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Trawl and acoustic survey of hoki and middle depth fish abundance on the west coast South Island, July–August 2013 (TAN1308)

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A combined trawl and acoustic survey of the west coast South Island (WCSI) was carried out from 26 July to 23 August 2013. This was the tenth in a series of acoustic surveys of WCSI hoki spawning areas, and the third in a new time-series of trawl estimates for middle depth species from the WCSI. Species monitored by the trawl survey include important commercial species such as hake and ling, as well as a wide range of non-commercial fish and invertebrate species.

Three acoustic snapshots of the area from Hokitika Canyon south, and two snapshots north of Hokitika Canyon, were completed, with 18 targeted tows to identify acoustic marks and collect biological samples. 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, and gave an average 2013 survey abundance index across the snapshots of 357 000 t. This was 13% lower than the equivalent acoustic index from 2012 and slightly below the long-term average of the time-series. The 2013 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 35%. '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 2013 survey, and gave an average over the three snapshots of 87 000 t (CV 50%) for the area north of the Hokitika Canyon and 123 000 t (26%) from the southern area. The combined 'new' estimate of 210 000 t was 20% lower than the equivalent 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. 'Revised' estimates which updated 'old' estimates for changes in sound absorption, hoki target strength, and stratum areas (but not species decomposition), reduced absolute estimates of hoki abundance by about 40%, but relative indices were similar to those from the 'old' series.

Using 'old' estimates, about 38% of the hoki from the WCSI in 2013 was from the area north of the Hokitika Canyon. This was similar to the proportion in the northern area in 2012 (39%), but higher than the northern abundance in previous acoustic surveys (where only 10–34% of total WCSI hoki abundance was in the north). About 56% of the estimated hoki abundance was from hoki schools, where marks were assumed to contain 100% hoki. The proportion of hoki abundance from school marks was highest in Hokitika Canyon (strata 5A and 5B). Remaining abundance came from mixed species 'fuzz' marks. The proportion of backscatter in fuzz marks attributed to hoki (based on research tows) varied between strata, ranging from 10% hoki in stratum 4D to 61% hoki in stratum 4B.

A total of 65 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 14 356 t (27 %) for hoki, 2009 t (18 %) for ling, and 747 t (21 %) for hake. The trawl estimate of hoki abundance in 2013 was less than half of that from 2012 (32 602 t). Estimates for hake and silver warehou from the trawl survey were also lower than those from 2012, but ling abundance was similar to that in 2012, and estimates for some other species (e.g., lookdown dory) were higher in 2013. Hoki catch rates were highest in 300–430 m depth, which was shallower than in 2012 when catch rates were highest from 400 to 500 m, but the observed hoki distribution in 2013 broadly matched that 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 120.3 t consisting of 162 species or species groups was recorded from all trawl tows, 38 300 fish and squid individuals from 91 different species were measured, and 12 431 fish were also individually weighed. Several modes were present in the hoki scaled length frequency, including numbers of small hoki at 27–38 cm (age 1 year from the 2012 year-class). Relatively high numbers of hoki at 40–58 cm (age 2 years from the 2011 year-class) were observed in 2013, following on from high numbers at age 1 recorded from the 2012 survey. Some of these young hoki (particularly the males) were in spawning condition. The main length mode of larger hoki was between 60 and 100 cm. Ling and hake length data showed broad length ranges, with most ling between 80 and 130 cm, and most hake between 70 and 100 cm, although some very small hake (30–40 cm) were caught.

1. INTRODUCTION

Hoki is New Zealand's largest finfish fishery with a TACC of 150 000 t from 1 October 2013. 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.

The main spawning fisheries for hoki occur from mid-June to late August on the west coast South Island (WCSI) and in Cook Strait. About 54 000 t of hoki was taken from the WCSI in 2011–12, making this the largest New Zealand hoki fishery (Ministry for Primary Industries 2013). The WCSI is also an important fishing area for hake and ling, with reported landings of 4459 t in HAK 7 and 2771 t in LIN 7 in 2011–12 (Ministry for Primary Industries 2013).

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. Two initial surveys were carried out in 2012 and 2013. The survey series will continue at 2-year intervals if these initial surveys are considered 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. The trawl component of a combined survey would also provide relative abundance estimates for other species in the northern area, including ling, hake, silver warehou, and lookdown dory (O'Driscoll et al. 2004).

The first WCSI survey using the new combined trawl and acoustic design was from 20 July to 19 August 2012 (O'Driscoll et al. 2014). This was the ninth in the series of acoustic surveys of WCSI hoki spawning areas, but the first since 2000. Hoki abundance was estimated using the same methods used for the previous surveys in the acoustic time-series (O'Driscoll et al. 2014) and the 2012 acoustic abundance index was included in the 2013 hoki stock assessment (Ministry for Primary Industries 2013). The 2012 survey was also the second in a new time series of trawl estimates for middle depth species from the WCSI, with results that were comparable to the random trawl component from the 2000 WCSI survey. Trawl abundance estimates of hoki were not included in the 2013 assessment pending the evaluation of the reliability of the trawl-based indices for the western hoki stock (Ministry for Primary Industries 2013). However, the trawl survey provided the only fisheries independent estimates of ling and hake abundance on the WCSI and results from the 2012 survey were influential in stock assessments for both of these species in 2013 (Ministry for Primary Industries 2013).

This report describes results from the second combined trawl and acoustic survey of the WCSI from 26 July to 23 August 2013 (TAN1308) and updates trawl and acoustic abundance indices. The 2013 survey followed the same survey design and methods used in 2012. The results of this survey will be critical for evaluating the utility of continuing the WCSI time series.

1.1 Project objectives

This report is the final reporting requirement for Ministry for Primary Industries Research Project HOK2010/04C. 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 in all previous WCSI acoustic surveys, retaining the sub-stratification of Strata 1&2, and 4 used in the 2000 survey (Cordue 2002). In 2012 there were four changes to the survey area to improve coverage of other key species, particularly hake and ling (O'Driscoll et al. 2014):

- 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.

These changes were retained in 2013, so the survey area was the same as that in 2012.

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 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 followed a stratified random trawl survey design (after Francis 1984). A total of 66 stations were planned, based on a statistical analysis of catch rate data from the 2000 and 2012 surveys using the *allocate* programme (Francis 2006). A minimum of 3 and a maximum of 15 stations per stratum was used, with target CVs of 20% for hoki, hake, and ling, and 25% for silver warehou. There was no allowance for phase 2 stations, and strata 1&2S and 4S were to be given lower priority and only carried out if time permitted. Random bottom trawls 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).

The survey design also allowed time for targeted mark identification trawling, acoustic calibration, and target strength data collection.

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 using towed and vessel-mounted Simrad EK60 echosounders. The generally good weather during the first snapshot 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. When wind speeds exceeded 25 knots (much of the second and third snapshots), data were collected using a towed EK60 system (Towbody 3), with a 38 kHz split-beam transducer. A second towbody (Towbody 4), with a CREST 38 kHz echosounder 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 28 July 2013. 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 this calibration was also of excellent quality.

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 119 midwater trawl. This net has a headline height of about 40 m, 150 m bridles, and 40 mm codend mesh. The trawl doors used with both nets 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 by NIWA. 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. As noted in Section 2.1, random bottom tows were only carried out during daylight hours, with all random tows carried out between 0801 h and 1750 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 was 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). Target trawling was carried out both day and night. 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.

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 Marel motion-compensating electronic scales accurate to about 0.1 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 silver warehou for future aging 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 currently contradictory length-to-target strength relationships for hoki obtained from *in situ* measurements and swimbladder modelling (Macaulay 2006, Kloser et al. 2011). To attempt to resolve these differences, and improve our estimates of TS of hoki, hake, and associated species, in 2012 *in situ* data were collected on some mark identification trawls using an acoustic-optical system (AOS) (O'Driscoll et al. 2014). The AOS uses an autonomous EK60 38-kHz echosounder coupled to a high-definition underwater video, which can be mounted in a frame in the headline of a trawl. The trawl is used to herd fish under the AOS where visually verified estimates of TS can be made. Estimates of TS from the AOS in 2012 were used to derive new TS-length relationships for hoki (Dunford et al. 2015).

During the 2013 survey, we collected additional *in situ* data using the AOS on some mark identification trawls. 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 600 m depth during the survey on 19 August 2013.

2.6 Other data collection

A Seabird SM-37 Microcat CTD datalogger was mounted on the headline of the bottom trawl net during each tow 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.

2.7 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 20 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 2.8.3).

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 600 hoki otoliths and 520 ling 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. All available hake otoliths were aged.

Numbers at age were calculated from observed length frequencies from successful random tows and age-length keys using custom 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 zone measurements to improve the consistency of age estimation.

2.8 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).

2.8.1 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 based on their appearance on the echogram (shape, structure, depth, relative strength on multiple frequencies), and using information from mark identification tows. The classification procedure was described in detail by O’Driscoll et al. (2014) and is summarised here.

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. 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 were more homogeneous, 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 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.

2.8.2 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 of backscatter per m^2 of area). 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 2.8.4). 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 was adopted for surveys of New Zealand deepwater fish species. O'Driscoll (2006) and O'Driscoll et al. (2014) both updated the time series of acoustic estimates for the WCSI using the updated sound absorption, but the revised series were 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 2013 was carried out using the estimated sound absorption of 8.80 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.

2.8.3 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. In reality, species mixes occur. There were a number of approaches to deal with the problem of species mix in hoki acoustic surveys in the past and these were described in detail by O'Driscoll et al. (2014).

Two methods of species decomposition were used in the analysis of the 2013 survey. The 'old' method attempted to emulate what was done in 2000 (Cordue 2002, O'Driscoll et al. 2004). All backscatter from the area south of Hokitika Canyon (strata 5A, 5B, 6, and 7) and from hoki school marks in the northern area (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 the "standard method" of species decomposition which partitions acoustic backscatter in each tow based on the composition of the catch and acoustic TS according to equation (2):

$$p_i = \frac{c_i \sigma_i}{\sum_{i=1}^{n} c_i \sigma_i} \tag{2}$$

The proportion of backscatter contributed by each species i (p_i) in a tow is proportional to the product of its catch rate (c_i) and its mean TS (σ_i) as a proportion of the summed acoustic contribution of all species $i = 1 \ldots n$ in the 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. When estimating average acoustic proportion of hoki by substratum (P(hoki) = $\overline{\boldsymbol{p_{hoki}}}$), all tows were assigned equal weighting, regardless of catch. 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:

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

$TS = 30.7 \log_{10}(L) - 95.3$ Dunford et al. (2015) (4)

Equation (3) is the relationship used in species decomposition by Cordue (2002). Equation (4) is the most recent TS-L relationship, derived from combined Australian and New Zealand data.

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, 2014). 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).

2.8.4 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)

$$w = (4.79 \times 10^{-6})\, L^{2.89} \tag{5}$$

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

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

A single ratio was estimated and applied to all substrata. 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 abundance in the northern strata was lower.

Estimates were also calculated following the 'old' method, but updated the TS-L relationship used to estimate r to that of Dunford et al (2015) (see Equation (4)). We termed this the 'revised' method.

In the 'new' method, applied to the 2013 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 2013 survey;

3. the TS-L relationship for hoki from Dunford et al. (2015) 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. The stratum areas of Cordue (2002) were used to update the 'old' estimates of abundance. The updated stratum areas were used for the 'revised' and 'new' abundance estimates. Stratum estimates were combined to produce snapshot estimates, and the snapshots were averaged to obtain the abundance index for 2013. 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 accounted 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 was ignored. The second method assumed 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).

2.8.5 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 was created for each of the variables of interest. Second, random samples from each of the probability distributions were 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 abundance 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' method, assumed distributions were used for species composition in both school and fuzz marks. For the 'revised' and 'new' methods, uncertainty in mix marks in surveys since 2000 was estimated by resampling with replacement (bootstrapping) from the observations (tows) within a substratum. A reduced error component (again based on an assumed distribution) was then added to account for potential variability in trawl catchability and relative TS (Table 3). 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. The CV for the total area using the 'new' method is not the simple sum of squares because errors in the northern and southern areas are not independent.

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

Three different acoustic methodologies were used to estimate abundance of hoki from the 2013 acoustic survey which we have termed: 1) 'old'; 2) 'revised'; and 3) 'new'. The methods are the same as those used to analyse results from the 2012 survey (O'Driscoll et al. 2014), and were described in the preceding sections.

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

The 'old' methods 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 2013).

The 'revised' method was based on O'Driscoll et al. (2014) which updated WCSI acoustic abundance indices from 1988–2012 for changes in sound absorption, more accurately estimated stratum areas, and used the TS-L relationship of Macaulay (2006):

$$TS = 12.2 \log_{10}(L) - 63.9 \quad (7)$$

In this report the same revised method was used, but the most recent TS-L relationship (Equation (4)) was used instead of Equation (7) to estimate *r*. The revised series of O'Driscoll et al. (2014) was not accepted by the HFAWG in 2013 because the update ignored the effect of changing the hoki TS-L relationship on the species decomposition of acoustic backscatter before 2000. This criticism is applicable to both the 'old' and 'revised' methods, because the TS-L 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 latest TS-L relationship (Equation (4)) gave similar estimates of hoki TS to that of Coombs & Cordue (1995) (Dunford et al. 2015), and therefore the effect on decomposition is likely to be insignificant.

The 'new' method follows current best practice. It is important to note that it was not possible to estimate hoki abundance using the 'new' method 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 methods.

The 'new' and 'revised' survey estimates from 2012 were updated from those presented by O'Driscoll et al. (2014) to reflect the change in the most recent hoki TS-L relationship from Macaulay (2006) to Dunford et al. (2015).

2.9 Target strength data analysis

Estimates of mean TS and confidence intervals (95% CI) from bootstrapping were calculated for all optically-verified fish tracks using the methods of O'Driscoll et al. (2013). As the AOS has only one camera, it was not possible to use stereo-photogrammetry to obtain fish lengths. However, by using accurate range derived from the acoustic track and component geometry, pixel counts from the video images were used to estimate fork length of the fish.

3. RESULTS

3.1 Data collection

All survey objectives were completed. Weather conditions were very good during the first half of the survey period, but deteriorated in the second half, and a total of 32 hours of survey time was lost due to bad weather (6 hours on 13–14 August, 10 hours on 16–17 August, and 16 hours on 21 August). We also lost 5 hours on 31 July responding to a distress call, which resulted in the successful rescue of three recreational fishers from a disabled jet boat. We made two trips to Westport on 3 and 18 August (dropping off, then picking up, a vessel crew member for family reasons) for a combined loss of another 16 hours of survey time.

Three acoustic snapshots of the southern area and two acoustic snapshots of the northern area were carried out (see Table 4, Figure 2). A total of 468 acoustic data files (426 hull and 42 towbody) were recorded during the survey, constituting 72.2 GB of data.

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

1. Thirteen mark identification tows were carried out with the NIWA 8-seam hoki bottom trawl including 5 with the acoustic-optical system (AOS) mounted on the headline to provide additional (video) information on species composition and to opportunistically collect data on target strength (see below).
2. Five tows were carried out with the NIWA 119 midwater trawl.

Tow length for mark identification tows ranged from 0.3 to 3.2 n. miles at an average speed of 3.5 knots. Acoustic recordings were made for all tows using the hull-mounted echosounders.

A total of 65 successful random trawl survey tows were completed in the northern area (Table 1, Figure 3). Only 3 of 4 planned tows in stratum 1&2S were completed as shallow strata had lower priority than other objectives when time was lost during the second snapshot due to bad weather and other reasons. One other tow (station 43) was considered unsuitable for abundance estimation because of very high headline height. This tow was abandoned after 5 minutes. Individual station details from all tows, including the catch of hoki, hake and ling are listed in Appendix 5.

3.2 Gear performance

Gear parameters by depth for valid trawl survey tows are summarised in Table 6. The headline height was obtained for all successful tows, and doorspread readings collected for all but one of the valid tows. The missing doorspread value was estimated from data collected in the same depth range on this voyage. Measured gear parameters in 2013 were within the range of those obtained on the valid tows from the 2000 and 2012 surveys where the same gear was used (Table 7). Mean doorspread distances and headline heights for the 2000–13 WCSI surveys were also consistent with those from the *Tangaroa* hoki and middle depths time series surveys on the Chatham Rise (e.g., Stevens et al. 2014) and Sub-Antarctic (Bagley et al. 2014).

3.3 Catch

A total catch of 120.3 t was recorded from all tows. Of the 162 species or species groups caught, 89 were teleosts, 23 elasmobranchs, 6 squids or octopuses, 12 crustaceans, and 17 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 68.6%, ling 8.2%, hake 2.0%, and silver warehou 1.1% of the total catch from all tows.

3.4 Trawl abundance estimates

Abundance estimates and the trawl survey catch for all, and for the core strata for the top 20 species are given in Table 9. Abundance estimates and CVs (in parentheses) for all strata were 14 356 t (26.5 %) for hoki, 2009 t (18.3 %) for ling, and 747 t (21.3 %) for hake. Core strata abundance estimates were similar to total estimates for hoki and ling at 14 184 t and 2000 t respectively (Table 9). The estimate for hake from the core strata was lower, at 331 t, with the remaining abundance coming from the deep 650–800 m stratum (4D). The target CV of 20% was met for ling and core strata hake estimates but exceeded the targets for hoki and all strata hake. The target CV of 25% for silver warehou (see Section 2.1), was achieved with 22% for both core and all strata. There was no allowance for phase 2 tows in this survey.

Abundance estimates by stratum for the top 20 species are given in Table 10. No hoki, hake or ling were caught in the 200–300 m shallow strata 4S and 1&2S. Hoki were abundant in all strata within the core survey area. Stratum 1&2A accounted for 64% of the ling abundance, similar to the 70% estimate from the 2012 survey. For strata deeper than 300 m ling abundance decreased with increasing depth. The shallow strata between 200–300 m accounted for most of the abundance of giant stargazer, barracouta, northern spiny dogfish and tarakihi, and were also important for school shark and silver dory. The deep stratum 4D (650–800 m) had higher abundance estimates for hake, ribaldo and shovelnose dogfish.

The trawl estimate of hoki abundance in the core strata in 2013 (14 184 t) was much lower than the core trawl abundance estimate from the 2012 survey (32 495 t), but higher than that from daytime random tows in the equivalent strata in the 2000 WCSI survey (5385 t) (Table 11). Strata 1&2C and 4B, and to a lesser extent stratum 4C, had much lower estimates of hoki abundance in 2013 than in 2012, with stratum 1&2C having the largest difference (664 t in 2013 compared with 9042 t in 2012). Of the other top 20 species, four species (lookdown dory, barracouta, tarakihi and smooth skate) had higher core abundance estimates in 2013 than in 2012, four species (ling, giant stargazer, sea perch, northern spiny dogfish) had similar estimates (abundance within 10%), while core estimates for the other 11 species (barracouta, spiny dogfish, hake, silver warehou, school shark, javelinfish, alfonsino, ghost shark, shovelnose spiny dogfish, arrow squid, and ribaldo) 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 random trawl survey tows only, are given in Figures 7–8. Hoki catch rates were highest in 300–500 m in all strata (Figure 4). Hoki at ages 1 and 2 years had the highest catch rates in the southern stratum 4A 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 the southern part of stratum 1&2A (Figure 6). Spiny dogfish, silver dory and giant stargazer had higher catch rates to the south, while catch rates of barracouta were higher in the northern part of the trawl survey area (Figure 8).

3.6 Biological data

A total of 38 300 fish and squid of 91 different species were measured (Table 12). Of these, 12 431 fish (totalling 18.6 t) were also individually weighed (Table 12). Additional data on fish condition (liver and gutted weight) were recorded from 1274 hoki. Pairs of otoliths were removed from 1394 hoki, 776 ling, 619 hake, and 390 silver warehou.

Population scaled length frequencies were calculated using length-weight data collected during the 2013 survey (Table 13), and are presented for the top 20 species for core and all strata in Figure 9. Population scaled length frequencies from the 2012 survey are also presented for comparison. Length frequencies by stratum for hoki, hake, ling and silver warehou are given in Figures 10–13. Several modes were present in the hoki scaled length frequency (Figure 9), including small hoki at 27–38 cm (age 1 year from the 2012 year-class) and relatively high numbers at 40–58 cm (age 2 years from the 2011 year-class). Numbers of male hoki were 2.3 times higher than females for fish between 27–38 cm (age 1) and 2.5 times higher for hoki at 40–58 cm (age 2). The main length mode of larger hoki was between 60 to 100 cm. Ling and hake length data showed broad length ranges, with most ling between 80 and 130 cm, and most hake between 70 and 100 cm (Figure 9). Some very small hake (30–40 cm) were caught, with almost all of the larger hake taken to the south in strata 4B, 4C and 4D (Figure 11). Larger ling (males above 80 cm and females greater than 90 cm) were taken in strata 1&2A (300–430 m) in the north and strata 4A and 4B (300–500 m) in the south, while some small ling were caught in the deeper strata 1&2C and 4C (Figure 12). Few small silver warehou (under 30 cm) were caught with most between 40 and 60 cm (Figure 13).

Figures 14–17 compare the length distributions of hoki, hake, ling, and silver warehou in core strata in 2012 and 2013 with those in 2000. There were more small (less than 50 cm) hoki caught in 2012 and 2013 than in the 2000 survey, but fewer hoki less than 40 cm in 2013 than in 2012 (Figure 14). Hake (Figure 15) and ling (Figure 16) showed a similar, broad, length range for all three surveys, although there was a higher proportion of larger female hake in 2000. The modal length of adult silver warehou in 2013 was similar to that in the 2000 and 2012 surveys with modes for males at about 48 cm and 50 cm for female, but few of the small (less than 30 cm) silver warehou, observed in 2012, were taken in 2013 (Figure 17).

Figures 18–20 compare the age distributions of hoki in core strata from the 2012 and 2013 WCSI surveys, and hake and ling in core strata from the 2000, 2012 and 2013 surveys. Hoki from the 2000 survey were not aged. The 2013 survey showed a mode for hoki at age 2, following on from reasonable numbers of fish observed at age 1 in 2012 (Figure 18). The hoki modal peak at age 3 in the 2012 survey (2009 year-class) did not follow on as a stronger 4 year old age class in 2013. There were few male hoki older than age 6 and few females older than age 8 in 2013 (Figure 18). The age distribution of hake showed a higher proportion of younger fish in 2013 than was observed in 2000, with a mode at age 1 (Figure 19). There were fewer male hake older than age 8 and females older than age 10 in 2013 compared with 2012 and 2000 (Figure 19). Ling had a broad range of ages in all three surveys, 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 34% of ling, 27% of hoki, 16% of hake, and 5% of silver warehou from all observations. Most female hoki, hake, and silver warehou were maturing (gonad stage 3) (Table 14). Hoki were actively spawning throughout the survey period, with an increase in the proportion of immature and resting fish from 10 August (Figure 21). Other species of teleosts with more than 90 females sampled and over 50% of fish in maturing and spawning condition (gonad stages 3–6) included giant stargazer, silver dory, barracouta, Bollon’s rattail and Oliver’s rattail. Many female lookdown dory and tarakihi were post-spawning (gonad stage 7), while most javelinfish and ribaldo were resting (gonad stage 2). For elasmobranchs, 68% 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 Hokitika Canyon (strata 5A and 5B). Hoki aggregations were typically at depths of 320 m to 450 m during the day, rising up off the bottom at night (e.g., Figure 23). 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 24). Mesopelagic marks, which usually did not contain hoki, were common. Mesopelagic marks were usually in layers, often with a wavy, undulating appearance. These were typically shallower than hoki schools, and more homogeneous, with no obvious single targets. Mesopelagic layers tended to be stronger on 18 kHz than on 38 kHz suggesting that the organisms were small fish with gas-bladders.

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

Of the 18 mark identification tows, 3 were targeted at hoki schools, 2 at pelagic layers, and 13 at fuzz marks. Catches are summarised in Table 15. The two tows targeted at hoki using the midwater trawl caught 95 and 99% hoki by weight. A tow on hoki marks with the bottom trawl flown above the seabed caught 82% hoki. Tows targeted on bottom fuzz marks with the bottom trawl caught an average of 48% hoki by weight. Tows targeted on pelagic fuzz marks with the midwater trawl had low catch rates but caught 80% hoki by weight (Table 15). The two tows on pelagic marks, which were not thought to contain hoki, caught 15 and 74% hoki by weight. However, catch rates in both of these tows were very low (Table 15), and many mesopelagic species were too small to be retained by the 40–60 mm codends used in hoki trawls.

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 only a weak positive correlation (number of tows, $n = 62$; Spearman’s rank correlation, $rho = 0.19$; $p = 0.14$) between acoustic backscatter in the bottom 100 m recorded during the trawl and hoki catch rates in all bottom tows (Figure 26). The correlation improved, and became statistically significant, (rho = 0.41, $p < 0.001$) when acoustic backscatter was restricted to that within 10 m of the bottom. The vertical distribution of acoustic backscatter recorded during daytime random tows in the northern area in 2013 differed from that in 2012, with a higher proportion of backscatter displaced away from the bottom in 2013 (Figure 27).

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 28). Maps show unpartitioned backscatter from hoki schools and hoki fuzz marks separately. Dense hoki schools were present in Hokitika Canyon (strata 5A and 5B) in all snapshots. In the northern area, few hoki schools were observed, and these occurred further north in the second snapshot (Figure 28). Hoki schools were also detected in the southern area (strata 6 and 7) in all snapshots.

Hoki fuzz marks were widespread in all strata throughout the survey period, with highest (unpartitioned) densities in strata 4, 5A, and 6 (Figure 28). Few hoki marks (schools or fuzz) were seen shallower than 300 m or deeper than 600 m.

The acoustic survey area appeared to encompass all of the commercial fishing effort during the survey period (Figure 29). As for the distribution of acoustic backscatter (see Figure 28), most commercial fishing targeting hoki occurred from 300–600 m depth (Figure 29). There was much more fishing south of Hokitika Canyon in 2013 compared to 2012, when there were very few tows in strata 6 and 7 (O'Driscoll et al. 2014). The acoustic survey was within the period of highest commercial catches, which peaked in the first week of August and then declined (Figure 30).

3.9 Species decomposition

The 13 targeted tows on fuzz marks (i.e., excluding the 5 tows targeted at hoki schools and pelagic layers) and the 59 successful random bottom tows in the acoustic survey area (i.e., excluding the 6 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 9 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 18% (stratum 4D) and 77% (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 25–61% of the backscatter from mixed species marks in the northern area excluding stratum 4D (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 was 19–64% in the same strata (Table 16). The estimated proportion of backscatter from hoki in fuzz marks in the southern area was 57% (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' 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 2.8.4). The hoki length frequency from the 2013 WCSI fishery based on scientific observer data is shown in Figure 31. The mean length of hoki was 79.1 cm (Table 17). Mean weight (obtained by transforming the scaled length frequency distribution in Figure 31 by equation (5) and then calculating the mean of the transformed distribution) was 1.56 kg. The estimated ratios, *r*, for 2013 based on equation (6) ('old' method) and equation (4) ('revised old' method) were 14 728 kg m^{-2} and 7388 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 r from the commercial fishery (r = 7886 kg m^{-2}) for backscatter from all hoki school marks. The r estimates from the commercial fishery differed from that in Table 17 because the survey length-weight relationship (Table 13) was used to transform the scaled length frequency, rather than the generic length-weight relationship of Francis (2003). This resulted in a higher estimated average fish weight of 1.66 kg.

Hoki from research catches in the same region as the main commercial fishery (strata 1&2B and 4B) had similar length composition (Figure 32) to the commercial catch (Figure 31), 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. Surprisingly, small fish were also taken in deeper strata (1&2C and 4C) (Figure 32). Figure 32 includes all research tows (target and random), while Figure 10 was based on random trawl survey tows only. Ratios, r, based on the TS of Dunford et al. (2015) (equation (4)) and the estimated length-weight relationship of hoki from the survey (Table 13) ranged from 7815 kg m^{-2} in stratum 5B to 8230 kg m^{-2} in stratum 1&2A (Table 18).

Hoki abundance estimates by snapshot and strata are given in Table 19 and plotted in Figure 33. Estimates of hoki abundance using the ‘old’ method for 2013 were 349 000 t in the first snapshot and 404 000 t in the second snapshot. Abundance estimates using the ‘revised’ method were about 40% lower than those using ‘old’ methods. ‘New’ estimates, based on current best practice, were very similar to ‘revised’ estimates, although the distribution of abundance between strata varied slightly. Sampling precision (CV) of individual snapshots ranged between 15 and 28% (Table 19).

When results from Table 19 were averaged over all snapshots, 38% of the hoki abundance was in the northern area (strata 12 and 4), 36% in Hokitika Canyon (strata 5A and 5B), and 26% from south of Hokitika Canyon (strata 6 and 7). Using the ‘new’ method, the average proportion of the abundance from hoki schools ranged from 19% in stratum 4 to 96% in stratum 5A (Table 20). On average, using the ‘new’ method across all snapshots, 34% of the hoki abundance in the northern area and 77% of the abundance in the southern area was from hoki schools.

Estimates from all three snapshots were averaged to obtain the overall acoustic abundance index for 2013. Time-series based on ‘old’ and ‘revised’ methodologies are given in Table 21 and plotted in Figure 33. The 2013 acoustic estimate was 13% lower than the equivalent estimate from 2012 using the ‘old’ method and 20% lower using the ‘revised’ method.

Using the ‘new’ method, the acoustic abundance estimate for the northern area was 87 000 t, and the acoustic abundance in the southern area (including Hokitika Canyon) was estimated as 123 000 t (Table 22). The combined ‘new’ estimate of 210 000 t was 21% lower than the equivalent estimate from 2012. The ‘new’ estimate cannot be easily compared with previous surveys in time-series which had more limited mark identification trawling.

3.11 Acoustic weighting for stock assessment

The overall survey weighting estimated from the Monte Carlo simulation model for the 2013 WCSI estimate using the ‘old’ method was 0.53 (see Table 21). The survey weighting using the ‘new’ method, which estimates uncertainty associated with fuzz marks by bootstrapping from research tows within each stratum (see Section 2.8.5) was 0.35 (Table 22). This was lower than that estimated using the ‘old’ method due to much reduced contribution of the uncertainty associated with mark identification (Table 23).

3.12 Target strength

The five AOS deployments provided only 7 optically-verified acoustic tracks from hoki (Figure 34). These covered a wide range of estimated fish lengths from 37–86 cm and gave estimated mean TS between -55.3 and -42.3 dB. These estimates were within the range of TS values estimated from the much larger dataset (62 New Zealand hoki and 24 Australian blue grenadier) presented by Dunford et al. (2015), and are not inconsistent with the new TS-L relationship (Figure 34).

3.13 Hydrological data

The water column was weakly stratified with surface temperatures ranging between 13.3 and 14.3 °C (Figure 35) and bottom temperatures between 6.9 and 13.9 °C (Figure 36). Highest surface temperatures were in the north of the survey area (Figure 35). Bottom temperature decreased with depth, with the lowest bottom temperatures in the west of stratum 6 (Figure 36).

4. DISCUSSION

The 2013 combined trawl and acoustic survey of the WCSI was successfully completed. This was the tenth in a series of acoustic surveys of WCSI hoki spawning areas, and the third in a new time-series of trawl estimates for middle depth species from the WCSI. The trawl survey also provided biological data for important middle depth species (otoliths for ageing, length, weight, sex, gonad stage, and liver weight and gutted fish weight for hoki). Catch composition and weight from the 162 species or species groups along with length and biological data routinely recorded from 91 species during the survey helps fulfil an important “ecosystem monitoring” role, as well as providing inputs into single-species stock assessments.

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 30), 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 29). Research trawl catch rates of hoki (see Figure 4) and the distribution of acoustic backscatter (see Figure 28) also broadly matched the distribution of catch in the northern area and in the Hokitika Canyon (see Figure 29).

The acoustic survey provided relative estimates of spawning hoki abundance. At a meeting on 3 March 2014, the HFAWG decided to continue to use acoustic estimates calculated using the ‘old’ method in the 2014 hoki assessment. This decision meant that it would not require re-calculation of the prior for the acoustic catchabilty (q) and also because there was little difference between relative abundance indices calculated using the ‘old’ and ‘revised’ method (see Figure 33). However, the HFAWG recommended but that the ‘revised’ series should be adopted for future hoki assessments, once the priors on acoustic q were formally updated. This would resolve the inconsistency between acoustic estimates from the WCSI and Cook Strait, which are currently calculated using different TS-L relationships and estimates of sound absorption. The HFAWG further agreed that ‘new’ estimates of survey weighting should be used for surveys from 2000 onwards, with ‘old’ estimates used for previous surveys which had limited mark identification trawling. Revised estimates of survey CVs ranged from 0.28 in 2000 to 0.73 in 1991 (see Table 21).

‘Old’ acoustic estimates estimated that hoki abundance on the WCSI in 2013 was 13% lower than that in 2012 and 10% lower than that in 2000 (see Table 21). However the last three acoustic estimates (2000–13) were all within 10% of the average for the ‘old’ time-series (402 000 t). Recent acoustic abundance indices are consistent with estimates of western hoki spawning stock biomass from the assessment model, which indicate that stock status in 2012–13 is similar to that in 2000 (McKenzie 2014). Acoustic indices contrast with indices based on commercial catch-per-unit-effort (CPUE) on the WCSI which suggest a doubling in CPUE since 2000 (Figure 37).

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, all species have equal catchability, and TS-length relationships (see Table 2) are known. None of these assumptions are likely to be fully met (O'Driscoll et al. 2014). Before 2000, there was the further problem that there was little or no research trawl data to carry out species decomposition and commercial data were used to derive estimates of P(hoki) (Cordue 2002). This uncertainty is now reflected in the revised CVs used for model weighting, which assign lower weights (higher CVs) to surveys before 2000 (see Table 21).

The 'old' and 'revised' analysis methods assume that hoki contribute 100% of the backscatter from all hoki marks (schools and fuzz) outside the northern area. This is not consistent with catch composition from mark identification trawls on fuzz marks in strata 5B, 6, and 7 in 2012 and 2013. In 2012, 13 tows on fuzz marks south of Hokitika Canyon only caught an average of about 44% hoki by weight (O'Driscoll et al. 2014), and, in 2013, 9 tows caught an (unweighted) average of 57% hoki (see Table 16). Estimates of species composition in the southern strata were incorporated when estimating abundance from the 2012 and 2013 surveys using the 'new' method (see Table 22). These 'new' estimates were similar to 'revised' estimates (see Table 21), suggesting that the assumption of 100% hoki in marks in the southern area does not have a major impact on estimated hoki abundance. However, 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.

Estimates of acoustic TS for hoki also affect absolute estimates of hoki abundance. 'Revised' and 'new' estimates which used the most recent hoki TS-L relationship based on AOS measurements by Dunford et al. (2015), are about 40% lower than 'old' estimates (see Figure 33). Although relative indices were very similar, and choice of TS-L relationship will not have a major impact on hoki assessment, experimental work should continue to refine estimates of hoki TS. Measurements of TS based on recent AOS data remove uncertainty around target identification (as all are visually verified), but there is potential bias because fish are being herded into a trawl and their orientation may not be representative of free-swimming fish (Dunford et al. 2015). TS measurements from the AOS are also more likely to overestimate TS due to the potential bias in orientation, and therefore underestimate hoki abundance (Dunford et al. 2015).

Trawl estimates of hoki abundance in the northern area were highly variable between the 2000, 2012, and 2013 trawl surveys. There was a six-fold increase in estimated hoki abundance in core trawl strata between 2000 and 2012, and a halving decrease in 2013 (see Table 11). Variability in trawl estimates of hoki was reflected in both the catch rates and the proportion of hoki in the total catch (Table 24). For example, hoki made up 44–92% of the catch by substrata in the northern area (excluding the new stratum 4D) in 2012, but were only 17–40% of the catch in equivalent strata in 2000, and 36–77% in 2013 (Table 23).

Possible hypotheses to explain the variability in trawl survey abundance of hoki include:
1. Changes in spatial distribution (especially proportion of fish in the northern area);
2. Changes in vertical availability of hoki to the trawl;
3. Differences in survey method

Although the acoustic survey provided some evidence for an increased proportion of hoki in the northern area in 2012–13 compared to 2000, this was not enough to explain the large changes in trawl abundance. In 2013, about 38% of the hoki acoustic abundance (estimated using the 'old' method) was in the northern strata compared to 39% in 2012 and 25% in 2000.

