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Acoustic survey of spawning hoki in Cook Strait during winter 2015 and update of acoustic *q* priors for hoki stock assessment modelling

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R. L. O'Driscoll
Y. Ladroit
A.J. Dunford
D.J. MacGibbon

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An acoustic survey of spawning hoki abundance in Cook Strait was carried out from the industry vessels *Thomas Harrison* and *Aukaha* from 24 July to 2 September 2015 (voyage codes THH1501 and AUK1501). Six acoustic snapshots of the main Cook Strait spawning grounds were completed. Three of the six snapshots utilised both vessels, coordinating their activities to carry out about half of the planned transects each. Acoustic data collection was supervised by vessel officers, but a NIWA staff member was on board *Thomas Harrison* for one trip from 10–19 August to direct mark identification trawling. During this trip, two acoustic snapshots were carried out, and biological data were collected from 18 trawls, including 6 mark identification tows and 12 commercial tows.

Three of the six snapshots were carried out according to agreed protocols. In snapshots 3–5 there was a 3–4 hour gap to trawl between transects in stratum 2 and those in stratum 5A, which could lead to potential bias due to fish movement. However, the Deepwater Fisheries Assessment Working Group (DWFAWG) agreed to accept these snapshots, and to use snapshots 1–5 to estimate hoki abundance. Snapshot 6 was rejected by the DWFAWG because it was slightly later than the agreed survey period (15 July – 31 August) and because acoustic data quality was marginal.

Acoustic estimates of hoki abundance used the most recent target strength length relationship for New Zealand hoki and ranged from 112 000 t on 1–2 September to 304 000 t on 23–25 August, with an average estimate over the five accepted snapshots of 204 000 t. This was 21% higher than the equivalent estimate from 2013 (168 000 t). The survey weighting (expressed as a coefficient of variation, CV) for the 2015 survey, which included uncertainty associated with survey timing, sampling precision, acoustic detectability, mark identification, calibration, and target strength was 33%.

About 73% of the hoki abundance in Cook Strait in 2015 was from hoki schools. Commercial trawls on hoki schools caught an average of 99% hoki by weight (12 trawls sampled, range 96–100%). The remaining hoki came from hoki 'fuzz' marks that also contained other species. The average proportion of hoki by weight from six research trawls on fuzz marks in 2015 was 71% (range 59–86%).

Hoki from the Narrows Basin were predominantly male and were much smaller than hoki from the main Cook Strait Canyon, where commercial catches were dominated by females. Gonad staging showed that fish were actively spawning during the survey period, with 78% of female hoki sampled staged as ripening, ripe, running ripe, or partially spent.

Priors on the acoustic survey proportionality constant *q* were re-evaluated for both the Cook Strait and west coast South Island (WCSI) survey time-series to reflect recent revisions to hoki target strength estimates. The new lognormal prior for Cook Strait had a mean of 0.55 and CV of 0.90. The new WCSI prior had lognormal parameters of a mean of 0.39 and CV of 0.77. We recommend that the revised acoustic time-series and *q* priors are used in the 2016 hoki stock assessment.

1. INTRODUCTION

Hoki is New Zealand's largest finfish fishery with a TACC of 160 000 t in 2014–15. 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. Spawning occurs in winter (June to September), with the major spawning areas on the west coast of the South Island (WCSI) for the western stock, and in Cook Strait for the eastern stock.

On the spawning grounds hoki typically form large midwater aggregations. The occurrence of readily identifiable, single species aggregations clear of the seabed allows for accurate abundance estimation using acoustic methods. Acoustic surveys of spawning hoki have been conducted regularly since a 1984 pilot survey of the WCSI spawning grounds (Coombs & Cordue 1995). The results of acoustic surveys of spawning hoki in Cook Strait and the WCSI have been important inputs into hoki stock assessments for 25 years (e.g., O'Driscoll 2002a).

Previous acoustic surveys of Cook Strait were carried out on research vessels annually from 1991–2008 (except 2000, 2004, and 2007). Surveys in 2006 and 2008 also included the east coast South Island areas of Pegasus and Conway Trough (O'Driscoll 2007, 2009). Since 2007, industry vessels have also surveyed part of Cook Strait during the hoki spawning season using the same (NIWA) protocols as for the research vessel surveys (O'Driscoll & Dunford 2008, O'Driscoll & Macaulay 2009, 2010, O'Driscoll 2012). The most recent survey was in 2013 (O'Driscoll et al. 2015a). A continuation of this approach was used in 2015, where the main fishing grounds in Cook Strait was surveyed throughout the spawning season from two industry vessels: *Thomas Harrison* and *Aukaha*.

The 10-year Deepwater Research Programme involves acoustic surveys of the Cook Strait hoki spawning grounds every two years to update the abundance indices. Although the acoustic results from Cook Strait have not been very influential on the results of the stock assessment model it is considered necessary to monitor the abundance of the eastern spawning stock independently of the Chatham Rise, where both eastern and western hoki are mixed together.

1.1 Project objectives

This report fulfils the reporting requirements for Objectives 1 and 2 of Ministry for Primary Industries Research Project DEE2015/06:

1. To continue the time series of relative abundance indices of spawning hoki in Cook Strait using acoustic surveys, with a target coefficient of variation (CV) of the estimate of 30 %.

2. To calibrate acoustic equipment used in the acoustic survey.

2. METHODS

2.1 Survey design

Hoki have a long spawning season, from July to September. It is thought that during the spawning season there is a turnover of fish on the grounds. Therefore, there is no time at which all of the spawning fish are available to be surveyed. The survey design devised to deal with this problem consists of a number of subsurveys or "snapshots" spread over the spawning season. Each snapshot consists of a series of random transects (following the design of Jolly & Hampton (1990)) across strata covering the known distribution of spawning hoki. Estimates of spawning biomass are calculated for each of the snapshots, and these are then averaged to obtain an estimate of the "mean plateau height" (average abundance during the main spawning season). Under various assumptions about the timing and length of the spawning season (Cordue et al. 1992, Coombs & Cordue 1995), estimates of mean plateau height form a valid relative abundance time series.

The stratum boundaries and areas in Cook Strait (Figure 1, Table 1) were the same as in previous surveys, with six main strata (strata 1, 2, 3, 5A, 5B, and 6), covering the areas with depth greater than 200 m (or 180 m in stratum 2). The acoustic survey area in Cook Strait includes grounds which are not commercially fished by the fleet. For example, targeting of hoki by vessels greater than 28 m is not permitted in the Narrows Basin (stratum 1) under the industry agreed Operational Procedures for the Hoki Fishery (version 13), to reduce the catch of small hoki.

2.2 Vessels and equipment

FV Thomas Harrison is a 42.5 m freezer trawler. The vessel is fitted with a Simrad ES70 echosounder with a hull-mounted split-beam 38 kHz transducer, and was used successfully to carry out research surveys of orange roughy on the Challenger Plateau in 2005, 2006, 2009, 2010, 2011, 2013, and 2014, and hoki in Cook Strait in 2007, 2008, 2009, 2011, and 2013 (O'Driscoll & Dunford 2008, O'Driscoll & Macaulay 2009, 2010, O'Driscoll 2012, O'Driscoll et al. 2015a). *FV Aukaha* is a 45.6 m freezer trawler, formerly known as *Independent 1*. *Aukaha* is also fitted with a Simrad ES70 echosounder and hull-mounted split-beam 38 kHz transducer, and was used previously to carry out research surveys for hoki around the South Island in 2002 and 2003 (O'Driscoll 2003b, O'Driscoll et al. 2004), and in Cook Strait in 2009, 2011, and 2015 (O'Driscoll & Macaulay 2010, O'Driscoll 2012, O'Driscoll et al. 2015a), and for research surveys (using different acoustic equipment) in Oman. Both vessels are operated by Sealord Limited.

Echosounders on both vessels were calibrated by NIWA using standard scientific methods (Demer et al. 2015). The ES70 on *Thomas Harrison* was calibrated in Tasman Bay on 10 August 2015, and the ES70 on *Aukaha* was calibrated in Tasman Bay on 17 September 2015. Calibrations were of excellent (*Thomas Harrison*) or good (*Aukaha*) quality and indicated that the echosounders were functioning correctly. The calibration coefficients for *Thomas Harrison* in 2015 were similar to those in 2013 (Appendix 1). Calibration coefficients for *Aukaha* in 2015 were about 0.5 dB lower than those obtained in the three calibrations from 2009–13, suggesting a decline in echosounder sensitivity since 2013 (Appendix 2). Other long-term time series of echosounder calibrations have also observed gradual declines in peak gain, possibly as a function of transducer ageing (Knudsen 2009). Estimated calibration coefficients from 2015, based on the mean sphere target strength (TS) were used in these analyses.

2.3 Acoustic data collection

NIWA provided start and finish positions for up to eight snapshots in Cook Strait, each consisting of 28 random transects in the six strata (see Table 1).

Key aspects of acoustic survey protocol provided to vessel officers were as follows:

- Acoustic data quality needs to be good. Weather is important (typically winds less than 25 knots, swell less than 2 m). All other echosounders and sonars need to be switched off to avoid acoustic interference.
- Vessel speed when running transects should be kept constant at 6–10 knots.
- A separate acoustic file should be recorded for each transect. It is not necessary to record the joining legs between transects. A logsheet should be completed.
- Estimates of species composition, hoki size, and spawning condition in commercial catches are needed (to estimate target strength), in addition to the requirement for targeted mark identification trawling (see Section 2.4).

- The ES70 echosounder needs to be set-up using scientific 'hoki' settings (key ones are power = 2000 W, pulse length = 1.024 ms, ping interval = 2 seconds, GPS position integrated into acoustic file).
- To generate an abundance index with a reasonable CV in Cook Strait requires six completed snapshots. These should be spread as evenly as possible between 15 July and 31 August.
- The entire snapshot needs to be completed within 48 hours (preferable, 72 hours absolute maximum) for it to be useful. All transects in the main Cook Strait Canyon (strata 5A and 2) need to be run sequentially (i.e., without breaks), because of fish movement related to tide in this area.

Acoustic data were stored on removable USB hard drives.

2.4 Mark identification trawling

Mark identification is one of the critical steps in acoustic analysis and requires directed trawling on different mark types. This was an integral part of the proposed survey, and six targeted mark identification trawls were carried out on a trip on *Thomas Harrison* from 10–19 August 2015, when a NIWA staff member (Dan MacGibbon) was on board.

Commercial tows and research tows were carried out using the *Thomas Harrison* 28-17 midwater hoki trawl, which was towed either in midwater or along the bottom. This trawl has a headline length of 88 m and wingspread of about 53 m, and was rigged with 150 m bridles. A 60 mm codend was fitted for the designated research tows. This is smaller than the mesh size legally required for hoki trawling (100 mm). All commercial tows were carried out using a 100 mm codend.

Associated with mark identification trawling, there is a requirement to collect biological data. This was carried out by the NIWA staff member on *Thomas Harrison*. For each trawl, all items in the catch were sorted into species and weighed (or estimated from processed weights when catch sizes were large). Where possible, fish, squid, and crustaceans were identified to species level, and other benthic fauna to family. A random sample of up to 200 individuals of each species from every tow was measured for length, and the sex and macroscopic gonad stage of all hoki in the length sample was also determined.

2.5 Other data collection

A Seabird SM-37 Microcat CTD datalogger (serial number 2416) was mounted to the headline of the net during two research tows to estimate the absorption coefficient and speed of sound during the survey.

2.6 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). Echograms were visually examined, and the bottom determined by a combination of an in-built bottom tracking algorithm and manual editing. Regions corresponding to various acoustic mark types were then identified. Marks were classified subjectively (e.g. O’Driscoll 2002b), based on their appearance on the echogram (shape, structure, depth, strength and so on), and using information from mark identification trawls.

Backscatter from marks (regions) identified as hoki was then integrated to produce an estimate of acoustic density, expressed as the mean area backscattering coefficient (m^2 m^{-2}). During integration, acoustic backscatter was corrected for a systematic error in ES70 data (Ryan & Kloser 2004) and calculated sound absorption by seawater.

