Ministry for Primary Industries
Manatū Ahu Matua

Trawl and acoustic survey of hoki and middle depth fish abundance on the west coast South Island, July–August 2012 (TAN1210)

New Zealand Fisheries Assessment Report 2014/09

R.L. O'Driscoll
N.W. Bagley
S.L. Ballara
J. Oeffner

ISSN 1179-5352 (online)
ISBN 978-0-478-42358-7 (online)

February 2014

New Zealand Government

Growing and Protecting New Zealand

Requests for further copies should be directed to:

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

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

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

TABLE OF CONTENTS

EXECUTIVE SUMMARY

O'Driscoll, R.L.; Bagley, N.W.; Ballara, S.L.; Oeffner, J. (2014). Trawl and acoustic survey of hoki and middle depth fish abundance on the west coast South Island, July–August 2012 (TAN1210).

***New Zealand Fisheries Assessment Report 2014/09*. 102 p.**

A combined trawl and acoustic survey of the west coast South Island (WCSI) was carried out from 20 July to 19 August 2012. This was the ninth in a series of acoustic surveys of WCSI hoki spawning areas, but the first since 2000. The survey was also the second in a new time series of trawl estimates for middle depth species from the WCSI, with results that are comparable to the random trawl component from the 2000 WCSI survey. Other middle depth species were also monitored by the trawl survey. These include important commercial species such as hake and ling, as well as a wide range of non-commercial fish and invertebrate species. For most of these species, the trawl survey provides the only fisheries-independent estimate of abundance on the WCSI, as well as providing biological data (length, sex, reproductive condition, age etc.).

Three acoustic snapshots of the main WCSI hoki spawning areas were completed, with 27 targeted tows to identify acoustic marks and collect biological samples. Moored cameras were also used to study species composition on untrawlable ground. Acoustic estimates of hoki abundance were sensitive to the choice of hoki target strength, sound absorption, stratum areas, and the method used to correct for species composition in mixed marks. 'Old' acoustic estimates were calculated using the same methods as previous surveys in the time series. These estimates ranged from 348 000 t in the first snapshot to 478 000 t in the second snapshot, with an average across all three snapshots of 412 000 t. This was 4% higher than the equivalent acoustic index from 2000 and slightly above the long-term average of the time-series. The acoustic survey weighting (expressed as a coefficient of variation, CV), which includes uncertainty associated with survey timing, sampling precision, mark identification, calibration, and target strength was 0.51. 'New' acoustic estimates were calculated using updated estimates of sound absorption, hoki target strength, and stratum areas, and revised methods for species decomposition based on trawl data collected during the 2012 survey. 'New' acoustic estimates had an average over the three snapshots of 236 000 t (weighting CV 0.22) for the area north of the Hokitika Canyon and 299 000 t (CV 0.28) from the southern area. The combined 'new' estimate of 535 000 t was 30% higher than the 'old' estimate for 2012, but the 'new' estimate cannot be easily compared with previous surveys (before 2000) in the time-series which had less mark identification trawling.

Using 'old' estimates, about 39% of the hoki from the WCSI in 2012 was from the area north of the Hokitika Canyon. This was higher than the northern abundance in previous acoustic surveys (where 10–34% of total WCSI biomass was in the north). About 60% of the estimated hoki abundance was from hoki schools, where marks were assumed to contain 100% hoki. The proportion of hoki backscatter in mixed 'fuzz' marks estimated from research tows varied between strata, ranging from 5% in stratum 4D to 78% in stratum 4B. Only 51% of backscatter in mixed marks from the southern area (strata 5A, 5B, 6, and 7) was estimated to be from hoki.

A total of 63 successful random trawl survey tows were completed in the northern area. Trawl abundance estimates and sampling CVs (in parentheses as a percentage) for all strata were 32 602 t (24 %) for hoki, 2194 t (15 %) for ling, and 1103 t (13 %) for hake. The trawl estimate of hoki abundance in 2012 was much higher than the abundance estimated from daytime random tows in the equivalent strata in the 2000 WCSI survey. Hoki catch rates were highest in 400–500 m in all strata, and broadly matched the estimated hoki distribution observed in the acoustic survey and in the commercial fishery. Hake mainly occurred deeper than 500 m, with highest catch rates between 650 and 800 m. Ling catch rates were highest from 300–430 m in the north of the survey area.

A total catch of 182.6 t consisting of 191 species or species groups was recorded from all trawl tows, 39 842 fish and squid individuals from 100 different species were measured, and 12 001 fish were also individually weighed. Several modes were present in the hoki scaled length frequency including small (1-year old) hoki at 25–35 cm. Most male hoki were between 50 and 80 cm (ages 2–7 years), and most females were 60–100 cm (ages 3–10 years). Ling and hake data showed broad length ranges, but the age distribution of hake showed a higher proportion of young fish (ages 5–8 years) in 2012 compared to the 2000 survey samples.

1. INTRODUCTION

Hoki is New Zealand's largest finfish fishery with a TACC of 130 000 t in 2012–13. Although managed as a single stock, hoki are assessed as two stocks, western and eastern. The hypothesis is that juveniles from both stocks mix on the Chatham Rise and recruit to their respective stocks as they approach sexual maturity.

Historically, the main fishery for hoki has operated from mid-July to late August on the west coast South Island (WCSI) and in Cook Strait where hoki aggregate to spawn. About 48 000 t of hoki was taken from the WCSI in 2010–11, making this the largest New Zealand hoki fishery (Ballara & O'Driscoll 2012). The WCSI is also an important fishing area for hake and ling, with reported landings of 3754 t in HAK 7 and 2792 t in LIN 7 in 2010–11. There are no other fisheries independent estimates of ling and hake abundance on the WCSI. An assessment for LIN 7WC was carried out in 2008 based on trawl and longline CPUE, but there was a high level of uncertainty about the status of this stock (Ministry for Primary Industries 2012). Similarly, HAK 7 has been assessed but with high uncertainty (Ministry for Primary Industries 2012).

The 10-year Deepwater Research Programme includes a series of trawl and acoustic surveys of the WCSI to provide estimates of abundance for hoki, hake and ling. This report describes the initial survey carried out in 2012. Another survey is planned for 2013 and the survey series will continue at 2-year intervals if the initial surveys are successful.

Previous acoustic surveys of the WCSI hoki spawning grounds were carried out in 1988–93, 1997, and 2000 (reviewed by O'Driscoll 2002). However, there was much uncertainty over the abundance indices from the 1997 and 2000 surveys because of the species mix in the northern strata. Following a review of results from the 2000 survey, Francis & O'Driscoll (2004) proposed a combined trawl and acoustic survey as a practical approach to measuring hoki abundance more consistently. Simulation studies suggested that there would be a gain in information by switching from the previous method of producing one acoustic abundance index for the whole WCSI to a new method where three relative abundance estimates are produced – a northern acoustic index, a southern acoustic index, and a northern trawl index. Estimates based on information from the 2000 survey suggested that the gain from making this change would be equivalent to reducing a simple survey CV from 31% to 21%. The trawl component of a combined survey would also provide relative abundance estimates for other species in the northern area. Relatively precise (CV less than 25%) trawl estimates of abundance were obtained for hoki, ling, hake, silver warehou, and lookdown dory during the 2000 acoustic survey (O'Driscoll et al. 2004).

To maintain consistency with the relative acoustic time series which dates back to 1988 (see O'Driscoll (2002) for references), the survey design retained key aspects of the acoustic survey methodology. The 2012 survey used the same vessel (*Tangaroa*) and gear used in 2000 to allow comparison of trawl estimates from this survey with those obtained from random trawling in northern strata in 2000 (O'Driscoll et al. 2004).

1.1 Project objectives

This report is the final reporting requirement for Ministry for Primary Industries Research Project HOK2010/04B. The overall objective of this project is to estimate relative abundance indices for hoki, hake, and ling off the WCSI. The specific objectives were as follows:

1. To carry out combined trawl and acoustic surveys to obtain relative abundance indices for hoki, hake (HAK 7) and ling (LIN 7) on the WCSI.

2. To continue the time series of relative abundance indices of spawning hoki on the WCSI using acoustic surveys, with a target coefficient of variation (CV) of the estimate of 30 %.

3. To collect data for determining the age and size structure and reproductive biology of hoki, hake and ling.

4. To determine species composition of fish marks measured acoustically during the survey by target trawling.

5. To collect and preserve specimens of unidentified organisms taken during the trawl survey.

2. METHODS

2.1 Survey design

The survey design (Figure 1, Table 1) was based on the same six strata used for previous WCSI acoustic surveys, retaining the sub-stratification for Strata 1&2 and 4 used in the 2000 survey (Cordue 2002), but adding additional strata in an attempt to cover the depth range of other key species (particularly hake and ling). Survey boundaries were determined based on an analysis of commercial fishing catch and effort in FMA 7, over the period June–September in all years from 2000 to 2010, and where bottom depth was in the range 100 to 1000 m (O'Driscoll et al. 2011a). There were four main changes to the strata used in 2000:

- Stratum 1&2 was extended further north from 40.8°S to 40.6°S to better cover the distribution of hoki and ling catches;
- Stratum 4D (650–800 m) was added to fully sample the offshore distribution of hoki, hake, and ribaldo in that area;
- The offshore boundary of the northern part of acoustic stratum 6 (north of 42.85°S) was shifted from 750 m to 850 m to comprehensively sample hake;
- Stratum 1&2S and 4S (200–300 m) were added to improve trawl indices for silver warehou, barracouta, frostfish, and gemfish.

The acoustic survey design was based on the approach used in previous WCSI surveys, and described in detail by Coombs & Cordue (1995), Cordue (2002), and O'Driscoll (2002). Briefly, this design follows the methods of Jolly & Hampton (1990), as adapted by Coombs & Cordue (1995), to produce an abundance index for transient fish populations. Estimates of the spawning abundance during the "main" spawning season were obtained from several sub-surveys or "snapshots", each consisting of random parallel transects within strata. These estimates were then averaged to obtain an estimate of the "mean plateau height" (the average abundance during the main spawning season). Under various model assumptions, annual estimates of mean plateau height form a valid relative abundance time series (Cordue et al. 1992). The 2012 WCSI survey provided two acoustic abundance indices – northern (Strata 1&2 and 4), and southern (Strata 5A, 5B, 6, and 7) – instead of the single acoustic index from previous WCSI surveys. The aim was to carry out two acoustic snapshots of the northern area and three snapshots of the southern area.

The trawl survey was carried out north of Hokitika Canyon (Strata 1&2 and 4) only and was based on a stratified random trawl survey design (after Francis 1984). Tow allocation was based on a statistical analysis of catch rate data from daytime random bottom tows in 2000 using the *allocate* programme (Francis 2006). A minimum of three tows per stratum was used, with target CVs of 20% for hoki, hake, and ling, and 25% for silver warehou. A total of 66 tows were planned (Table 1), with 51 tows in the six core strata surveyed in 2000, and 5 tows in each of the additional three strata (4D, 1&2S and 4S). There was no allowance for phase 2 tows, and strata 1&2S and 4S were to be given lower priority and only carried out if time permitted.

The survey design also allowed time for targeted mark identification trawling, acoustic calibration, target strength data collection, and opportunistic adaptive surveying of any hake aggregations encountered.

2.2 Vessel and equipment

R.V. *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.

Acoustic data were collected with NIWA's Computerised Research Echo Sounder Technology (CREST) system (Coombs et al. 2003) and the multifrequency (18, 38, 70, 120, and 200 kHz) Simrad EK60 system on *Tangaroa*. Data were collected using the hull-mounted EK60 system throughout the voyage. The towed CREST system (Towbody 3), with a 38-kHz split-beam transducer, was used for acoustic data collection along survey transects when the weather was poor (typically more than 25 knots of wind and 2 m swell). A second towbody (Towbody 4) was carried as a spare, and was calibrated, but was not used during the survey. The 38 kHz hull transducer was not transmitting during survey transects with the towed system to prevent interference, but was switched on when the towbody was on board the vessel.

Both towbodies and the multifrequency hull echosounders were calibrated in Tasman Bay at the start of the voyage on 21 July 2012. The hull calibration showed that all five frequencies were operating correctly, with good or excellent quality calibrations on all frequencies (Appendix 1). Calculated calibration parameters for Towbody 3 are provided in Appendix 2 and were comparable with previous calibrations.

Two trawl types were used during the survey. The bottom trawl used for all random (trawl survey) tows and for mark identification tows on near-bottom marks 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). Targeted tows on pelagic marks were carried out with the NIWA mesopelagic (fine-mesh midwater) trawl. This trawl has a headline height of about 12 m, which allowed us to target a narrow depth band in shallow water. This trawl has a cod-end where the mesh-size reduces along its length ending with 10 mm mesh. The trawl doors were Super Vee type with an area of 6.1 m^2.

2.3 Acoustic data collection

Transect locations were randomly generated, and were carried out at right angles to the depth contours (i.e., from shallow to deep or vice versa). The minimum distance between transect midpoints varied between strata, and was calculated as follows:

$$m = 0.5 * L/n \qquad (1)$$

where m is minimum distance, L is length of stratum, and n is the number of transects.

Transects were run at speeds of 6–10 knots (depending on the weather and sea conditions). When the acoustic towbody was used, it was deployed 30–70 m below the surface. Acoustic transects were mainly run in the northern strata during the night (with random tows during the day), but the area from Hokitika Canyon south was acoustically surveyed day and night. Acoustic data collection was interrupted (generally between transects) for mark identification tows.

2.4 Trawling procedure and biological sampling

Random 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 tows 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. Random bottom tows were only carried out during daylight hours when a greater proportion of fish are near the bottom and catch rates are typically higher (O'Driscoll et al. 2004). All random trawling was between 0800 h and 1803 h NZST. 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 trawl hauled early due to reducing daylight or strong marks on the net monitor, the tow was included as valid only if at least 2 n. miles had been covered.

Targeted trawling was carried out for mark identification, to collect biological data, and in support of target strength data collection (see Section 2.5). Most target identification work was focused on:

1. establishing species mix proportions away from dominant heavy marks, which are easily identified as hoki schools (additional information on mark identification and composition of dense marks was also available from the commercial fishery);
2. determining species composition in low density hoki mix marks, particularly in the southern strata (5B, 6, and 7) where there was no random trawling component;
3. sampling marks away from the bottom to separate hoki from mesopelagic fish;
4. obtaining a sample of adult hoki in areas which were not being fished by the commercial fleet.

Target trawling was carried out both day and night.

Measurements of doorspread (from a SCANMAR ScanBas system), headline height (from a Furuno CN22 net monitor), and vessel speed (GPS speed over the ground, cross checked against distance travelled during the tow) were recorded every 5 min during each tow and average values calculated. Towing speed and gear configuration for random tows were maintained as constant as possible during the survey, following the guidelines given by Hurst et al. (1992). Acoustic recordings were made for all tows using the five frequency hull-mounted transducers.

From each tow, 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 were identified to species, genus, or family. Unidentified organisms were collected and frozen at sea for subsequent identification ashore.

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, contents, and prey condition. Otoliths were taken from hake, hoki, and ling for age determination. Otoliths were also taken from sliver warehou for future ageing work. A description of the macroscopic gonad stages used for teleosts and elasmobranchs is given in Appendix 3. Liver and gutted weights were recorded from up to 20 hoki per tow to determine condition indices.

2.5 Target strength data collection

Acoustic target strength (TS) is still an important area of research. There are contradictory length-to-TS relationships for hoki obtained from *in situ* measurements and swimbladder modelling (Macaulay 2006, Kloser et al. 2011). To resolve these differences, and improve our estimates of TS of hoki, hake, and associated species, we attempted to collect in situ data using the acoustic-optical system (AOS) developed by NIWA (O'Driscoll et al. 2013). The AOS uses an autonomous EK60 38-kHz echosounder coupled to a high-definition underwater video, which is mounted in a frame in the headline of the hoki bottom trawl. A 60 mm panel of cod-end mesh was used to provide support and strength for the AOS. This panel was removed on other bottom trawl deployments.

The trawl is used to herd fish under the AOS where visually verified estimates of TS can be made. The advantage of using the AOS to collect TS data on targeted tows is that minimal additional time was required outside the survey framework. The AOS was calibrated down to about 500 m depth during the survey on 8 August.

2.6 Moorings

Moored video cameras show considerable promise as a technique to investigate species composition and fish behaviour (e.g., orientation) in deepwater fish aggregations *in situ* (O'Driscoll et al. 2012). Two camera moorings were deployed in the Hokitika Canyon during the voyage: on the south side at 435 m depth overnight on 26–27 July; and on the north side at 430 m depth overnight on 14–15 August. Moorings used the same camera system used successfully by NIWA on the Chatham Rise for orange roughy on TAN1208 (MPI Research Project DEE2011/05).

2.7 Other data collection

A Seabird SM-37 Microcat CTD datalogger was mounted on the headline of the net during 89 bottom tows to determine the absorption coefficient and speed of sound, and to define water mass characteristics in the area (Appendix 4). CTD drops were also carried out in conjunction with all the acoustic calibrations.

2.8 Trawl data analysis

Doorspread biomass was estimated by the swept area method of Francis (1981, 1989) as implemented in the analysis programme *SurvCalc* (Francis 2009). Total survey abundance was estimated for the top 28 species in the catch. 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 trawl doors were caught. Only data from random trawl tows where the gear performance was satisfactory (codes 1 or 2) were included for estimating abundance.

Scaled length frequencies were calculated for the key species with *SurvCalc*, using length-weight data from this survey. Length frequencies were estimated for the trawl survey component of the survey from random trawl tows only, but length frequencies by stratum were also estimated including both random and targeted tows for estimating hoki TS and species decomposition (see Section 2.9).

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)). Sub-samples of 706 hoki otoliths, 609 ling and 700 hake otoliths were selected for ageing. Sub-samples were derived by randomly selecting otoliths from each of a series of 1 cm length bins covering the bulk of the catch, and then systematically selecting additional otoliths to ensure that the tails of the length distribution were represented. The chosen sample size approximates that necessary to produce a mean weighted CV of less than 20% across all age classes.

Numbers at age were calculated from observed length frequencies from successful random tows 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 measurements to improve the consistency of age estimation.

To enable comparisons with the 2012 survey, abundance and scaled length frequencies from the daytime random trawl component of the 2000 survey (O'Driscoll et al. 2004) were re-run using the revised 2012 stratum areas. This assumes that densities in the extension to the northern strata (the regions of strata 1&2A, 1&2B, and 1&2C from 40.8°S to 40.6°S) were similar to, and could be extrapolated from, densities within these strata south of 40.6°S in 2000. An alternative choice would be to exclude tows in the 2012 survey which were between 40.8°S to 40.6°S and calculate 2012 abundance using 2000 survey areas. Results using this alternative calculation are not reported here, but made relatively little difference to the relative ratio of the abundance estimates from 2012 to 2000 for most species (typically less than 5%).

2.9 Acoustic data analysis

Acoustic data collected during the survey were analysed using standard echo-integration methods (MacLennan & Simmonds 1992), as implemented in NIWA's Echo Sounder Package (ESP2) software (McNeill 2001).

2.9.1 Mark identification

Echograms were visually examined, and the bottom determined by a combination of an in-built bottom tracking algorithm and manual editing. Regions corresponding to various acoustic mark types were then identified. Marks were classified subjectively (e.g. O'Driscoll 2002), based on their appearance on the echogram (shape, structure, depth, relative strength on multiple frequencies), and using information from mark identification tows. Hoki form large, dense, single-species aggregations during spawning which are readily identifiable acoustically. Mark classification initially involved distinguishing hoki schools from other non-hoki marks and layers. The classification procedure is largely subjective, and dependent on the experience of the analyst. In discussion with acoustic analysts of previous WCSI acoustic surveys (Sira Ballara and Patrick Cordue), it was apparent that there were some unwritten "guiding rules". Schools classified as hoki were between 200 and 750 m water depth, forming elongated schools in midwater, but sometimes making contact with the bottom. Hoki schools were usually of moderate to high density (echo amplitude), with single target echoes sometimes visible around the margins. Other, non-hoki, pelagic marks were usually layers rather than schools, often with a wavy, undulating appearance. Non-hoki layers were typically shallower than hoki schools, and there was less "structure" in the mark, with no obvious single targets. Non-hoki pelagic layers tended to be much stronger on lower frequencies (12 kHz in surveys up to 2000 and 18 kHz now) than on 38 kHz, possibly because the swimbladders of the small pelagic species involved resonate at these lower frequencies (Bull 2000). Tows on hoki school marks typically produced clean catches (over 90 % by weight) of hoki and bycatch of commercial vessels during the hoki spawning fishery is also low. Other pelagic layers typically contain mesopelagic fish species and jack mackerel.

Mark identification is much more difficult away from hoki school marks. A common mark type on the WCSI is a bottom-oriented, low density, 'fuzzy' layer, which may extend up to 50 m above the bottom during the day. These 'hoki bottom fuzz' marks consisted of a variety of species including hoki. Similarly, 'hoki pelagic fuzz' marks are low-density midwater marks containing hoki and other species and are more commonly observed at night.

2.9.2 Integration

Backscatter at 38 kHz from marks (regions) identified as hoki schools and hoki fuzz were integrated separately to produce estimates of acoustic density, expressed as the mean area backscattering coefficient (m^2 m^{-2}). Acoustic density was output in two ways. First, average acoustic density over each transect and substratum was calculated. These values were used in abundance estimation (see Section 2.9.4). Second, acoustic backscatter was integrated over 10-ping bins to produce a series of acoustic densities for each transect (typically 30–100 values per transect). These data had a high spatial resolution, with each value (10 pings) corresponding to about 100 m along a transect, and were used to produce plots showing the spatial distribution of acoustic density.

For hoki surveys before 2003, the standard procedure (Coombs & Cordue 1995, O'Driscoll 2002) was to use an estimate of sound absorption of 8.0 dB km^{-1}, calculated using the formula of Fisher & Simmons (1977), which was based on laboratory measurements of artificial seawater. Doonan et al. (2003) reviewed the absorption of sound in seawater focusing on the frequencies and water properties used in fisheries acoustics in New Zealand and published a new formula based on a statistical reanalysis of existing data. This new formula has been adopted for surveys of New Zealand deepwater fish species. O'Driscoll (2006) updated the time series of acoustic estimates for the WCSI using the updated sound absorption, but the revised series was not accepted by the Hoki Fishery Assessment Working Group (HFAWG) and so the WCSI acoustic time series currently used in assessment is based on the old sound absorption of 8.0 dB km^{-1}. Acoustic integration of data from 2012 was carried out using the estimated sound absorption of 8.83 dB km^{-1} from the survey (see Appendix 4), and also the older value of 8.0 dB km^{-1} to allow comparison with the existing time series.

2.9.3 Species decomposition

Ideally, all species could be distinguished acoustically and classified separately, so all backscatter from hoki marks came from hoki, and there were no hoki present in other marks. Of course, in reality, species mixes occur. There have been a number of approaches to deal with the problem of species mix in hoki acoustic surveys.

Before 2000 on the WCSI and in all years in Cook Strait, it was assumed that all (Cook Strait), or almost all (WCSI), of the acoustic backscatter from marks containing hoki came from hoki. On the WCSI, a small correction factor used to be applied to correct for species mix. A constant "background density estimate" of 0.30×10^{-6} fish m^{-2} was subtracted from the observed acoustic densities before abundance was calculated. The correction factor was derived from the minimum observed density for a stratum in all surveys from 1988 to 1991 (0.33×10^{-6} fish m^{-2}), which was assumed to correspond to a hoki proportion of 10% (Coombs & Cordue 1995). The effect of this correction was relatively small, except in strata where observed acoustic densities were very low.

There was a very large increase in the hoki abundance index on the WCSI estimated using the constant correction factor method between 1993 and 1997. This increase was due entirely to an increase in abundance in the northern strata (Cordue & Ballara 1998). Most marks in the northern strata were low density marks close to the bottom ('bottom fuzz'), and there was concern raised by the HFAWG (Ballara et al. 1998) and an external reviewer hired by the then Ministry of Fisheries (Rose 1998) that a large amount of the backscatter in these marks did not come from hoki. Unfortunately, there were only four tows on the bottom fuzz marks in the northern strata in 1997. These tows suggested that hoki was the dominant species in the mixed layers, but that there were many other species present which would contribute to the acoustic backscatter.

In the 2000 WCSI acoustic survey, a large amount of effort was directed at the mixed marks in the strata north of Hokitika Canyon (Cordue 2002). The aim of the design chosen for the 2000 WCSI survey was to allow acoustic backscatter to be partitioned using a model-based estimation method which would account for differences in species' vulnerabilities to the trawl (Cordue 2002). Although the model-based method motivated the survey design, the results of this model-based method were rejected by the HFAWG in 2001 (Cordue 2002). The model was complex with penalty functions and bounds introduced to generate "sensible" output. Estimated catchabilities (in the trawl) of several species were at or close to the imposed lower bounds, and hoki catchability varied widely between depth substrata (Cordue 2002). The method also attributed 35% of the backscatter in the northern strata to hake, which was considered unrealistic. The major problem appeared to be a lack of contrast between trawl catches, which led to ambiguity in maximum likelihood estimates.

The existing time-series of acoustic estimates on the WCSI (O'Driscoll 2002) are based on the "standard method" of species decomposition which partitions acoustic backscatter based on the composition of trawl catches and acoustic TS. The catch from tows on the species mix layer is sampled to determine the species composition, as well as the lengths and weights of individual fish. The standard approach assumes that the backscatter contributed by each species i (B_i) is proportional to the product of its catch rate (c_i) and its mean TS (σ_i), as a weighted average of the total catch:

$$B_i = \frac{c_i \sigma_i}{\sum_{i=1}^{n} c_i \sigma_i} B \qquad (2)$$

where B is the total acoustic backscatter recorded from the species mix layer. Catch rates (c_i) are usually expressed as numbers of fish, but may also be expressed as weights (kg) if mean target strengths (σ_i) are expressed per kilogram, instead of per fish (O'Driscoll et al. 2004). The mean target strength of species i in each trawl is estimated from the length distribution of fish sampled from the catch using a species-specific TS-length relationship. If catch rates are expressed in kilograms, then individual fish weights, or a length-weight relationship are also required to calculate TS kg^{-1}. Where there is more than one tow on a species mix layer, B_i may be calculated by combining catches. MacLennan & Simmonds (1992) suggested three methods of weighting individual tows: equal weighting; weighting by catch-rate; and weighting by proximity of the individual tows to the acoustic transect being estimated. For the WCSI 2000 survey, Cordue (2002) estimated the acoustic proportion of hoki (P(hoki) = B_{hoki} / B) for each snapshot and strata using equal weightings of all tows on the mixed layer in that snapshot and stratum. Species decomposition was only carried out for northern strata, with the assumption that most of the hoki biomass in the southern strata comes from hoki schools and that these contain 100% hoki.

It was difficult to recalculate abundance indices before 2000 using a species decomposition method, because there were very few tows targeted at the species mix layers from 1988 to 1997. Cordue (2002) was forced to use scientific observer data to determine species composition for these earlier WCSI surveys. The approach taken was convoluted. First, the proportions by weight of each "reliably recorded" species in the observed commercial catch from Stratum 1&2 and Stratum 4 were determined for each year in the acoustic time-series from 1988 to 2000. In 2000, commercial proportions by weight were compared to proportions by number from *Tangaroa* research tows targeted on the bottom mix marks, to calculate "calibration constants" for each reliably recorded species. The commercial proportions by weight in previous surveys (1988–97) were then scaled by the calibration constants to correct for differences between targeted commercial catches and those in random research tows, and also to convert weight to numbers. Finally, because some species present in the species mix were not routinely recorded by scientific observers, the proportion of these species in 1988–97 was assumed to be the same as in the 2000 research tows.

Two methods of species decomposition were used in the analysis of the 2012 survey. The 'old' method attempted to emulate what was done in 2000 (Cordue 2002, O'Driscoll et al. 2004). All backscatter from strata 5A, 5B, 6, and 7 and from hoki school marks in strata 1&2 and 4 was assumed to be 100% hoki. The proportion of hoki in fuzz marks in strata 1&2 and 4 was estimated using equation (2) with equal weighting of all tows, regardless of catch. All catch rates (c_i) were expressed as kg km^{-2} and mean target strengths (σ_i) were expressed per kilogram, instead of per fish. This was done for simplicity since fish in trawl catches were weighed rather than counted. The mean TS per kilogram of species in each tow were estimated from the mean lengths of fish in the catch using estimated length-weight parameters (determined from the subsample of fish weighed during each survey) and best available target strength-length relationships (Table 2). Hoki TS in species decomposition was estimated using two different TS-total length (L) relationships:

$$TS = 22.32 \log_{10}(L) - 79.84 \qquad \text{Coombs \& Cordue (1995)} \qquad (3)$$

$$TS = 12.2 \log_{10}(L) - 63.9 \qquad \text{Macaulay (2006)} \qquad (4)$$

Equation (3) is the relationship used in species decomposition by Cordue (2002). Equation (4) is the most recent New Zealand TS-L relationship.

The 'new' method of species decomposition was based on current best practice and the recommendations of O'Driscoll (2002, 2006) and O'Driscoll et al. (2004). As in the 'old' method, all backscatter from hoki school marks was assumed to be 100% hoki. The assumption is probably reasonable for hoki schools where commercial trawl catches typically contain 90–100% hoki (O'Driscoll 2002). The proportion of hoki in fuzz marks in all strata (i.e., not just the northern area) was estimated using equation (2) based on all tows (including both random and target tows) on the mixed layer in that substratum. Estimated proportions from each tow were weighted by the square root of the total tow catch rate when calculating the average P(hoki) in a substratum. Doonan et al. (2006) found that square root weightings were more robust to large catches than weighting by the catch rate when numbers of tows within a stratum were low. As in the 'old' approach, all catch rates (c_i) were expressed as kg km^{-2} and mean target strengths (σ_i) were expressed per kilogram using values in Table 2. Hoki TS was estimated from equation (4).

2.9.4 Abundance estimation

Transect acoustic density estimates were converted to hoki biomass using a ratio, r, of mean weight to mean backscattering cross section (linear equivalent of target strength, TS) for hoki.

The 'old' method of calculating r was based on that of O'Driscoll (2002):

1. using the length frequency distribution of the commercial catch from the year of the survey;

2. using the generic length-weight regression of Francis (2003) to determine mean hoki weight (w in kilograms)

$$w = (4.79\times10^{-6})\, L^{2.89} \qquad (5)$$

3. using the TS-L relationship for hoki from Macaulay (2001):

$$TS = 18\ \log_{10}(L) - 74 \qquad (6)$$

A single ratio was estimated and applied to all substrata. Note that the TS-L relationship for hoki used in abundance estimation by O'Driscoll (2002) (Equation (6)) differs from that used for species decomposition by Cordue (2002), so the 'old' method is internally inconsistent. However, O'Driscoll (2006) found that the influence of the choice of TS-L relationship on the estimated acoustic proportion of hoki in northern strata in 2000 was relatively small, and the effect is likely to have been even smaller in some of the earlier surveys (1988–1993) when the proportion of the hoki biomass in the northern strata was lower.

Estimates were also calculated following the 'old' method, but updating the TS-L relationship used to estimate r to that of Macaulay (2006) (see Equation (4)). We termed this the 'revised old' methodology.

In the 'new' method, applied to the 2012 survey, different ratios, r_s, were estimated for each substratum based on:

1. the length frequency distribution from research target and random tows in that substratum for hoki from fuzz marks, and the length frequency distribution of the commercial catch for hoki from school marks;

2. the length-weight regression estimated for hoki from the survey;

3. the TS-L relationship for hoki from Macaulay (2006) given in Equation (4).

Abundance estimates and variances were obtained for each substratum in each snapshot using the formulae of Jolly & Hampton (1990), as described by Coombs & Cordue (1995). During a re-analysis of the 2000 WCSI survey, O'Driscoll et al. (2004) re-calculated stratum areas for the WCSI based on recorded depth cut-offs for stratum boundaries. Stratum areas differed slightly from those used by Cordue (2002) and O'Driscoll (2002), which were based on less detailed boundaries. To update the 'old' estimates of abundance the stratum areas of Cordue (2002) were used. For the 'revised old' and 'new' abundance estimates, the updated stratum areas were used. Stratum estimates were combined to produce snapshot estimates, and the snapshots were averaged to obtain the abundance index for 2012. In the 'new' method separate abundance estimates were calculated for the northern (strata 1&2 and 4) and southern (strata 5A, 5B, 6, and 7) areas.

The sampling precision of the abundance index was calculated in two ways, as described by Cordue & Ballara (2001). The first method was to average the variances from each snapshot. This method potentially underestimates the sampling variance as it accounts only for the observation error in each snapshot. The imprecision introduced by the inherent variability of the abundance in the survey area during the main spawning season is ignored. The second method assumes the snapshot abundance estimates are independent and identically distributed random variables. The sample variance of the snapshot means divided by the number of snapshots is therefore an unbiased estimator of the variance of the index (the mean of the snapshots).

2.9.5 Acoustic survey weighting for stock assessment

The sampling precision will greatly underestimate the overall survey variability, which also includes uncertainty in TS, calibration, and mark identification (Rose et al. 2000). The model weightings (expressed as proportional coefficient of variation or CV) used in the hoki stock assessment model are calculated for individual surveys using a Monte Carlo procedure which incorporates these additional uncertainties (O'Driscoll 2002, 2004).

The simulation method used to combine uncertainties and estimate an overall weighting (CV) for each acoustic survey of the WCSI was described in detail by O'Driscoll (2002, 2004), and is summarised below.

Five sources of variance were considered:

- plateau model assumptions about timing and duration of spawning and residence time;
- sampling precision;
- mark identification;
- fish weight and target strength;
- acoustic calibration.

The method has two main steps. First, a probability distribution is created for each of the variables of interest. Second, random samples from each of the probability distributions are selected and combined multiplicatively in Monte Carlo simulations of the process of acoustic abundance estimation.

In each simulation an abundance model was constructed by randomly selecting values for each variable from the distributions in Table 3. This model was then 'sampled' at dates equivalent to the mid dates of each snapshot (Table 4). The precision of sampling was determined by the snapshot CV, and the biomass adjusted for variability in detectability. The simulated abundance estimate in each snapshot was then split, based on the proportion of acoustic backscatter in 'hoki school' and 'hoki fuzz' marks, and mark identification uncertainties applied to each part. For the 'old' and 'revised old' methods, assumed distributions were used for species composition in both school and fuzz marks. For the 'new' method, uncertainty in mix marks was estimated by resampling with replacement (bootstrapping) from the observations (tows) within a substratum. The abundance estimates were recombined and calibration and TS uncertainties applied in turn. The same random value for calibration and TS was applied to all snapshots in each simulated ‘survey’. Abundance estimates from all snapshot estimates from the simulated survey were averaged to produce an abundance index. This whole process was repeated 1000 times (1000 simulated surveys) and the distribution of the 1000 abundance indices was output. The overall CV was the standard deviation of the 1000 abundance (mean biomass) indices divided by their mean. In the ‘new’ method separate weightings were calculated for abundance estimates from the northern (strata 1&2 and 4) and southern (strata 5A, 5B, 6, and 7) areas.

2.9.6 Summary of different methodologies used to estimate acoustic abundance of hoki

As described in the preceding sections, three different acoustic methodologies were used to estimate abundance of hoki from the 2012 acoustic survey which we have termed: 1) ‘old’; 2) ‘revised old’; and 3) ‘new’.

The key differences between the methodologies are summarised in Table 5.

The ‘old’ methodology follows O’Driscoll (2002). It is based on the methods of Cordue (2002) updated using the TS of Macaulay (2001) and using consistent stratum areas. This is the method used to calculate the WCSI time series used in recent hoki stock assessments (e.g., Ministry for Primary Industries 2012).

The ‘revised old’ methodology was based on O’Driscoll (2006) who updated WCSI acoustic indices from 1988–2000 for changes in sound absorption, more accurately estimated stratum areas, and used an intermediate TS-L relationship:

$$TS = 13.4 \log_{10}(L) - 65.8 \qquad \text{Macaulay (2004)} \qquad (7)$$

In this report the same methodology was used, but the most recent TS-L relationship (Equation (4)) was used to estimate r. The updated series of O’Driscoll (2006) was not accepted by the HFAWG in 2006 because the update ignored the small effect of changing the hoki TS-length relationship on the species decomposition of acoustic backscatter before 2000. This criticism is applicable to both the ‘old’ and ‘revised old’ methods, because the TS-length relationship of Coombs & Cordue (1995) was used to estimate hoki TS in species decomposition in surveys from 1988–2000 (Cordue 2002) and this could not be easily recalculated without detailed re-analysis of research and commercial trawl data.

The ‘new’ methodology follows current best practice. It is important to note that it was not possible to estimate hoki abundance using the ‘new’ methodology for surveys before 2000 because there was insufficient trawling (either commercial or research) to allow mark decomposition in the area south of Hokitika Canyon. Separate north and south indices were only estimated using the ‘new’ acoustic methodology.

3. RESULTS

3.1 Data collection

All survey objectives were completed. Weather conditions were very good during the survey period, with only about 8 hours lost on 1–2 August due to bad weather. Another 30 hours were lost on 8–10 August dropping off two vessel crew members in Westport for family and medical reasons. No hake aggregations were detected, so the 24-hours allocated for opportunistic adaptive surveying were used to carry out a third acoustic snapshot of the northern area at the end of the survey period.

Three acoustic snapshots of the southern area and three acoustic snapshots of the northern area were carried out (see Table 4, Figure 2). Because the time available for the third acoustic snapshot of the northern area was limited, the number of transects in this snapshot were reduced (see Table 4) and transects in stratum 4 did not extend to cover substratum 4D (650–800 m).

The generally good weather allowed acoustic data along most transects to be collected using the multi-frequency *Tangaroa* EK60 hull system operating at 18, 38, 70, 120, and 200 kHz. A total of 286 acoustic data files (259 hull and 27 towbody) were recorded during the survey, constituting 98.2 GB of data.

Twenty-seven tows were made to identify targets and collect biological samples in support of the acoustic survey work (see Table 4, Figure 2, Appendix 5).

1. Eighteen tows were carried out with the NIWA 8-seam hoki bottom trawl. On seven of these mark identification tows the acoustic-optical system (AOS) was mounted on the headline to provide additional (video) information on species composition and to opportunistically collect data on target strength.
2. Nine tows were carried out with the NIWA mesopelagic (fine-mesh midwater) trawl.

Tow length for mark identification tows ranged from 0.15 to 3.01 n. miles at an average speed of 3.7 knots. Acoustic recordings were made for all tows using the hull-mounted echosounders.

A total of 63 successful random trawl survey tows were completed in the northern area (see Table 1, Figure 3). Only 3 of the 5 planned tows in stratum 1&2S, and 4 of the 5 planned tows in stratum 4S, were completed as these strata had lower priority than other objectives. Three tows were considered unsuitable for abundance estimation: tow 63 had net damage; tow 75 had low headline height because a float was tangled; and tow 81 was rejected because the codend was choked due to a tangled becket. Individual station details from all trawl tows, including the catch of hoki, hake and ling are listed in Appendix 5.

The Seabird SM-37 Microcat CTD datalogger was mounted on the headline of the net during 89 bottom tows to determine the absorption coefficient and speed of sound, and to define water mass characteristics in the area.

3.2 Gear performance

Gear parameters by depth for valid tows are summarised in Table 6. The headline height was obtained for all successful tows, and doorspread readings collected for 60 of the 63 valid tows. Missing doorspread values were calculated from data collected in the same depth range on this voyage. Measured gear parameters in 2012 were within the range of those obtained on the valid tows from the 2000 survey where the same gear was used (Table 7), Mean doorspread distances and headline heights for the 2000 and 2012 surveys are in keeping with the *Tangaroa* hoki and middle depths time series surveys on the Chatham Rise (O'Driscoll et al. 2011b) and Sub-Antarctic (Bagley et al. 2013).

3.3 Catch

A total catch of 182.6 t was recorded from all tows. From the 191 species or species groups caught, 102 were teleosts, 24 elasmobranchs, 13 squids or octopuses, 20 crustaceans, and 18 echinoderms, the remainder comprising assorted benthic and pelagic animals (Appendix 6). The green weight of the top 30 species is given in Table 8 with hoki accounting for 76.4%, ling 5.8%, hake 2.0%, and silver warehou 1.9% of the total catch from all tows.

3.4 Trawl abundance estimates

Abundance estimates and the trawl survey catch for all and core strata for the top 28 species are given in Table 9. Abundance estimates and CVs (in parentheses) for all strata were 32 602 t (24.1 %) for hoki, 2194 t (14.7 %) for ling, and 1103 t (13.0 %) for hake. Core strata abundance estimates were similar to total estimates for hoki and ling at 32 495 t and 2169 t respectively (Table 9). The estimate for hake from the core strata was lower, at 583 t, with the remaining biomass coming from the deep 650–800 m stratum (4D). The target CV of 20% was met for hake and ling but exceeded slightly for hoki. As noted in Section 2.1, there was no allowance for phase 2 tows in this survey.

Abundance estimates by stratum for the top 28 species are given in Table 10. No hoki or hake and few ling were caught in the shallow strata 4S and 1&2S. Hoki were abundant in all strata within the core survey area. Stratum 1&2A accounted for 70% of the ling biomass. The shallow strata below 300 m accounted for most of the biomass of giant stargazer, barracouta, northern spiny dogfish and tarakihi, and were also important for sea perch and silver warehou. The deep stratum 4D had higher abundance estimates for hake, ribaldo, shovelnose dogfish and white warehou.