Similarly, any change in trawl survey catchability between 2000, 2012, and 2013 WCSI surveys was unlikely to be related to changes in gear or gear performance. The trawl has been within consistent specifications in all surveys and the same specifications were used for other middle-depth surveys on the Sub-Antarctic and Chatham Rise. The catch of other species over the same period did not show the same variability as hoki, although core abundance of 12 of the top 20 species decreased from 2012 to 2013 (see Table 11).

The most likely explanation for variability in trawl indices for hoki is that there were changes in vertical availability. Acoustic backscatter observed in the bottom 10 m during bottom tows in 2012 was higher than that observed in 2000 and 2013 for most strata (Table 24). The vertical distribution of acoustic backscatter recorded in the northern area in 2013 differed from that in 2012, with a higher proportion of backscatter displaced away from the bottom in 2013 (Figure 27). This may help explain the reduced trawl catch rates in 2013.

Regardless of the explanation, the amount of variability in northern trawl estimates on the WCSI is not consistent with changes in WCSI acoustic indices over the same period (see Table 21), estimated hoki abundance from trawl surveys in the Sub-Antarctic (Bagley et al. 2014), or western spawning stock biomass estimated from the hoki stock assessment model (McKenzie 2014). Trawl estimates of hoki on the WCSI were not included in the 2014 hoki assessment.

Annual variability in trawl estimates will also impact acoustic indices because trawl catches were also used to decompose acoustic estimates from hoki fuzz marks. There is a strong positive correlation between hoki catch rates and the proportion of hoki in the catch (number of tows, $n = 62$; Spearman's rank correlation, $rho = 0.88$; $p < 0.001$ in 2013). However, estimated changes in species composition are much less variable than hoki catch rates (see Table 24), so the effect of any changes in trawl catchability or availability will not be as great on acoustic indices as on trawl estimates. For example, if the catch composition from 2012 was used to decompose acoustic estimates from 2013, then the estimated abundance using the 'old' method would only increase by 3%. This is well within the estimated overall uncertainty (CV) of 35%.

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 were 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 assessments.

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7. TABLES

Table 1: Stratum depth boundaries, areas, and acoustic transect and random trawl allocations for the 2013 WCSI survey. Stratum locations are shown in Figure 1. Curly bracket ({) indicates that the same transects crossed several substrata.

			No. of transects			No. of trawls	
Stratum	Depth (m)	Area (km^2)	Snap 1	Snap 2	Snap 3	Planned	Actual
1&2S	200–300	1 450	0	0	0	4	3
1&2A	300–430	1 214	{4	{4	0	7	7
1&2B	430–500	1 028	{4	{4	0	10	10
1&2C	500–650	3 148	{4	{4	0	15	15
4S	200–300	1 600	0	0	0	3	3
4A	300–430	786	{8	{7	0	10	10
4B	430–500	592	{8	{7	0	8	8
4C	500–650	1 455	{8	{7	0	4	4
4D	650–800	1 655	(8	{7	0	5	5
5A	300–300	254	7	7	6	0	0
5B	position–position	529	3	3	3	0	0
6	250–850 (north of 42.85°S) 250–750 (south of 42.85°S)	2 165	9	8	8	0	0
7	position–position	565	4	4	4	0	0
Total		16 441	35	33	21	66	65

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 8), 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' method)	66	0.9	-38.7	22.32	79.84
Hoki ('new' method)	66	1.1	-39.7	30.69	95.32
Ling	87	3.5	-34.0	20	68
Hake	81	4.2	-37.5	27.1	83.5
Silver warehou	46	1.9	-49.0	20	80
Spiny dogfish	74	1.8	-44.9	20	80
Javelinfish	34	0.1	-32.0	20	73.5
Bigeyed rattail	41	0.4	-33.2	20	70
Lookdown dory	26	0.5	-31.0	20	64
Silver dory	19	0.1	-29.9	20	64
Dark ghost shark	52	0.8	-44.9	20	80
Ribaldo	40	0.8	-30.3	21.7	66.7
Alfonsino	23	0.2	-34.5	20	68
Pale ghost shark	66	1.6	-45.6	20	80
School shark	105	5.4	-46.8	20	80
Leafscale gulper shark	123	13.0	-49.2	20	80
Shovelnosed dogfish	88	2.7	-45.0	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 abundance indices (see Section 2.8.5).

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 CV)
Mark identification – “mix” strata ‘old’	id_{mix}	Lognormal	-0.2 (0.5) +
Mark identification – “mix” strata ‘new’ 2000–13	id_{mix}	Lognormal	0 (0.3) +
Mark identification – “hoki” strata	id_{hoki}	Lognormal	0 (0.08)
Calibration (1988–90)	$cal_{88\text{-}90}$	Uniform	0.75–1.25
Calibration (1991–99)	$cal_{91\text{-}99}$	Uniform	0.88–1.12
Calibration (post 2000)	$cal_{00\text{-}01}$	Uniform	0.95–1.05
Target strength	TS	Uniform	0.88–1.12

*For uniform distributions the 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’ and ‘revised’ methods, uncertainty in mixed marks in 2000–13 was estimated by bootstrapping from observed trawl catches in each survey and then applying a reduced error component to account for potential variability in trawl catchability and relative TS.

Table 4: Summary of acoustic snapshots and mark identification tows in 2013 WCSI survey. South area includes strata 5A, 5B, 6, and 7. North area includes strata 1&2 and 4.

Snapshot	Area	Transect start time	Transect end time	No. of transects	No. of trawls
1	South	29 Jul 16:08	31 Jul 17:08	23	5
	North	1 Aug 17:53	6 Aug 02:36	12	3
2	South	9 Aug 03:18	11 Aug 07:50	22	6
	North	11 Aug 19:33	17 Aug 05:29	11	1
3	South	19 Aug 04:09	20 Aug 22:19	21	3
Total				**89**	**18**

Table 5: Summary of different methods used to estimate hoki abundance from the 2013 WCSI acoustic survey.

	Method		
Parameter	'Old'	'Revised'	'New'
Sound absorption	8.0 dB km^{-1}	8.80 dB km^{-1} (Appendix 4)	8.80 dB km^{-1} (Appendix 4)
Hoki TS used to estimate abundance	Macaulay (2001)	Dunford et al. (2015)	Dunford et al. (2015)
Hoki length-weight	Francis (2003)	Francis (2003)	TAN1308 data
Hoki length distribution	2013 commercial fishery (all strata)	2013 commercial fishery (all strata)	TAN1308 data by substrata for fuzz marks, 2013 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)	Dunford et al. (2015)
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 2013 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 bootstrapping tow data from 2000 on	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 2013 assessment	Comparable to 'old revised' WCSI indices of O'Driscoll et al. (2014) adjusted for change in hoki TS from Macaulay (2006) to Dunford et al. (2015)	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 2013 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)	65	2.8	0.40	1.98–3.07
Tow speed (knots)	65	3.5	0.03	3.4–3.6
Gear parameters (m)				
200–300 m				
Headline height	6	6.9	0.16	6.7–7.1
Doorspread	6	117.0	5.04	109.1–122.6
300–650 m				
Headline height	54	7.0	0.24	6.5–7.7
Doorspread	53	124.9	8.65	108.5–138.3
650–800 m				
Headline height	5	7.0	0.18	6.8–7.3
Doorspread	5	121.3	6.40	114.7–131.8
All tows 200–800 m				
Headline height	65	7.0	0.23	6.5–7.7
Doorspread	64	123.9	8.50	108.5–138.3

Table 7: Comparison of doorspread and headline measurements from valid trawl survey tows from the *Tangaroa* WCSI 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
2013	64	123.9	8.50	108.5	138.3	7.0	0.23

Table 8: Total catch of the top 30 species from all tows (bottom and midwater) during the 2013 WCSI survey.

Code	Common name	Scientific name	Catch (kg)
HOK	Hoki	*Macruronus novaezelandiae*	82 631
LIN	Ling	*Genypterus blacodes*	9 822
SPD	Spiny dogfish	*Squalus acanthias*	6 887
SDO	Silver dory	*Cyttus novaezealandiae*	2 664
HAK	Hake	*Merluccius australis*	2 432
BAR	Barracouta	*Thyrsites atun*	1 828
SSK	Smooth skate	*Dipturus innominatus*	1 414
SWA	Silver warehou	*Seriolella punctata*	1 319
GIZ	Giant stargazer	*Kathetostoma giganteum*	1 222
LDO	Lookdown dory	*Cyttus traversi*	892
SCH	School shark	*Galeorhinus galeus*	872
SPE	Sea perch	*Helicolenus* spp.	633
JAV	Javelinfish	*Lepidorhynchus denticulatus*	628
CBO	Bollons rattail	*Coelorinchus bollonsi*	573
BYS	Alfonsino	*Beryx splendens*	566
SRH	Silver roughy	*Hoplostethus mediterraneus*	532
GSH	Ghost shark (dark)	*Hydrolagus novaezealandiae*	473
NMP	Tarakihi	*Nemadactylus macropterus*	470
SND	Shovelnose spiny dogfish	*Deania calcea*	379
RCO	Red cod	*Pseudophycis bachus*	335
NSD	Northern spiny dogfish	*Squalus griffini*	308
SQU	Arrow squid	*Nototodarus sloanii* & *N. gouldi*	227
CSQ	Leafscale gulper shark	*Centrophorus squamosus*	221
RBY	Rubyfish	*Plagiogeneion rubiginosum*	181
RIB	Ribaldo	*Mora moro*	176
SSH	Slender smooth-hound	*Gollum attenuatus*	176
HAP	Hapuku	*Polyprion oxygeneios*	129
CAR	Carpet shark	*Cephaloscyllium isabellum*	126
YBO	Yellow boarfish	*Pentaceros decacanthus*	125
CYO	Smooth skin dogfish	*Centroscymnus owstoni*	121
Total			120 330

Table 9: Catch and total abundance estimates with coefficient of variation (CV in parentheses) of 20 species ranked by abundance, for valid trawl tows in core strata (300–650 m) and all strata (200–800 m) in 2013. Abundance estimates are provided by sex for core strata. Total abundance includes unsexed fish. – most fish were unsexed.

		Catch (kg)		Biomass (t)			
Common name	Code	Core	All	Core male	Core female	Core total	All total
Hoki	HOK	71 082	71 134	6 201	7 982 (29.6)	14 184 (26.9)	14 356 (26.5)
Ling	LIN	9 218	9 232	861 (21.5)	1 139 (17.6)	2 000 (18.4)	2 009 (18.3)
Barracouta	BAR	31	1 793	0 (100)	5 (55.6)	5 (52.1)	1 617 (36.8)
Spiny dogfish	SPD	6 570	6 623	65 (24.3)	801 (29.6)	867 (29.0)	928 (27.2)
Hake	HAK	1 238	2 024	67 (28.0)	262 (16.4)	331 (17.4)	747 (21.3)
Silver dory	SDO	2 338	2 648	–	–	304 (77.9)	602 (45.9)
Giant stargazer	GIZ	537	1 059	40 (25.9)	52 (21.4)	92 (21.8)	592 (21.4)
Silver warehou	SWA	1 085	1 090	50 (27.4)	264 (25.1)	313 (22.7)	317 (22.4)
Tarakihi	NMP	182	468	22 (49.7)	2 (42.5)	24 (48.5)	311 (22.8)
Smooth skate	SSK	1 182	1 238	110 (25.5)	118 (23.7)	228 (19.6)	272 (23.1)
School shark	SCH	745	855	86 (24.6)	73 (31.7)	159 (21.8)	252 (18.3)
Lookdown dory	LDO	794	856	49 (13.9)	156 (11.6)	205 (11.1)	236 (11.6)
Sea perch	SPE	565	586	55 (13.9)	40 (12.2)	126 (9.2)	142 (9.8)
Javelinfish	JAV	560	604	18 (17.9)	66 (14.7)	122 (13.1)	141 (11.5)
Northern spiny dogfish	NSD	210	299	45 (31.5)	3 (27.9)	48 (29.5)	131 (22.7)
Alfonsino	BYS	564	564	74 (26.8)	46 (25.9)	120 (26.2)	120 (26.3)
Ghost shark (dark)	GSH	426	453	41 (24.6)	34 (21.8)	75 (21.4)	101 (20.2)
Shovelnose spiny dogfish	SND	170	263	2 (100)	47 (25.5)	49 (24.8)	95 (28.0)
Arrow squid	SQU	170	203	15 (12.2)	13 (12.9)	28 (9.9)	52 (17.6)
Ribaldo	RIB	52	134	2 (26.3)	13 (35.3)	16 (29.9)	57 (25.7)

Table 10: Estimated trawl abundance (t) and coefficient of variation (% CV) of the top 20 species by stratum. See Table 9 for species common names. – less than 1 t.

	Species code					
Stratum	HOK	LIN	SPD	HAK	SWA	SDO
1&2A	2 543 (27.4)	1 275 (27.3)	3 (64.6)	4 (65.5)	14 (45.7)	–
1&2B	4 416 (72.5)	73 (15.6)	–	20 (35.1)	36 (35.1)	–
1&2C	664 (13.7)	50 (21.7)	–	73 (27.1)	142 (27.6)	–
4A	4 291 (43.8)	425 (26.3)	683 (34.4)	8 (47.9)	7 (39.8)	304 (77.9)
4B	1 541 (28.4)	135 (25.6)	180 (49.4)	58 (47.3)	6 (41.7)	–
4C	728 (28.8)	42 (35.3)	–	168 (27.1)	108 (53.1)	–
Subtotal (core)	14 184 (26.9)	2 000 (18.4)	867 (29.0)	331 (17.4)	313 (22.7)	304 (77.9)
1&2S	–	–	–	–	1 (100.0)	231 (60.0)
4S	–	–	61 (38.9)	–	2 (100.0)	68 (55.2)
4D	173 (29.9)	8 (49.4)	–	416 (35.6)	1 (100.0)	–
Total	14 356 (26.5)	2 009 (18.3)	928 (27.2)	747 (21.3)	317 (22.4)	602 (45.9)

	Species code					
Stratum	GIZ	BAR	SCH	NSD	NMP	BYS
1&2A	33 (27.3)	2 (100.0)	99 (36.4)	35 (39.1)	1 (100.0)	50 (50.6)
1&2B	2 (66.7)	–	1 (100.0)	7 (41.1)	–	1 (53.1)
1&2C	– (100.0)	–	13 (74.3)	1 (100.0)	–	17 (49.7)
4A	41 (41.8)	3 (50.2)	41 (30.2)	5 (38.0)	23 (50.4)	44 (33.3)
4B	13 (42.1)	–	6 (83.8)	–	–	–
4C	3 (60.0)	–	–	–	–	8 (96.9)
Subtotal (core)	92 (21.8)	5 (52.1)	159 (24.8)	48 (29.5)	24 (48.5)	120 (26.2)
1&2S	49 (52.6)	922 (48.0)	60 (31.5)	47 (34.6)	120 (36.4)	–
4S	448 (27.3)	690 (57.8)	33 (42.7)	36 (57.0)	167 (32.7)	–
4D	2 (100.0)	–	–	–	–	–
Total	592 (21.4)	1 617 (36.8)	252 (18.3)	131 (22.7)	311 (22.8)	120 (26.2)

	Species code					
Stratum	SSK	SPE	JAV	LDO	GSH	SND
1&2A	62 (47.3)	24 (22.3)	26 (40.6)	15 (57.0)	31 (38.2)	–
1&2B	82 (27.7)	19 (16.0)	11 (21.2)	33 (20.2)	6 (48.1)	–
1&2C	33 (60.5)	55 (14.6)	39 (22.1)	124 (15.3)	–	49 (24.8)
4A	40 (35.2)	8 (27.3)	22 (27.9)	1 (78.4)	39 (27.4)	–
4B	11 (42.7)	11 (31.2)	7 (21.7)	5 (28.3)	–	–
4C	–	9 (43.8)	16 (28.1)	29 (23.6)	–	–
Subtotal (core)	228 (19.6)	126 (9.2)	122 (13.1)	205 (11.1)	75 (21.4)	49 (24.8)
1&2S	44 (100.0)	10 (72.6)	–	–	23 (52.0)	–
4S	–	2 (50.0)	–	–	2 (100.0)	–
4D	–	4 (25.3)	19 (14.0)	31 (49.1)	–	46 (51.4)
Total	272 (23.1)	142 (9.8)	1141 (11.5)	226 (11.6)	101 (20.2)	95 (28.0)

Table 10: continued.

	Species code	
Stratum	RIB	SQU
1&2A	–	7 (15.4)
1&2B	–	2 (27.7)
1&2C	12 (35.9)	–
4A	–	13 (14.2)
4B	–	5 (31.4)
4C	3 (59.8)	1 (57.7)
Subtotal (core)	16 (29.9)	28 (9.9)
1&2S	–	13 (38.5)
4S	–	12 (62.3)
4D	41 (33.6)	–
Total	57 (25.7)	52 (17.6)

Table 11: Trawl abundance estimates, coefficients of variation comparisons for the core strata (300–650 m) from the 2000, 2012, and 2013 WCSI trawl surveys. The 2000 survey abundance estimates were re-calculated using 2012–13 stratum areas. Giant stargazer was coded as STA, and tarakihi was TAR in 2000.

		Core area abundance (t) and CV (%)		
Common name	Code	2000	2012	2013
Hoki	HOK	5 385 (20.6)	32 495 (24.2)	14 184 (26.9)
Ling	LIN	1 861 (17.3)	2 169 (14.8)	2 000 (18.4)
Barracouta	BAR	4 (42.8)	12 (42.8)	5 (52.1)
Silver dory	SDO	113 (62.0)	259 (46.5)	304 (77.9)
Spiny dogfish	SPD	233 (53.6)	1 095 (24.7)	867 (29.0)
Hake	HAK	803 (13.4)	583 (12.8)	331 (17.4)
Silver warehou	SWA	1 507 (24.6)	617 (32.2)	313 (22.7)
Smooth skate	SSK	186 (28.0)	167 (29.5)	228 (19.6)
School shark	SCH	98 (69.8)	186 (24.8)	159 (21.8)
Lookdown dory	LDO	169 (14.4)	155 (11.9)	205 (11.1)
Tarakihi	NMP	22 (32.2)	21 (41.7)	24 (48.5)
Giant stargazer	GIZ	74 (27.3)	97 (22.6)	92 (21.8)
Sea perch	SPE	123 (6.7)	136 (15.9)	126 (9.2)
Javelinfish	JAV	198 (17.4)	166 (11.3)	122 (13.1)
Alfonsino	BYS	14 (41.0)	262 (58.8)	120 (26.2)
Northern spiny dogfish	NSD	96 (23.1)	49 (20.4)	48 (29.5)
Ghost shark (dark)	GSH	77 (32.5)	106 (16.9)	75 (21.4)
Shovelnose spiny dogfish	SND	153 (29.5)	68 (70.6)	49 (24.8)
Arrow squid	SQU	18 (22.6)	95 (18.3)	28 (9.9)
Ribaldo	RIB	104 (26.3)	43 (25.3)	16 (29.9)

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	916	562	354	37	261	21
Arrow squid	483	209	155	47	252	19
Banded rattail	1	0	0	1	1	1
Barracouta	553	274	279	14	256	12
Basketwork eel	12	10	2	1	0	0
Bigeye cardinalfish	170	67	56	12	11	2
Black slickhead	143	66	69	7	91	5
Bluenose	1	1	0	1	1	1
Bollons rattail	1 302	799	489	49	1 133	41
Capro dory	358	0	0	4	0	0
Carpet shark	11	8	3	2	11	2
Common roughy	21	12	9	1	0	0
Cucumber fish	337	12	5	4	108	2
Deepsea cardinalfish	2	2	0	1	2	1
Deepsea flathead	18	3	14	4	18	4
Eucla cod	77	9	68	1	0	0
Frostfish	129	37	46	23	120	19
Gemfish	15	5	10	12	14	11
Ghost shark (dark)	551	319	231	33	335	27
Giant stargazer	328	207	120	37	300	32
Greenback jack mackerel	10	4	6	2	10	2
Gurnard	6	1	5	2	6	2
Hairy conger	5	2	3	2	0	0
Hake	635	259	375	52	633	51
Hapuku	13	4	9	8	13	8
Hector's lanternfish	1	0	0	1	1	1
Hoki	13 662	6 113	7 541	77	1 430	69
Humpback rattail	1	0	1	1	1	1
Javelinfish	3 032	730	1507	61	610	18
John dory	29	4	25	5	29	5
Johnson's cod	21	13	8	2	14	1
Leafscale gulper shark	16	4	12	10	16	10
Lestidiops spp	1	0	0	1	1	1
Lighthouse fish	1	0	0	1	0	0
Ling	1 898	1 083	815	67	824	62
Longfinned beryx	1	1	0	1	1	1
Longnose velvet dogfish	42	19	23	8	39	5
Long-nosed chimaera	1	1	0	1	1	1
Lookdown dory	1 481	660	818	59	1 121	54
Lucifer dogfish	65	26	39	23	42	19
Mahia rattail	21	13	8	5	21	5
Northern spiny dogfish	198	145	53	26	165	23
Notable rattail	2	0	0	1	0	0
Olivers rattail	966	585	261	24	851	22
Orange perch	76	36	40	3	51	2
Orange roughy	72	36	33	3	72	3
Pale ghost shark	52	30	22	21	51	21
Plunket's shark	10	7	3	3	10	3
Prickly deepsea skate	1	1	0	1	1	1
Red cod	405	323	79	31	311	23
Redbait	108	43	65	44	79	30
Ribaldo	129	27	102	31	127	31
Rig	3	2	1	3	3	3

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
Rough skate	13	7	6	8	13	8
Rubyfish	109	50	59	4	41	4
Rudderfish	4	0	4	2	4	2
Scabbard fish	2	1	1	1	2	1
Scaly gurnard	3	1	2	1	3	1
Scampi	69	52	17	25	66	23
School shark	140	75	65	31	110	28
Sea perch	3 167	1 356	951	74	688	29
Seal shark	18	9	9	13	16	11
Serrulate rattail	1	0	1	1	0	0
Sharpnose sevengill shark	8	0	8	5	8	5
Shovelnose spiny dogfish	130	55	75	19	111	17
Silver dory	744	228	286	11	201	2
Silver roughy	2 420	90	137	39	12	1
Silver warehou	587	131	456	57	494	55
Silverside	17	0	0	2	0	0
Slender jack mackerel	1	0	1	1	1	1
Slender smooth-hound	96	46	50	23	86	21
Small-headed cod	2	1	1	1	2	1
Smallscaled slickhead	1	0	1	1	1	1
Smooth deepsea skate	1	1	0	1	1	1
Smooth skate	91	45	46	34	89	32
Smooth skin dogfish	16	7	9	3	16	3
Southern boarfish	1	1	0	1	1	1
Southern rays bream	54	25	29	13	53	12
Spiky oreo	91	43	47	3	91	3
Spineback	1	1	0	1	0	0
Spiny dogfish	1 377	230	1 147	29	349	21
Spotted gurnard	1	1	0	1	1	1
Swollenhead conger	8	2	6	2	2	1
Tarakihi	430	306	124	14	395	13
Two saddle rattail	63	38	25	7	60	6
Viper fish	22	0	1	1	0	0
White rattail	25	8	17	6	17	4
White warehou	19	4	15	12	19	12
Widenosed chimaera	1	0	1	1	1	1
Witch	1	0	1	1	1	1
Yellow boarfish	174	25	27	4	28	1
Total	38 300	15 613	17 389	83	12 431	81

†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 2013 (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).

	Regression parameters				Length	
Species	*a*	*b*	r^2	*n*	range (cm)	Data source
Alfonsino	0.015798	3.0909	0.94	261	19.2 – 29.7	TAN1308
Arrow squid	0.061926	2.7652	0.99	238	8.8 – 40.8	TAN1308
Barracouta	0.035711	2.5473	0.80	256	59.5 – 91.2	TAN1308
Dark ghost shark	0.001210	3.4051	0.98	335	24.0 – 69.2	TAN1308
Giant stargazer	0.003231	3.4150	0.97	300	29.1 – 77.2	TAN1308
Hake	0.003459	3.1721	0.99	626	27.1 – 119.8	TAN1308
Hoki	0.005070	2.8832	0.99	1 424	27.8 – 117.0	TAN1308
Javelinfish	0.000734	3.3118	0.97	576	22.5 – 59.4	TAN1308
Ling	0.000868	3.3853	0.99	822	31.6 – 161.2	TAN1308
Lookdown dory	0.020831	3.0087	0.99	1 112	10.5 – 54.6	TAN1308
Northern spiny dogfish	0.002249	3.1494	0.97	164	45.1 – 84.3	TAN1308
Ribaldo	0.004832	3.2013	0.99	127	21.3 – 71.3	TAN1308
School shark	0.012690	2.7878	0.96	109	77.3 – 143.5	TAN1308
Sea perch	0.011844	3.0736	0.99	680	12.1 – 47.1	TAN1308
Shovelnose dogfish	0.000707	3.3673	0.95	111	44.9 – 113.5	TAN1308
Silver dory	0.005810	3.3687	0.96	198	13.5– 23.5	TAN1308
Silver warehou	0.007648	3.2238	0.99	494	22.1 – 57.1	TAN1308
Smooth skate	0.017829	3.0090	0.99	85	39.8 – 150.7	TAN1308
Spiny dogfish	0.000373	3.5681	0.88	344	60.3 – 92.0	TAN1308
Tarakihi	0.013232	3.0709	0.95	395	28.5 – 47.8	TAN1308

* 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 200 observations for elasmobranchs.

Species and sex	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7
Teleosts							
Hoki males	683	355	419	2 536	1 051	727	301
Hoki females	1 091	900	2 037	1 163	67	820	1 451
Hake males	74	7	2	22	57	87	10
Hake females	48	28	165	19	8	33	72
Ling males	112	140	58	595	94	75	9
Ling females	143	231	138	258	8	14	21
Silver warehou males	2	1	3	75	50	0	0
Silver warehou females	3	4	425	18	3	1	1
Lookdown dory males	189	230	11	14	0	0	31
Lookdown dory females	220	203	0	0	1	1	186
Oliver’s rattail males	11	500	5	13	0	0	0
Oliver’s rattail females	7	10	86	99	7	33	4
Bollon’s rattail males	12	471	24	3	0	0	0
Bollon’s rattail females	46	9	7	46	1	44	9
Elasmobranchs							
Spiny dogfish males	0	1	40				
Spiny dogfish females	3	5	21	42	160	3	
Dark ghost shark males	39	26	62				
Dark ghost shark females	19	32	23	0	0	0	

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

Table 15: Summary and catch information from mark identification tows during the 2013 WCSI survey. Mark type refers to the categories described in the text: HOK = hoki school; PMIX = hoki pelagic fuzz; BMIX = hoki bottom fuzz; Pelagic = pelagic layer.

				Catch (kg)						
Station	Trawl	Stratum	Mark type	Hoki	Hake	Spiny dogfish	Ling	Silver warehou	Other	% Hoki
3	Midwater	5B	Pelagic	2	0	0	0	0	0	74
4	Bottom	6	BMIX	3 583	70	1	21	3	61	96
5	Bottom	6	BMIX	72	45	0	0	0	273	19
6	Bottom	6	BMIX	543	42	14	114	170	175	51
7	Midwater	7	PMIX	4	0	0	0	0	2	65
17	Bottom+	4A	BMIX	51	0	82	21	0	89	21
27	Bottom	12C	BMIX	40	10	0	4	5	87	27
38	Bottom+	12B	BMIX	387	13	0	19	2	24	87
49	Bottom	5A	PMIX	761	12	24	154	0	94	73
50	Midwater	5B	HOK	1 709	14	0	0	0	9	99
51	Midwater	6	HOK	2 073	56	55	0	0	3	95
52	Bottom	6	BMIX	48	32	0	0	6	178	18
53	Bottom+	6	Pelagic	34	3	12	3	35	133	15
54	Midwater	7	PMIX	341	12	3	5	0	3	94
81	Bottom*+	12A	PMIX	153	0	0	179	2	52	40
85	Bottom*+	5A	HOK	319	0	42	24	0	3	82
86	Bottom	6	BMIX	20	17	0	0	1	90	16
87	Bottom	6	PMIX	1 090	82	32	46	3	156	77

* Net was flown above the bottom and did not contact the seabed.
+ Tow with acoustic-optical system (AOS) attached.

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'). South area includes strata 5A, 5B, 6, and 7. In the 'old' analysis method P(hoki) from the south area was assumed to be 1 and stratum 4D was excluded.

		Mean % hoki in catch		P(hoki)	
Stratum	No. of tows	Unweighted	Weighted	'Old' method	'New' method
1&2A	7	55	57	0.42	0.37
1&2B	11	67	80	0.47	0.64
1&2C	17	42	43	0.25	0.19
4A	11	52	61	0.46	0.48
4B	8	77	77	0.61	0.61
4C	4	58	60	0.39	0.34
4D	5	18	18	–	0.10
South	9	57	72	1.00	0.60

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 31) using the TS-length relationships of Macaulay (2001), Macaulay (2006), and Dunford et al. (2015). Estimates based on Macaulay (2001) were used to generate 'old' time-series of hoki abundance estimates. Estimates based on Dunford et al. (2015) were used to generate the 'revised' time-series.

			Macaulay (2001)		Macaulay (2006)		Dunford et al. (2015)	
Year	Mean length (cm)	Mean weight (kg)	Mean TS (dB)	*r* (kg m^{-2})	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	-36.5	7 367
1989	81.6	1.67	-39.5	15 006	-40.6	19 009	-36.5	7 372
1990	81.9	1.69	-39.5	15 073	-40.6	19 134	-36.4	7 365
1991	80.5	1.63	-39.6	14 967	-40.6	18 879	-36.5	7 370
1992	79.3	1.54	-39.8	14 600	-40.7	18 208	-36.8	7 403
1993	78.2	1.49	-39.9	14 400	-40.8	17 831	-37.0	7 421
1997	74.1	1.31	-40.3	13 861	-41.1	16 733	-37.6	7 458
2000	80.3	1.59	-39.7	14 763	-40.7	18 523	-36.7	7 390
2012	75.4	1.37	-40.1	14 090	-41.0	17 154	-37.4	7 438
2013	79.1	1.56	-39.8	14 728	-40.7	18 403	-36.8	7 388

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 32). Estimates were derived using the TS-length relationships Macaulay (2006) and Dunford et al. (2015).

			Macaulay (2006)		Dunford et al. (2015)	
Stratum	Mean length (cm)	Mean weight (kg)	Mean TS (dB)	*r* (kg m^{-2})	Mean TS (dB)	*r* (kg m^{-2})
1&2A	58.5	0.74	-42.3	12 580	-40.5	8 230
1&2B	78.4	1.62	-40.8	19 336	-36.9	7 899
1&2C	58.8	0.82	-42.3	13 797	-40.0	8 116
4A	58.1	0.78	-42.3	13 384	-40.2	8 149
4B	73.2	1.37	-41.1	17 716	-37.7	7 961
4C	65.2	1.05	-41.7	15 587	-38.9	8 035
4D	70.7	1.26	-41.3	16 996	-38.0	7 985
5A	60.1	0.80	-42.2	13 209	-40.1	8 188
5B	84.0	1.97	-40.4	21 597	-36.0	7 815
6	67.8	1.15	-41.5	16 280	-38.4	8 024
7	61.5	0.99	-42.0	15 711	-39.1	8 007

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).

		Abundance ('000 t)							
Method	Snapshot	12	4	5A	5B	6	7	Total	CV (%)
'Old'	1	43	69	96	64	66	10	349	19
	2	130	32	47	81	92	23	404	28
	3	–	–	66	27	65	24	181	15
	Mean	86	50	70	57	74	19	357	13
'Revised'	1	25	40	61	37	39	6	208	18
	2	72	18	30	47	53	15	234	27
	3	–	–	42	16	38	15	110	15
	Mean	48	29	44	33	43	12	210	13
'New'	1	27	43	64	36	32	6	209	20
	2	84	19	31	46	47	11	238	28
	3	–	–	44	13	29	11	97	18
	Mean	56	31	46	32	36	9	210	15

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	19	28	97	81	38	77	60
	2	55	0	85	83	59	22	59
	3	–	–	94	43	27	20	54
	Mean	46	19	93	76	44	31	56
'Revised'	1	19	28	97	80	38	77	60
	2	54	0	85	82	59	22	59
	3	–	–	94	43	27	19	54
	Mean	45	19	93	75	43	31	55
'New'	1	18	28	98	87	50	84	64
	2	49	0	90	89	70	31	61
	3	–	–	96	56	38	28	66
	Mean	42	19	96	84	55	42	59

Table 21: Recalculated acoustic abundance indices for WCSI. Indices using 'old' method updated from O'Driscoll (2002). Indices using 'revised' method based on O'Driscoll et al. (2014) but updated using hoki TS of Dunford et al. (2015) instead of Macaulay (2006). The CV is the estimated model weighting (see Table 23).

	'Old'		'Revised'	
Year	Abundance ('000 t)	CV	Abundance ('000 t)	CV
1988	417	0.60	237	0.60
1989	249	0.38	147	0.38
1990	255	0.40	150	0.40
1991	341	0.73	203	0.73
1992	345	0.49	207	0.49
1993	549	0.38	347	0.38
1997	655	0.60	415	0.60
2000	397	0.60	237	0.28
2012	412	0.50	261	0.34
2013	357	0.53	210	0.35

Table 22: New acoustic abundance indices for northern and southern areas on the WCSI. 'New' estimates could not be calculated for surveys before 2012 because there was insufficient mark identification trawling. The CV is the estimated model weighting (see Table 23). CV for the total area is not the simple sum of squares as errors are not independent.

	Northern area		Southern area		Total	
Year	Abundance ('000 t)	CV	Abundance ('000 t)	CV	Abundance ('000 t)	CV
2012	123	0.39	143	0.30	266	0.34
2013	87	0.50	123	0.26	210	0.35

Table 23: Results of Monte Carlo simulations to determine model weighting for the 2013 WCSI acoustic survey (see Section 2.8.5 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. CV for the total area is not the simple sum of squares as errors are not independent.

	'Old' Method	'New' Method		
	Entire area	North	South	Total
Timing	0.100	0.075	0.097	
+ Sampling	0.167	0.299	0.183	
+ Mark identification	0.516	0.487	0.255	
+ Calibration	0.517	0.488	0.256	
+ TS	0.526	0.496	0.264	
Total	0.526	0.316	0.264	0.353

Table 24: 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, 2012, and 2013.

