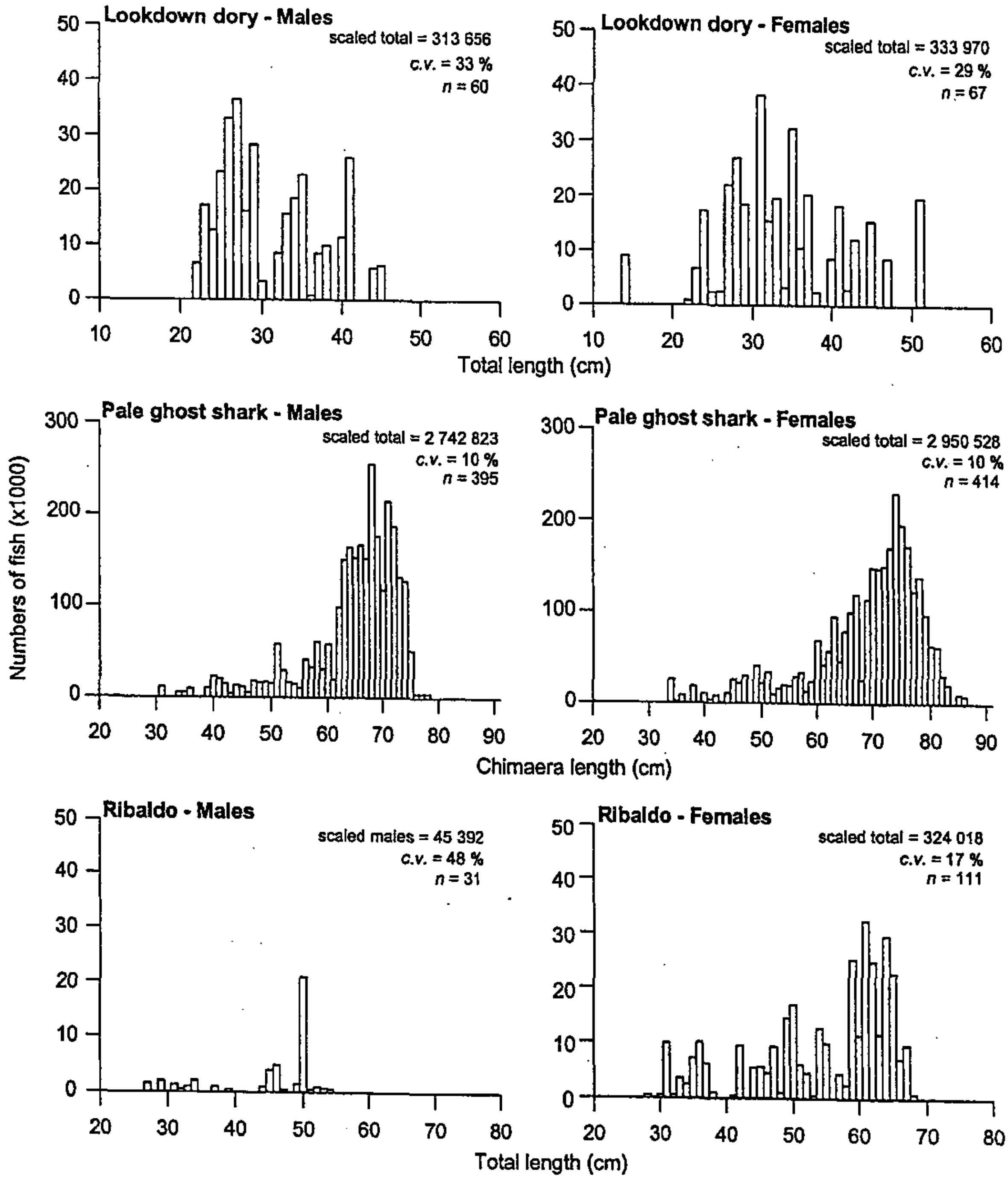


Figure 10 cont: Length frequency by sex of other major species in the November–December 2003 survey. Scaled total is the estimated total number of fish in the surveyed area, c.v. is the coefficient of variation, *n* is the number of fish measured.

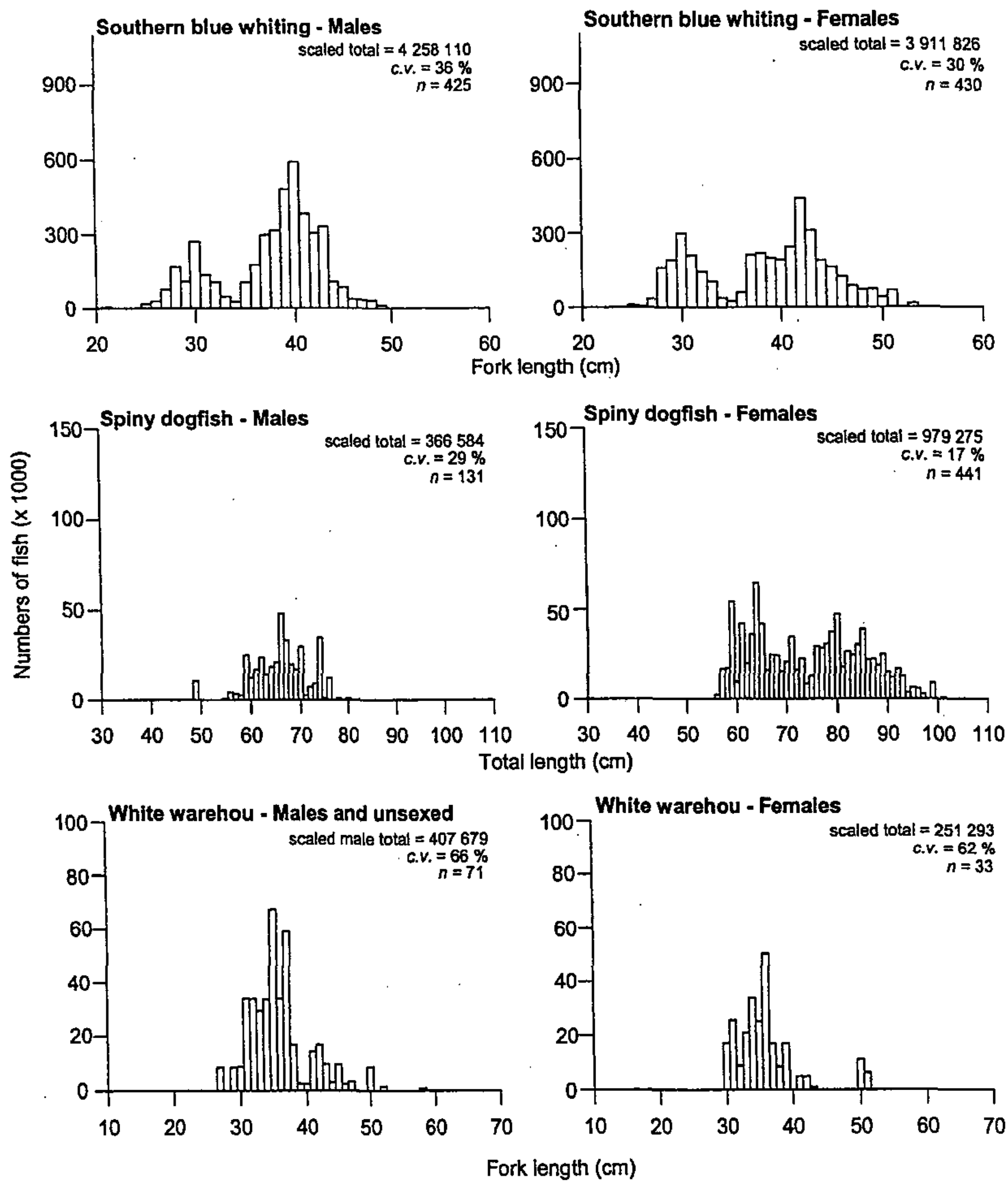


Figure 10 cont: Length frequency by sex of other major species in the November–December 2003 survey. Scaled total is the estimated total number of fish in the surveyed area, c.v. is the coefficient of variation, *n* is the number of fish measured.