Trawl survey estimates from 2000 were recalculated using the 2012 stratum areas (Table 11). The trawl estimate of hoki abundance in 2012 was much higher than the abundance estimated from daytime random tows in the equivalent strata in the 2000 WCSI survey. Abundance estimates for 15 other species, including spiny dogfish, school shark, ling, and sliver dory were higher in 2012 than those in 2000, while estimates for 12 species, including hake and silver warehou were lower (Table 11).

3.5 Species distribution

Catch rates of hoki, hake, and ling from all trawl tows are given in Figures 4–6 respectively. Catch rates of the top 20 species including a breakdown by size classes for hoki for valid tows only are given in Figures 7–8. Hoki catch rates were highest in 400–500 m in all strata (Figure 4), with 1+ hoki occurring shallower between 300–430 m (Figure 7). Hake mainly occurred deeper than 500 m, with highest catch rates between 650 and 800 m in stratum 4D (Figure 5). Ling catch rates were highest between 300–430 m in stratum 1&2A (Figure 6). Spiny dogfish had higher catch rates to the south while higher silver warehou catch rates were in the northern part of the trawl survey area (Figure 8).

3.6 Biological data

A total of 39 842 fish and squid individuals of 100 different species were measured (Table 12). Of these, 12 001 fish (totalling 23.4 t) were also individually weighed (Table 12). Additional data on fish condition (liver and gutted weight) were recorded from 1340 hoki. Pairs of otoliths were removed from 1327 hoki, 932 ling, 855 hake, and 574 silver warehou.

Population scaled length frequencies were calculated using length-weight data collected during the 2012 survey (Table 13), and are presented for the top 21 species for core and all strata in Figure 9. Length frequencies by stratum for hoki, hake, ling and silver warehou are given in Figures 10–13. Several modes were present in the provisional hoki scaled length frequency (Figure 9) including small (1-year old) hoki at 25–35 cm, which were concentrated in strata 1&2A and 4A (Figure 10). Most male hoki were between 50 and 80 cm, and most females were 60–100 cm (Figures 9–10). Ling and hake data showed broad length ranges (Figure 9). Some small hake were taken deeper than 500 m with almost all of the larger hake taken to the south in strata 4C and 4D (Figure 11).There were no clear differences in size distribution of ling between strata, although some small ling were caught in the deeper strata 1&2C and 4C (Figure 12). Small silver warehou (under 30 cm) were taken in strata 4S and 4A with low numbers also recorded from stratum 1&2S. In other strata most silver warehou were larger than 40 cm (Figure 13).

The modal length of hoki caught in 2012 was smaller than the 2000 mode and that there were few small (less than 40 cm) hoki caught in 2000 (Figure 14). Hake and ling showed a similar broad length range for both surveys, although there was a higher proportion of larger female hake in 2000 (Figures 15–16). The modal length of adult silver warehou was similar in 2000 and 2012, but there was also a mode of small (less than 30 cm) fish in 2012 (Figure 17). The absence of small silver warehou in 2000 may be because strata shallower than 300 m were not included in the survey.

The modal age of hoki in the 2012 survey was age 3 years (2009 year-class) with few males older than age 7 and few females older than age 10 (Figure 18). Hoki were not aged from the 2000 survey. The age distribution of hake showed a higher proportion of younger fish in 2012 than was observed in 2000 (Figure 19). Most male hake in 2012 were 5–7 years while females were slightly older at 6–9 years. Ling had a broad range of ages in both 2000 and 2012, with most ling aged from 3–20 years (Figure 20).

Gonad staging of fish and elasmobranchs showed that many species were in spawning condition during the survey (Table 14). For the key species, actively spawning females (gonad stages 4–6) accounted for 43% of ling, 25% of hoki, 15% of hake, and 5% of silver warehou from all observations. Most female hoki, hake, and silver warehou were maturing, but pre-spawning (gonad stage 3) (Table 14). Hoki were actively spawning throughout the survey period, with a slight decrease in the percentage of maturing fish during the first week of August (Figure 21). Other species of teleosts with more than 50 females sampled and over 50% of fish in maturing and spawning condition (gonad stages 3–6) included giant stargazer, white warehou, silver dory, barracouta and Oliver's rattail. Lookdown dory, tarakihi and orange perch were post-spawning, with over 50% of females spent (gonad stage 7). For elasmobranchs, 62% of the spiny dogfish females had pups (stage 5).

3.7 Acoustic mark types

Spawning hoki aggregations were detected in all strata (e.g., Figure 22), with the strongest marks observed in inner Hokitika Canyon (stratum 5A). Hoki aggregations were typically at depths of 350 to 500 m during the day, rising up off the bottom at night. Lower density marks consisting of hoki and a variety of other species were also present, either as a bottom-oriented 'fuzz' layer or in midwater (e.g., Figure 23). Mesopelagic marks, which do not contain hoki, were common. Mesopelagic marks were usually in layers, often with a wavy, undulating appearance. These were typically shallower than hoki schools, with less 'structure' in the mark, and with no obvious single targets, and exhibited diel migration patterns (e.g., Figure 24). Mesopelagic layers tended to be stronger on 18 kHz than on 38 kHz.

Separating different mark types was not always straightforward and was subjective. An example of mark classification along a daytime transect in stratum 6 is shown in Figure 25. In this example, three different mark types were distinguished consisting of a midwater hoki school, bottom fuzz, and pelagic marks. Mark classification was generally more straightforward at night when pelagic layers migrated towards the surface, and hoki aggregations moved up off the bottom allowing more separation of mark types.

Of the 27 mark identification tows, 5 were targeted at hoki schools, 4 at pelagic layers, and 18 on fuzz marks. Catches by mark type are summarised in Table 15. Four of the 5 tows targeted on hoki caught more than 86% hoki by weight. The exception was bottom tow 95 in stratum 5A which caught only 29% hoki with high bycatch of spiny dogfish and ling (Table 15). Tows targeted on bottom fuzz marks with the bottom trawl caught an average of 45% hoki by weight. Tows targeted on pelagic fuzz marks with the mesopelagic trawl had very low catch rates and caught only 16% hoki by weight (Table 15). Experience in Cook Strait suggests that the mesopelagic trawl may not be suitable for catching hoki in low density midwater marks, with much higher catch rates of hoki taken from similar marks using commercial midwater gear (e.g., O'Driscoll 2012). Surprisingly, the 4 tows on pelagic marks, which were not thought to contain hoki, caught 38% hoki by weight (Table 15). This result was influenced by tow 51 which was a bottom trawl on pelagic marks close to the bottom in shallow water in stratum 6, which had a relatively high catch rate (65% by weight) of small (1 year-old) hoki. However, even when this bottom tow was excluded, the 3 mesopelagic tows on pelagic marks had higher proportions of hoki (average 30% by weight) than mesopelagic tows on pelagic fuzz marks.

Random trawl survey tows in the northern area were also useful for mark identification of daytime bottom fuzz marks and were used extensively in decomposition of species mix (see Section 3.9). There was a significant positive correlation (number of tows, $n = 69$; Spearman's rank correlation, rho $= 0.53$; $p < 0.001$) between acoustic backscatter in the bottom 100 m recorded during the trawl and hoki catch rates in all bottom tows (Figure 26).

3.8 Distribution of hoki backscatter

Expanding symbol plots show the spatial distribution of hoki backscatter along each transect during the three snapshots of the WCSI (Figure 27). Maps show unpartitioned backscatter from hoki schools and hoki fuzz marks separately. Dense hoki schools were present in inner Hokitika Canyon (stratum 5A) in all snapshots. In the northern area hoki schools appeared to move to the north during the survey period, which matched the distribution of commercial fishing effort (Figure 28). Hoki schools were also detected in the southern area (strata 6 and 7). As in the northern area, there appeared to be a northward movement of aggregations during the survey period, with dense schools appearing in outer Hokitika Canyon (stratum 5B) in Snapshot 3 on 13–17 August.

Hoki fuzz marks were widespread in all strata throughout the survey period, with highest (unpartitioned) densities in strata 4, 5A, and 6 (Figure 27). Few hoki marks (schools or fuzz) were seen shallower than 300 m or deeper than 600 m. Spatial distribution of acoustic backscatter in the northern area (Figure 27) broadly matched the distribution of hoki observed in random tows (see Figure 4).

The acoustic survey area appeared to encompass all of the commercial fishing effort during the survey period (Figure 28), but there was little fishing south of Hokitika Canyon. As for the distribution of acoustic backscatter (see Figure 27), most commercial fishing targeting hoki occurred from 300–600 m depth (Figure 28). The timing of the acoustic snapshots was also within the period of highest commercial catches, which peaked in the first week of August and then declined (Figure 29).

3.9 Species decomposition

The 18 targeted tows on fuzz marks (i.e., excluding the 9 tows targeted at hoki schools and pelagic layers) and the 56 successful random bottom tows in the acoustic survey area (i.e., excluding the 7 tows in strata 1&2S and 4S) were used to partition acoustic backscatter. Decomposition was done by substrata in the northern area, but there were only 13 tows on mixed marks in the southern area (strata 5A, 5B, 6, and 7), so a single ratio was estimated for these strata combined (Table 16).

On average hoki made up between 16% (stratum 4D) and 92% (stratum 4B) of the trawl catch by substratum. Species decomposition was based on catch rates in research tows and best estimates of acoustic TS (see Table 2). Using the 'old' method (hoki TS from equation (3) and equal weighting of tows) hoki contributed 10–87% of the backscatter from mixed species marks in the northern area (Table 16). Using the 'new' method (hoki TS from equation (4) and weighting by the square root of the tow catch rate), the proportion of hoki reduced to 5–78% (Table 16). The estimated proportion of backscatter from hoki in fuzz marks in the southern area was 51% (Table 16). Values in Table 16 were used to scale integrated acoustic backscatter from fuzz marks when estimating hoki abundance

3.10 Acoustic abundance estimates

'Old' and 'revised old' estimates of hoki abundance were based on a single ratio, r, of mean weight to mean backscattering cross section from the commercial fishery (see Section 2.9.4). The hoki length frequency from the 2012 WCSI fishery based on scientific observer data is shown in Figure 30. The mean length of hoki was 75.4 cm (Table 17). Mean weight (obtained by transforming the scaled length frequency distribution in Figure 30 by equation (5) and then calculating the mean of the transformed distribution) was 1.37 kg. The estimated ratios, r, for 2012 based on equation (6) ('old' methodology) and equation (4) ('revised old' methodology) were 14 090 kg m^{-2} and 17 154 kg m^{-2} respectively (Table 17).

'New' estimates of hoki abundance were based on stratum-specific estimates of r from research tow data for backscatter from fuzz marks and the single ratio from the commercial fishery (r = 17 154 kg m^{-2}) for backscatter from all hoki school marks. Hoki from research catches in the same region as the main commercial fishery (strata 1&2B and 4B) had similar length composition to the commercial catch, but there was considerable variability in the size composition from other areas, with a higher proportion of smaller, younger fish in the shallower strata (1&2A and 4A) and in stratum 6 (Figure 31). Ratios based on the TS of Macaulay (2006) (equation (4)) and the estimated length-weight relationship of hoki from the survey ($w = 4.8744*10^{-6} L^{2.9009}$) ranged from 9340 kg m^{-2} in stratum 1&2A to 18 911 kg m^{-2} in stratum 4D (Table 18).

Hoki abundance estimates by snapshot and strata are given in Table 19 and plotted in Figure 32. Estimates of hoki abundance using the 'old' method for 2012 ranged from 348 000 t in the first snapshot to 478 000 t in the second snapshot. Abundance estimates were about 45% higher using the 'revised old' methodology. 'New' estimates, based on current best practice, were intermediate between 'old' and 'revised old' estimates and ranged from 422 000 to 639 000 t (Table 19). The relative ratio of snapshot estimates was similar for all three methods (Figure 32). Sampling precision (CV) of individual snapshots ranged between 17 and 29% (Table 19).

When results from Table 19 were averaged over all snapshots, 38–44% of the hoki biomass was in the northern area (strata 12 and 4), 29–33% in Hokitika Canyon (strata 5A and 5B), and 24–32% south of Hokitika Canyon (strata 6 and 7). Using the 'new' method, the average proportion of the biomass from hoki schools ranged from 45% in stratum 1&2 to 98% in stratum 5A (Table 20). On average, using the 'new' method across all snapshots, 49% of the hoki biomass in the northern area and 77% of the biomass in the southern area was from hoki schools. Changes in hoki abundance estimates between snapshots were mainly driven by the contribution from hoki school marks, with the biomass from hoki fuzz marks remaining relatively constant throughout the survey period (Figure 33).

Estimates from all three snapshots were averaged to obtain the overall acoustic abundance index for 2012. Time-series based on 'old' and 'revised old' methodologies are given in Table 21 and plotted in Figure 34. Under both methods, the 2012 acoustic estimate was within 4% of the equivalent acoustic index from 2000 and slightly above the long-term average of the time-series. The combined 'new' estimate of 535 000 t was 30% higher than the 'old' estimate for 2012, but the 'new' estimate cannot be easily compared with previous surveys in time-series which had more limited mark identification trawling.

Using the 'new' method, the acoustic abundance estimate for the northern area was 236 000 t, and the acoustic abundance in the southern area (including Hokitika Canyon) was estimated as 299 000 t (Table 19).

3.11 Acoustic weighting for stock assessment

The overall survey weighting estimated from the Monte Carlo simulation model for the 2012 WCSI estimate using the 'old' and 'revised old' methodology was 0.51 (Table 22). Mark identification was the major source of uncertainty, with survey timing (including uncertainties about plateau timing and residence time) and sampling also important (Table 22). Uncertainties due to calibration and TS contributed relatively little to the overall CV of the relative index. However, incorrect choice of TS and calibration coefficients do have potential to introduce bias, which is not reflected in the CV in Table 21. Previous surveys in the WCSI time series had CVs ranging from 0.38 to 0.73 (see Table 21).

Separate CVs were calculated for northern and southern areas using the 'new' methodology, which estimates uncertainty associated with fuzz marks by bootstrapping from research tows within each stratum (see Section 2.9.5). The CVs were lower than those estimated using the 'old' method (0.22 for the northern area and 0.28 for the southern area) due to much reduced contribution of the uncertainty associated with mark identification (Table 22). This was because the distribution of the average P(hoki) estimated by bootstrapping was very tight due to the large number of samples (61 tows in the north and 13 in the south) – analogous to the effect of taking the standard error from a distribution. However, this 'new' method assumes that variability within tows was the only factor contributing uncertainty associated with species mix, ignoring uncertainty associated with subject classification of marks and methodological uncertainties associated with TS and catchability of bycatch species.

3.12 Moorings

Two camera moorings were deployed in the Hokitika Canyon during the voyage: on the south side at 435 m depth overnight on 26–27 July; and on the north side at 430 m depth overnight on 14–15 August. Cameras were positioned 8, 30, and 70 m above the bottom and timed to come on for 2 minutes every hour.

All three cameras on the first mooring showed hoki, with highest densities on the camera closest to the bottom (Figure 35). Unlike orange roughy, hoki appeared attracted to the lights and densities increased during the filming period. The hoki were also a lot more active than orange roughy. We also observed hake (only on the bottom camera), Oliver's rattails, and a ling.

The second mooring was on a mark with a lower acoustic density and the cameras showed fewer hoki than seen during the first deployment. Hoki densities were again highest in the bottom camera, and very few hoki were seen on the top camera. Other species observed in the second mooring were spiny dogfish, squid, Oliver’s rattail, and silverside.

As well as giving pictures such as in Figure 36, moored camera information is helpful for understanding species composition close to the edges of the canyon, which is difficult to sample with a trawl. Unfortunately water clarity was not as good as on the Chatham Rise, so the images were not "TV quality". Repeated acoustic transects over the mooring locations showed diurnal variability in the vertical distribution of hoki, with fish further away from the bottom at night than during the day (e.g., Figure 35).

3.13 Target strength

The AOS was deployed on 7 mark identification tows and 6 AOS-only tows (where the cod-end was left open). Ten of the 13 AOS deployments were successful. The other 3 deployments (tows 16, 55, and 56) were unsuccessful because the microprocessor controller did not switch on the camera. The successful AOS deployments yielded images and acoustic data from hoki and associated species including silver warehou, spiny dogfish, ling, and squid (Figure 37).

Data on TS of hoki and associated species will be analysed and reported separately.

3.14 Hydrological data

The water column was weakly stratified with surface temperatures ranging between 12.9 and 14.2 °C (Figure 38) and bottom temperatures between 7.2 and 13.9 °C (Figure 39). Highest surface temperatures were in the northeast of the survey area (Figure 38). Bottom temperature decreased with depth, with lowest bottom temperatures in the west (Figure 39).

4. DISCUSSION

The 2012 combined trawl and acoustic survey of the WCSI was successfully completed. This was the ninth in a series of acoustic surveys of WCSI hoki spawning areas, but the first since 2000. The survey was also the second in a new time series of trawl estimates for a suite of middle depth species, including (in addition to hoki), ling, hake, silver warehou, and other species from the WCSI, with results comparable to the random trawl component of the 2000 WCSI survey. The trawl survey also provided biological data (otoliths for ageing, length, weight, sex, gonad stage, etc) for important middle depth species.

The survey was designed primarily for hoki and the timing and spatial coverage were appropriate for that species. The survey period was within the period of peak commercial catches (see Figure 29), gonad stage information showed that hoki were actively spawning (see Figure 21), and the survey area encompassed most of the commercial catch and effort (see Figure 28). Research trawl catch rates of hoki (see Figure 4) and the distribution of acoustic backscatter (see Figure 27) also broadly matched the distribution of catch in the northern area and in the Hokitika Canyon (see Figure 28). There was very little commercial effort south of Hokitika Canyon. Revisions to survey strata from 2000 had little influence on the estimated abundance of hoki, as most hoki occurred within the original core survey area. However, the new, deeper, stratum 4D was important for hake, contributing 47% of the estimated trawl biomass for this species. The addition of shallower strata was also important for inshore species such as giant stargazer and tarakihi.

There was a large (sixfold) increase in trawl estimates of hoki abundance in the northern area between the 2000 and 2012 trawl surveys. The increase in the trawl estimates was driven by consistently large catches of hoki in 2012. This is reflected in both catch rates and the proportion of hoki in the total catch, both of which increased across all strata (Table 23). In 2012, hoki made up 44–92% of the catch by substrata in the northern area (excluding the new stratum 4D), but were only 17–40% of the catch in equivalent strata in 2000 (Table 23).

Possible hypotheses to explain the large increase in trawl survey abundance of hoki include:
1. Change in spatial distribution towards the north;
2. Increase in vertical availability of hoki to the trawl;
3. Differences in survey methodology;

Although the acoustic survey provided some evidence for an increased proportion of hoki in the northern area in 2012 compared to 2000, this was not enough to explain the large change in trawl abundance. In 2012 about 39% of the hoki acoustic abundance (estimated using the 'old' method) was in the northern strata compared to 25% in 2000, and 10–34% in 1988–1997 (see Table 19). Note that this result is partially confounded by the increased proportion of hoki in research tows (see Table 23) which was used to partition the acoustic backscatter from hoki fuzz marks.

To investigate the hypothesis that there had been a change in vertical availability of hoki, we compared the amount of acoustic backscatter recorded close to the bottom during random tows in 2000 and 2012 (Table 23). Backscatter observed during bottom tows in 2012 was greater than that observed in 2000, notably in strata 1&2B and 4B, but there was no evidence for a change in vertical availability. In both 2000 and 2012, acoustic backscatter in the bottom 10 m accounted for about 20% of the backscatter recorded in the bottom 100 m (Table 23).

Any change in trawl survey catchability between 2000 and 2012 was unlikely to be related to changes in gear or gear performance. The trawl has been within consistent specifications in both surveys and the same specifications are used for other middle-depth surveys in the Sub-Antarctic and Chatham Rise. The catch of other species over the same period did not show the same large increase as hoki (Table 11). Abundance estimates for 16 species, including spiny dogfish, school shark, ling, and sliver dory were higher in 2012 than those in 2000, while estimates for 12 species, including hake and silver warehou were lower (Table 11). Similarly, there was no clear evidence for a change in trawl survey methodology between 2000 and 2012. The 2012 survey was designed to allow comparison with results from 2000, and some of the same vessel and scientific personnel were involved in both surveys.

Regardless of the explanation, a sixfold increase in abundance on the WCSI is not supported by the acoustic indices, the trawl index of the adult western stock in the Sub-Antarctic, or the most recent hoki assessment. Acoustic indices for the WCSI using consistent methodology were similar in 2012 and 2000 (see Table 21). Over the same time period the estimated hoki abundance in the Sub-Antarctic has decreased from 55 700 t in 2000 to 46 100 t in 2012 – a 17% decline. Biomass trajectories from stock assessment suggest that spawning stock biomass on the WCSI in 2012 was at a similar level to that in 2000 (Ministry for Primary Industries 2012). The planned WCSI survey in 2013 should confirm whether the high trawl estimate of hoki abundance in 2012 was anomalous. Trawl estimates of hoki on the WCSI were not included in the 2013 hoki assessment, pending further evaluation of the reliability of the indices.

Species decomposition remains a major source of uncertainty in acoustic estimates of hoki on the WCSI. The standard decomposition method (Equation (2)) assumes that all species which contribute to the backscatter are caught in the net, and that all species have equal catchability. This is almost certainly incorrect. It seems likely that fast swimming species such as hake would be more likely to avoid the net than smaller, more sedentary species such as rattails. There are also mesopelagic species like lanternfishes and pearlsides which may contribute to the backscatter but are too small to be sampled in the hoki net. The decomposition method also assumes that the TS-length relationships are known for all species caught in the net (see Table 2). This is not the case in hoki acoustic surveys, where even the TS of the target species is poorly understood. The TS-length relationships used for many of the bycatch species were based on "educated guesswork" (Cordue 2002). Before 2000, there was the further problem that there was little or no research trawl data to carry out species decomposition. The method developed by Cordue (2002), using commercial scientific observer data, was probably the best that could be done, but there are major problems with basing species composition on commercial data. The assumptions of equal catchability and catching all species contributing to the backscatter discussed above in relation to research tows, are even less likely to be fulfilled by a commercial fishery targeting a specific species and using gears with larger mesh sizes. There are also additional problems with data quality, such as the accuracy of reporting of non-target, non-commercial "minor" species, which may nevertheless contribute significantly to acoustic backscatter.

The survey design in 2000 and 2012 had greatly increased mark identification trawling in the northern strata, which allowed more detailed decomposition methods to be applied. However, there is still uncertainty about mark composition. Subjectively, the practice of carrying out acoustic transects in the northern area at night only in 2012 (with random bottom trawling during the day) helped to distinguish mark types because pelagic layers migrated towards the surface, and hoki aggregations moved up off the bottom away from other demersal species.

The 'old' and 'revised old' analysis methods assume that hoki contribute 100% of the backscatter from all hoki marks (schools and fuzz) outside the northern area. O'Driscoll et al. (2004) reanalysed 2000 survey data and found that low density hoki mix marks, similar to those observed in the northern areas, were common in Strata 5B, 6, and 7. They recommended that the assumption that these contain 100% hoki needs to be reconsidered, and future surveys should include increased trawling in these southern areas to assess the extent of the species mix problem. This was done in 2012, with 18 targeted tows south of Hokitika Canyon. Tows on mix marks in the southern area only, caught an average of about 44% hoki by weight (see Table 16) and estimates of species composition in the southern strata were incorporated when estimating abundance from the 2012 survey using the 'new' method. However, previous surveys in the time-series had more limited mark identification trawling in the southern area and so estimates of species mix in the southern strata were not available from these surveys. In 2000, five tows on hoki fuzz marks in Stratum 6 averaged 44% hoki by weight, and one tow in Stratum 7 caught 79% hoki by weight (O'Driscoll et al. 2004), which was similar to the observed catch composition in 2012 (see Table 16). In future WCSI surveys consideration should be given to further increasing the level of mark identification trawling in the southern areas, or even introducing a random trawling component, to allow for more detailed decomposition by stratum.

At a meeting of the HFAWG on 1 March 2013, it was decided to continue to use acoustic estimates calculated using the 'old' methodology in the 2013 hoki assessment. This decision was made on the basis that it would not require re-calculation of the prior for the acoustic catchabilty (q) and that there was little difference between relative indices calculated using the 'old' and 'revised old' methodology (see Figure 34). However, we note that there is continued inconsistency with acoustic estimates from Cook Strait, which are calculated using the latest TS and sound absorption (e.g., O'Driscoll 2012). The best method for estimating the appropriate weighting (CV) for WCSI acoustic abundance estimates has yet to be resolved and is outside the scope of this report. The HFAWG adopted a pragmatic approach and used the weightings estimated using the 'old' method (see Table 21), but ran a sensitivity analysis of the stock assessment model where the weightings were arbitrarily halved (i.e., upweighting the WCSI acoustic series). This sensitivity showed little effect on model outputs (Andy McKenzie, NIWA, pers. comm.).

Other middle depth species were also monitored by this survey. These include important commercial species such as hake and ling, as well as a wide range of non-commercial fish and invertebrate species. For some of these species, the trawl survey provides the only fisheries-independent estimate of abundance on the WCSI, as well as providing biological data (length, sex, reproductive condition, age etc.). Trawl abundance estimates from the 2012 WCSI survey have already been accepted as inputs into stock assessments for hake and ling, and the new survey time-series will fulfil an important "ecosystem monitoring" role in the future (e.g., Tuck et al. 2009), as well as providing inputs into single-species stock assessment.

Acoustic TS and moorings data collected as part of the 2012 survey provided further insights into the behaviour and acoustic properties of hoki and associated species. These data will be analysed and reported separately.

5. ACKNOWLEDGMENTS

Thanks to the officers and crew of the *Tangaroa* and to the scientific staff for making this a successful voyage. We are also grateful to members of the fishing industry who provided useful information during the survey. New Zealand Diving Services and Bruce Lines provided dive support for the acoustic calibration. Peter McMillan reviewed a draft of this report and made many helpful comments. This work was funded by Ministry for Primary Industries Research Project HOK2010/04B.

6. REFERENCES

Bagley, N.W.; O'Driscoll, R.L.; Oeffner, J. (2013). Trawl survey of hoki and middle-depth species in the Southland and Sub-Antarctic areas, November–December 2011 (TAN1117). *New Zealand Fisheries Assessment Report 2013/23.* 70 p.

Ballara, S.L.; Cordue, P.L.; Livingston, M.E. (1998). A review of the 1996–97 hoki fishery and assessment of hoki stocks for 1998. New Zealand Fisheries Assessment Research Document 98/25. 58 p. (Unpublished report held in NIWA library, Wellington.)

Ballara, S.L.; O'Driscoll, R.L. (2012). Catches, size, and age structure of the 2010–11 hoki fishery, and a summary of input data used for the 2012 stock assessment. *New Zealand Fisheries Assessment Report 2012/23.* 117 p.

Bull, B. (2000). An acoustic study of the vertical distribution of hoki on the Chatham Rise. *New Zealand Fisheries Assessment Report 2000/5*. 59 p.

Bull, B.; Dunn, A. (2002). Catch-at-age user manual v1.06.2002/09/12. NIWA Internal Report 114. 23 p. (Unpublished report held in NIWA library, Wellington.)

Chatterton, T.D.; Hanchet, S.M. (1994). Trawl survey of hoki and associated species in the Southland and Sub-Antarctic areas, November–December 1991 (TAN9105). *New Zealand Fisheries Data Report 41*. 55 p.

Coombs, R.F.; Cordue, P.L. (1995). Evolution of a stock assessment tool: acoustic surveys of spawning hoki (*Macruronus novaezelandiae*) off the west coast of South Island, New Zealand, 1985–91. *New Zealand Journal of Marine and Freshwater Research 29*: 175–194.

Coombs, R.F.; Macaulay, G.J.; Knol, W.; Porritt, G. (2003). Configurations and calibrations of 38 kHz fishery acoustic survey systems, 1991–2000. *New Zealand Fisheries Assessment Report 2003/49.* 24 p.

Cordue, P.L. (2002). An analysis of an acoustic survey of spawning hoki off the west coast South Island during winter 2000. *New Zealand Fisheries Assessment Report 2002/26*. 51 p.

Cordue, P.L.; Ballara, S.L. (1998). Acoustic surveys of spawning hoki off the west coast South Island and in Cook Strait during winter 1997. New Zealand Fisheries Assessment Research Document 98/24. 31 p. (Unpublished report held in NIWA library, Wellington.)

Cordue, P.L.; Ballara, S.L. (2001). An acoustic survey of spawning hoki in Cook Strait during winter 1999. *New Zealand Fisheries Assessment Report 2001/15.* 18 p.

Cordue, P.L.; Ballara, S.L.; Horn, P.L. (2000). Hoki ageing: recommendation of which data to routinely record for hoki otoliths. Final Research Report to the Ministry of Fisheries for Project MOF1999/01 (Hoki ageing). 24 p. (Unpublished report held by Ministry for Primary Industries, Wellington.)

Cordue, P.L., McAllister, M.K., Pikitch, E.K.; Sullivan, K.J. (1992). Stock assessment of hoki 1991. New Zealand Fisheries Assessment Research Document 92/10. 41 p. (Unpublished report held by NIWA library, Wellington.)

Demer, D.A.; Renfree, J.S. (2008). Variations in echosounder-transducer performance with water temperature. *ICES Journal of Marine Science 65*: 1021–1035.

Doonan, I.; Coombs, R.; McClatchie, S. (2003). The absorption of sound in seawater in relation to estimation of deep-water fish biomass. *ICES Journal of Marine Science 60* (*5*): 1047–1055.

Doonan, I.J.; Dunn, M.; Dunford, A.: Hart, A.C.; Tracey. D. (2006). Acoustic estimates of orange roughy abundance on the Northeastern and Eastern Chatham Rise, July 2004: wide-area survey and hill survey. *New Zealand Fisheries Assessment Report 2006/58* 45 p.

Fisher, F.H.; Simmons, V.P. (1977). Sound absorption in seawater. *Journal of the Acoustical Society of America 44*: 473–482.

Fofonoff, P.; Millard, R., Jr (1983). Algorithms for computation of fundamental properties of seawater. *UNESCO Technical Papers in Marine Science 44*. 53 p.

Francis, R.I.C.C. (1981). Stratified random trawl surveys of deep-water demersal fish stocks around New Zealand. *Fisheries Research Division Occasional Publication 32.* 28 p.

Francis, R.I.C.C. (1984). An adaptive strategy for stratified random trawl surveys. *New Zealand Journal of Marine and Freshwater Research 18:* 59–71.

Francis, R.I.C.C. (1989). A standard approach to biomass estimation from bottom trawl surveys. New Zealand Fisheries Assessment Research Document 89/3. 3 p. (Unpublished report held in NIWA library, Wellington.)

Francis, R.I.C.C. (2001). Improving the consistency of hoki age estimation. *New Zealand Fisheries Assessment Report 2001/12.* 18 p.

Francis, R.I.C.C. (2003). Analyses supporting the 2002 stock assessment of hoki. *New Zealand Fisheries Assessment Report 2003/5.* 34 p.

Francis, R.I.C.C. (2006). Optimum allocation of stations to strata in trawl surveys. *New Zealand Fisheries Assessment Report 2006/23*. 50 p.

Francis, R.I.C.C. (2009). SurvCalc User Manual. 39 p. (Unpublished report held at NIWA, Wellington.)

Francis, R.I.C.C.; O'Driscoll, R.L. (2004). Proposed design for a 2004 west coast South Island hoki survey combining acoustic and trawl data. *New Zealand Fisheries Assessment Report 2004/3*. 28 p.

Francois, R.E.; Garrison, G.R. (1982). Sound absorption based on ocean measurements. Part II: Boric acid contribution and equation for total absorption. *Journal of the Acoustical Society of America 72*: 1879–1890.

Horn, P.L. (1993). Growth, age structure, and productivity of ling, *Genypterus blacodes* (Ophidiidae), in New Zealand waters. *New Zealand Journal of Marine and Freshwater Research 27:* 385–397.

Horn, P.L. (1997). An ageing methodology, growth parameters and estimates of mortality for hake (*Merluccius australis*) from around the South Island, New Zealand. *Marine and Freshwater Research 48:* 201–209.

Horn, P.L.; Sullivan, K.J. (1996). Validated aging methodology using otoliths, and growth parameters for hoki (*Macruronus novaezelandiae*) in New Zealand waters. *New Zealand Journal of Marine and Freshwater Research 30*: 161–174.

Hurst, R.J.; Bagley, N.; Chatterton, T.; Hanchet, S.; Schofield, K.; Vignaux, M. (1992). Standardisation of hoki/middle depth time series trawl surveys. MAF Fisheries Greta Point Internal Report No. 194. 89 p. (Unpublished report held in NIWA library, Wellington.)

Jolly, G.M.; Hampton, I. (1990). A stratified random transect design for acoustic surveys of fish stocks. *Canadian Journal of Fisheries and Aquatic Sciences 47*: 1282–1291.

Kloser, R.J.; Ryan, T.E.; Macaulay, G.J.; Lewis, M.E. (2011). In situ measurements of target strength with optical and model verification: a case study for blue grenadier, *Macruronus novaezelandiae. ICES Journal of Marine Science 68*: 1986–1995.
Macaulay, G. (2001). Estimates of the target strength of hoki. Final Research Report for Ministry of Fisheries Research Project HOK1999/03 Objective 3. 12 p. (Unpublished report held by Ministry for Primary Industries, Wellington.)
Macaulay, G.J. (2004). Target strength estimates of hoki. Final Research Report for Ministry of Fisheries Project HOK2002/03 Objective 3. 22 p. (Unpublished report held by Ministry for Primary Industries, Wellington.)
Macaulay, G.J. (2006). Target strength estimates of hoki. Final Research Report for Ministry of Fisheries Project HOK2004/03 Objective 3. 13 p. (Unpublished report held by Ministry for Primary Industries, Wellington.)
MacLennan, D.N. (1981). The theory of solid spheres as sonar calibration targets. *Scottish Fisheries Research 22*. 17 p.
MacLennan, D.N.; Simmonds, E.J. (1992). Fisheries Acoustics. Chapman & Hall, London. *Fish and Fisheries Series 5.* 325 p.
McNeill, E. (2001). ESP2 phase 4 user documentation. NIWA Internal Report 105. 31 p. (Unpublished report held by NIWA library, Wellington.)
Ministry for Primary Industries (2012). Report from the Fisheries Assessment Plenary, May 2012: stock assessments and yield estimates. Compiled by the Fisheries Science Group, Ministry for Primary Industries, Wellington, New Zealand. 1194 p.
O'Driscoll, R.L. (2002). Review of acoustic data inputs for the 2002 hoki stock assessment. *New Zealand Fisheries Assessment Report 2002/36*. 66 p.
O'Driscoll, R.L. (2004). Estimating uncertainty associated with acoustic surveys of spawning hoki (*Macruronus novaezelandiae*) in Cook Strait, New Zealand. *ICES Journal of Marine Science 61*: 84–97.
O'Driscoll, R.L. (2006). Acoustic survey of spawning hoki in Cook Strait during winter 2005, and revision of hoki acoustic abundance indices for Cook Strait and the west coast South Island. *New Zealand Fisheries Assessment Report 2006/44*. 46 p.
O'Driscoll, R.L. (2012). Acoustic survey of spawning hoki in Cook Strait during winter 2011. *New Zealand Fisheries Assessment Report 2012/17*. 50 p.
O'Driscoll, R.L.; Bagley, N.W.; Dunn, A. (2004). Further analysis of an acoustic survey of spawning hoki off the west coast South Island in winter 2000. *New Zealand Fisheries Assessment Report 2004/2*. 53 p.
O'Driscoll, R.L.; de Joux, P.; Nelson, R.; Macaulay, G.J.; Dunford, A.J.; Marriott, P.M.; Stewart, C.; Miller, B.S. (2012). Species identification in seamount fish aggregations using moored underwater video. *ICES Journal of Marine Science, 69*: 648–659.
O'Driscoll, R.L.; Horn, P.L.; Ballara, S.L.; MacGibbon, D. (2011a). Design & methodology for trawl survey of hoki and middle depth fish abundance on the West Coast South Island. Presentation to the Hoki Fisheries Assessment Working Group, Ministry for Primary Industries, Wellington, 14 December 2011. Project HOK2010/04A. (Unpublished presentation held by Ministry for Primary Industries.)
O'Driscoll, R.L.; MacGibbon, D.; Fu, D.; Lyon, W.; Stevens, D.W. (2011b). A review of hoki and middle depth trawl surveys of the Chatham Rise, January 1992–2010. *New Zealand Fisheries Assessment Report 2011/47*. 814 p.
O'Driscoll, R.L.; Oeffner, J.; Dunford, A.J. (2013). *In situ* target strength estimates of optically verified southern blue whiting (*Micromesistius australis*). *ICES Journal of Marine Science 70*: 431–439.
Rose, G.A. (1998). Review of hoki acoustic projects for the Ministry of Fisheries, Wellington, New Zealand, August 1, 1998. 19 p. (Unpublished report held by Ministry for Primary Industries, Wellington.)
Rose, G.; Gauthier, S.; Lawson, G. (2000). Acoustic surveys in the full monte: simulating uncertainty. *Aquatic Living Resources 13*: 367–372.
Tuck I., Cole, R., Devine, J. (2009). Ecosystem indicators for New Zealand fisheries. *New Zealand Aquatic Environment and Biodiversity Report 42*. 188 p.

7. TABLES

Table 1: Stratum depth boundaries, areas, and acoustic transect and random tow allocations for the 2012 WCSI survey. Stratum locations are shown in Figure 1. Curly bracket ({) indicates the same transects crossed several substrata. Snap, snapshot.

			No. of transects		No. of tows	
Stratum	Depth (m)	Area (km^2)	Snaps 1 & 2	Snap 3	Planned	Actual
1&2S*	200–300	1 450	0	0	5	3
1&2A	300–430	1 214	{4	{3	8	8
1&2B	430–500	1 028	{4	{3	9	9
1&2C	500–650	3 148	{4	{3	8	8
4S*	200–300	1 600	0	0	5	4
4A	300–430	786	{8	{6	12	12
4B	430–500	592	{8	{6	6	6
4C	500–650	1 455	{8	{6	8	8
4D	650–800	1 655	(8	0	5	5
5A	300–300	254	7	7	0	0
5B	position–position	529	3	3	0	0
6	250–850 (north of 42.85°S) 250–750 (south of 42.85°S)	2 165	9	9	0	0
7	position–position	565	4	4	0	0
Total		16 441	35	32	66	63

* Shallow strata were assigned lower priority in the survey.

Table 2: Mean fish size and derived target strength (TS) for species used in species decomposition. Smooth skate and sea perch were also an important part of the catch (see Table 7), but were not included in the species decomposition as it was assumed that these species were in the acoustic "deadzone" close to the bottom. Minor species were considered as a group ('Other'), and an average TS was assigned.

Species name	Mean length⁺ (cm)	Mean weight⁺ (kg)	TS⁺ (dB kg^{-1})	TS-length relationship* *a*	*b*
Hoki ('old' TS)	67	1.2	-38.8	22.32	79.84
Hoki ('new' TS)	67	1.2	-41.9	12.2	63.9
Ling	93	4.3	-34.4	20	68
Hake	79	3.8	-37.6	27.1	83.5
Silver warehou	44	1.7	-48.7	20	80
Spiny dogfish	72	1.6	-44.8	20	80
Javelinfish	33	0.1	-31.4	20	73.5
Bigeyed rattail	42	0.4	-33.3	20	70
Lookdown dory	33	0.8	-32.3	20	64
Silver dory	19	0.2	-30.1	20	64
Dark ghost shark	48	0.7	-44.1	20	80
Ribaldo	41	0.8	-30.3	21.7	66.7
Alfonsino	21	0.2	-34.1	20	68
Pale ghost shark	66	1.6	-45.6	20	80
School shark	102	5.2	-46.7	20	80
Leafscale gulper shark	119	11.5	-49.0	20	80
Shovelnosed dogfish	89	2.6	-45.2	20	80
Other	–	–	-35.2	–	–

* TS = $a \log_{10}$ (length) – b. Best estimates from *in situ* measurements, swimbladder modelling, or related species.
⁺ Values of mean length, weight, and TS were estimated by substratum, but averages across all strata are summarised here.

Table 3: Values of parameters and their distributions used in Monte Carlo uncertainty simulations to estimate weighting (CV) of WCSI acoustic survey indices.

Term	Notation	Distribution	Value
Mean arrival date	$\bar{d}$	Uniform	197–212
Mean residence time	$\bar{r}$	Uniform	27–47
Individual arrival date	d_i	Normal	$\bar{d}$ (5)
Individual residence time	r_i	Normal	$\bar{r}$ (10)
Sampling	s	Normal	1.0 (snapshot c.v)
Mark identification – "mix" strata	id_{mix}	Lognormal	-0.2 (0.5) +
Mark identification – "hoki" strata	id_{hoki}	Lognormal	0 (0.08)
Calibration (1988–90)	cal_{88-90}	Uniform	0.75–1.25
Calibration (1991–99)	cal_{91-99}	Uniform	0.88–1.12
Calibration (post 2000)	cal_{00-01}	Uniform	0.95–1.05
Target strength	TS	Uniform	0.88–1.12

*For uniform distribution values are ranges; for normal distributions values are means with s.d. in parentheses; for lognormal distributions values are the mean and s.d. of $\log_{10}$(variable). Plateau model variables (mean and individual arrival dates, mean and individual residence times) are in days. All other variables are relative (scaled to one).
+ For 'new' methodology in 2012 uncertainty in mixed marks was estimated by bootstrapping from observed trawl catches.