Acoustic density was output in two ways. First, average acoustic density over each transect was calculated. These values were used in abundance estimation (see Section 2.7). 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.

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 method of calculating *r* was based on that of O'Driscoll (2002a):

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

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

$$w = (4.79\times10^{-6})\, L^{2.89} \qquad (1)$$

3. using the most recent TS-length relationship for New Zealand hoki (Dunford et al. 2015):

$$TS = 24.5 \log_{10}(TL) - 83.9 \qquad (2)$$

   where *TL* is total fish length in centimetres.

2.7 Abundance estimation

Abundance estimates and variances were obtained for each stratum in each snapshot using the formulae of Jolly & Hampton (1990), as described by Coombs & Cordue (1995). Stratum estimates were combined to produce snapshot estimates, and the snapshots were averaged to obtain the abundance index for 2015.

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 underestimated the sampling variance as it accounts only for the observation error in each snapshot. The imprecision introduced by the inherent variability of the abundance in the survey area during the main spawning season was ignored. The second method assumes that 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 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 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 2004).

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

Six sources of variance are considered:

- plateau model assumptions about timing and duration of spawning and residence time
- sampling precision
- detectability
- 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 a biomass model was constructed by randomly selecting values for each variable from the distributions in Table 2. This model was then ‘sampled’ at dates equivalent to the mid dates of each snapshot (Table 3). The precision of sampling was determined by the snapshot CV, and the biomass adjusted for variability in detectability. The simulated biomass estimate in each snapshot was then split, based on the proportion of acoustic backscatter in ‘school’ and ‘fuzz’ marks (see Section 3.3), and mark identification uncertainties applied to each part. The biomass 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.

2.9 Update of Cook Strait acoustic time-series and *q* prior

Previous Cook Strait acoustic estimates (e.g., O’Driscoll et al. 2015a) were based on the TS-length relationship of Macaulay (2006):

$$TS = 12.2 \log_{10}(TL) - 63.9 \qquad (3)$$

Recent work suggests that this may overestimate hoki biomass. Kloser et al. (2011) collected optically verified *in situ* measurements of Australian hoki (blue grenadier) and found that the TS was considerably higher than that predicted by equation (3). They provided a TS-to-standard length (SL) relationship for hoki of:

$$TS = 25.4 \log_{10}\mathrm{SL} - 81.5 \qquad (4)$$

O’Driscoll (2012) noted that if we apply this equation in place of Equation (1) in calculating the ratio of mean weight to mean backscattering cross section (after converting total length to standard length and adjusting for the larger cavity/swimbladder volume of Australian hoki using the relationship TL = 1.18 SL, from Kloser et al. (2011)), we obtain estimates of hoki biomass which are only 25–30% of those obtained using the TS-length relationship of Macaulay (2006). However, equation (4) was based on a relatively narrow length range of large hoki (17 fish of TL 84–110 cm), which are larger than those typically found in Cook Strait.

Further research on hoki TS was carried out using an acoustic-optical system (AOS) on the west coast South Island (WCSI) in June-July 2012 (O’Driscoll et al. 2014). Dunford et al. (2015) estimated a new TS-TL relationship based on a weighted non-linear least-squares fit to individual points for the WCSI dataset (Equation (2)). Equation (2) was based on a sample size of 62 New Zealand hoki from 35–93 cm TL. We re-calculated all previous acoustic abundance estimates for Cook Strait using this new TS-TL relationship.

The implication for stock assessment of adopting the new TS-TL relationship of Dunford et al. (2015) is a change in the estimate of the acoustic survey proportionality constant, q. The current prior on the Cook Strait acoustic survey q is lognormal with a mean (in natural space) of 0.77 and CV of 0.77 (McKenzie 2015). This was derived by O'Driscoll et al. (2002) based on the estimated bounds on each of six factors influencing the acoustic q: plateau height and timing; target strength; calibration; mark identification and species mix; acoustic availability; and areal availability (Table 4).

The prior on q was re-calculated in this report. Estimated bounds on three of the six factors were the same as those used by O'Driscoll et al. (2002) and assumed uniform priors on calibration, acoustic availability, and areal availability (Table 4). Revision of the bounds on TS was required due to the change in TS-length relationship. Target strength was further divided into two contributing factors: uncertainty and tilt angle. Target strength uncertainty was the uncertainty in the fit to Equation (2) from bootstrapping of the hoki AOS data. This was estimated based on Dunford et al. (2015) as a uniform distribution with bounds of about ±1.5 dB (70–160% in linear space). Target strength tilt angle was the estimated bias due to the difference between the tilt angle distribution of hoki as they pass through the trawl under the AOS (approximately horizontal) and that of free-swimming hoki *in situ*. This uncertainty was derived from swimbladder models comparing the relative TS estimated using the orientation of hoki measured on the AOS (mean tilt of 3° standard deviation, s.d. 14°) with the estimated TS from hoki with tilt angles observed *in situ* on the WCSI by Dunford et al (2015) (mean tilt -1°, s.d. 26°) and in Cook Strait by Coombs & Cordue (1995) (mean tilt 12°, s.d. 29°). The estimated TS was 2.9 dB lower for the tilt distribution observed by Dunford et al. (2015) and 4.0 dB lower for the tilt distribution of Coombs & Cordue (1995). We assumed a uniform uncertainty distribution with a range of 0–6 dB (25–100% in linear space), and a 'best guess' of 3 dB (50% in linear space) (Table 4). The distributions from simulations of uncertainty from all previous surveys (Figure 2) were re-sampled directly to generate the prior, rather than using the bounds and assuming uniform distribution for plateau height, timing, mark identification, and species mix.

The 'best guess' estimates for each factor were derived as the medians from simulations (e.g., for plateau height and timing) or from other prior information. For example, the main factor affecting areal availability is the proportion of spawning eastern hoki which is outside the Cook Strait spawning area. Recent acoustic estimates from Pegasus Canyon on the east coast South Island suggest that 20–40% of eastern hoki may be spawning in this area (O'Driscoll et al. 2015a), so the best guess for areal availability was 0.7.

Uncertainties were combined to create the prior on q using the basic procedure of Cordue (1996) implemented in R.

3. RESULTS

3.1 2015 commercial fishery

A total catch of 20 092 t was taken from Cook Strait between 1 June and 30 September 2015, with most hoki caught between 15 July and 15 September (Figure 3). The acoustic survey was within the period of high catches. The hoki length frequency distribution from the 2015 commercial fishery in Cook Strait based on scientific observer data, market sampling, and trawl data collected for this project is shown in Figure 4. The mean length of hoki was 75.2 cm TL (Table 5). Mean weight and mean backscattering cross-section (obtained by transforming the scaled length frequency distribution in Figure 4 by equations (1) and (2) and then calculating the means of the transformed distributions) were 1.34 kg and 0.000167 m^2 (equivalent to –37.8 dB) respectively, giving a ratio, r, for Cook Strait in 2015 of 8025 kg m^{-2} (Table 5).

3.2 Data collection

3.2.1 Acoustic data

Six acoustic snapshots of the main Cook Strait spawning grounds (see Figure 1) were completed from 24 July to 2 September 2015 (see Table 3). Acoustic data collection was supervised by vessel officers, but a NIWA scientist (Dan MacGibbon) was on board *Thomas Harrison* for one trip from 10–19 August to direct mark identification trawling (see Section 3.2.2). During this trip, two acoustic snapshots were carried out (snapshots 3 and 4 in Table 3).

Three of the six snapshots utilised both vessels (see Table 3), coordinating their activities to carry out about half of the planned transects each. All snapshots were completed within the recommended 48 hours except for snapshot 2 which took only slightly longer (49 hours) (see Table 3). In three of the six snapshots, all transects in strata 2 and 5A were carried out sequentially to avoid potential bias due to fish movement as instructed. However, in snapshots 3–5, there was a 3–4 hour gap to trawl between transects in stratum 2 and those in stratum 5A. Most transects were carried out in suitable weather conditions, but there were examples of missing pings or interference from wave-generated bubbles, especially in snapshot 6 (e.g., Figure 5). There was no interference from other acoustic instruments. Echosounder settings followed NIWA recommendations.

3.2.2 Trawl data

There were 18 tows for target identification purposes and to collect hoki length frequency and biological data during the trip on *Thomas Harrison* from 10–19 August (Table 6, Figure 6). Six of these tows were specifically targeted on marks where the species composition was uncertain. These were designated as research tows. The remaining 12 were commercial tows which were sampled by the NIWA staff member on *Thomas Harrison*. Of the six research tows, two were in the Narrows Basin (stratum 1), two in outer Cook Strait Canyon (stratum 5B), and two in Nicholson Canyon (stratum 3). Hoki made up 70% of the total catch of 4.0 t from research tows for mark identification (Table 7). Bycatch species included frostfish, jack mackerel, rattails, ling, red cod, silver warehou, and spiny dogfish (Table 7).

A further 233 t of catch was sampled from the 12 commercial trawls, of which 99% was hoki (see Table 6). Other commercial trawls were not sampled because the one NIWA person on board *Thomas Harrison* was unable to cover 24-hour operations.

A total of 3555 fish of 33 species were measured, including 2067 hoki measured for length, sex and macroscopic gonad stage. Otoliths were collected from 362 hoki.

3.2.3 CTD data

CTD profiles were obtained for Cook Strait from two research tows. The average water temperature over the entire depth range was 10.8 ºC, with an average salinity of 34.8 PSU. Estimates of sound absorption from the two individual CTD profiles in 2015 were 9.00 and 8.86 dB km^{-1} respectively, with an average of 8.93 dB km^{-1}. This was similar to the average sound absorption estimated in Cook Strait in 2013 (8.97 dB km^{-1}).

3.3 Mark identification

Marks in Cook Strait were similar to those observed in 2001–13. Example echograms of some of these mark types are shown in Figures 7–11. Further examples are provided by O’Driscoll (2002b, 2003a, 2007, 2009, 2012), O'Driscoll & Dunford (2008), O'Driscoll & Macaulay (2009, 2010), and O'Driscoll et al. (2015a).

1. Hoki schools
Hoki schools were characterised by relatively dense marks with clearly defined edges, typically occurring at 200–700 m water depth, and often in midwater over canyon features. During the night, schools tended to disperse and descend to the bottom or to 350–600 m depth. In the day, schools were denser and higher in the water column, at 200–450 m depth. The densest hoki schools were observed in Cook Strait Canyon during snapshots 4 and 5 (e.g., Figure 7), but hoki schools were also observed in Nicholson Canyon (e.g., Figure 8). All commercial tows sampled on *Thomas Harrison* were targeted at hoki schools in Cook Strait Canyon (see Figure 6) and caught an average of 99% hoki by weight (see Table 6).

2. Hoki bottom fuzz
Hoki bottom fuzz occurred as bottom-referenced layers, sometimes extending more than 50 m above the seabed, and usually at water depths shallower than 300 m. This mark type was commonly observed in the Narrows Basin (e.g., Figure 9) and over the Terawhiti Sill (e.g., Figure 10). The two mark identification tows on bottom fuzz marks in 2015 caught 59% and 61% of hoki by weight respectively (see Table 6).

3. Hoki pelagic fuzz
Hoki pelagic layers were relatively low density (diffuse), surface-referenced layers occurring at 200–700 m depth, typically over deep water (500–1000 m). Single targets are often visible in these layers. In 2015, these marks were common in outer Cook Strait Canyon, in the deepwater between Cook and Wairarapa Canyons (e.g., Figure 11), and in Nicholson Canyon. The average proportion of hoki by weight from the four research tows on pelagic fuzz marks was 76% (range 68–86%) (see Table 6).

4. Bottom non-hoki
Bottom non-hoki layers were bottom-referenced layers, which were typically denser and shallower (less than 200 m depth) than hoki bottom fuzz layers. Bottom non-hoki marks were occasionally observed in 2015 adjacent to Cook Strait Canyon. Previous research trawling on this mark type caught less than 10% hoki, with catches typically dominated by ling.