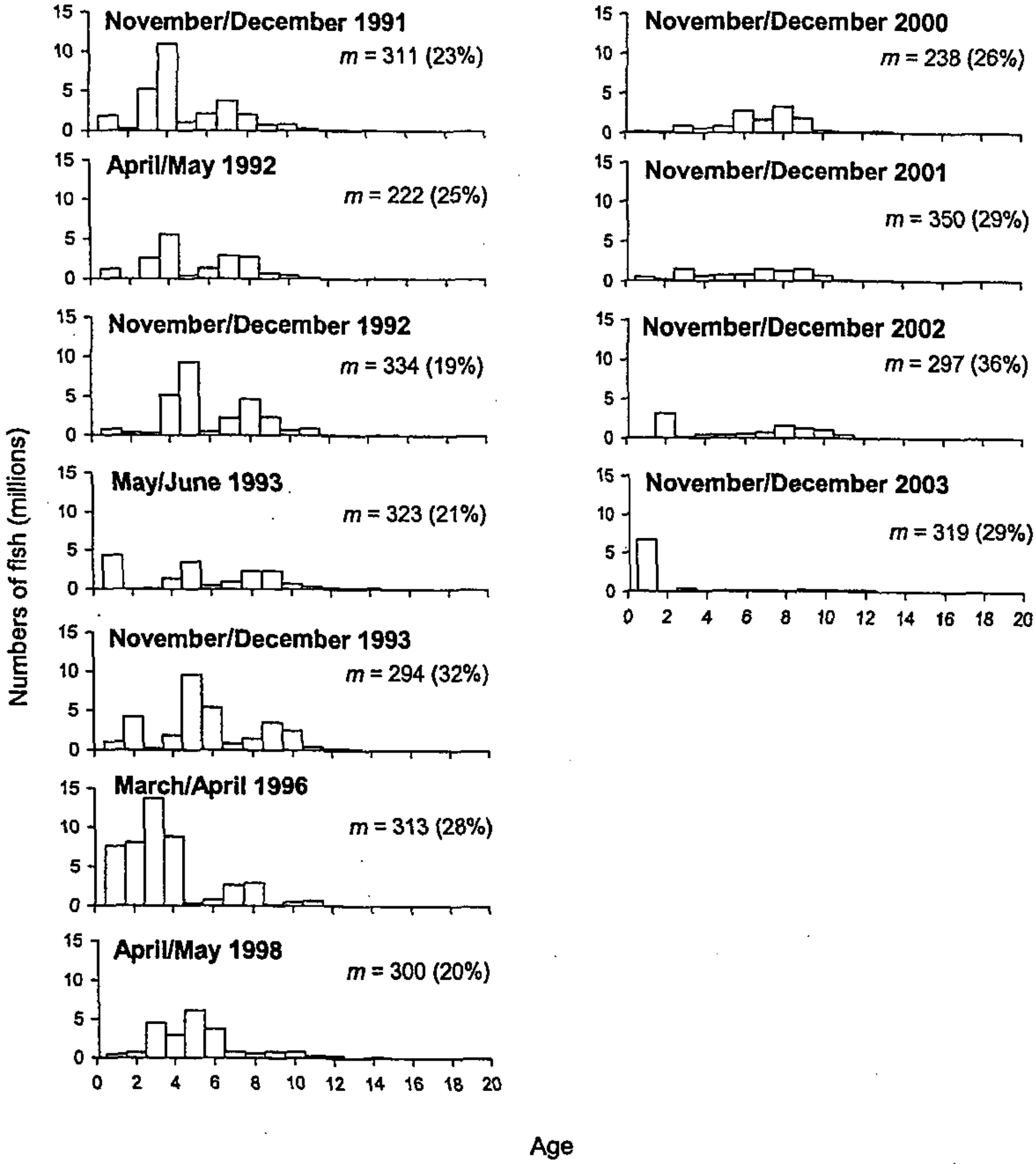


Figure 11a: Scaled age frequency for male hoki from all Sub-Antarctic *Tangaroa* trawl surveys for the core 300–800 m survey area. Number of fish aged (*m* values) are given with c.v.s in parentheses.

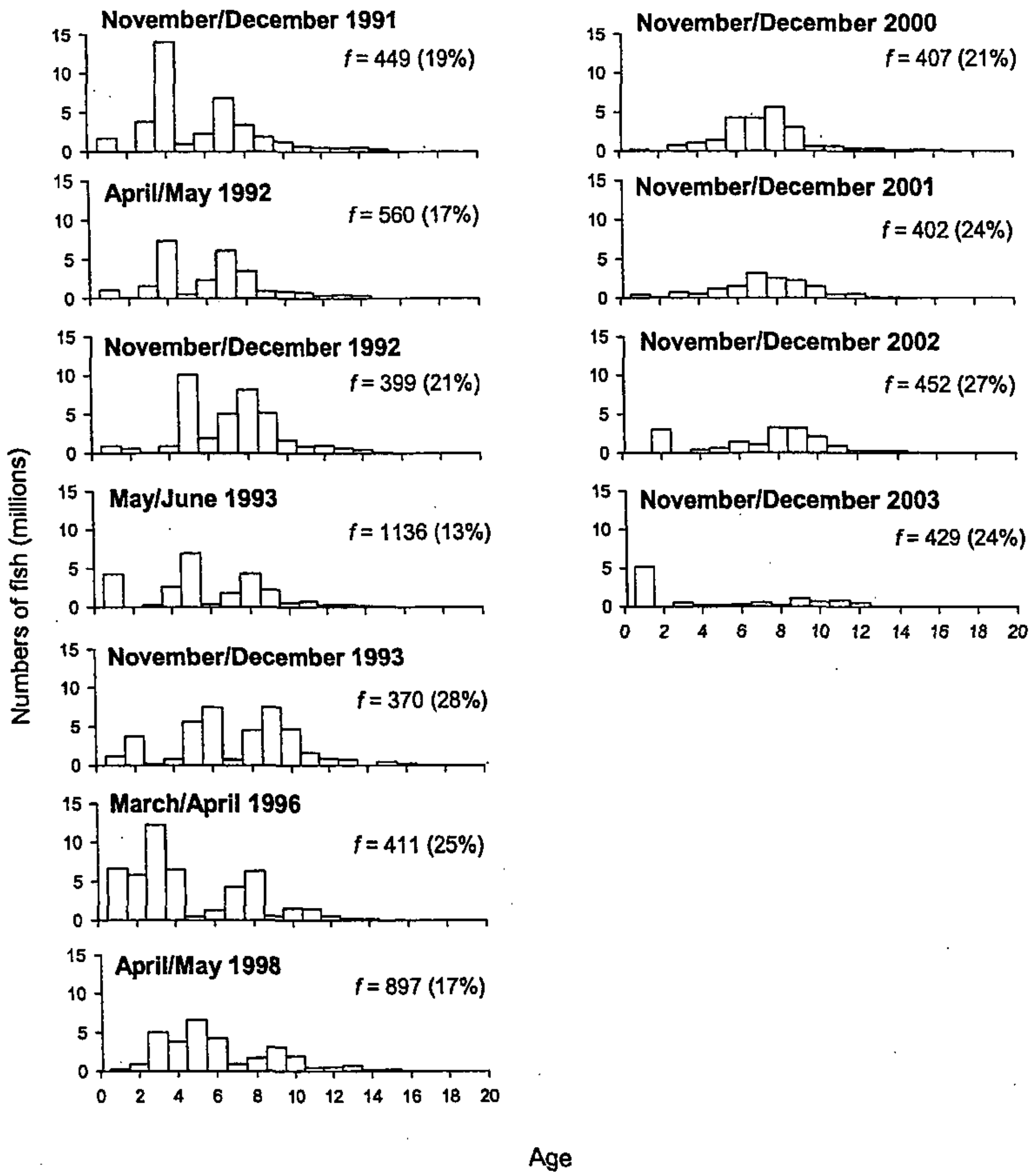


Figure 11b: Scaled age frequency for female hoki from all Sub-Antarctic *Tangaroa* trawl surveys for the core 300–800 m survey area. Number of fish aged (*f* values) are given with c.v.s in parentheses.