Table 4: Summary of acoustic snapshots and mark identification tows in 2012 WCSI survey. South area includes strata 5A, 5B, 6, and 7. North area includes strata 1&2 and 4.

Snapshot	Area	Start time	End time	No. of transects	No. of tows
1	South	22 Jul 17:22	25 Jul 00:53	23	7
	North	25 Jul 06:29	2 Aug 13:07	12	1
2	South	3 Aug 03:16	5 Aug 06:04	23	8
	North	5 Aug 20:55	11 Aug 04:30	12	3
3	South	13 Aug 22:13	17 Aug 00:45	23	8
	North	17 Aug 05:59	18 Aug 09:04	9	0
Total				102	27

Table 5: Summary of different methodology used to estimate hoki abundance from 2012 WCSI acoustic survey.

	Method		
Parameter	'Old'	'Old revised'	'New'
Sound absorption	8.0 dB km^{-1}	8.83 dB km^{-1} (Appendix 4)	8.83 dB km^{-1} (Appendix 4)
Hoki TS used to estimate abundance	Macaulay (2001)	Macaulay (2006)	Macaulay (2006)
Hoki length-weight	Francis (2003)	Francis (2003)	TAN1210 data
Hoki length distribution	2012 commercial fishery (all strata)	2012 commercial fishery (all strata)	TAN1210 data by substrata for fuzz marks, 2012 commercial fishery for school marks (all strata)
Species decomposition of hoki schools	None (assumed 100% hoki)	None (assumed 100% hoki)	None (assumed 100% hoki)
Species decomposition of mixed marks	Northern strata only	Northern strata only	All strata
Hoki TS used in species decomposition	Coombs & Cordue (1995)	Coombs & Cordue (1995)	Macaulay (2006)
Tow weighting for species decomposition	Equal weighting	Equal weighting	Square root of catch rate
Survey area	Exclude substrata 4D and 6D	Exclude substrata 4D and 6D	All 2012 substrata
Stratum areas	2000 stratum areas (Cordue 2002)	Revised areas based on bathymetry (O'Driscoll 2006)	Table 1
Survey weighting	Error in mix marks based on assumed distribution (Table 3)	Error in mix marks based on assumed distribution (Table 3)	Error in mix marks based on bootstrapping tow data
Abundance estimate	One (entire area)	One (entire area)	Two (north and south)
Backward comparability	Comparable to WCSI time-series used in 2012 assessment	Comparable to revised WCSI indices of O'Driscoll (2006) adjusted for change in hoki TS from Macaulay (2004) to Macaulay (2006)	Not comparable. Cannot calculate equivalent index for previous surveys because insufficient trawling south of Hokitika Canyon to do species decomposition

Table 6: Survey tow and gear parameters (recorded values only) for valid tows on the 2012 trawl survey. 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)	63	2.6	0.47	1.99–3.03
Tow speed (knots)	63	3.5	0.04	3.4–3.7
Gear parameters (m)				
200–300 m				
Headline height	7	7.2	0.16	7.1–7.5
Doorspread	5	106.0	3.25	101.3–110.3
300–650 m				
Headline height	51	7.0	0.35	6.3–7.8
Doorspread	50	120.8	7.43	102.3–135.1
650–800 m				
Headline height	5	7.1	0.16	6.9–7.3
Doorspread	5	117.8	4.11	112.8–121.3
All tows 200–800 m				
Headline height	63	7.0	0.32	6.3–7.8
Doorspread	60	119.2	8.04	101.3–135.1

Table 7: Comparison of doorspread and headline measurements from valid trawl survey tows from the west coast *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.
2000	42	123.9	6.91	106.4	138.0	6.7	0.28
2012	60	119.2	8.04	101.3	135.1	7.0	0.32

Table 8: Total catch of the top 30 species from all tows (bottom and midwater) during the 2012 WCSI survey.

Code	Common name	Scientific name	Catch (kg)
HOK	Hoki	*Macruronus novaezelandiae*	139 571
LIN	Ling	*Genypterus blacodes*	10 669
SPD	Spiny dogfish	*Squalus acanthias*	7 917
HAK	Hake	*Merluccius australis*	3 620
SWA	Silver warehou	*Seriolella punctata*	3 416
SDO	Silver dory	*Cyttus novaezealandiae*	2 223
GIZ	Giant stargazer	*Kathetostoma giganteum*	1 173
SCH	School shark	*Galeorhinus galeus*	1 160
SSK	Smooth skate	*Dipturus innominatus*	1 130
BYS	Alfonsino	*Beryx splendens*	913
JAV	Javelinfish	*Lepidorhynchus denticulatus*	800
SQU	Arrow squid	*Nototodarus sloanii* & *N. gouldi*	717
LDO	Lookdown dory	*Cyttus traversi*	715
GSH	Dark ghost shark	*Hydrolagus novaezealandiae*	677
SPE	Sea perch	*Helicolenus spp.*	650
BAR	Barracouta	*Thyrsites atun*	539
SND	Shovelnose spiny dogfish	*Deania calcea*	529
NSD	Northern spiny dogfish	*Squalus griffini*	512
SRH	Silver roughy	*Hoplostethus mediterraneus*	456
NMP	Tarakihi	*Nemadactylus macropterus*	453
CBO	Bollons rattail	*Coelorinchus bollonsi*	445
RIB	Ribaldo	*Mora moro*	355
CSQ	Leafscale gulper shark	*Centrophorus squamosus*	322
HAP	Hapuku	*Polyprion oxygeneios*	275
CAR	Carpet shark	*Cephaloscyllium isabellum*	230
SSH	Slender smooth-hound	*Gollum attenuatus*	200
SCO	Swollenhead conger	*Bassanago bulbiceps*	192
WWA	White warehou	*Seriolella caerulea*	192
FRO	Frostfish	*Lepidopus caudatus*	173
OPE	Orange perch	*Lepidoperca aurantia*	167
Total			182 581

Table 9: Catch and total abundance estimates with coefficient of variation (CV in parentheses) of 28 species ranked by abundance, for valid trawl tows in core strata (300–650 m) and all strata (200–800 m). Abundance estimates are provided by sex for core strata. Total abundance includes unsexed fish.

		Catch (kg)		Biomass (t)			
Common name	Code	Core	All	Core male	Core female	Core total	All total
Hoki	HOK	126 507	126 718	12 467 (24.1)	20 022 (27.0)	32 495 (24.2)	32 602 (24.1)
Ling	LIN	9 610	9 651	956 (14.9)	1 213 (16.4)	2 169 (14.8)	2 194 (14.7)
Spiny dogfish	SPD	6 607	7 043	114 (25.5)	981 (24.9)	1 095 (24.7)	1 453 (22.6)
Hake	HAK	1 889	2 905	194 (18.2)	387 (14.9)	583 (12.8)	1 103 (13.0)
Silver warehou	SWA	1 872	2 141	142 (23.8)	475 (37.7)	617 (32.2)	877 (26.5)
Silver dory	SDO	1 830	2 220	142 (57.5)	88 (51.3)	259 (46.5)	677 (44.2)
Giant stargazer	GIZ	500	1 052	32 (27.2)	65 (23.7)	97 (22.6)	608 (24.8)
Barracouta	BAR	74	533	6 (44.9)	6 (43.9)	12 (42.8)	417 (34.8)
School shark	SCH	971	1 133	95 (28.6)	91 (24.4)	186 (24.8)	323 (15.8)
Northern spiny dogfish	NSD	216	477	44 (21.1)	5 (49.9)	49 (20.4)	269 (28.7)
Tarakihi	NMP	136	449	18 (44.5)	3 (41.1)	21 (41.7)	267 (23.0)
Alfonsino	BYS	912	912	150 (71.2)	76 (65.7)	262 (58.8)	262 (58.8)
Smooth skate	SSK	857	945	76 (26.9)	91 (45.6)	167 (29.5)	239 (30.4)
Sea perch	SPE	502	580	73 (18.6)	52 (16.0)	136 (15.9)	205 (26.9)
Javelinfish	JAV	655	714	12 (19.3)	124 (13.8)	166 (11.3)	195 (10.9)
Lookdown dory	LDO	516	569	44 (14.2)	110 (15.2)	155 (11.9)	181 (10.6)
Dark ghost shark	GSH	534	580	48 (18.2)	59 (18.2)	106 (16.9)	146 (15.1)
Shovelnose spiny dogfish	SND	123	275	14 (66.0)	54 (77.2)	68 (70.6)	146 (44.4)
Ribaldo	RIB	105	293	11 (35.7)	32 (30.6)	43 (25.3)	140 (21.6)
Arrow squid	SQU	567	609	50 (16.2)	44 (24.2)	95 (18.3)	137 (14.9)
Silver roughy	SRH	402	411	1 (66.7)	1 (64.2)	101 (23.3)	101 (23.3)
Bollons rattail	CBO	290	315	47 (14.6)	45 (12.3)	93 (10.8)	105 (11.1)
Hapuku	HAP	176	244	11 (42.8)	24 (51.9)	35 (39.3)	99 (29.0)
White warehou	WWA	49	125	5 (78.5)	21 (72.1)	26 (60.4)	65 (34.2)
Pale ghost shark	GSP	64	80	12 (51.9)	20 (25.5)	32 (28.2)	40 (25.4)
Frostfish	FRO	155	163	11 (79.9)	19 (38.7)	30 (51.9)	38 (46.1)
Red cod	RCO	110	110	13 (19.5)	9 (27.4)	22 (17.5)	22 (17.5)
Redbait	RBT	67	70	6 (34.7)	7 (32.9)	13 (32.2)	16 (27.3)

Table 10: Estimated trawl biomass (t) and coefficient of variation (% CV) of the top 28 species by stratum (see Table 9 for species common names). – indicates estimated biomass less than 1 t.

						Species code
Stratum	HOK	LIN	SPD	HAK	SDO	SWA
1&2A	3 071 (23.1)	1 548 (19.8)	1 (100.0)	– (81.2)	1 (37.1)	141 (39.7)
1&2B	3 934 (45.7)	134 (32.7)	51 (74.5)	42 (26.4)	–	22 (50.5)
1&2C	9 042 (68.2)	47 (45.0)	3 (100.0)	171 (33.3)	–	310 (58.2)
4A	5 816 (47.7)	229 (24.3)	833 (30.2)	9 (43.6)	258 (46.7)	96 (58.5)
4B	8 625 (38.3)	158 (40.0)	196 (46.7)	37 (34.6)	1 (63.2)	19 (36.0)
4C	2 007 (59.1)	53 (43.6)	12 (60.4)	323 (13.8)	–	30 (77.4)
Subtotal (core)	32 495 (24.2)	2 169 (14.8)	1 095 (24.7)	583 (12.8)	259 (46.5)	617 (32.2)
1&2S	–	7 (100.0)	1 (100.0)	–	386 (71.0)	238 (50.3)
4S	–	–	356 (52.5)	–	33 (55.1)	12 (49.6)
4D	107 (21.8)	18 (43.8)	–	520 (23.7)	–	10 (41.3)
Total	32 602 (24.1)	2 194 (14.7)	1 453 (22.6)	1 103 (13.0)	677 (44.2)	877 (26.5)

						Species code
Stratum	SCH	GIZ	SSK	BYS	JAV	SQU
1&2A	86 (34.5)	51 (30.9)	24 (44.0)	258 (59.7)	26 (18.3)	10 (29.1)
1&2B	4 (77.9)	1 (52.4)	40 (59.9)	–	20 (31.6)	3 (31.7)
1&2C	–	–	35 (100.0)	1 (66.2)	65 (21.2)	6 (65.5)
4A	77 (41.0)	39 (38.2)	52 (41.1)	1 (100.0)	26 (29.6)	46 (32.7)
4B	19 (81.4)	7 (54.9)	15 (59.2)	1 (79.7)	13 (36.4)	24 (26.0)
4C	–	–	1 (100.0)	–	15 (23.8)	7 (58.2)
Subtotal (core)	186 (24.8)	97 (22.6)	167 (29.5)	262 (58.8)	166 (11.3)	95 (18.3)
1&2S	87 (15.6)	102 (60.5)	5 (100.0)	–	–	23 (35.1)
4S	50 (34.2)	409 (33.2)	50 (100.0)	–	–	18 (36.3)
4D	–	–	18 (100.0)	–	29 (35.0)	–
Total	323 (15.8)	608 (24.8)	239 (30.4)	262 (58.8)	195 (10.9)	137 (14.9)

						Species code
Stratum	SPE	GSH	LDO	BAR	NSD	NMP
1&2A	27 (18.8)	67 (21.7)	19 (52.9)	4 (100.0)	34 (26.9)	2 (33.1)
1&2B	15 (13.2)	7 (45.9)	21 (35.7)	–	4 (37.2)	–
1&2C	57 (34.3)	–	70 (11.3)	–	3 (65.9)	–
4A	14 (39.4)	31 (32.0)	9 (40.7)	8 (41.4)	9 (43.4)	19 (46.7)
4B	15 (29.9)	1 (96.5)	9 (26.2)	–	–	–
4C	8 (39.7)	–	27 (37.1)	–	–	–
Subtotal (core)	136 (15.9)	106 (16.9)	155 (11.9)	12 (42.8)	49 (20.4)	21 (41.7)
1&2S	–	14 (50.5)	–	122 (80.5)	93 (34.4)	45 (36.3)
4S	63 (81.1)	26 (40.8)	–	282 (37.7)	126 (54.9)	201 (29.1)
4D	6 (35.4)	–	27 (21.6)	–	–	–
Total	205 (26.9)	146 (15.1)	181 (10.6)	417 (34.8)	269 (28.7)	267 (23.0)

Table 10: continued.

Stratum	Species code SRH	CBO	RIB	SND	HAP	FRO
1&2A	38 (57.3)	2 (65.5)	–	–	12 (64.2)	9 (34.3)
1&2B	6 (32.7)	20 (18.8)	–	–	10 (100.0)	1 (52.1)
1&2C	25 (21.7)	46 (17.3)	28 (35.6)	68 (70.6)	–	1 (100.0)
4A	7 (35.1)	–	–	–	13 (39.5)	19 (80.2)
4B	11 (29.0)	12 (24.3)	–	–	–	–
4C	13 (40.1)	13 (27.1)	15 (30.6)	–	–	–
Subtotal (core)	101 (23.3)	93 (10.8)	43 (25.3)	68 (70.6)	35 (39.3)	30 (51.9)
1&2S	–	–	–	–	59 (41.9)	–
4S	–	–	–	–	5 (100.0)	8 (100.0)
4D	–	13 (48.5)	97 (29.0)	78 (55.9)	–	–
Total	101 (23.3)	105 (11.1)	140 (21.6)	146 (44.4)	99 (29.0)	38 (46.1)

Stratum	Species code WWA	RCO	GSP	RBT
1&2A	–	11 (23.3)	–	1 (51.0)
1&2B	–	2 (76.0)	–	–
1&2C	21 (72.1)	–	30 (30.0)	1 (66.3)
4A	–	7 (35.8)	–	4 (82.5)
4B	–	3 (46.2)	–	6 (46.4)
4C	5 (79.9)	–	2 (69.6)	1 (50.5)
Subtotal (core)	26 (60.4)	22 (17.5)	32 (28.2)	13 (32.2)
1&2S	–	–	–	2 (21.3)
4S	–	–	–	1 (15.8)
4D	39 (40.5)	–	8 (57.9)	–
Total	65 (34.2)	22 (17.5)	40 (25.4)	16 (27.3)

Table 11: Trawl abundance estimates, coefficients of variation comparisons for the core strata (300–650 m) from the 2000 and 2012 WCSI trawl surveys. The 2000 survey abundance estimates were re-calculated using 2012 stratum areas. Giant stargazer was coded as STA, and tarakihi was TAR in 2000.

		Core area biomass (t) and CV (%)	
Common name	Code	2012	2000
Hoki	HOK	32 495 (24.2)	5 385 (20.6)
Ling	LIN	2 169 (14.8)	1 861 (17.3)
Spiny dogfish	SPD	1 095 (24.7)	233 (53.6)
Sliver warehou	SWA	617 (32.2)	1 507 (24.6)
Hake	HAK	583 (12.8)	803 (13.4)
Alfonsino	BYS	262 (58.8)	14 (41.0)
Sliver dory	SDO	259 (46.5)	113 (62.0)
School shark	SCH	186 (24.8)	98 (69.8)
Smooth skate	SSK	167 (29.5)	186 (28.0)
Javelinfish	JAV	166 (11.3)	198 (17.4)
Lookdown dory	LDO	155 (11.9)	169 (14.4)
Sea perch	SPE	136 (15.9)	123 (6.7)
Dark ghost shark	GSH	106 (16.9)	77 (32.5)
Silver roughy	SRH	101 (23.3)	23 (18.0)
Giant stargazer	STA/GIZ	97 (22.6)	74 (27.3)
Arrow squid	SQU	95 (18.3)	18 (22.6)
Bollon's rattail	CBO	93 (10.8)	192 (11.3)
Shovelnose spiny dogfish	SND	68 (70.6)	153 (29.5)
Northern spiny dogfish	NSD	49 (20.4)	96 (23.1)
Ribaldo	RIB	43 (25.3)	104 (26.3)
Hapuku	HAP	35 (39.3)	36 (46.6)
Pale ghost shark	GSP	32 (28.2)	23 (28.2)
Frostfish	FRO	30 (51.9)	31 (27.3)
White warehou	WWA	26 (60.4)	12 (50.9)
Red cod	RCO	22 (17.5)	12 (31.8)
Tarakihi	TAR/NMP	21 (41.7)	22 (32.2)
Redbait	RBT	13 (32.2)	3 (29.2)
Barracouta	BAR	12 (42.8)	4 (72.7)

Table 12: Numbers of fish for which length, sex, and biological data were collected.

	Length frequency data				Length-weight data	
	No. of fish measured			No. of	No. of	No. of
Species	Total †	Male	Female	samples	fish	samples
Alfonsino	398	188	108	17	108	14
Arrow squid	1 089	499	529	65	758	52
Austral lanternfish	1	0	0	1	1	1
Banded bellowsfish	4	0	1	2	1	1
Banded rattail	25	12	12	5	23	4
Barracouta	287	143	144	16	237	16
Basketwork eel	3	0	1	1	0	0
Bigeye cardinalfish	58	20	27	7	35	4
Black slickhead	210	122	81	10	29	3
Bluenose	5	2	3	4	5	4
Bogue lanternfish	54	0	0	3	2	1
Bollons rattail	797	471	310	45	476	29
Broadnose sevengill shark	1	1	0	1	1	1
Capro dory	398	1	0	9	1	1
Carpet shark	46	37	9	8	29	5
Common roughy	15	5	9	4	13	2
Common warehou	8	2	6	2	8	2
Cubehead	1	0	0	1	0	0
Cucumber fish	223	85	137	5	18	2
Dana lanternfish	124	0	0	1	50	1
Deepsea cardinalfish	6	2	4	4	6	4
Deepsea flathead	4	0	3	2	3	1
Diaphus spp	22	0	0	2	0	0
Electric ray	1	0	1	1	1	1
Eucla cod	111	2	103	3	0	0
Flaccid lanternfish	1	0	0	1	0	0
Frostfish	166	79	81	22	77	21
Gemfish	24	16	8	10	24	10
Dark ghost shark	741	366	375	35	429	31
Giant stargazer	337	214	123	38	317	37
Greenback jack mackerel	3	1	2	3	3	3
Gurnard	1	0	1	1	1	1
Hairy conger	13	3	5	4	7	2
Hake	899	479	419	55	898	55
Hapuku	30	14	16	14	30	14
Hector's lanternfish	820	0	1	7	0	0
Hoki	12 753	5 630	7 098	83	1 521	75
Hudson's lanternfish	13	0	0	1	0	0
Humpback rattail	1	0	1	1	1	1
Javelin fish	3 400	525	2 069	72	378	24
John dory	22	2	20	4	22	4
Johnson's cod	5	0	3	1	0	0
Leafscale gulper shark	30	13	17	13	30	13
Lighthouse fish	6	0	0	1	6	1
Ling	1 836	1 057	779	72	1 034	72
Longfinned beryx	6	5	1	4	6	4
Longnose velvet dogfish	30	15	15	7	30	7
Long-nosed chimaera	2	2	0	2	2	2
Lookdown dory	744	359	346	61	626	56
Lucifer dogfish	51	17	34	20	50	19
Lucifer lanternfish	5	0	0	1	5	1
Mahia rattail	10	7	3	4	8	2
Nezumia namatahi	1	0	0	1	0	0

Table 12 continued:

	Length frequency data				Length-weight data	
	No. of fish measured			No. of	No. of	No. of
Species	Total †	Male	Female	samples	fish	samples
Norman's lanterrnfish	1	1	0	1	1	1
Northern spiny dogfish	412	221	191	28	268	27
Notable rattail	9	0	1	2	1	1
Oliver's rattail	1 055	277	394	29	69	9
Orange perch	225	119	102	7	107	7
Orange roughy	4	1	3	2	4	2
Ostenfeld's lanternfish	1	0	0	1	0	0
Pale ghost shark	70	35	35	20	70	20
Pearlside	238	0	0	4	0	0
Plunket's shark	13	5	8	9	13	9
Red cod	234	171	55	30	201	27
Redbait	150	66	70	30	149	30
Ribaldo	273	76	197	27	273	27
Rig	2	1	1	2	2	2
Rough skate	17	9	8	12	17	12
Rubyfish	11	3	7	5	11	5
Rudderfish	3	0	3	3	3	3
Scabbardfish	6	2	1	3	6	3
Scampi	53	35	18	16	49	15
School shark	205	104	101	31	203	30
Sea perch	2 732	1 284	1 058	72	521	30
Seal shark	16	6	10	12	16	12
Sharpnose sevengill shark	2	0	2	2	2	2
Shovelnose spiny dogfish	191	97	94	15	160	15
Silver dory	1 141	515	320	13	161	7
Silver roughy	2 171	46	45	37	43	3
Silver warehou	1 551	507	1 044	68	757	68
Silverside	8	0	1	4	1	1
Slender jack mackerel	10	9	1	5	10	5
Slender smooth-hound	91	38	53	13	91	13
Small banded rattail	19	5	12	5	3	2
Smooth skate	75	39	36	31	74	30
Smooth skin dogfish	11	5	6	3	11	3
Softnose longtail skate	2	1	1	2	2	2
Southern rays bream	56	28	26	18	51	16
Spiky oreo	87	59	28	5	28	3
Spineback	2	1	1	2	2	2
Spiny dogfish	1 993	312	1 681	45	697	41
Spotted gurnard	3	2	1	2	3	2
Swollenhead conger	103	72	31	11	45	6
Tarakihi	416	270	146	21	354	21
Two saddle rattail	87	27	60	7	64	4
Viper fish	1	0	0	1	1	1
White rattail	21	10	11	3	18	2
White warehou	45	23	22	14	45	14
Witch	2	0	2	1	2	1
Yellow boarfish	183	44	37	6	84	4
Grand total	39 842	14 922	18 829	91	12 003	90

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

Table 13: Length-weight regression parameters* used to scale length frequencies for the top 20 key species in 2012 (above) and length-weight regression parameters* used to re-calculate scaled length frequencies for hoki, hake ling and silver warehou for the 2000 survey (below).

2012 (TAN1210)

Species	Regression parameters *a*	*b*	r^2	*n*	Length range (cm)	Data source
Alfonsino	0.022780	2.9700	0.86	108	18.9 – 31.2	TAN1210
Arrow squid	0.093382	2.6253	0.98	755	9.5 – 44.1	TAN1210
Barracouta	0.030495	2.5752	0.89	237	56.6 – 106.0	TAN1210
Dark ghost shark	0.001885	3.2987	0.98	426	24.6 – 68.3	TAN1210
Giant stargazer	0.002425	3.4910	0.97	313	28.9 – 80.5	TAN1210
Hake	0.002322	3.2664	0.98	892	30.8 – 126.4	TAN1210
Hoki	0.004961	2.8968	0.99	1 513	27.3 – 118.5	TAN1210
Javelinfish	0.000617	3.3676	0.98	352	13.3 – 64.4	TAN1210
Ling	0.001042	3.3506	0.99	1 028	30.4 – 157.2	TAN1210
Lookdown dory	0.028792	2.9272	0.99	102	10.0 – 56.1	TAN1210
Northern spiny dogfish	0.003744	3.0382	0.97	267	32.9 – 87.4	TAN1210
Ribaldo	0.006134	3.1436	0.99	272	17.4 – 75.3	TAN1210
School shark	0.004699	3.0011	0.96	202	72.0 – 146.9	TAN1210
Sea perch	0.009440	3.1496	0.99	516	12.9 – 48.4	TAN1210
Shovelnose dogfish	0.000328	3.5452	0.95	159	62.3 – 119.4	TAN1210
Silver dory	0.009648	3.2112	0.96	161	14.6 – 25.7	TAN1210
Silver warehou	0.003890	3.4159	0.99	756	21.6 – 57.2	TAN1210
Smooth skate	0.020793	2.9774	0.99	74	39.7 – 140.0	TAN1210
Spiny dogfish	0.000469	3.5197	0.88	682	52.9 – 95.9	TAN1210
Tarakihi	0.030434	2.8506	0.96	352	27.4 – 49.1	TAN1210

2000 (TAN0007)

Hake	0.001666	3.3345	0.98	1 099	29.6 – 118.4	TAN0007
Hoki	0.004484	2.9088	0.97	3 656	27.8 – 119.4	TAN0007
Ling	0.000951	3.3651	0.99	1 639	29.6 – 172.2	TAN0007
Silver warehou	0.017768	3.0028	0.78	1 588	34.9 – 49.9	TAN0007

Tows from 44 onwards were selected to match the timing of the 2012 survey

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

Table 14: Teleost and elasmobranch species gonad stage observations* by each reproductive stage. Species selected are those with more than 500 observations for teleosts and 300 observations for elasmobranchs.

Species and sex	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7
Teleosts							
Hoki males	599	150	434	911	2 691	442	125
Hoki females	699	362	3 396	1 119	92	533	839
Hake males	36	24	5	21	282	99	7
Hake females	35	17	268	17	10	34	37
Ling males	87	212	61	306	236	100	23
Ling females	95	218	98	273	36	13	20
Silver warehou males	86	18	51	123	174	0	1
Silver warehou females	79	15	759	37	9	1	0
Lookdown dory males	57	108	20	6	10	0	53
Lookdown dory females	45	69	3	0	0	8	152
Tarakihi males	17	129	1	0	0	1	72
Tarakihi females	13	52	0	0	0	0	72
Elasmobranchs							
Spiny dogfish males	0	5	120				
Spiny dogfish females	14	32	42	195	511	25	
Northern spiny dogfish males	99	31	61				
Northern spiny dogfish females	149	4	0	0	1	0	
Dark ghost shark males	52	67	72				
Dark ghost shark females	79	40	42	13	0	1	

*See Appendix 3 for description of gonad stages for teleosts and elasmobranchs.

Table 15: Summary and catch information from mark identification tows during the 2012 WCSI survey. Mark type refers to the categories described in text: HOK = hoki school; PMIX = hoki pelagic fuzz; BMIX = hoki bottom fuzz; P = pelagic layer.

				Catch (kg)						
Station	Trawl	Stratum	Mark type	Hoki	Hake	Spiny dogfish	Ling	Silver warehou	Other	% Hoki
2	Mesopelagic	5A	PMIX	10.9	0.0	18.9	33.0	0.0	37.8	11
3	Bottom	4D	BMIX	186.2	119.4	0.0	0.0	2.2	40.9	53
4	Bottom	6C	BMIX	73.5	36.8	0.0	0.0	0.0	146.4	29
5	Mesopelagic	6A	Pelagic+	4.4	0.0	0.0	0.0	0.0	4.0	52
6	Mesopelagic	6B	Pelagic	0.0	0.0	0.0	0.0	0.0	6.4	0
7	Bottom	6C	BMIX	311.5	48.3	0.0	22.1	39.2	293.3	44
8	Bottom*	7	PMIX	67.7	0.0	5.0	32.1	0.0	3.6	62
35	Bottom	1&2C	BMIX	35.7	25.4	2.2	10.4	5.8	67.9	24
47	Bottom	5A	HOK	1 639.3	11.4	15.4	120.7	0.0	12.0	91
48	Mesopelagic	6B	PMIX	5.2	0.0	0.0	7.1	0.0	7.6	26
49	Bottom	6B	BMIX	56.4	0.0	26.8	18.3	4.0	163.6	21
50	Bottom	6B	BMIX	940.9	11.8	0.0	0.0	2.0	25.4	96
51	Bottom	6A	Pelagic	97.1	0.0	3.4	4.9	0.0	44.6	65
52	Bottom	6B	HOK	941.0	0.0	18.5	1.1	24.0	28.6	93
53	Bottom	6B	BMIX	556.3	24.1	4.8	13.3	344.4	95.5	54
54	Mesopelagic	7	HOK	210.9	0.0	1.9	28.9	0.0	3.0	86
66	Bottom	1&2A	BMIX	130.1	8.4	29.5	119.1	1.9	22.9	42
67	Bottom	4A	BMIX	94.1	0.0	85.7	14.0	40.8	22.5	37
77	Bottom	1&2A	BMIX	20.4	0.0	0.0	69.6	2.4	57.6	14
92	Mesopelagic	5B	PMIX+	5.0	2.9	7.7	17.3	0.0	6.2	13
95	Bottom	5A	HOK	468.3	0.0	617.4	338.5	0.0	174.6	29
97	Bottom	6C	BMIX	58.9	238.6	2.5	14.2	15.3	280.1	10
98	Mesopelagic	6A	HOK	419.7	34.5	0.0	0.0	0.0	1.0	92
99	Mesopelagic	6C	Pelagic	5.7	0.0	0.0	0.0	0.0	9.1	39
100	Bottom	6B	BMIX	7.3	0.0	0.0	0.0	0.0	8.7	46
101	Bottom	6B	BMIX	1 834.6	17.7	20.3	29.8	683.3	107.0	68
102	Bottom	6B	BMIX	4 544.8	30.2	15.8	9.7	107.4	99.1	95

* Net was flown above the bottom and did not contact the seabed.
+ Tow did not go through main mark.

Table 16: Estimates of the proportion of acoustic backscatter from hoki (P(hoki)) in mixed species marks by substratum for all snapshots combined. Average percentage of hoki by weight in the catch is also given with equal weighting of all tows ('unweighted') and weighted by the square root of the catch rate ('weighted'). Southern area includes strata 5A, 5B, 6, and 7. In the 'old' analysis method P(hoki) from the southern area is assumed to be 1.

		Mean % hoki in catch		P(hoki)	
Stratum	No. of tows	Unweighted	Weighted	'Old' method	'New' method
1&2A	10	49	53	0.37	0.32
1&2B	9	75	84	0.59	0.58
1&2C	9	44	69	0.35	0.56
4A	13	46	62	0.43	0.51
4B	6	92	93	0.87	0.78
4C	8	49	64	0.37	0.40
4D	6	16	17	0.10	0.05
South	13	44	62	1.00	0.51

Table 17: Estimates of the ratio *r* for converting hoki acoustic backscatter to biomass using acoustic TS derived from commercial length frequency data (see Figure 30) using the TS-length relationships of Macaulay (2001) and Macaulay (2006). Estimates based on Macaulay (2001) are used to generate 'old' time-series of hoki abundance estimates. Estimates based on Macaulay (2006) are used to generate the 'revised old' time-series, and for hoki from schools for 'new' estimates.

			Macaulay (2001)		Macaulay (2006)	
Year	Mean length (cm)	Mean weight (kg)	Mean TS (dB)	*r* (kg m^{-2})	Mean TS (dB)	*r* (kg m^{-2})
1988	81.1	1.66	-39.6	15 026	-40.6	19 011
1989	81.6	1.67	-39.5	15 006	-40.6	19 009
1990	81.9	1.69	-39.5	15 073	-40.6	19 134
1991	80.5	1.63	-39.6	14 967	-40.6	18 879
1992	79.3	1.54	-39.8	14 600	-40.7	18 208
1993	78.2	1.49	-39.9	14 400	-40.8	17 831
1997	74.1	1.31	-40.3	13 861	-41.1	16 733
2000	80.3	1.59	-39.7	14 763	-40.7	18 523
2012	75.4	1.37	-40.1	14 090	-41.0	17 154

Table 18: Estimates of the ratios *r* for converting hoki acoustic backscatter from mixed species marks to biomass by strata using acoustic TS derived from research tow data (see Figure 31). All estimates were derived using the TS-length relationships in Macaulay (2006). Strata 5A and 5B (Hokitika Canyon) were combined.

			Macaulay (2006)	
Stratum	Mean length (cm)	Mean weight (kg)	Mean TS (dB)	*r* (kg m^{-2})
1&2A	47.1	0.42	-43.4	9 340
1&2B	75.2	1.43	-41.0	18 034
1&2C	76.2	1.49	-40.9	18 467
4A	56.5	0.69	-42.5	12 241
4B	74.3	1.39	-41.1	17 773
4C	76.4	1.51	-40.9	18 574
4D	77.5	1.56	-40.8	18 911
5A&B	67.4	1.06	-41.6	15 174
6	54.7	0.87	-42.6	15 682
7	69.3	1.29	-41.4	17 827

Table 19: Hoki acoustic abundance estimates from the 2012 WCSI by snapshot and stratum. Estimates were generated using three analysis methodologies (see text for details).

		Biomass ('000 t)							
Method	Snapshot	12	4*	5A	5B	6	7	Total	CV (%)
'Old'	1	23	114	81	11	86	32	348	17
	2	69	104	159	23	98	25	478	28
	3	143	32	52	30	135	18	410	28
	Mean	78	83	97	22	106	25	412	15
'Revised'	1	32	161	127	16	126	48	509	17
	2	97	145	247	34	141	38	702	27
	3	201	45	80	41	199	28	595	28
	Mean	110	117	151	30	155	38	602	15
'New'	1	29	162	123	9	59	41	422	19
	2	112	142	244	26	89	25	639	29
	3	220	44	75	40	151	15	545	28
	Mean	120	116	147	25	100	27	535	16

*** Substratum 4D was not surveyed in snapshot 3, but no hoki were detected in this stratum during the first two snapshots.**

Table 20: Percentage of the hoki abundance estimate from hoki school marks in each snapshot and strata. Percentages were calculated in relation to abundance estimates in Table 19.

		% hoki in schools						
Method	Snapshot	12	4*	5A	5B	6	7	Total
'Old'	1	12	54	94	16	0	69	49
	2	41	55	98	60	32	24	62
	3	61	48	90	92	54	0	61
	Mean	50	54	95	67	32	37	58
'Revised'	1	12	53	94	16	0	68	48
	2	40	55	98	60	32	24	62
	3	60	47	90	92	54	0	60
	Mean	49	53	95	67	33	37	57
'New'	1	13	53	97	29	0	80	58
	2	35	56	99	77	50	37	68
	3	55	48	95	96	72	0	66
	Mean	45	53	98	82	51	52	65

Table 21: Recalculated acoustic abundance indices for WCSI. Indices using 'old' method updated from O'Driscoll (2002). Indices using 'revised old' method based on O'Driscoll et al. (2004) but updated using hoki TS of Macaulay (2006). 'New' estimates could not be calculated for previous surveys because there was insufficient mark identification trawling. The CV is the estimated model weighting (see text for details).

	Biomass ('000 t)			
Year	'Old'	'Revised old'	'New'	CV
1988	417	612	–	0.60
1989	249	380	–	0.38
1990	255	391	–	0.40
1991	341	519	–	0.73
1992	345	510	–	0.49
1993	549	833	–	0.38
1997	655	930	–	0.60
2000	397	593	–	0.60
2012	412	602	535	0.51

Table 22: Results of Monte Carlo simulations to determine model weighting for the 2012 WCSI acoustic survey (see Section 2.9.5 for details). The CV for the survey is given in a stepwise cumulative fashion to allow the contribution of each component of the abundance estimation process to be assessed. 'Timing' refers to uncertainties associated with the timing of snapshots relative to the plateau height model and includes uncertainties associated with assumptions about fish arrival date and residence time.

	'Old' Method	'New' Method	
	Entire area	North	South
Timing	0.089	0.091	0.090
+ Sampling	0.179	0.206	0.205
+ Mark identification	0.505	0.214	0.264
+ Calibration	0.506	0.215	0.265
+ TS	0.509	0.222	0.275
Total	0.509	0.222	0.275

Table 23: Estimated acoustic backscatter in the bottom 10 m (s_a 10 m) and bottom 100 m (s_a 100 m), catch rates (all species combined), and the average percentage of hoki by weight in the catch in random bottom tows by substrata from WCSI surveys in 2000 and 2012.

	2000				2012			
Substratum	s_a 10 m (m^2 km^{-2})	s_a 100 m (m^2 km^{-2})	Mean catch (kg km^{-2})	% hoki in catch	s_a 10 m (m^2 km^{-2})	s_a 100 m (m^2 km^{-2})	Mean catch (kg km^{-2})	% hoki in catch
1&2A	0.88	3.75	1 451	17	1.30	4.05	4 567	54
1&2B	0.66	3.57	1 355	40	0.84	11.45	4 263	75
1&2C	0.79	6.47	567	29	1.16	8.66	2 918	44
4A	1.05	4.20	2 023	21	2.01	8.02	9 058	46
4B	1.66	8.12	926	37	3.75	15.13	15 529	92
4C	0.90	7.08	657	20	0.98	8.35	1 761	49

8. FIGURES

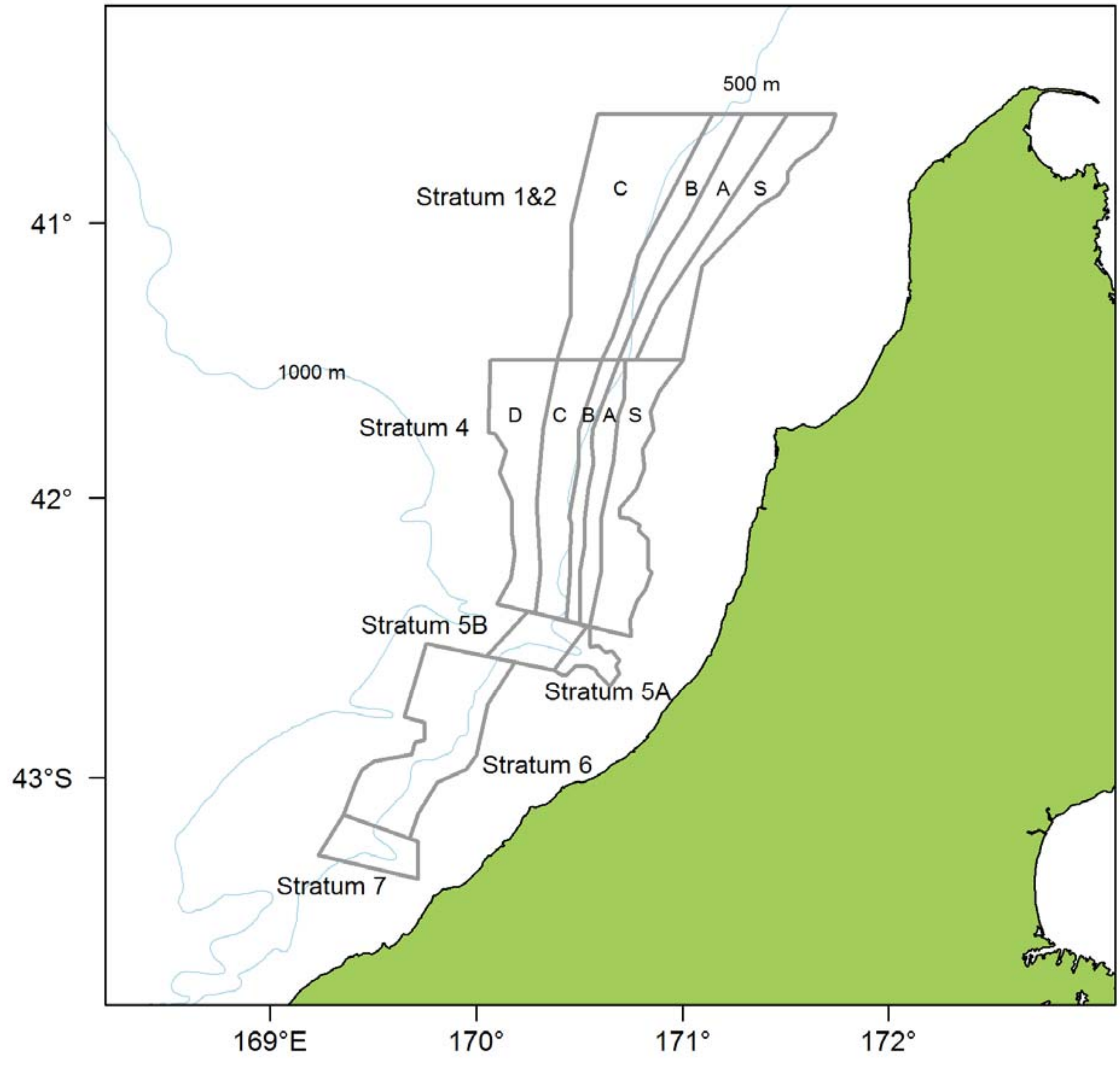


Figure 1: Stratum boundaries for the 2012 survey of the WCSI. Stratum areas are given in Table 1.