	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

	2013			
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
1&2A	0.41	2.19	3 601	55
1&2B	0.43	5.08	4 668	64
1&2C	0.85	5.45	531	36
4A	2.48	5.56	7 739	55
4B	1.25	6.16	3 386	77
4C	1.23	5.31	806	62

8. FIGURES

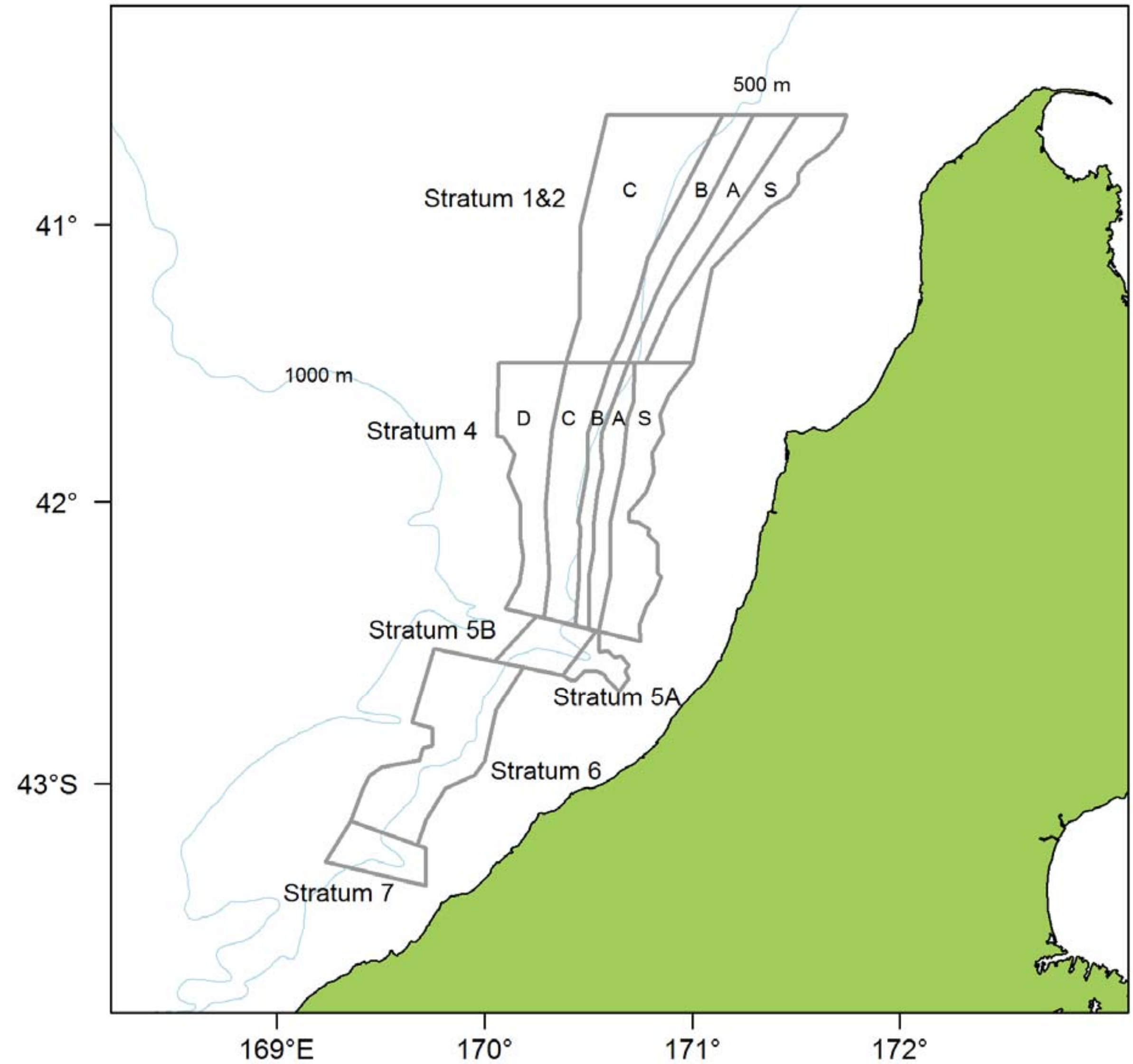

Figure 1: Stratum boundaries for the 2013 survey of the WCSI. Stratum areas are given in Table 1.

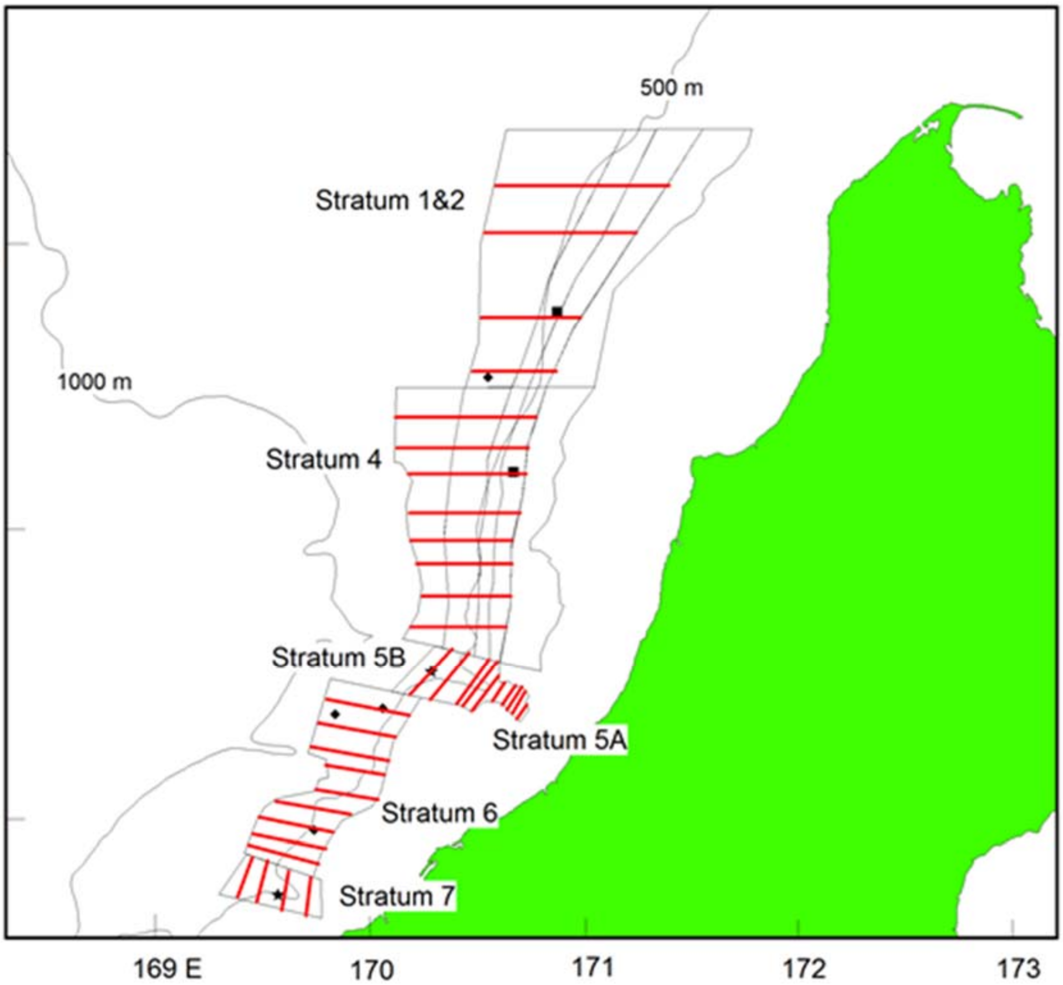

Figure 2: Location of acoustic transects (red lines) and mark identification trawls during snapshot 1 on 29 July to 6 August 2013. Squares are AOS trawls, diamonds are bottom trawls, and stars are midwater trawls.

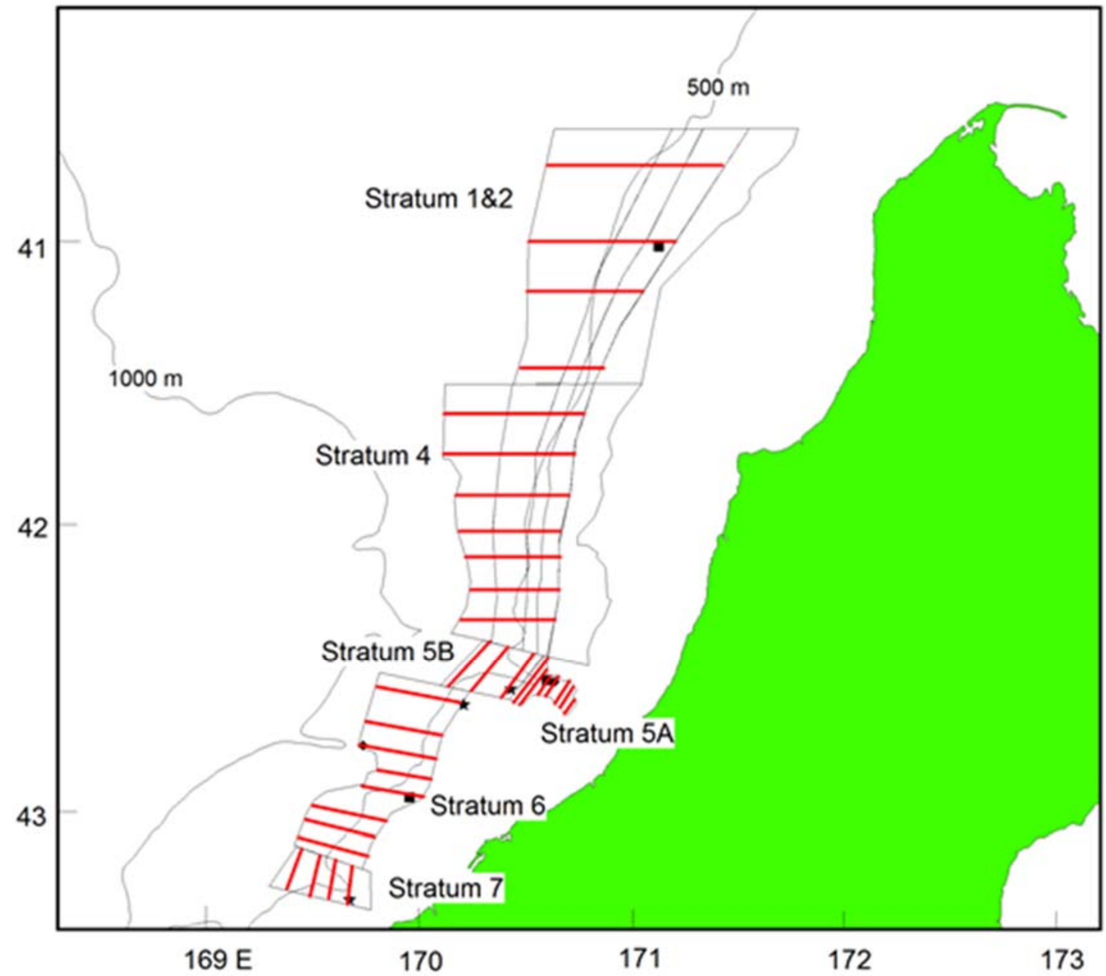

Figure 2 cont: Location of acoustic transects (red lines) and mark identification trawls during snapshot 2 on 9–17 August 2013. Squares are AOS trawls, diamonds are bottom trawls, and stars are midwater trawls.

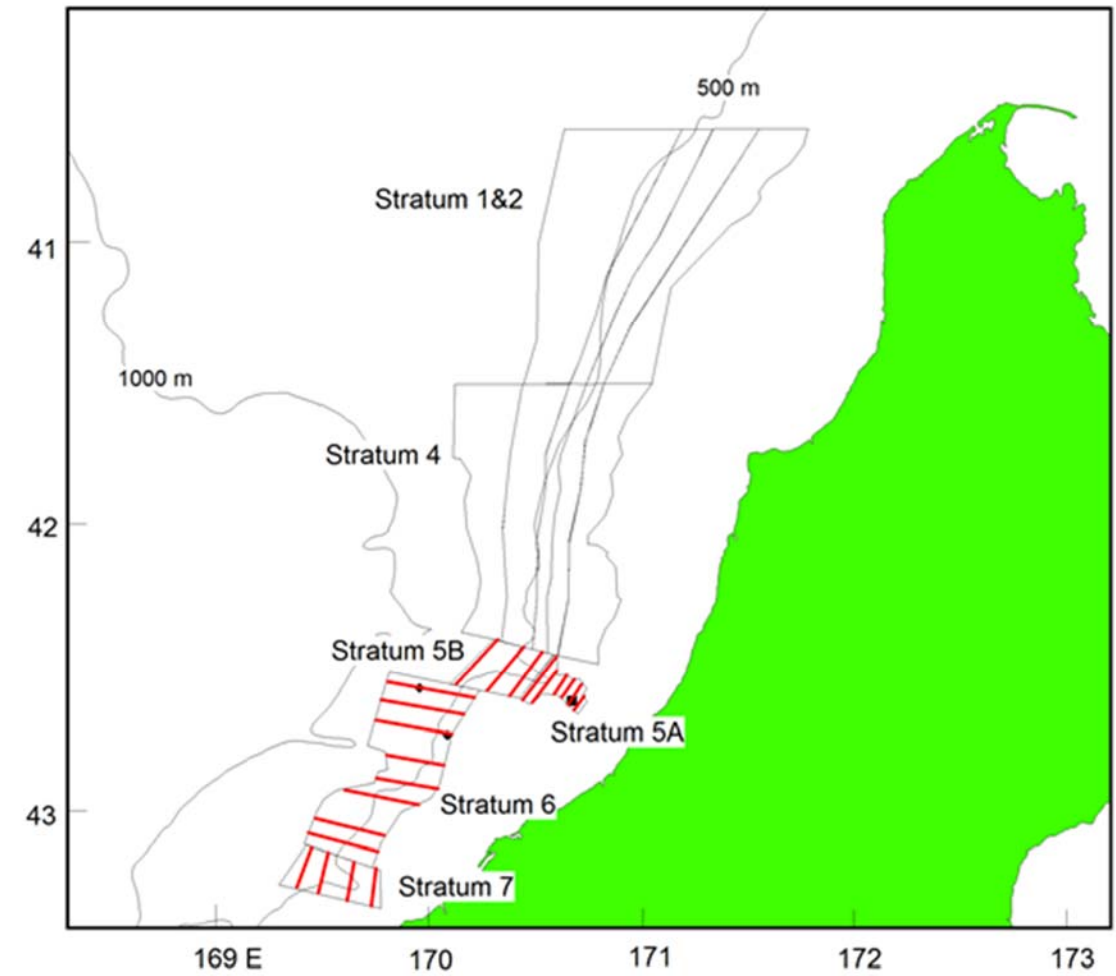

Figure 2 cont: Location of acoustic transects (red lines) and mark identification trawls during snapshot 3 on 19–21 August 2013. Squares are AOS trawls, diamonds are bottom trawls, and stars are midwater trawls.

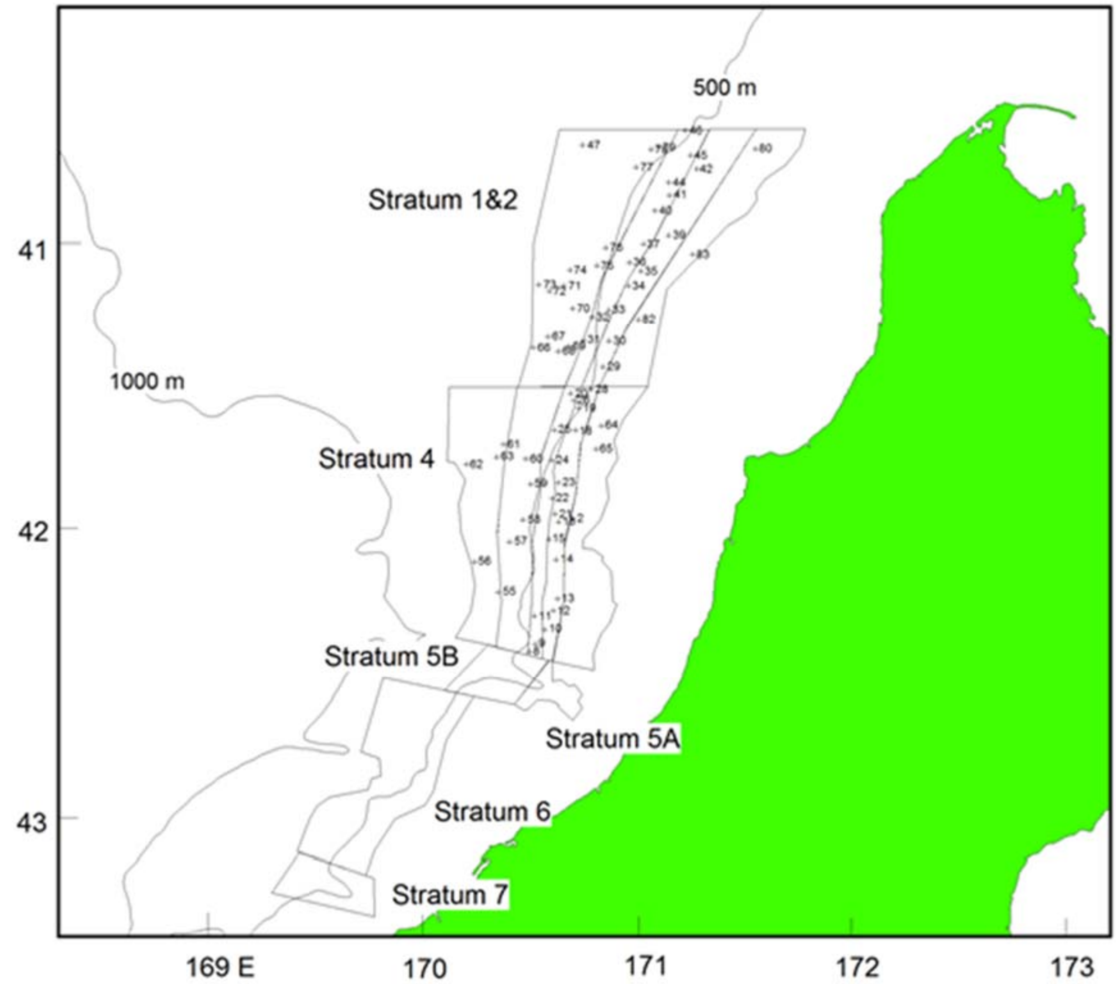

Figure 3: Trawl tow positions for the random trawl survey of the WCSI. Labels show station numbers. Station details are given in Appendix 5.

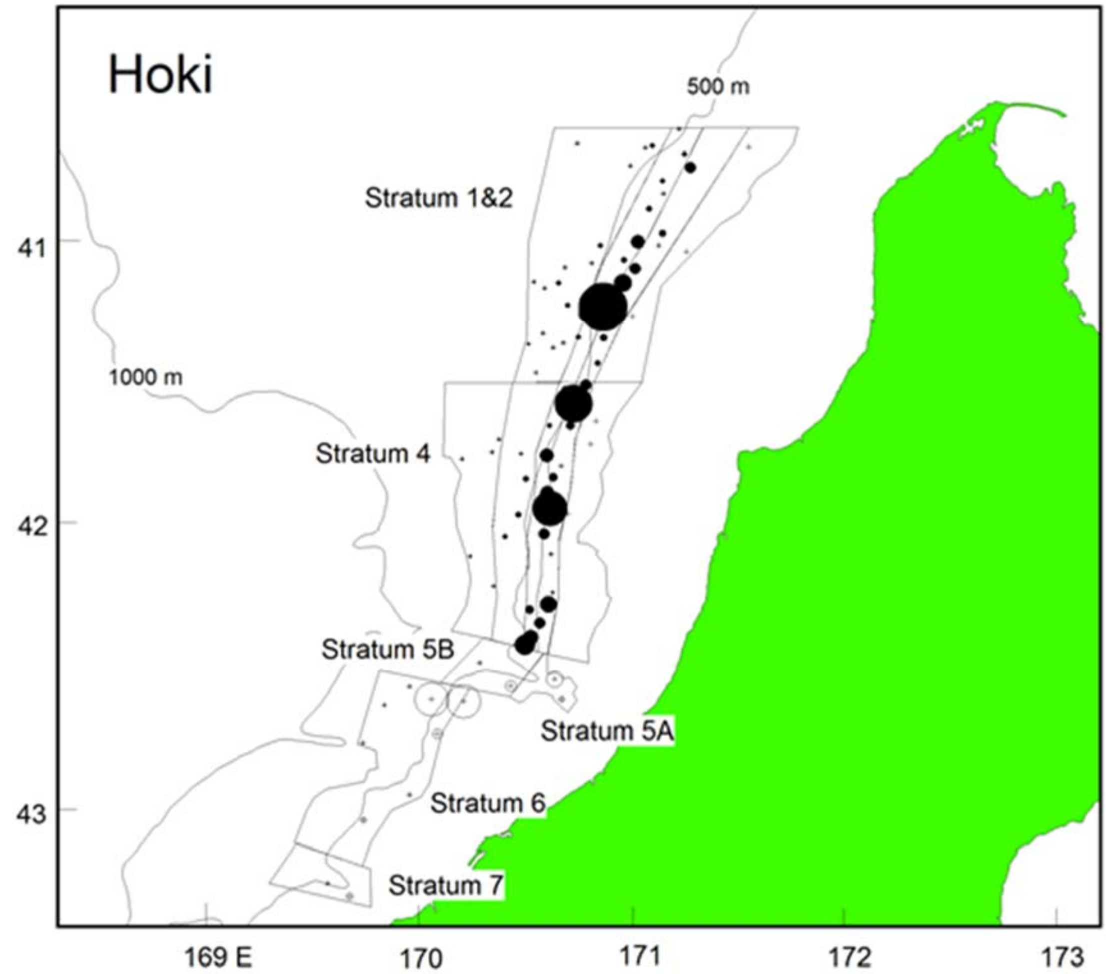

Figure 4: Catch rates (kg km^{-2}) of hoki in bottom tows carried out during the random trawl survey (filled circles) and tows for mark identification (open circles) during the 2013 WCSI survey. Circle area is proportional to catch rate. Maximum symbol size is equivalent to a catch rate of 32 000 kg km^{-2}. Crosses indicate zero catches.

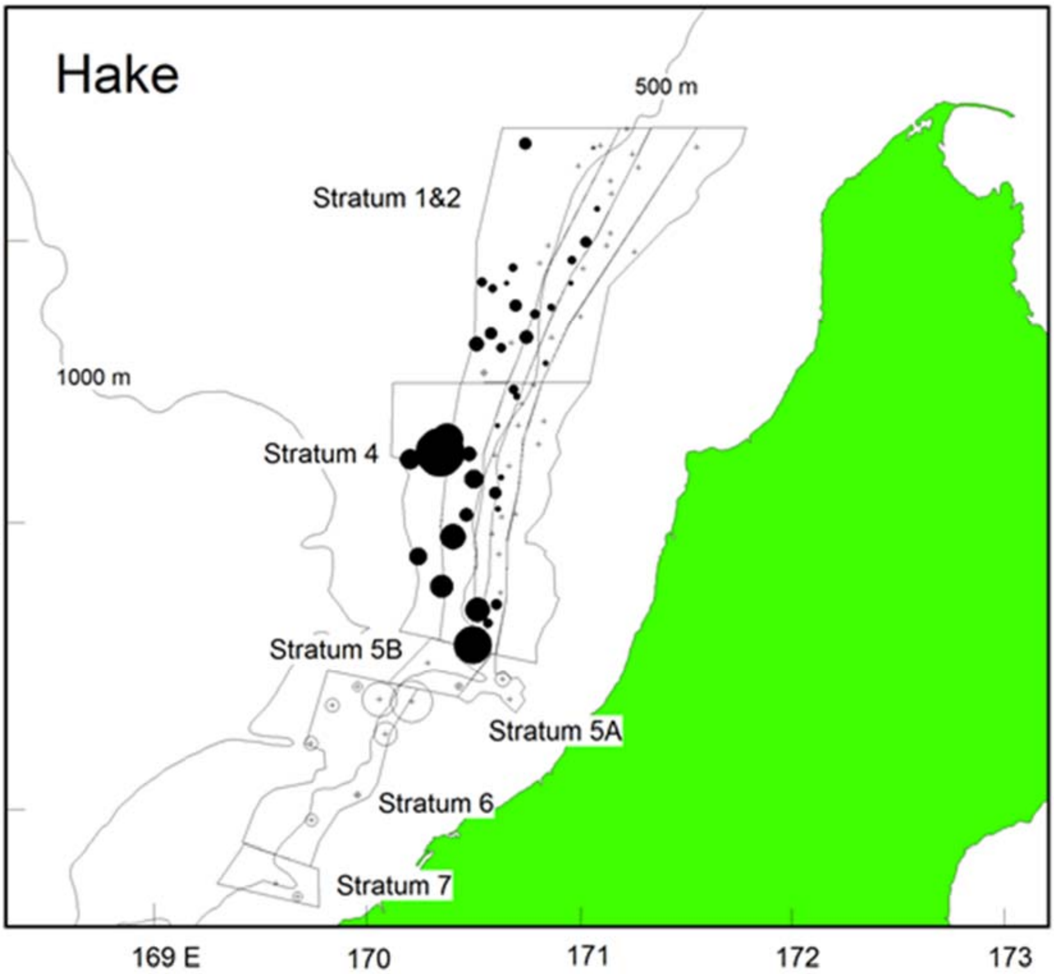

Figure 5: Catch rates (kg km^{-2}) of hake in bottom tows carried out during the random trawl survey (filled circles) and tows for mark identification (open circles) during the 2013 WCSI survey. Circle area is proportional to catch rate. Maximum symbol size is equivalent to a catch rate of 600 kg km^{-2}. Crosses indicate zero catches.

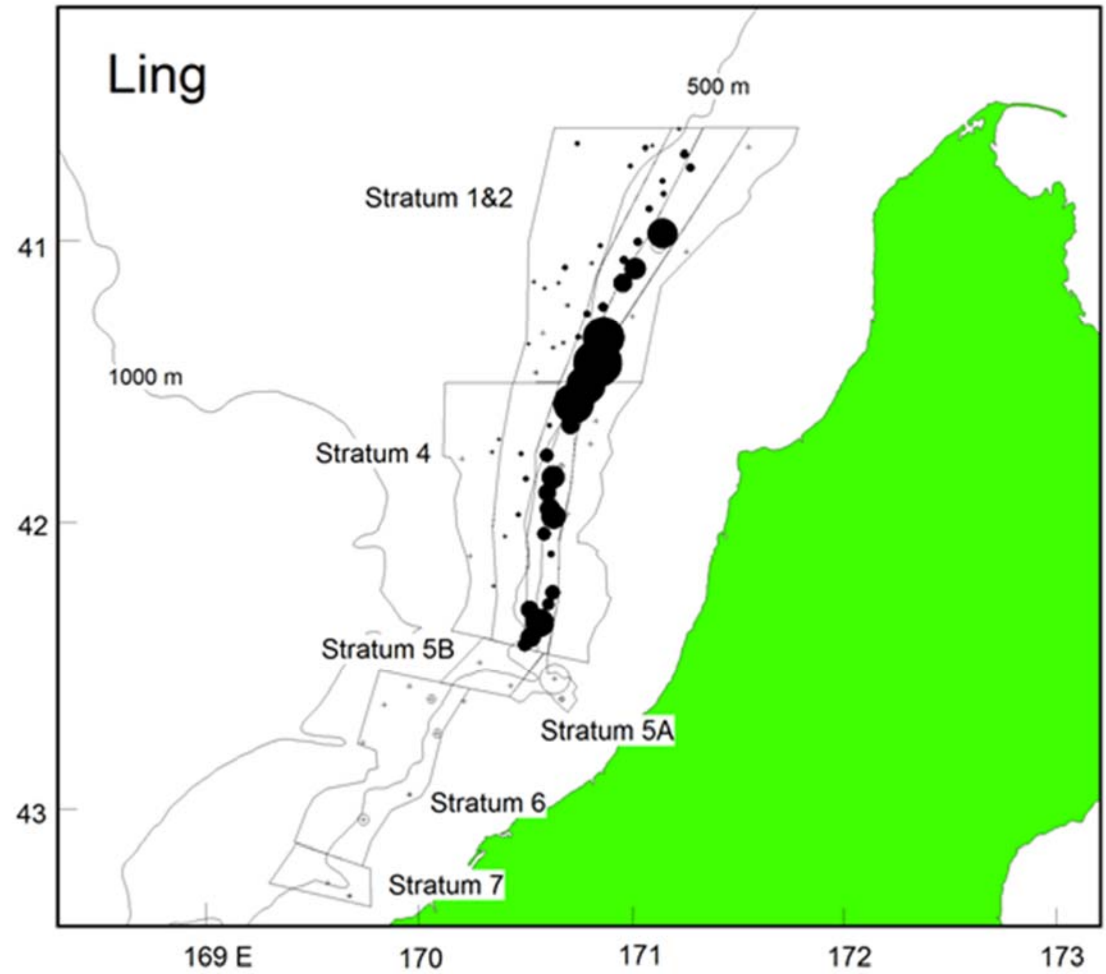

Figure 6: Catch rates (kg km^{-2}) of ling in bottom tows carried out during the random trawl survey (filled circles) and tows for mark identification (open circles) during the 2013 WCSI survey. Circle area is proportional to catch rate. Maximum symbol size is equivalent to a catch rate of 2200 kg km^{-2}. Crosses indicate zero catches.

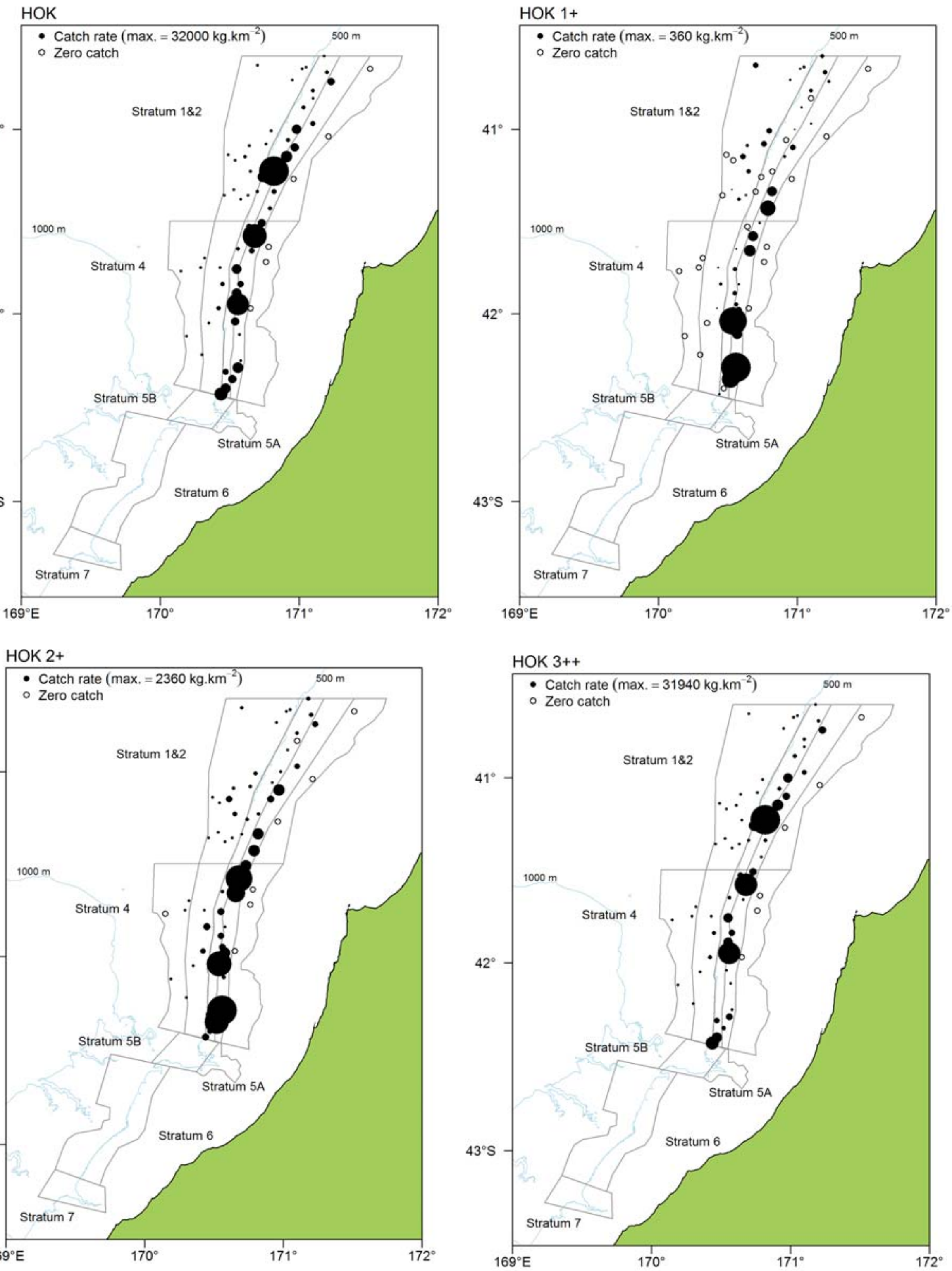

Figure 7: Distribution and catch rates of all, 1+ (less than 39 cm), 2+ (40–54 cm), and 3++ year old (more than 54 cm) hoki (HOK) on the WCSI 2013 trawl survey. Circle area is proportional to catch rate. Open circles indicate zero catches.

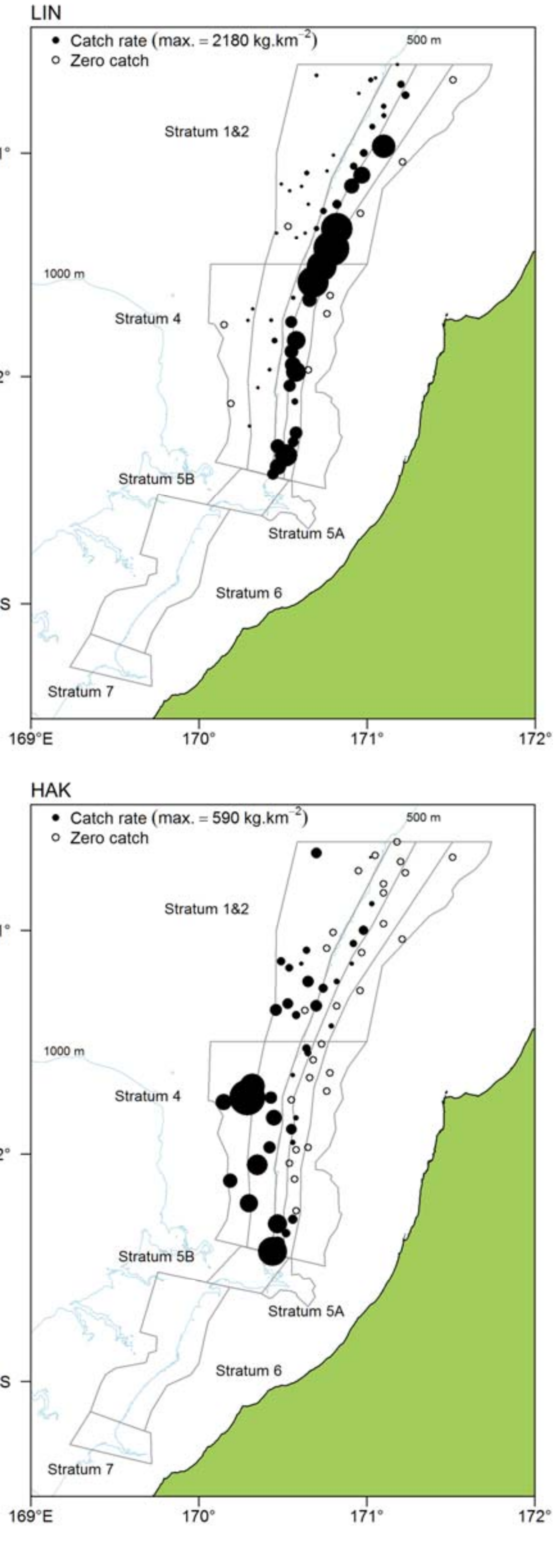

Figure 8: Distribution and catch rates of ling (LIN), spiny dogfish (SPD), hake (HAK), and silver warehou (SWA) on the WCSI 2013 trawl survey. Circle area is proportional to catch rate. Open circles indicate zero catches.