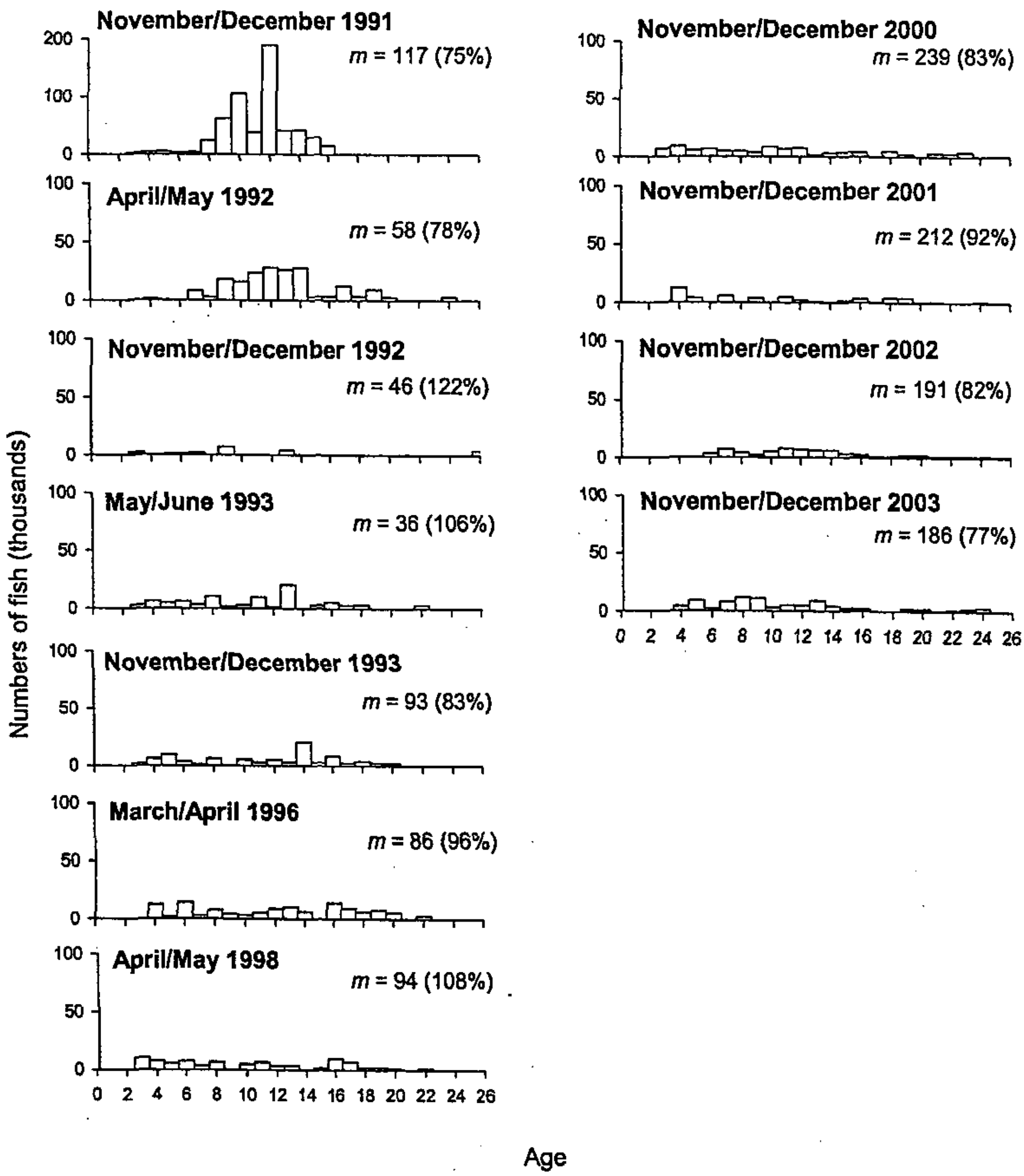


Figure 12a: Scaled age frequency for male hake from all Sub-Antarctic *Tangaroa* trawl surveys for the core 300–800 m survey area. Number of fish aged (*m* values) are given with c.v.s in parentheses.

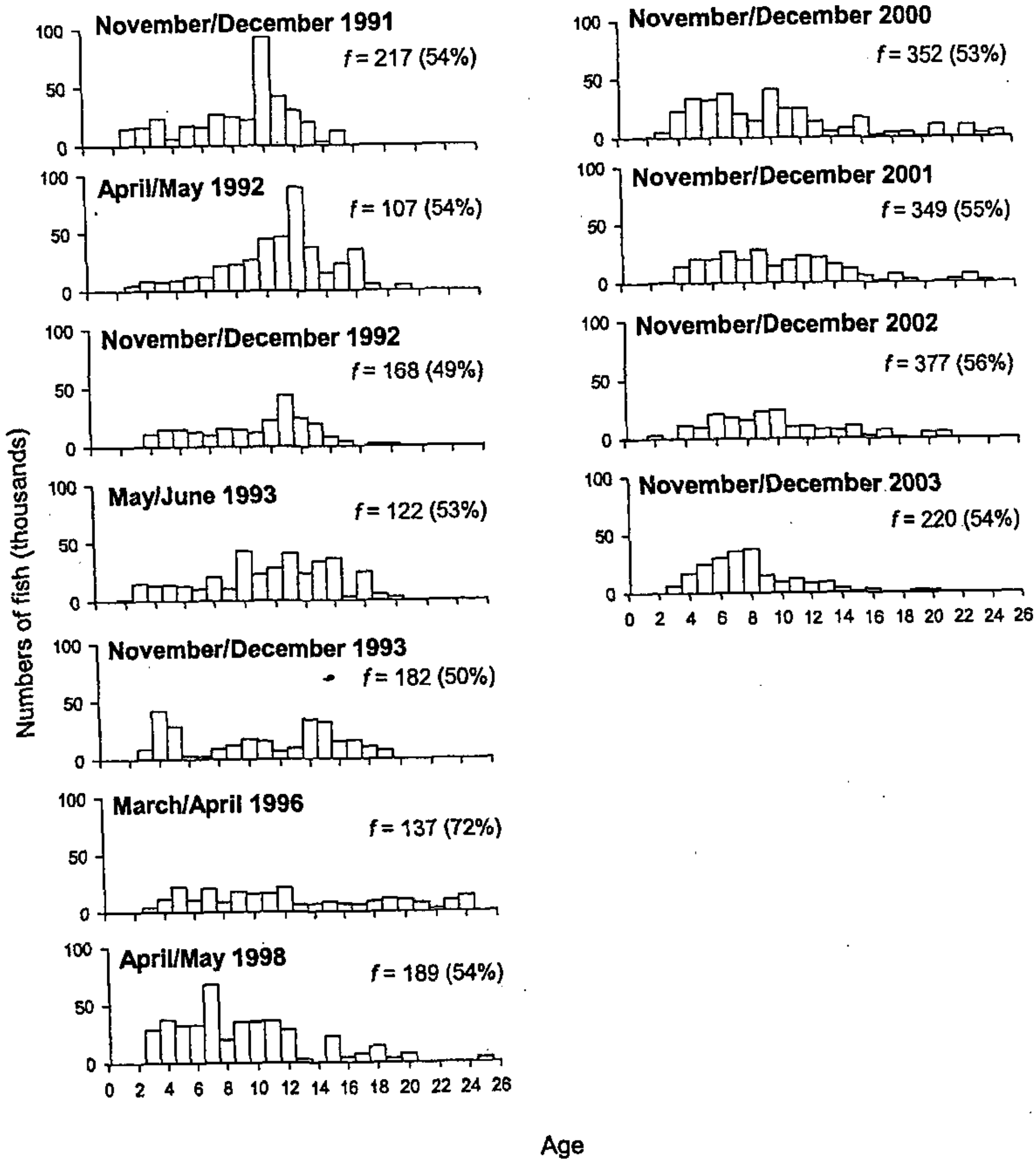


Figure 12b: Scaled age frequency for female hake from all Sub-Antarctic *Tangaroa* trawl surveys for the core 300–800 m survey area. Number of fish aged (*m* values) are given with c.v.s in parentheses.