5. Jack mackerel
Jack mackerel were observed as strong surface-referenced layers consisting of small schools and strong single targets at depths of 50 to 200 m. As in previous surveys, jack mackerel marks were usually observed in the Narrows Basin (e.g., Figure 9). Previous research trawling on this mark type caught mainly jack mackerel and few hoki. They were an important bycatch in all six 2015 research tows although the mark identification tows were not targeted at jack mackerel marks (see Table 6).

6. Mesopelagic layers
Strong surface-referenced pelagic layers usually occurred from 0 to 300 m, and exhibited strong diurnal vertical migration patterns. Pelagic layers were widespread throughout the survey areas (e.g., Figure 11). Targeted trawling on this mark type in the past only caught a few very small (less than 30 cm) hoki.

7. Spiny dogfish
Spiny dogfish were characterised by surface-referenced layers similar to jack mackerel marks, and consisted of small schools and single targets at depths of 100–200 m, above hoki schools. Midwater spiny dogfish marks are sometimes observed in Cook Strait Canyon, but were not conspicuous during the 2015 survey. Livingston (1990) found that midwater aggregations of spiny dogfish above hoki schools were feeding on recently spawned hoki eggs.

Acoustic backscatter from regions corresponding to hoki schools, hoki bottom fuzz, and hoki pelagic fuzz were integrated to obtain acoustic density estimates. This is consistent with mark identification in previous years (O'Driscoll 2002a). Although we know that hoki fuzz marks contain a proportion of other species, all backscatter from these marks was assumed to be from hoki. Again, this is consistent with previous years. No species decomposition of acoustic backscatter in mixed layers was attempted because of the limited mark identification trawling. If there was a change in the proportion of hoki in fuzz marks over time (as suggested by O'Driscoll (2006) for bottom fuzz marks) this approach will lead to a bias in the relative abundance estimates. However, the Monte Carlo estimation of survey uncertainty will incorporate some of this potential bias because the lognormal distribution of uncertainty associated with species mix is very broad (see Table 2). In Section 3.6, abundance estimates are presented for hoki school marks only (where mark identification is relatively certain), as well as for hoki school and hoki fuzz marks combined.

3.4 Distribution of hoki backscatter

Expanding symbol plots show the spatial distribution of hoki backscatter along each transect during the six snapshots of Cook Strait (Figure 12). The distribution of hoki in Cook Strait was generally similar to that observed in previous research and industry surveys in 2001–13 (O'Driscoll 2002b, 2003a, 2006, 2007, 2009, 2012, O'Driscoll & McMillan 2004, O'Driscoll & Dunford 2008, O'Driscoll & Macaulay 2009, 2010, O'Driscoll et al. 2015a). Hoki densities were highest in Cook Strait Canyon (strata 2 and 5A) with peak densities in snapshots 4 and 5 (see example in Figure 7). Hoki were concentrated in the central part of stratum 2 during all snapshots, with more variable densities in the outer canyon (stratum 5A) (Figure 12).

Most of the acoustic backscatter in the deep water between Cook Strait and Wairarapa Canyons (stratum 5B) came from pelagic fuzz marks (e.g., Figure 11) and densities in this area were relatively low (Figure 12). Acoustic densities were also generally low in the Narrows Basin (stratum 1) and over the Terawhiti Sill (stratum 6), and most of the backscatter from these areas was from bottom fuzz marks (e.g., see Figures 9 and 10). Densities were higher in Nicholson Canyon (stratum 3) in snapshots 1 and 2 (Figure 12), when some hoki schools were present in this stratum (e.g., see Figure 8). No particularly dense marks were observed in Nicholson Canyon during the 2011 or 2013 surveys (O'Driscoll 2012, O'Driscoll et al. 2015a), but in some earlier surveys hoki schools were abundant in this stratum.

3.5 Hoki size and maturity

Unscaled length frequency distributions of hoki by strata are given in Figure 13. Although the number of mark identification trawls in 2015 was low (only six tows), there appeared to be variation in hoki length frequency distributions between these tows and those from commercial trawls in the main Cook Strait Canyon. Hoki from the Narrows Basin (stratum 1) were predominantly male and were much smaller than hoki from the main Cook Strait Canyon (stratum 2), where commercial catches were dominated by large females. Modes at 25–39 cm and 60–70 cm in stratum 1 probably correspond to fish of ages 1 and 3 years respectively. The hoki sampled from strata 3 and 5B had more similar length distributions to those from commercial tows in stratum 2, but with a higher proportion of small fish (Figure 13).

Gonad staging showed that fish were actively spawning during the survey period, with 78% of female hoki sampled (n = 1517) staged as ripening (research stage 3 = 48%), ripe (research stage 4 = 13%), running ripe (research stage 5 = 6%), or partially spent (research stage 6 = 11%). About 20% of the sampled female hoki were spent (research stage 7).

3.6 Hoki abundance estimates

Hoki abundance estimates by snapshot and strata for Cook Strait are given in Table 8 and plotted in Figure 14. Estimates of hoki abundance in the six snapshots using the value of r calculated for 2015 ranged from 112 000 t (CV 18%) in snapshot 6 on 1–2 September to 304 000 t (CV 33%) in snapshot 5 on 23–25 August. The estimates from snapshot 4 and 5 were considerably higher those from the other four snapshots, and there was a large increase in estimated abundance between snapshot 3 on 12–13 August and snapshot 4 on 14–15 August (Figure 14). It seems unlikely that hoki abundance increased by 50% over this two-day period. Differences between individual snapshots was probably due to sampling variability (transect location and fish behaviour) as well as changes in abundance. One or two very high snapshots were also observed in previous surveys, in 2006, 2007, 2011, and 2013 (Figure 15).

When results from Table 8 were averaged over the six snapshots, 75% of the hoki biomass was in stratum 2, 8% in stratum 1, 7% in stratum 5A, 6% in stratum 5B, and 2% in each of strata 3 and 6. Hoki densities in strata 1 and 5B were generally low (see Figure 12), and the importance of these strata to the overall abundance was due to their relatively large areas. The contribution of biomass from outside Cook Strait Canyon (strata 2 and 5A) may also be overestimated because most of the estimated biomass in the other strata was from hoki fuzz marks which contain other species (Table 9).

The average proportion of the biomass from hoki schools in 2015 was 73% (Table 9). This was lower than the proportion in schools in 2013 (78%), but near the top end of the range of proportion in previous surveys (30–74% of hoki in schools in 1991–2011). Most (95%) of the hoki observed in stratum 2 were in schools (Table 9). Hoki schools were also observed in strata 3 and 5A. As in previous surveys, changes in abundance over the survey period were driven mainly by changes in the biomass of hoki schools (Figure 14). The biomass from hoki fuzz marks remained relatively constant between 31 000 and 45 000 t in snapshots 1–5, but increased to 61 000 t in snapshot 6 with stronger bottom fuzz observed in the Narrows Basin (stratum 1), and a doubling of the estimated biomass in this stratum (see Table 8).

At its meeting on 16 November 2015, the Deepwater Fisheries Assessment Working Group (DWFAWG) decided to use snapshots 1–5 for estimating hoki abundance. Snapshot 6 was rejected by the DWFAWG because it was carried out slightly later than the agreed survey period (15 July – 31 August) and because acoustic data quality was marginal (see Figure 5). The mean abundance from snapshots 1–5 was 204 000 t (see Table 8). The average of the snapshot variances was 17%. The variance of the abundance estimates from the five snapshots was 18%. The similarity of the two estimates of sampling variance provides further evidence that variation in estimated abundance between individual snapshots was consistent with sampling variability

3.7 Survey weighting for stock assessment

The overall survey weighting estimated from the Monte Carlo simulation model for Cook Strait was 33% (Table 10). As in previous Cook Strait surveys (O'Driscoll 2004), timing (including uncertainties about plateau timing and residence time), sampling error, and mark identification were the major sources of uncertainty (Table 10). Uncertainties due to calibration, detectability, and TS contributed relatively little to the overall CV. However, incorrect choice of TS and calibration coefficients do have potential to introduce bias, which is not reflected in the CV in Table 10 (see Section 4).

3.8 Updated prior for acoustic *q*

The re-calculated prior for the acoustic *q* had lognormal parameters with a mean of 0.55 and CV of 0.90. The new prior is plotted and compared to the previous prior in Figure 16.

4. DISCUSSION

Six acoustic snapshots of the Cook Strait spawning grounds were completed from the industry vessels *Thomas Harrison* and *Aukaha* during winter 2015. The DWFAWG agreed to use snapshots 1–5 for estimating hoki abundance. Snapshots 3–5 were accepted by the DWFAWG, despite some deviations from agreed survey protocol: there was a 3–4 hour gap to trawl between transects in stratum 2 and those in stratum 5A, which could lead to potential bias due to fish movement. Snapshot 6 was rejected by the DWFAWG because it was slightly later than the agreed survey period and because acoustic data quality was marginal. Survey timing for the five accepted snapshots was appropriate, and these snapshots occurred within the timing of peak commercial catches (see Figure 3) and within the period of previous surveys (see Figure 15).

The abundance index for 2015, calculated using the length frequency from the 2015 commercial fishery and the latest TS-length relationship, was 204 000 t, which was 21% higher than the equivalent estimate from 2013, and the highest estimate since 1995 (Table 11, Figure 17). The overall CV of the 2015 estimate (33%) which was within the range of estimated uncertainty in research and industry vessel surveys since 2001 (CV 30–46%), reflecting the consistent survey design and execution over this period.

Survey requirements to complete an entire snapshot within 48 hours and to run all transects in the main Cook Strait Canyon (strata 5A and 2) without interruptions involves considerable investment and commitment on the part of the industry vessel(s), as it is not possible to just carry out transects in the 'down-time' while processing between commercial trawls (e.g., O'Driscoll & Macaulay 2005). Rather, fishing activities needed to be suspended to collect acoustic data. The approach first used in 2013, where two vessels coordinated their activities to carry out about half of the planned transects each reduces the burden on an individual vessel at the same time as ensuring near-synoptic sampling (O'Driscoll et al. 2015a). This approach was used in three of six snapshots in 2015. However, as noted above, the *Aukaha* used a 3–4 hour gap to commercially trawl between transects in stratum 2 and those in stratum 5A in snapshots 3–5.

A major limitation of acoustic surveys of Cook Strait from industry vessels in 2007 and 2009 was the lack of targeted mark identification trawls (O'Driscoll & Macaulay 2009). Regular sampling of all mark types is important to understand species composition, especially as this can change over time (e.g., O'Driscoll 2007). This is particularly important for hoki fuzz marks, which typically contribute 30–50% of the hoki biomass in Cook Strait, but which are not usually targeted commercially because of low fish density. This was partly addressed since 2011 with provision in the survey design for a limited number of mark identification trawls with a scientist on board (O'Driscoll 2012, O'Driscoll et al. 2015a). In 2015, six (of the eight proposed) mark identifications trawls were carried out by *Thomas Harrison* on 10–19 August. A disadvantage of this strategy is that mark type and composition may change during the spawning season, so that mark types during the trip with targeted trawling may differ from those in snapshots at the start and end of the spawning period. An example of this in 2015 was the appearance of dense hoki bottom fuzz marks in the Narrows Basin (stratum 1) during snapshot 6 on 1–2 September, two weeks after the sampling period. It is important to retain mark identification trawling on future surveys. It is also important to ensure adequate sampling by scientific observers throughout the survey period to provide adequate biological data to estimate size distribution of hoki and progression of maturity stages to allow interpretation of acoustic survey results.

Absolute estimates of abundance using the most recent hoki TS-length relationship of Dunford et al. (2015) were about half of those obtained using the TS-TL relationship of Macaulay (2006) (Figure 17). Because the alternative TS-length relationships have very different slopes, there is potential to bias relative indices of abundance where the size of hoki varies between surveys. However, the size (length) of hoki caught in Cook Strait was quite similar over the acoustic time-series (see Table 5), and the choice of the TS-length relationship had relatively little impact on relative indices (Figure 17).