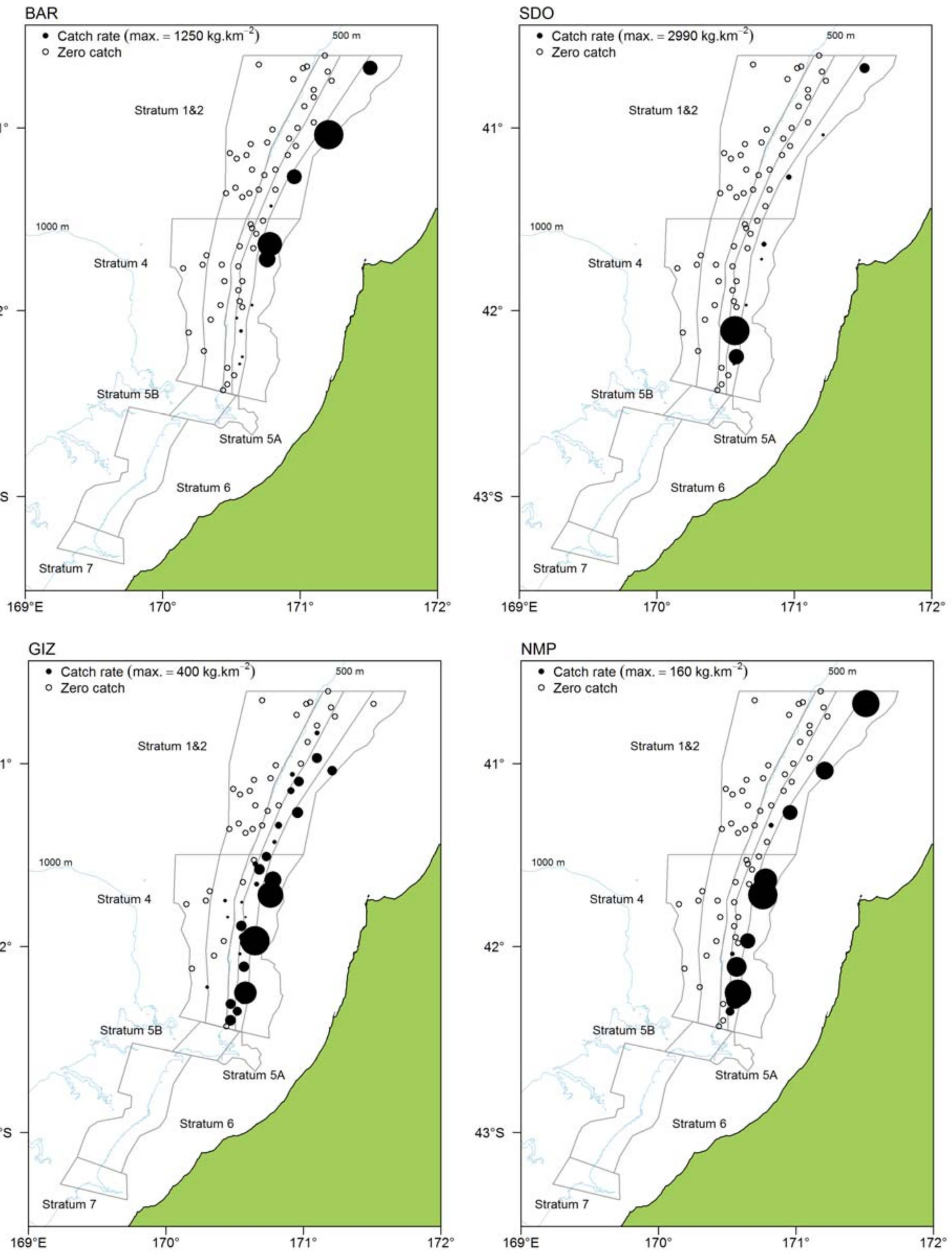

Figure 8 continued: Distribution and catch rates of barracouta (BAR), silver dory (SDO), giant stargazer (GIZ), and tarakihi (NMP) on the WCSI 2013 trawl survey. Circle area is proportional to catch rate. Open circles indicate zero catches.

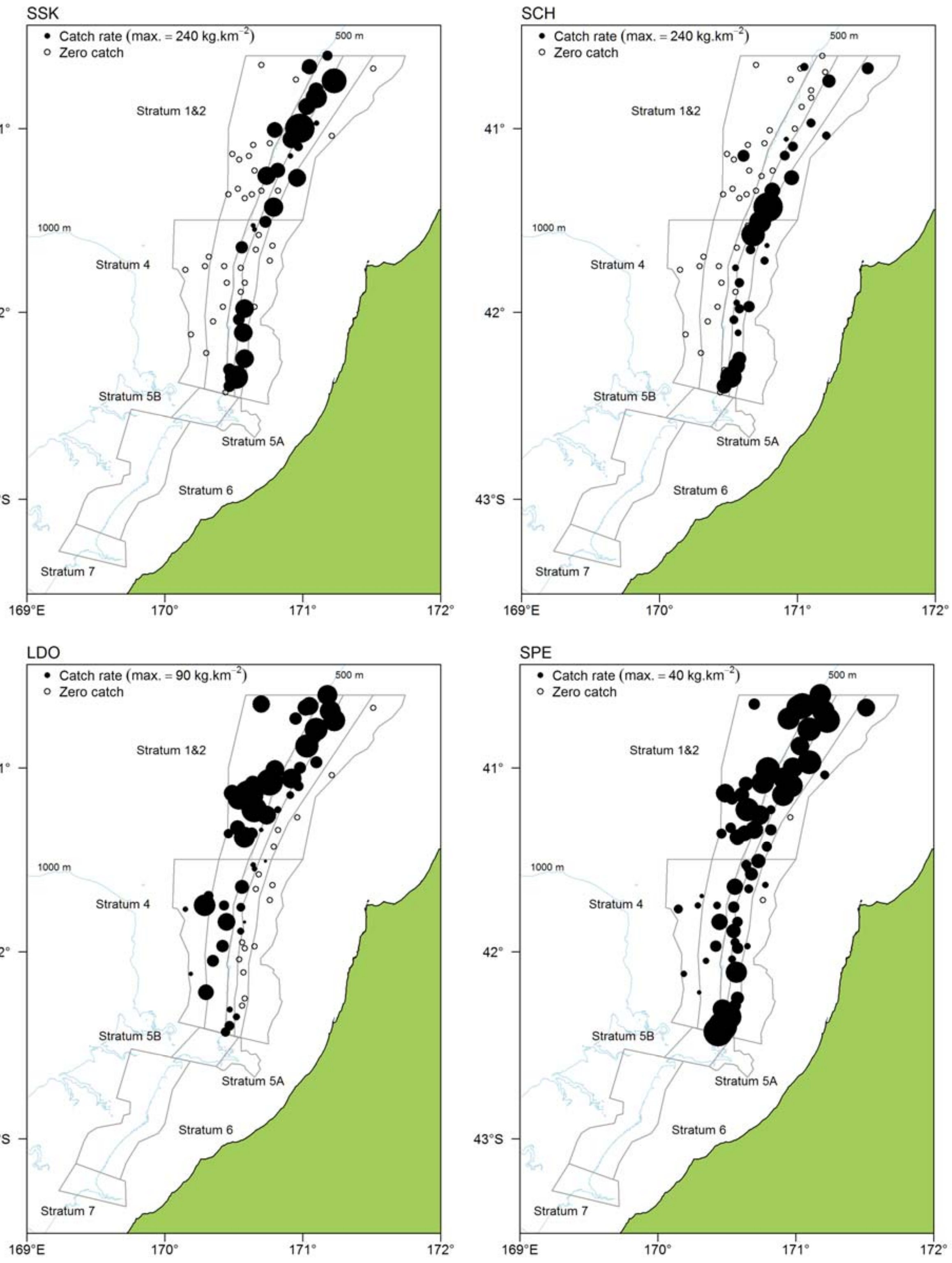

Figure 8 continued: Distribution and catch rates of smooth skate (SSK), school shark (SCH), look down dory (LDO) and sea perch (SPE) on the WCSI 2013 trawl survey. Circle area is proportional to catch rate. Open circles indicate zero catches.

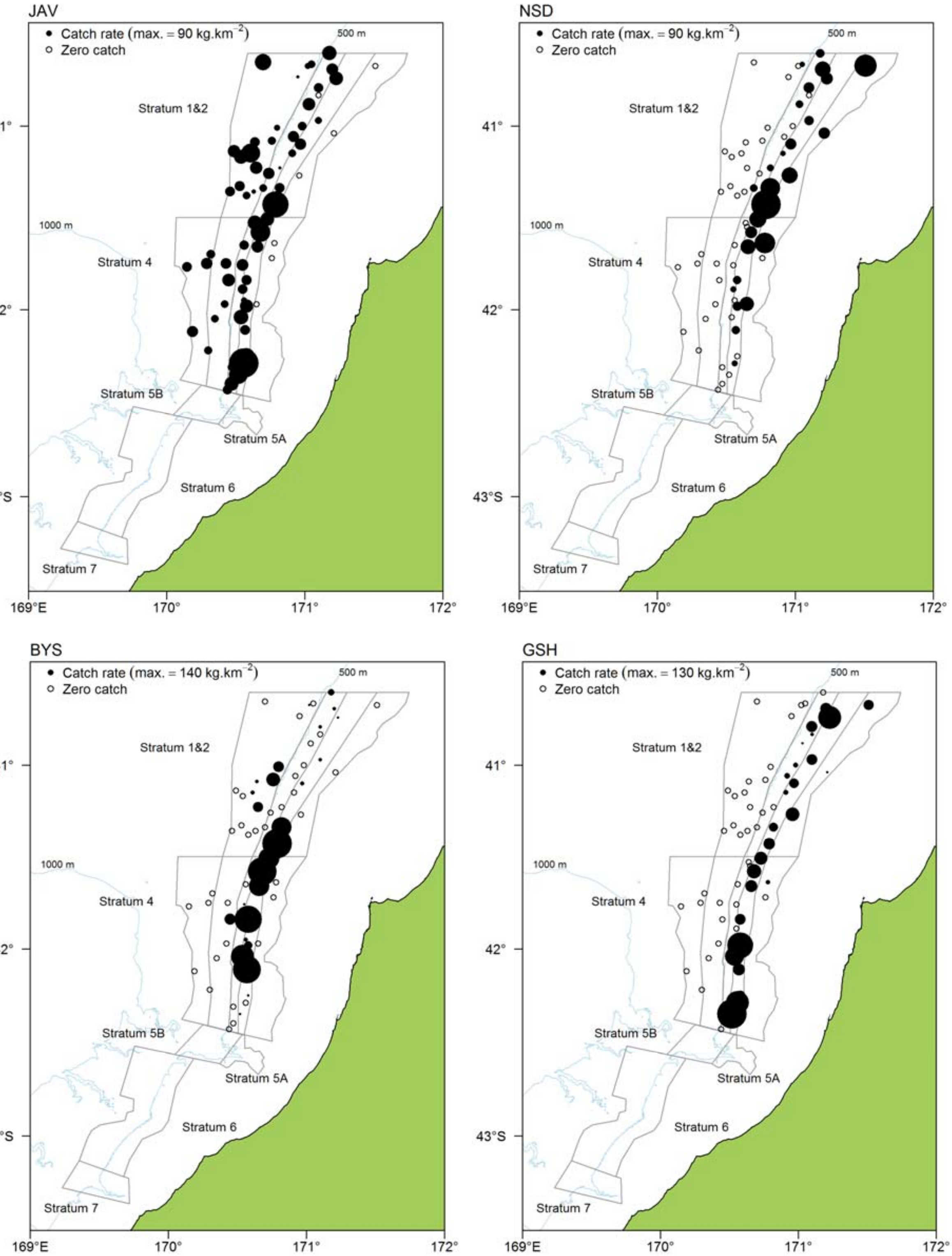

Figure 8 continued: Distribution and catch rates of javelinfish (JAV), northern spiny dogfish (NSD), alfonsino (BYS), and dark ghost shark (GSH) on the WCSI 2013 trawl survey. Circle area is proportional to catch rate. Open circles indicate zero catches.

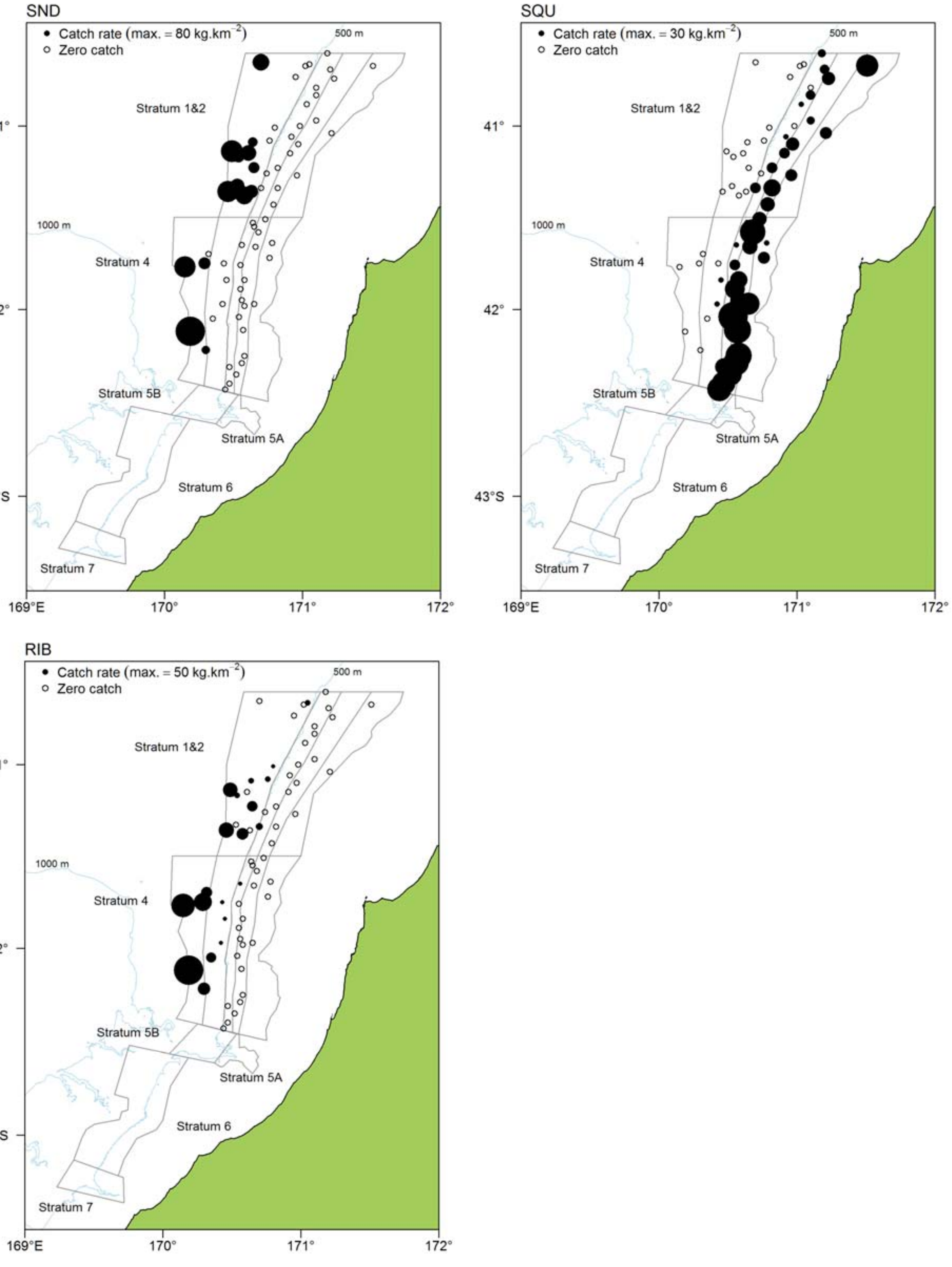

Figure 8 continued: Distribution and catch rates of shovelnose dogfish (SND), arrow squid (SQU), and ribaldo (RIB), on the WCSI 2013 trawl survey. Circle area is proportional to catch rate. Open circles indicate zero catches.

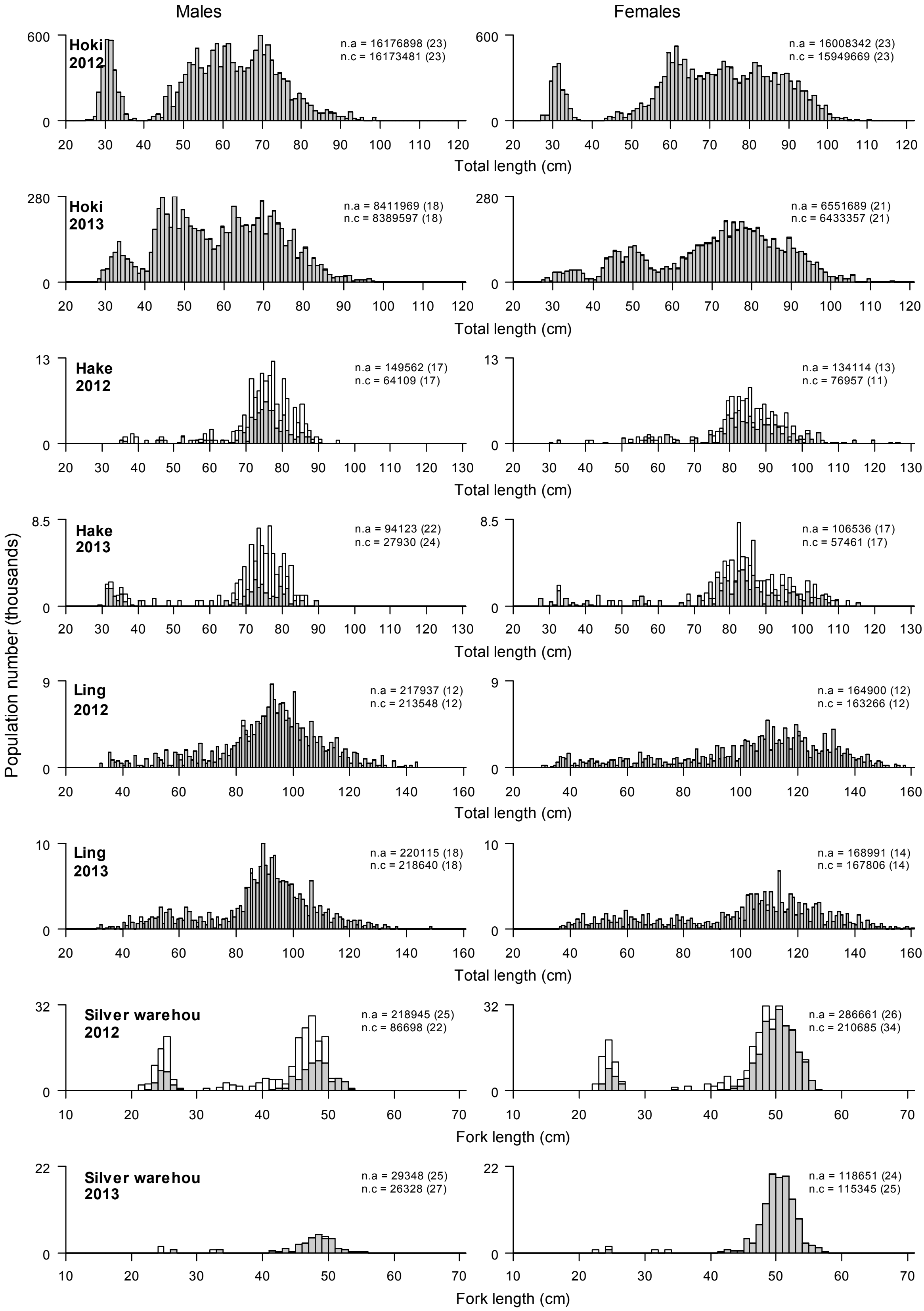

Figure 9: Length frequency distributions by sex of key species for core (grey) and all (white) strata from the 2012 and 2013 WCSI trawl surveys. n.a, estimated scaled total number of fish for all strata; n.c, estimated scaled total number of fish for core strata; and CV, the coefficient of variation (in parentheses).

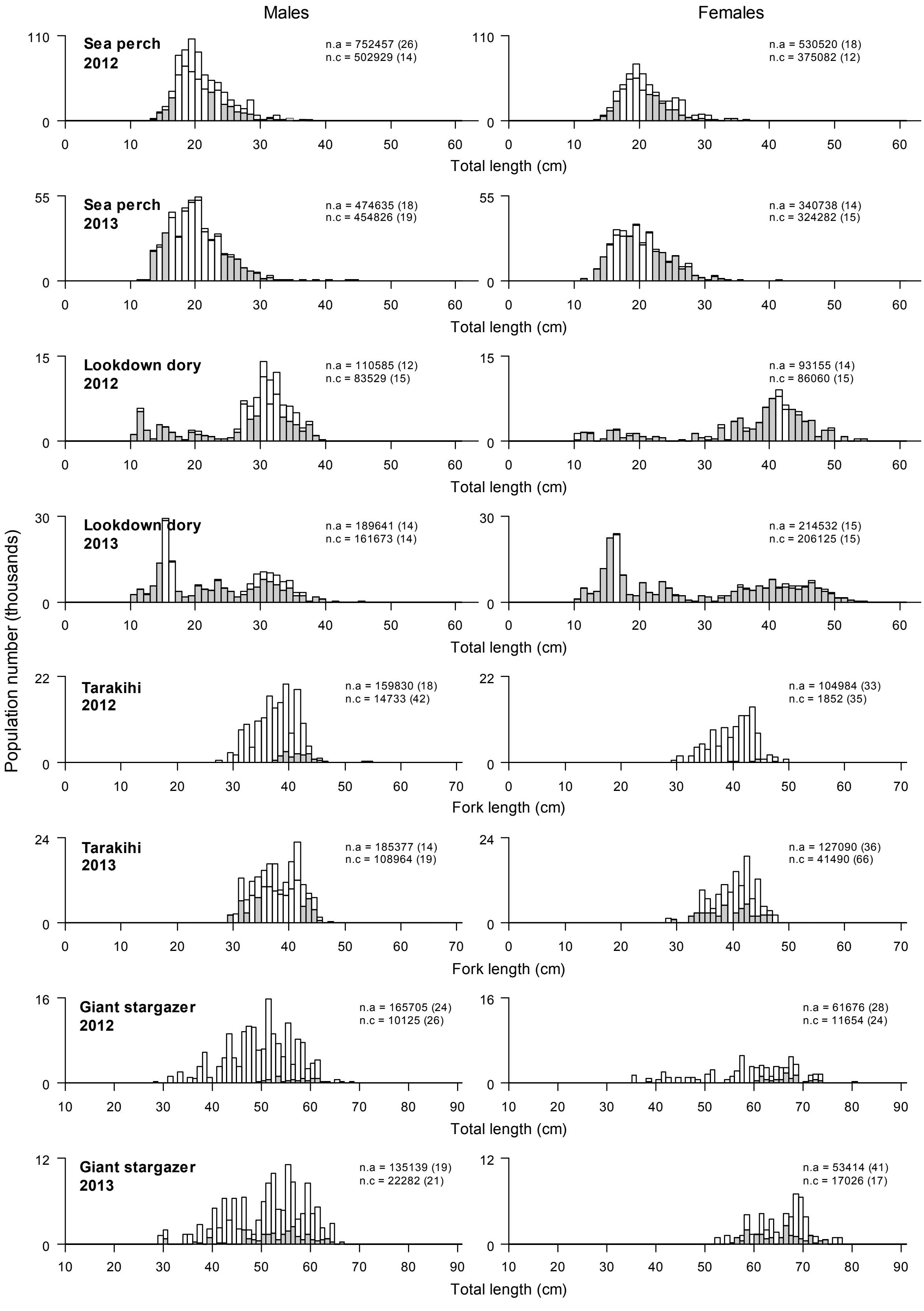

Figure 9 continued: Length frequency distributions by sex of key species for core (grey) and all (white) strata from the WCSI 2012 and 2013 trawl surveys. n.a, estimated scaled total number of fish for all strata; n.c, estimated scaled total number of fish for core strata; and CV, the coefficient of variation (in parentheses).

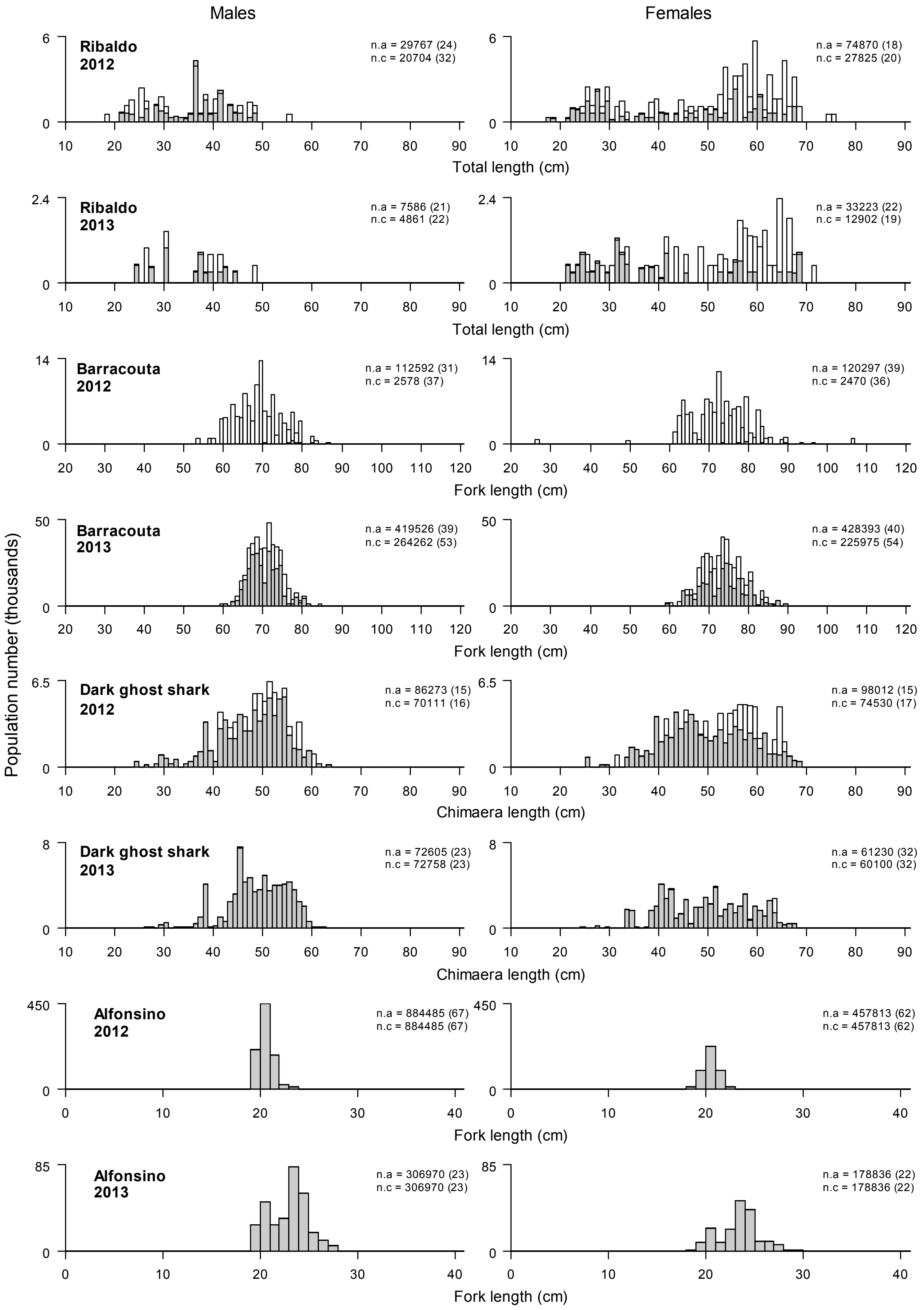

Figure 9 continued: Length frequency distributions by sex of key species for core (grey) and all (white) strata from the 2012 and 2013 WCSI trawl surveys. n.a, estimated scaled total number of fish for all strata; n.c, estimated scaled total number of fish for core strata; and CV, the coefficient of variation (in parentheses).

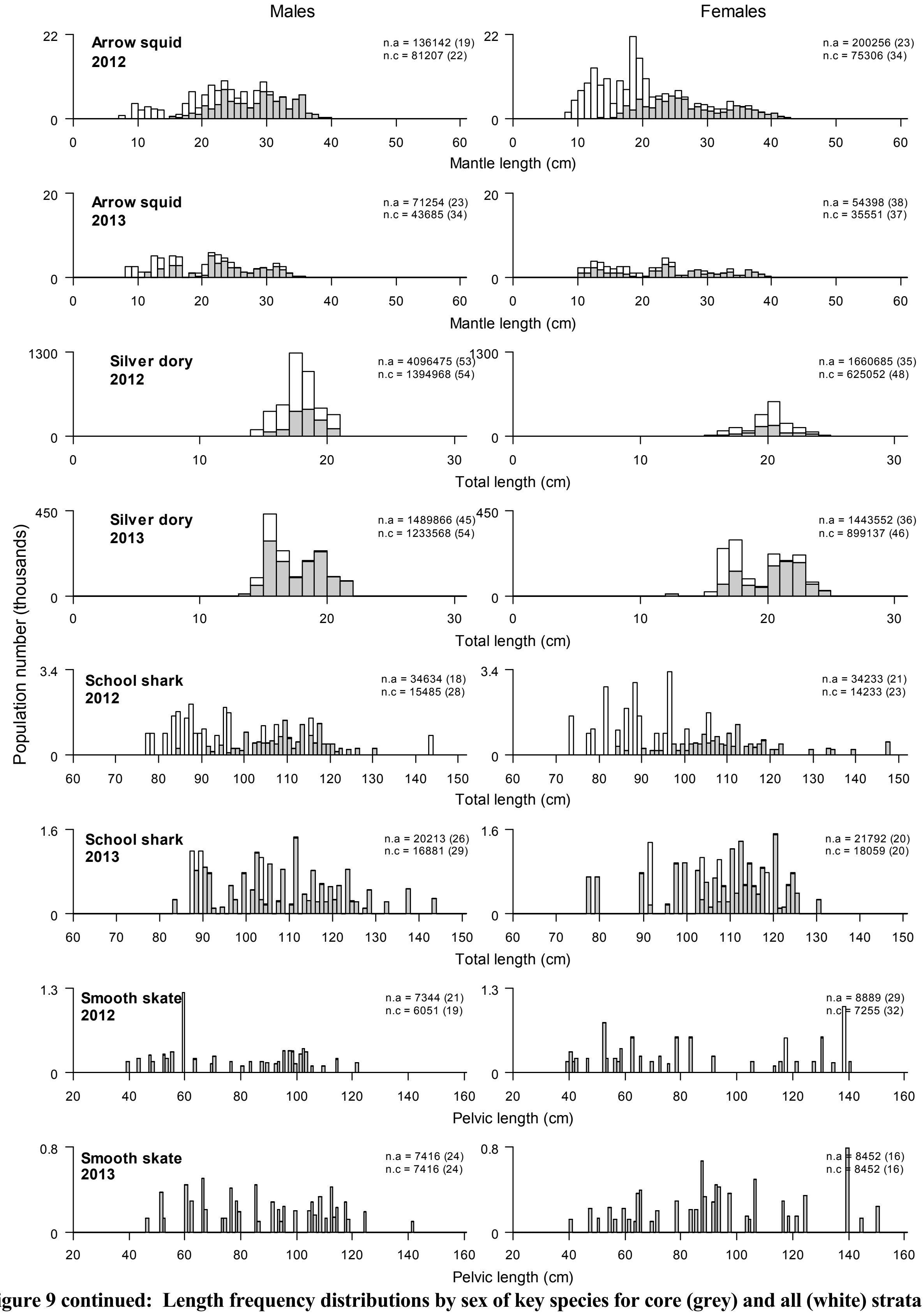

Figure 9 continued: Length frequency distributions by sex of key species for core (grey) and all (white) strata from the 2012 and 2013 WCSI trawl surveys. n.a, estimated scaled total number of fish for all strata; n.c, estimated scaled total number of fish for core strata; and CV, the coefficient of variation (in parentheses).

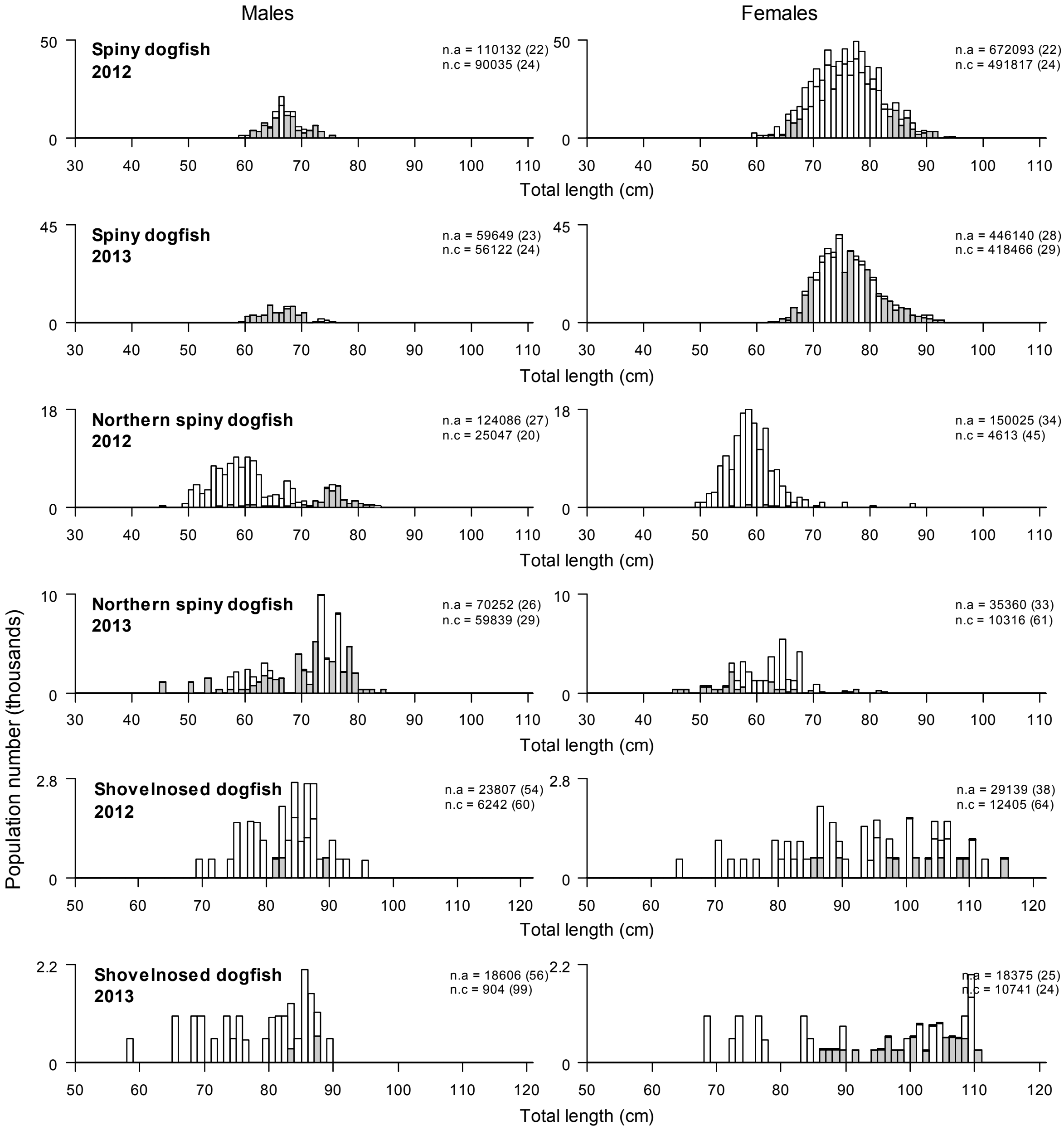

Figure 9 continued: Length frequency distributions by sex of key species for core (grey) and all (white) strata from the 2012 and 2013 WCSI trawl surveys. n.a, estimated scaled total number of fish for all strata; n.c, estimated scaled total number of fish for core strata; and CV, the coefficient of variation (in parentheses).

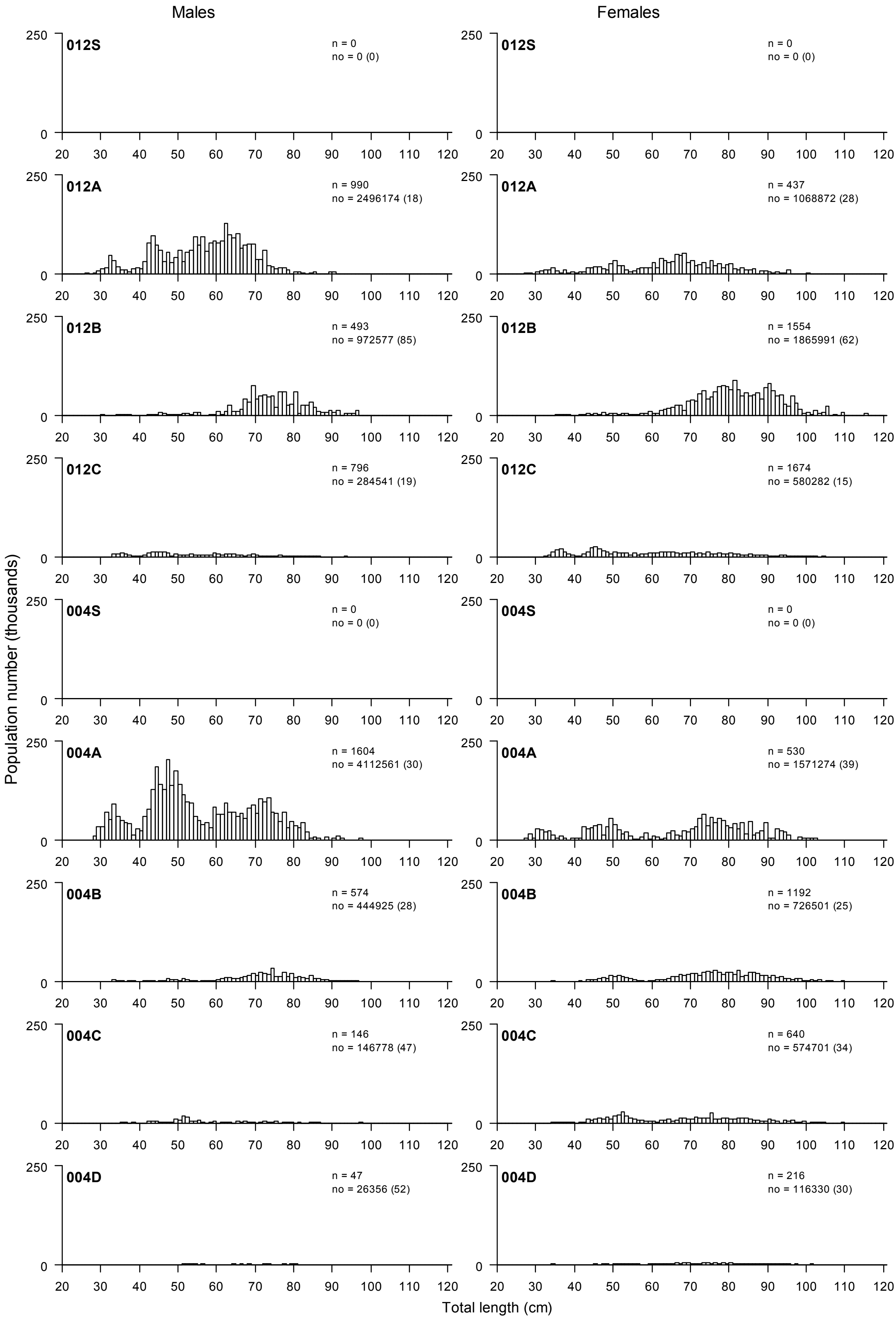

Figure 10: Length frequency distributions of hoki by strata in the WCSI trawl survey. n values are the number of males and females measured; no., scaled number of fish; CV is the coefficient of variation (in parentheses).