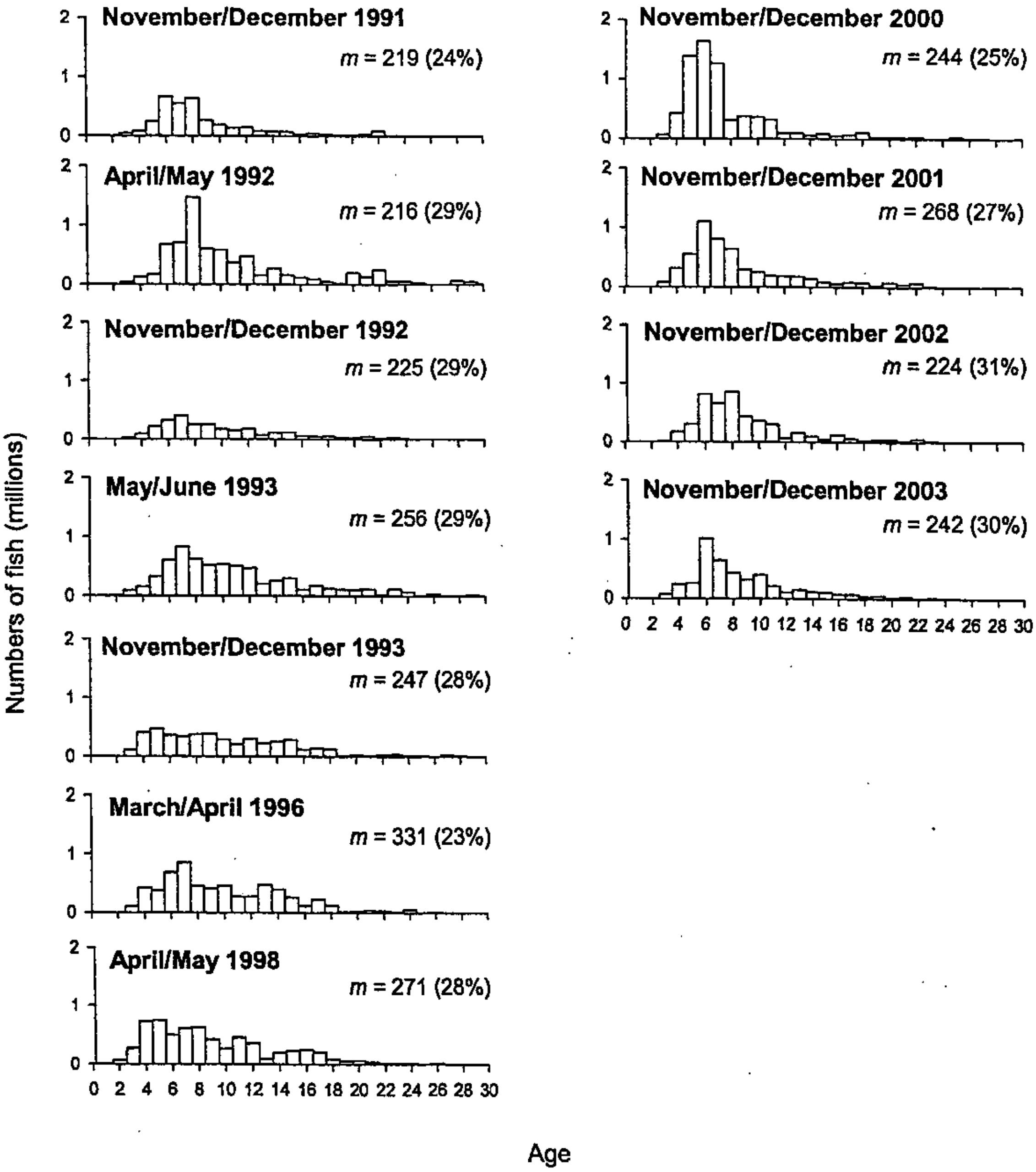


Figure 13a: Scaled age frequency for male ling from all Sub-Antarctic *Tangaroa* trawl surveys for the core 300–800 m survey area. Number of fish aged (*m* values) are given with c.v.s in parentheses.

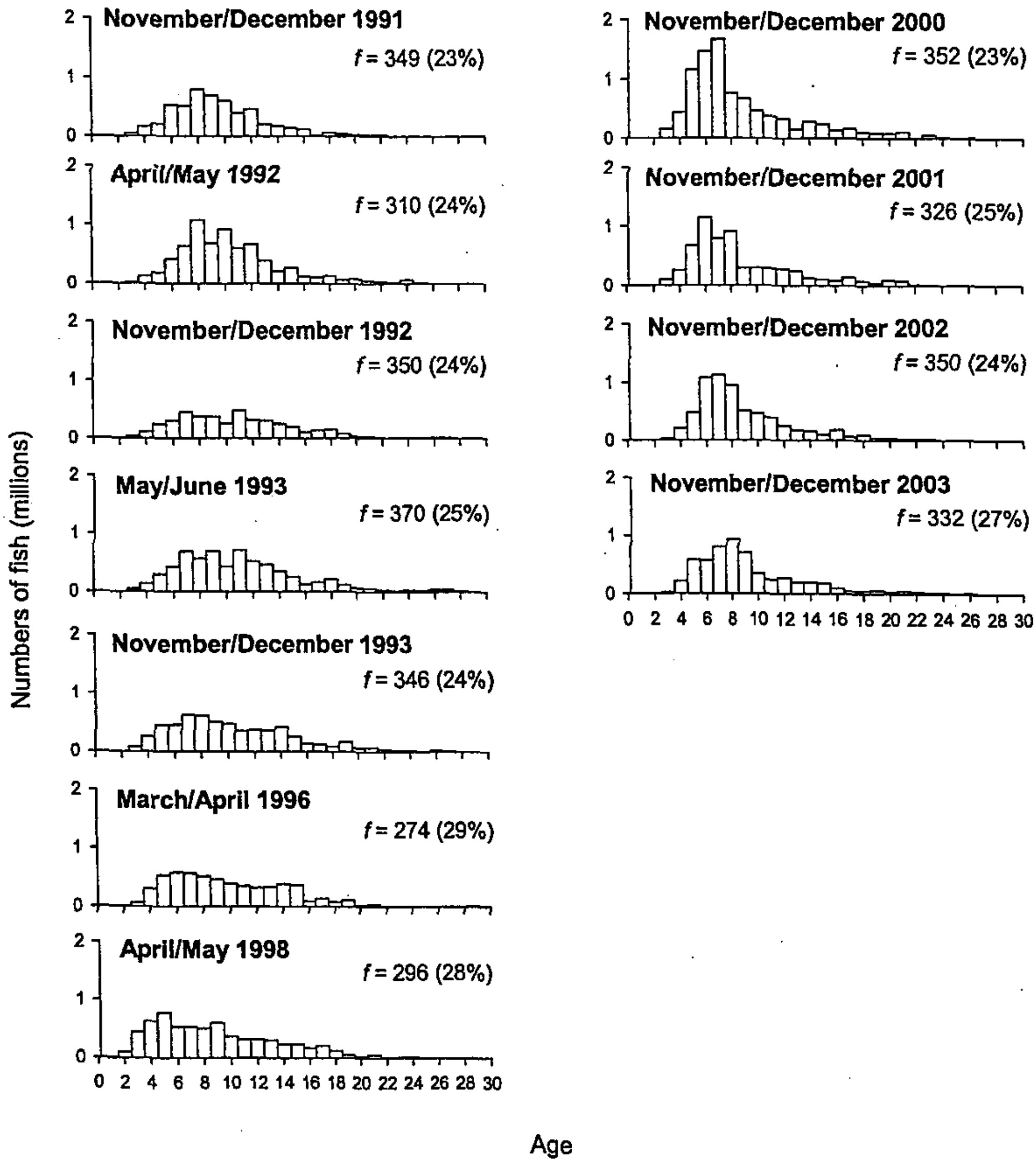


Figure 13b: Scaled age frequency for female ling from all Sub-Antarctic *Tangaroa* trawl surveys for the core 300–800 m survey area. Number of fish aged (*m* values) are given with c.v.s in parentheses.

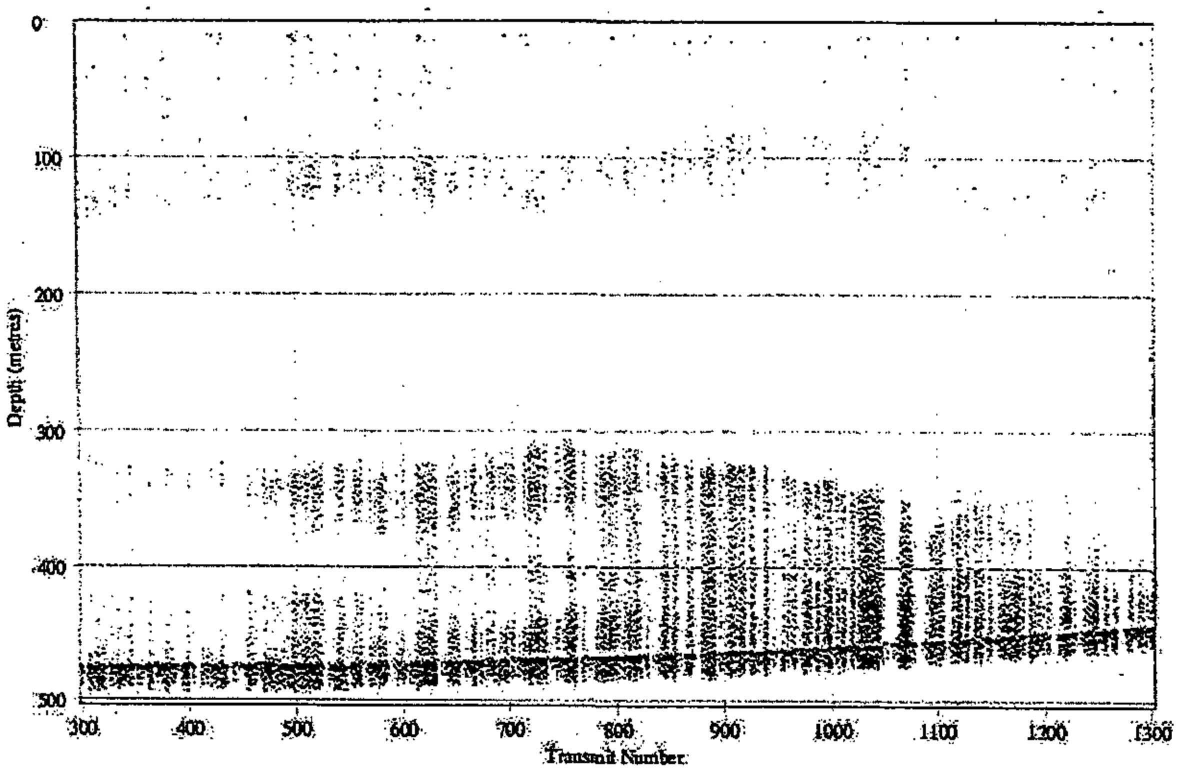


Figure 14: Acoustic echogram collected during tow 73 at Puysegur showing strong bottom layer. The horizontal scale (1000 pings) is equivalent to about 5.4 km at the tow speed of 3.5 knots. The trawl caught 1556 kg km^{-2} of 1 year-old hoki