The most recent hoki assessment (McKenzie 2015) used acoustic indices for Cook Strait based on the TS-length relationship of Macaulay (2006), but used the same (average) r value for all surveys in the time-series because of recent uncertainty about the representativeness of the estimated size distribution of the commercial catch from Cook Strait due to poor observer coverage (O'Driscoll et al. 2015a). Because the slope (24.5) of the new TS-length relationship (equation (2)) is close to 30, there is relatively little variability in the ratio, r, of mean weight to mean backscattering cross section (Table 5), meaning that relative estimates of abundance based on the new TS-length relationship (Table 11) are not as sensitive to the annual length frequency data as those using the previous TS-length relationship of Macaulay (2006).

The new TS-TL relationship would imply very high exploitation rates (E) in Cook Strait in some years if the acoustic $q = 1$. For example, the estimated catch from Cook Strait in 1996 was 67 000 t compared to the estimated biomass of 92 000 t (E = 0.73). Similarly, the Cook Strait catch in 1998 was 53 000 t compared to the estimated biomass of 80 000 t (E = 0.66) However, it is likely that q for this series will be less than 1 due to the turnover of fish on the spawning grounds (Harley 2002), likely bias in TS estimates due to the difference between the tilt angle distribution of hoki measured with the AOS (approximately horizontal) and that of free-swimming hoki *in situ* (Dunford et al. 2015), and the occurrence of eastern spawning hoki on satellite spawning grounds off the east coast South Island (e.g., O'Driscoll et al. 2015a). The prior on q was re-calculated in this report to take into account the change in the hoki TS-length relationship (see Table 2). The new prior shifted to the left of the existing prior and had a median of 0.32 (see Figure 16).

Acoustic indices and the q prior for hoki acoustic surveys of the west coast South Island (WCSI) were also updated for the 2016 hoki stock assessment (Appendix 3).

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7. TABLES

Table 1: Stratum boundaries, areas and transect allocation for the 2015 acoustic survey of spawning hoki in Cook Strait. Stratum locations are shown in Figure 1.

Area	Stratum	Name	Boundary	Area (km^2)	No. of transects
Cook Strait	1	Narrows Basin	200–200 m	330	4
	2	Cook Strait Canyon	180–180 m	220	9
	3	Nicholson Canyon	200–200 m	55	4
	5A	Cook Strait Canyon extension	position to 200 m	90	4
	5B	Deep water	position to 200 m	215	3
	6	Terawhiti Sill	200–200 m	65	4

Table 2: Values of parameters and their distributions used in Monte Carlo uncertainty simulations to determine model weighting (from O'Driscoll 2004).

Term	Notation	Distribution	Values*
Mean arrival date	$\bar{d}$	Uniform	1 July–9 August
Mean residence time	$\bar{r}$	Uniform	24–47 days
Individual arrival date	d_i	Normal	$\bar{d}$ (5 days)
Individual residence time	r_i	Normal	$\bar{r}$ (10 days)
Sampling	s	Normal	1.0 (snapshot CV)
Detectability	D	Uniform	0.85–0.97
Mark identification – 'fuzz' marks	Id_{fuzz}	Lognormal	0.78 (0.72)
Mark identification – 'school' marks	Id_{school}	Lognormal	0.10 (0.16)
Calibration	cal	Uniform	cal ± 0.2 dB
Target strength$^+$	TS	Uniform	TS ± 0.5 dB

* For uniform distribution, values are ranges; for normal distributions, values are means with standard deviations (in parentheses); for lognormal distributions, values are the mean and standard deviation (in parentheses) of $\log_e$(variable).

$^+$ Uncertainty associated with TS arises from variation in fish size, and from differences in the slope of alternative TS-length relationships. Potential bias due to differences in the intercept of alternative TS-length models was ignored because it will not affect the relative values of acoustic indices (see O'Driscoll 2004 for details).

Table 3: Summary of snapshots carried out during the 2015 Cook Strait hoki acoustic survey. Times are NZST.

Snapshot	Vessel(s)	Start time	End time	No. of transects
1	*Thomas Harrison*	24 Jul 08:14	25 Jul 20:31	28
2	*Thomas Harrison*	7 Aug 13:41	9 Aug 14:56	28
3	*Thomas Harrison* and *Aukaha*	12 Aug 14:00	13 Aug 16:56	28
4	*Thomas Harrison* and *Aukaha*	14 Aug 16:09	15 Aug 13:45	28
5	*Aukaha*	23 Aug 22:22	25 Aug 02:06	28
6	*Thomas Harrison* and *Aukaha*	1 Sep 23:57	2 Sep 16:43	28

Table 4: Estimated bounds on factors influencing acoustic *q*. Lower and upper bounds from O'Driscoll et al. (2002) used in the old prior are given in parentheses. Target strength parameters were changed due to the new TS-length relationship based on AOS measurements (see text for details). Bounds on plateau height and timing, and mark identification and species mix were based on 95% confidence intervals of distributions from simulations from all previous surveys (see Figure 2). "Best guess" estimates are medians based on simulations or other prior knowledge.

Factor	Lower bound	Upper bound	Best guess
Plateau height and timing	0.13 (0.10)	0.96 (1.00)	0.64
Target strength: uncertainty	0.70 (0.50)	1.60 (2.00)	1.00
Target strength: tilt angle	0.25	1.00	0.50
Calibration	0.88 (0.88)	1.12 (1.12)	1.00
Mark identification and species mix	1.18 (1.06)	3.08 (2.00)	1.60
Acoustic availability	0.80 (0.80)	0.95 (0.95)	0.90
Areal availability	0.60 (0.60)	0.90 (0.90)	0.70
Product (overall bounds)	**0.01 (0.02)**	**4.53 (3.80)**	**0.32**

Table 5: Estimates of the ratio *r* for converting hoki acoustic backscatter to biomass used the acoustic TS derived from commercial length frequency data and the most recent TS-length relationships of Dunford et al. (2015).

			Dunford et al. (2015)	
Year	Mean length (cm)	Mean weight (kg)	Mean TS (dB)	*r* (kg m^{-2})
1991	73.1	1.25	-38.0	7 964
1993	74.7	1.29	-37.7	8 056
1994	76.9	1.40	-37.6	8 041
1995	78.4	1.50	-37.4	8 148
1996	77.4	1.46	-37.5	8 138
1997	74.9	1.33	-37.8	8 026
1998	75.7	1.38	-37.7	8 082
1999	75.6	1.37	-37.7	8 056
2001	76.9	1.43	-37.5	8 099
2002	78.5	1.50	-37.3	8 148
2003	76.8	1.43	-37.5	8 112
2005	78.7	1.54	-37.3	8 205
2006	74.7	1.34	-37.8	8 065
2007	73.8	1.30	-37.9	8 018
2008	72.9	1.23	-38.1	7 934
2009	73.3	1.25	-38.0	7 959
2011	79.1	1.54	-37.3	8 179
2013	79.7	1.57	-37.2	8 206
2015	75.2	1.34	-37.8	8 025
Mean				8 077

Table 6: Summary and catch information from mark identification and commercial tows where NIWA collected biological data during the 2015 hoki acoustic survey. Mark type refers to the categories described by O'Driscoll (2002b): HOK = hoki school; PMIX = hoki pelagic fuzz; BMIX = hoki bottom fuzz.

				Catch (kg)						
Station	Type	Stratum	Mark type	Hoki	Jack mackerel	Spiny dogfish	Silver warehou	Ling	Other	% Hoki
1	Commercial	2	HOK	7 527	0	20	0	10	0	100
2	Commercial	2	HOK	5 018	0	11	0	4	0	100
3	Commercial	2	HOK	14 000	0	120	0	2	8	99
4	Commercial	2	HOK	10 890	0	115	6	0	6	99
5	Research	3	PMIX	818	196	6	91	89	4	68
6	Research	3	PMIX	481	66	0	15	0	43	80
7	Research	5B	PMIX	449	130	0	29	0	37	70
8	Research	5B	PMIX	383	47	0	10	0	6	86
9	Commercial	2	HOK	16 335	3	50	69	0	18	99
10	Commercial	2	HOK	38 115	0	11	20	42	73	100
11	Research	1	BMIX	302	48	1	0	0	161	59
12	Research	1	BMIX	339	14	11	0	79	109	61
13	Commercial	2	HOK	9 466	16	1	262	1	66	96
14	Commercial	2	HOK	7 260	0	10	50	0	1	99
15	Commercial	2	HOK	14 520	0	20	31	0	0	100
16	Commercial	2	HOK	89 279	2	1	187	0	18	100
17	Commercial	2	HOK	10 163	0	5	10	0	17	100
18	Commercial	2	HOK	9 075	0	0	222	9	46	97

Table 7: Total catch by species for the six designated research tows carried out in the 2015 hoki acoustic survey.

Code	Common name	Catch (kg)
BAR	Barracouta	6.4
BNS	Bluenose	2.7
BYS	Alfonsino	1.1
CAS	Oblique banded rattail	3.0
CBO	Bollons rattail	13.4
CHA	Viperfish	0.1
COL	Oliver’s rattail	4.5
CSQ	Cranchid squid	0.5
CSU	Four-rayed rattail	0.1
CYP	Longnose velvet dogfish	10.6
DCS	Dawson’s catshark	0.6
EPO	Limp eel pout	0.2
ETL	Lucifer's dogfish	4.2
FRO	Frostfish	225.3
HAK	Hake	2.7
HAP	Hapuku	13.6
HOK	Hoki	2 771.6
JAV	Javelinfish	6.3
JMD	Greenback jack mackerel	499.5
LAN	Lanternfish	0.8
LIN	Ling	168.3
MIQ	Warty squid	3.2
PHO	Lighthouse fish	0.1
RCO	Red cod	34.7
RIB	Ribaldo	2.4
SBK	Spineback	1.1
SND	Shovelnosed dogfish	20.4
SPD	Spiny dogfish	17.9
SWA	Silver warehou	145.0
VSQ	Violet squid	1.3
	Total	3 961.6

Table 8: Hoki acoustic abundance estimates from the 2015 Cook Strait survey by snapshot and stratum. The mean is the average of snapshots 1–5.

	Stratum biomass (‘000 t)						Total	Snapshot
Snapshot	1	2	3	5A	5B	6	(‘000 t)	CV
1	10	78	8	15	11	1	124	18
2	16	97	5	9	15	2	143	28
3	12	137	3	11	11	2	176	35
4	13	233	4	12	6	3	271	45
5	12	251	3	21	8	10	304	33
6	29	53	2	12	13	4	112	18
Mean	13	159	4	14	10	4	204	17

Table 9: Percentage of the hoki abundance estimate from hoki school marks in each snapshot and strata for the 2015 Cook Strait survey. Percentages were calculated in relation to abundance estimates in Table 8.

	Percentage of biomass in schools						
Snapshot	1	2	3	5A	5B	6	Total
1	0	97	87	67	0	0	75
2	0	95	80	24	0	0	68
3	0	95	25	36	0	0	77
4	0	97	27	73	0	0	88
5	0	98	0	85	0	0	87
6	0	86	0	44	0	0	45
Mean	0	95	36	55	0	0	73

Table 10: Results of Monte Carlo simulations to determine model weighting for the 2015 Cook Strait acoustic survey (see O’Driscoll 2004 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.

Timing	0.247
+ Sampling	0.299
+ Detectability	0.300
+ Mark identification	0.319
+ Calibration	0.319
+ TS	0.327
Total	0.327

Table 11: Acoustic abundance indices for Cook Strait hoki 1988–2015. All indices were re-calculated for this report using the acoustic TS derived from commercial length frequency data in each survey year using the most recent hoki TS-length relationship of Dunford et al. (2015) (see Table 5). The 2015 estimate is the mean of snapshots 1–5.

Year	No of accepted snapshots	Abundance ('000 t)	CV
1991	4	88	0.41
1993	4	283	0.52
1994	3	278	0.91
1995	4	194	0.61
1996	5	92	0.57
1997	6	141	0.40
1998	5	80	0.44
1999	6	114	0.36
2001	11	102	0.30
2002	9	145	0.35
2003	9	104	0.34
2005	9	59	0.32
2006	7	60	0.34
2007*	4	104	0.46
2008	7	82	0.30
2009*	5	166	0.39
2011*	6	141	0.35
2013*	7	168	0.30
2015*	5	204	0.33

* Surveys from industry vessels.