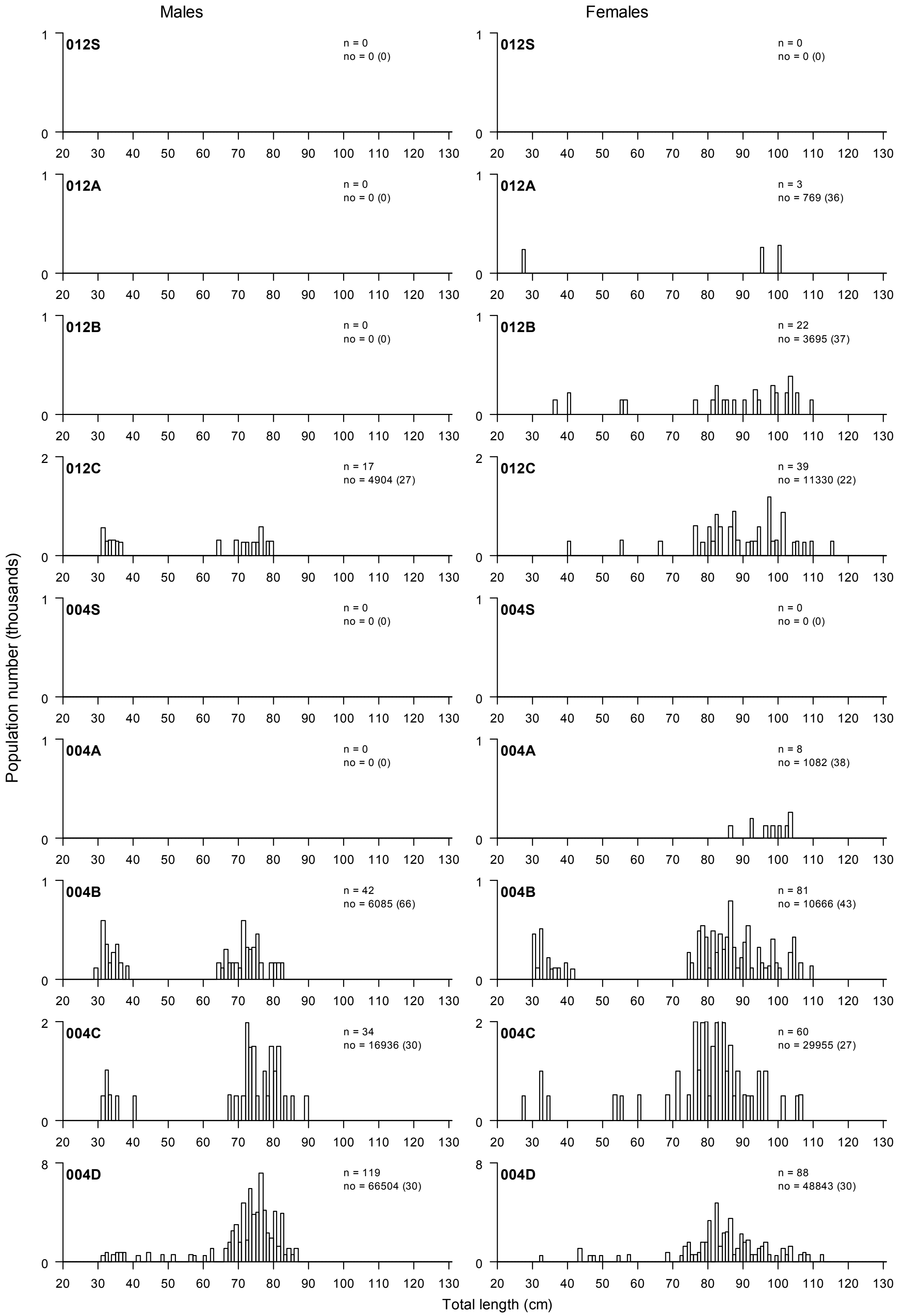

Figure 11: Length frequency distributions of hake by strata in the WCSI trawl survey. n values are the number of males and females measured; no., scaled number of fish; CV is the coefficient of variation (in parentheses).

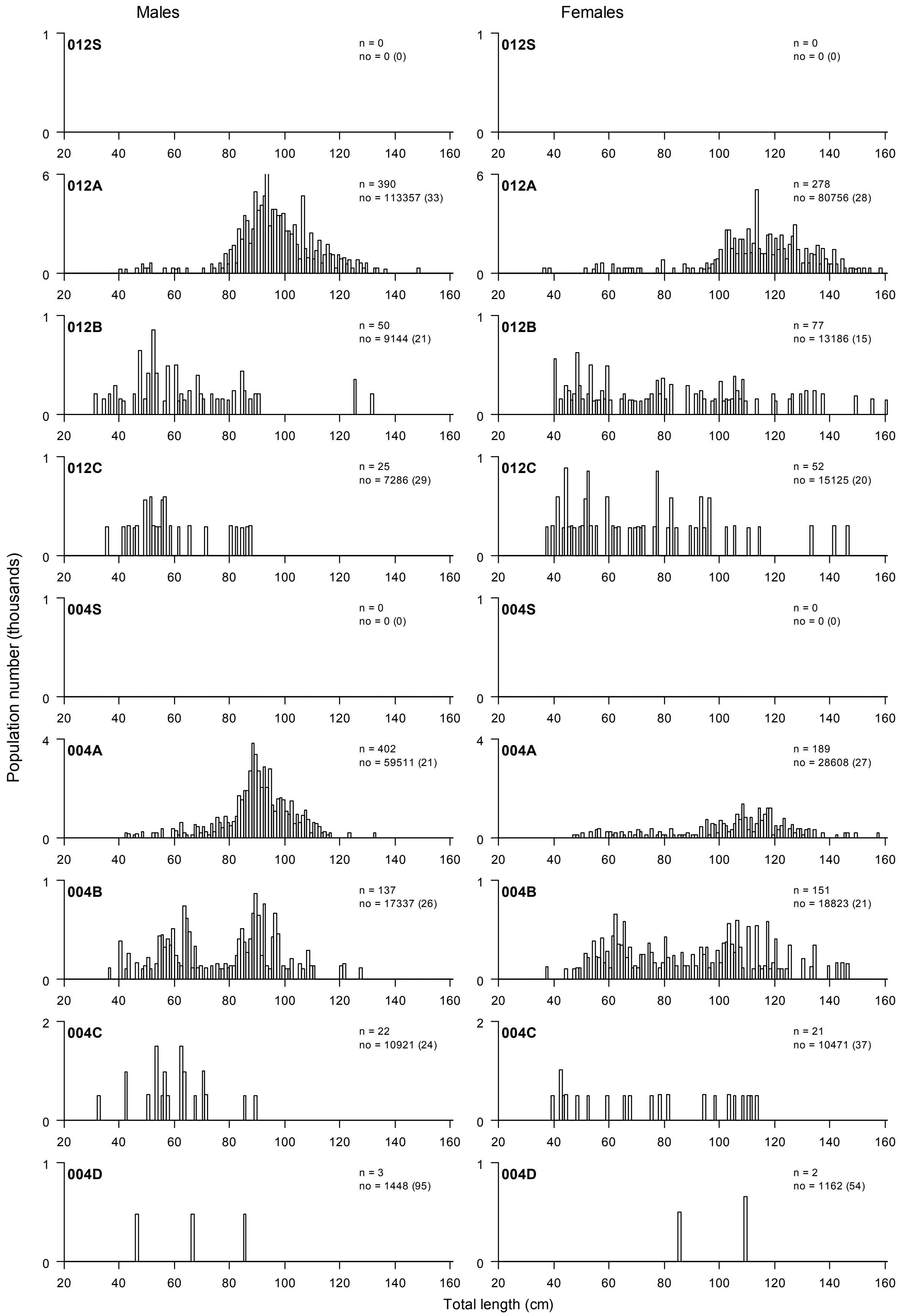

Figure 12: Length frequency distributions of ling by strata in the WCSI trawl survey. n, number of fish measured; no., population numbers of fish; CV is the coefficient of variation (in parentheses).

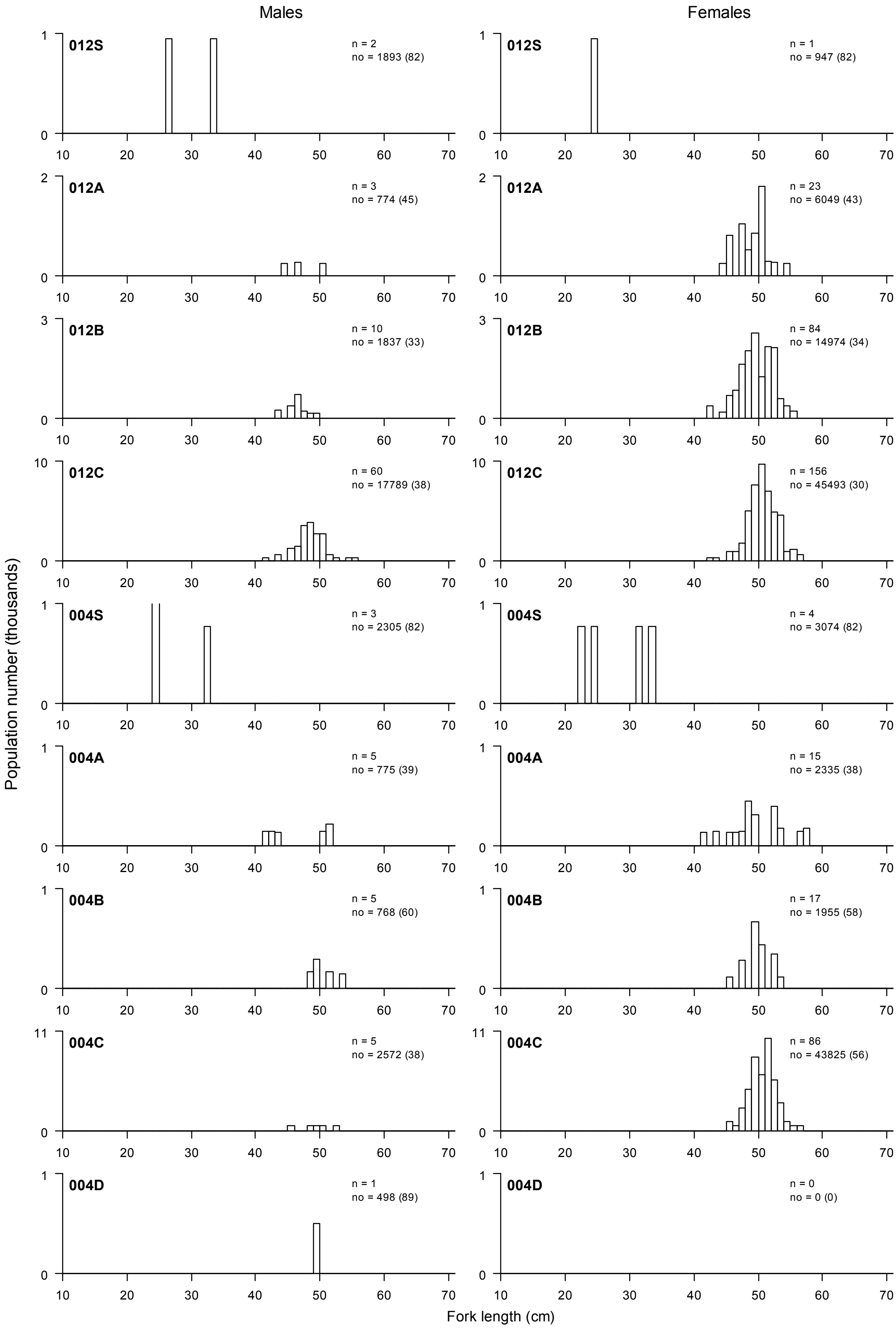

Figure 13: Length frequency distributions of silver warehou by strata in the WCSI trawl survey. n, number of fish measured; no., population numbers of fish; CV is the coefficient of variation (in parentheses).

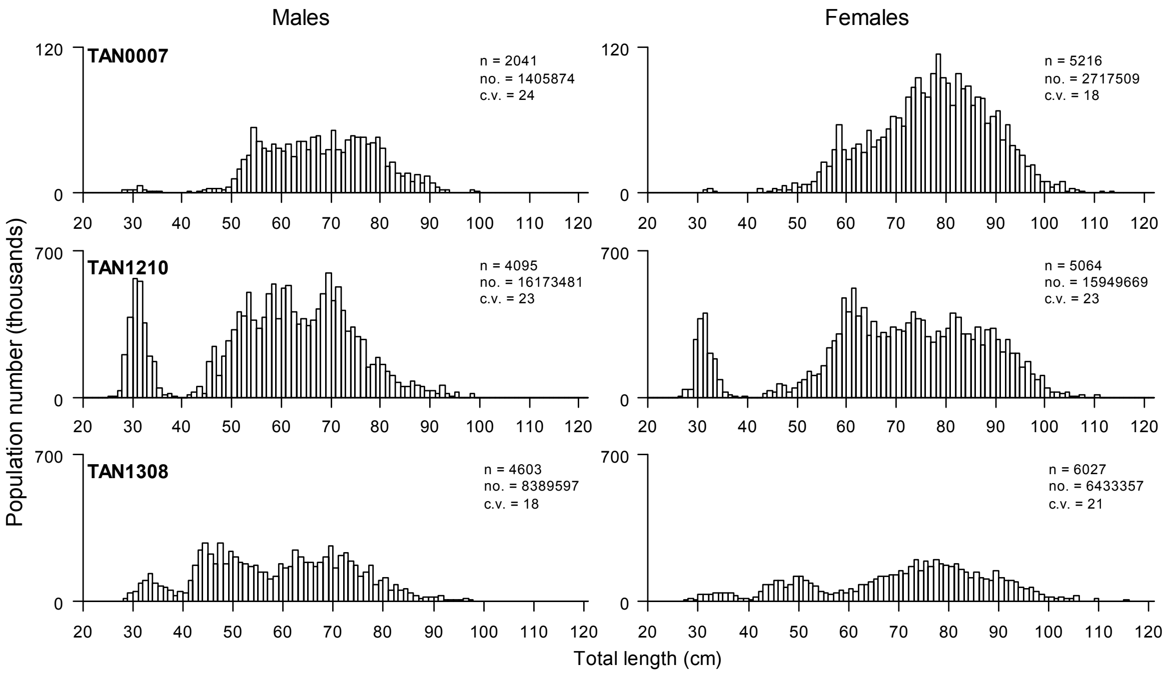

Figure 14: Scaled length frequency for male and female hoki in core strata from WCSI *Tangaroa* trawl surveys in 2000 (TAN0007), 2012 (TAN1210) and 2013 (TAN1308). n, number of fish measured; no., population numbers of fish; CV, coefficients of variation.

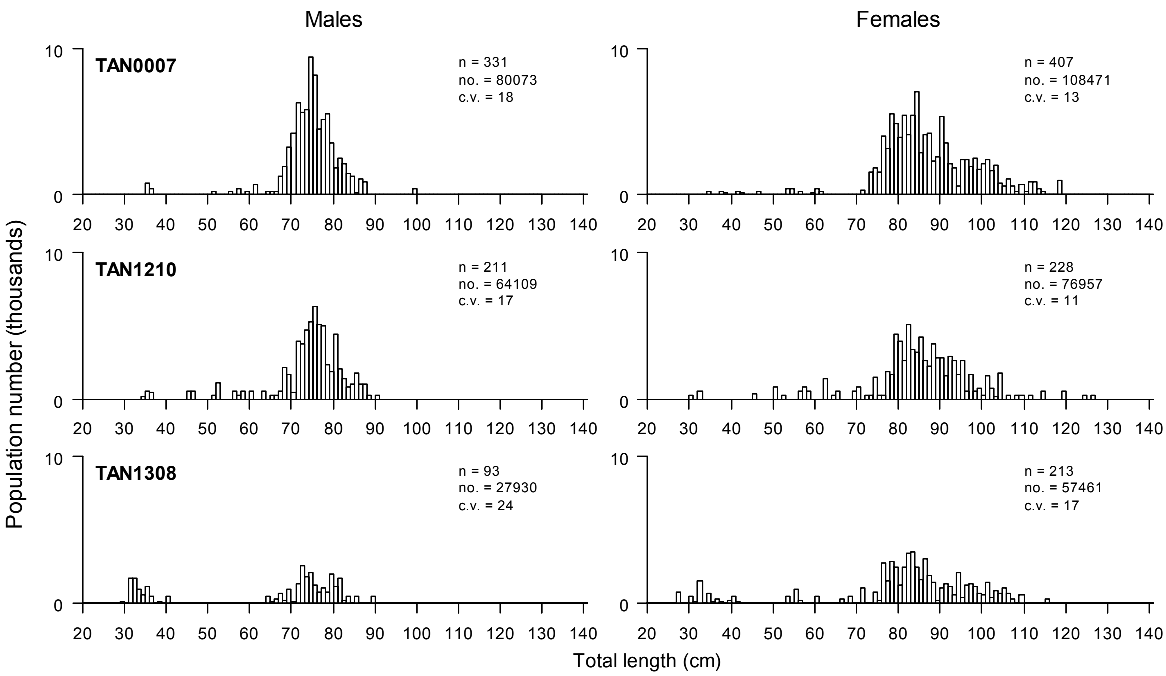

Figure 15: Scaled length frequency for male and female hake in core strata from WCSI *Tangaroa* trawl surveys in 2000 (TAN0007), 2012 (TAN1210) and 2013 (TAN1308). n, number of fish measured; no., population numbers of fish; CV, coefficients of variation.

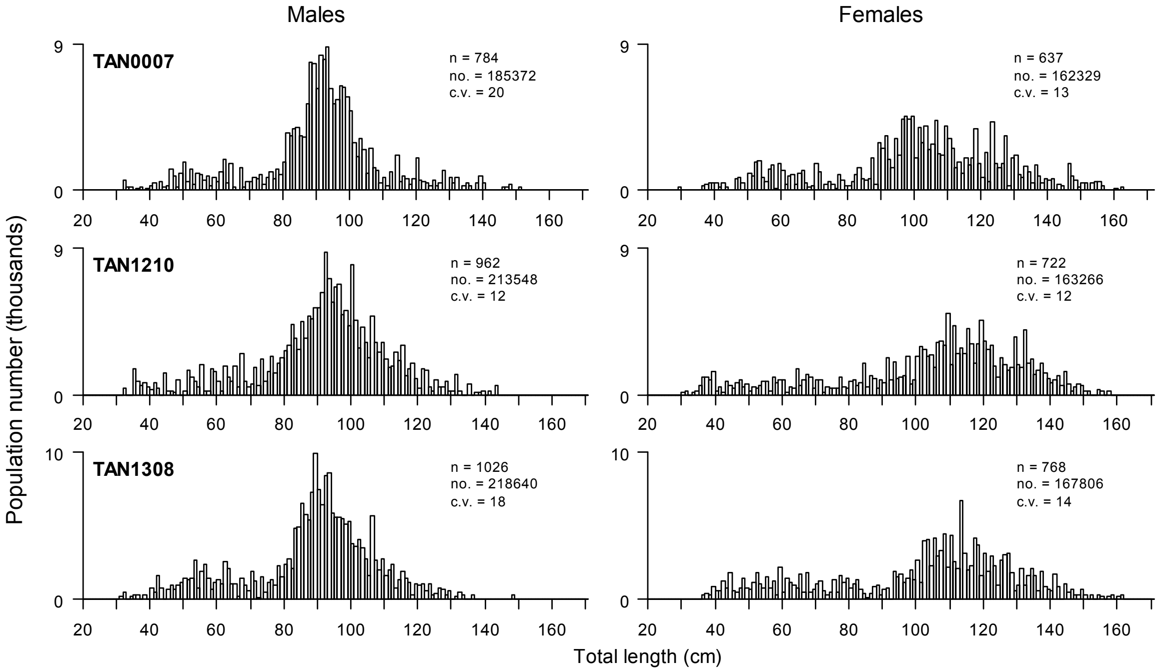

Figure 16: Scaled length frequency for male and female ling in core strata from WCSI *Tangaroa* trawl surveys in 2000 (TAN0007), 2012 (TAN1210) and 2013 (TAN1308). n, number of fish measured; no., population numbers of fish; CV, coefficients of variation.

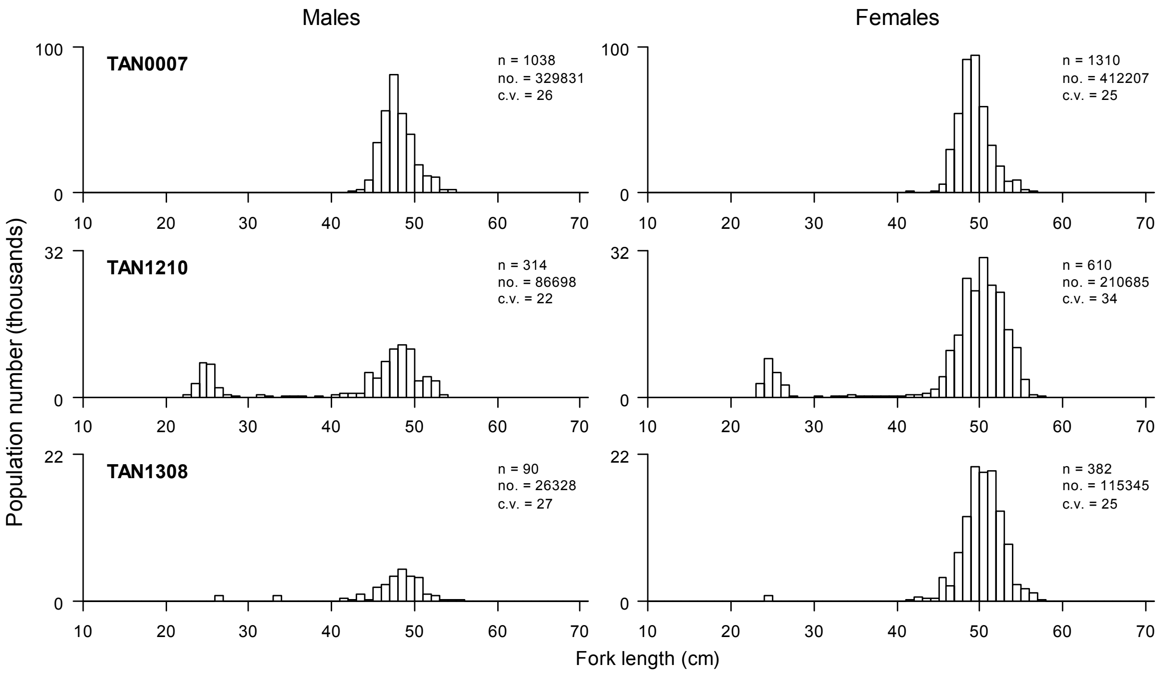

Figure 17: Scaled length frequency for male and female silver warehou in core strata from WCSI *Tangaroa* trawl surveys in 2000 (TAN0007), 2012 (TAN1210) and 2013 (TAN1308). n, number of fish measured; no., population numbers of fish; CV, coefficients of variation.

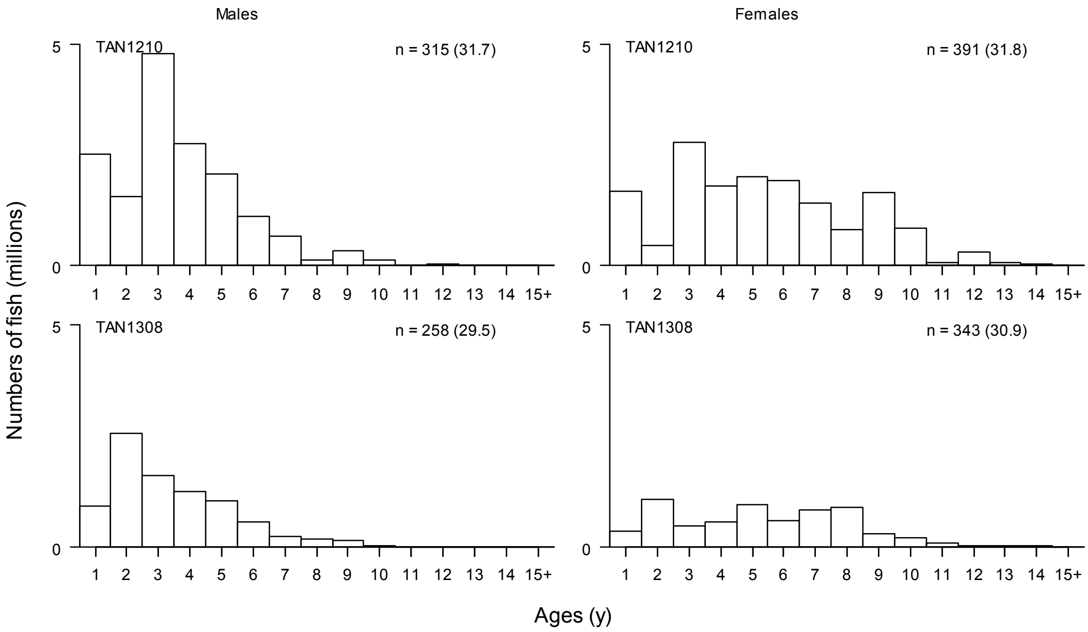

Figure 18: Scaled age frequency for hoki from core strata from the 2012 (TAN1210) and 2013 (TAN1308) WCSI trawl surveys. Number of fish aged (*n* values) are given with CVs in parentheses. Hoki were not aged for the 2000 survey.

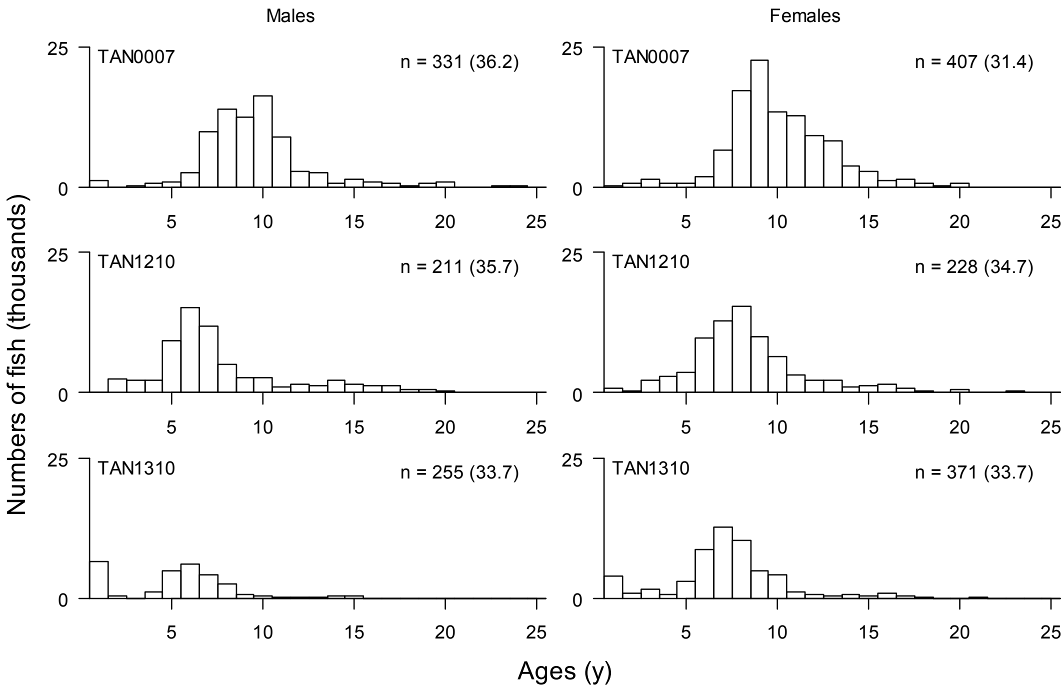

Figure 19: Scaled age frequency for hake in core strata from the WCSI trawl surveys in 2000 (TAN0007), 2012 (TAN1210), and 2013 (TAN1308). Number of fish aged (*n* values) are given with CVs in parentheses.

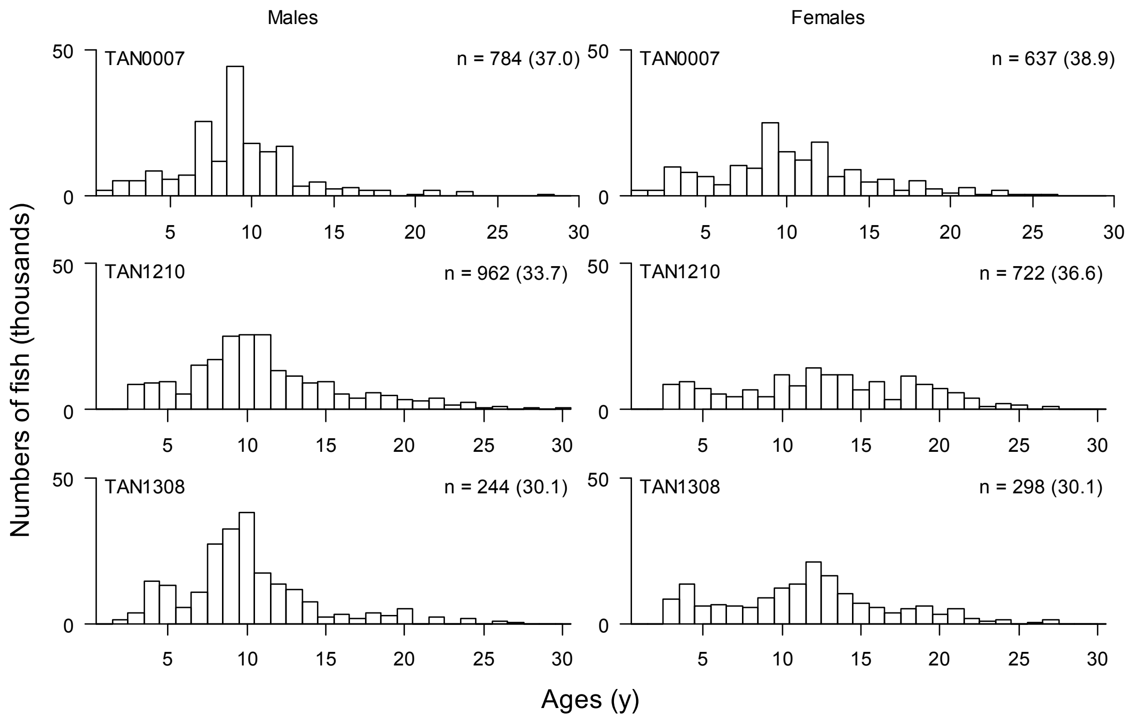

Figure 20: Scaled age frequency for ling in core strata from the WCSI trawl surveys in 2000 (TAN0007), 2012 (TAN1210), and 2013 (TAN1308. Number of fish aged (*n* values) are given with CVs in parentheses.

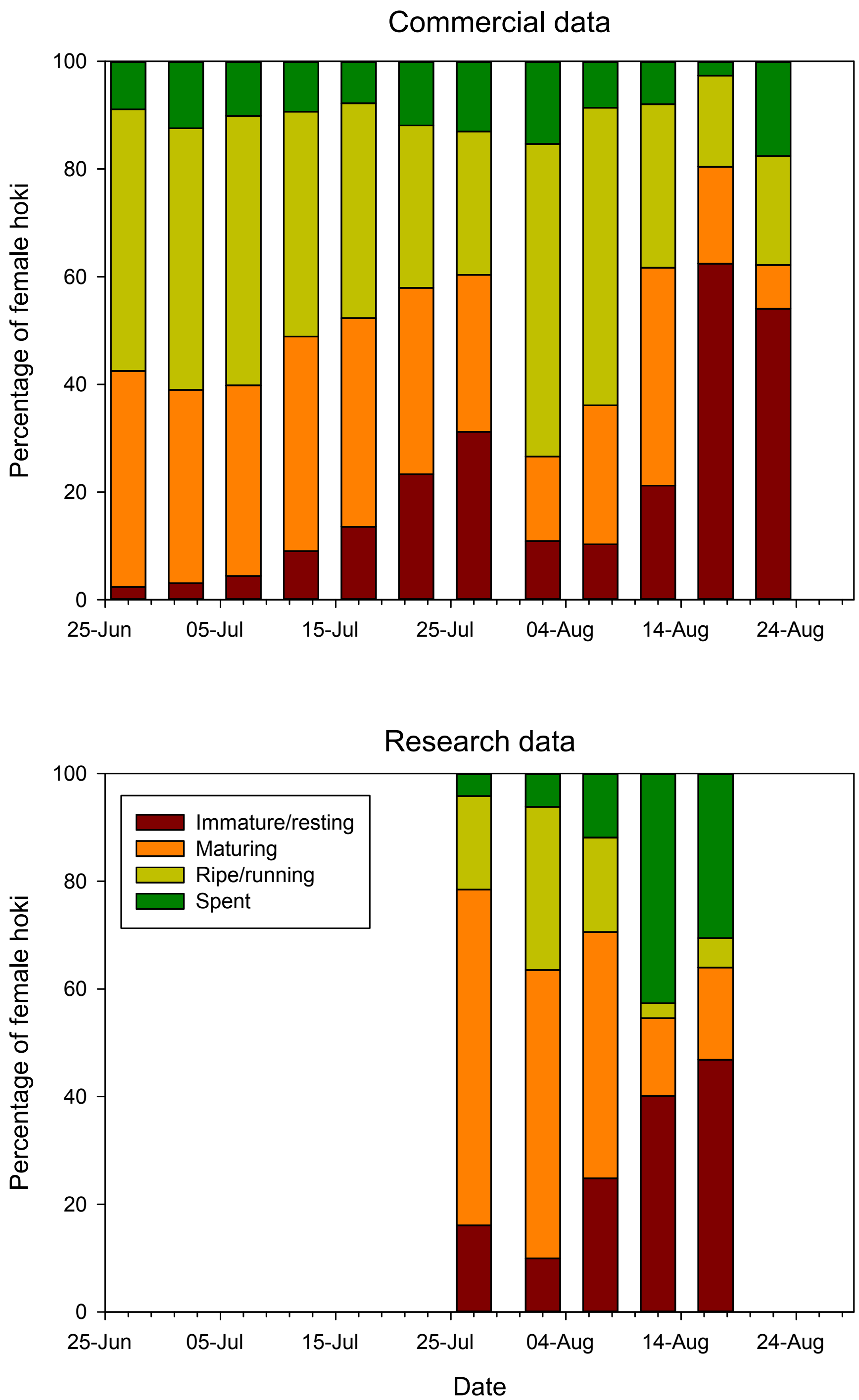

Figure 21: Proportion of female hoki in different maturity states from the commercial fishery and research tows on the WCSI in 2013. Data are summarised as means within 5-day periods. Immature/resting = observer stage 1, research stage 1 and 2; Maturing = observer stage 2, research stage 3 and 6; Ripe/running = observer stage 3 and 4, research stage 4 and 5; Spent = observer stage 5, research stage 7.