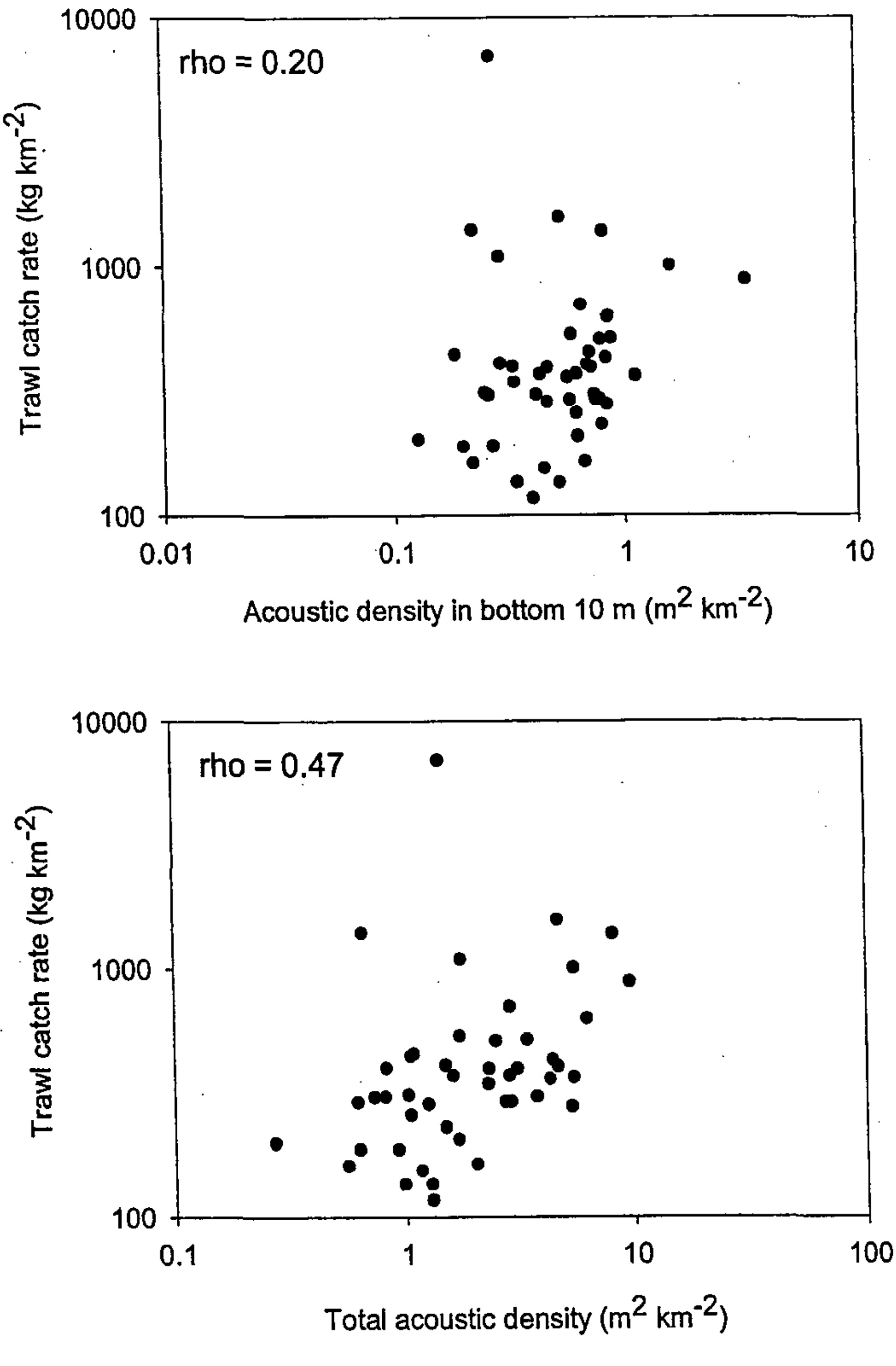


Figure 15. Relationship between total trawl catch rate (all species combined) and acoustic backscatter recorded during the trawl in the Sub-Antarctic in 2003. Rho values are Spearman's rank correlation coefficients.

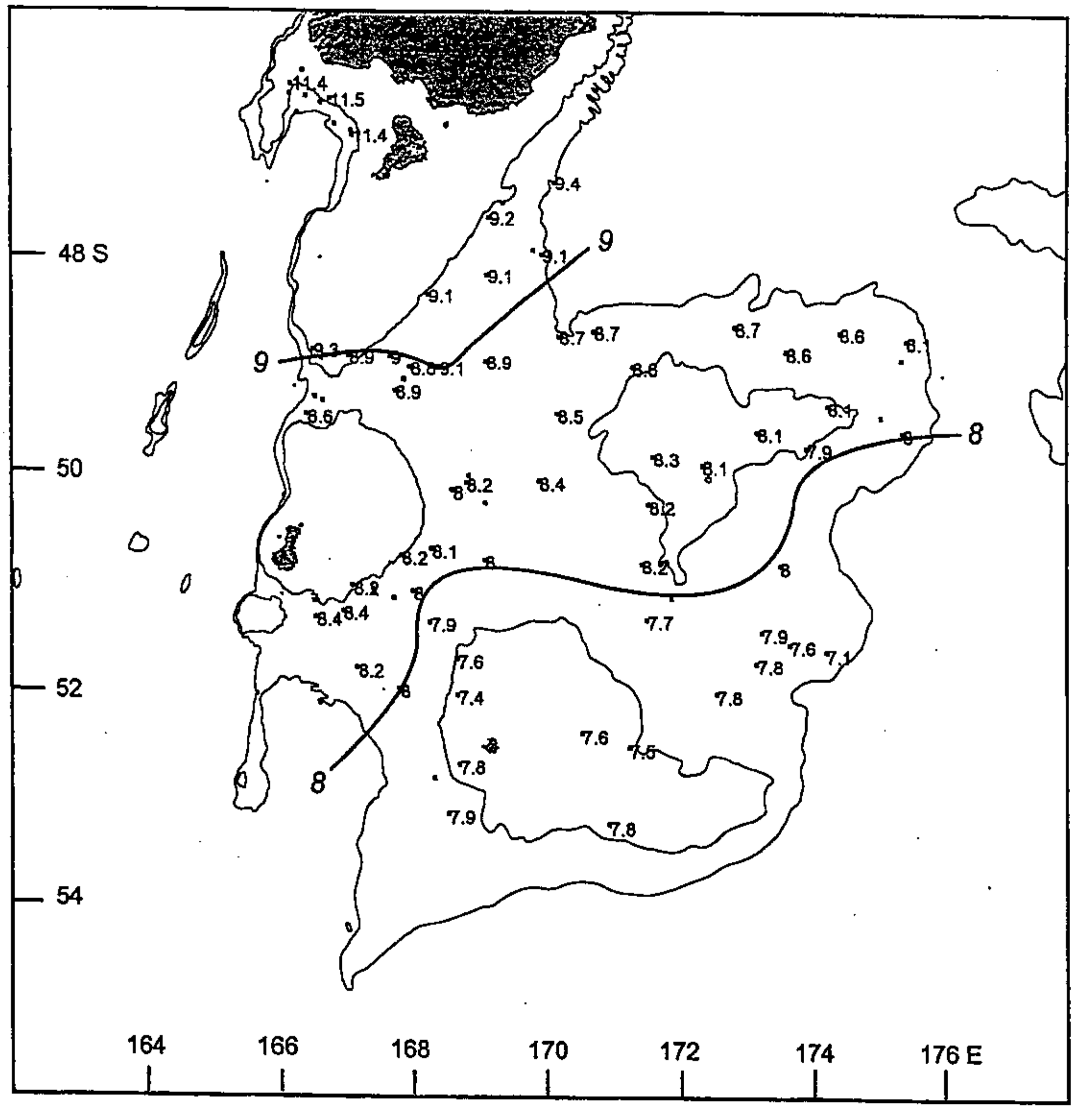


Figure 16: Surface water temperatures (°C). Squares indicate station positions. Not all temperatures are labelled where two or more stations were close together. Contours show estimated isotherms.