8. FIGURES

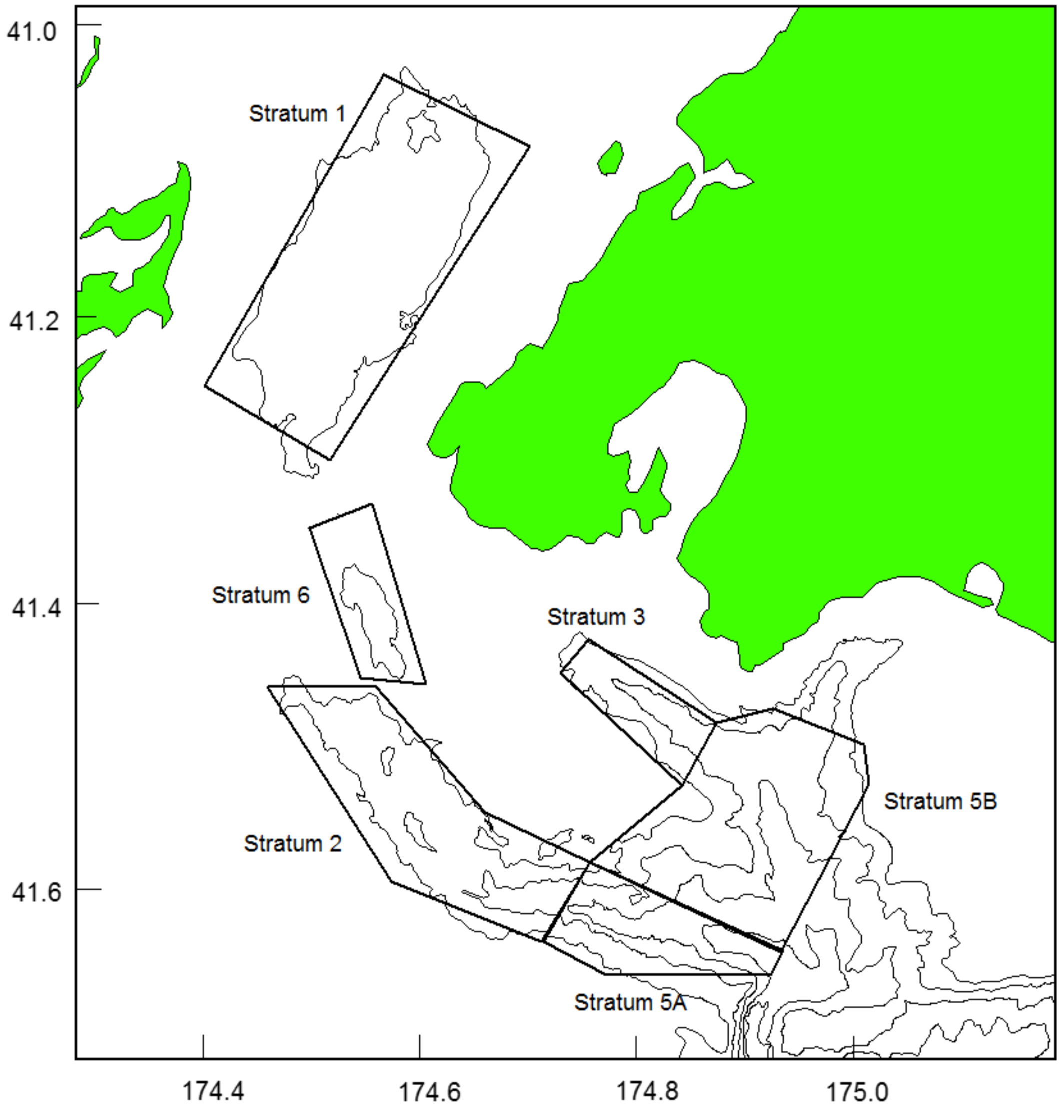


Figure 1: Stratum boundaries for the 2015 acoustic survey of Cook Strait spawning hoki: 1, Narrows Basin; 2, Cook Strait Canyon; 3, Nicholson Canyon; 5A, Cook Strait Canyon extension; 5B, Deepwater outside Nicholson and Wairarapa Canyons; 6, Terawhiti Sill. Depth contours are 250, 500, 750, and 1000 m.

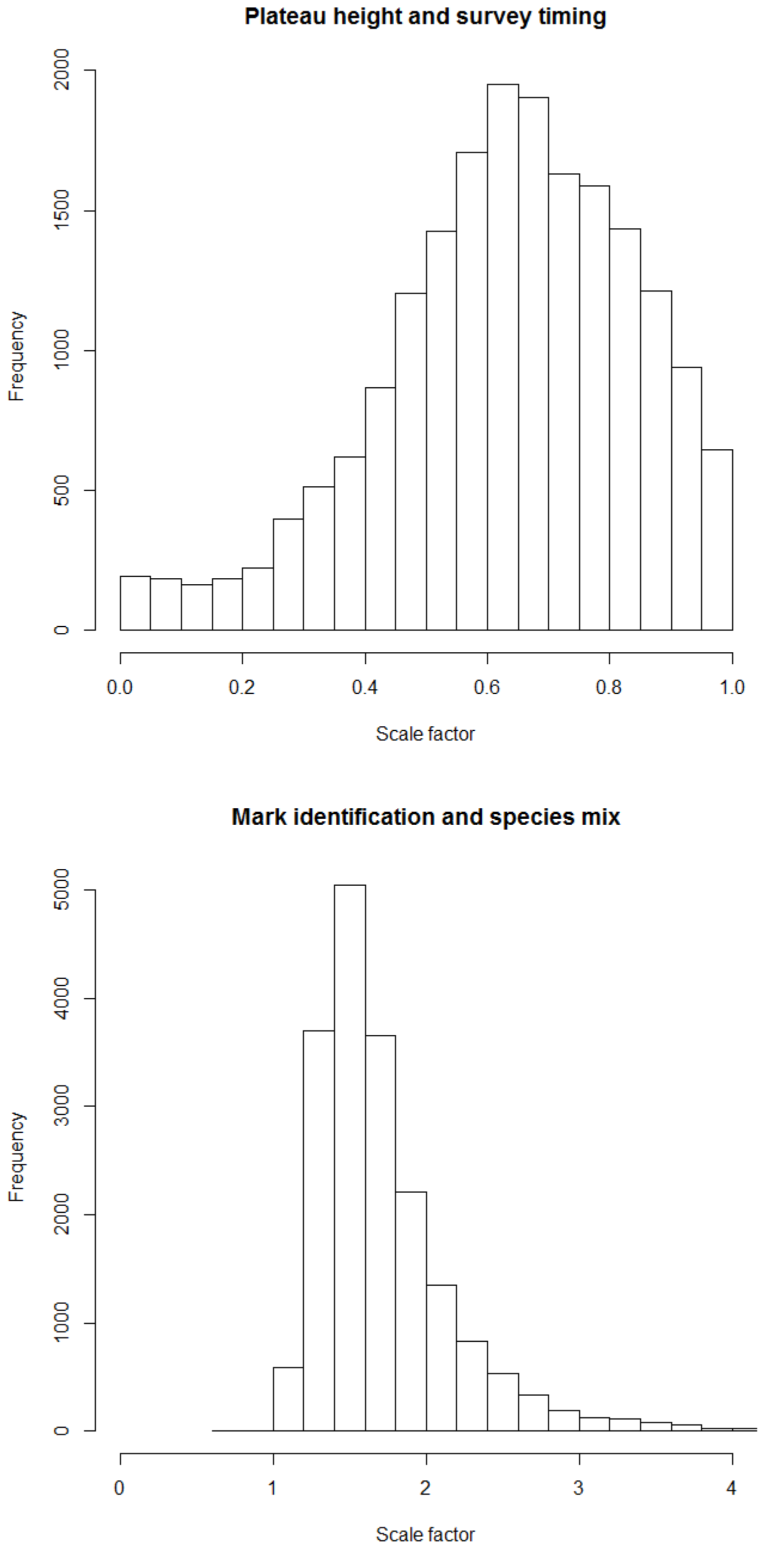


Figure 2: Distributions of survey scale factors associated with plateau height and survey timing and mark identification and species mix estimated from simulations of uncertainty from all previous Cook Strait surveys. These distributions were used to generate priors on acoustic *q* (see Table 4).

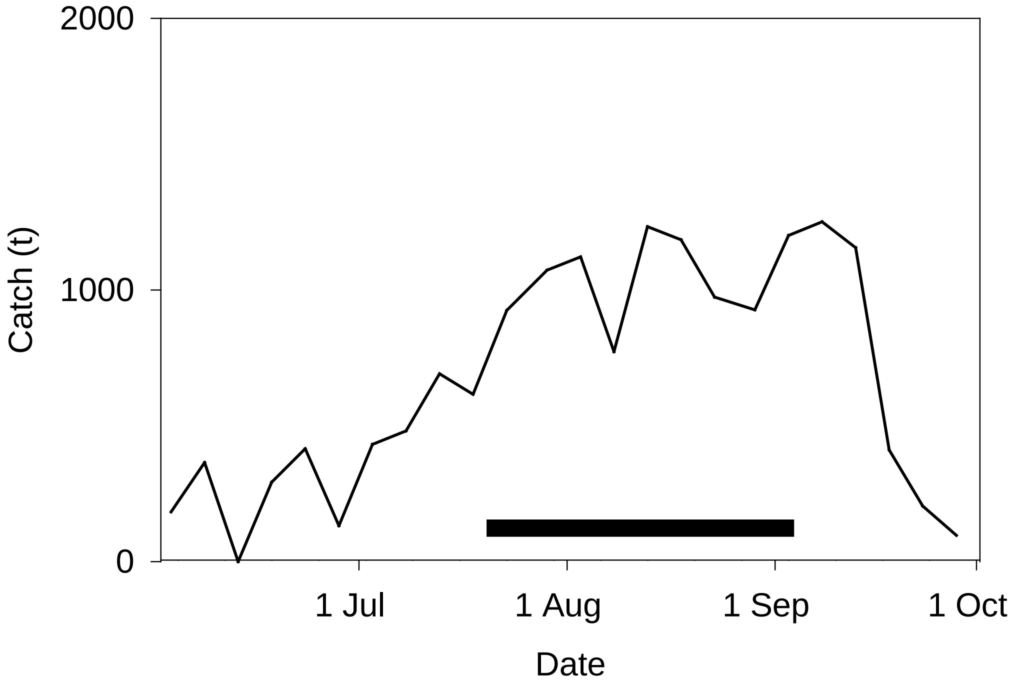


Figure 3: Timing of acoustic survey in 2015 (bar along the x axis) in relation to the commercial hoki catch from Cook Strait in 5-day periods.