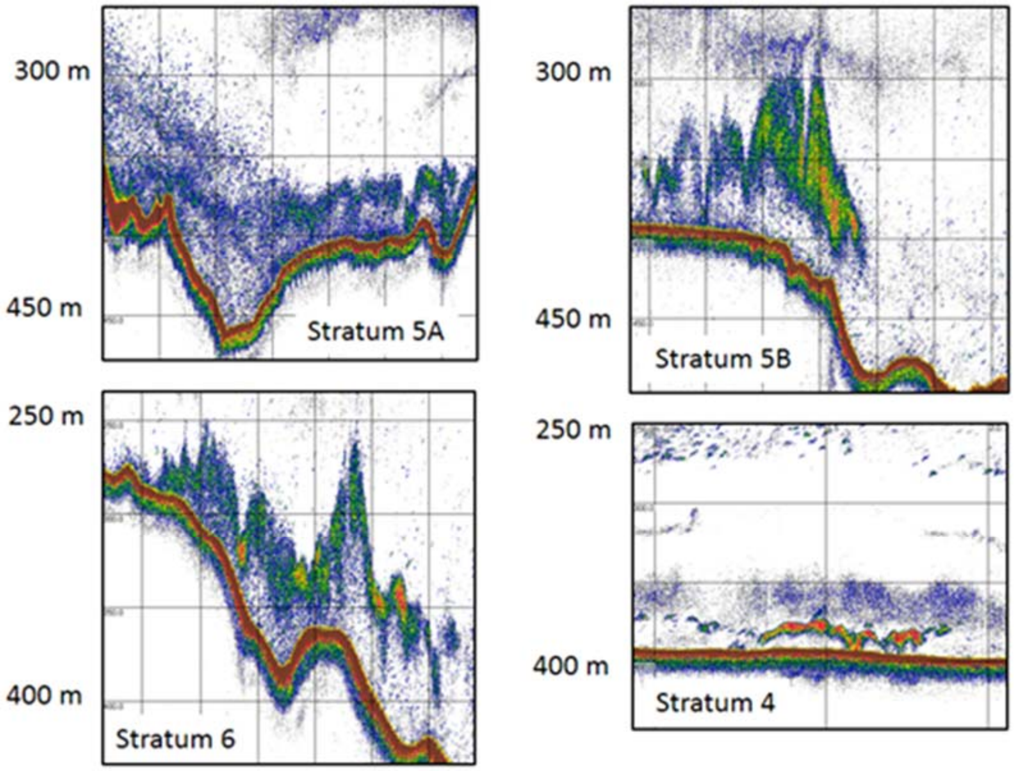

Figure 22: Examples of echograms showing hoki school marks by strata: stratum 5A at 17:30 on 29 July; stratum 5B at 23:00 on 29 July; stratum 4A at 14:00 on 3 August; stratum 6 at 00:00 on 10 August. Echograms are divided into cells of 50 m by 0.5 n. miles. Minimum echogram threshold is -70 dB.

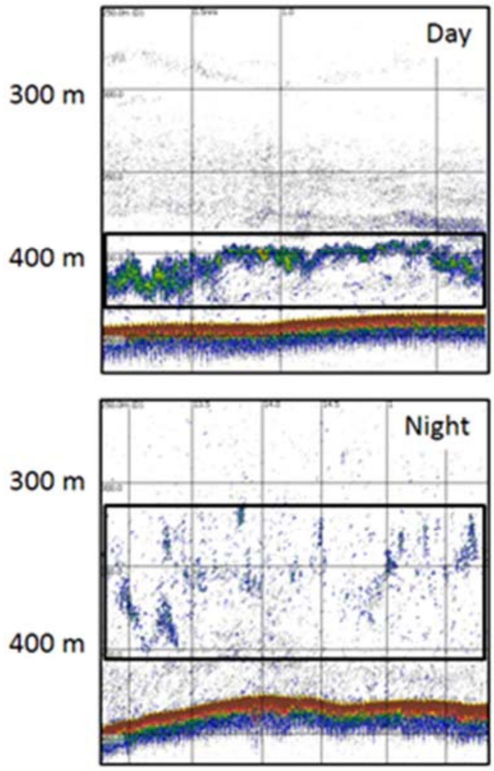

Figure 23: Examples of echograms showing a hoki school in stratum 1&2B close to the bottom during the day and dispersed away from the bottom at night on 5-6 August. Echograms are divided into cells of 50 m by 0.5 n. miles. Minimum echogram threshold is -70 dB.

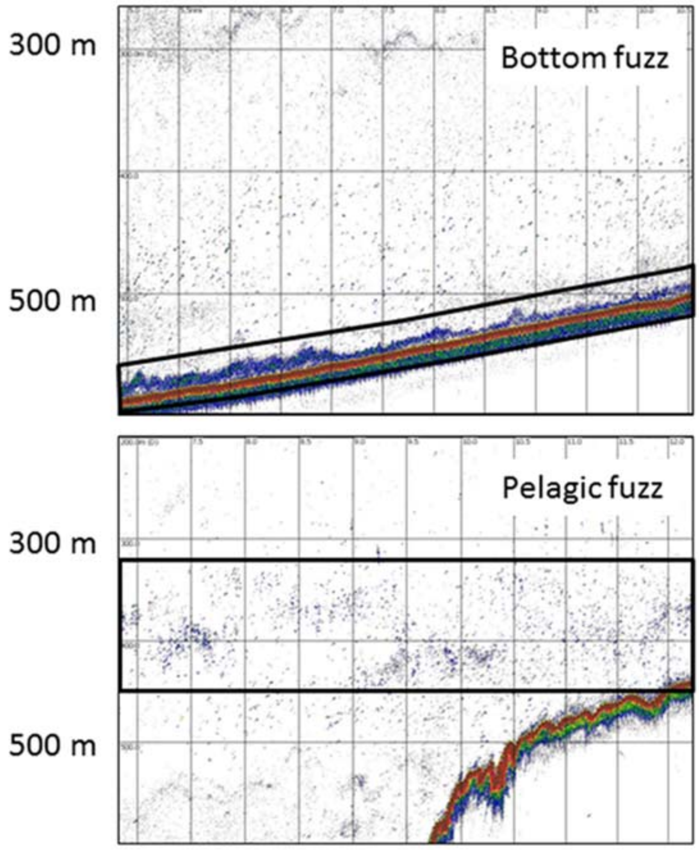

Figure 24: Examples of echograms showing hoki fuzz marks. Approximate boundaries of marks are shown by black boxes. Upper echogram is from stratum 1&2. Lower echogram is from stratum 5B. Echograms are divided into cells of 50 m by 0.5 n. miles. Minimum echogram threshold is -70 dB.

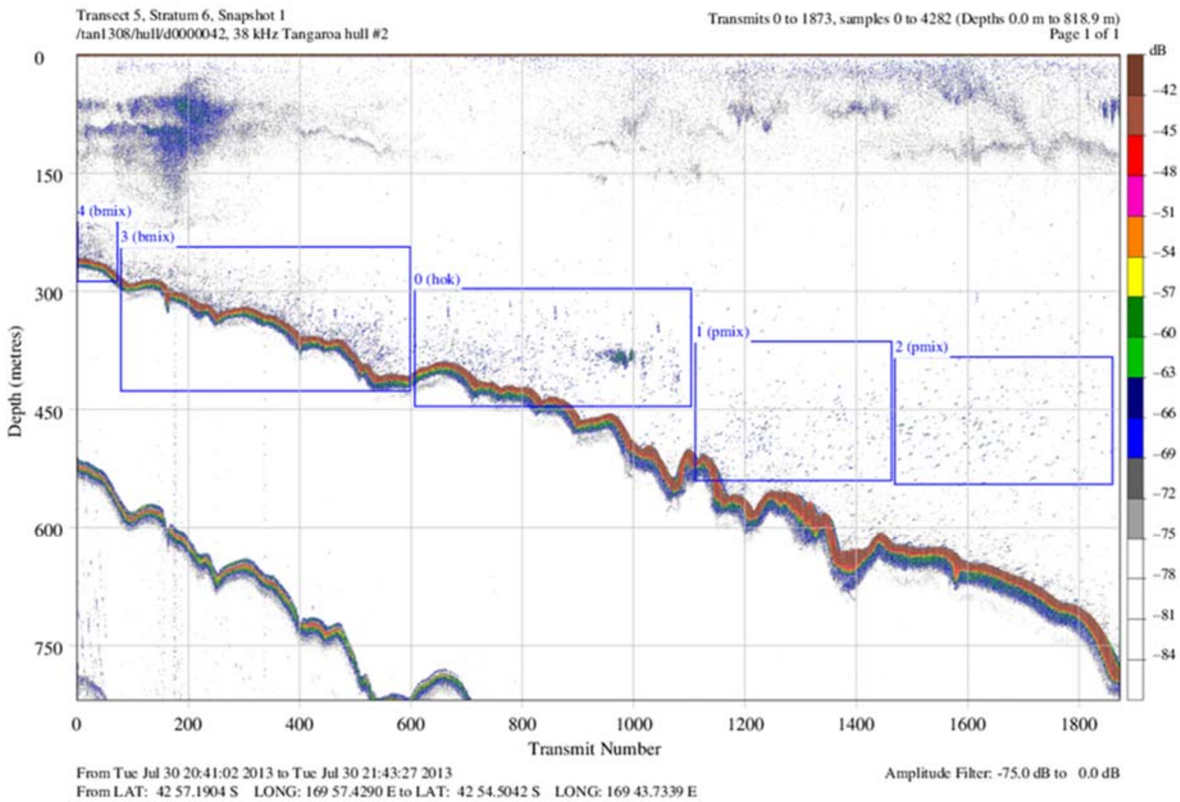

Figure 25: Example of mark classification on transect 5 of stratum 6 during snapshot 1 on 30 July. Approximate boundaries of hoki marks are shown by blue boxes ('hok' is hoki school, 'bmix' is hoki bottom fuzz, 'pmix' is hoki pelagic fuzz). Marks shallower than 150 m are pelagic.

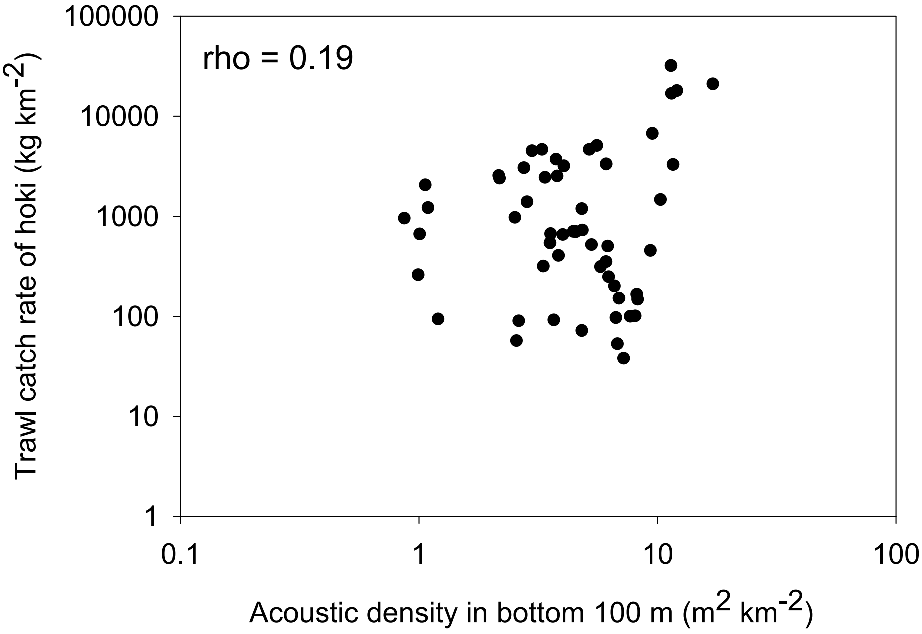

Figure 26: Relationship between trawl catch rate of hoki and bottom-referenced acoustic backscatter recorded during bottom tows during the 2013 WCSI survey. Rho value is Spearman's rank correlation coefficient.

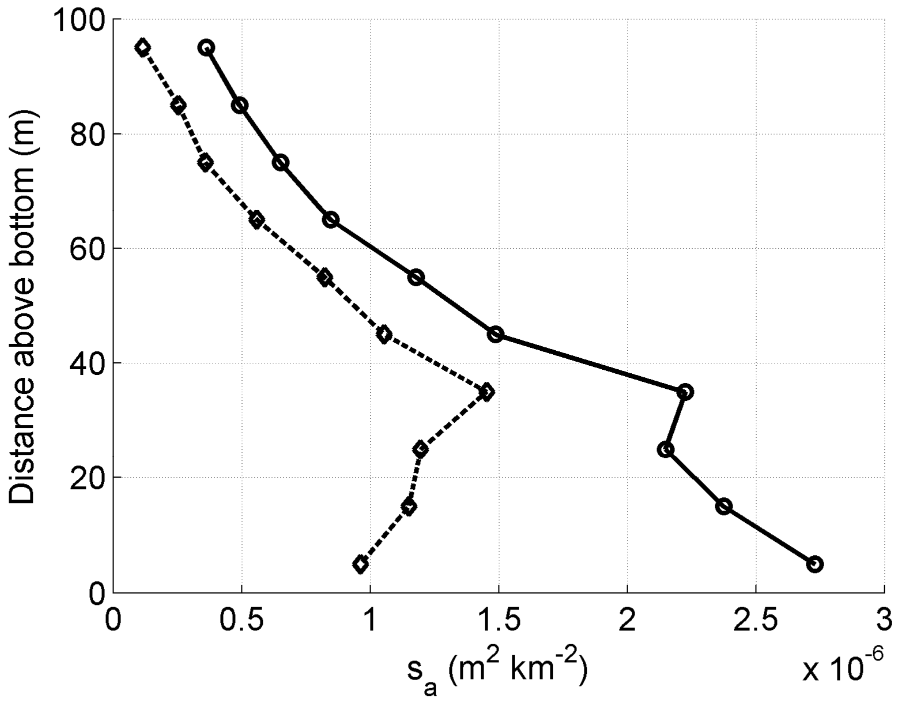

Figure 27: Vertical distribution bottom-referenced acoustic backscatter recorded during random bottom tows during the 2012 (solid line) and 2013 (dotted line) WCSI surveys.

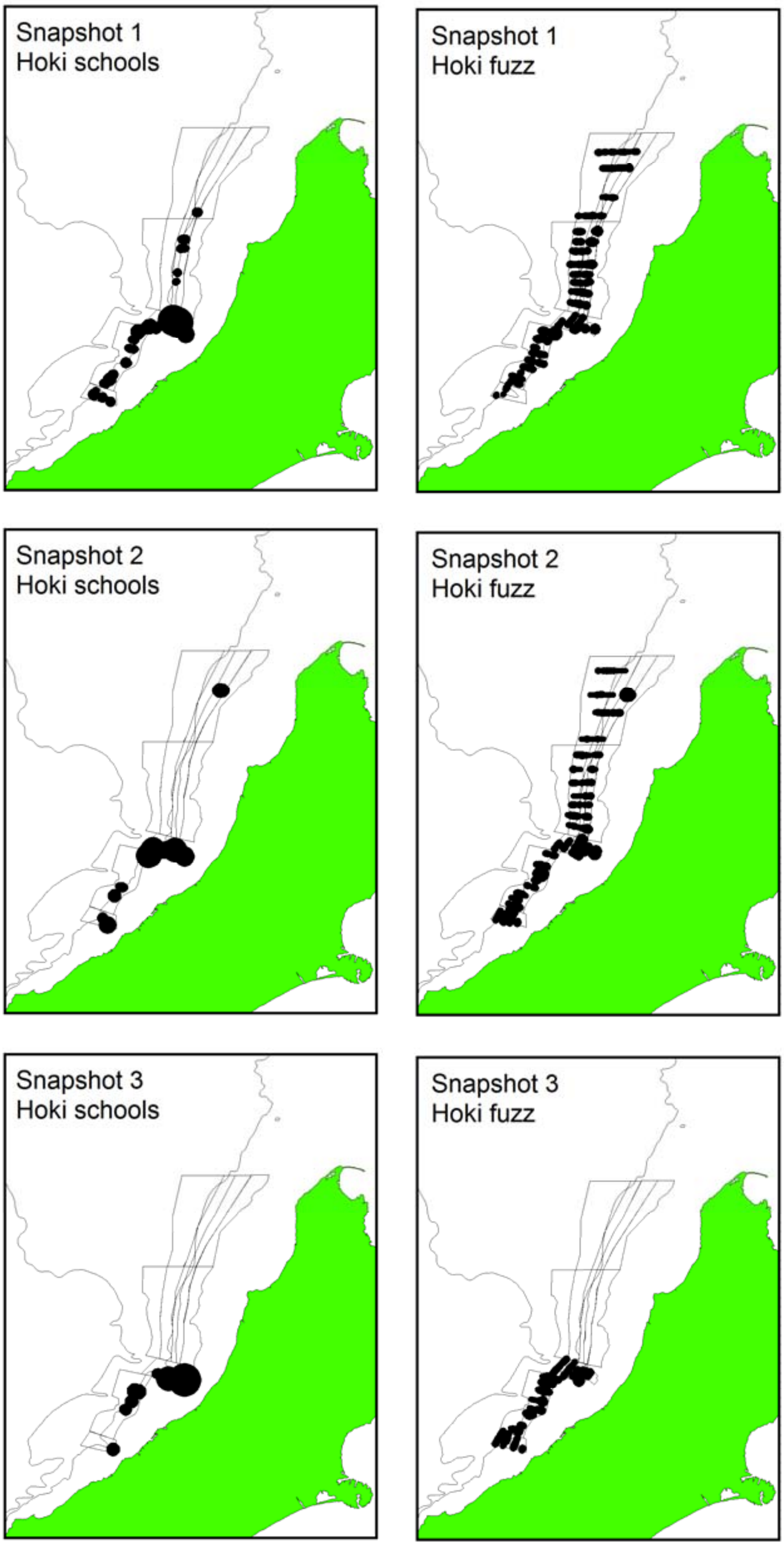

Figure 28: Spatial distribution of acoustic backscatter from hoki schools and hoki fuzz marks plotted in 10 ping (approximately 100 m) bins for the three snapshots of the WCSI. Symbol size is proportional to the log of the acoustic backscatter.

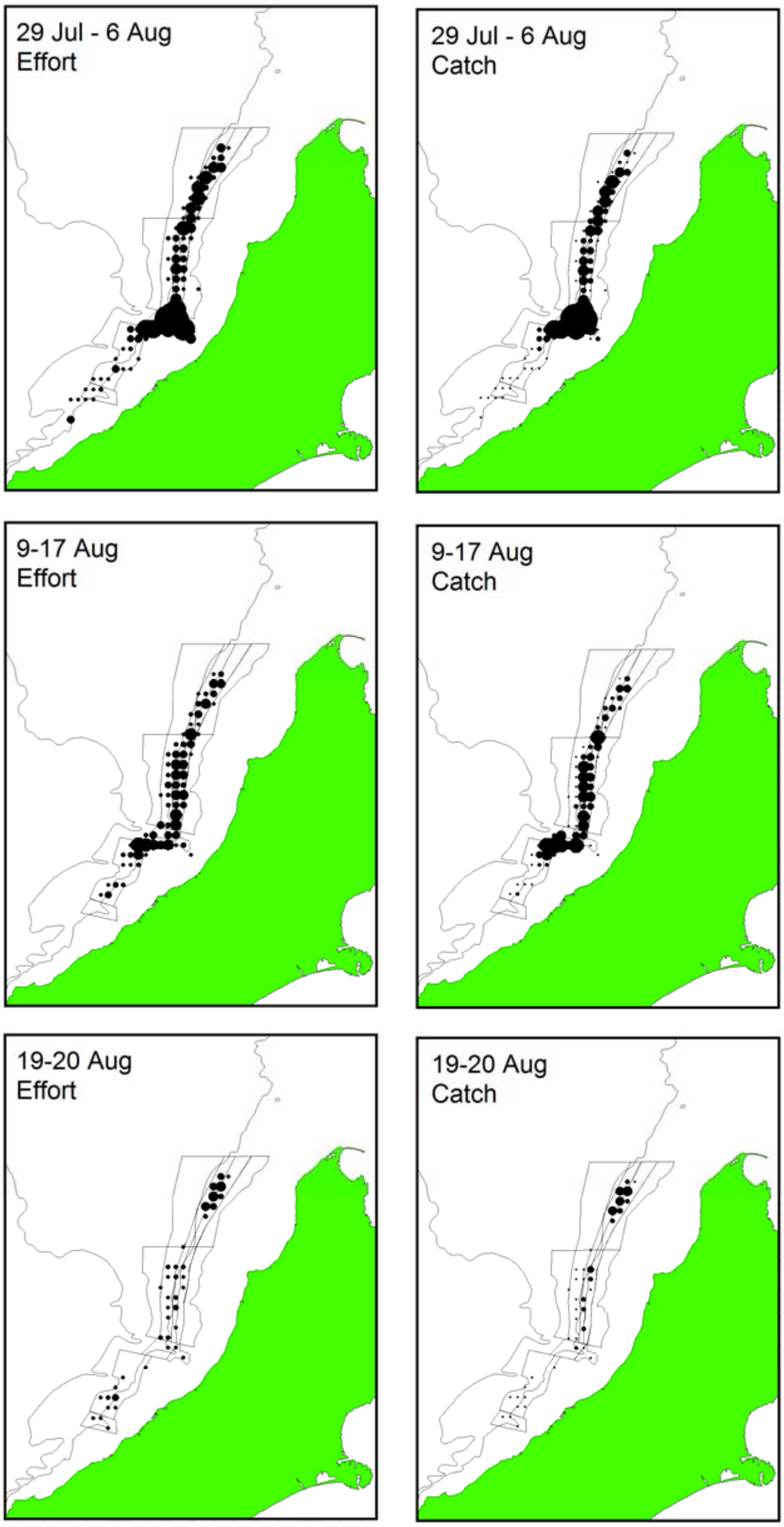

Figure 29: Spatial distribution of commercial effort (number of tows) and catch (tonnes) from hoki target tows during the 2013 survey period. Data are aggregated by decimal degree. Symbol size is proportional to the square root of either effort or catch.

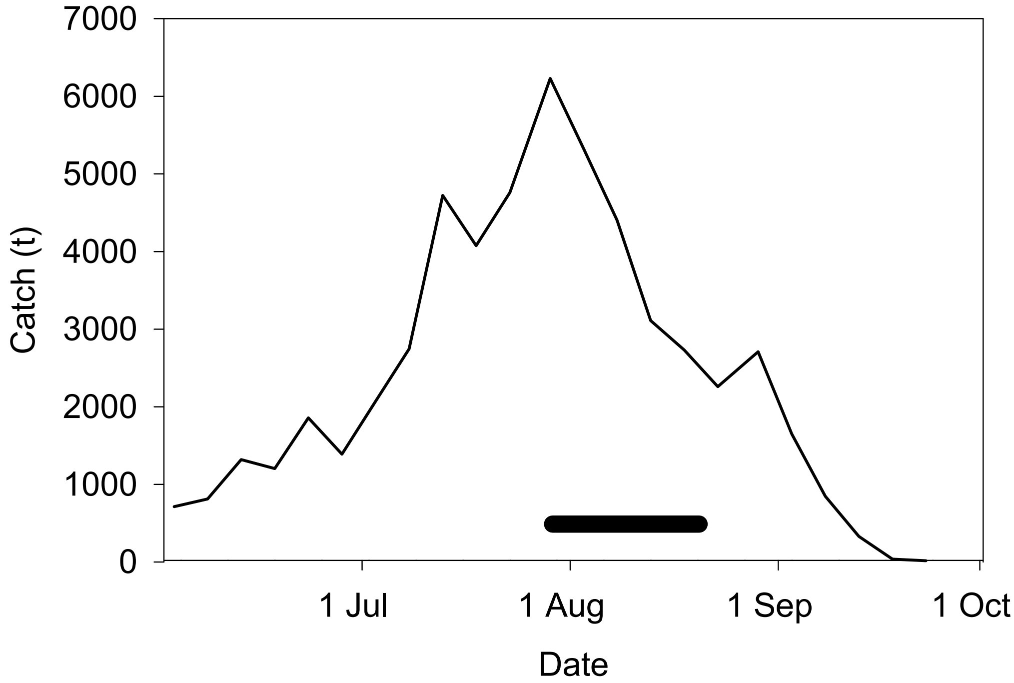

Figure 30: Timing of acoustic survey in 2013 (thick black line) in relation to the commercial hoki catch from the WCSI in 5-day periods.

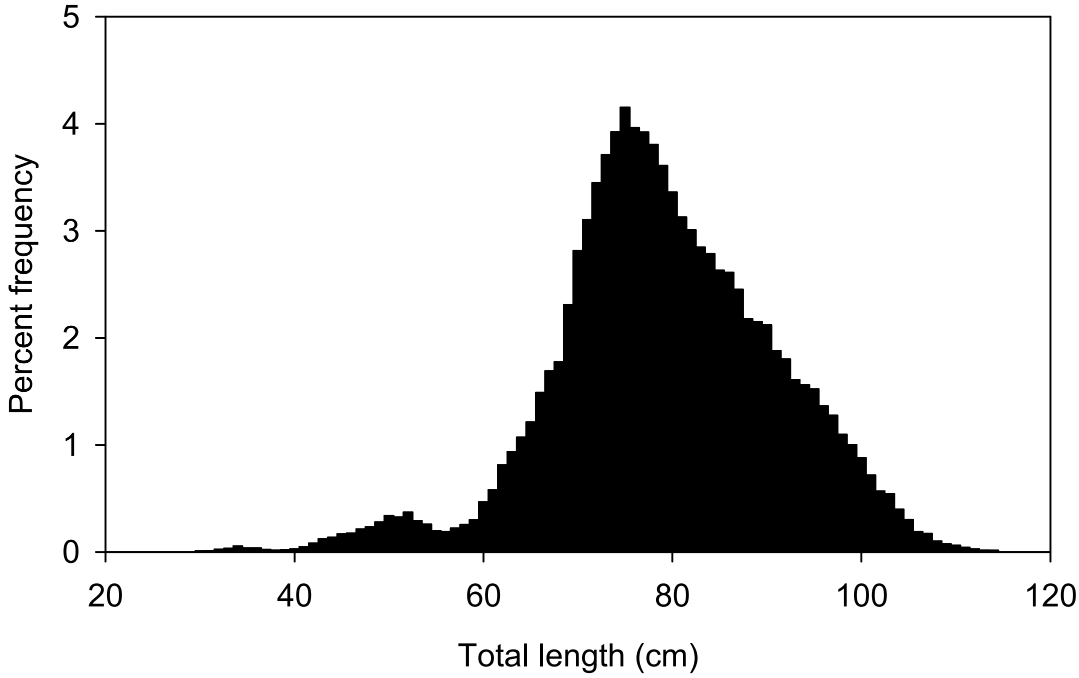

Figure 31: Scaled unsexed length frequencies of hoki caught in the commercial fishery on the WCSI in 2013 based on at-sea observer sampling (from Ballara & O'Driscoll 2014). Data were used to estimate the ratio, *r*, of mean weight to mean backscattering cross-section (see Table 17).

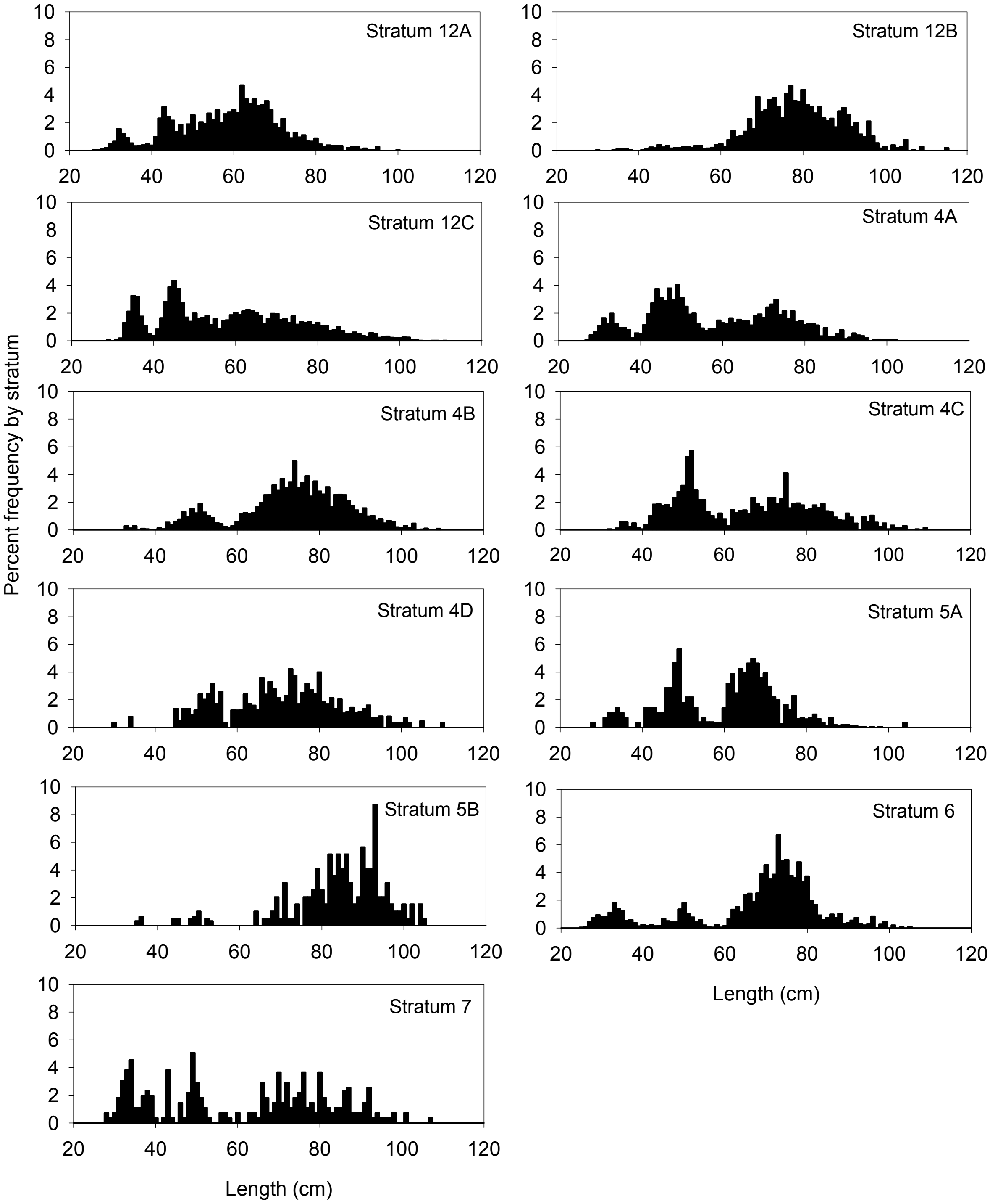

Figure 32: Scaled length frequencies of hoki by stratum from all research tows on the WCSI in 2013. Data were used to estimate the ratio, *r*, of mean weight to mean backscattering cross-section from fuzz marks following the 'new' method (see Table 18).

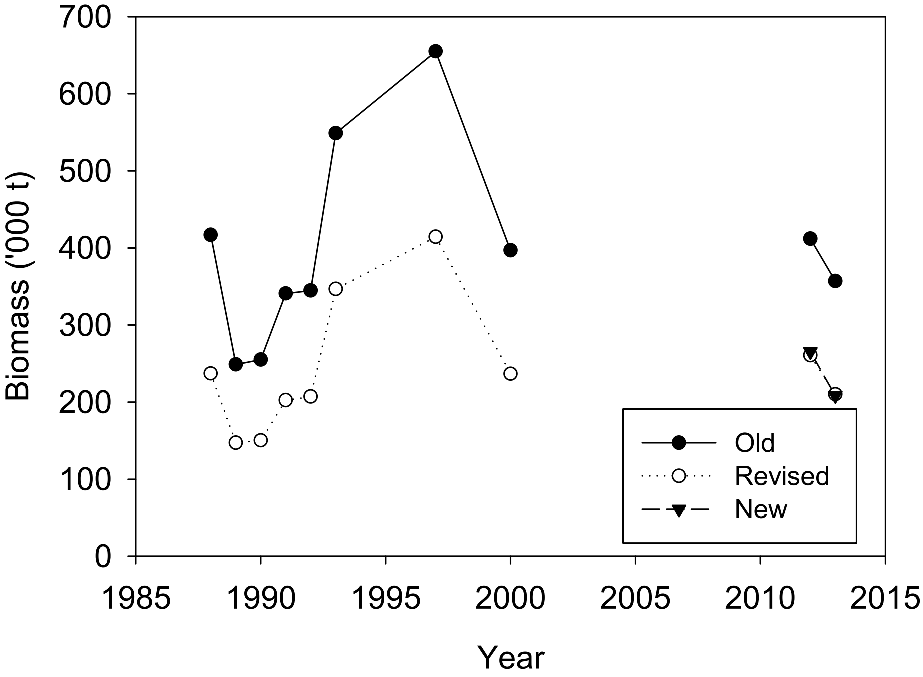

Figure 33: Time-series of research survey acoustic abundance indices for hoki on the WCSI.

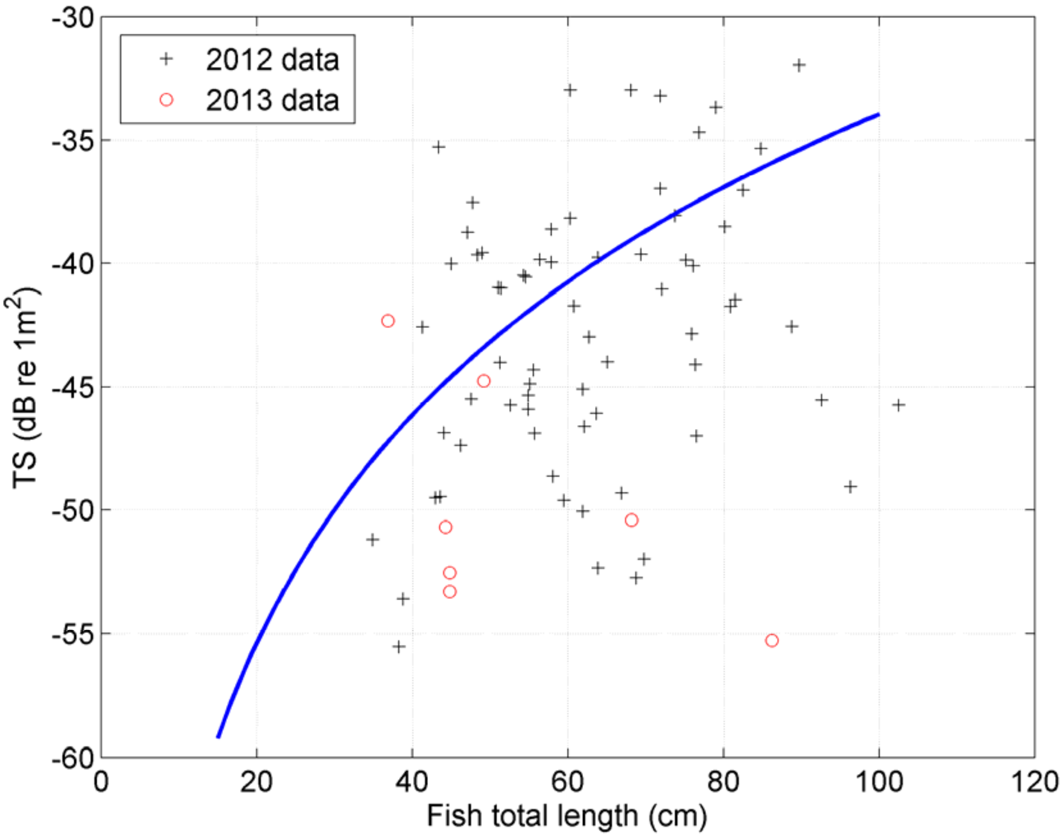

Figure 34: Estimates of mean target strength (TS) from seven optically-verified hoki tracks in 2013 (open circles), compared with equivalent 2012 data from Dunford et al. (2015), and the new TS-L relationship (Equation 4, blue line).