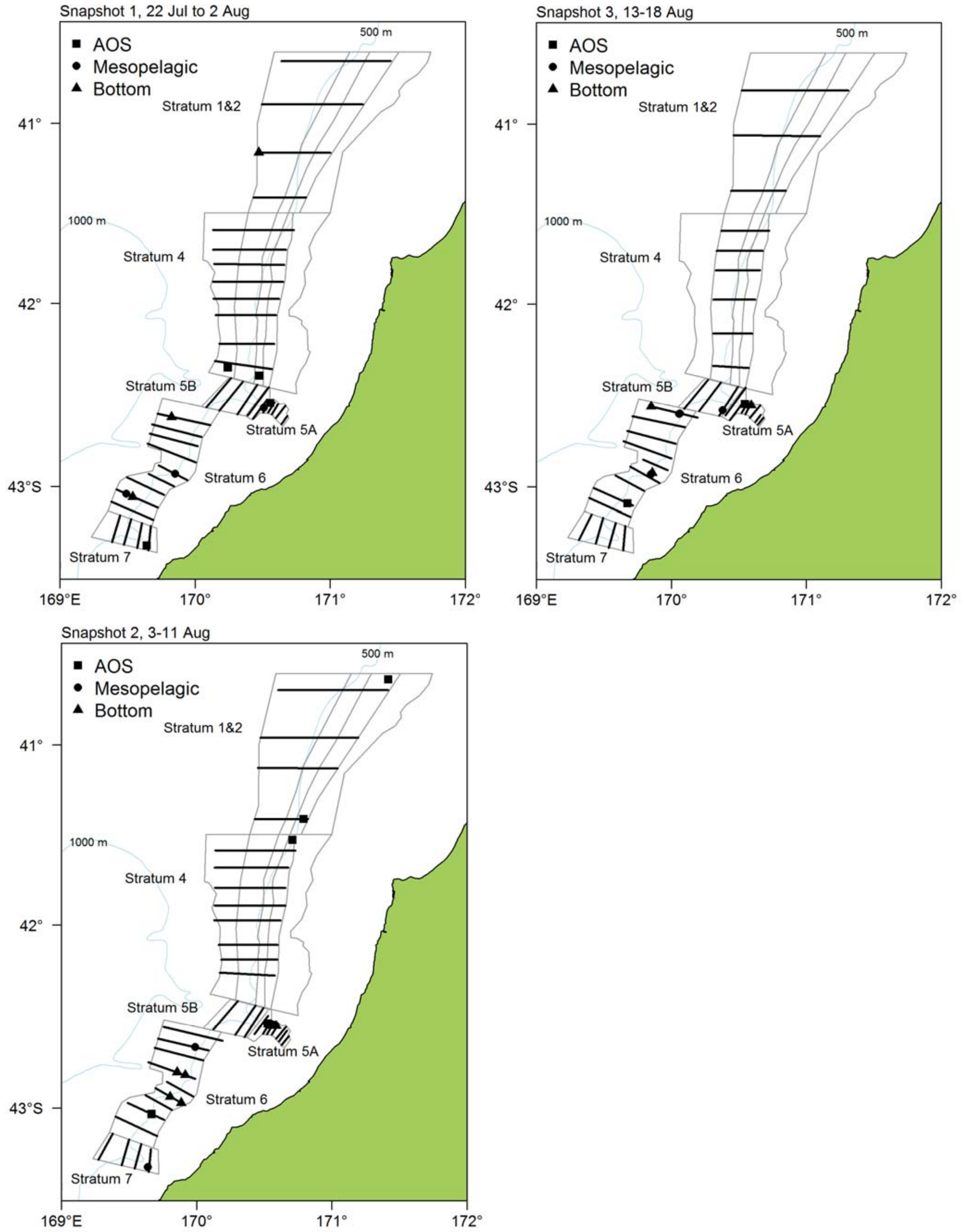


Figure 2: Location of acoustic transects and mark identification tows during snapshots 1–3.

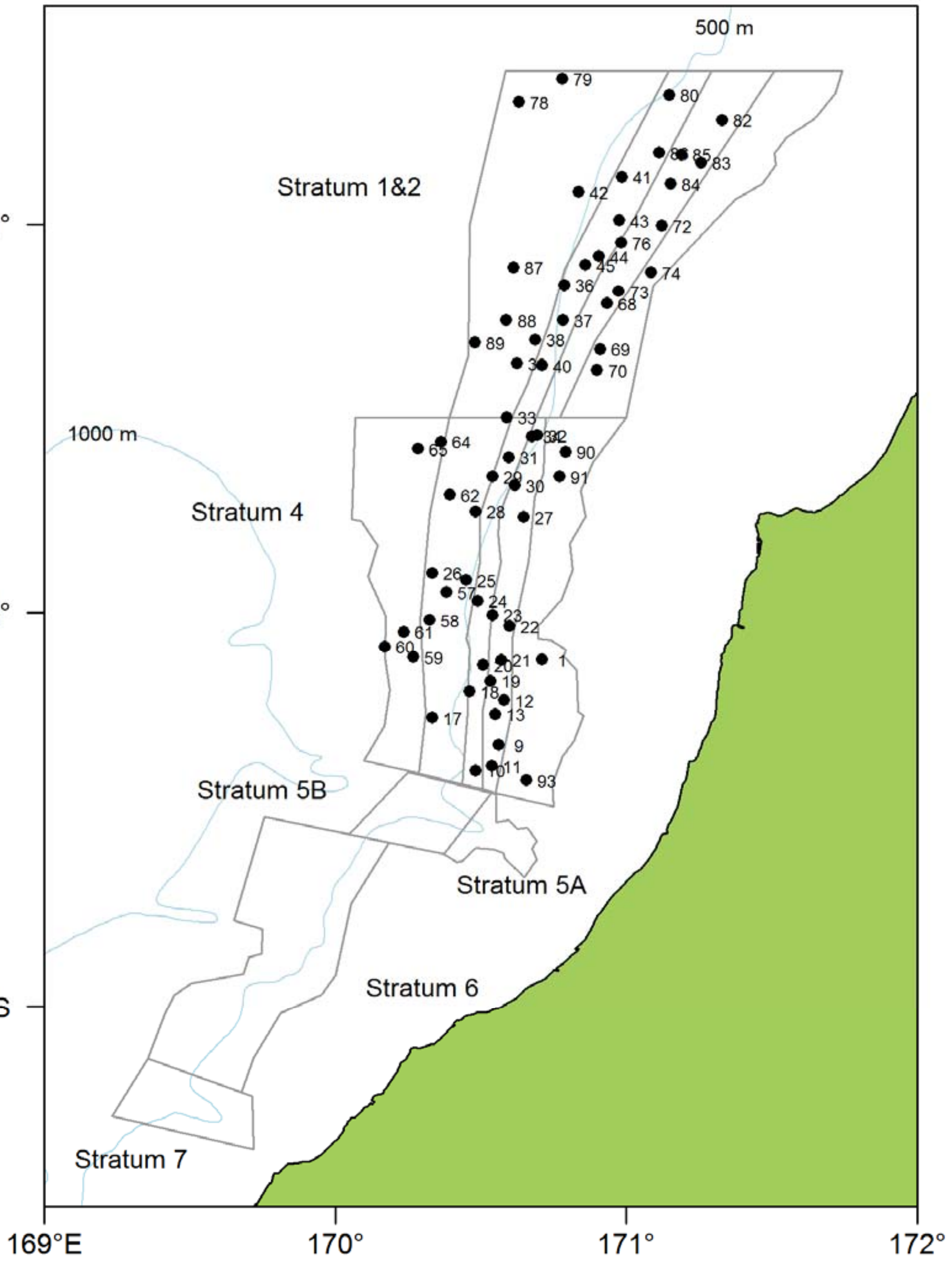


Figure 3: Trawl tow positions for the random trawl survey of the WCSI. Labels show station numbers. Station details are given in Appendix 5.

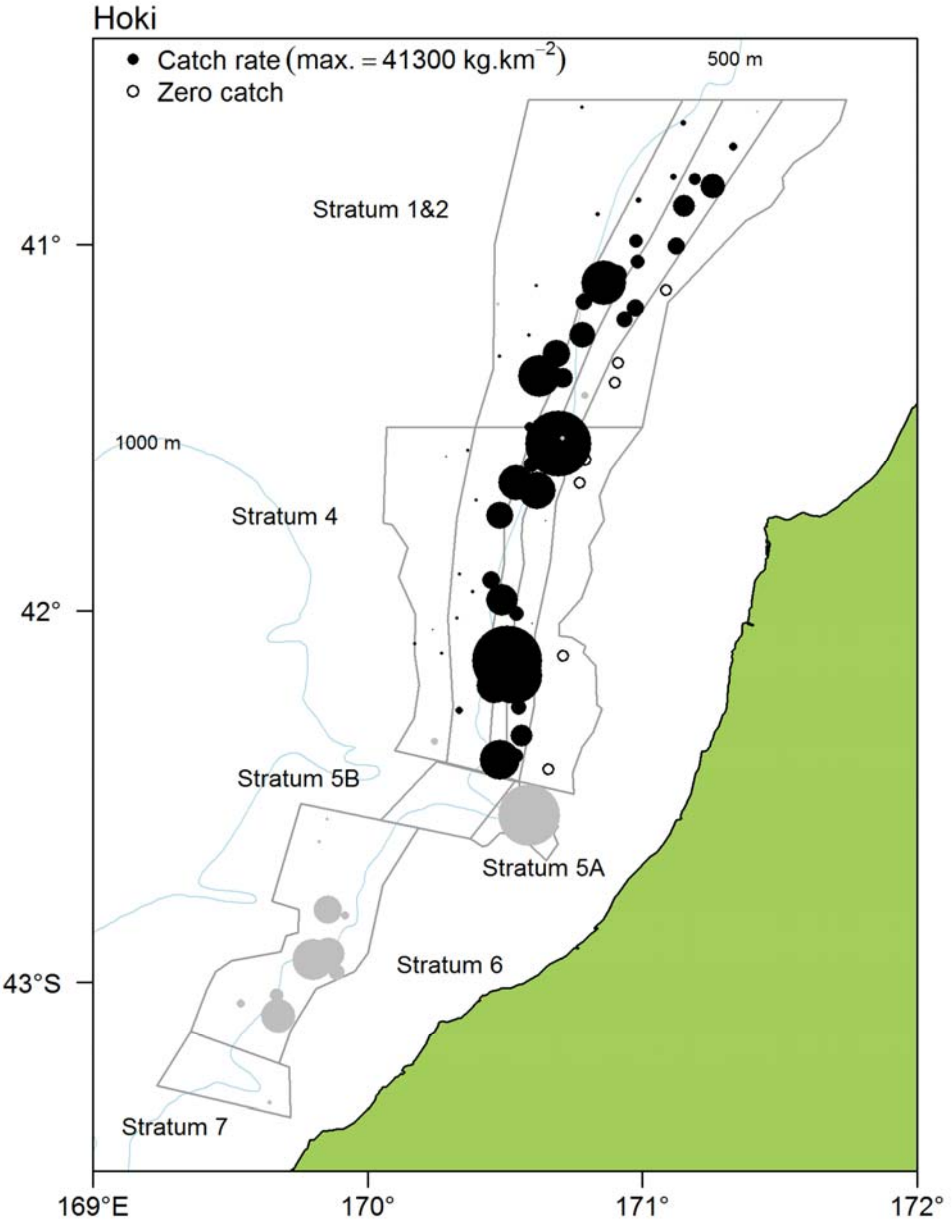


Figure 4: Catch rates (kg km^{-2}) of hoki in bottom tows carried out during the random trawl survey (black) and for mark identification (grey) during the 2012 WCSI survey. Circle area is proportional to catch rate.

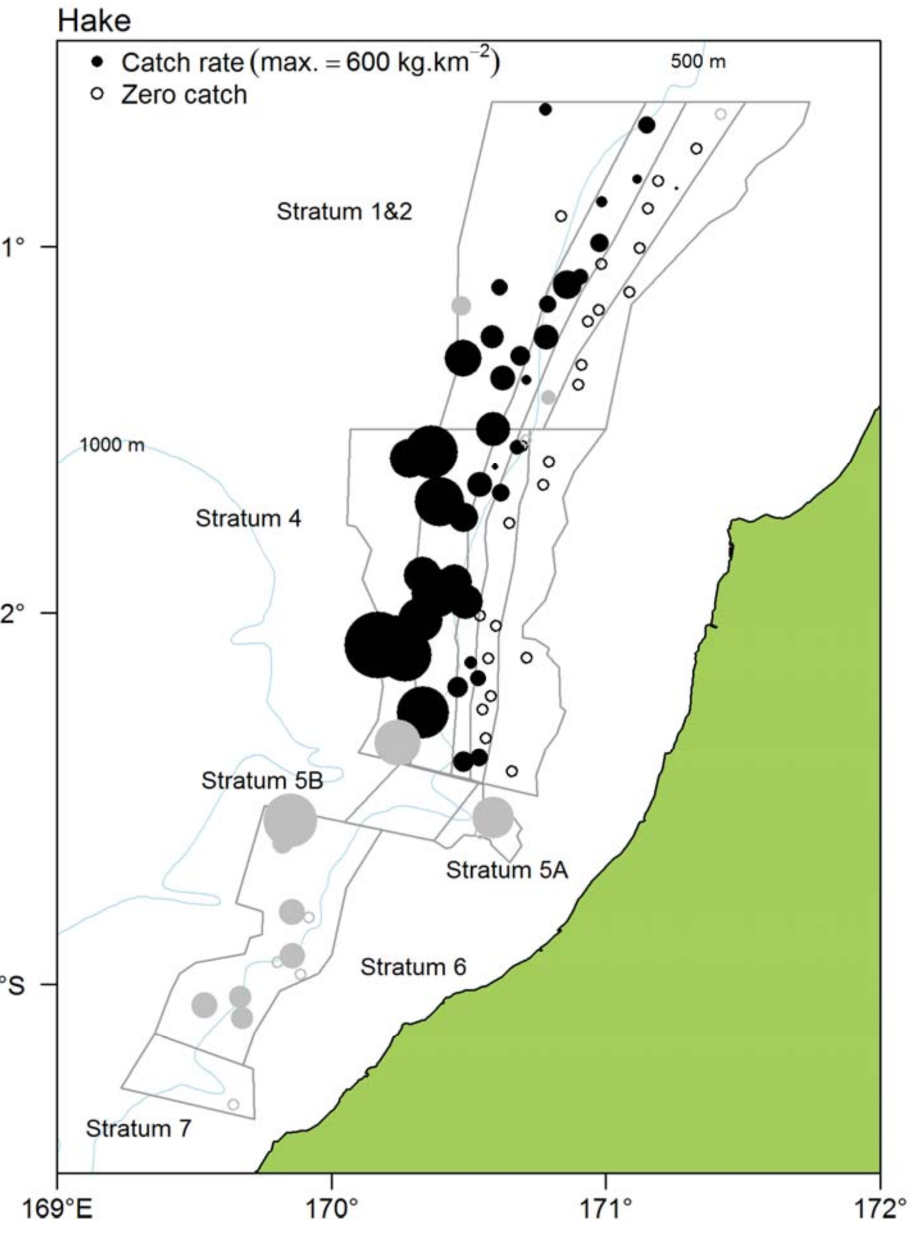


Figure 5: Catch rates (kg km^{-2}) of hake in all bottom tows carried out during the random trawl survey (black) and for mark identification (grey) during the 2012 WCSI survey. Circle area is proportional to catch rate.

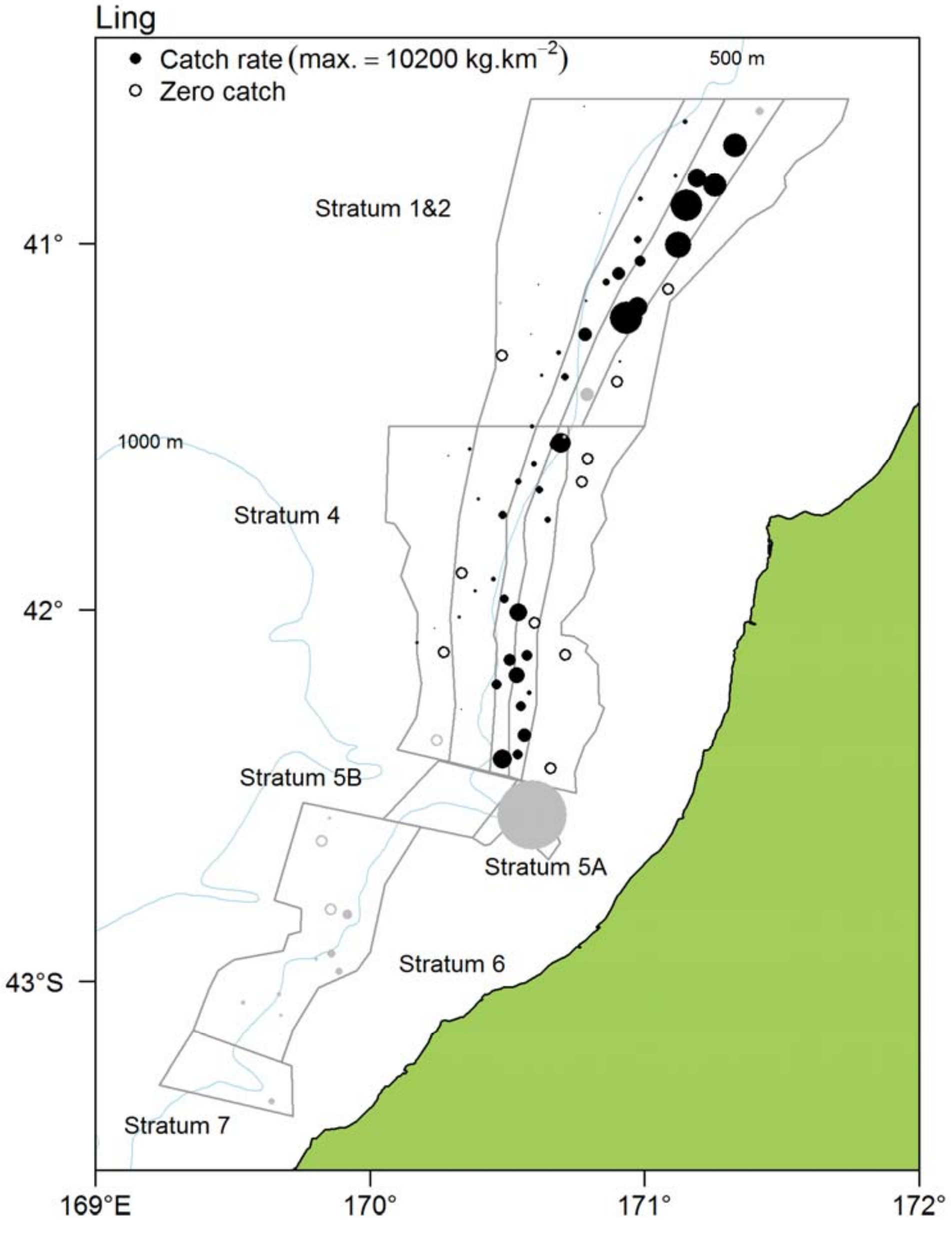


Figure 6: Catch rates (kg km^{-2}) of ling in all bottom tows carried out during the random trawl survey (black) and for mark identification (grey) during the 2012 WCSI survey. Circle area is proportional to catch rate.

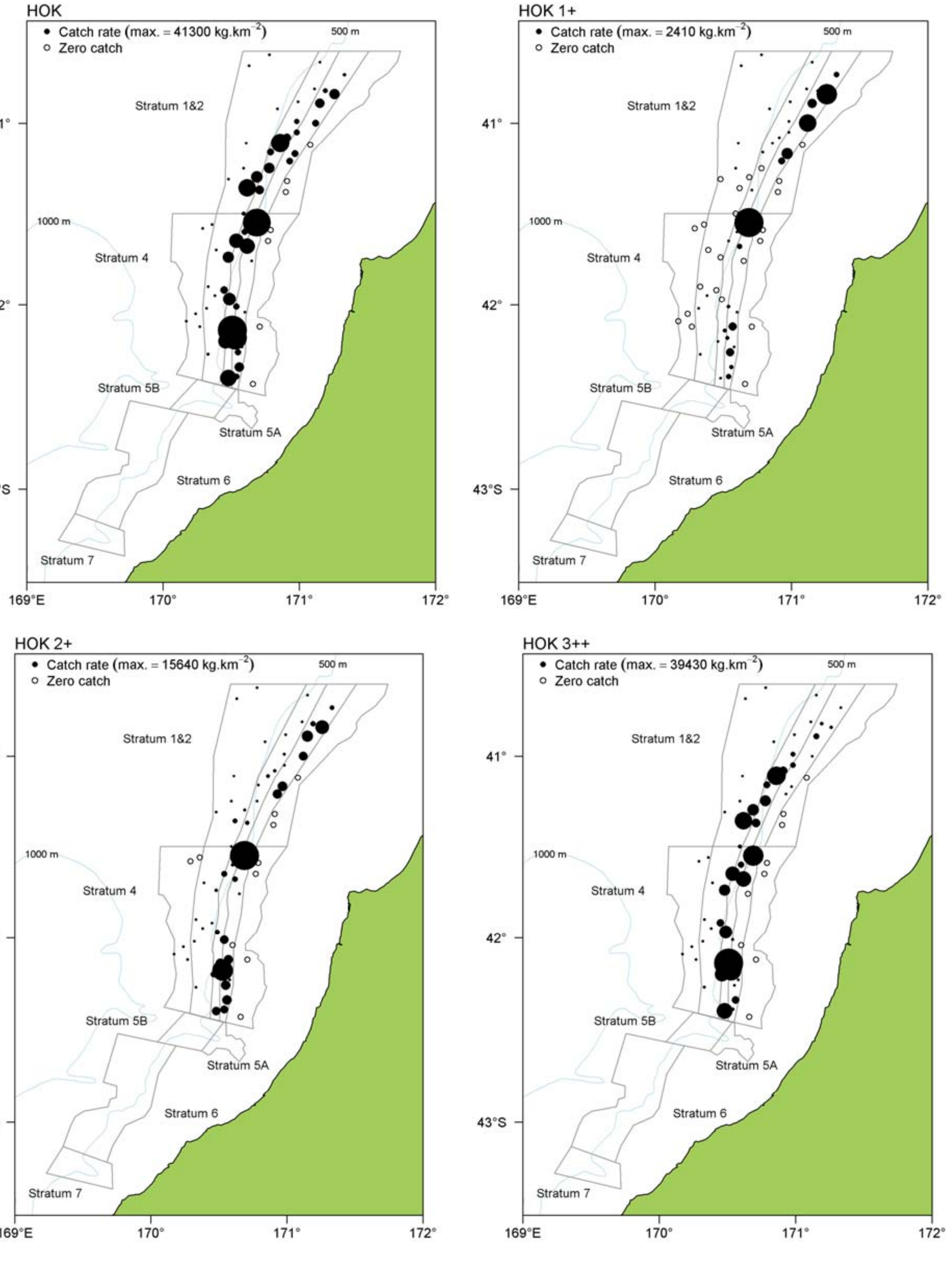


Figure 7: Distribution and catch rates of all, 1+ (less than 48 cm), 2+ (48–62 cm), and 3++ (more than 62 cm) hoki (HOK) on the WCSI 2012 trawl survey. Circle area is proportional to catch rate.

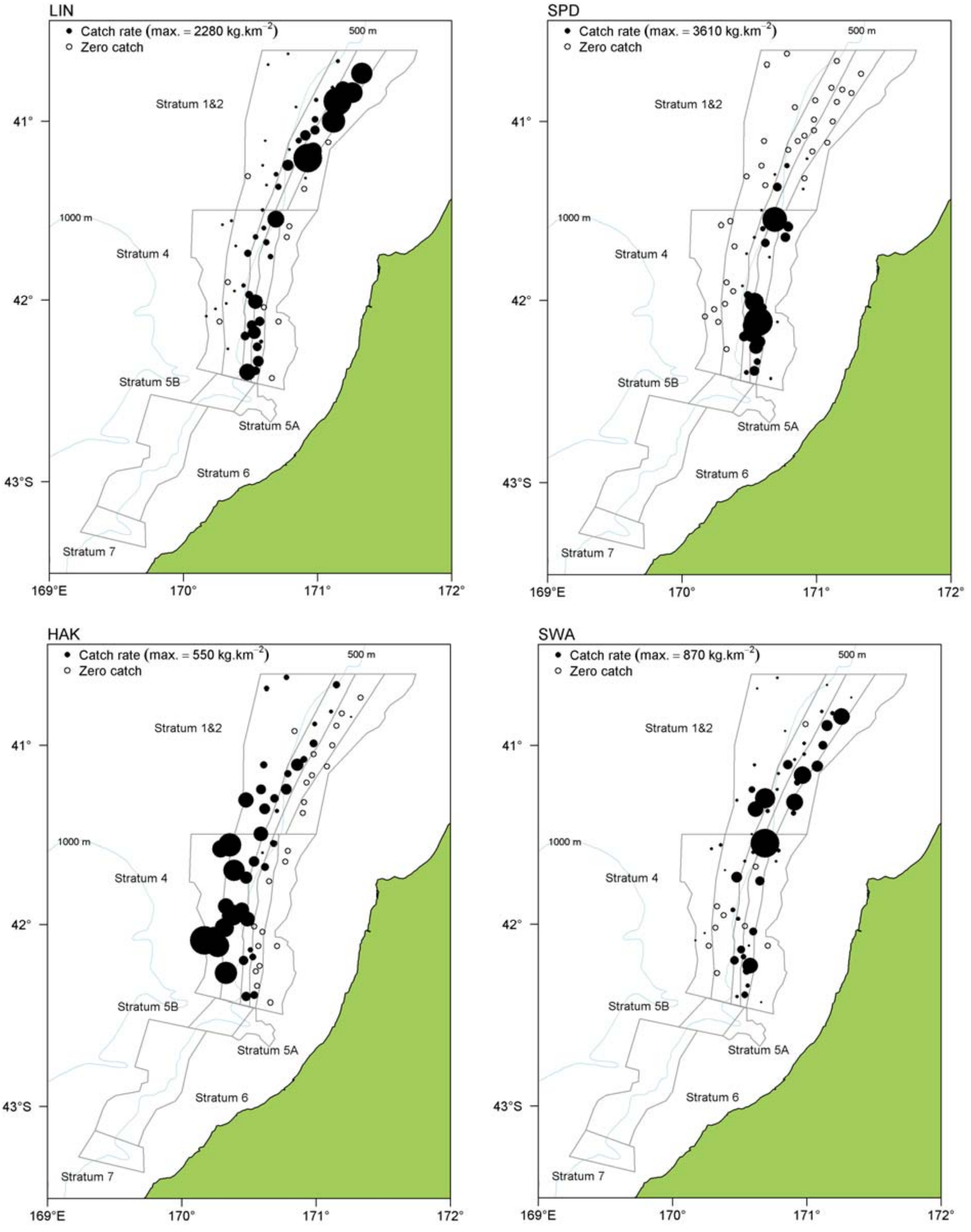


Figure 8: Distribution and catch rates of ling (LIN), spiny dogfish (SPD), hake (HAK), and silver warehou (SWA) on the WCSI 2012 trawl survey. Circle area is proportional to catch rate.

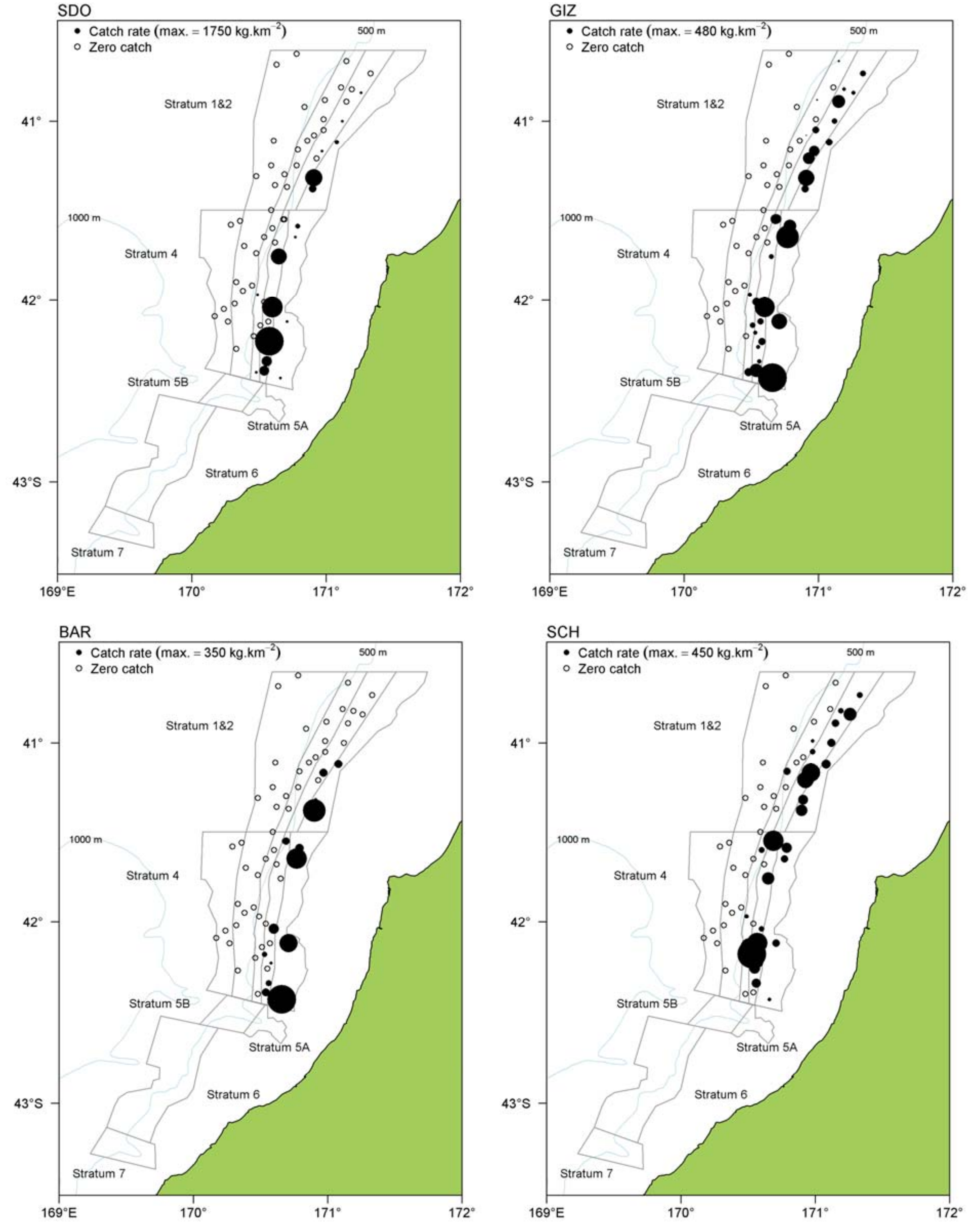


Figure 8 continued: Distribution and catch rates of silver dory (SDO), giant stargazer (GIZ), barracouta (BAR), and school shark (SCH) on the WCSI 2012 trawl survey. Circle area is proportional to catch rate.

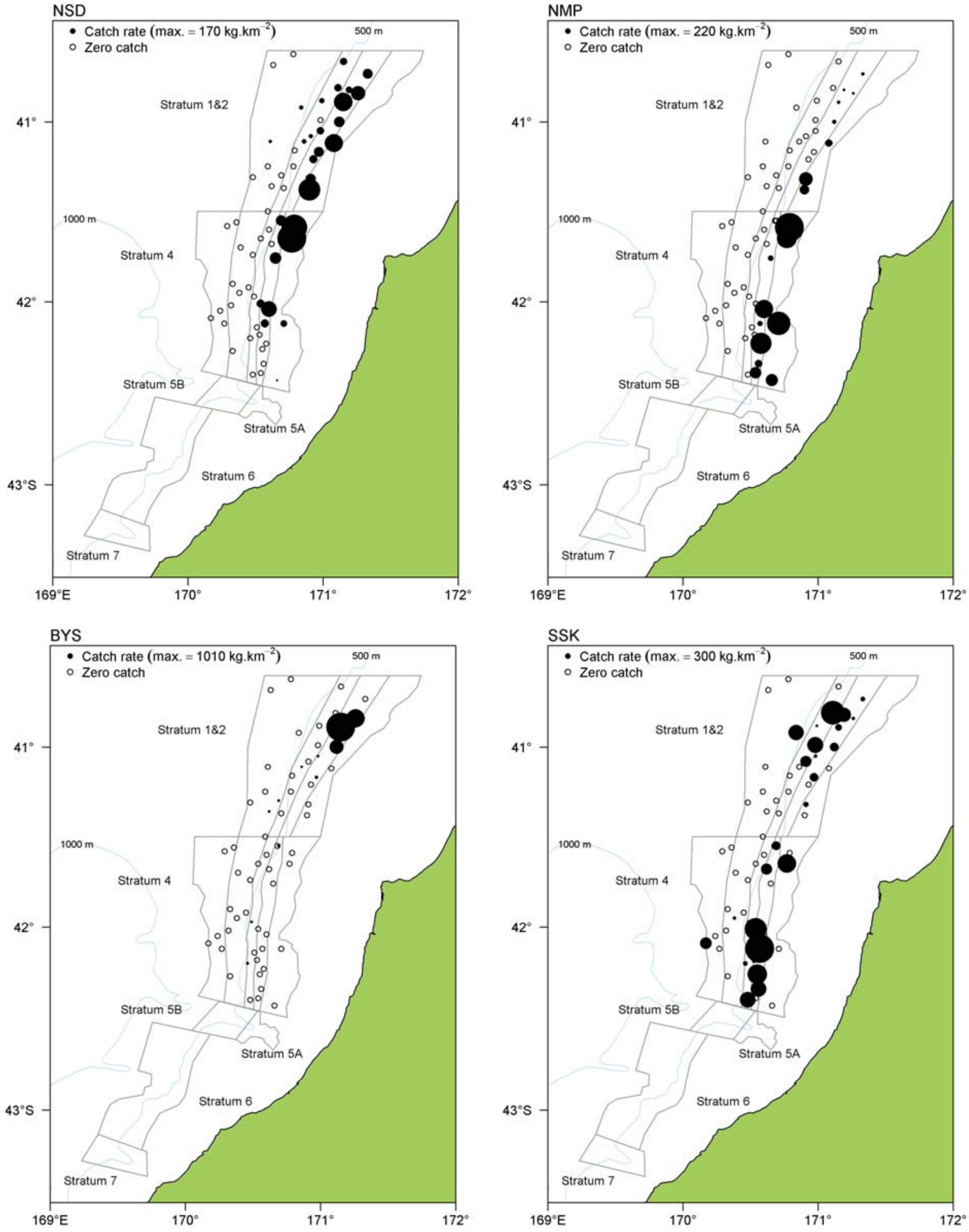


Figure 8 continued: Distribution and catch rates of northern spiny dogfish (NSD), tarakihi (NMP), alfonsino (BYS), and smooth skate (SSK) on the WCSI 2012 trawl survey. Circle area is proportional to catch rate.

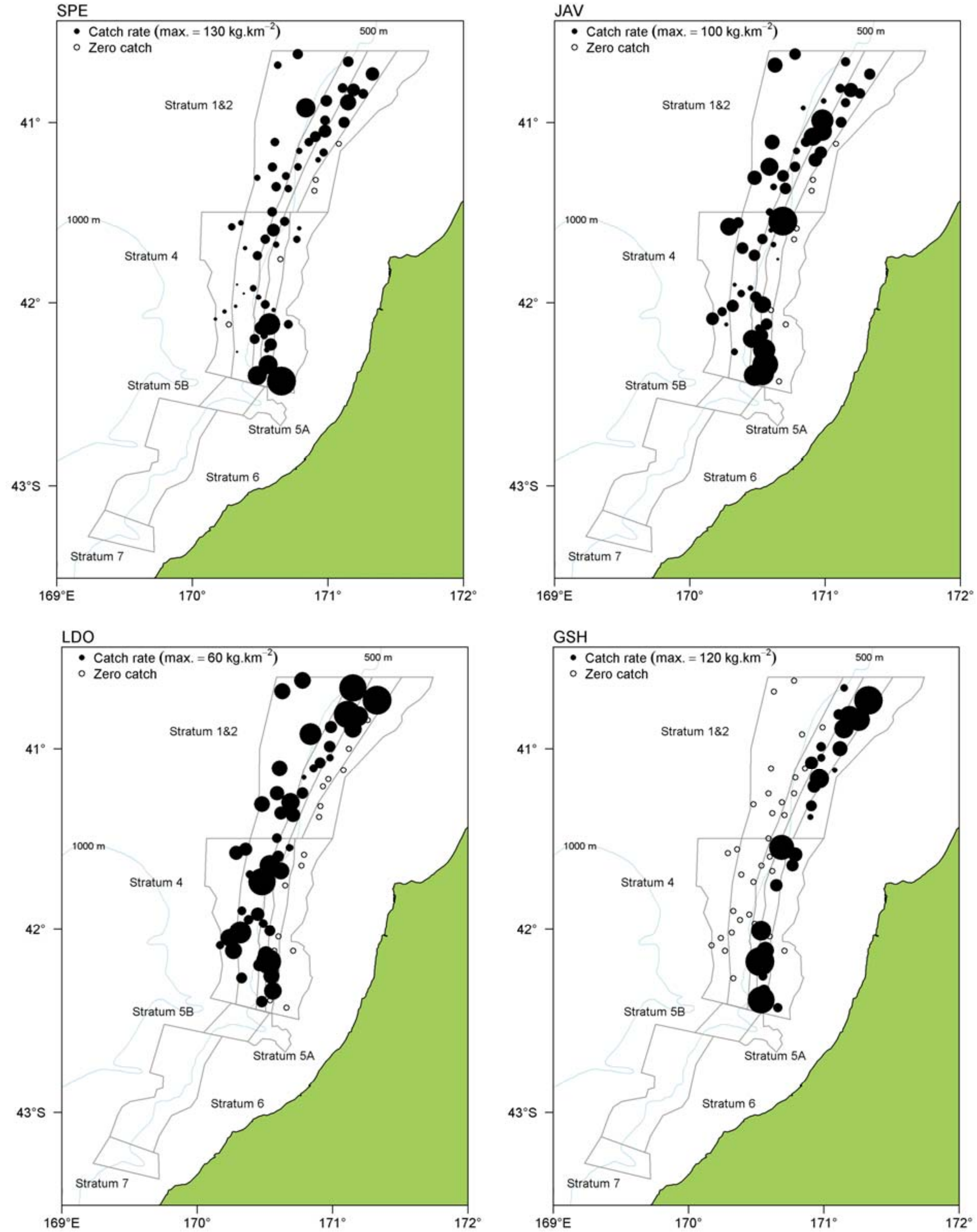
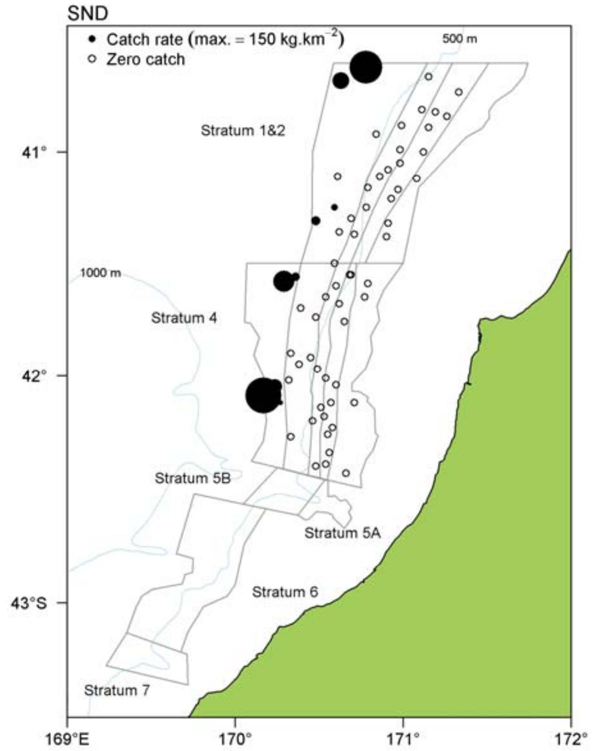
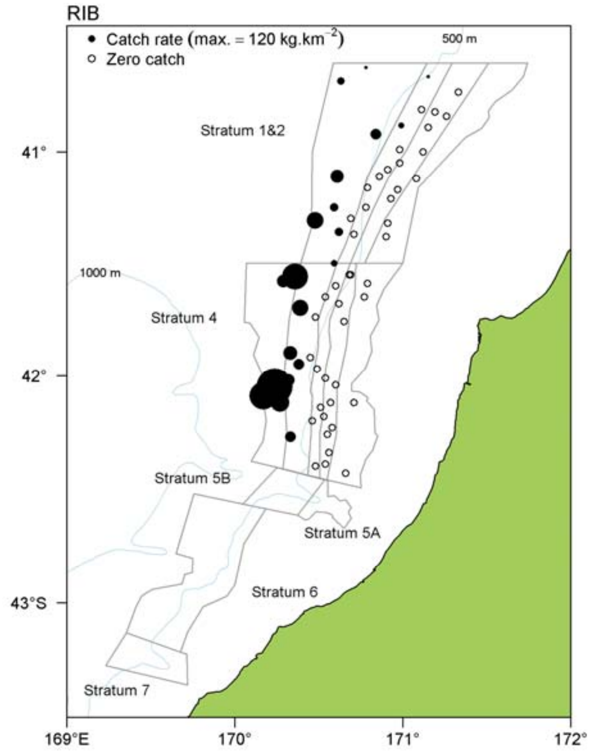


Figure 8 continued: Distribution and catch rates of sea perch (SPE), javelinfish (JAV), look down dory (LDO), and dark ghost shark (GSH) on the WCSI 2012 trawl survey. Circle area is proportional to catch rate.