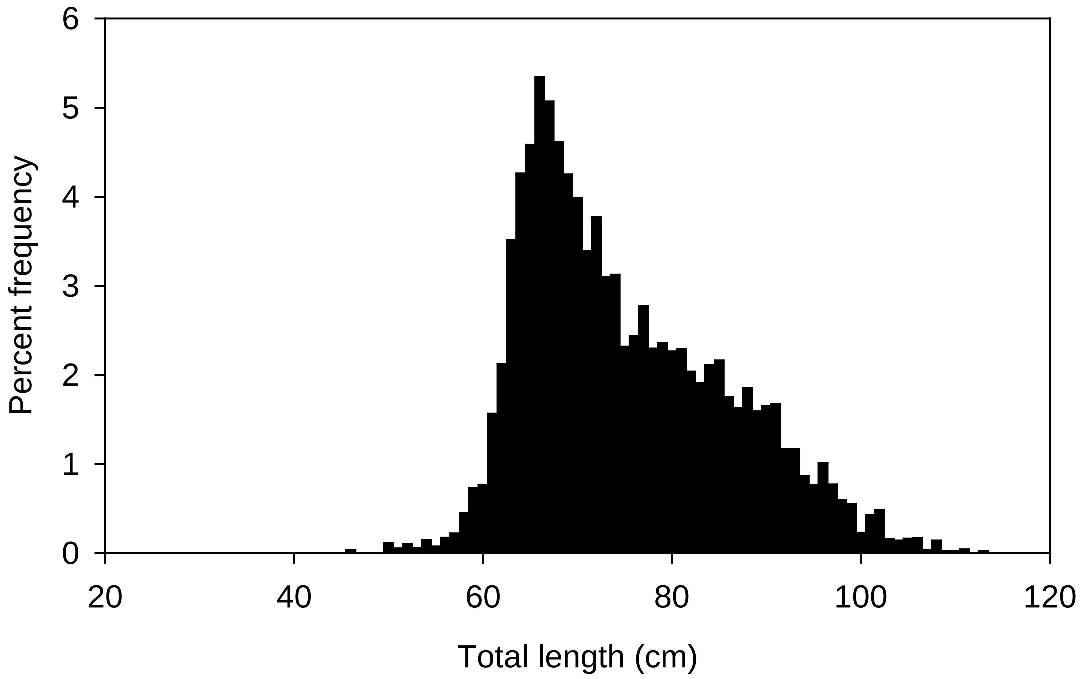


Figure 4: Scaled unsexed length frequencies of hoki caught in the commercial fishery in Cook Strait in 2015 based on at-sea observer sampling, market sampling, and sampling by NIWA on *Thomas Harrison*. Data were used to estimate the ratio, *r*, of mean weight to mean backscattering cross-section for Cook Strait hoki (see Table 5).

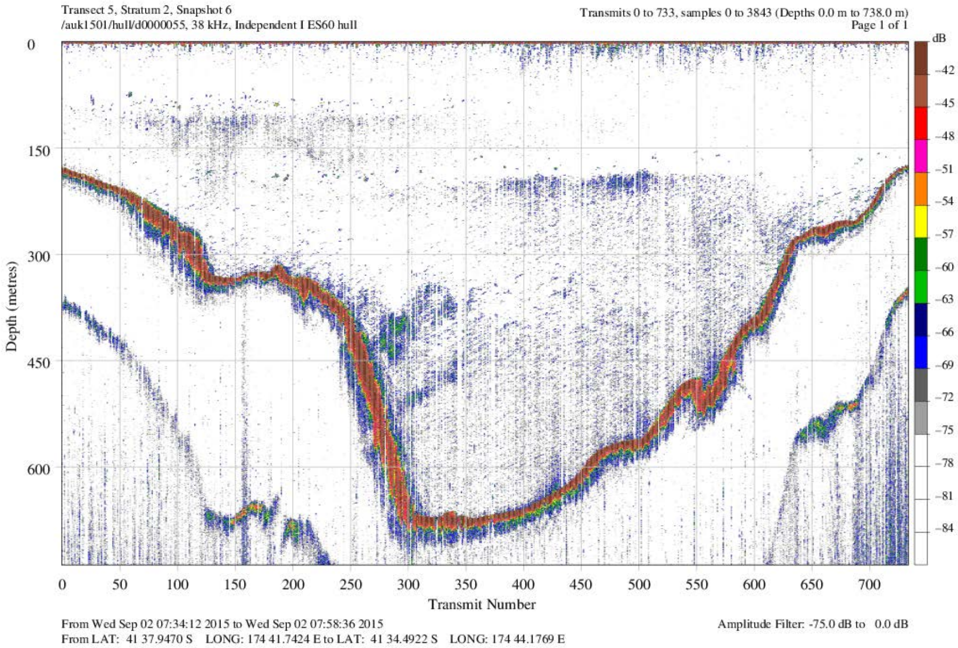


Figure 5: Acoustic echogram from Cook Strait Canyon (stratum 2) collected by *Aukaha* during snapshot 6 showing missing data due to wave-generated bubbles (vertical white lines).

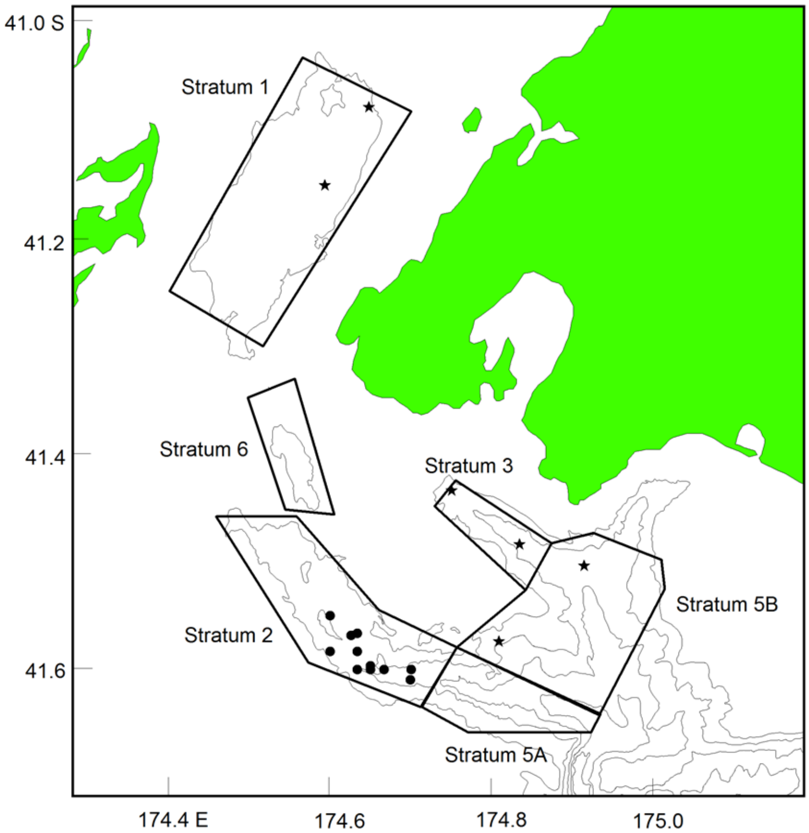


Figure 6: Location of trawls sampled on *Thomas Harrison* from 10–19 August 2015: stars show research tows; and circles show commercial tows.

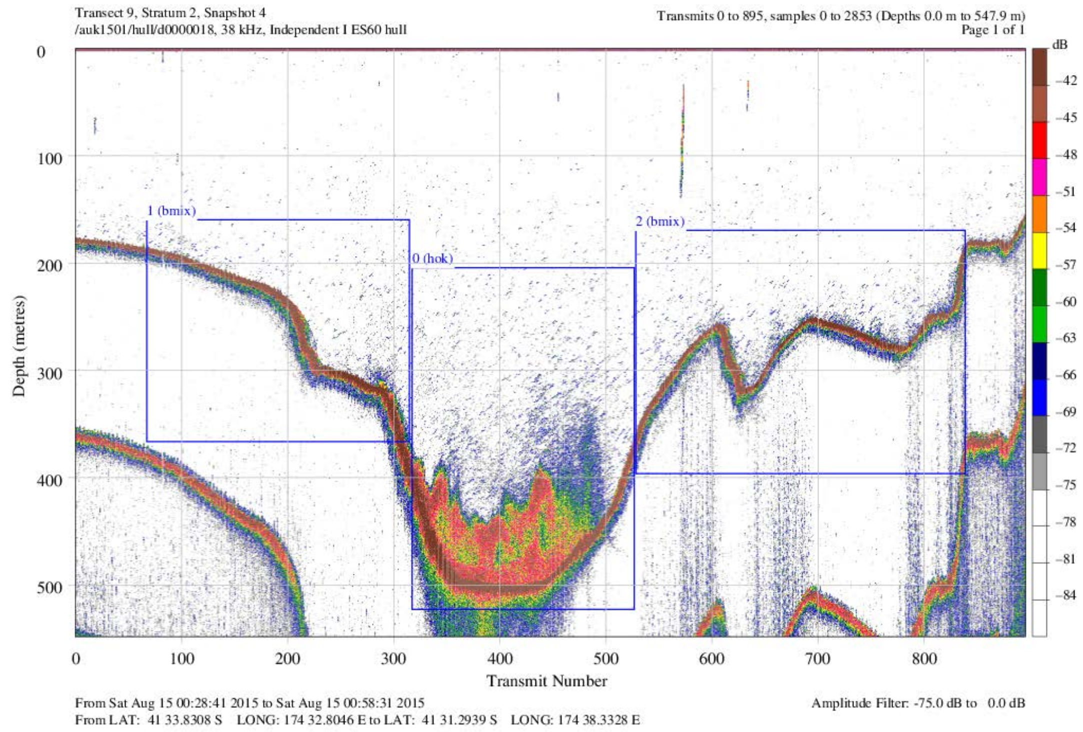


Figure 7: Acoustic echogram from Cook Strait Canyon (stratum 2) during snapshot 4 showing a very dense hoki school (blue rectangle labelled 'hok') close to the bottom of the canyon at night. Dispersed bottom fuzz ('bmix') layers occur to either side.

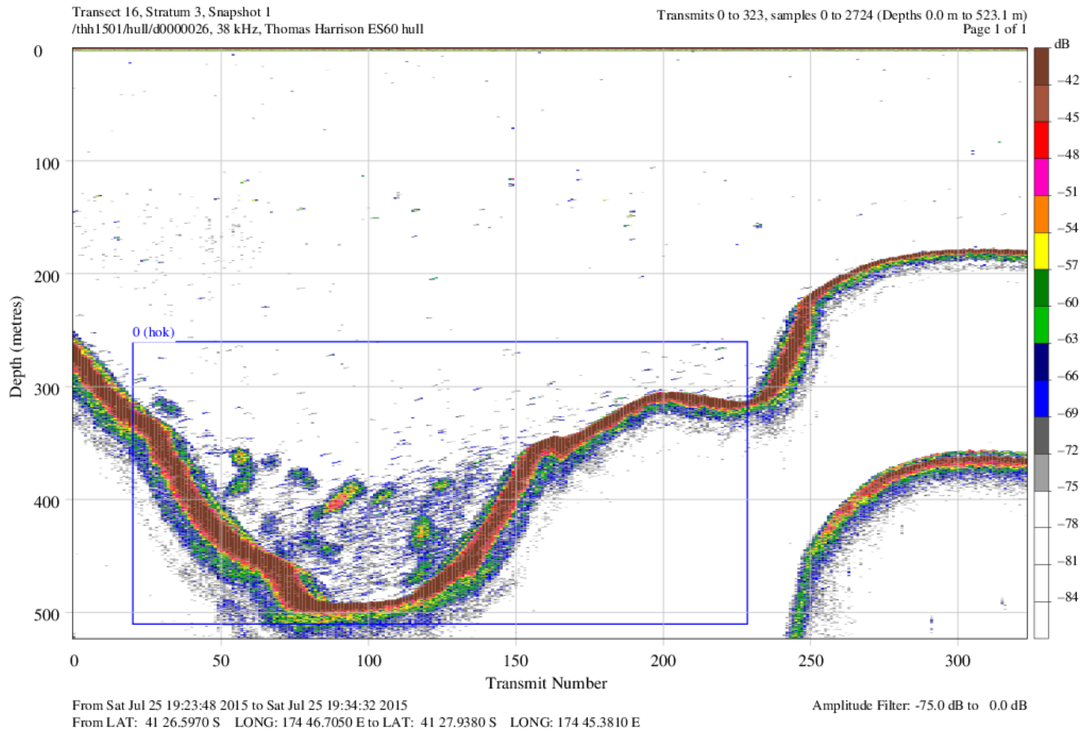


Figure 8: Acoustic echogram from Nicholson Canyon (stratum 3) during snapshot 1 showing hoki schools in midwater.