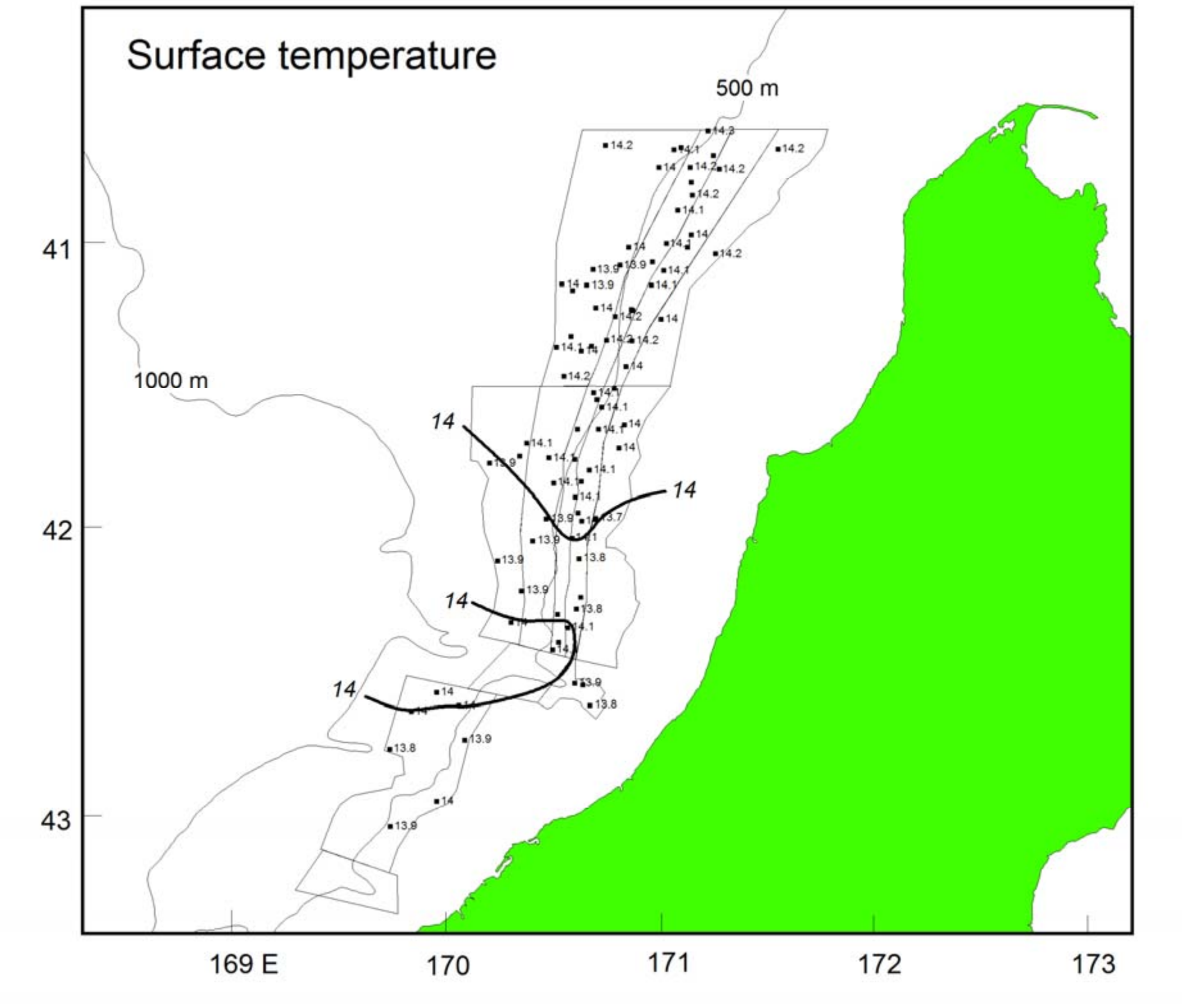

Figure 35: Surface water temperatures (°C) during the 2013 WCSI survey. Squares indicate bottom trawl tow positions. Not all temperatures are labelled where two or more tows were close together. Contours show isotherms estimated by eye.

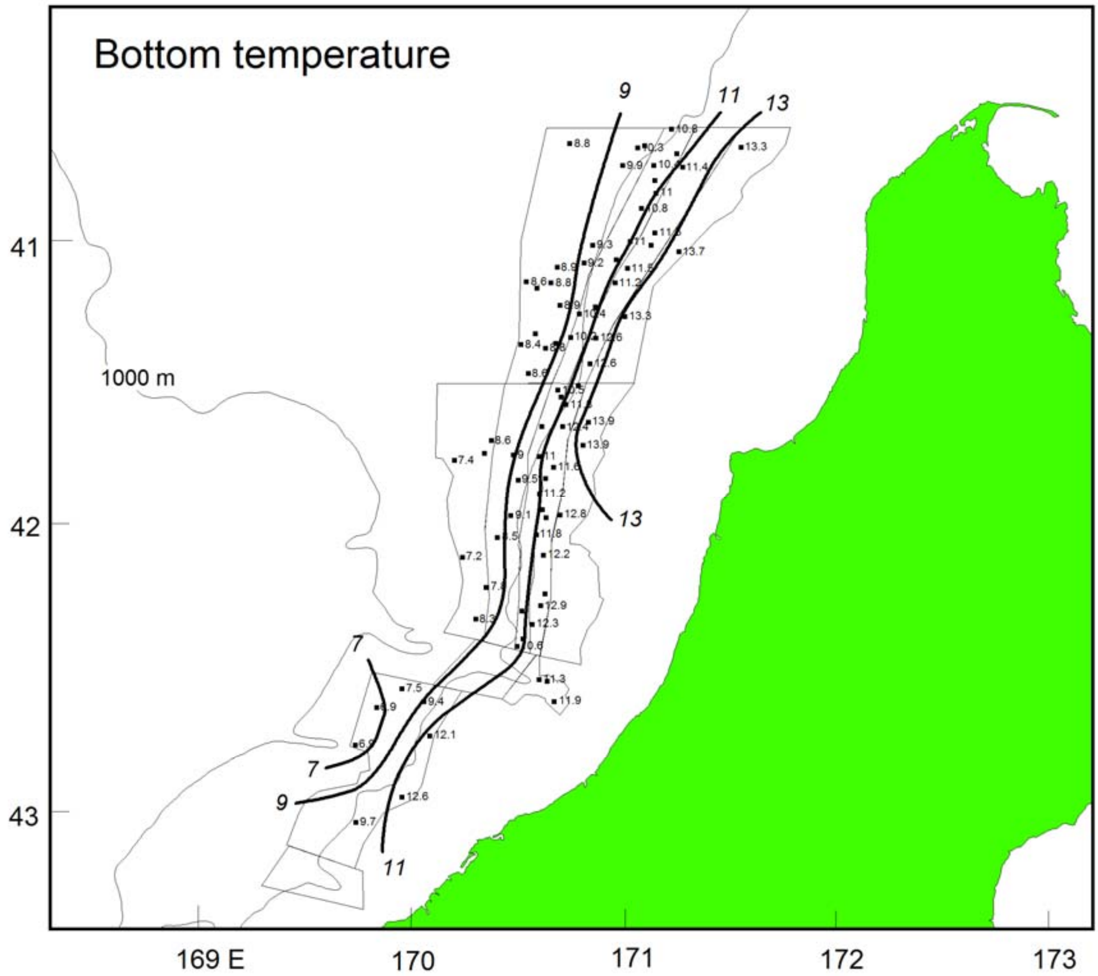

Figure 36: Bottom water temperatures (°C) during the 2013 WCSI survey. Squares indicate bottom trawl tow positions. Not all temperatures are labelled where two or more tows were close together. Contours show isotherms estimated by eye.

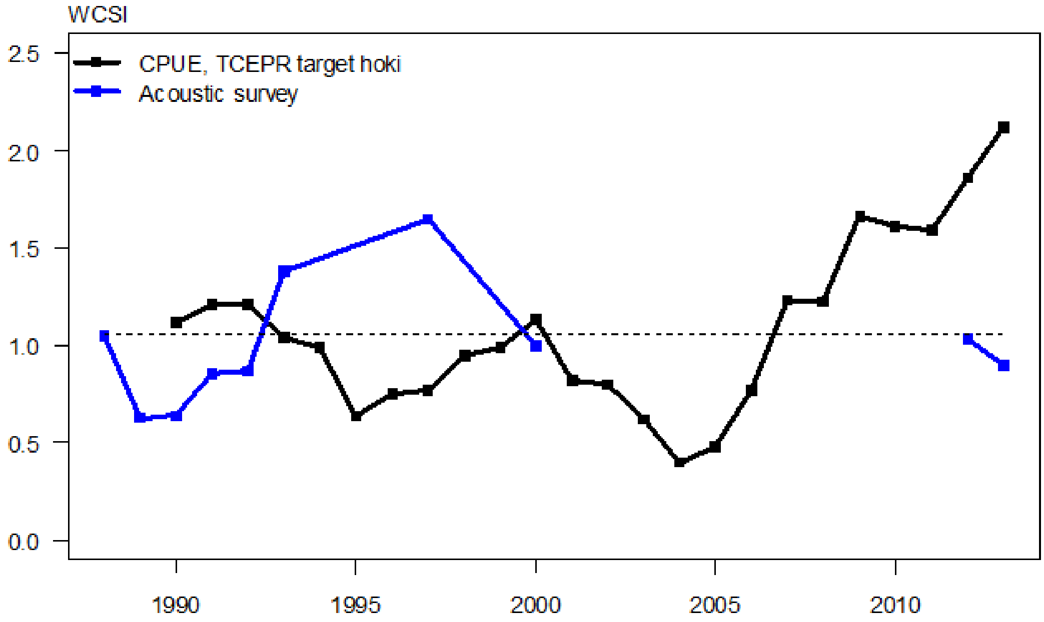

Figure 37: Comparison between the relative acoustic abundance index of spawning hoki on the WCSI and standardised catch-per-unit-effort (CPUE) from commercial tows targeting hoki reported on TCEPR forms from 1990 to 2013 (from Ballara & O'Driscoll 2014).

APPENDIX 1: Calibration Report for *Tangaroa* EK60 echosounders

The 18, 38, 70, 120, and 120 kHz EK60 echosounders on *Tangaroa* were calibrated on 28 July 2013 in Tasman Bay (41˚ 03.58' S, 173˚ 22.80' E), at the start of the combined trawl and acoustic survey of hoki and middle depth species on the west coast South Island (TAN1308). The calibration was conducted broadly as per the procedures in MacLennan & Simmonds (1992).

As for other recent calibrations of the hull echosounders on *Tangaroa*, we used divers to minimise set-up time. New Zealand Diving Services provided dive support from their vessel *Topside*. Bruce Lines was the chief diver. The calibration started at 10:25 NZST. The diver located and cleaned the transducers, attached the lines, and made sure that these were not fouled. Pole locations were the same as those for the calibrations in August 2011 and July 2012. The sphere and associated lines were immersed in a soap solution prior to entering the water. A lead weight was also deployed about 3 m below the sphere to steady the arrangement of lines.

The weather during the calibration was very good, with 10–15 knots of south-westerly wind and no swell. The vessel was drifting at an average speed of about 0.4 knots. Water depth was about 35 m.

The sphere was located in the beam immediately at 10:50, and the divers and support boat returned to Nelson at 11:15. 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 two EK60 raw format files (tan1308-D20130727-T224049.raw and tan1308-D20130727-T234359.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 12:07 NZST.

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 according to 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. Results for all frequencies have been relatively consistent (usually within 0.5 dB) across all calibrations, with higher frequencies (70, 120, and 200 kHz) being more variable over time. The calibration coefficients for the 38 kHz echosounder (the frequency used for abundance estimation) were relatively stable from May 2008 to February 2012, but decreased (became less sensitive) by 8% in July 2012, and by a further 7% to July 2013. A trend of gradually declining performance over time is common for scientific echosounders (Knudsen 2009), but it will be important to continue to regularly calibrate this system to monitor this change, and allow appropriate corrections when estimating abundance. If the deterioration continues, consideration should be given to replacing the 38 kHz transducer when the *Tangaroa* is in dry-dock in 2014.

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 0.08 dB for 18 kHz, 0.09 dB for 38 kHz, 0.10 dB for 70 kHz, 0.15 dB for 120 kHz, and 0.20 dB for 200 kHz (Table 1.3), 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 23 sphere echoes at 18 kHz, 720 echoes at 38 kHz, 86 echoes at 70 kHz, 4 echoes at 120 kHz, and 61 echoes at 200 kHz.

Calibration coefficients estimated from this calibration were used for analysis of results from the WCSI survey (TAN1308) and the acoustic survey of spawning southern blue whiting on the Campbell Plateau (TAN1309).

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) except for the 120 kHz which was set at Simrad default values.

Parameter					
Frequency (kHz)	18	38	70	120	200
GPT model	00907205c476	0090720580ea	00907205ca98	009072058148	00907205da23
GPT serial number	652	650	674	668	692
GPT software version	050112	050112	050112	050112	050112
ER60 software version	2.4.3	2.4.3	2.4.3	2.4.3	2.4.3
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	750*	250*	150*
Pulse length (ms)	1.024	1.024	1.024	1.024	1.024
Transducer peak gain (dB)	22.96	25.81	26.43	27.00	24.96
Sa correction (dB)	-0.81	-0.57	-0.35	0.00	-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)	2.7	9.8	22.8	37.4	52.7
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 (°) along/athwartship	10.8/10.8	7.0/7.0	6.6/6.6	6.5/6.6	6.8/6.9
Angle offset (°) along/athwartship	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0

*Maximum transmit power of 70, 120, and 200 kHz echosounders was reduced when ER60 software was upgraded in April 2013. Previously transmit power was 1000 W, 500 W, and 300 W respectively.

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 (NZST, start)	28 July 2013 09:12
Position	41˚ 03.31' S 173˚ 22.06' E
Mean sphere range (m)	20.8 (18 kHz), 20.7 (38), 20.7 (70), 20.5 (120), 20.4 (200)
Mean temperature (ºC)	12.0
Mean salinity (psu)	34.7
Sound speed (m/s)	1496.7
Water density (kg/m^3)	1026.5
Sound absorption (dB/km)	2.35 (18 kHz) 9.18 (38 kHz) 22.66 (70 kHz) 39.12 (120 kHz) 58.02 (200 kHz)
Sphere target strength (dB re 1m^2)	–42.65 (18 kHz) –42.41 (38 kHz) –41.39 (70 kHz) –39.50 (120 kHz) –39.11 (200 kHz)

Table A1.3: Estimated calibration coefficients for all calibrations of *Tangaroa* hull EK60 echosounders. Transducer peak gain was estimated from mean sphere TS using Matlab calibration code version 6818.

		Jul 2013	Jul 2012	Feb 2012	Aug 2011	Jan 2010	May 2008
18 kHz							
	Transducer peak gain (dB)	22.99	22.97	22.81	22.78	23.36	22.96
	Sa correction (dB)	-0.78	-0.84	-0.69	-0.69	-0.76	–0.81
	Beamwidth (º) along/athwartship	10.6/10.7	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	0.00/-0/.00	-0.02/0.08	0.00/0.00	0.00/0.00
	RMS deviation (dB)	0.08	0.09	0.14	0.08	0.14	0.26
38 kHz							
	Transducer peak gain (dB)	25.42	25.62	25.75	25.75	25.98	25.81
	Sa correction (dB)	-0.55	-0.61	-0.57	-0.58	-0.58	–0.57
	Beamwidth (º) along/athwartship	6.8/6.9	6.8/6.9	6.8/6.8	6.8/6.9	6.9/7.0	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	0.00/0.00
	RMS deviation (dB)	0.09	0.10	0.14	0.08	0.10	0.16
70 kHz							
	Transducer peak gain (dB)	26.43	26.04	26.78	26.23	26.78	26.43
	Sa correction (dB)	-0.37	-0.31	-0.35	-0.32	-0.30	–0.35
	Beamwidth (º) along/athwartship	6.6/6.3	6.6/6.6	6.3/6.1	6.5/6.6	6.3/6.4	6.6/6.6
	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	0.00/0.00
	RMS deviation (dB)	0.10	0.10	0.21	0.10	0.14	0.25
120 kHz							
	Transducer peak gain (dB)	26.22	26.11	26.80	25.96	26.79	26.17
	Sa correction (dB)	-0.39	-0.34	-0.38	-0.39	-0.35	–0.36
	Beamwidth (º) along/athwartship	6.5/6.4	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	0.00/0.00	-0.13/0.11	0.00/0.00	0.00/0.00
	RMS deviation (dB)	0.15	0.17	0.19	0.17	0.17	0.35
200 kHz							
	Transducer peak gain (dB)	25.27	25.31	25.16	25.25	25.35	24.96
	Sa correction (dB)	-0.31	-0.24	-0.21	-0.29	-0.36	–0.25
	Beamwidth (º) along/athwartship	6.4/6.3	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	0.00/0.00	-0.27/-0.10	0.08/-0.08	0.00/0.00	0.00/0.00	0.00/0.00
	RMS deviation (dB)	0.20	0.21	0.18	0.21	0.18	0.39

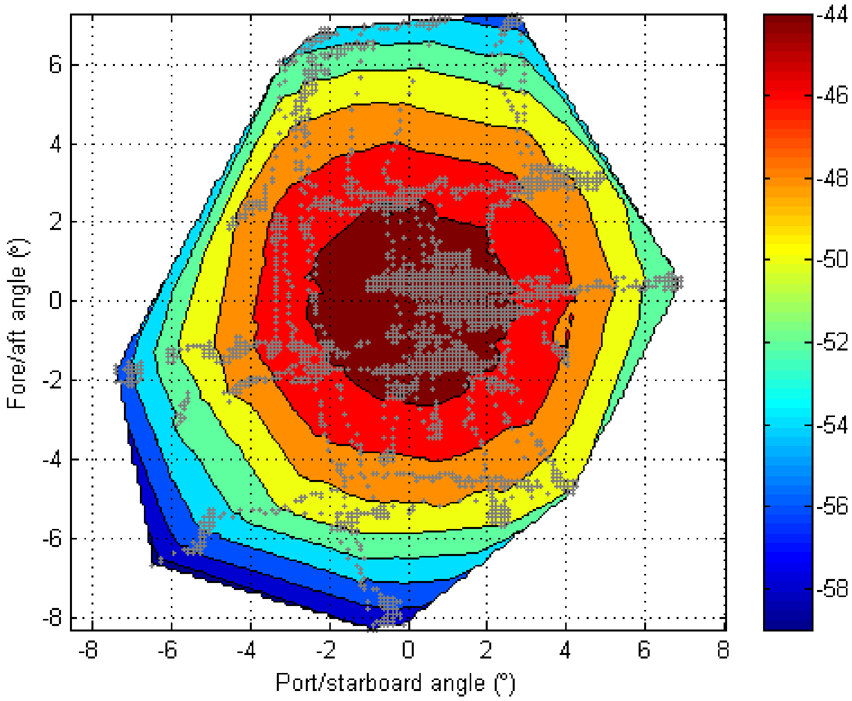

Figure A1.1: The 18 kHz estimated beam pattern from the sphere echo strength and position. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

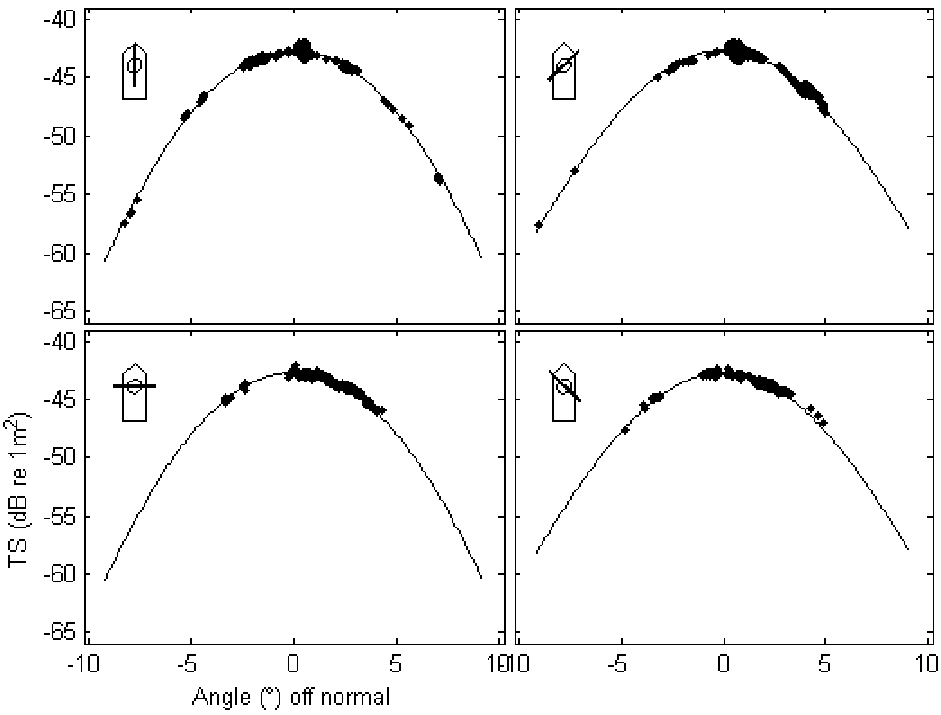

Figure A1.2: Beam pattern results from the 18 kHz analysis. The solid line is the ideal beam pattern fit to the sphere echoes for four slices through the beam.

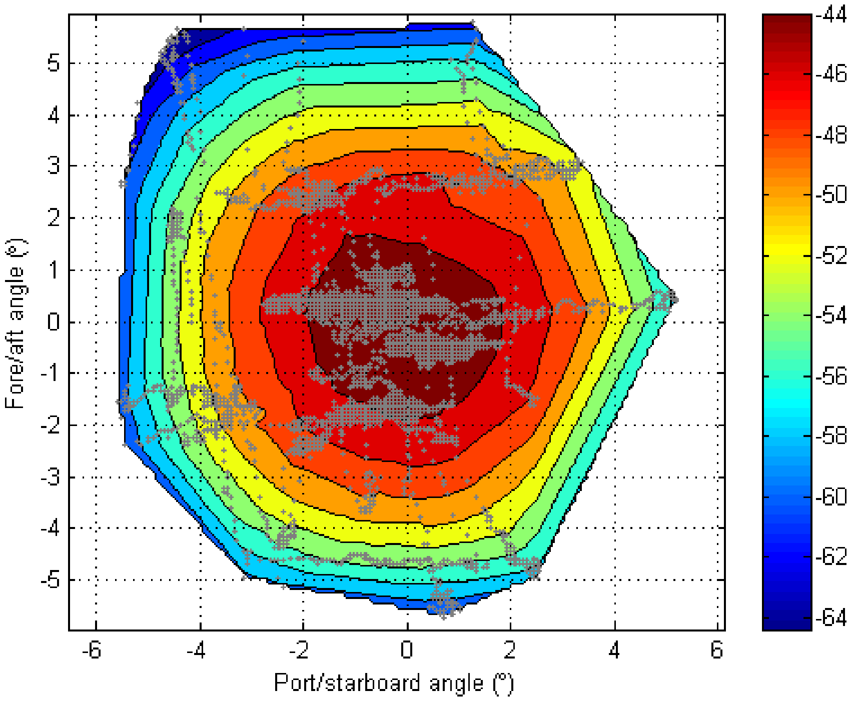

Figure A1.3: The 38 kHz estimated beam pattern from the sphere echo strength and position. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

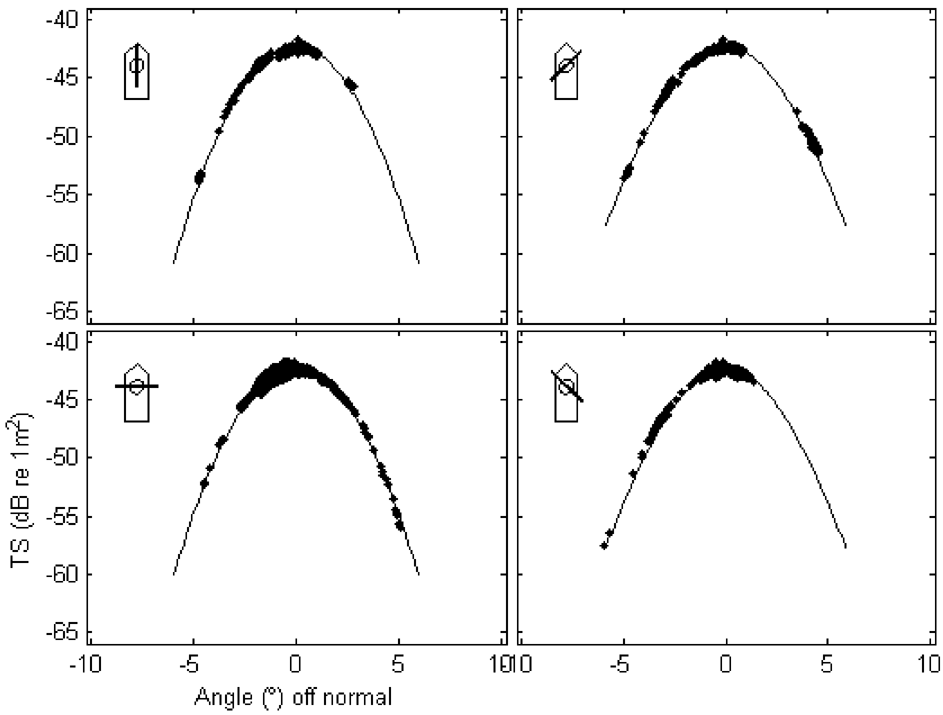

Figure A1.4: Beam pattern results from the 38 kHz analysis. The solid line is the ideal beam pattern fit to the sphere echoes for four slices through the beam.

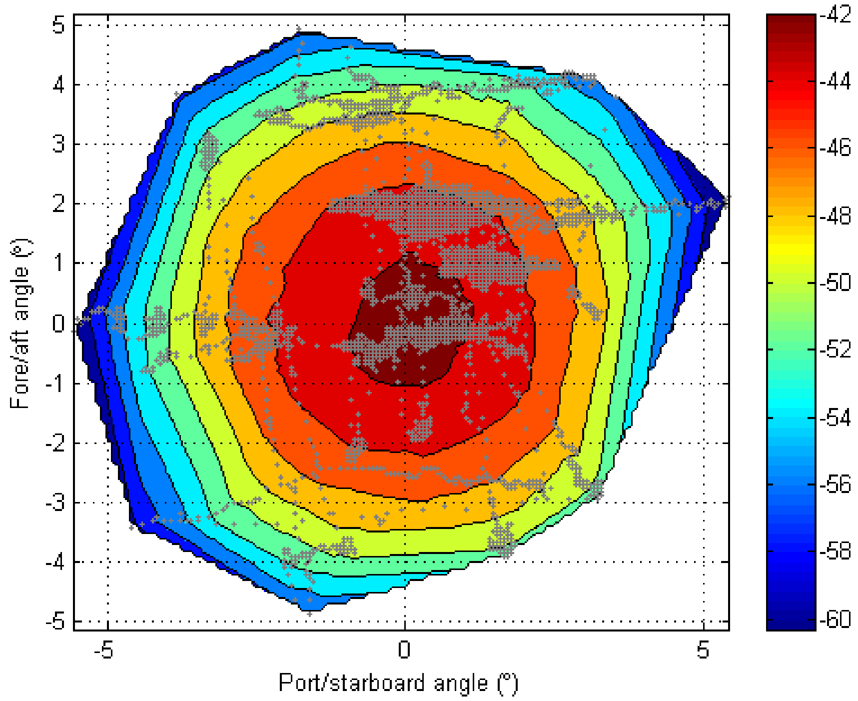

Figure A1.5: The 70 kHz estimated beam pattern from the sphere echo strength and position. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

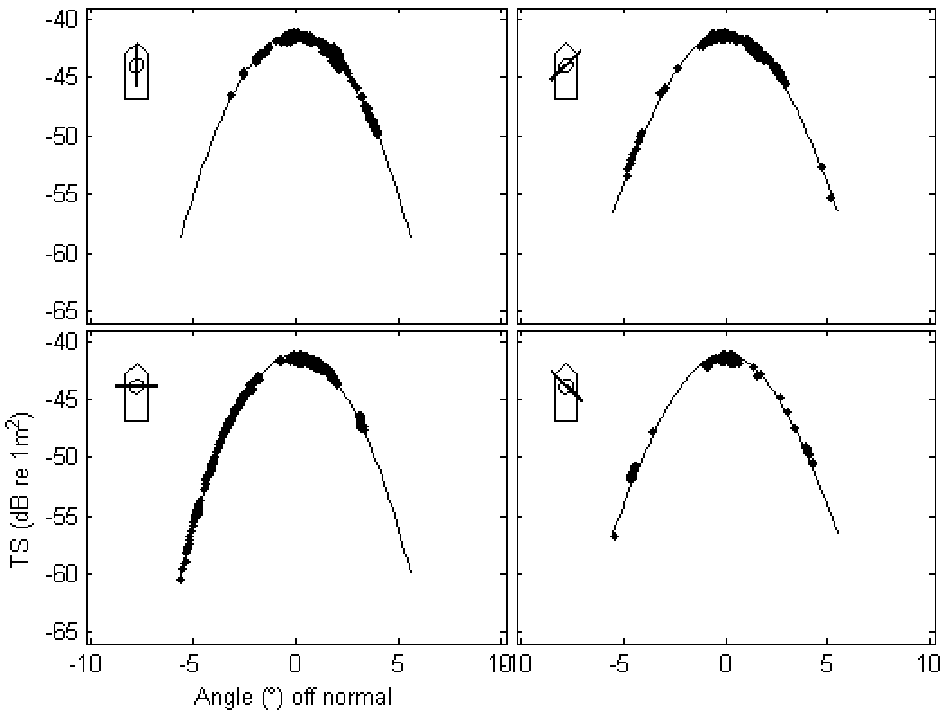

Figure A1.6: Beam pattern results from the 70 kHz analysis. The solid line is the ideal beam pattern fit to the sphere echoes for four slices through the beam.

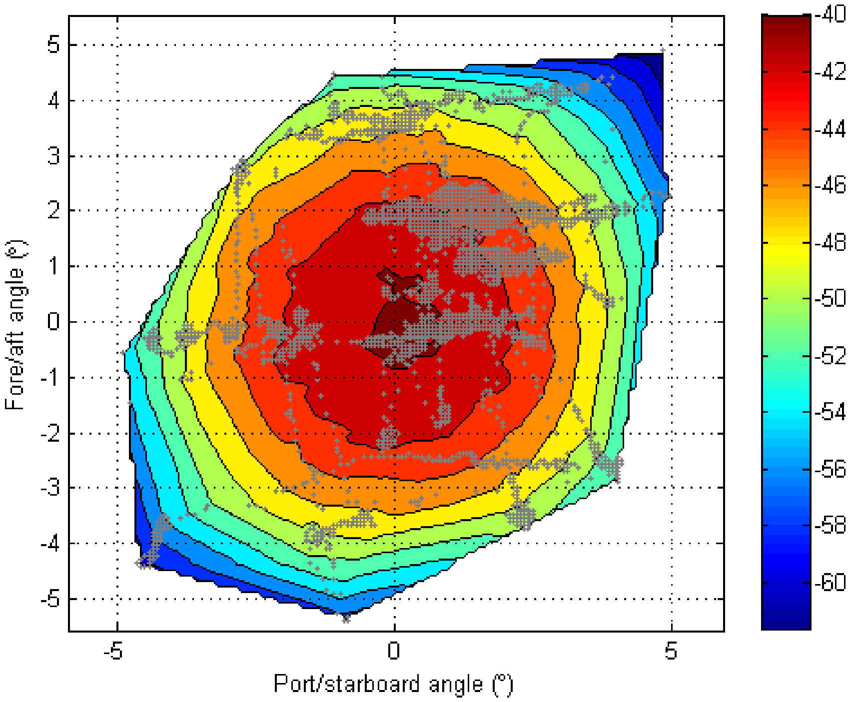

Figure A1.7: The 120 kHz estimated beam pattern from the sphere echo strength and position. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

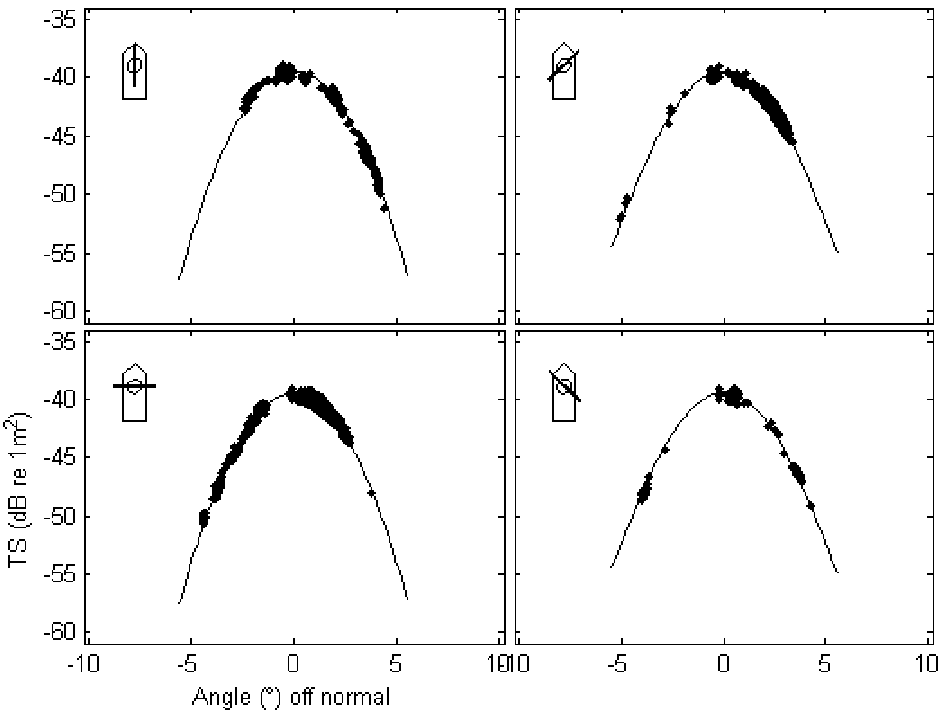

Figure A1.8: Beam pattern results from the 120 kHz analysis. The solid line is the ideal beam pattern fit to the sphere echoes for four slices through the beam.

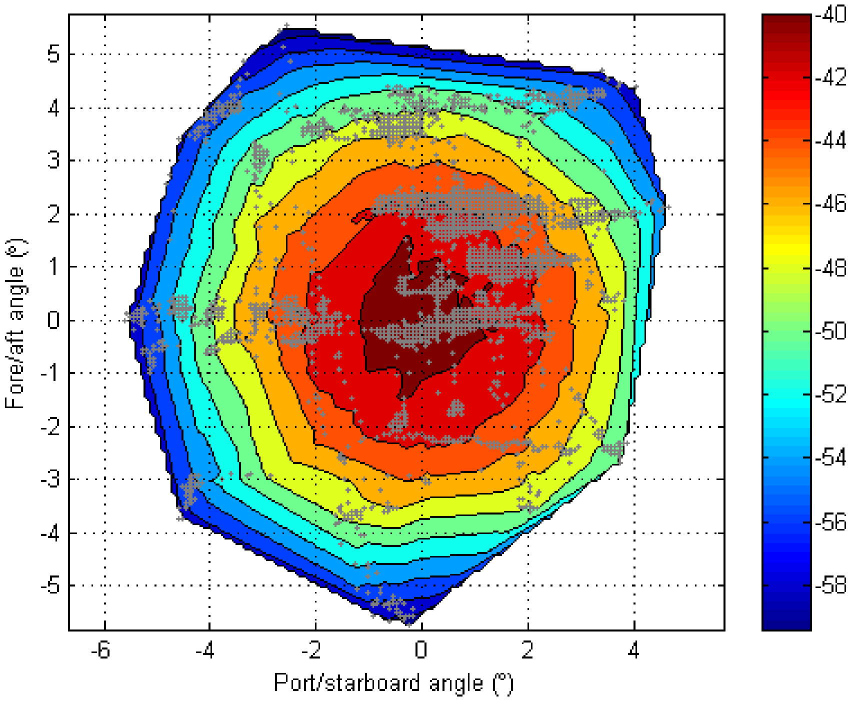

Figure A1.9: The 200 kHz estimated beam pattern from the sphere echo strength and position. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m².