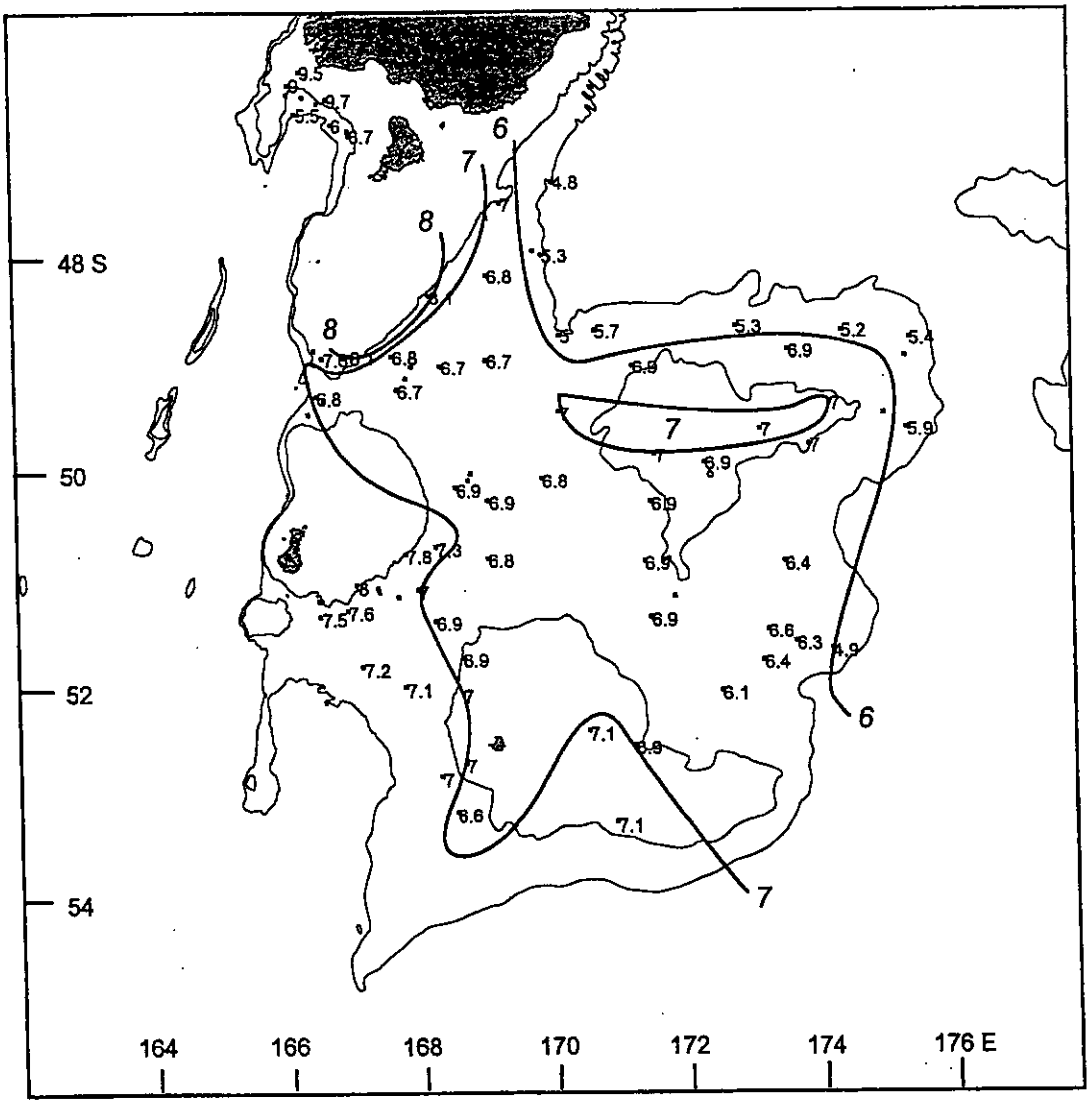


Figure 17: Bottom water temperatures (°C). Squares indicate station positions. Not all temperatures are labelled where two or more stations were close together. Contours show estimated isotherms.

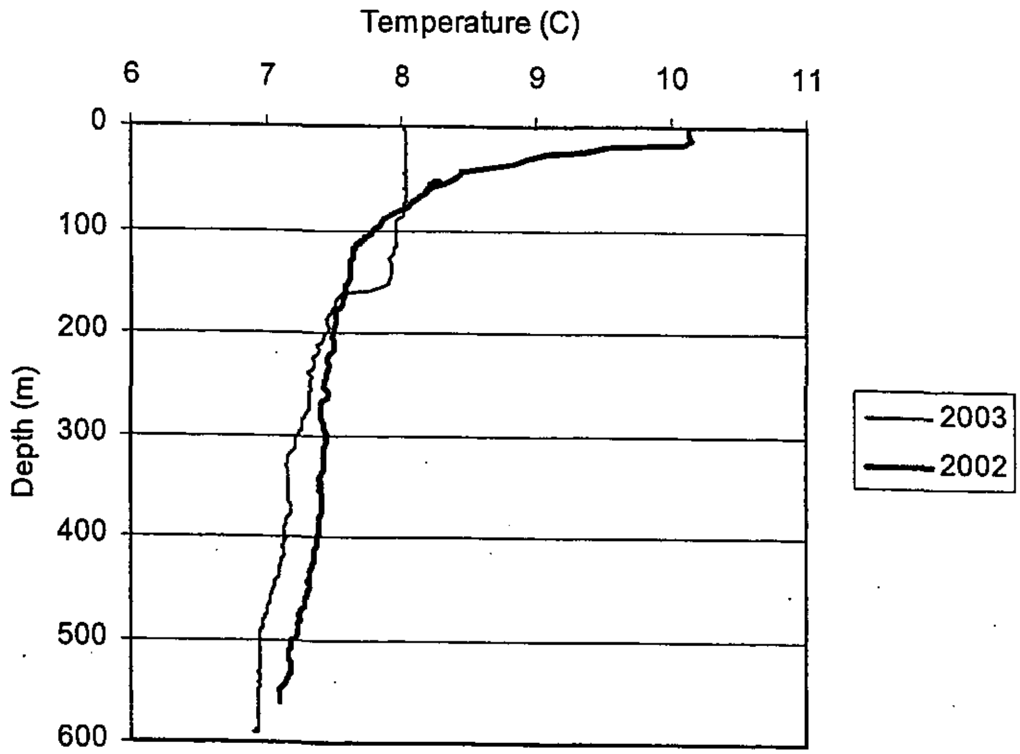


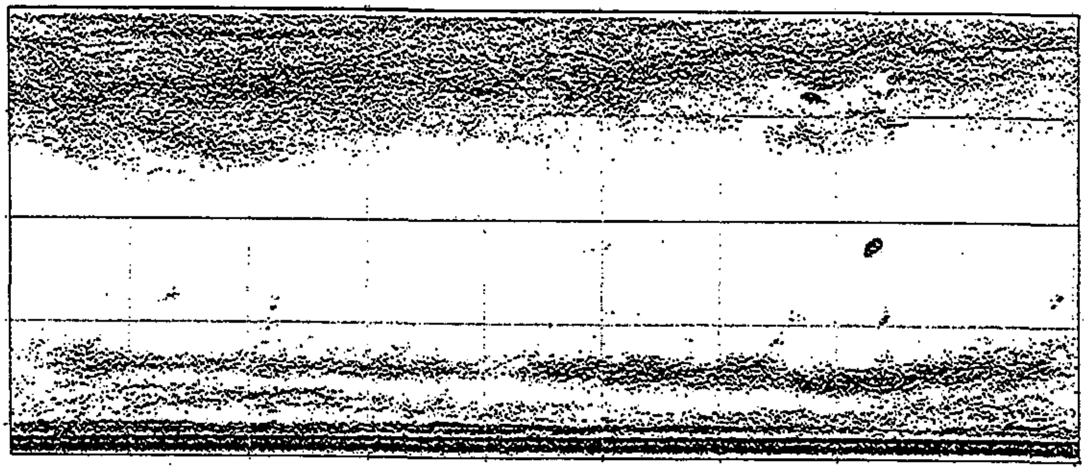
Figure 18: Comparison of vertical profiles of temperature from the net-mounted CTD on tows in Stratum 9 at approximately 50 45' S and 169 00' E in 2002 (TAN0219 Tow 54, on 6 December) and 2003 (TAN0317 Tow 45, on 29 November).