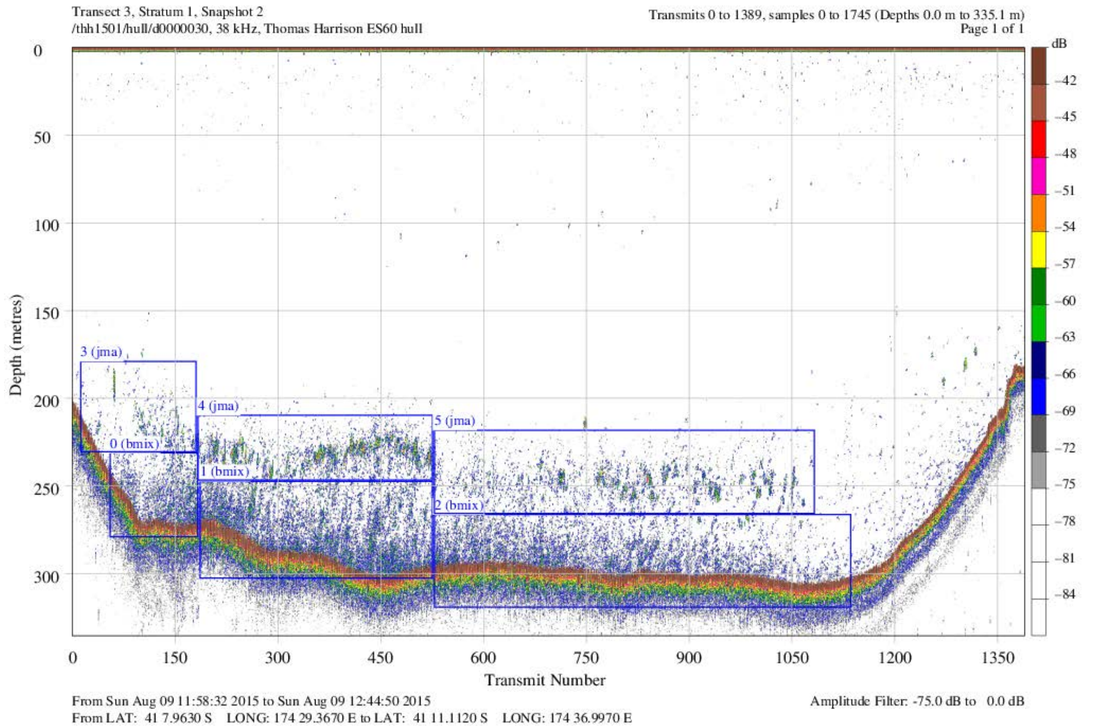


Figure 9: Acoustic echogram from Narrows Basin (stratum 1) during snapshot 2 showing hoki bottom fuzz within 100 m of the bottom during the day (blue rectangles labelled 'bmix') and small jack mackerel schools ('jma') above.

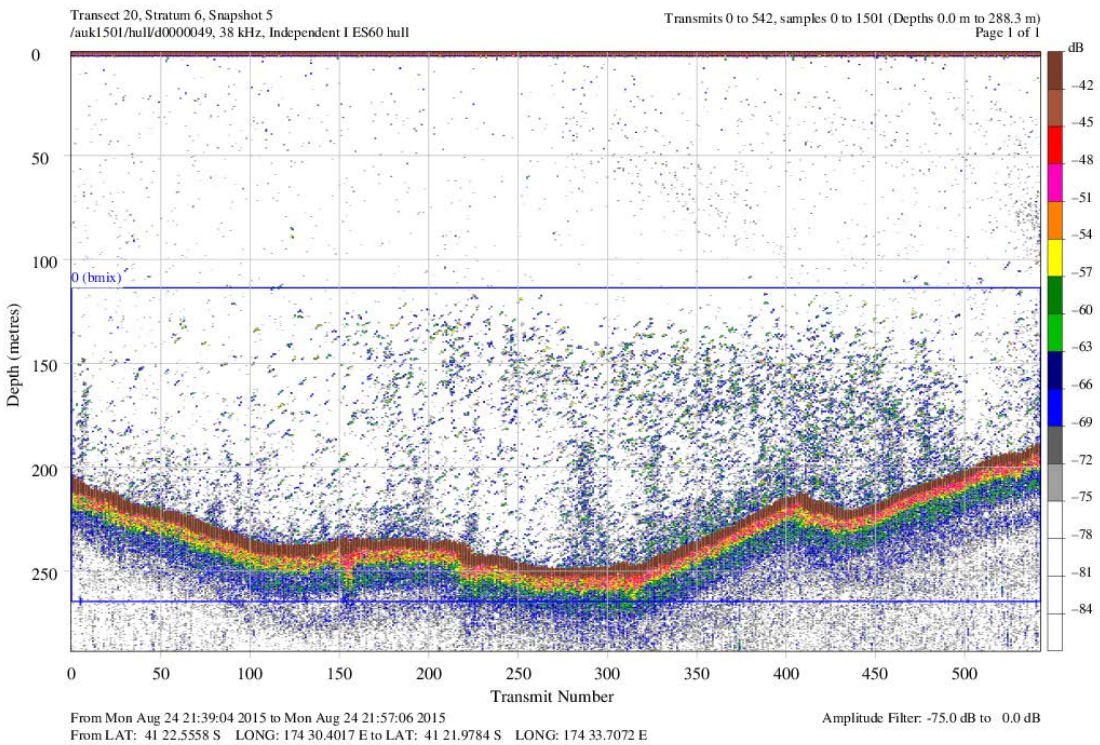


Figure 10: Acoustic echogram from Terawhiti Sill (stratum 6) during snapshot 5 showing hoki bottom fuzz at night.

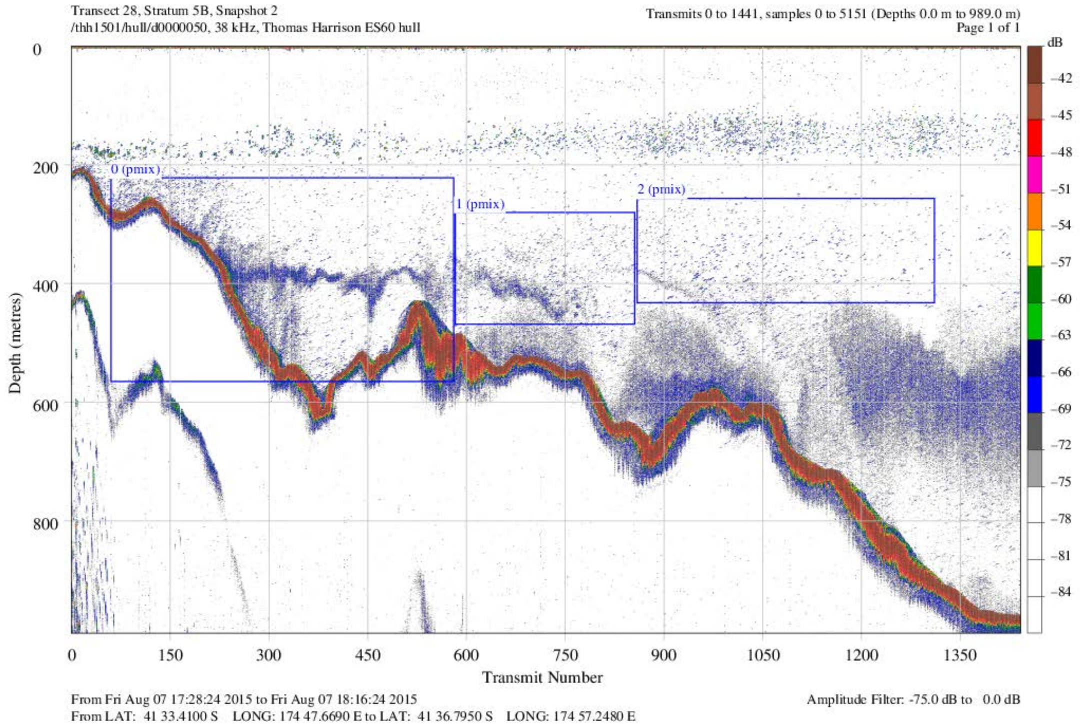


Figure 11: Acoustic echogram from the deepwater between Cook Strait and Wairarapa Canyons (stratum 5B) during snapshot 2 showing dispersed hoki pelagic fuzz marks (three blue rectangles labelled 'pmix'). The layers above and below are probably mesopelagic fish.

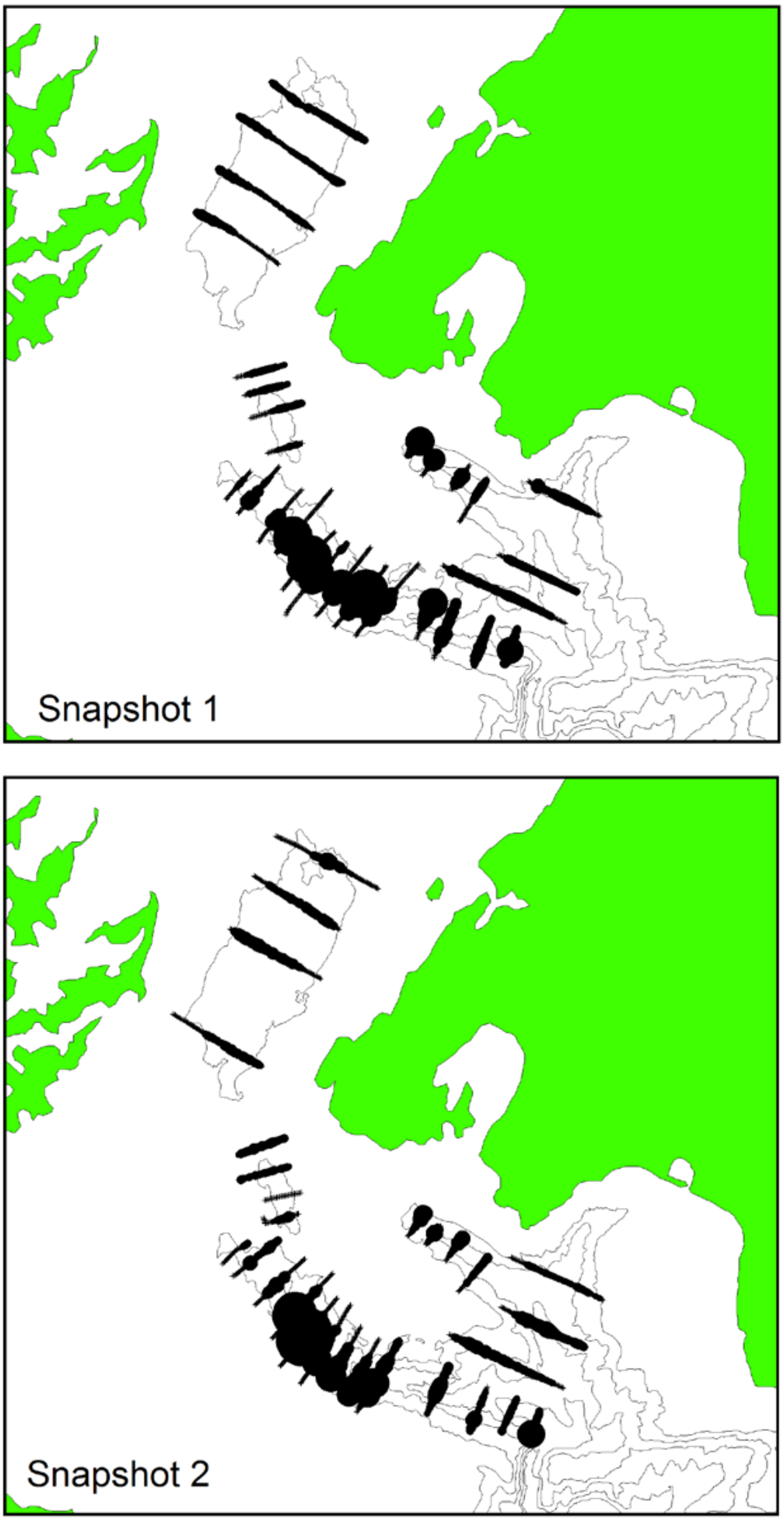
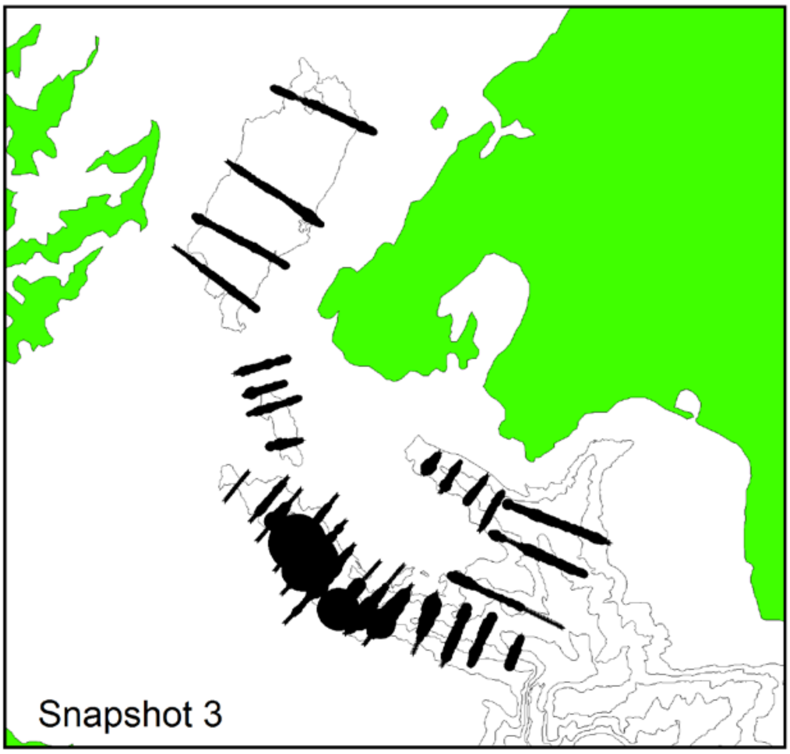


Figure 12: Spatial distribution of hoki acoustic backscatter plotted in 10 ping (about 100 m) bins for snapshots 1–2 in 2015. Symbol size is proportional to the log of the acoustic backscatter.