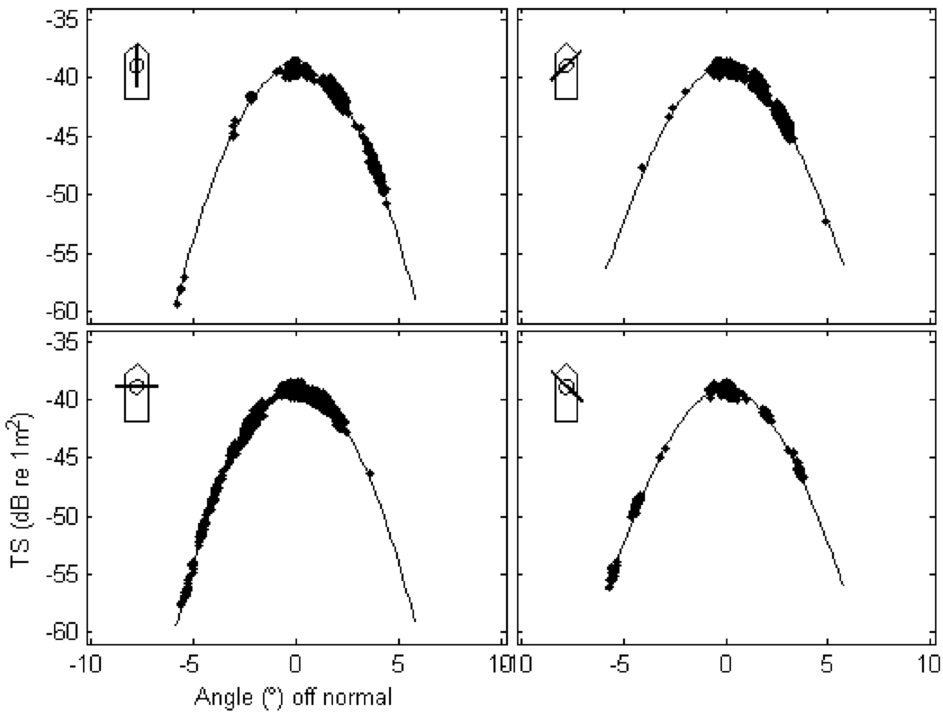

Figure A1.10: Beam pattern results from the 200 kHz analysis. The solid line is the ideal beam pattern fit to the sphere echoes for four slices through the beam.

APPENDIX 2: Towbody 3 calibration.

Calibration of the Simrad EK60 echosounder in Towbody 3 took place in Tasman Bay (41˚ 03.31' S, 173˚ 21.98' E) on 28 July 2013, at the start of the combined trawl and acoustic survey of hoki and middle depth species on the west coast South Island (TAN1308). This was the first full at-sea calibration of the new EK60 echosounder in Towbody 3 (previously it was a CREST system). A partial calibration was carried out during sea-trials on *Kaharoa* on 30 June 2013, but only four sphere echoes were obtained on axis.

The calibration started at 09:00 NZST. The towbody was lowered about 4 m below the surface, supported by the deployment wires and a nose rope to allow the pitch to be adjusted. A 38.1 mm tungsten carbide sphere was suspended by a single line about 26 m below the transducer. A weight was also deployed about 3 m below the sphere to steady the line. The transducer face, towbody window, sphere and associated lines were washed with a soap solution prior to entering the water.

The weather was good with a 10–15 knot south-westerly wind and 0.5 m wind chop. The vessel was allowed to drift, and the drift speed was about 0.4 knots. The sphere was first centred in the beam to obtain data for the on-axis calibration. The towbody pitch was then adjusted using the nose-rope to obtain data for the beam shape calibration. The echosounder was run from a PC (ER60-3) onboard *Tangaroa* and calibration data were saved into one EK60 raw format file (tan1308-D20130727-T205932). Raw data are stored in the NIWA *acoustics* database. The EK60 transceiver settings in effect during the calibration are given in Table A2.1. The calibration was completed at 10:10 NZST.

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). Estimates of seawater sound speed and density were calculated using the formulae of Fofonoff & Millard (1983). The sphere target strength was calculated according to 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 as described in Appendix 1.

Results

The results from the CTD cast are given in Table A2.2, along with estimates of the sphere target strength, sound speed, and acoustic absorption.

The calibration results are given in Table A2.3. The estimated beam pattern and sphere coverage are given in Figure A2.1. The symmetrical nature of the pattern and the zero centre of the beam pattern indicate that the transducer and EK60 transceiver were operating correctly. The fits between the theoretical beam pattern and the sphere echoes is shown in Figure A2.2 and confirms that the transducer beam pattern is correct. The estimated peak gain (G_0) was 24.69 dB and the Sa correction of -0.69 dB were estimated from 124 sphere echoes within 0.21° of the beam centre (Table A2.3). The RMS of the difference between the Simrad beam model and the sphere echoes out to 3.6° off axis was 0.08 dB (Table A2.3), indicating that the calibration was of excellent quality (<0.4 dB is poor, <0.3 dB good, and <0.2 dB excellent).

Calibration coefficients estimated from this calibration were used for analysis of results from the WCSI survey (TAN1308). A further calibration of the system was carried out during the acoustic survey of spawning southern blue whiting on the Campbell Plateau (TAN1309).

Table A2.1: EK60 transceiver settings and other relevant parameters during the calibration.

Parameter	Value
Echosounder	Towbody 3 EK60
ER60 software version	2.4.3
Transducer model	ES38DD
Transducer serial number	28332B
EK60 GPT serial number	009072069o87
GPT software version	Not recorded
Sphere type/size	tungsten carbide/38.1 mm diameter
Operating frequency (kHz)	38
Towbody depth (m)	3
Transmit power (W)	2000
Pulse length (ms)	1.024
Transducer peak gain (dB)	26.5
Sa correction (dB)	0.0
Bandwidth (Hz)	2425
Sample interval (m)	0.192
Two-way beam angle (dB)	–20.60
Absorption coefficient (dB/km)	9.75
Speed of sound (m/s)	1500
Angle sensitivity (dB) alongship/athwartship	21.90/21.90
3 dB beamwidth (°) alongship/athwartship	7.10/7.10
Angle offset (°) alongship/athwartship	0.0/0.0

Table A2.2: Auxiliary calibration parameters derived from conductivity, temperature, depth measurements.

Parameter	Value
Mean sphere range (m)	26.2
Mean temperature (ºC)	12.0
Mean salinity (psu)	34.7
Sound speed (m/s)	1496.7
Mean absorption (dB/km)	9.18
Sphere TS (dB re 1m2)	–42.41

Table A2.3: Echosounder calibration values. Transducer peak gain was estimated from mean sphere TS using Matlab calibration code version 6818.

Parameter	Value
Mean TS within 0.21° of centre	-46.04
Std dev of TS within 0.21° of centre	0.12
Max TS within 0.21° of centre	-45.86
No. of echoes within 0.21° of centre	124
On axis TS from beam-fitting	-46.02
Transducer peak gain (dB)	24.69
Sa correction (dB)	-0.69
Beamwidth (º) alongship/athwarthship	7.09/7.13
Beam offset (º) alongship/athwarthship	0.10/-0.02
RMS deviation	0.08
Echoes used to estimate the beam shape	9 460

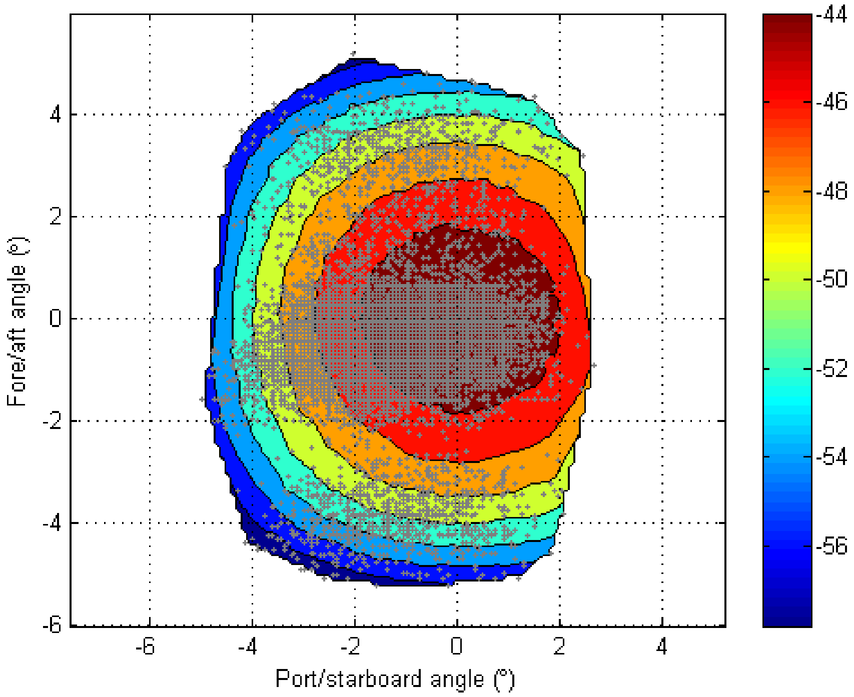

Figure A2.1: The estimated beam pattern from the sphere echo strength and position for the calibration. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

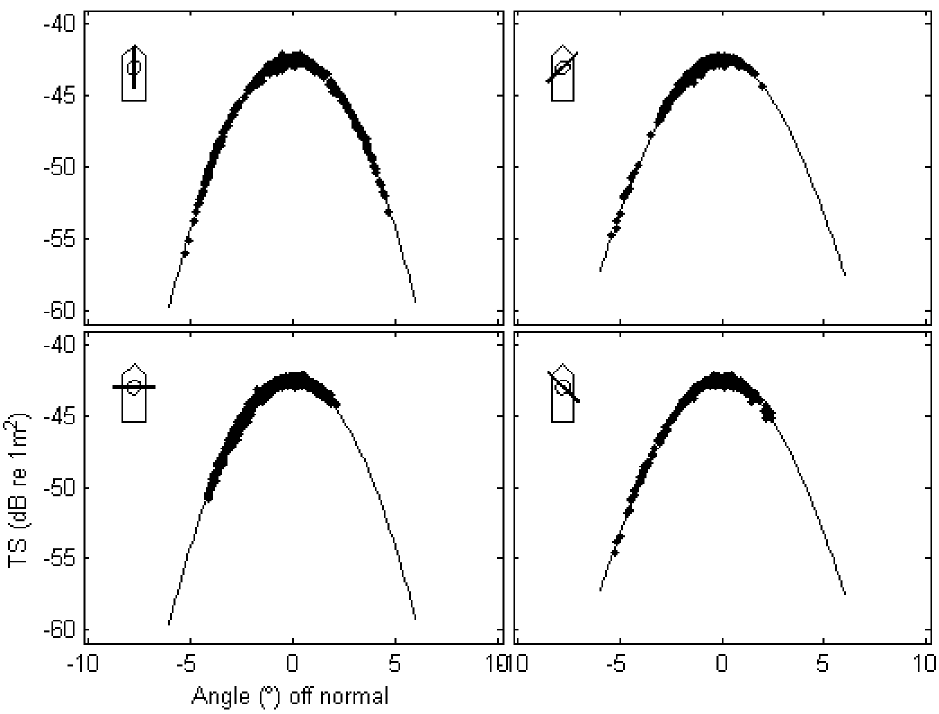

Figure A2.2: Beam pattern results from the calibration analysis. The solid line is the theoretical beam pattern fit to the sphere echoes for four slices through the beam.

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 80 tows as part of the 2013 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 8.80 dB km^{-1} from the absorption profile over the upper 400 m (Figure A4.1c) was used when estimating hoki abundance (see Section 2.8.2).

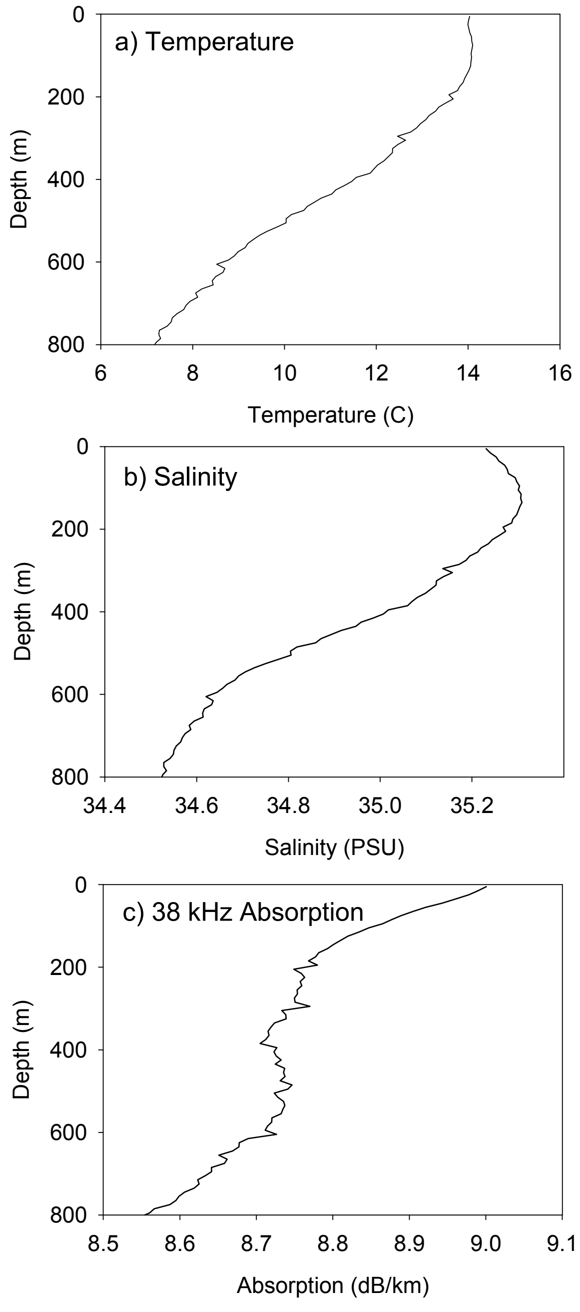

Figure A4.1: Profiles of average temperature, salinity, and sound absorption at 38 kHz from the 84 CTD casts carried out during 2013 WCSI survey.

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

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

Station	Date	Type	Stratum	Start latitude (S)	Start longitude (E)	Distance (n. mile)	Hoki (kg)	Ling (kg)	Hake (kg)
1	27-Jul-13	CAL		41 03.31	173 22.06	-	-	-	-
2	29-Jul-13	RBT	4S	41 57.98	170 38.92	2.94	0.0	0.0	0.0
3	30-Jul-13	IDMW	5B	42 29.73	170 13.98	1.20	1.7	0.0	0.0
4	30-Jul-13	ID	6	42 37.52	170 00.27	0.95	3 582.9	20.5	70.1
5	30-Jul-13	ID	6	42 38.75	169 46.80	3.03	72.3	0.0	45.2
6	31-Jul-13	ID	6	43 03.09	169 40.91	3.20	543.1	113.8	41.8
7	31-Jul-13	IDMW	7	43 16.47	169 30.65	0.30	3.9	0.0	0.0
8	1-Aug-13	RBT	4B	42 25.79	170 26.67	2.04	3 255.5	105.8	189.2
9	1-Aug-13	RBT	4B	42 24.21	170 28.36	2.42	2 140.2	272.2	63.5
10	1-Aug-13	RBT	4A	42 21.17	170 31.06	3.01	1 648.0	560.3	20.7
11	1-Aug-13	RBT	4B	42 18.36	170 28.15	3.01	1 019.7	268.5	125.4
12	1-Aug-13	RBT	4A	42 17.20	170 33.45	3.01	2 915.0	118.7	25.5
13	2-Aug-13	RBT	4A	42 14.76	170 34.64	2.98	155.5	175.3	0.0
14	2-Aug-13	RBT	4A	42 06.49	170 34.21	3.01	57.3	44.3	0.0
15	2-Aug-13	RBT	4A	42 02.18	170 32.18	2.21	1 182.9	122.1	0.0
16	2-Aug-13	RBT	4A	41 58.52	170 34.97	1.98	1 221.7	272.9	0.0
17	3-Aug-13	ID/AOS	4A	41 47.94	170 37.11	2.51	51.3	21.1	0.0
18	3-Aug-13	RBT	4A	41 39.31	170 39.66	2.90	740.8	229.0	0.0
19	3-Aug-13	RBT	4A	41 34.58	170 40.57	2.01	8 883.3	686.2	0.0
20	3-Aug-13	RBT	4B	41 31.58	170 38.35	3.02	832.6	36.4	21.1
21	4-Aug-13	RBT	4A	41 56.91	170 33.90	2.00	7 656.8	196.0	5.7
22	4-Aug-13	RBT	4B	41 53.60	170 33.07	2.22	1 595.3	169.1	25.1
23	4-Aug-13	RBT	4A	41 50.33	170 34.75	3.01	941.2	390.8	8.2
24	4-Aug-13	RBT	4B	41 45.67	170 33.06	3.01	2 309.9	179.0	0.0
25	4-Aug-13	RBT	4B	41 39.22	170 33.72	3.03	378.7	24.9	7.7
26	4-Aug-13	RBT	4B	41 32.97	170 39.16	2.79	451.1	44.2	13.9
27	5-Aug-13	ID	12C	41 28.06	170 29.98	3.00	39.8	3.7	10.4
28	5-Aug-13	RBT	12A	41 30.64	170 44.06	3.04	1 478.8	932.5	0.0
29	5-Aug-13	RBT	12A	41 26.00	170 47.46	3.00	406.0	1 332.4	7.9
30	5-Aug-13	RBT	12A	41 20.45	170 49.17	2.94	574.3	1 004.1	0.0
31	5-Aug-13	RBT	12B	41 20.37	170 42.02	3.00	305.2	35.2	47.2
32	5-Aug-13	RBT	12B	41 15.41	170 44.46	2.05	2 331.5	38.7	19.3
33	6-Aug-13	RBT	12B	41 13.94	170 48.95	2.00	14 104.9	58.0	7.1
34	6-Aug-13	RBT	12A	41 08.80	170 54.57	3.06	3 396.7	279.9	5.9
35	6-Aug-13	RBT	12A	41 05.75	170 58.17	3.01	1 814.1	367.9	0.1
36	6-Aug-13	RBT	12B	41 03.88	170 54.99	3.01	483.6	68.8	18.5
37	6-Aug-13	RBT	12B	41 00.04	170 58.83	2.05	1 571.5	52.7	19.6
38	7-Aug-13	ID/AOS	12B	41 14.10	170 49.46	2.77	386.6	19.4	12.8
39	7-Aug-13	RBT	12A	40 58.23	171 05.86	2.93	666.5	662.8	0.0
40	7-Aug-13	RBT	12B	40 52.96	171 02.07	3.01	453.8	41.3	9.0
41	7-Aug-13	RBT	12B	40 49.80	171 06.20	2.22	50.2	23.0	0.0
42	7-Aug-13	RBT	12A	40 44.29	171 13.76	3.05	1 463.0	72.1	0.0
43*	7-Aug-13	RBT	12B	40 43.89	171 05.56	0.39	0.0	0.0	0.0
44	8-Aug-13	RBT	12B	40 47.13	171 05.97	2.20	255.6	23.2	0.0
45	8-Aug-13	RBT	12B	40 41.45	171 12.13	3.02	362.9	61.4	0.0

Station	Date	Type	Stratum	Start latitude (S)	Start longitude (E)	Distance (n. mile)	Hoki (kg)	Ling (kg)	Hake (kg)
46	8-Aug-13	RBT	12B	40 36.19	171 10.68	3.02	174.2	10.9	0.0
47	8-Aug-13	RBT	12C	40 39.25	170 41.74	2.99	116.0	19.7	35.8
48	9-Aug-13	AOS	5A	42 32.88	170 32.99	2.48	0.0	0.0	0.0
49	9-Aug-13	ID	5A	42 33.25	170 35.30	0.66	760.9	153.6	12.2
50	9-Aug-13	IDMW	5B	42 34.65	170 22.83	2.55	1 709.1	0.0	13.7
51	10-Aug-13	IDMW	6	42 37.95	170 09.32	0.48	2 073.1	0.0	56.4
52	10-Aug-13	ID	6	42 46.70	169 40.67	2.23	47.6	0.0	32.0
53	10-Aug-13	ID/AOS	6	42 57.78	169 53.96	1.41	34.0	3.0	3.3
54	11-Aug-13	IDMW	7	43 19.19	169 36.95	1.51	340.7	4.8	12.2
55	11-Aug-13	RBT	4D	42 13.33	170 17.94	3.02	25.8	5.3	107.3
56	11-Aug-13	RBT	4D	42 06.94	170 11.12	3.01	37.7	0.0	67.3
57	12-Aug-13	RBT	4C	42 02.73	170 21.13	3.01	235.1	4.2	152.4
58	12-Aug-13	RBT	4C	41 58.16	170 24.91	2.98	544.8	20.3	49.4
59	12-Aug-13	RBT	4C	41 50.65	170 27.06	3.01	571.4	41.5	90.4
60	12-Aug-13	RBT	4C	41 45.27	170 25.69	2.99	142.9	20.4	53.5
61	12-Aug-13	RBT	4D	41 42.25	170 19.43	2.04	76.6	6.4	142.9
62	13-Aug-13	RBT	4D	41 46.41	170 08.94	3.06	48.9	0.0	84.7
63	13-Aug-13	RBT	4D	41 44.95	170 17.50	3.07	130.8	2.7	382.3
64	13-Aug-13	RBT	4S	41 38.32	170 46.99	2.09	0.0	0.0	0.0
65	13-Aug-13	RBT	4S	41 43.24	170 45.45	2.00	0.0	0.0	0.0
66	14-Aug-13	RBT	12C	41 21.82	170 27.77	3.00	68.5	5.0	50.7
67	14-Aug-13	RBT	12C	41 19.56	170 31.91	3.01	96.0	0.0	37.7
68	14-Aug-13	RBT	12C	41 22.62	170 34.85	3.01	108.9	2.6	23.1
69	15-Aug-13	RBT	12C	41 21.59	170 37.69	3.01	67.8	12.1	0.0
70	15-Aug-13	RBT	12C	41 13.62	170 38.89	3.01	257.3	0.8	40.7
71	15-Aug-13	RBT	12C	41 08.79	170 36.37	3.07	332.3	9.6	6.3
72	15-Aug-13	RBT	12C	41 09.99	170 32.38	3.02	107.9	1.2	18.9
73	15-Aug-13	RBT	12C	41 08.58	170 29.39	2.99	69.9	14.0	21.4
74	16-Aug-13	RBT	12C	41 05.47	170 38.11	2.99	105.5	28.7	17.1
75	16-Aug-13	RBT	12C	41 04.63	170 45.83	3.02	177.4	8.6	0.0
76	16-Aug-13	RBT	12C	41 00.80	170 48.27	3.01	250.9	15.3	0.0
77	17-Aug-13	RBT	12C	40 43.97	170 56.84	3.00	139.1	17.1	0.0
78	17-Aug-13	RBT	12C	40 40.19	171 00.99	3.03	189.8	30.3	0.6
79	16-Aug-13	RBT	12C	40 39.68	171 03.04	3.01	222.4	6.3	0.0
80	17-Aug-13	RBT	12S	40 40.08	171 30.47	2.15	0.0	0.0	0.0
81	17-Aug-13	ID/AOS	12C	41 00.82	171 04.85	2.99	153.1	179.2	0.0
82	18-Aug-13	RBT	12C	41 15.99	170 57.34	3.00	0.0	0.0	0.0
83	18-Aug-13	RBT	12S	41 02.20	171 12.72	3.01	0.0	0.0	0.0
84	19-Aug-13	CAL		42 20.08	170 14.99	-	-	-	-
85	19-Aug-13	ID/AOS	5A	42 37.49	170 37.30	2.31	318.6	23.8	0.0
86	19-Aug-13	ID	6	42 34.87	169 54.00	2.11	20.1	0.0	16.5
87	20-Aug-13	ID	6	42 44.77	170 01.85	2.22	1 090.4	46.1	82.0

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	3
Cnidaria			
Scyphozoa	unspecified jellyfish	JFI	1
Anthozoa	unspecified coral	COU	1
Plexauridae	plexaurid sea fan	PLE	1
Octocorallia			
Actinostolidae	deepsea anemone	ACS	3
Actiniaria			
Hormathiidae	warty deepsea anemone	HMT	2
Pennatulacea	unspecified seapen	PTU/SPN	2
Pennaatulidae			
Pennatula spp.	purple sea pen	PNN	6
Hydrozoa	unspecified hydroid	HDR	1
Annelida			
Eunicida			
Hyalinoecia tubicola	quill worm	HTU	1
Thaliacea	unspecified salps	SAL	6
Salpidae			
Pyrosoma atlanticum		PYR	23
Mollusca			
Gastropoda	gastropods	GAS	2
Volutidae			
Provocator mirabilis	golden volute	GVO	1
Cephalopoda			
Teuthoidea: squids			
Histioteuthidae			
Histioteuthis spp.	violet squid	VSQ	1
Enoploteuthidae			
Enoploteuthis spp.	enoploteuthis squid	ESQ	2
Ommastrephidae			
Nototodarus sloanii & *N.gouldi*	arrow squid	SQU	49
Todarodes fillippovae	todarodes squid	TSQ	4
Octopoda: Octopus	unspecified octopus	OCP	1
Octopodidae			
Graneledone spp.	deepwater warty octopus	OCO	1
Arthropoda			
Crustacea			
Malacostraca			
Nematocarcinidae			
Lipkius holthuisi	omega prawn	LHO	4
Oplophoridae			
Oplophorus novaezeelandiae		ONO	3
Pasiphaeidae			
Pasiphaea aff. tarda	deepwater prawn	PTA	5
Polychelidae			
Polycheles spp.	deepsea blind lobster	PLY	1
Solenoceridae			
Haliporoides sibogae	jack-knife prawn	HSI	19

Scientific name	Common name	Species code	Occ.
Anomura			
Atelecyclidae			
Trichopeltarion fantasticum	frilled crab	TFA	1
Inachidae			
Platymaia maoria	Dell's spider crab	PTM	1
Brachyura			
Majidae			
Leptomithrax garricki	Garrick's masking crab	GMC	1
Teratomaia richardsoni	spiny masking crab	SMK	1
Nephropidae			
Metanephrops challengeri	scampi	SCI	25
Scyllaridae			
Ibacus alticrenatus	prawn killer	PRK	12
Cirripedia	barnacle unspecified	BRN	16
Echinodermata			
Asteroidea Sea stars			
Asteriidae			
Sclerasterias mollis	cross-fish	SMO	1
Astropectinidae			
Dipsacaster magnificus	magnificent sea-star	DMG	4
Plutonaster knoxi	abyssal star	PKN	7
Psilaster acuminatus	geometric star	PSI	30
Proserpinaster neozelanicus		PNE	1
Brisingidae	armless stars	BRG	1
Goniasteridae			
Lithosoma novaezelandiae	rock star	LNV	1
Mediaster sladeni	Sladen's star	MSL	12
Solasteridae			
Crossaster multispinus	sun star	CJA	5
Solaster torulatus	chubby sun-star	SOT	2
Zoroasteridae			
Zoroaster spp.	rat-tail star	ZOR	1
Echinoidea			
Echinothuriidae, Phormosomatidae	unspecified Tam O'Shanter urchin	TAM	9
Phormosomatidae			
Phormosoma spp.	Tam O'Shanter urchin	PHM	1
Spatangidae			
Spatangus multispinus	purple heart urchin	SPT	6
Holothuroidea	sea cucumbers	HTH	2
Aspidochirotida			
Synallactidae			
Bathyplotes spp.	sea cucumber	BAM	1
Pannychia moseleyi		PAM	1
Agnatha			
Myxinidae: hagfishes			
Eptatretus cirrhatus	hagfish	HAG	3
Chondrichthyes			
Triakidae: smoothhounds			
Galeorhinus galeus	school shark	SCH	31
Mustelus lenticilatus	spotted dogfish	SPO	3
Hexanchidae: cow sharks			
Heptranchias perlo	sharpnose sevengill shark	HEP	6
		Species	

Scientific name	Common name	code	Occ.
Squalidae: dogfishes			
Centrophorus squamosus	deepwater spiny dogfish	CSQ	10
Centroscymnus crepidater	longnose velvet dogfish	CYP	9
C. owstoni	smooth skin dogfish	CYO	3
Deania calcea	shovelnose dogfish	SND	19
Etmopterus lucifer	lucifer dogfish	ETL	26
Proscymnodon plunketi	Plunket's shark	PLS	3
Scymnorhinus licha	seal shark	BSH	13
Squalus acanthias	spiny dogfish	SPD	29
Squalus griffini	northern spiny dogfish	NSD	27
Proscylliidae: finback cat sharks			
Gollum attenuatus	slender smoothhound	SSH	23
Scyliorhinidae: cat sharks			
Cephaloscyllium isabellum	carpet shark	CAR	15
Torpedinidae: torpedo electric rays			
Torpedo fairchildi	electric ray	ERA	8
Rajidae: skates			
Brochiraja asperula	smooth deepsea skate	BTA	5
B. spinifera	prickly deepsea skate	BTS	5
Dipturus innominata	smooth skate	SSK	35
Zearaja nasuta	rough skate	RSK	8
Chimaeridae: chimaeras, ghost sharks			
Hydrolagus bemisi	pale ghost shark	GSP	22
H. novaezelandiae	dark ghost shark	GSH	33
Rhinochimaeridae: longnosed chimaeras			
Harriotta raleighana	longnose chimaera	LCH	1
Rhinochimaera pacifica	widenose chimaera	RCH	1
Osteichthyes			
Notacanthidae: spiny eels			
Notocanthus sexspinis	spineback	SBK	10
Synaphobranchidae: cutthroat eels			
Diastobranchus capensis	basketwork eel	BEE	3
Congridae: conger eels			
Bassanago bulbiceps	swollenheaded conger	SCO	17
B. hirsutus	hairy conger	HCO	26
Argentinidae: silversides			
Argentina elongata	silverside	SSI	29
Alepocephalidae: slickheads			
Alepocephalus antipodianus	smallscaled brown slickhead	SSM	1
Xenodermichthys copei	black slickhead	BSL	8
Platytroctidae: tubeshoulders			
Persparsia kopua	tubeshoulder	PER	1
Chauliodontidae: viperfishes			
Chauliodus sloani	viperfish	CHA	5
Stomiidae: scaly dragonfishes			
Stomias spp.	scaly dragonfish	STO	1
Melanostomiidae: scaleless black dragonfishes			
Melanostomias spp.	scaleless black dragonfish	MEN	2
Paraulopidae: cucumber fishes			
Paraulopus nigripinnis	cucumber fish	CUC	17
Paralepididae: barracudinas			
Lestidiops spp.		LTD	1
Photichthyidae: lighthouse fishes			
Phosichthys argenteus	lighthouse fish	PHO	5

Scientific name	Common name	Species code	Occ.
Myctophidae: lanternfishes			
Diaphus danae	dana lanternfish	DDA	3
Diaphus spp.	lanternfish	DIA	1
Lampanyctodes hectoris	Hector’s lanternfish	LHE	1
Lampanyctus australis	austral lanternfish	LAU	1
Lampanyctus spp.	lanternfish	LPA	6
Moridae: morid cods			
Halargyreus johnsonii	Johnson’s cod	HJO	3
Lepidion microcephalus	small-headed cod	SMC	1
Mora moro	ribaldo	RIB	31
Pseudophycis bachus	red cod	RCO	31
Pseudophycis barbata	southern bastard cod	SBR	2
Euclichthyidae: eucla cods			
Euclichthys polynemus	eucla cod	EUC	34
Merlucciidae: hakes			
Macruronus novaezelandiae	hoki	HOK	77
Merluccius australis	hake	HAK	52
Macrouridae: rattails, grenadiers	rattails	RAT	1
Coelorinchus biclinozonalis	two saddle rattail	CBI	14
C. bollonsi	Bollons’s rattail	CBO	51
C. fasciatus	banded rattail	CFA	17
C. innotabilis	notable rattail	CIN	7
C. matamua	Mahia rattail	CMA	6
C. maurofasciatus	dark banded rattail	CDX	17
C. oliverianus	Oliver's rattail	COL	48
C. parvifasciatus	small-banded rattail	CCX	35
Coryphaenoides dossenus	humpback rattail	CBA	1
C . serrulatus	serrulate rattail	CSE	4
C . subserrulatus	four rayed rattail	CSU	1
Lepidorhynchus denticulatus	javelinfish	JAV	71
Lucigadus nigromaculatus	blackspot rattail	VNI	6
Trachyrincus aphyodes	white rattail	WHX	6
Ophidiidae: cusk eels			
Genypterus blacodes	ling	LIN	67
Trachichthyidae: roughies			
Hoplostethus atlanticus	orange roughy	ORH	3
H. mediterraneus	silver roughy	SRH	62
Paratrachichthys trailli	common roughy	RHY	2
Diretmidae: discfishes			
Diretmus argentus	discfish	DIR	1
Diretmichthys parini	spinyfin	SFN	1
Berycidae: alfonsinos			
Beryx decadactylus	longfinned beryx	BYD	1
B. splendens	alfonsino	BYS	37
Macrorhamphosidae: snipefishes			
Centriscops humerosus	banded bellowsfish	BBE	16
Scorpaenidae: scorpionfishes			
Helicolenus spp.	sea perch	SPE	75
Trachyscorpia eschmeyeri	cape scorpionfish	TRS	1
Oreosomatidae: oreos			
Neocyttus rhomboidalis	spiky oreo	SOR	3
Zeidae: dories			
Capromimus abbreviatus	capro dory	CDO	38
Cyttus novaezealandiae	silver dory	SDO	17
C. traversi	lookdown dory	LDO	59
Zeus faber	john dory	JDO	5

Scientific name	Common name	Species code	Occ.
Triglidae: searobins gurnards			
Chelidonichthys kumu	red gurnard	GUR	2
Lepidotrigla brachyoptera	scaly gurnard	SCG	3
Pterygotrigla picta	spotted gurnard	JGU	4
Hoplichthyidae: ghostflatheads			
Hoplichthys haswelli	deepsea flathead	FHD	32
Psychrolutidae: toadfishes			
Ambophthalmos angustus	pale toadfish	TOP	4
Neophrynichthys latus	dark toadfish	TOD	2
Percichthyidae: temperate basses			
Polyprion oxygeneios	hapuku	HAP	8
Serranidae: sea basses			
Lepidoperca aurantia	orange perch	OPE	3
Apogonidae: cardinalfishes			
Epigonus denticulatus	white cardinalfish	EPD	2
E. lenimen	bigeye cardinalfish	EPL	21
E. telescopus	black cardinalfish	EPT	1
Emmelichthyidae: rovers			
Emmelichthys nitidus	redbait	RBT	46
Plagiogeneion rubiginosum	rubyfish	RBY	4
Carangidae: jacks, pompanos			
Trachurus declivis	greenback jack mackerel	JMD	2
T. murphyi	slender jack mackerel	JMM	1
Bramidae: pomfrets			
Brama australis	southern Ray's bream	SRB	15
Pentacerotidae: armorheads			
Pentaceros decacanthus	yellow boarfish	YBO	44
Pseudopentaceros richardsoni	southern boarfish	SBO	1
Cheilodactylidae: morwongs			
Nemadactylus macropterus	tarakihi	TAR/NMP	14
Uranoscopidae: armourhead stargazers			
Kathetostoma giganteum	giant stargazer	STA/GIZ	38
Gempylidae: snake mackerels			
Rexea solandri	gemfish	RSO	12
Thyrsites atun	barracouta	BAR	14
Trichiuridae: cutlassfishes			
Benthodesmus elongatus	bigeye scabbard fish	BNE	2
B. tenuis	scabbard fish	BNT	1
Benthodesmus spp.	scabbard fish	BEN	6
Lepidopus caudatus	frostfish	FRO	23
Centrolophidae: raftfishes, medusafishes			
Centrolophus niger	rudderfish	RUD	4
Seriolella caerulea	white warehou	WWA	12
S. punctata	silver warehou	SWA	58
Bothidae: lefteyed flounders			
Arnoglossus scapha	witch	WIT	7
Diodontidae: porcupinefishes			
Allomycterus pilatus	porcupine fish	POP	1