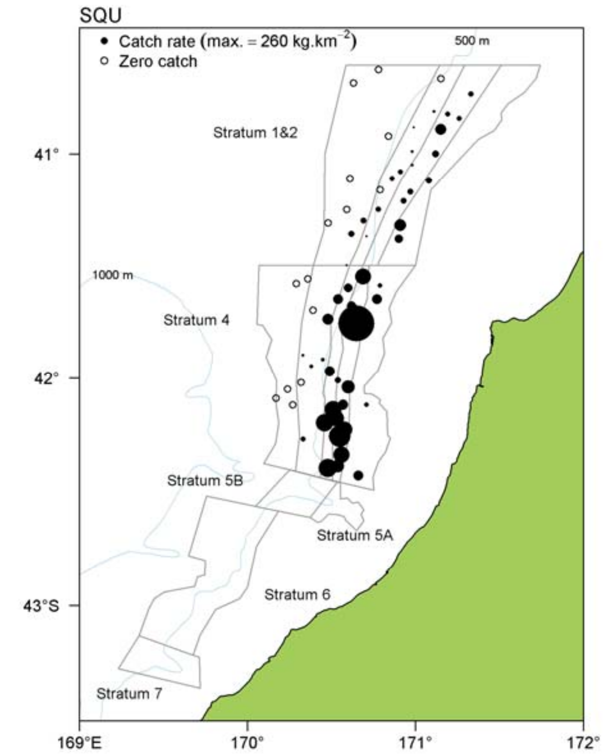


Figure 8 continued: Distribution and catch rates of shovelnosed dogfish (SND), ribaldo (RIB), and arrow squid (SQU) on the WCSI 2012 trawl survey. Circle area is proportional to catch rate.

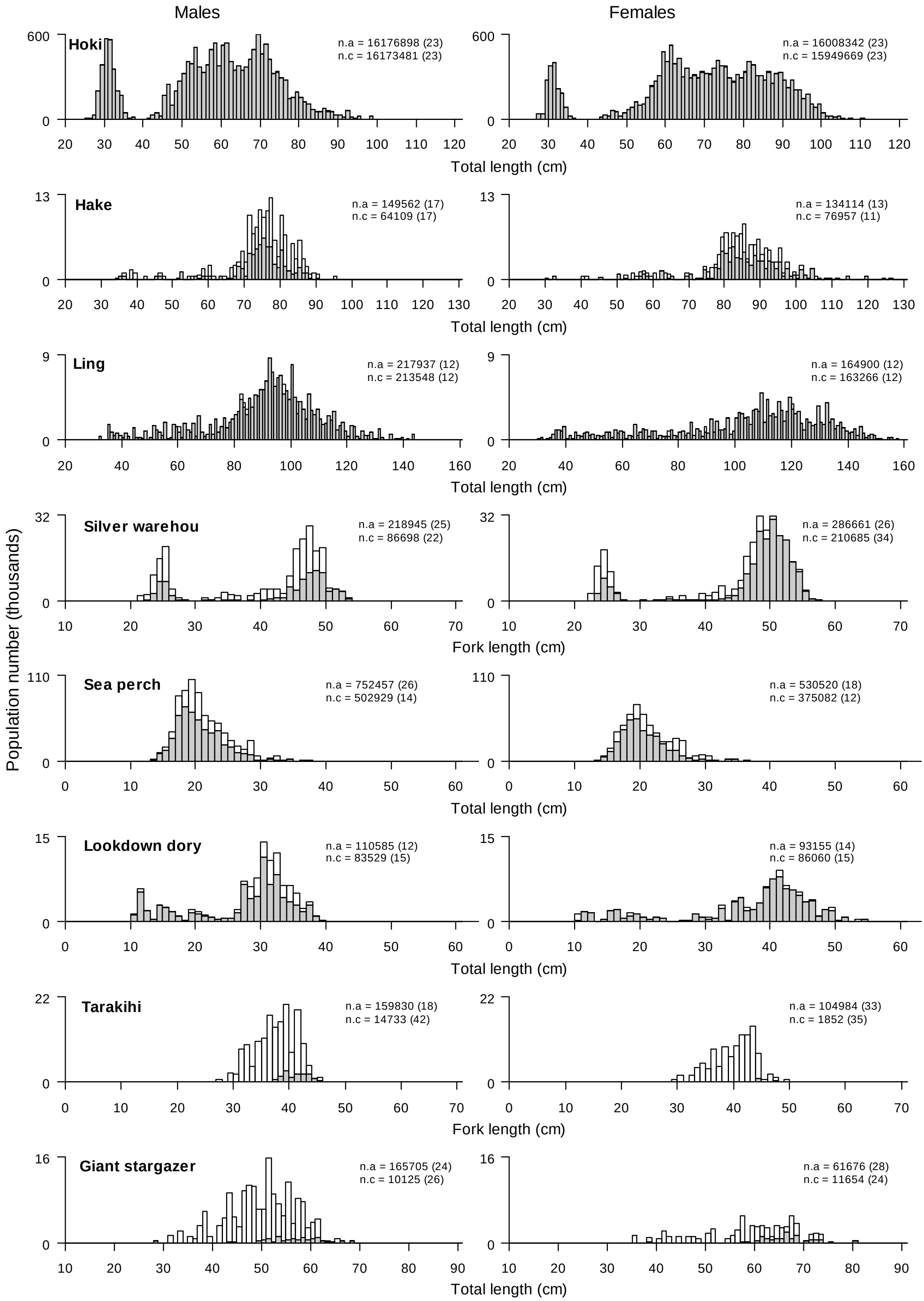


Figure 9: Length frequency distributions by sex of key species for core (grey) and all (white) strata in the WCSI trawl survey. n.a, estimated scaled total number of fish for all strata; n.c, estimated scaled total number of fish for core strata; and CV, the coefficient of variation (in brackets).

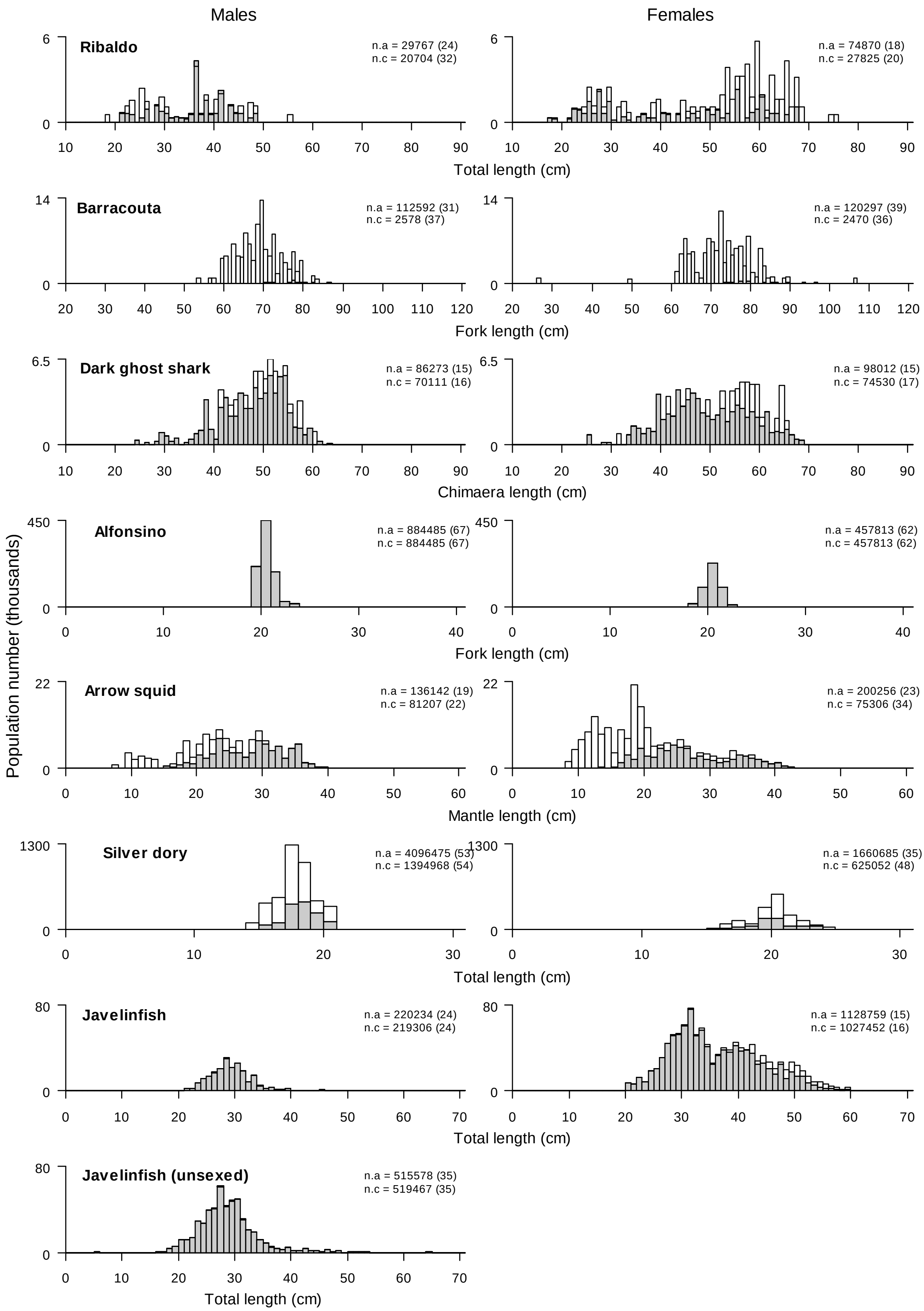


Figure 9 continued: Length frequency distributions by sex of key species for core (grey) and all (white) strata in the WCSI trawl survey. n.a, estimated scaled total number of fish for all strata; n.c, estimated scaled total number of fish for core strata; and CV, the coefficient of variation (in brackets).

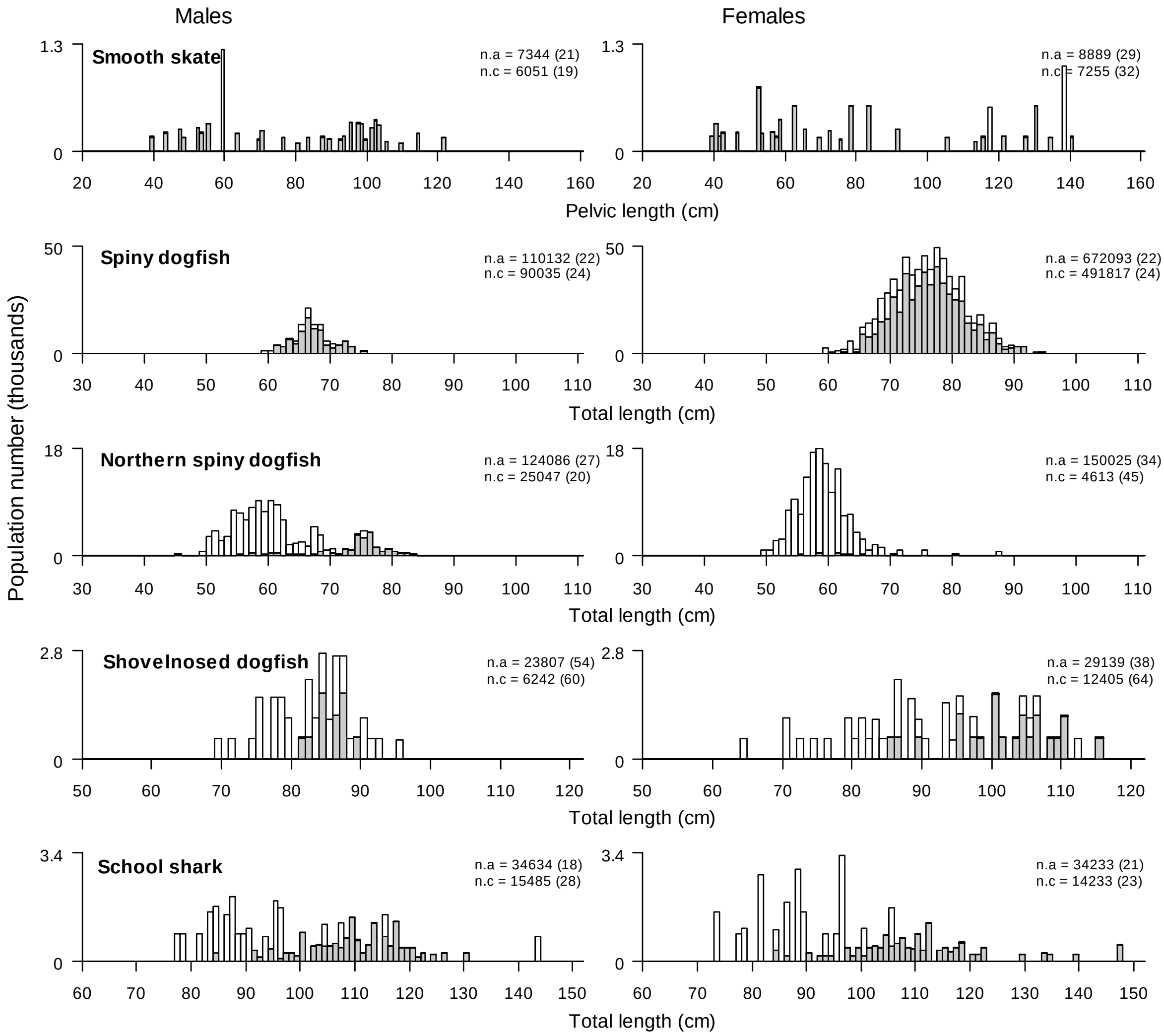


Figure 9 continued: Length frequency distributions by sex of key species for core (grey) and all (white) strata in the WCSI trawl survey. n.a, estimated scaled total number of fish for all strata; n.c, estimated scaled total number of fish for core strata; and CV, the coefficient of variation (in brackets).

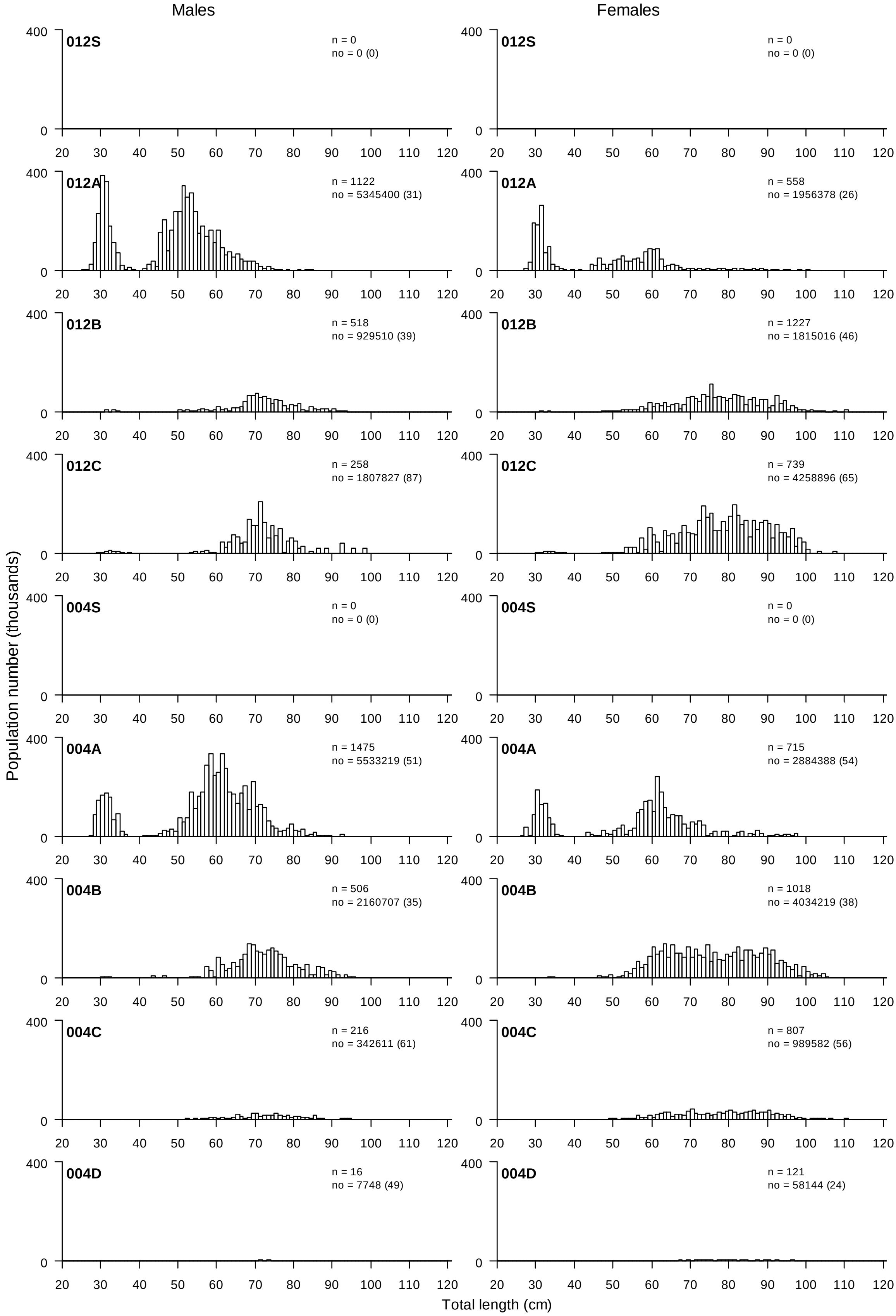


Figure 10: Length frequency distributions of hoki by strata in the WCSI trawl survey. n values are the number of males and females measured; no., scaled number of fish; CV is the coefficient of variation.

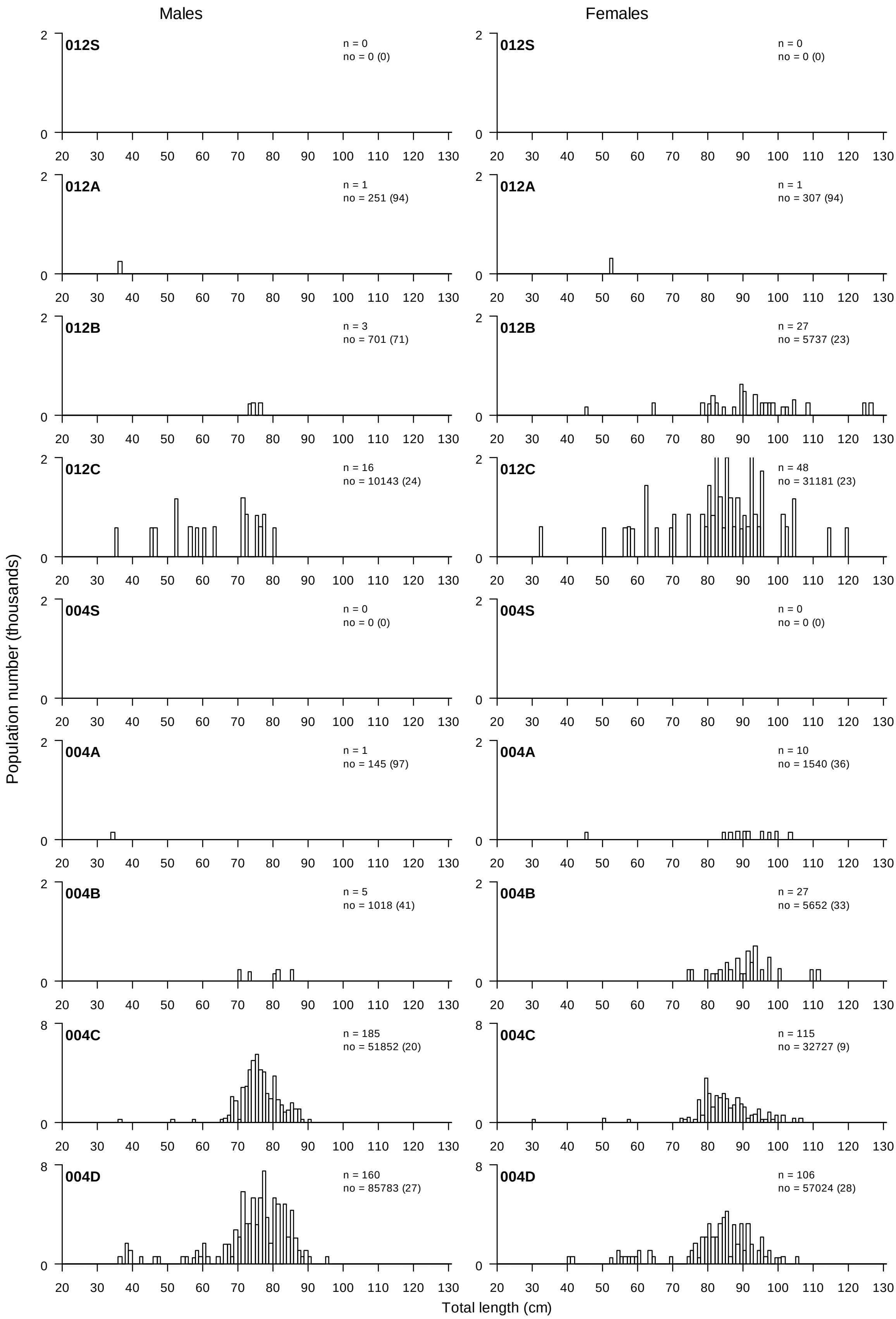


Figure 11: Length frequency distributions of hake by strata in the WCSI trawl survey. n values are the number of males and females measured; no., scaled number of fish; CV is the coefficient of variation.

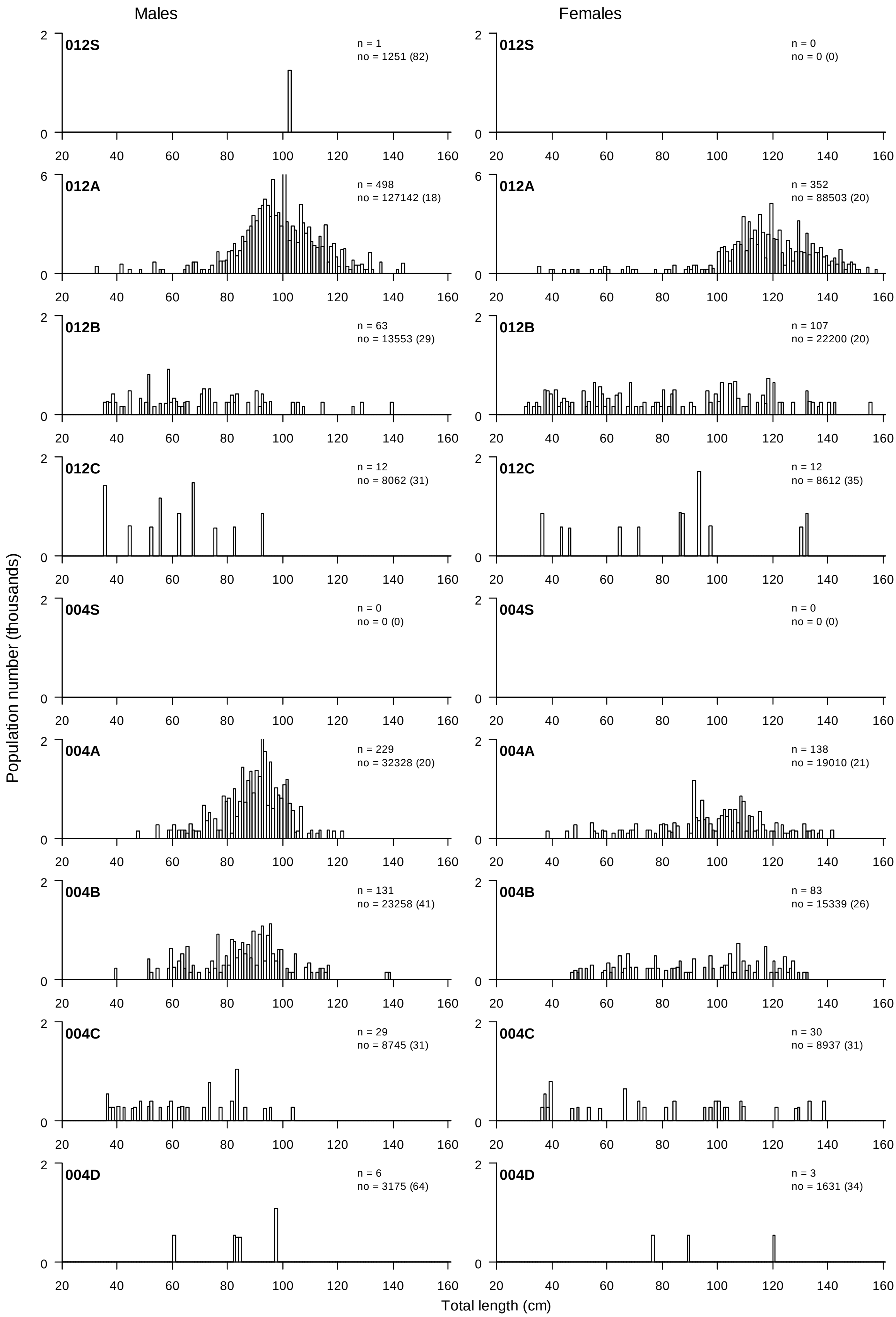


Figure 12: Length frequency distributions of ling by strata in the WCSI trawl survey. n, number of fish measured; no., population numbers of fish; CV is the coefficient of variation.

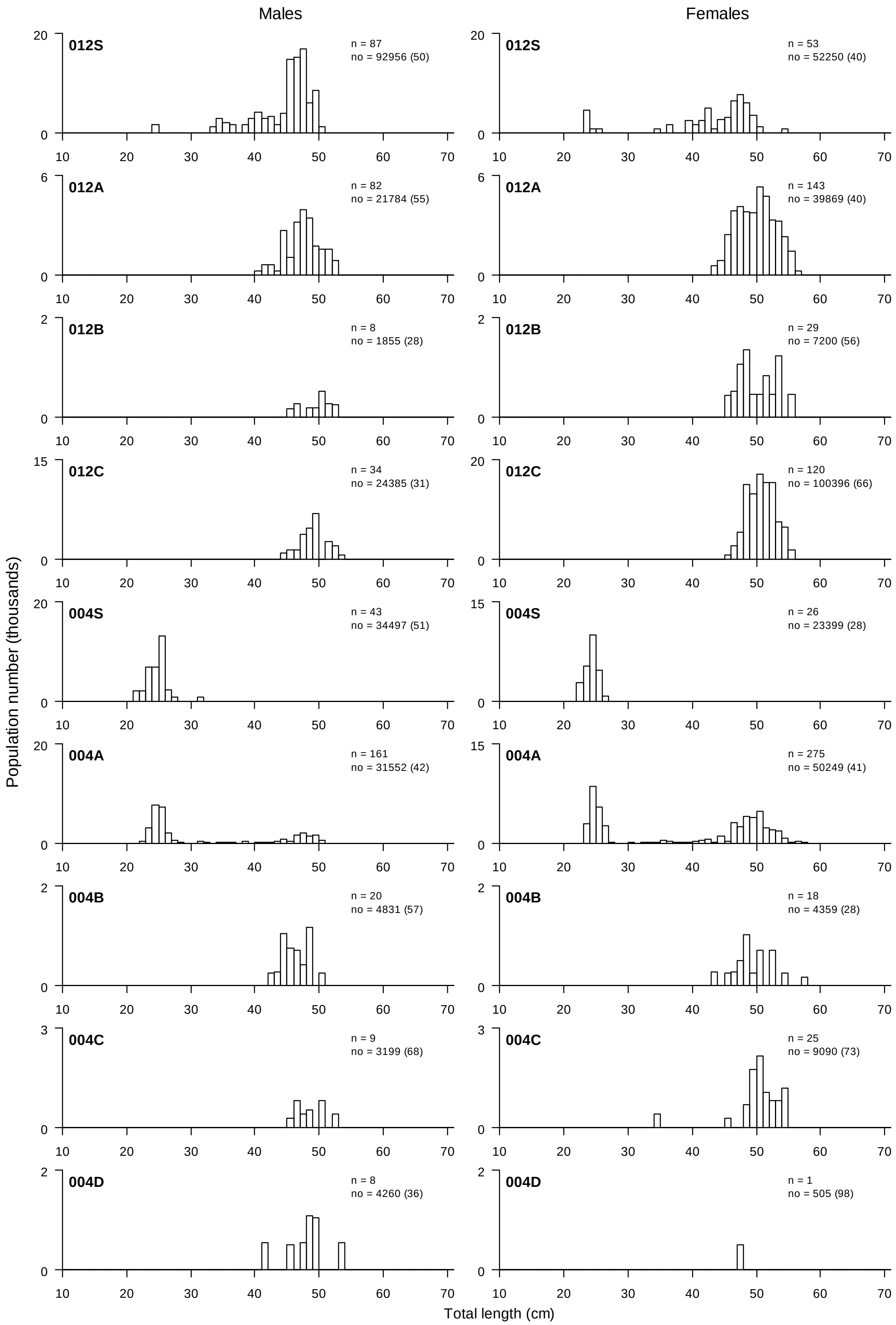


Figure 13: Length frequency distributions of silver warehou by strata in the WCSI trawl survey. n, number of fish measured; no., population numbers of fish; CV is the coefficient of variation.

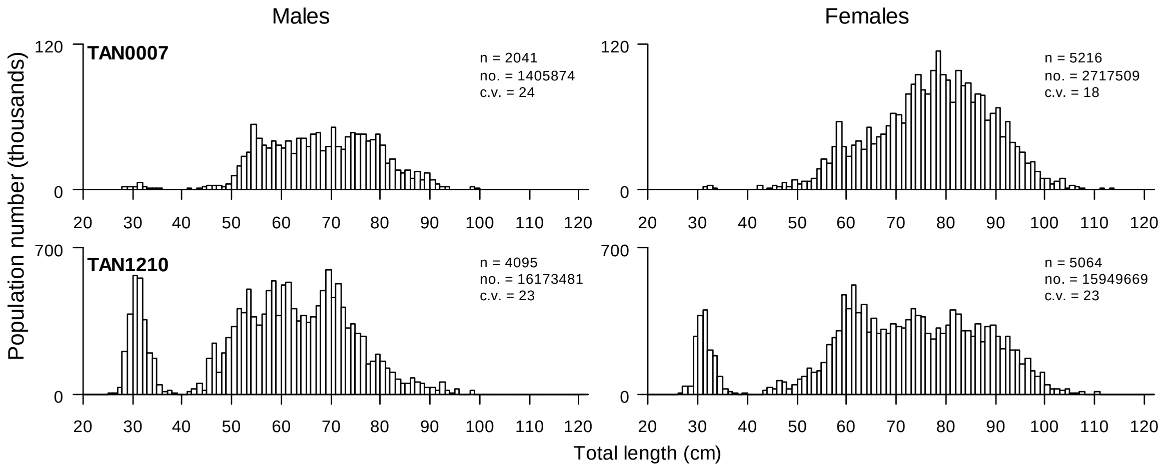


Figure 14: Scaled length frequency for male and female hoki in core strata from WCSI *Tangaroa* trawl surveys in 2000 (TAN0007) and 2012 (TAN1210). n, number of fish measured; no., population numbers of fish; CV, coefficients of variation.

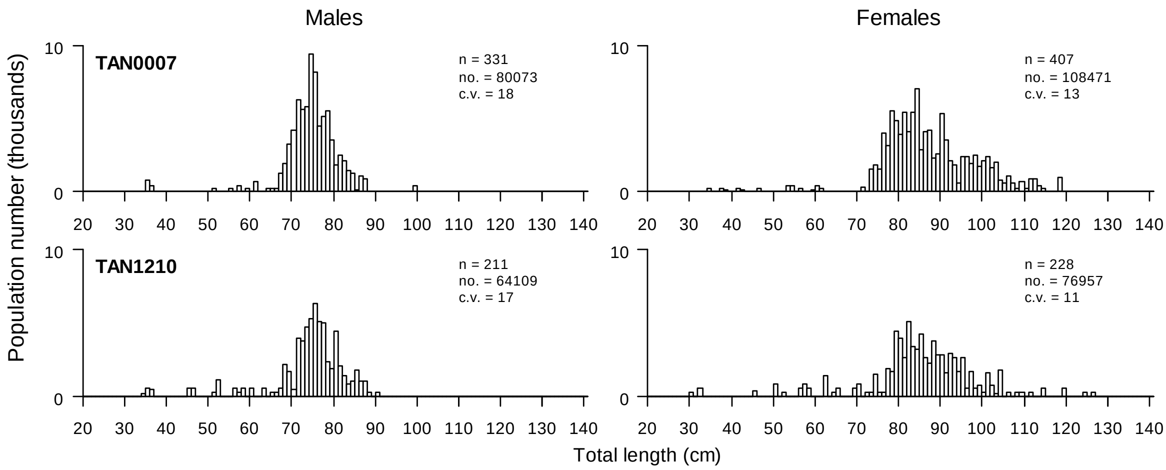


Figure 15: Scaled length frequency for male and female hake in core strata from WCSI *Tangaroa* trawl surveys in 2000 (TAN0007) and 2012 (TAN1210). n, number of fish measured; no., population numbers of fish; CV, coefficients of variation.

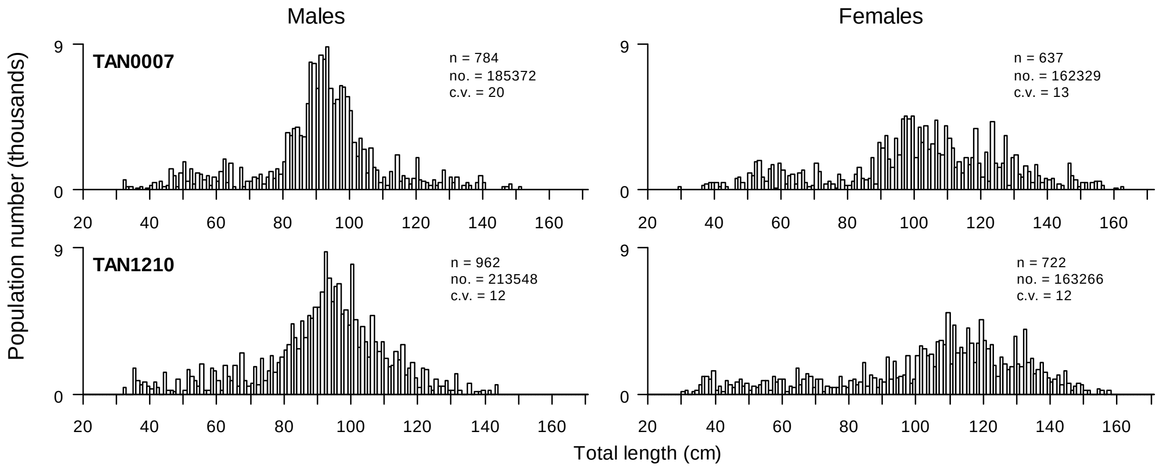


Figure 16: Scaled length frequency for male and female ling in core strata from WCSI *Tangaroa* trawl surveys in 2000 (TAN0007) and 2012 (TAN1210). n, number of fish measured; no., population numbers of fish; CV, coefficients of variation.

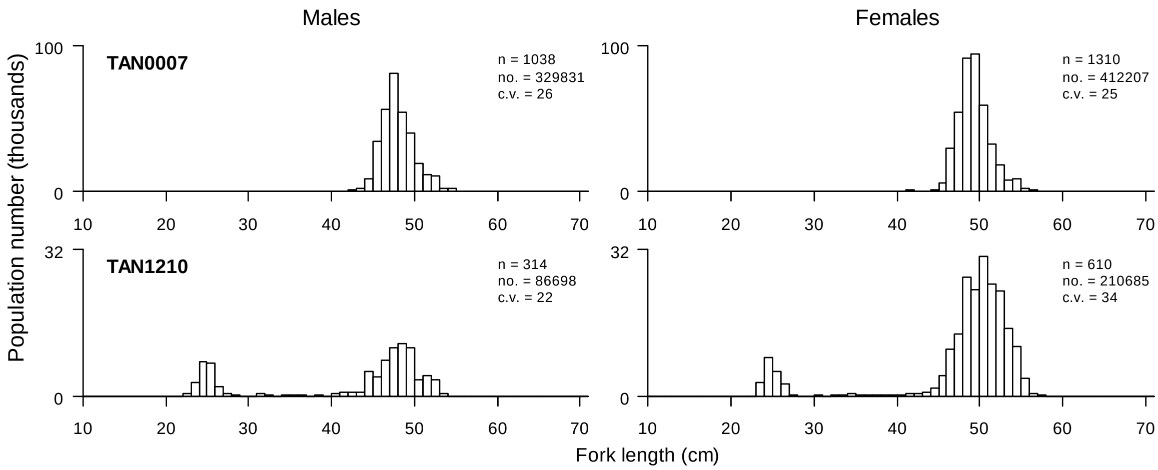


Figure 17: Scaled length frequency for male and female silver warehou in core strata from WCSI *Tangaroa* trawl surveys in 2000 (TAN0007) and 2012 (TAN1210). n, number of fish measured; no., population numbers of fish; CV, coefficients of variation.

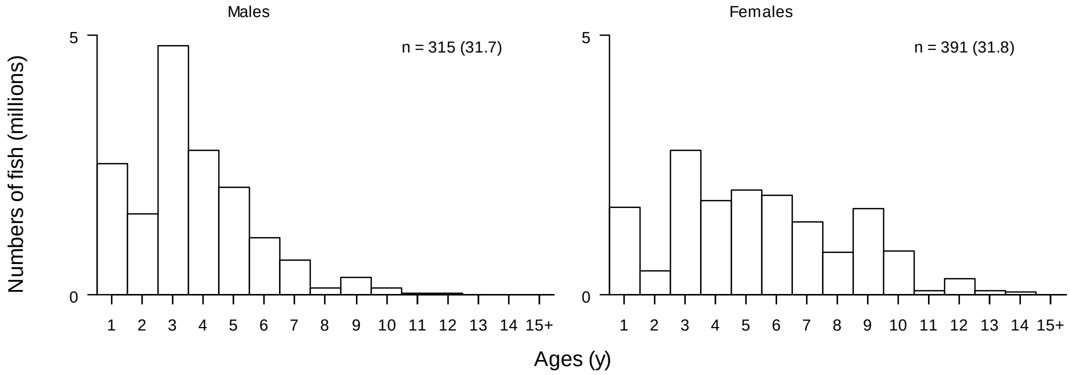


Figure 18: Scaled age frequency for hoki from core strata in the 2012 trawl survey. Number of fish aged (*n* values) are given with CVs in parentheses. Hoki were not aged for the 2000 survey.

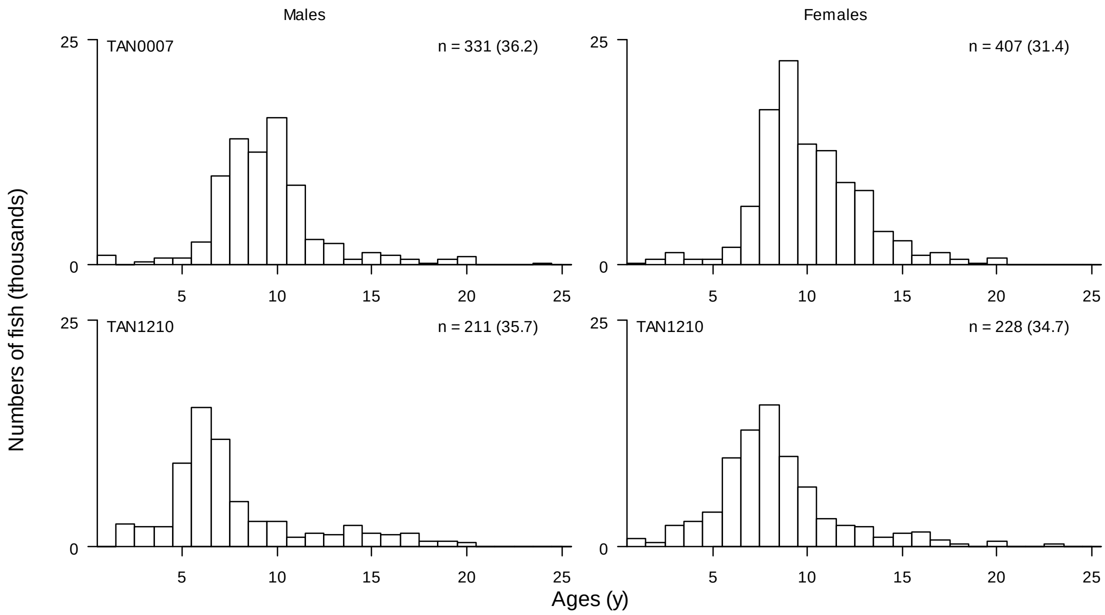


Figure 19: Scaled age frequency for hake in core strata from the WCSI *Tangaroa* trawl surveys in 2000 (TAN0007) and 2012 (TAN1210). Number of fish aged (*n* values) are given with CVs in parentheses.