Appendix 1: Description of gonad development used for staging male and female teleosts

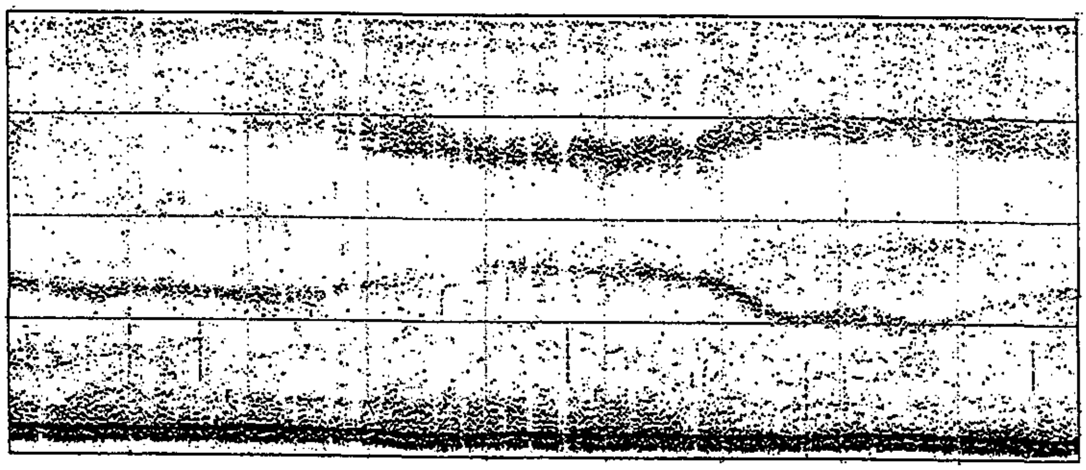
Research gonad stage		Males	Females
1	Immature	Testes small and translucent, threadlike or narrow membranes.	Ovaries small and translucent. No developing oocytes.
2	Resting	Testes are thin and flabby; white or transparent.	Ovaries are developed, but no developing eggs are visible.
3	Ripening	Testes are firm and well developed, but no milt is present.	Ovaries contain visible developing eggs, but no hyaline eggs present.
4	Ripe	Testes large, well developed; milt is present and flows when testis is cut, but not when body is squeezed.	Some or all eggs are hyaline, but eggs are not extruded when body is squeezed.
5	Running-ripe	Testis is large, well formed; milt flows easily under pressure on the body.	Eggs flow freely from the ovary when it is cut or the body is pressed.
6	Partially spent	Testis somewhat flabby and may be slightly bloodshot, but milt still flows freely under pressure on the body.	Ovary partially deflated, often bloodshot. Some hyaline and ovulated eggs present and flowing from a cut ovary or when the body is squeezed.
7	Spent	Testis is flabby and bloodshot. No milt in most of testis, but there may be some remaining near the lumen. Milt not easily expressed even when present.	Ovary bloodshot; ovary wall may appear thick and white. Some residual ovulated eggs may still remain but will not flow when body is squeezed.

Appendix 2: Description of criteria used to describe acoustic data quality

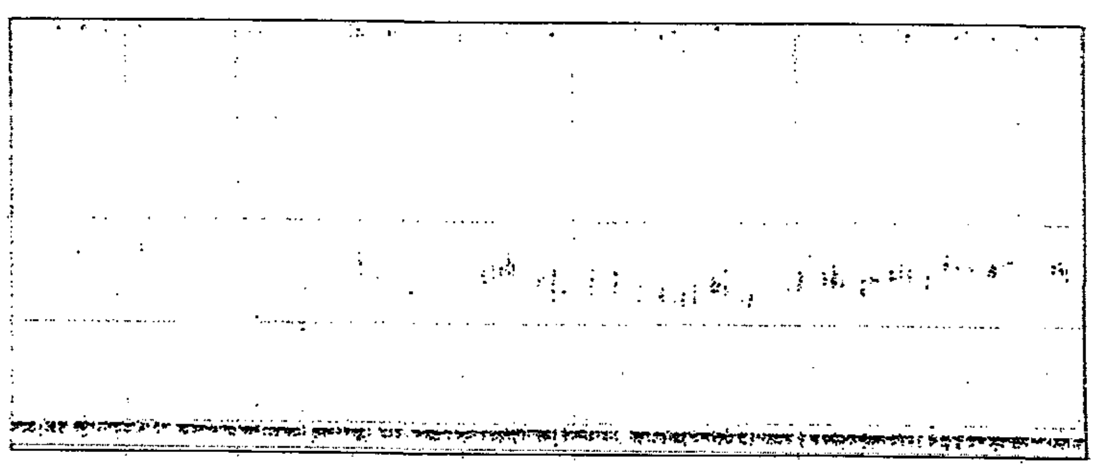
Good quality recordings
Little visible noise. Less than 1% of transmits need to be edited out.



Marginal quality recordings
Some missing transmits and noise spikes. 1–10% of transmits require editing.



Poor quality recordings
Signal very broken with numerous missing transmits and/or noise interference. More than 10% of transmits would need be edited out.



Appendix 3: Scientific and common names, species codes and occurrence (Occ.) of fish, squid, and other organisms.

Scientific name	Common name	Species code	Occ.
Chondrichthyes			
Squalidae: dogfishes			
Centrophorus squamosus	deepwater spiny dogfish	CSQ	12
Centroscymnus crepidater	longnose velvet dogfish	CYP	16
C. owstoni	smooth skin dogfish	CYO	5
C. plunketi	Plunket's shark	PLS	7
Deania calcea	shovelnose dogfish	SND	9
Etmopterus baxteri	Baxter's dogfish	ETB	26
E. lucifer	Lucifer dogfish	ETL	32
Scymnorhinus licha	seal shark	BSH	5
Squalus acanthias	spiny dogfish	SPD	39
Oxynotidae: rough sharks			
Oxynotus bruniensis	prickly dogfish	PDG	2
Scyliorhinidae: cat sharks			
Apristurus spp	deepsea catsharks	APR	5
Halaelurus dawsoni	Dawson's catshark	DCS	1
Rajidae: skates			
Bathyraja shuntovi	longnosed deepsea skate	PSK	2
Dipturus innominata	smooth skate	SSK	10
D. nasuta	rough skate	RSK	7
Pavoraja asperula	smooth bluntnosed skate	BTA	8
P. spinifera	prickly bluntnosed skate	BTS	3
Chimaeridae: chimaeras, ghost sharks			
Chimaera sp	brown chimaera	CHP	1
Hydrolagus novaezelandiae	dark ghost shark	GSH	13
Hydrolagus sp. B	pale ghost shark	GSP	67
Rhinochimaeridae: longnosed chimaeras			
Harriotta raleighana	longnose chimaera	LCH	30
Rhinochimaera pacifica	widenose chimaera	RCH	5
Osteichthyes			
Notacanthidae: spiny eels			
Notacanthus chemnitzi	spiny eel	NOC	1
N. sexspinis	spineback	SBK	26
Synaphobranchidae: cutthroat eels			
Diastobranchus capensis	basketwork eel	BEE	12
Congridae: conger eels			
Bassanago bulbiceps	swollenheaded conger	SCO	16
B. hirsutus	hairy conger	HCO	27
Argentinidae: silversides			
Argentina elongata	silverside	SSI	43
Bathylagidae: deepsea smelts			
Bathylagus spp	deepsea smelt	DSS	2
Opisthoproctidae: spookfishes			
Opisthoproctus grimaldii	mirrorbelly	MBE	1
Alepocephalidae: slickheads			
Alepocephalus australis	small-scaled brown slickhead	SSM	5
Alepocephalus sp.	big-scaled brown slickhead	SBI	2
Platytroctidae: tubeshoulders			
Persparsia kopua	tubeshoulder	PER	6
Chauliodontidae: viperfishes			
Chauliodus sloani	viper fish	CHA	9

Appendix 3 cont: Scientific and common names, species codes and occurrence (Occ.) of fish, squid, and other organisms.