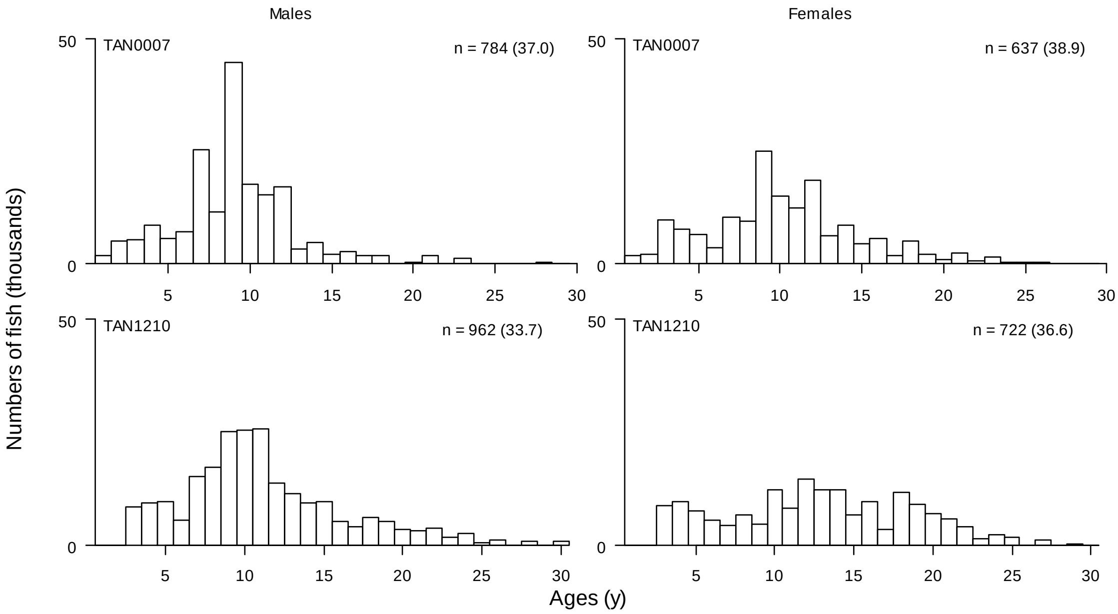


Figure 20: Scaled age frequency for ling in core strata from the WCSI *Tangaroa* trawl surveys in 2000 (TAN0007) and 2012 (TAN1210). Number of fish aged (*n* values) are given with CVs in parentheses.

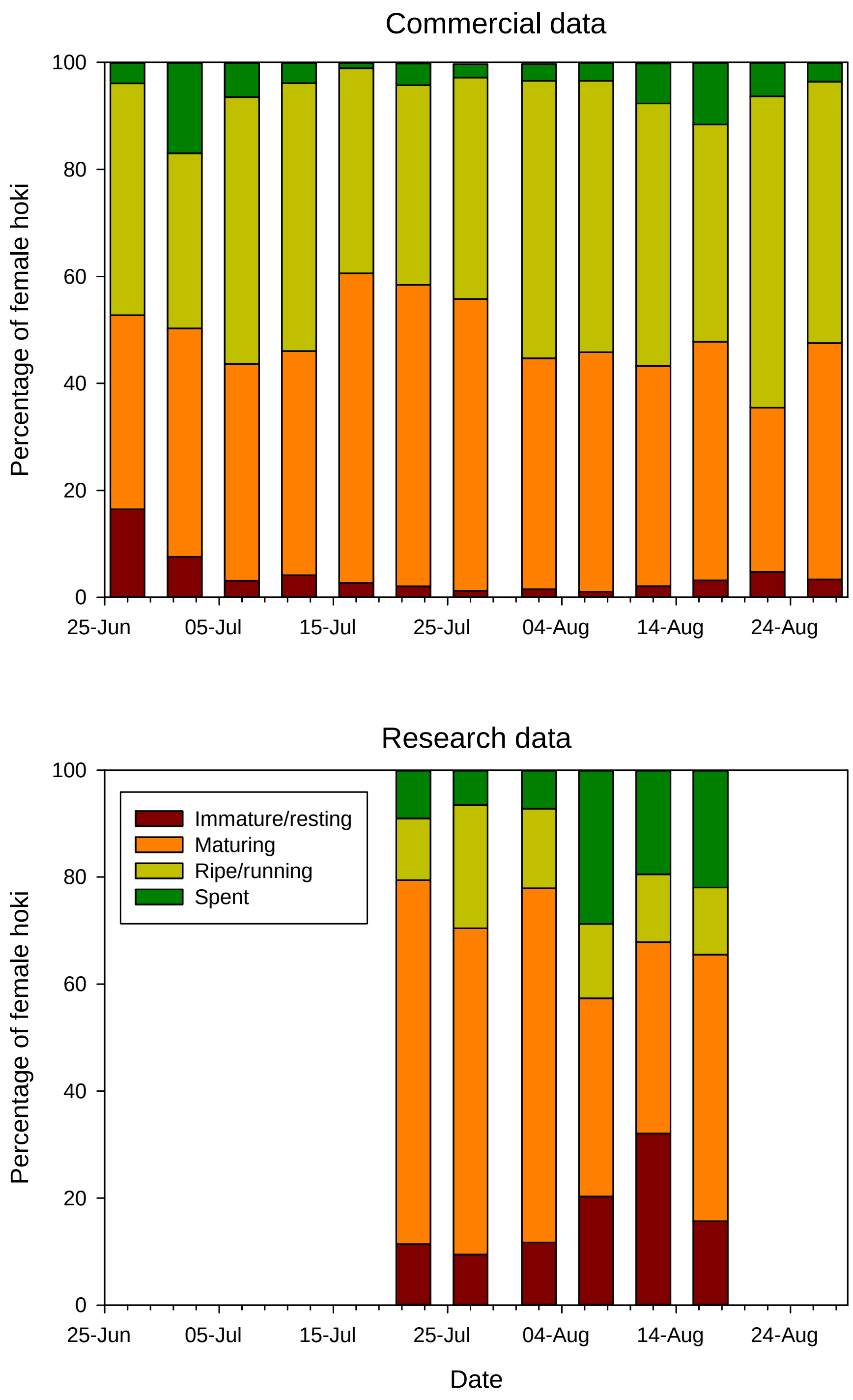


Figure 21: Proportion of female hoki in different maturity states from the commercial fishery and research tows on the WCSI in 2012. Data are summarised as means within 5-day periods. Immature/resting = observer stage 1, research stage 1 and 2; Maturing = observer stage 2, research stage 3 and 6; Ripe/running = observer stage 3 and 4, research stage 4 and 5; Spent = observer stage 5, research stage 7.

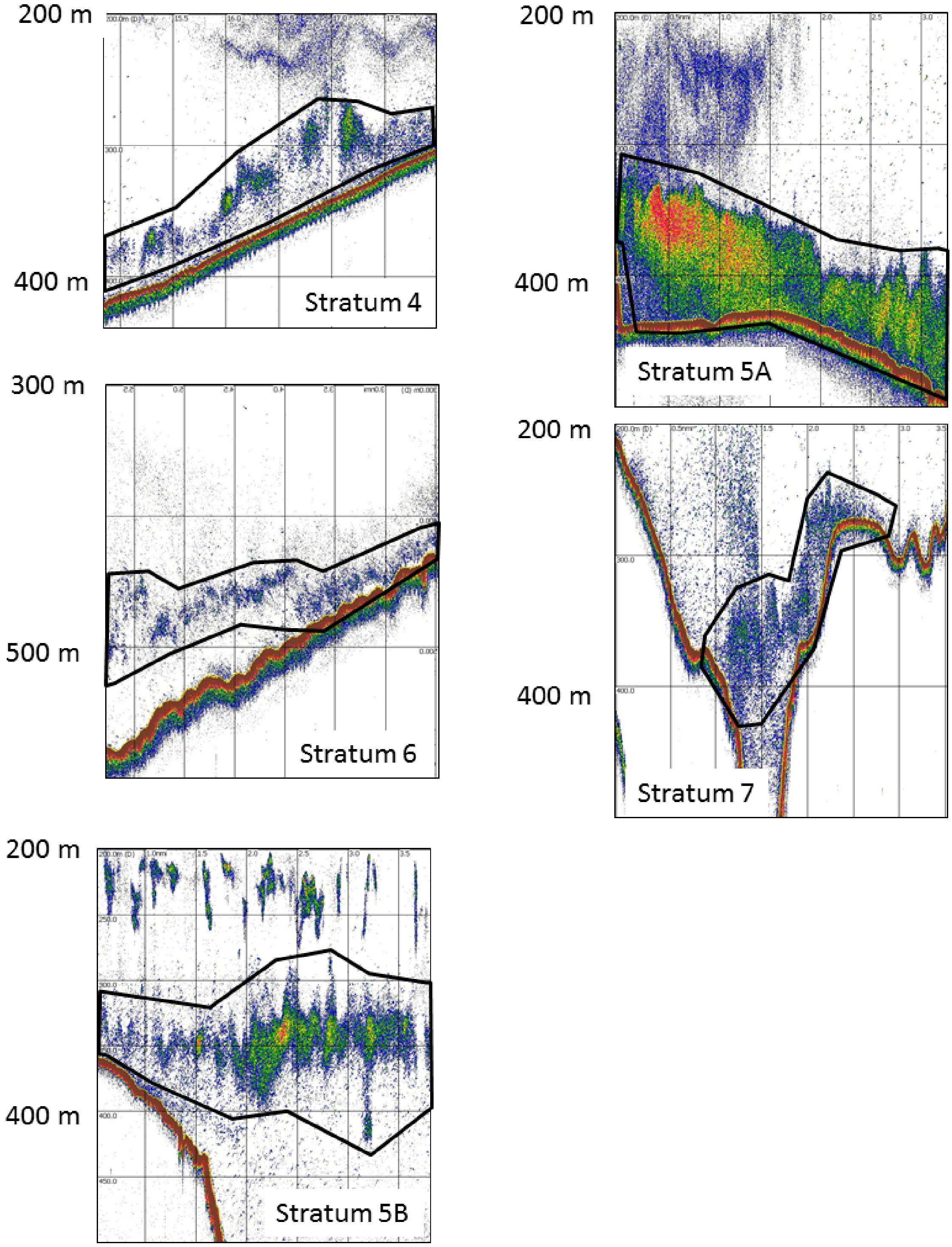


Figure 22: Examples of echograms showing hoki school marks by strata. Approximate boundaries of marks classified as hoki schools are shown by black boxes. Echograms are divided into cells of 50 m by 0.5 n. miles. Minimum echogram threshold is -70 dB.

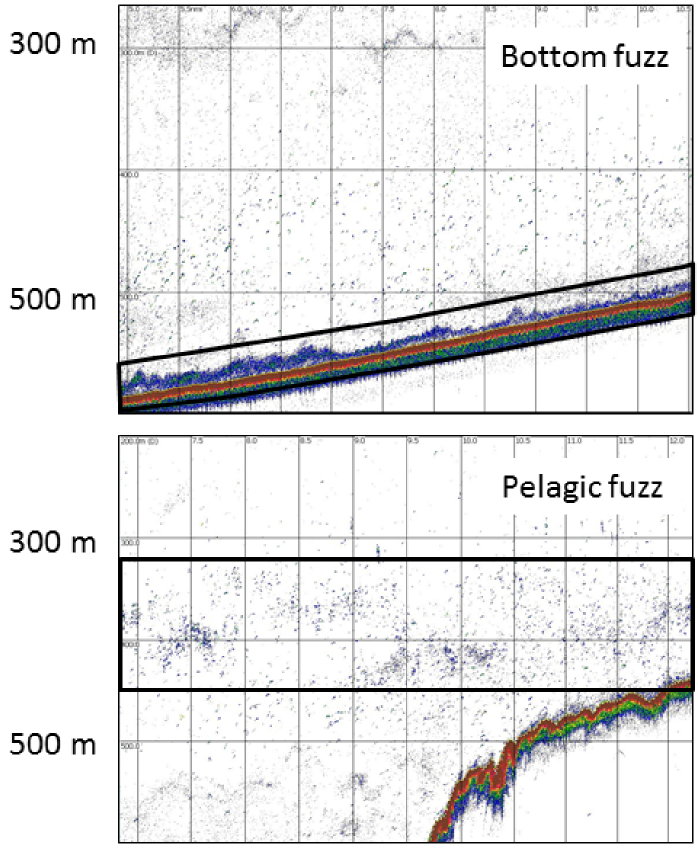


Figure 23: Examples of echograms showing hoki fuzz marks. Approximate boundaries of marks are shown by black boxes. Upper echogram is from stratum 1&2. Lower echogram is from stratum 5B. Echograms are divided into cells of 50 m by 0.5 n. miles. Minimum echogram threshold is -70 dB.

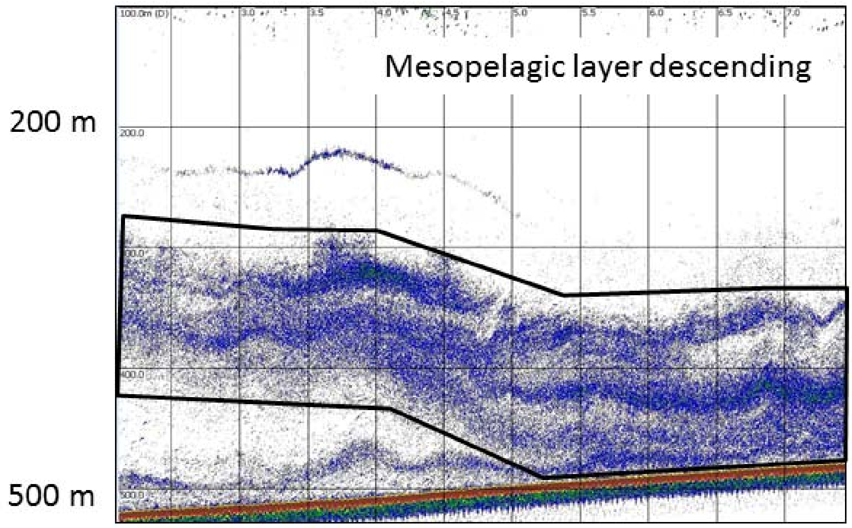


Figure 24: Examples of an echogram from stratum 1&2 showing mesopelagic layers descending at dawn. The approximate boundariy of the mark is shown by the black box. Echogram is divided into cells of 50 m by 0.5 n. miles. Minimum echogram threshold is -70 dB.

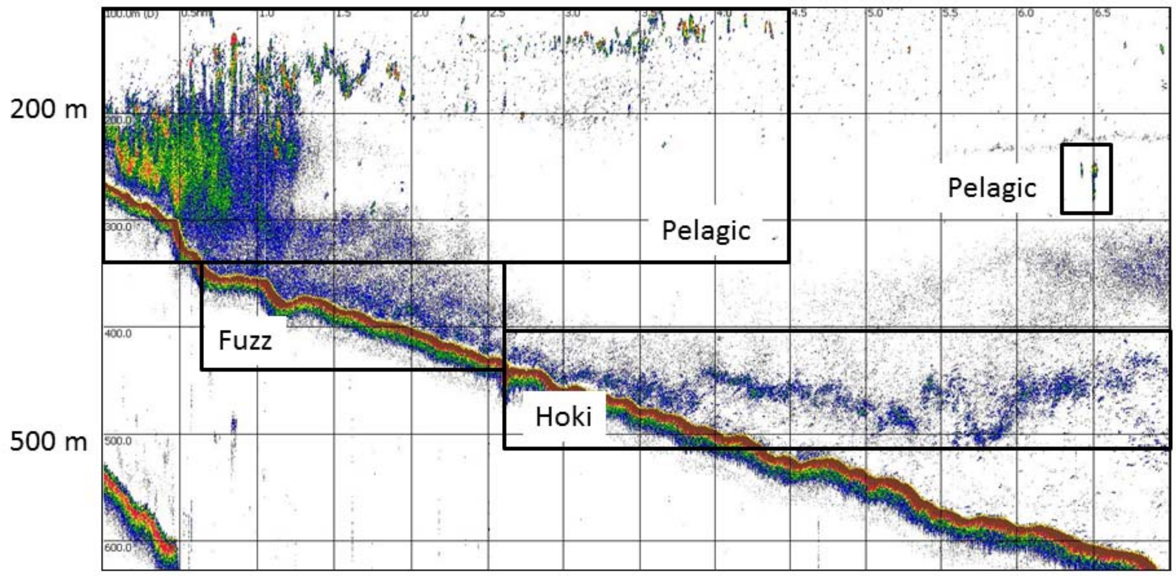


Figure 25: Example of mark classification on transect 7 of stratum 6 during the snapshot 2. Transect was between 16:22 and 17:22 NZST on 4 August. Approximate boundaries of marks are shown by black boxes. Echograms is divided into cells of 50 m by 0.5 n. miles. Minimum echogram threshold is -70 dB.

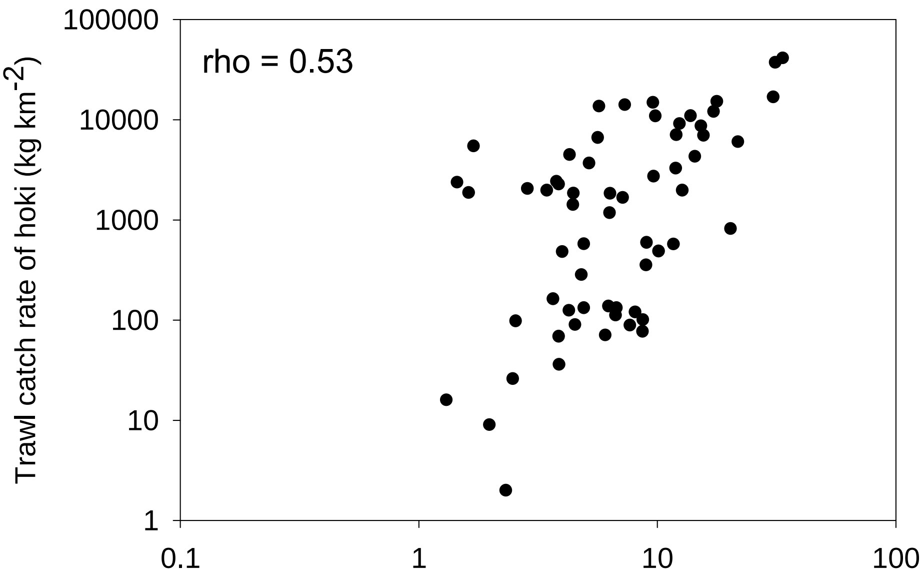


Figure 26: Relationship between trawl catch rate of hoki and bottom-referenced acoustic backscatter recorded during bottom tows during the 2012 WCSI survey. Rho value is Spearman's rank correlation coefficient.

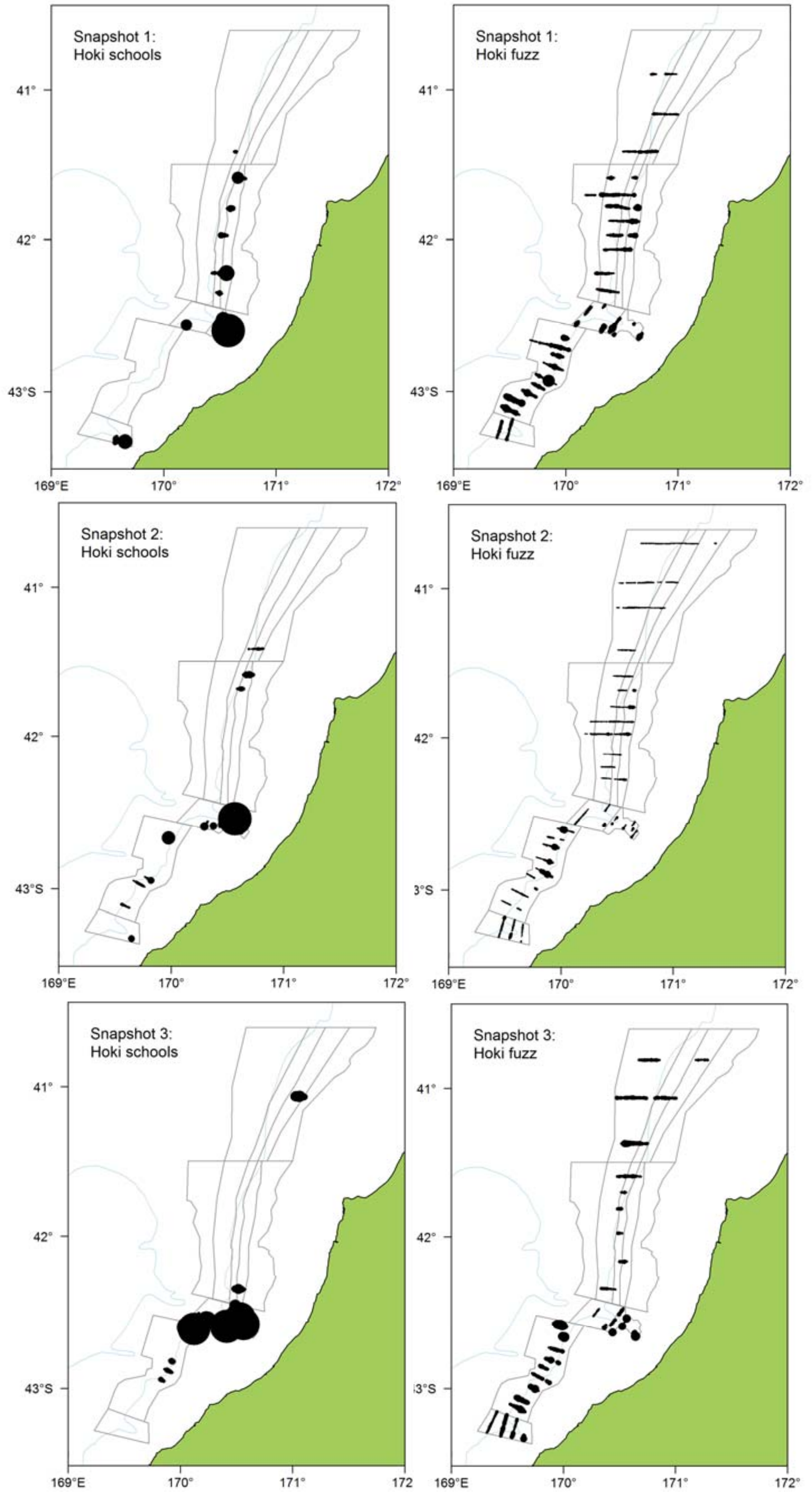


Figure 27: Spatial distribution of acoustic backscatter from hoki schools and hoki fuzz marks plotted in 10 ping (about 100 m) bins for the three snapshots of the WCSI. Symbol size is proportional to the log of the acoustic backscatter.

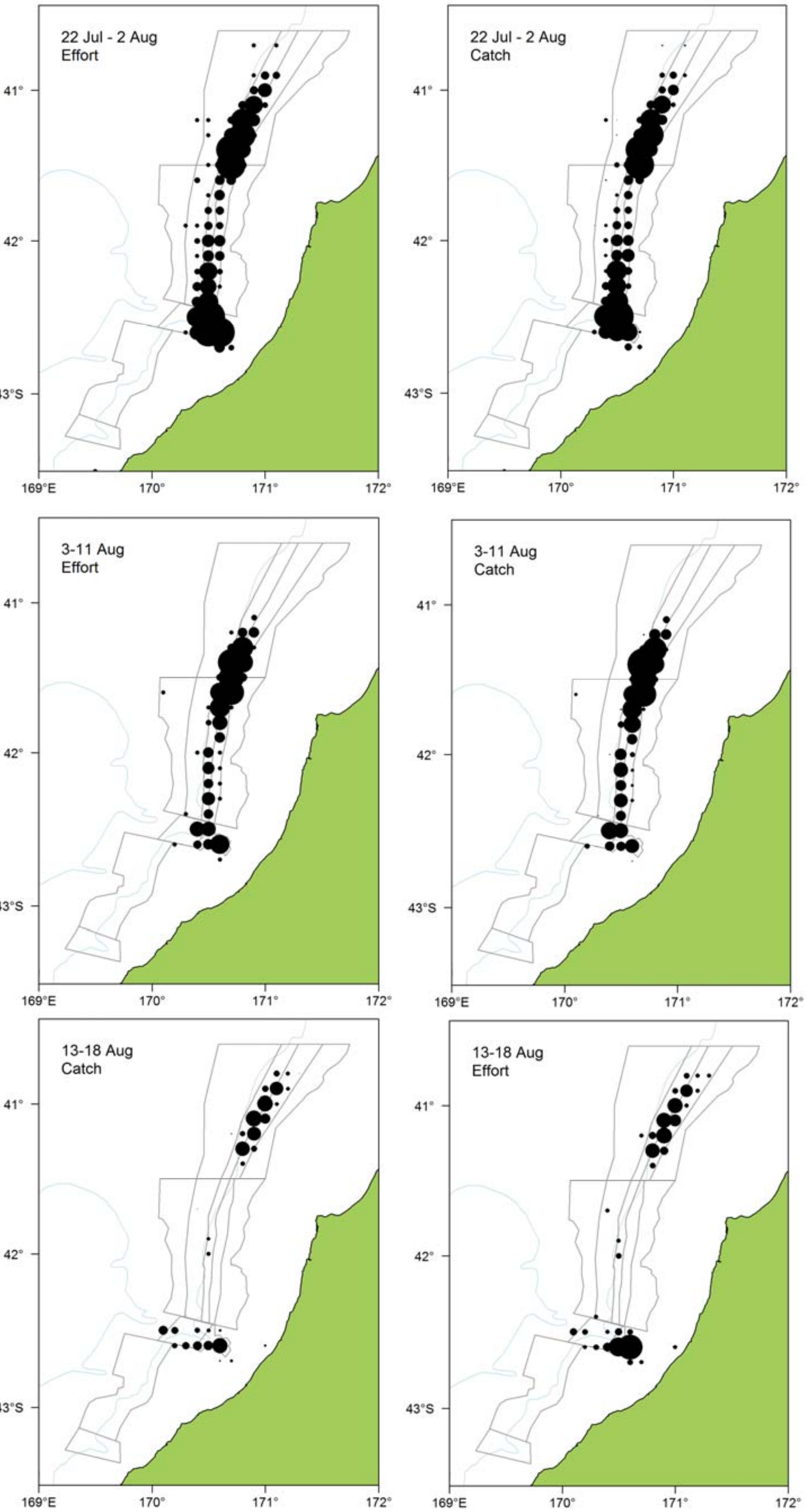


Figure 28: Spatial distribution of commercial effort (number of tows) and catch (tonnes) from hoki target tows during the 2012 survey period. Data are aggregated by decimal degree. Symbol size is proportional to the square root of either effort or catch.

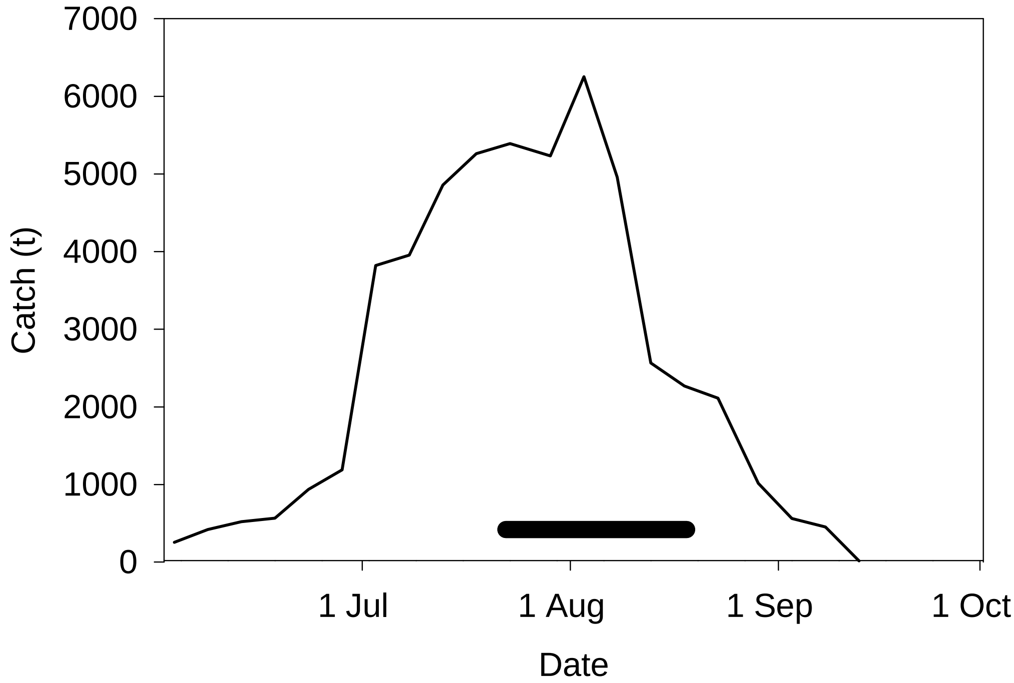


Figure 29: Timing of acoustic survey in 2012 in relation to the commercial hoki catch from the WCSI in 5-day periods.

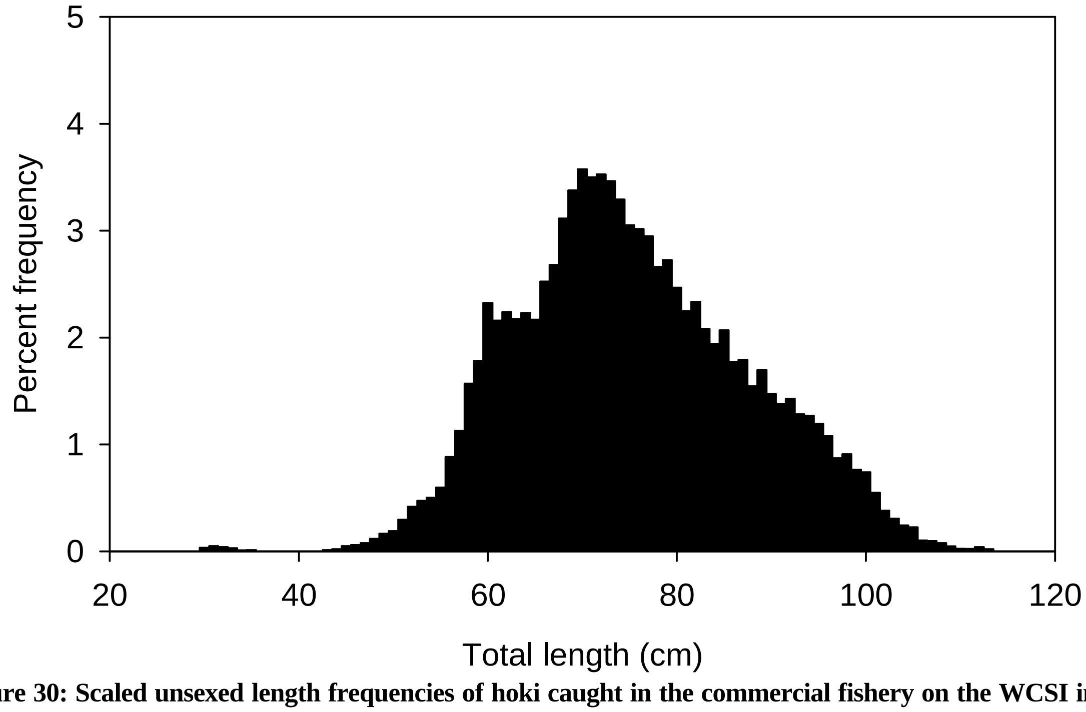


Figure 30: Scaled unsexed length frequencies of hoki caught in the commercial fishery on the WCSI in 2012 based on at-sea observer sampling. Data were used to estimate the ratio, *r*, of mean weight to mean backscattering cross-section (see Table 17).

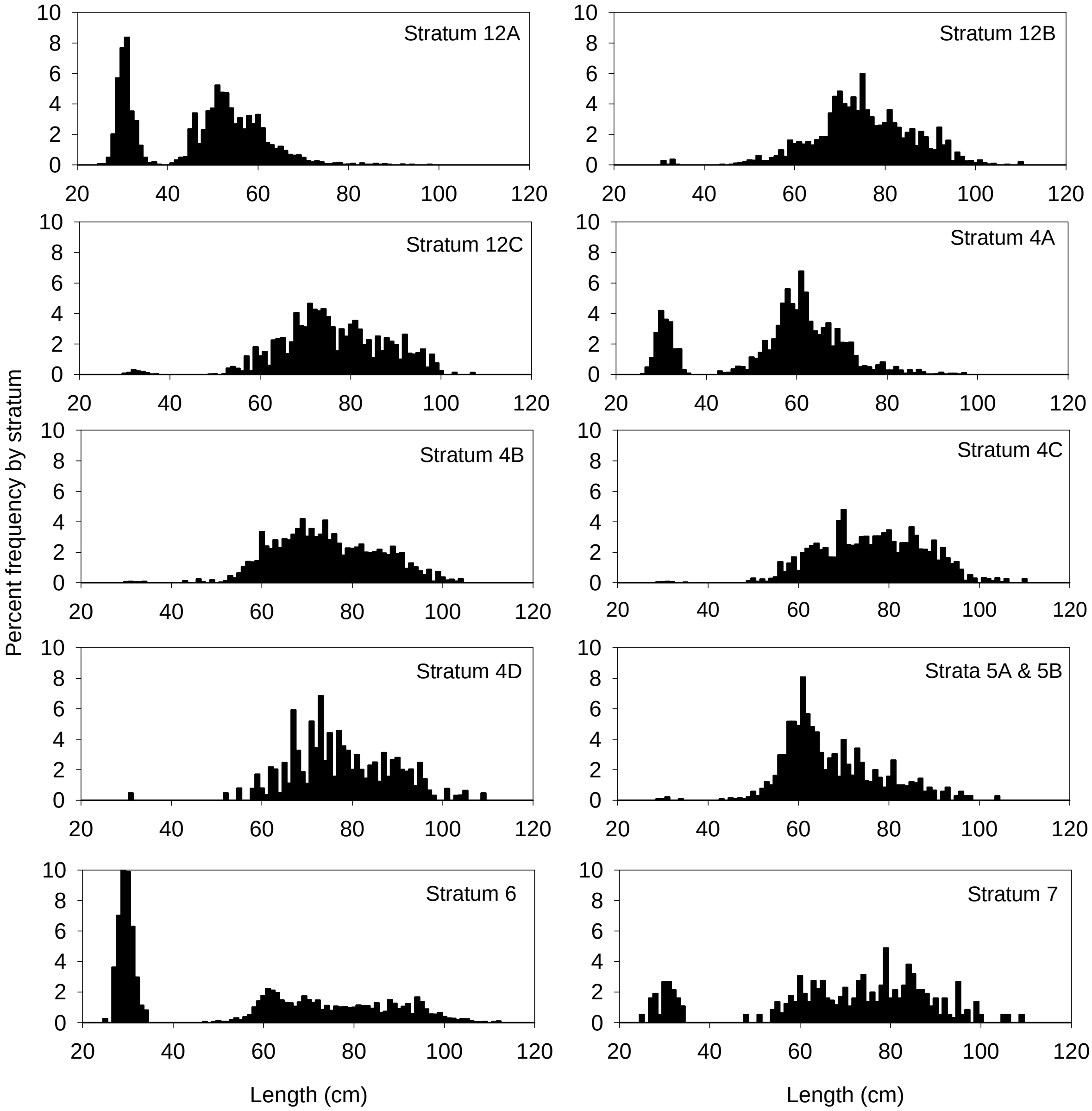


Figure 31: Scaled length frequencies of hoki by stratum from all research tows on the WCSI in 2012. Data were used to estimate the ratio, *r*, of mean weight to mean backscattering cross-section from fuzz marks following the 'new' methodology (see Table 18). Strata 5A and 5B (Hokitika Canyon) were combined because there were insufficient length data from stratum 5B alone.

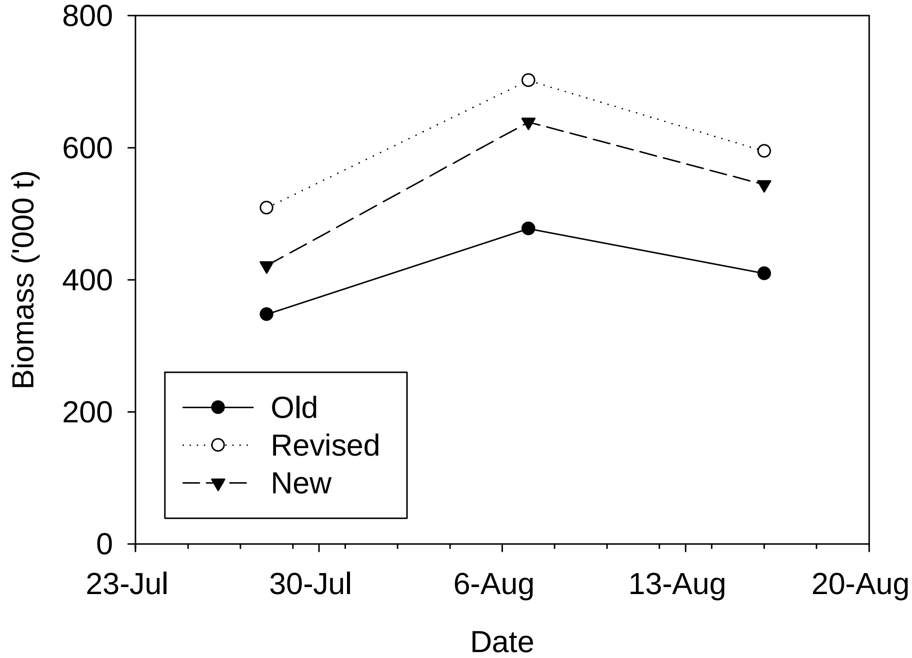


Figure 32: Estimated hoki abundance on the WCSI by snapshot over the 2012 survey period. Data were analysed using three methods (see text for details).

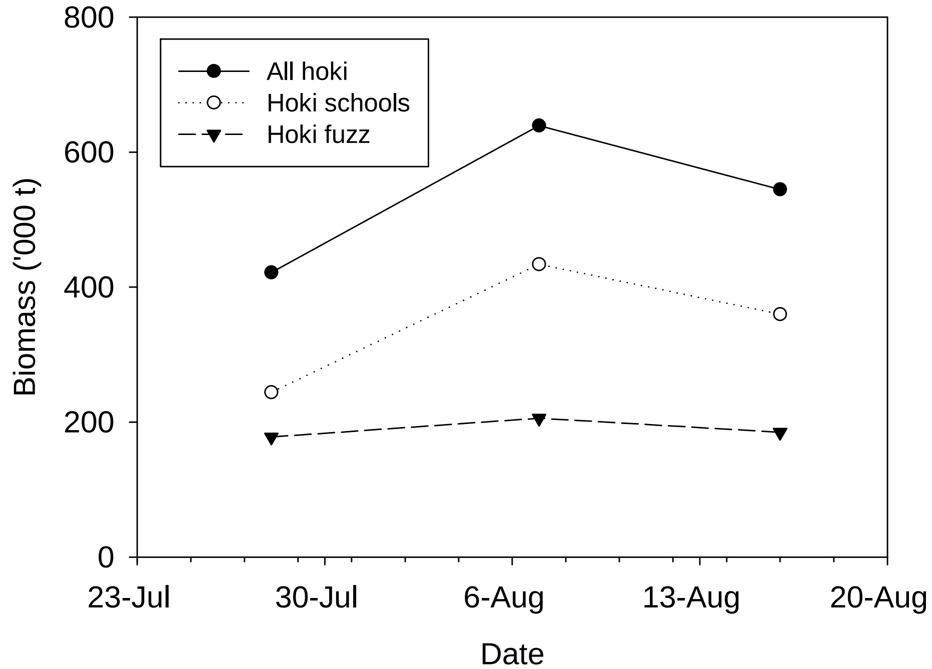


Figure 33: Estimated hoki abundance on the WCSI by mark type over the 2012 survey period using the 'new' analysis methodology.

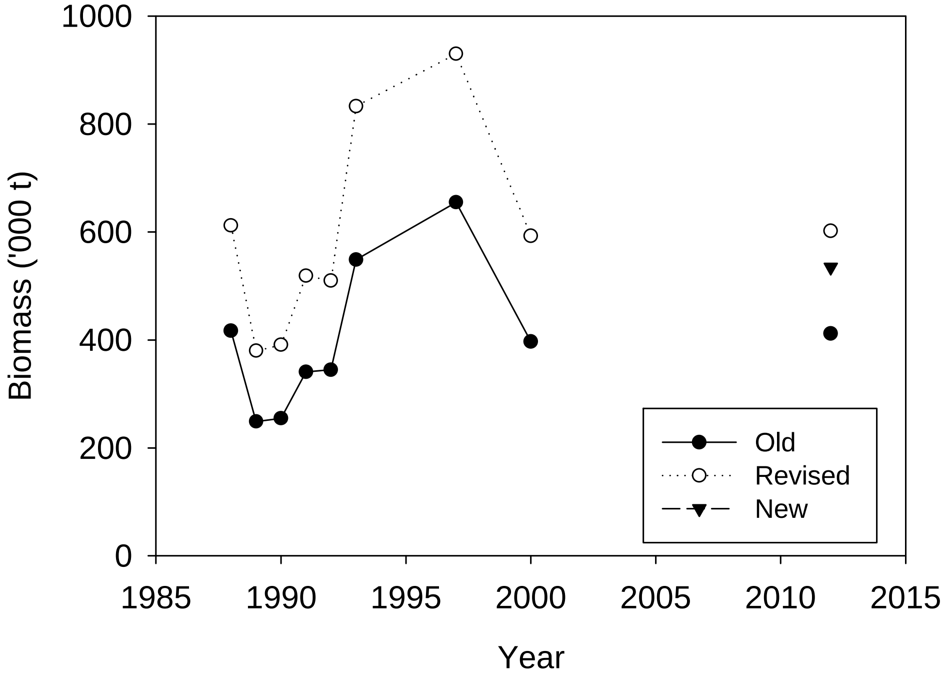


Figure 34: Time-series of acoustic abundance indices for hoki on the WCSI.

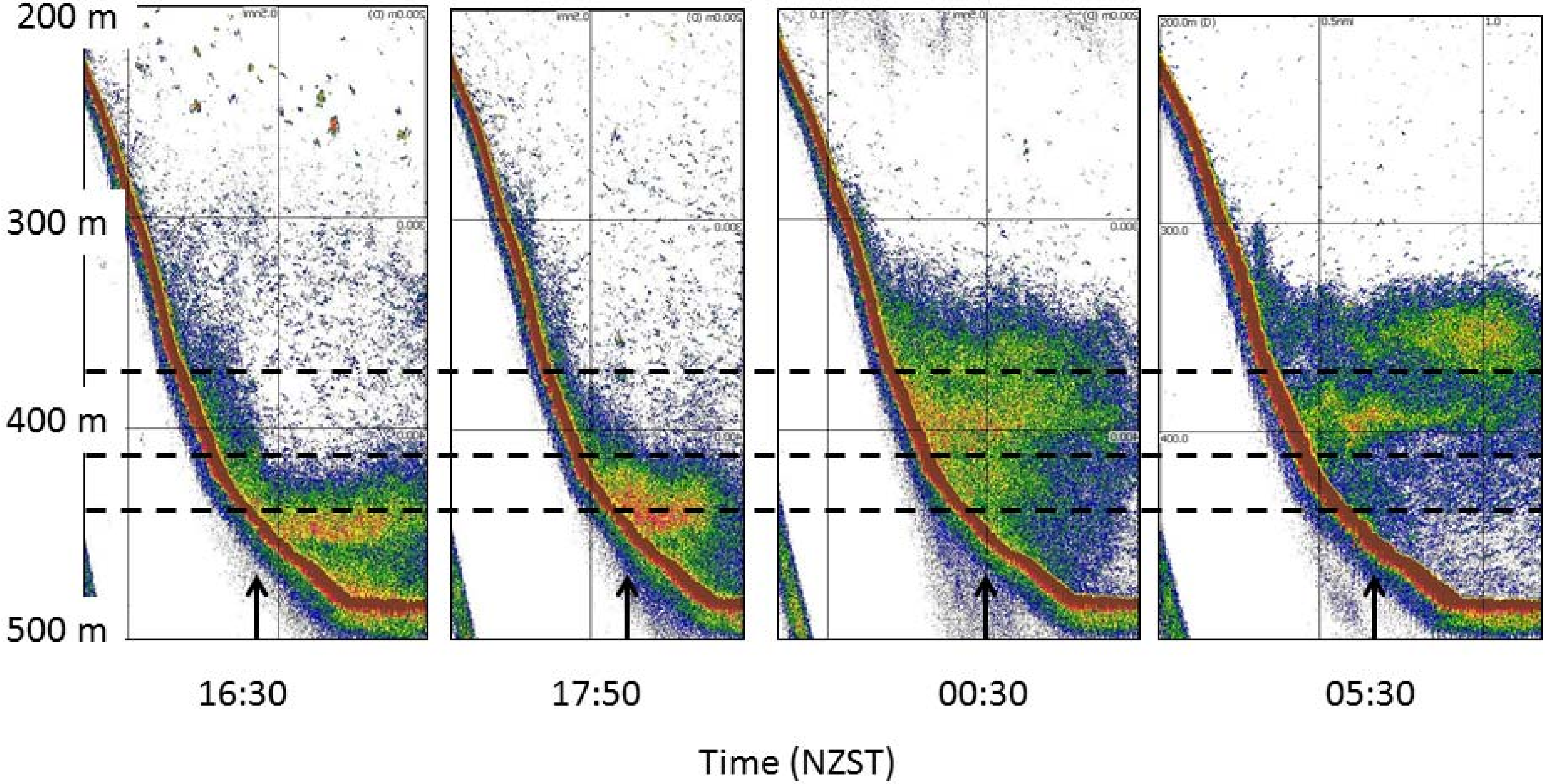


Figure 35: Echograms from four passes over the mooring on the south side of Hokitika Canyon on 26–27 July. Echograms have been oriented so that the south side is on the left. Arrows indicate approximate mooring location in each echogram. Dotted lines show approximate camera positions 8, 30, and 70 m above the seabed.

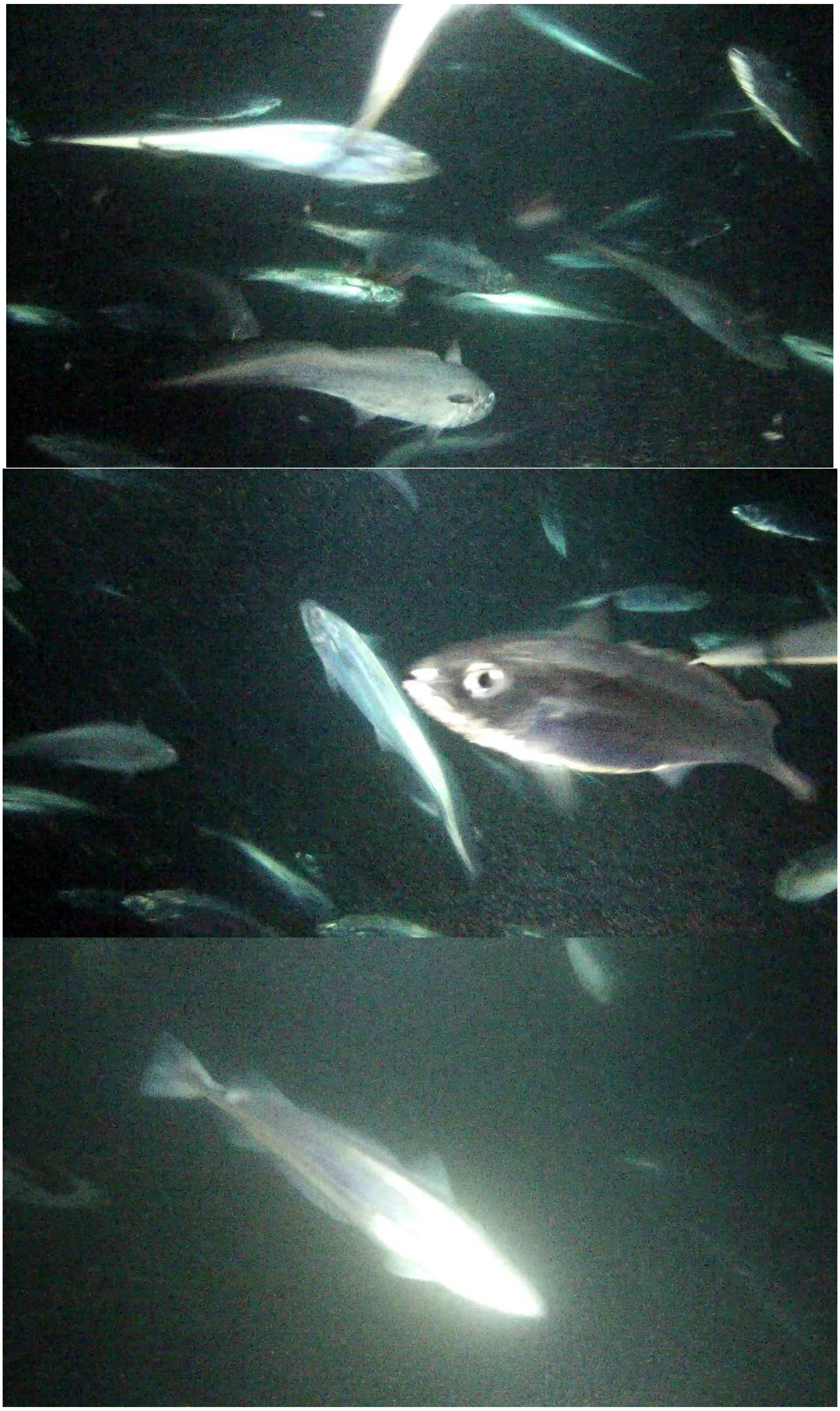


Figure 36: Selection of frame-grabs from mooring showing hoki (upper two pictures) and hake (lower picture) on bottom camera at about 425 m depth in Hokitika Canyon on 26–27 July.

Figure 37: Selection of frame-grabs from AOS showing hoki (upper two pictures), silver warehou (bottom left), and spiny dogfish (bottom right).

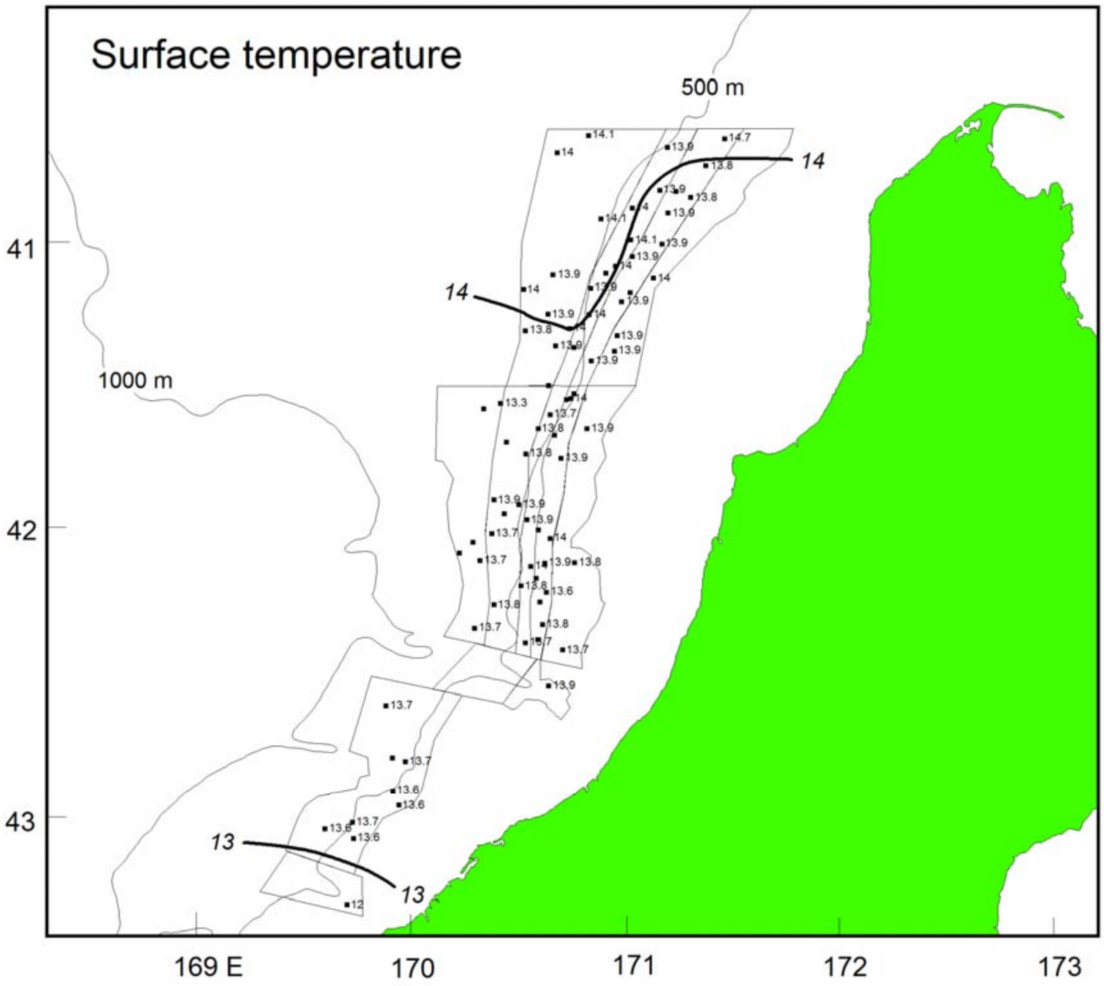


Figure 38: Surface water temperatures (°C) during the 2012 WCSI survey. Squares indicate bottom trawl tow positions. Not all temperatures are labelled where two or more tows were close together. Contours show isotherms estimated by eye.

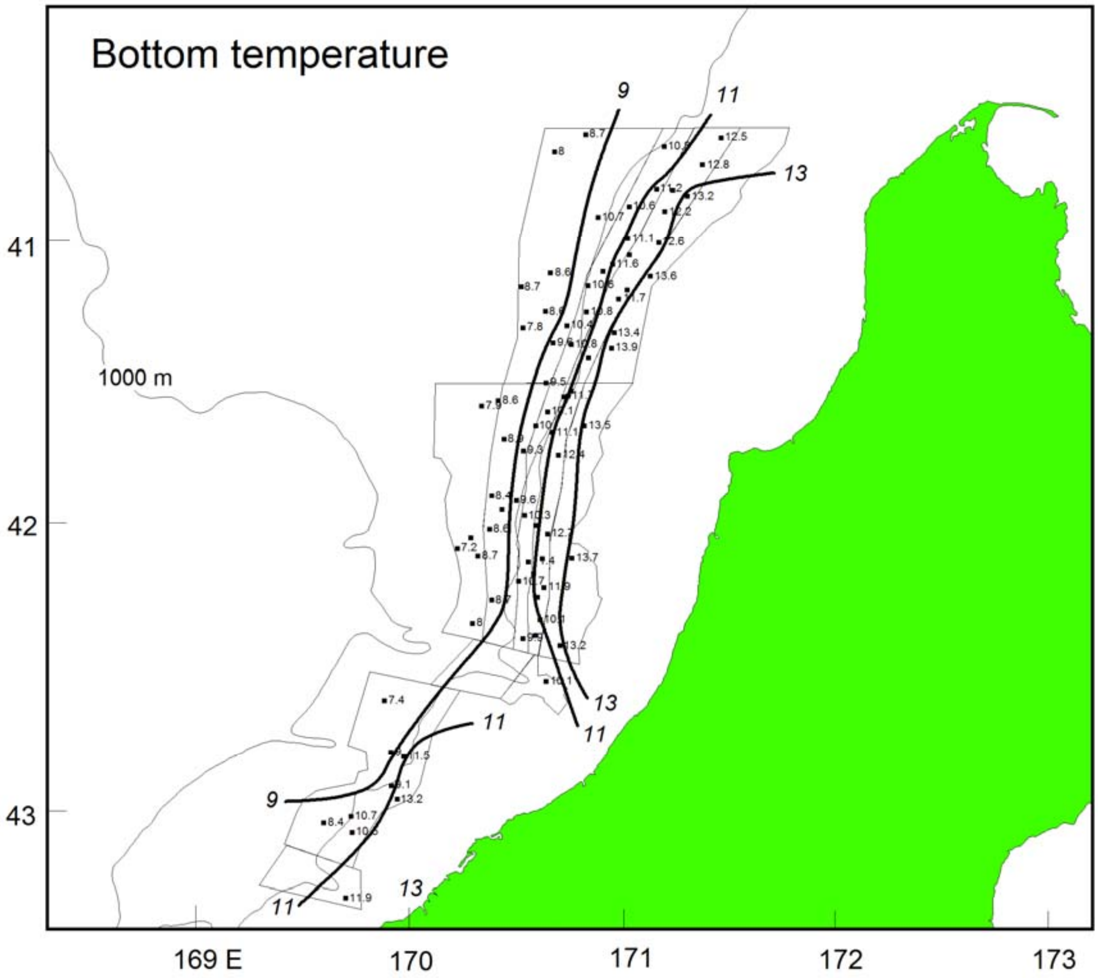


Figure 39: Bottom water temperatures (°C) during the 2012 WCSI survey. Squares indicate bottom trawl tow positions. Not all temperatures are labelled where two or more tows were close together. Contours show isotherms estimated by eye.

APPENDIX 1: Calibration Report for *Tangaroa* EK60 echosounders

The 18, 38, 70, 120, and 120 kHz EK60 echosounders on *Tangaroa* were calibrated on 21 July 2012 in Tasman Bay, at the start of the combined trawl and acoustic survey of hoki and middle depth species on the west coast South Island (TAN1210). The calibration was conducted broadly as per the procedures in MacLennan & Simmonds (1992).

As for the calibration on 30 August 2011 (TAN1112), we used divers to minimise set-up time. The most recent calibration of *Tangaroa* (on 6 February 2012, TAN1202) was achieved without divers, but there were considerable difficulties with calibration lines fouling on the anodes and bilge keels. New Zealand Diving Services provided dive support from their vessel *Topside*. Bruce Lines was the chief diver.

The vessel was allowed to drift in about 35 m of water in Tasman Bay (41˚ 04.45' S, 173˚ 23.21' E). The calibration started at 12:00 NZST. The divers located the transducers, attached the lines, and made sure these were not fouled. They also scraped clean the transducers before the calibration, as these had some fouling organisms. Long (3.8 m) fibreglass calibration poles were also used in place of our standard 1 m poles to help keep the calibration lines clear of the hull. Pole locations were the same as those for the calibration in August 2011. The sphere and associated lines were immersed in a soap solution prior to entering the water. A lead weight was also deployed about 2 m below the sphere to steady the arrangement of lines.

The weather during the calibration was excellent, with 5–10 knots of south-westerly wind and no swell. The vessel was drifting at an average speed of about 0.2 knots.

The sphere was located in the beam immediately at 12:26, and the divers and support boat left Nelson at 12:48. The sphere was first centred in the beam of the 38 kHz transducer to obtain data for the on-axis calibration. It was then moved around to obtain data for the beam shape calibration. Due to the close proximity of all five transducers, a number of echoes were recorded across all frequencies. After the 38 kHz calibration, the sphere was moved to ensure on-axis calibration of the other frequencies.

The calibration data were recorded in one EK60 raw format files (tan1210-D20120721-T002632.raw). These data are stored in the NIWA *acoustics* database. The EK60 transceiver settings in effect during the calibration are given in Table A1.1. The calibration was completed at 13:28 NZDT.

A temperature/salinity/depth profile was taken using a Seabird SBE21 conductivity, temperature, and depth probe (CTD). Estimates of acoustic absorption were calculated using the formulae in Doonan et al. (2003). The formula from Francois & Garrison (1982) was used at 200 kHz. Estimates of seawater sound speed and density were calculated using the formulae of Fofonoff & Millard (1983). The sphere target strength was calculated as specified in equations 6 to 9 in MacLennan (1981), using longitudinal and transverse sphere sound velocities of 6853 and 4171 m s^{-1} respectively and a sphere density of 14 900 kg m^{-3}.

The data in the .raw EK60 files were extracted using custom-written software. The amplitude of the sphere echoes was obtained by filtering on range, and choosing the sample with the highest amplitude. Instances where the sphere echo was disturbed by fish echoes were discarded. The alongship and athwartship beam widths and offsets were calculated by fitting the sphere echo amplitudes to the Simrad theoretical beam pattern:

$$compensation = 6.0206\left(\left(\frac{2\theta_{fa}}{BW_{fa}}\right)^2 + \left(\frac{2\theta_{ps}}{BW_{ps}}\right)^2 - 0.18\left(\frac{2\theta_{fa}}{BW_{fa}}\right)^2\left(\frac{2\theta_{ps}}{BW_{ps}}\right)^2\right),$$

where θ_{ps} is the port/starboard echo angle, θ_{fa} the fore/aft echo angle, BW_{ps} the port/starboard beamwidth, BW_{fa} the fore/aft beamwidth, and *compensation* the value, in dB, to add to an uncompensated echo to yield the compensated echo value. The fitting was done using an unconstrained nonlinear optimisation (as implemented by the Matlab fminsearch function). The S_a correction was calculated from:

$$Sa,corr = 5\log 10\left(\frac{\sum P_i}{4P_{\max}}\right),$$

where P_i is sphere echo power measurements and P_{max} the maximum sphere echo power measurement. A value for $S_{a,corr}$ is calculated for all valid sphere echoes and the mean over all sphere echoes is used to determine the final $S_{a,corr}$.

Results

The results from the CTD cast are given in Table A1.2, along with estimates of the sphere target strength, sound speed, and acoustic absorption for 18, 38, 70, 120, and 200 kHz.

The calibration parameters resulting from the calibration are given in Table A1.3, along with results from previous calibrations. It is important to note that the 38 kHz and 70 kHz systems were calibrated in the Ross Sea in February 2008, where the water temperature was -1.44 °C, considerably lower than during the subsequent calibrations. The effect of water temperature on transducer parameters and performance is not precisely known, but has been reported to have a significant effect at some frequencies (Demer & Renfree 2008) and any large differences between the two sets of results should not be taken as a permanent shift in system performance. Also, the 70 kHz transducer was in a different location during the voyage to the Ross Sea and this can also affect transducer performance. Despite this, results for all frequencies are relatively consistent (usually within 0.5 dB) across all calibrations. We have observed greater variability in our calibrations at higher frequencies (70, 120, and 200 kHz) and this was again observed in this calibration. The linear change (which can be interpreted as the percentage change in estimated abundance) between the calibration in May 2008 used for default settings and the calibration in February 2012 ranged between -15% (for 200 kHz) and +17% (for 70 kHz). The calibration coefficients for the 38-kHz echosounder most often used for abundance estimation were about 11% different (less sensitive) from those in May 2008 (Table A1.3) and 8% different from those from the two most recent calibrations in August 2011 and February 2012.

The estimated beam patterns, as well as the coverage of the beam by the calibration sphere, are given in Figures A1.1–A1.10. The symmetrical nature of the beam patterns and the centering on zero indicates that the transducers and EK60 transceivers were operating correctly. The root mean square (RMS) of the difference between the Simrad beam model and the sphere echoes out to the 3 dB beamwidth was 0.09 dB for 18 kHz, 0.10 dB for both 38 kHz and 70 kHz, 0.17 dB for 120 kHz, and 0.21 dB for 200 kHz (Table A1.3), indicating good or excellent quality calibrations on all frequencies (<0.4 dB is acceptable, <0.3 dB good, and <0.2 dB excellent). On-axis estimates were derived from 111 sphere echoes at 18 kHz, 300 echoes at 38 kHz, 1346 echoes at 70 kHz, 28 echoes at 120 kHz, and 91 echoes at 200 kHz.

The calibration coefficients estimated from this calibration were used for analysis of results from the WCSI survey (TAN1210).

Table A1.1. EK60 transceiver settings and other relevant parameters in effect during the calibration. These were derived from the May 2008 calibration (see Table A1.3).

Parameter					
Frequency (kHz)	18	38	70	120	200
GPT model	GPT-Q18(2)-S 1.0 00907205c476	GPT-Q38(4)-S 1.0 00907205c463	GPT-Q70(1)-S 1.0 00907205ca98	GPT-Q120(1)-S 1.0 009072058148	GPT-Q120(1)-S 1.0 009072058148
GPT serial number	652	650	674	668	692
GPT software version	050112	050112	050112	050112	050112
ER60 software version	2.2.1	2.2.1	2.2.1	2.2.1	2.2.1
Transducer model	ES18-11	ES38	ES70-7C	ES120-7C	ES200-7C
Transducer serial number	2080	23083	158	477	364
Sphere type/size	tungsten carbide/38.1 mm diameter (same for all frequencies)				
Transducer draft setting (m)	0.0	0.0	0.0	0.0	0.0
Transmit power (W)	2000	2000	1000	500	300
Pulse length (ms)	1.024	1.024	1.024	1.024	1.024
Transducer peak gain (dB)	22.96	25.81	26.43	26.17	24.96
Sa correction (dB)	-0.81	-0.57	-0.35	-0.36	-0.25
Bandwidth (Hz)	1574	2425	2859	3026	3088
Sample interval (m)	0.191	0.191	0.191	0.191	0.191
Two-way beam angle (dB)	–17.0	–20.6	–21.0	–21.0	–20.7
Absorption coefficient (dB/km)	2.67	9.79	22.79	37.44	52.69
Speed of sound (m/s)	1494	1494	1494	1494	1494
Angle sensitivity (dB) along/athwartship	13.90/13.90	21.90/21.90	23.0/23.0	23.0/23.0	23.0/23.0
3 dB beamwidth (º) along/athwartship	10.8/10.8	7.0/7.0	6.6/6.6	6.5/6.6	6.8/6.9
Angle offset (º) along/athwartship	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0

Table A1.2. CTD cast details and derived water properties. The values for sound speed, salinity and absorption are the mean over water depths 6 to 35 m.

Parameter	
Date/time (NZDT, start)	21 July 2012 13:33
Position	41˚ 04.45' S 173˚ 23.21' E
Mean sphere range (m)	25.5 (18 kHz), 25.6 (38), 25.3 (70), 25.2 (120), 25.3 (200)
Mean temperature (ºC)	12.3
Mean salinity (psu)	34.9
Sound speed (m/s)	1498.3
Water density (kg/m^3)	1026.6
Sound absorption (dB/km)	2.35 (18 kHz) 9.18 (38 kHz) 22.80 (70 kHz) 39.59 (120 kHz) 58.96 (200 kHz)
Sphere target strength (dB re 1m^2)	–42.63 (18 kHz) –42.41 (38 kHz) –41.41 (70 kHz) –39.51 (120 kHz) –39.09 (200 kHz)

Table A1.3. Estimated calibration coefficients for all calibrations of *Tangaroa* hull EK60 echosounders. Note that the February 2008 measurements were conducted in –1.4°C seawater and the 70 kHz was at a different location. For the latest calibration, linear percent difference from the May 2008 calibration values used as default (see Table A1.1) are shown in parentheses.

		Jul 2012	Feb 2012	Aug 2011	Jan 2010	May 2008	Feb 2008
18 kHz							
	Transducer peak gain (dB)	22.97 (+1%)	22.81	22.78	23.36	22.96	
	Sa correction (dB)	-0.84	-0.69	-0.69	-0.76	–0.81	
	Beamwidth (º) along/athwartship	10.7/11.2	10.7/10.9	10.9/11.1	11.1/11.3	10.8/10.8	
	Beam offset (º) along/athwartship	0.00/-0.00	0.00/-0/.00	-0.02/0.08	0.00/0.00	0.00/0.00	
	RMS deviation (dB)	0.09	0.14	0.08	0.14	0.26	
38 kHz							
	Transducer peak gain (dB)	25.62 (+11%)	25.75	25.75	25.98	25.81	25.85
	Sa correction (dB)	-0.61	-0.57	-0.58	-0.58	–0.57	–0.53
	Beamwidth (º) along/athwartship	6.8/6.9	6.8/6.8	6.8/6.9	6.9/7.0	7.0/7.0	7.0/7.0
	Beam offset (º) along/athwartship	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	–0.04/0.04
	RMS deviation (dB)	0.10	0.14	0.08	0.10	0.16	0.13
70 kHz							
	Transducer peak gain (dB)	26.04 (+17%)	26.78	26.23	26.78	26.43	26.58
	Sa correction (dB)	-0.31	-0.35	-0.32	-0.30	–0.35	–0.28
	Beamwidth (º) along/athwartship	6.6/6.6	6.3/6.1	6.5/6.6	6.3/6.4	6.6/6.6	6.7/6.6
	Beam offset (º) along/athwartship	0.00/0.00	0.00/0.00	-0.00/0.00	0.00/0.00	0.00/0.00	–0.03/0.00
	RMS deviation (dB)	0.10	0.21	0.10	0.14	0.25	0.15
120 kHz							
	Transducer peak gain (dB)	26.11 (+2%)	26.80	25.96	26.79	26.17	
	Sa correction (dB)	-0.34	-0.38	-0.39	-0.35	–0.36	
	Beamwidth (º) along/athwartship	6.5/6.6	6.0/6.0	6.4/6.6	6.1/6.4	6.5/6.6	
	Beam offset (º) along/athwartship	-0.00/-0.00	0.00/0.00	-0.13/0.11	0.00/0.00	0.00/0.00	
	RMS deviation (dB)	0.17	0.19	0.17	0.17	0.35	
200 kHz							
	Transducer peak gain (dB)	25.31 (-15%)	25.16	25.25	25.35	24.96	
	Sa correction (dB)	-0.24	-0.21	-0.29	-0.36	–0.25	
	Beamwidth (º) along/athwartship	6.8/6.5	6.2/6.2	6.3/6.7	6.7/6.7	6.8/6.9	
	Beam offset (º) along/athwartship	-0.27/-0.10	0.08/-0.08	0.00/0.00	0.00/0.00	0.00/0.00	
	RMS deviation (dB)	0.21	0.18	0.21	0.18	0.39	

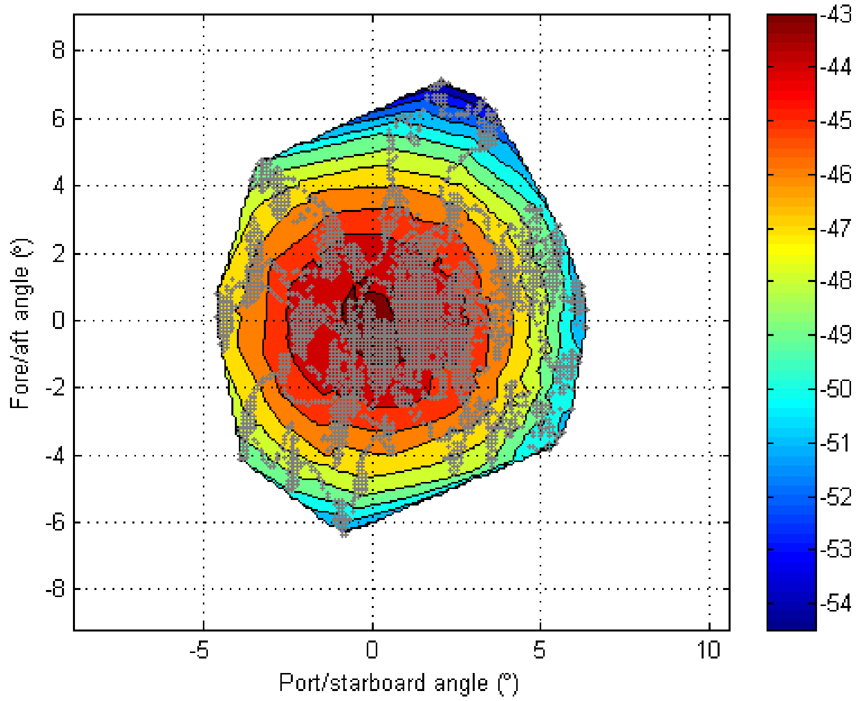


Figure A1.1. The 18 kHz estimated beam pattern from the sphere echo strength and position. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

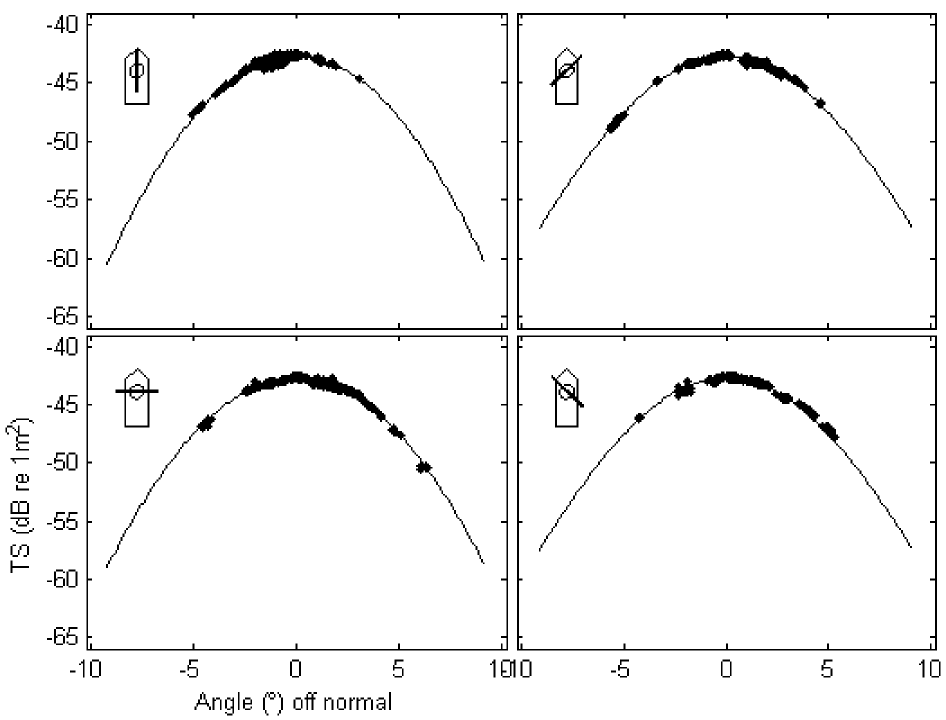


Figure A1.2. Beam pattern results from the 18 kHz analysis. The solid line is the ideal beam pattern fit to the sphere echoes for four slices through the beam.

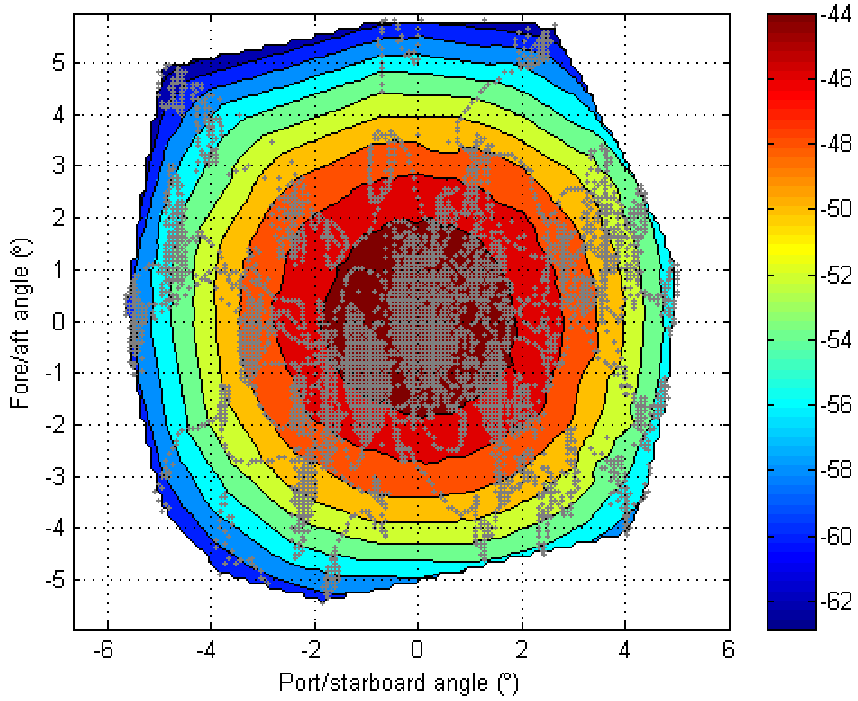


Figure A1.3. The 38 kHz estimated beam pattern from the sphere echo strength and position. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m².

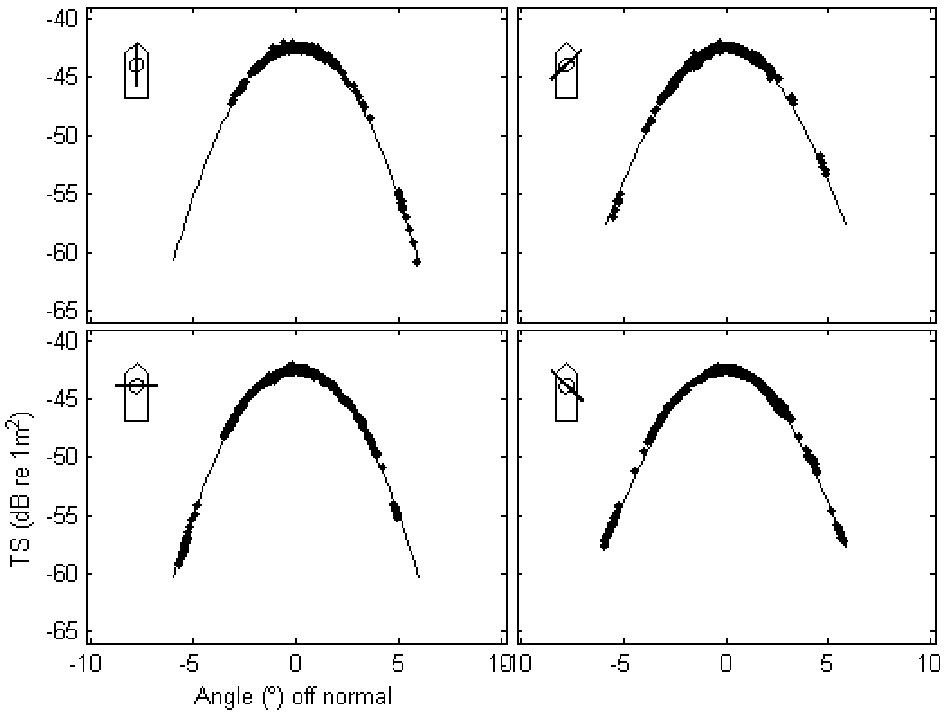


Figure A1.4. Beam pattern results from the 38 kHz analysis. The solid line is the ideal beam pattern fit to the sphere echoes for four slices through the beam.

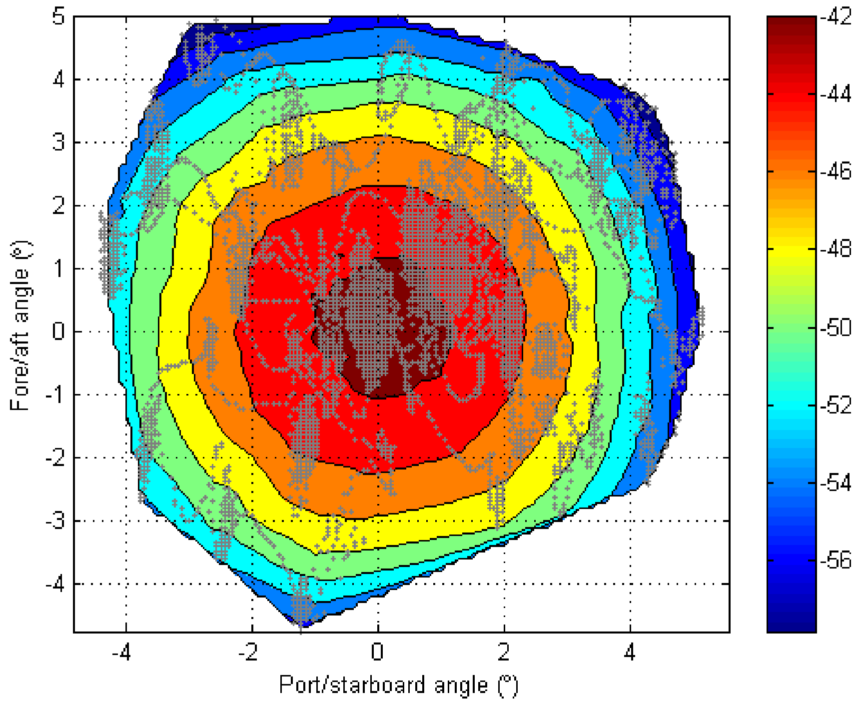


Figure A1.5. The 70 kHz estimated beam pattern from the sphere echo strength and position. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

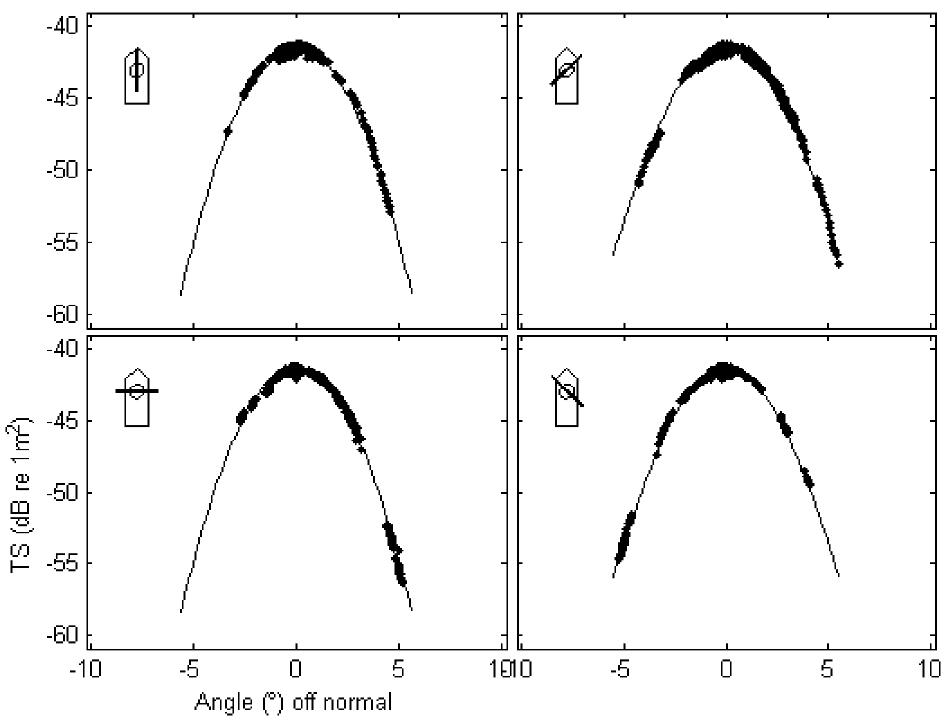


Figure A1.6. Beam pattern results from the 70 kHz analysis. The solid line is the ideal beam pattern fit to the sphere echoes for four slices through the beam.