Scientific name	Common name	Species code	Occ.
Stomiidae: scaly dragonfishes			
Stomias spp	scaly dragonfish	STO	4
Melanostomiidae: scaleless black dragonfishes			
Species not identified	scaleless black dragonfish	MST	1
Malacosteidae: loosejaws			
Species not identified	loosejaw	MAL	1
Idiacanthidae: black dragonfishes			
Idiacanthus sp	black dragonfish	IDI	3
Gonostomatidae: lightfishes			
Species not identified	lightfish	GST	2
Photichthyidae: lighthouse fishes			
Photichthys argenteus	lighthouse fish	PHO	13
Evermannellidae: sabretooth fishes			
Evermanella indica	sabretooth	SAB	1
Myctophidae: lanternfishes			
Species not identified	lanternfish	LAN	5
Moridae: morid cods			
Austrophycis marginata	dwarf cod	DCO	4
Halargyreus johnsoni	slender cod	HJO	11
Laemonema spp		LAE	2
Lepidion microcephalus	small-headed cod	SMC	9
Mora moro	ribaldo	RIB	35
Pseudophycis bachus	red cod	RCO	9
Tripterophycis gilchristi	grenadier cod	GRC	1
Gadidae: true cods			
Micromesistius australis	southern blue whiting	SBW	22
Merlucciidae: hakes			
Lyconus sp.		LYC	1
Macruronus novaezelandiae	hoki	HOK	77
Merluccius australis	hake	HAK	40
Macrouridae: rattails, grenadiers			
Caelorinchus aspercephalus	oblique-banded rattail	CAS	37
C. biclinozonalis	two saddle rattail	CBI	1
C. bollonsi	Bollons's rattail	CBO	15
C. fasciatus	banded rattail	CFA	71
C. innotabilis	notable rattail	CIN	15
C. kaiyomaru	Kaiyomaru rattail	CKA	13
C. matamua	Mahia rattail	CMA	3
C. oliverianus	Oliver's rattail	COL	56
C. parvifasciatus	small-banded rattail	CCX	4
Coryphaenoides dossenus	humpback rattail	CBA	4
C. serrulatus	serrulate rattail	CSE	8
C. subserrulatus	fourrayed rattail	CSU	20
Lepidorhynchus denticulatus	javelinfish	JAV	80
Macrourus carinatus	ridge-scaled rattail	MCA	22
Mesobius antipodum	black javelinfish	BJA	5
Trachyrincus aphyodes	white rattail	WHX	5
Ventrifossa nigromaculata	blackspot rattail	VNI	23
	species not identified	RAT	1

Appendix 3 cont: Scientific and common names, species codes and occurrence (Occ.) of fish, squid, and other organisms.

Scientific name	Common name	Species code	Occ.
Ophidiidae: cusk eels			
Genypterus blacodes	ling	LIN	72
Trachipteridae: dealfishes			
Trachipterus trachypterus	dealfish	DEA	3
Regalecidae: oarfishes			
Agrostichthys parkeri	ribbonfish	AGR	1
Trachichthyidae: roughies			
Hoplostethus atlanticus	orange roughy	ORH	7
H. mediterraneus	silver roughy	SRH	7
Diremidae: discfishes			
Diretmus argenteus	discfish	DIS	3
Zeidae: dories			
Capromimus abbreviatus	capro dory	CDO	3
C. traversi	lookdown dory	LDO	34
Scorpaenidae: scorpionfishes			
Helicolenus spp	sea perch	SPE	2
Trachyscorpia capensis	Cape scorpion fish	TRS	1
Oreosomatidae: oreos			
Allocyttus niger	black oreo	BOE	10
Pseudocyttus maculatus	smooth oreo	SSO	9
Macrorhamphosidae: snipefishes			
Centriscops obliquus	redbanded bellowsfish	BBE	3
Congiopodidae: pigfishes			
Alertichthys blacki	alert pigfish	API	3
Psychrolutidae: toadfishes			
Neophrynichthys angustus	pale toadfish	TOP	17
Psychrolutes sp	blobfish	PSY	3
Percichthyidae: temperate basses			
Polyprion oxygeneios	hapuku	HAP	1
Apogonidae: cardinalfishes			
Epigonus lenimen	bigeye cardinalfish	EPL	7
E. robustus	cardinalfish	EPR	1
E. telescopus	black cardinalfish	EPT	4
Rosenblattia robusta	rotund cardinalfish	ROS	1
Bramidae: pomfrets			
Brama australis	southern Ray's bream	SRB	2
Xenobrama microlepis	bronze bream	BBR	1
Emmelichthyidae: bonnetmouths			
Emmelichthys nitidus	redbait	RBT	1
Chiasmodontidae: swallowers			
Kali indica	swallower	KAI	1
Uranoscopidae: armourhead stargazers			
Kathetostoma giganteum	giant stargazer	STA	10
Gempylidae: snake mackerels			
Rexea solandri	gemfish	SKI	3
Centrolophidae: raftfishes, medusafishes			
Centrolophus niger	rudderfish	RUD	2
Hyperoglyphe antarctica	bluenose	BNS	2
Icichthys australis	ragfish	RAG	4
Seriolella brama	blue warehou	WAR	2
S. caerulea	white warehou	WWA	14
S. punctata	silver warehou	SWA	3

Appendix 3 cont: Scientific and common names, species codes and occurrence (Occ.) of fish, squid, and other organisms.

Scientific name	Common name	Species code	Occ.
Bothidae: lefteyed flounders			
Arnoglossus scapha	witch	WIT	1
Neoachiropsetta milfordi	finless flounder	MAN	24
Other marine organisms			
Porifera	unspecified sponges	ONG	32
Cnidaria			
Scyphozoa	unspecified jellyfish	JFI	7
Anthozoa			
Octocorallia	gorgonian coral	GOC	1
Zoanthidea			
Anctinaria	unspecified sea anemones	ANT	45
Tunicata			
Thaliacea	unspecified salps	SAL	9
Pyrosoma atlanticum		PYR	70
Mollusca			
Bivalvia	unidentified bivalve	BIV	1
Gastropoda	unspecified gastropods	GAS	4
Fusitron magellanicus		FMA	6
Aplysiomorpha	unspecified sea hare	SHR	1
Cephalopoda	unidentified squid	SQX	3
Cranchiidae		CHQ	4
Histioteuthidae			
Histioteuthis spp	violet squid	VSQ	8
Octopoteuthiidae			
Taningia danae		OSQ	5
Ommastrephidae			
Nototodarus sloanii	arrow squid	NOS	17
Ommastrephes bartrami	red squid	RSQ	1
Todarodes filippovae	Antarctic flying squid	TSQ	17
Onychoteuthidae			
Moroteuthis ingens	warty squid	MIQ	69
M. robsoni	warty squid	MRQ	7
Octopoda: octopods	unspecified octopus	OCP	1
Octopodidae			
Enteroctopus zealandicus	yellow octopus	EZE	1
Graneledone spp	deepwater octopus	DWO	10
Opisthoteuthididae			
Opisthoteuthis spp	umbrella octopus	OPI	7

Appendix 3 cont: Scientific and common names, species codes and occurrence (Occ.) of fish, squid, and other organisms.

Scientific name	Common name	Species code	Occ.
Arthropoda			
Chelicerata			
Pycnogonida	unspecified sea spider	PYC	1
Crustacea			
Decapdoda			
Penaeidea			
Sergia potens		SEP	1
Caridea	unspecified prawn	PRA	1
Acanthephyra spp		ACA	1
Acanthephyra pelagica		APE	2
Aristaeopsis edwardsianus	scarlet prawn	PED	2
Camplyonotus rathbonae	sabre prawn	CAM	1
Lipkius holthuisi	omega prawn	LHO	35
Oplophorus novaezeelandiae		ONO	5
Pasiphaea barnardi		PBA	4
Pasiphaea sp		PAS	7
Astacidea			
Nephropsidae			
Metanephrops challengeri	scampi	SCI	7
Polychelidae			
Stereomastis suhmi		PLY	1
Anomura + Brachyura	unspecified crabs	CRB	4
Anomura			
Lithodidae			
Lithodes murrayi	southern stone crab	LMU	6
Neolithodes brodiei		NEB	5
Paralomis hystrix		PHS	2
Paguridea	unspecified hermit crab	PAG	9
Brachyura			
Majidae			
Leptomithrax australis	masking crab	SSC	2
Echinodermata			
Asteroidea	unspecified asteroid	ASR	33
Goniasteridae			
Hippasteria trojana	starfish	HTR	16
Solasteridae			
Crossaster japonicus	sun star	CJA	1
Solaster torulatus	starfish	SOT	3
Zoroasteridae			
Zoroaster spp	rat-tail star	ZOR	29
Astropectinidae			
Plutonaster spp	starfish	PLT	1
Psilaster acuminatus	geometric star	PSI	10
Ophiuroidea			
Gorgonocephalidae			
Gorgonocephalus sp		GOR	2
Holothuroidea	unspecified sea cucumbers	HTH	34

Appendix 3 cont: Scientific and common names, species codes and occurrence (Occ.) of fish, squid, and other organisms.

Scientific name	Common name	Species code	Occ.
Echinoidea			
Cidaridae			
Goniocidaris parasol		GPA	4
Poriocidaris sp	cidarid urchin	PCD	1
Echinidae			
Gracilechinus multidentatus		GRM	2
Echinothuriidae			
Araeosoma spp	Tam O'Shanter urchin	ARA	15
Spatangidae			
Paramaretia multituberculata	heart urchin	PMU	1