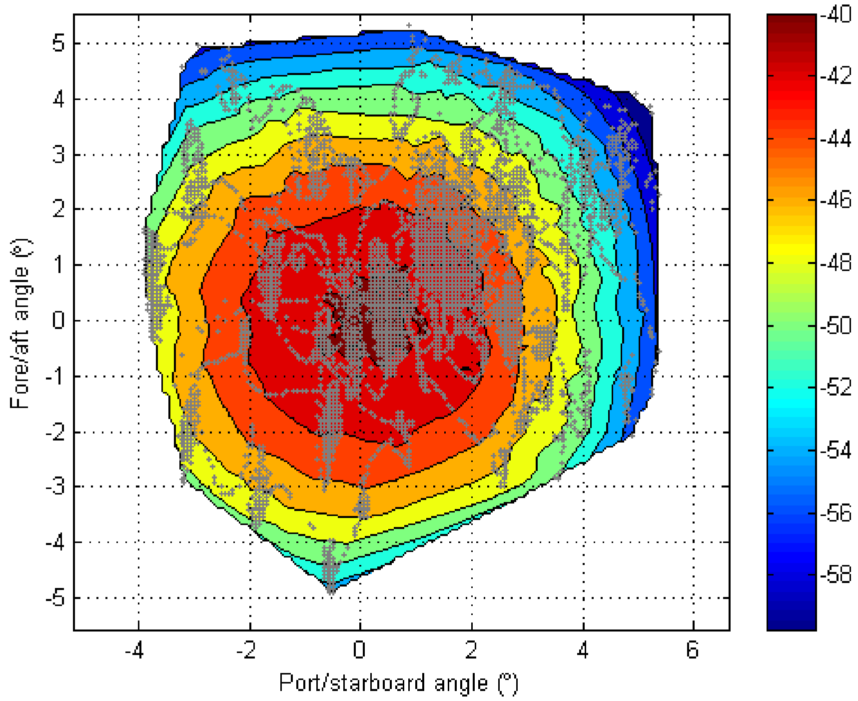


Figure A1.7. The 120 kHz estimated beam pattern from the sphere echo strength and position. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

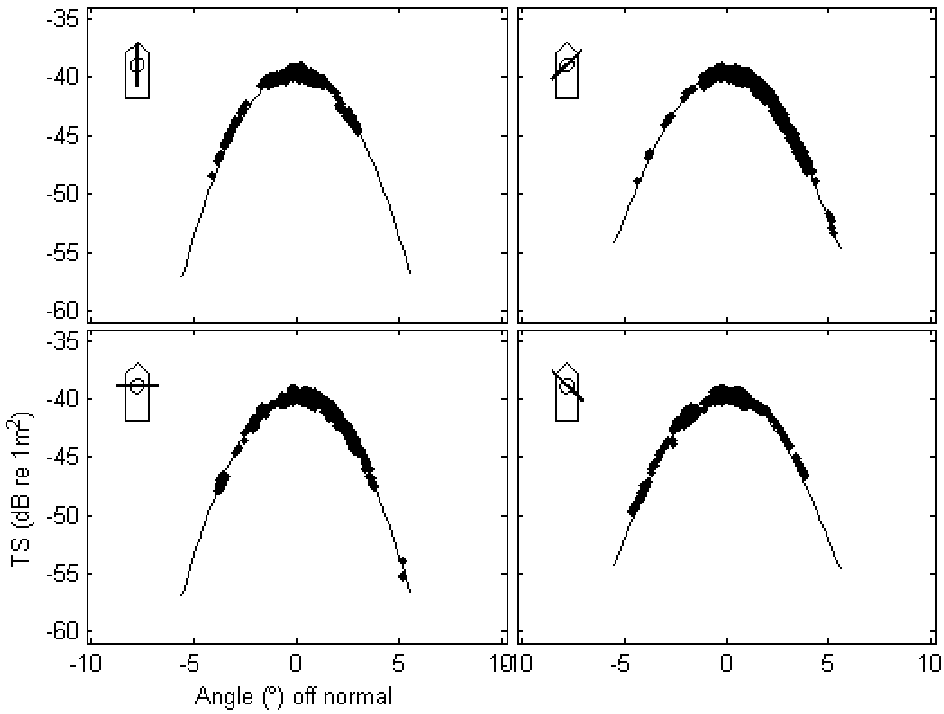


Figure A1.8. Beam pattern results from the 120 kHz analysis. The solid line is the ideal beam pattern fit to the sphere echoes for four slices through the beam.

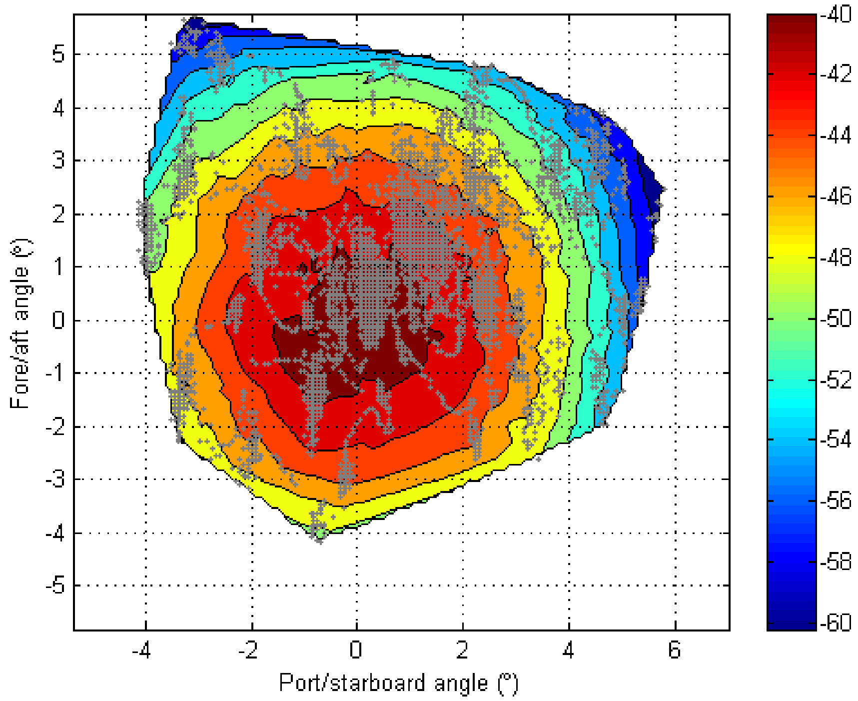


Figure A1.9. The 200 kHz estimated beam pattern from the sphere echo strength and position. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

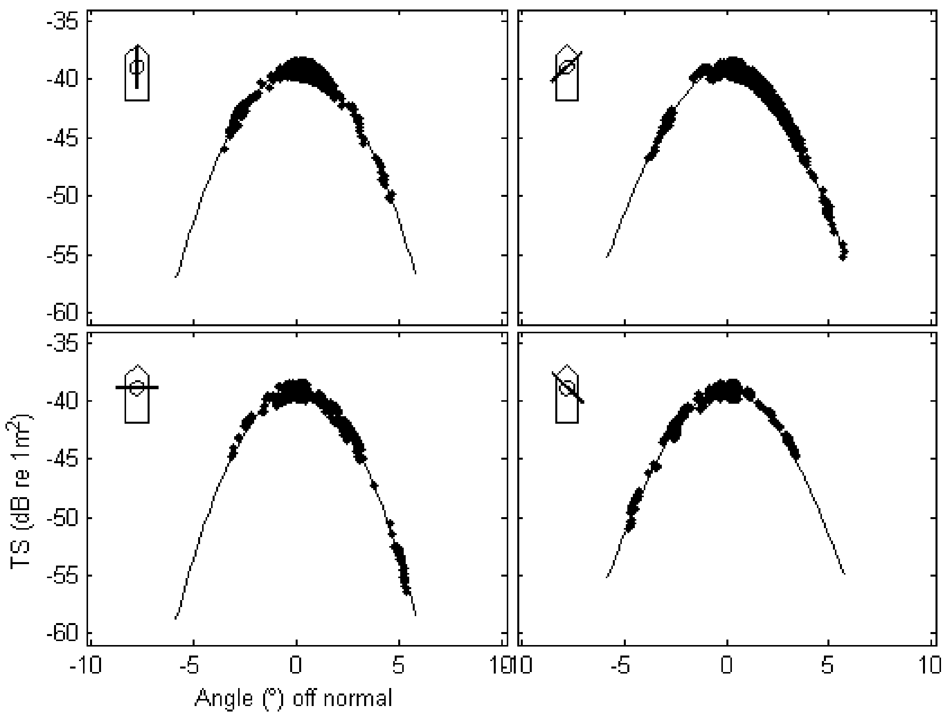


Figure A1.10. Beam pattern results from the 200 kHz analysis. The solid line is the ideal beam pattern fit to the sphere echoes for four slices through the beam.

APPENDIX 2: Towbody 3 calibration.

Table A2.1 provides the system settings and calculated calibration coefficients for towbody 3 used during the 2012 acoustic survey.

Table A2.1: System settings and calibration values for the 38 kHz CREST systems used for the 2012 WCSI survey. V_T is the in-circuit voltage at the transducer terminals for a target of unit backscattering cross-section at unit range. *G* is the voltage gain of the receiver at a range of 1 m with the system configured for echo-integration ('20 Log R').

	Towed body 3
Transducer model	ES38DD
Transducer serial no.	28332B
3 dB beamwidths (˚) alongship/athwartship	7.3/7.4
Effective beam angle (sr)	0.0093
Operating frequency (kHz)	38.16
Transmit interval (s)	2.00
Transmitter pulse length (ms)	1.00
Effective pulse length (ms)	0.78
Filter bandwidth (kHz)	1.5
Initial sample rate (kHz)	100
Decimated sample rate (kHz)	4
V_T (V)	1 050
G	12 866
Absorption (dB km^{-1})	
calibration	9.18
survey*	8.83

* See Appendix 4

APPENDIX 3: Description of gonad staging for teleosts and elasmobranchs

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 thin and flabby; white or transparent.	Ovaries are developed, but no developing eggs are visible.
3	Ripening	Testes 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.

Elasmobranchs

1	Immature	Claspers shorter than pelvic fins, soft and uncalcified, unable or difficult to splay open Testes small.	Ovaries small and undeveloped. Oocytes not visible, or small (pin-head sized) and translucent, whitish.
2	Maturing	Claspers longer than pelvic fins, soft and uncalcified, unable or difficult to splay open or rotate forwards.	Some oocytes enlarged, up to about pea-sized or larger, and white to cream.
3	Mature	Claspers longer than pelvic fins, hard and calcified, able to splay open and rotate forwards to expose clasper spine.	Some oocytes large (greater than pea-sized) and yolky (bright yellow).
4	Gravid I	-	Uteri contain eggs or egg cases but no embryos are visible.
5	Gravid II	-	Uteri contain visible embryos. Not applicable to egg laying sharks and skates
6	Post-partum	-	Uteri flaccid and vascularised Indicating recent birth.

APPENDIX 4: Calculation of sound absorption coefficients

CTD data were collected on 89 tows as part of the 2012 survey. Plots of average temperature, salinity, and sound absorption as a function of depth are given in Figure A4.1. Average sound absorption was estimated using the formula of Doonan et al. (2003). The average absorption estimate of 8.83 dB km^{-1} from the absorption profile over the upper 400 m (Figure A4.1c) was used when estimating hoki abundance (see Section 2.9.2).

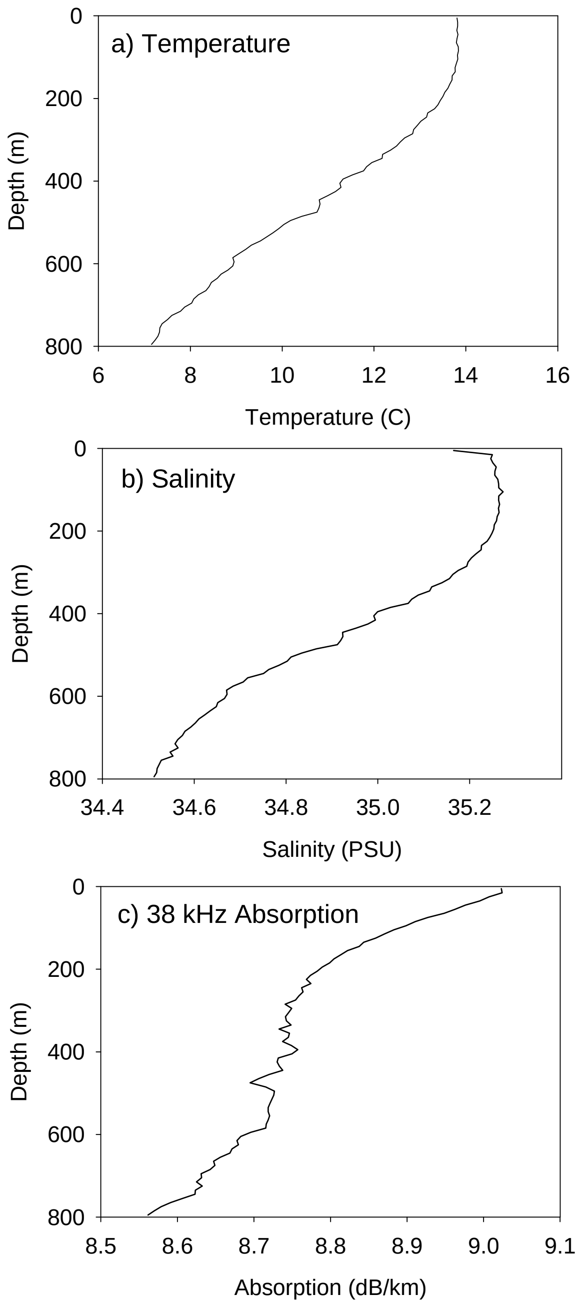


Figure A4.1: Profiles of average temperature, salinity, and sound absorption at 38 kHz from the 89 CTD casts carried out during 2012 WCSI survey.

APPENDIX 5: Station details and catch of hoki, ling, and hake.

Type abbreviations: RBT, random bottom trawl (* indicates tow unsuitable for abundance estimation); AOS, AOS only trawl (codend open); ID, mark identification with bottom trawl; IDMW, mark identification with mesopelagic trawl; ID/AOS, mark identification with bottom trawl and AOS; MOOR, mooring; CAL, acoustic calibration.

Station	Date	Type	Stratum	Start latitude (S)	Start longitude (E)	Distance (n. mile)	Hoki (kg)	Ling (kg)	Hake (kg)
1	22-Jul-12	RBT	4S	42 07.35	170 42.68	3.01	0.0	0.0	0.0
2	23-Jul-12	IDMW	5A	42 34.39	170 30.57	2.22	10.9	33.0	0.0
3	23-Jul-12	ID/AOS	4D	42 21.18	170 14.58	1.92	186.2	0.0	119.4
4	23-Jul-12	ID	6	42 37.44	169 49.48	3.00	73.5	0.0	36.8
5	24-Jul-12	IDMW	6	42 55.94	169 51.20	0.95	4.4	0.0	0.0
6	24-Jul-12	IDMW	6	43 02.44	169 29.59	2.76	0.0	0.0	0.0
7	24-Jul-12	ID	6	43 03.36	169 32.26	2.33	311.5	22.1	48.3
8	24-Jul-12	ID/AOS	7	43 19.16	169 38.55	2.09	67.7	32.1	0.0
9	25-Jul-12	RBT	4A	42 20.36	170 33.68	3.02	2 693.6	223.3	0.0
10	25-Jul-12	RBT	4B	42 24.23	170 28.94	3.03	9 678.0	548.7	40.4
11	25-Jul-12	RBT	4A	42 23.55	170 32.36	2.20	860.7	94.4	18.3
12	26-Jul-12	RBT	4A	42 13.54	170 34.76	2.17	7.0	20.8	0.0
13	26-Jul-12	RBT	4A	42 15.65	170 33.05	2.99	1 138.0	125.4	0.0
14	26-Jul-12	MOOR	5A	42 35.68	170 32.59	0.00	-	-	-
15	26-Jul-12	AOS	4B	42 23.82	170 28.52	2.42	-	-	-
16	27-Jul-12	AOS	5A	42 32.79	170 33.33	2.01	-	-	-
17	27-Jul-12	RBT	4C	42 16.22	170 20.06	2.97	363.4	3.4	252.5
18	27-Jul-12	RBT	4B	42 12.21	170 27.63	2.06	4 852.6	90.9	25.5
19	27-Jul-12	RBT	4A	42 10.59	170 31.97	2.02	11 227.7	207.8	13.0
20	27-Jul-12	RBT	4B	42 08.17	170 30.42	2.02	17 536.9	127.7	8.2
21	28-Jul-12	RBT	4A	42 07.38	170 34.29	1.99	746.1	92.1	0.0
22	28-Jul-12	RBT	4A	42 02.16	170 35.93	2.00	3.5	0.0	0.0
23	28-Jul-12	RBT	4A	42 00.44	170 32.50	2.02	754.3	256.7	0.0
24	28-Jul-12	RBT	4B	41 58.26	170 29.34	2.00	3 826.8	72.7	68.3
25	28-Jul-12	RBT	4C	41 55.07	170 27.05	3.03	1 907.8	34.3	106.3
26	28-Jul-12	RBT	4C	41 54.02	170 20.00	2.05	43.8	0.0	84.8
27	29-Jul-12	RBT	4A	41 45.39	170 38.90	2.55	1.1	46.8	0.0
28	29-Jul-12	RBT	4C	41 44.50	170 29.00	2.03	3 142.3	66.0	52.7
29	29-Jul-12	RBT	4B	41 39.16	170 32.49	2.03	4 989.9	41.4	36.9
30	29-Jul-12	RBT	4A	41 40.50	170 37.10	2.03	5 105.5	47.3	16.5
31	30-Jul-12	RBT	4B	41 36.16	170 35.81	2.48	1 091.6	36.7	3.0
32	30-Jul-12	RBT	4A	41 32.77	170 41.67	2.01	16 160.8	348.0	0.0
33	30-Jul-12	RBT	4C	41 30.03	170 35.41	2.99	556.8	25.7	101.4
34	30-Jul-12	RBT	4A	41 32.95	170 40.51	2.02	226.9	147.5	11.9
35	31-Jul-12	ID	1&2C	41 09.76	170 28.34	1.94	35.7	10.4	25.4
36	31-Jul-12	RBT	1&2B	41 09.47	170 47.28	2.03	1 072.6	6.6	16.3
37	31-Jul-12	RBT	1&2B	41 15.00	170 46.91	2.02	2 813.5	173.8	38.9
38	31-Jul-12	RBT	1&2C	41 17.98	170 41.30	2.03	3 403.8	28.3	22.8
39	31-Jul-12	RBT	1&2C	41 21.67	170 37.46	2.01	7 289.3	7.9	39.9
40	31-Jul-12	RBT	1&2B	41 21.99	170 42.62	2.10	1 804.8	54.2	6.0
41	1-Aug-12	RBT	1&2B	40 52.61	170 59.11	3.02	191.5	37.1	11.1
42	1-Aug-12	RBT	1&2C	40 54.98	170 50.20	3.00	118.7	6.1	0.0
43	1-Aug-12	RBT	1&2B	40 59.42	170 58.55	3.01	984.3	81.2	28.5
44	1-Aug-12	RBT	1&2B	41 04.99	170 54.32	2.01	1 459.1	143.4	14.0
45	1-Aug-12	RBT	1&2B	41 06.38	170 51.63	2.02	7 339.8	46.2	46.4

Station	Date	Type	Stratum	Start latitude (S)	Start longitude (E)	Distance (n. mile)	Hoki (kg)	Ling (kg)	Hake (kg)
46	3-Aug-12	AOS	5A	42 32.71	170 32.24	2.45	-	-	-
47	3-Aug-12	ID	5A	42 33.23	170 35.36	0.24	1 639.3	120.7	11.4
48	4-Aug-12	IDMW	6	42 40.13	169 59.34	1.83	5.2	7.1	0.0
49	4-Aug-12	ID	6	42 49.28	169 55.00	0.40	56.4	18.3	0.0
50	4-Aug-12	ID	6	42 48.40	169 51.39	0.57	940.9	0.0	11.8
51	4-Aug-12	ID	6	42 58.39	169 53.15	0.21	97.1	4.9	0.0
52	4-Aug-12	ID	6	42 56.38	169 48.24	0.29	941.0	1.1	0.0
53	4-Aug-12	ID/AOS	6	43 01.98	169 40.03	1.44	556.3	13.3	24.1
54	5-Aug-12	IDMW	7	43 19.13	169 38.37	0.87	210.9	28.9	0.0
55	5-Aug-12	AOS	5A	42 32.46	170 31.52	3.35	-	-	-
56	5-Aug-12	AOS	5A	42 32.94	170 33.59	1.85	-	-	-
57	6-Aug-12	RBT	4C	41 56.98	170 22.89	2.95	87.1	12.8	196.9
58	6-Aug-12	RBT	4C	42 01.21	170 19.49	2.97	45.4	14.1	162.3
59	6-Aug-12	RBT	4D	42 06.92	170 16.14	3.01	51.6	0.0	237.0
60	6-Aug-12	RBT	4D	42 05.33	170 10.21	3.01	61.7	11.3	346.2
61	6-Aug-12	RBT	4D	42 03.03	170 14.15	3.00	16.8	2.2	76.3
62	7-Aug-12	RBT	4C	41 41.99	170 23.60	2.95	50.7	12.8	219.7
63*	7-Aug-12	RBT	4D	41 34.88	170 12.05	3.00	49.2	0.0	105.6
64	7-Aug-12	RBT	4D	41 33.76	170 21.83	2.84	54.7	16.7	223.6
65	7-Aug-12	RBT	4D	41 34.88	170 17.14	3.03	24.7	5.2	132.9
66	7-Aug-12	ID/AOS	1&2A	41 24.81	170 47.44	1.49	130.1	119.1	8.4
67	8-Aug-12	ID/AOS	4A	41 31.78	170 42.56	2.59	94.1	14.0	0.0
68	8-Aug-12	RBT	1&2A	41 12.33	170 56.05	3.00	1 314.6	1 459.5	0.0
69	8-Aug-12	RBT	1&2S	41 19.46	170 54.71	2.03	0.0	5.8	0.0
70	8-Aug-12	RBT	1&2S	41 22.74	170 54.02	3.00	0.0	0.0	0.0
71	8-Aug-12	CAL		41 06.89	170 27.25	0.61	-	-	-
72	9-Aug-12	RBT	1&2A	41 00.26	171 07.37	3.02	1 627.5	1 035.5	0.0
73	10-Aug-12	RBT	1&2A	41 10.44	170 58.49	2.95	1 484.7	500.5	0.0
74	10-Aug-12	RBT	1&2S	41 07.49	171 05.07	3.01	0.0	0.0	0.0
75*	10-Aug-12	RBT	1&2A	41 02.69	170 59.23	0.22	-	-	-
76	10-Aug-12	RBT	1&2A	41 02.87	170 59.00	3.02	1 168.0	162.1	0.3
77	10-Aug-12	ID/AOS	1&2A	40 38.00	171 25.10	2.00	20.4	69.6	0.0
78	11-Aug-12	RBT	1&2C	40 40.93	170 37.84	3.02	85.1	15.5	13.6
79	11-Aug-12	RBT	1&2C	40 37.28	170 46.77	3.01	100.7	2.5	14.2
80	11-Aug-12	RBT	1&2B	40 39.82	171 08.95	3.00	193.2	33.1	24.4
81*	11-Aug-12	RBT	1&2A	40 38.44	171 20.84	3.02	86.0	118.3	0.0
82	12-Aug-12	RBT	1&2A	40 43.74	171 19.85	3.02	397.1	871.6	0.0
83	12-Aug-12	RBT	1&2A	40 50.36	171 15.48	2.51	3 125.3	692.6	1.1
84	12-Aug-12	RBT	1&2A	40 53.70	171 09.17	2.01	2 105.8	1 028.6	0.0
85	12-Aug-12	RBT	1&2A	40 49.11	171 11.35	3.01	842.0	492.7	0.0
86	12-Aug-12	RBT	1&2B	40 48.86	171 06.77	3.01	236.6	21.7	7.5
87	13-Aug-12	RBT	1&2C	41 06.74	170 36.71	3.02	69.7	5.7	22.9
88	13-Aug-12	RBT	1&2C	41 14.95	170 35.30	3.02	85.7	1.6	49.1
89	13-Aug-12	RBT	1&2C	41 18.44	170 28.86	3.01	88.8	0.0	113.3
90	13-Aug-12	RBT	4S	41 35.37	170 47.54	3.02	0.0	0.0	0.0
91	13-Aug-12	RBT	4S	41 39.17	170 46.28	2.03	0.0	0.0	0.0
92	14-Aug-12	IDMW	5B	42 34.91	170 22.89	0.85	5.0	17.3	2.9
93	14-Aug-12	RBT	4S	42 25.71	170 39.43	2.03	0.0	0.0	0.0
94	14-Aug-12	AOS	5A	42 32.88	170 32.64	2.62	-	-	-
95	14-Aug-12	ID	5A	42 33.36	170 35.50	0.15	468.3	338.5	0.0
96	14-Aug-12	MOOR	5A	42 33.66	170 36.10	0.00	-	-	-

Station	Date	Type	Stratum	Start latitude (S)	Start longitude (E)	Distance (n. mile)	Hoki (kg)	Ling (kg)	Hake (kg)
97	15-Aug-12	ID	6	42 33.71	169 51.07	3.01	58.9	14.2	238.6
98	15-Aug-12	IDMW	6	42 36.14	170 03.57	2.52	419.7	0.0	34.5
99	15-Aug-12	IDMW	6	42 36.08	170 03.77	0.72	5.7	0.0	0.0
100	16-Aug-12	IDMW	6	42 55.96	169 50.96	1.46	7.3	0.0	0.0
101	16-Aug-12	ID	6	42 55.47	169 51.54	0.86	1 834.6	29.8	17.7
102	16-Aug-12	ID/AOS	6	43 05.36	169 40.45	2.01	4 544.8	9.7	30.2

APPENDIX 6: Species list

Scientific and common names, species codes and occurrence (Occ.) of fish, squid, and other organisms from all trawl tows. Note species codes, particularly invertebrates are continually updated on the database following identification ashore.

Scientific name	Common name	Species code	Occ.
Porifera	unspecified sponges	ONG	1
Suberitidae			
Suberites affinis	fleshy club sponge	SUA	1
Tetillidae			
Tetilla leptoderma	furry oval sponge	TLD	1
Cnidaria			
Scyphozoa	unspecified jellyfish	JFI	1
Anthozoa			
Octocorallia			
Actinostolidae	deepsea anemone	ACS	3
Caryophylliidae			
Stephanoctathus platypus	solitary bowl coral	STP	3
Pennatulacea	unspecified seapen	PTU	3
Pennaatulidae			
Pennatula spp.	purple sea pen	PNN	1
Ascidiacea			
Tunicata			
Ascidacea	unspecified sea squirt	ASC	1
Thaliacea	unspecified salps	SAL	11
Salpidae			
Pyrosoma atlanticum		PYR	35
Mollusca			
Gastropoda	gastropods	GAS	1
Buccinidae			
Penion chathamensis		PCH	1
Ranellidae			
Fusitron magellanicus		FMA	1
Nudibranchia	nudibranchs	NUD	1
Cephalopoda			
Teuthoidea: squids	unspecified squid	SQX	2
Cranchiidae	glass squids	CHQ	1
Histioteuthidae			
Histioteuthis atlantica.	violet squid	HAA	2
Histioteuthis miranda.	violet squid	HMI	6
Histioteuthis spp.	violet squid	VSQ	1
Lycoteuthidae			
Lycoteuthis lorigera	crowned firefly squid	LSQ	2
Ommastrephidae			
Nototodarus gouldi	northern arrow squid	NOG	2
N. sloanii & *N.gouldi*	arrow squid	SQU	65
Onychoteuthidae			
Onykia ingens	warty squid	MIQ	1
Sepiadariidae			
Stoloteuthis maoria	bobtail squid	IRM	2

Species

Scientific name	Common name	code	Occ.
Octopoda			
Octopodidae			
Octopus spp.	octopus	OCO	1
Opisthoteuthididae			
Opisthoteuthis spp.	umbrella octopus	OPI	10
Octopoteuthidae			
Octopoteuthis spp.		OPO	1
Arthropoda			
Crustacea			
Malacostraca	prawn unspecified	NAT	1
Galatheidae	unspecified prawn	PRA	2
Munida spp.	squat lobster	MNI	1
Aristaeidae	unspecified prawn	PRA	2
Aristaeopsis edwardsiana	scarlet prawn	PED	1
Nematocarcinidae			
Lipkius holthuisi	omega prawn	LHO	2
Oplophoridae			
Oplophorus novaezeelandiae		ONO	1
Pasiphaeidae			
Pasiphaea spp.	deepwater prawn	PAS	7
P. aff. tarda	deepwater prawn	PTA	1
Sergestidae			
Sergestes arcticus		SAC	4
Sergestes spp.		SER	3
Polychelidae			
Polycheles spp.	deepsea blind lobster	PLY	2
Solenoceridae			
Haliporoides sibogae	jack-knife prawn	HSI	15
Anomura			
Atelecyclidae			
Trichopeltarion fantasticum	frilled crab	TFA	1
Parapoguridae	unidentified hermit crab	PAG	1
Sympagurus dimorphus	hermit crab	SDM	1
Brachyura			
Majidae			
Teratomaia richardsoni	spiny masking crab	SMK	2
Nephropidae			
Metanephrops challengeri	scampi	SCI	18
Scyllaridae			
Ibacus alticrenatus	prawn killer	PRK	15
Cymothoidae	isopod	ISO	1
Cirripedia	barnacle unspecified	BRN	4
Scalpellidae	stalked barnacles	SBN	2
Echinodermata			
Asteroidea	Sea stars	ASR	1
Asteriidae			
Sclerasterias mollis	cross-fish	SMO	1
Astropectinidae			
Dipsacaster magnificus	magnificent sea-star	DMG	2
Plutonaster knoxi	abyssal star	PKN	3
Psilaster acuminatus	geometric star	PSI	33
Proserpinaster neozelanicus		PNE	8

Scientific name	Common name	Species code	Occ.

Goniasteridae			
Lithosoma novaezelandiae	rock star	LNV	2
Mediaster sladeni	Sladen's star	MSL	7
Pterasteridae			
Diplopteraster spp.	starfish	DPP	1
Solasteridae			
Crossaster multispinus	sun star	CJA	10
Solaster torulatus	chubby sun-star	SOT	1
Zoroasteridae			
Zoroaster spp.	rat-tail star	ZOR	1
Crinoidea	sea lilies and feather stars	CRI	1
Echinoidea	unspecified sea urchin	ECT/ECN	2
Regularia			
Histocidaridae			
Histocidaris spp.	urchin	HIS	1
Pedinidae			
Caenopedina porphyrogigas	giant purple pedinid	CAL	1
Echinothuriidae, Phormosomatidae	unspecified Tam O'Shanter urchin	TAM	18
Spatangidae			
Spatangus multispinus	purple heart urchin	SPT	8
Agnatha			
Myxinidae: hagfishes			
Eptatretus cirrhatus	hagfish	HAG	5
Chondrichthyes			
Triakidae: smoothhounds			
Galeorhinus galeus	school shark	SCH	32
Mustelus lenticilatus	spotted dogfish	SPO	2
Hexanchidae: cow sharks			
Heptranchias perlo	sharpnose sevengill shark	HEP	2
Notorynchus cepedianus	broadnose sevengill shark	SEV	1
Squalidae: dogfishes			
Centrophorus squamosus	deepwater spiny dogfish	CSQ	13
Centroscymnus crepidater	longnose velvet dogfish	CYP	7
C. owstoni	smooth skin dogfish	CYO	3
Deania calcea	shovelnose dogfish	SND	16
Etmopterus lucifer	lucifer dogfish	ETL	27
E. molleri	Moller's lantern shark	EMO	1
Proscymnodon plunketi	Plunket's shark	PLS	10
Scymnorhinus licha	seal shark	BSH	13
Squalus acanthias	spiny dogfish	SPD	46
Squalus griffini	northern spiny dogfish	NSD	29
Proscylliidae: finback cat sharks			
Gollum attenuatus	slender smoothhound	SSH	15
Scyliorhinidae: cat sharks			
Cephaloscyllium isabellum	carpet shark	CAR	23
Torpedinidae: torpedo electric rays			
Torpedo fairchildi	electric ray	ERA	3
Rajidae: skates			
Brochiraja asperula	smooth deepsea skate	BTA	12
B. spinifera	prickly deepsea skate	BTS	4
Dipturus innominata	smooth skate	SSK	32
Zearaja nasuta	rough skate	RSK	14

Species

Scientific name	Common name	code	Occ.
Chimaeridae: chimaeras, ghost sharks			
Hydrolagus bemisi	pale ghost shark	GSP	20
H. novaezelandiae	dark ghost shark	GSH	36
Rhinochimaeridae: longnosed chimaeras			
Harriotta raleighana	longnose chimaera	LCH	2
Osteichthyes			
Notacanthidae: spiny eels			
Notocanthus sexspinis	spineback	SBK	9
Synaphobranchidae: cutthroat eels			
Diastobranchus capensis	basketwork eel	BEE	2
Nemichthyidae: snipe eels			
Nemichthys curvirostris	snipe eel	NCU	1
Congridae: conger eels			
Bassanago bulbiceps	swollenheaded conger	SCO	24
B. hirsutus	hairy conger	HCO	14
Argentinidae: silversides			
Argentina elongata	silverside	SSI	31
Alepocephalidae: slickheads			
Xenodermichthys copei	black slickhead	BSL	14
Gonostomatidae: bristlemouths			
Cyclothone spp.	lightfish	CYC	1
Gonostoma elongatum	elongate lightfish	GEL	1
Chauliodontidae: viperfishes			
Chauliodus sloani	viperfish	CHA	7
Notosudidae: waryfishes			
Scopelosaurus spp.	waryfishes	SPL	1
Stomiidae: scaly dragonfishes			
Stomias spp.	scaly dragonfish	STO	1
Paraulopidae: cucumber fishes			
Paraulopus nigripinnis	cucumber fish	CUC	20
Trachipteridae: ribbonfishes			
Trachipterus trachypterus	dealfish	DEA	1
Sternoptychidae: hatchetfishes			
Maurolicus australis	pearlside	MMU	7
Photichthyidae: lighthouse fishes			
Photichthys argenteus	lighthouse fish	PHO	6
Myctophidae: lanternfishes			
Diaphus danae	dana lanternfish	DDA	5
Diaphus hudsoni	Hudson's lanternfish	DHU	2
Diaphus ostenfeldi	Ostendeld's lanternfish	DOE	2
Diaphus spp.	lanternfish	DIA	3
Diplophos spp.	Twin light lanternfishes	DIP	1
Gymnoscopelus spp.	lanternfish	GYM	1
Lampadena notialis	notal lanternfish	LNT	2
Lampanyctodes hectoris	Hector's lanternfish	LHE	9
Lampanyctus australis	austral lanternfish	LAU	6
Lampanyctus spp.	lanternfish	LPA	2
Metelectrona ventralis	flaccid lanternfish	MVE	3
Protomyctophum luciferum	lucifer lanternfish	PLR	1
P. normani	Norman's lanternfish	PNM	1
P. spp.	lanternfish	PRO	3
Symbolophorus boops	bogue lanternfish	SBP	6
Symbolophorus spp.	lanternfish	SYM	1

Scientific name	Common name	Species code	Occ.
Moridae: morid cods			
Halargyreus johnsoni	Johnson’s cod	HJO	4
Mora moro	ribaldo	RIB	27
Pseudophycis bachus	red cod	RCO	32
Pseudophycis barbata	southern bastard cod	SBR	1
Euclichthyidae: eucla cods			
Euclichthys ploynemus	eucla cod	EUC	23
Merlucciidae: hakes			
Macruronus novaezelandiae	hoki	HOK	84
Merluccius australis	hake	HAK	55
Macrouridae: rattails, grenadiers	rattails	RAT	1
Coelorinchus biclinozonalis	two saddle rattail	CBI	19
C. bollonsi	Bollons’s rattail	CBO	51
C. fasciatus	banded rattail	CFA	13
C. innotabilis	notable rattail	CIN	6
C. matamua	Mahia rattail	CMA	7
C. maurofasciatus	dark banded rattail	CDX	15
C. oliverianus	Oliver's rattail	COL	52
C. parvifasciatus	small-banded rattail	CCX	30
Coryphaenoides dossenus	humpback rattail	CBA	1
C . subserrulatus	four rayed rattail	CSU	2
Lepidorhynchus denticulatus	javelinfish	JAV	82
Lucigadus nigromaculatus	blackspot rattail	VNI	10
Nezumia namatahi	velvet rattail	NNA	1
Trachyrincus aphyodes	white rattail	WHX	3
Ophidiidae: cusk eels			
Genypterus blacodes	ling	LIN	73
Regalecidae: oarfishes			
Agrostichthys parkeri	ribbonfish	AGR	1
Trachichthyidae: roughies			
Hoplostethus atlanticus	orange roughy	ORH	2
H. mediterraneus	silver roughy	SRH	67
Paratrachichthys trailli	common roughy	RHY	8
Emmelichthy lenimen	bigeye cardinalfish	EPL	22
Berycidae: alfonsions			
Beryx decadactylus	longfinned beryx	BYD	4
B. splendens	alfonsino	BYS	18
Zeidae: dories			
Capromimus abbreviatus	capro dory	CDO	47
Cyttus novaezealandiae	silver dory	SDO	24
C. traversi	lookdown dory	LDO	62
Macrorhamphosidae: snipefishes			
Centriscops humerosus	banded bellowsfish	BBE	14
Sygnathidae: pipefishes and seahorses			
Soleganthus spinosissimus	spiny seadragon	SDR	1
Scorpaenidae: scorpionfishes			
Helicolenus spp.	sea perch	SPE	78
Oreosomatidae: oreos			
Neocyttus rhomboidalis	spiky oreo	SOR	6
Zeidae: dories			
Zeus faber	john dory	JDO	4
Triglidae: searobins gurnards			
Chelidonichthys kumu	red gurnard	GUR	1
Lepidotrigla brachyoptera	scaly gurnard	SCG	2
Pterygotrigla picta	spotted gurnard	JGU	3

Scientific name	Common name	Species code	Occ.
Hoplichthyidae: ghostflatheads			
Hoplichthys haswelli	deepsea flathead	FHD	28
Percichthyidae: temperate basses			
Polyprion oxygeneios	hapuku	HAP	14
Serranidae: sea basses			
Polyprion oxygeneios	orange perch	OPE	9
Apogonidae: cardinalfishes			
Epigonus lenimen	bigeye cardinalfish	EPL	22
E. telescopus	black cardinalfish	EPT	4
Emmelichthyidae: rovers			
Emmelichthys nitidus	redbait	RBT	33
Plagiogeneion rubiginosum	rubyfish	RBY	5
Carangidae: jacks, pompanos			
Trachurus declivis	greenback jack mackerel	JMD	3
T. murphyi	slender jack mackerel	JMM	7
Bramidae: pomfrets			
Brama australis	southern Ray's bream	SRB	18
Pentacerotidae: armorheads			
Pentaceros decacanthus	yellow boarfish	YBO	30
Cheilodactylidae: morwongs			
Nemadactylus macropterus	tarakihi	TAR	22
Uranoscopidae: armourhead stargazers			
Kathetostoma giganteum	giant stargazer	STA	38
Gempylidae: snake mackerels			
Rexea solandri	gemfish	RSO	10
Thyrsites atun	barracouta	BAR	16
Trichiuridae: cutlassfishes			
Benthodesmus elongatus	bigeye scabbard fish	BEN	10
Lepidopus caudatus	frostfish	FRO	26
Centrolophidae: raftfishes, medusafishes			
Centrolophus niger	rudderfish	RUD	3
Hyperoglyphe antarctica	bluenose	BNS	4
Seriolella brama	blue warehou	WAR	2
S. caerulea	white warehou	WWA	14
S. punctata	silver warehou	SWA	68
Nomeidae: driftfishes			
Cubiceps spp.	scissortail	CUB	1
Bothidae: lefteyed flounders			
Arnoglossus scapha	witch	WIT	12
Diodontidae: porcupinefishes			
Allomycterus pilatus	porcupine fish	POP	1