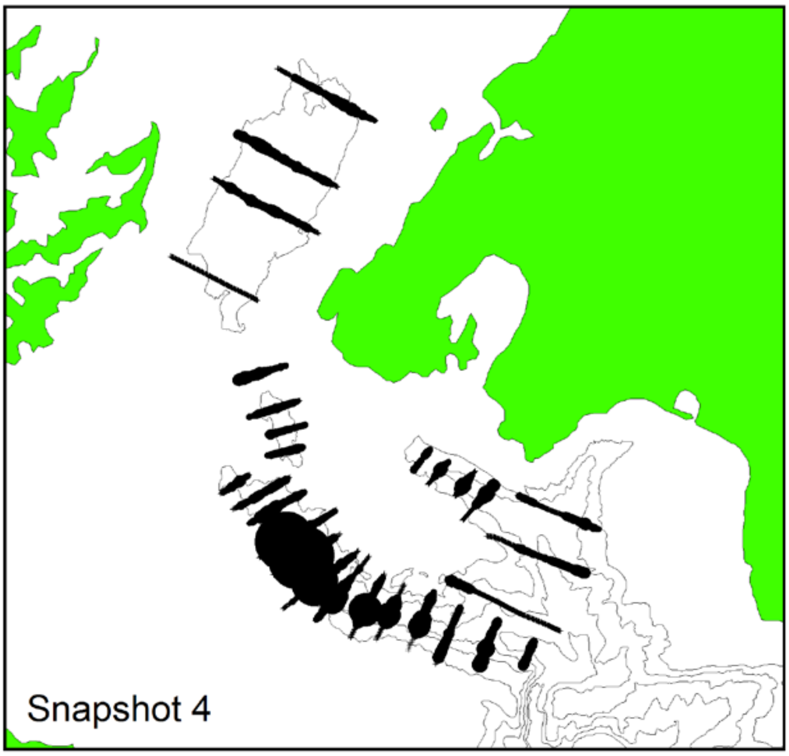


Figure 12 cntd: Spatial distribution of hoki acoustic backscatter plotted in 10 ping (about 100 m) bins for snapshots 3–4 in 2015. Symbol size is proportional to the log of the acoustic backscatter.

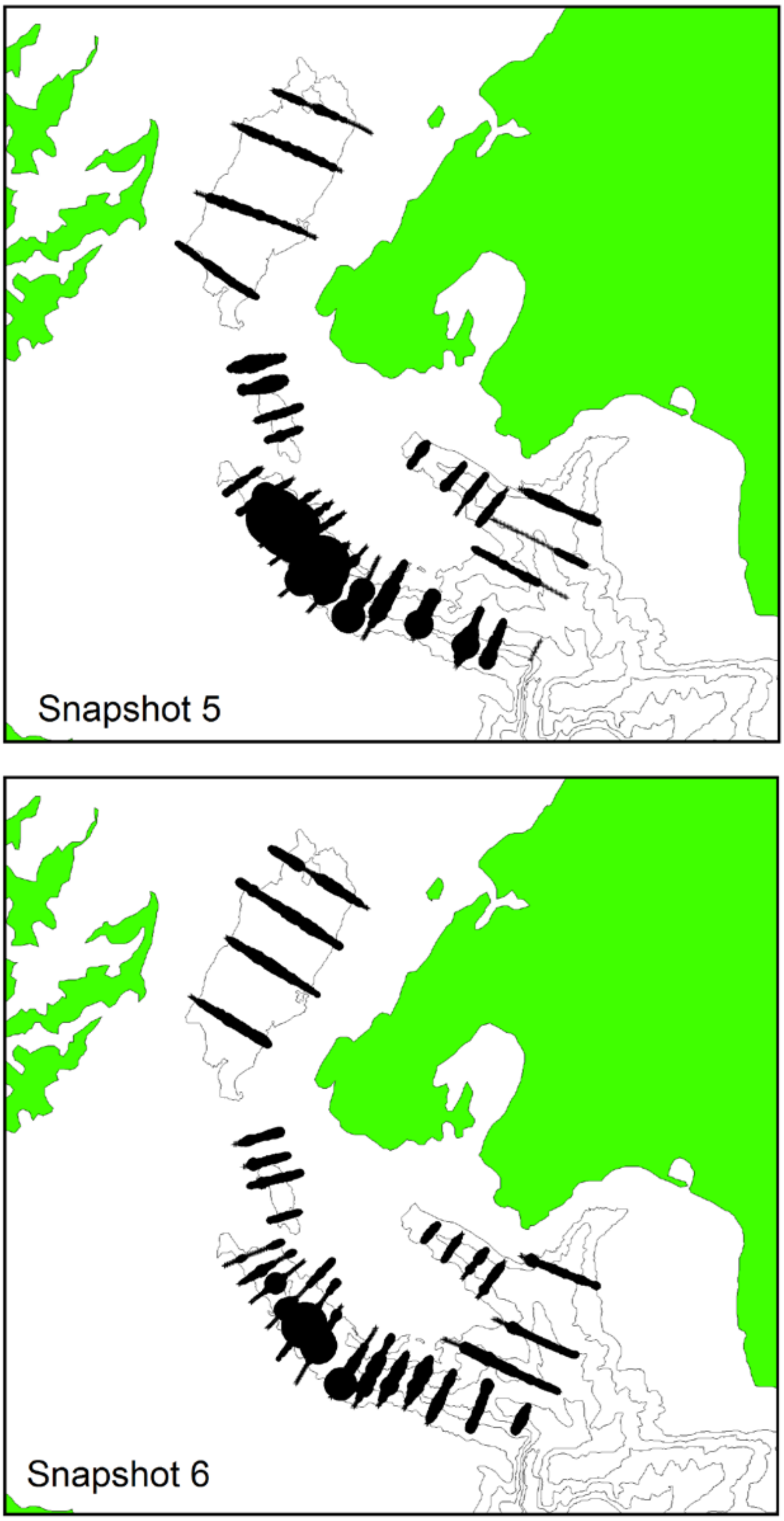


Figure 12 cntd: Spatial distribution of hoki acoustic backscatter plotted in 10 ping (about 100 m) bins for snapshots 5–6 in 2015. Symbol size is proportional to the log of the acoustic backscatter.

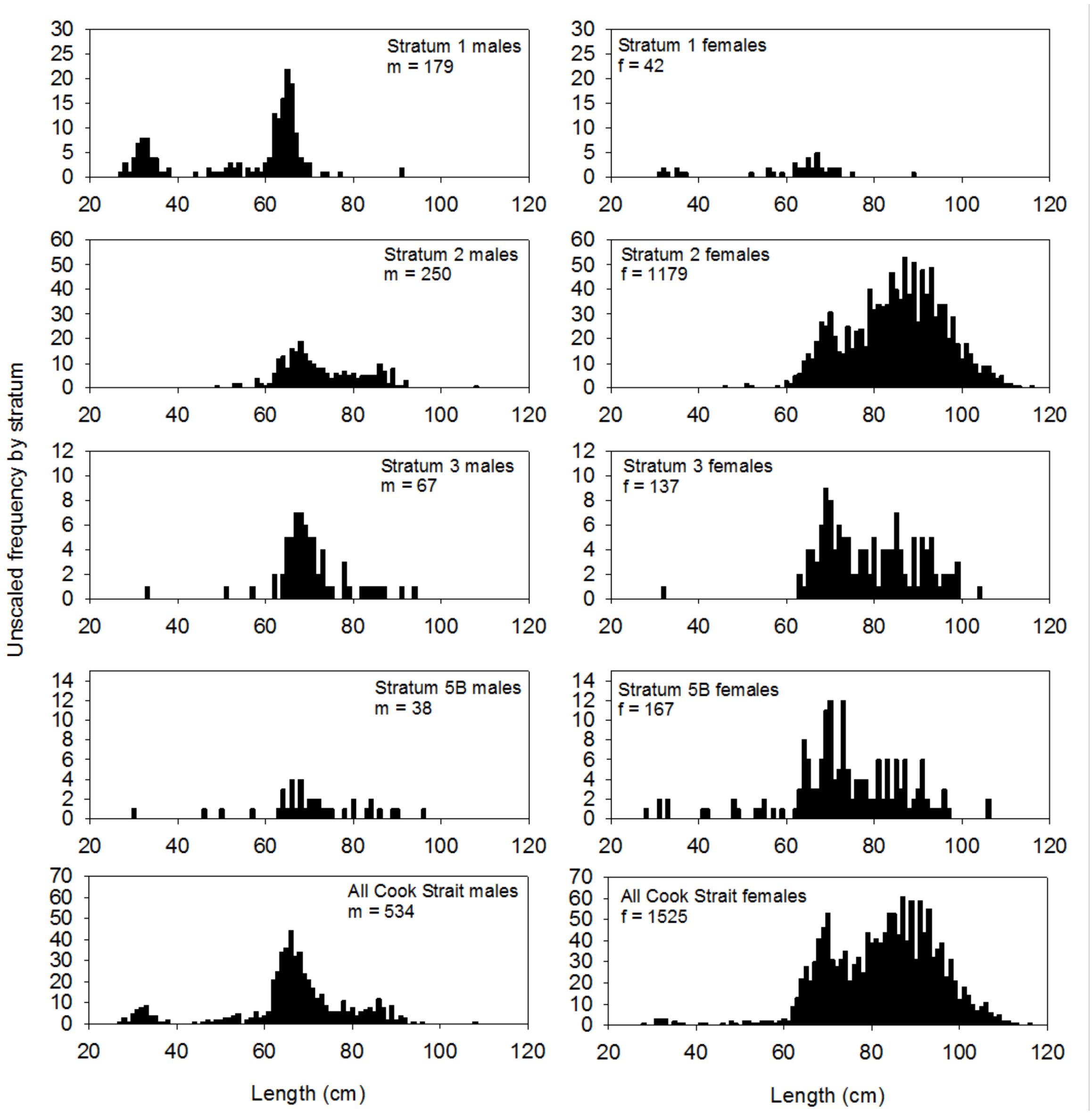


Figure 13: Unscaled length frequency distributions of hoki by sex and stratum from sampling in Cook Strait by *Thomas Harrison* in winter from 10–19 August 2015. The m (male) and f (female) values refer to the numbers of fish measured. Hoki in stratum 2 were taken in commercial tows. Hoki in all other strata were from designated research tows (see Figure 6).

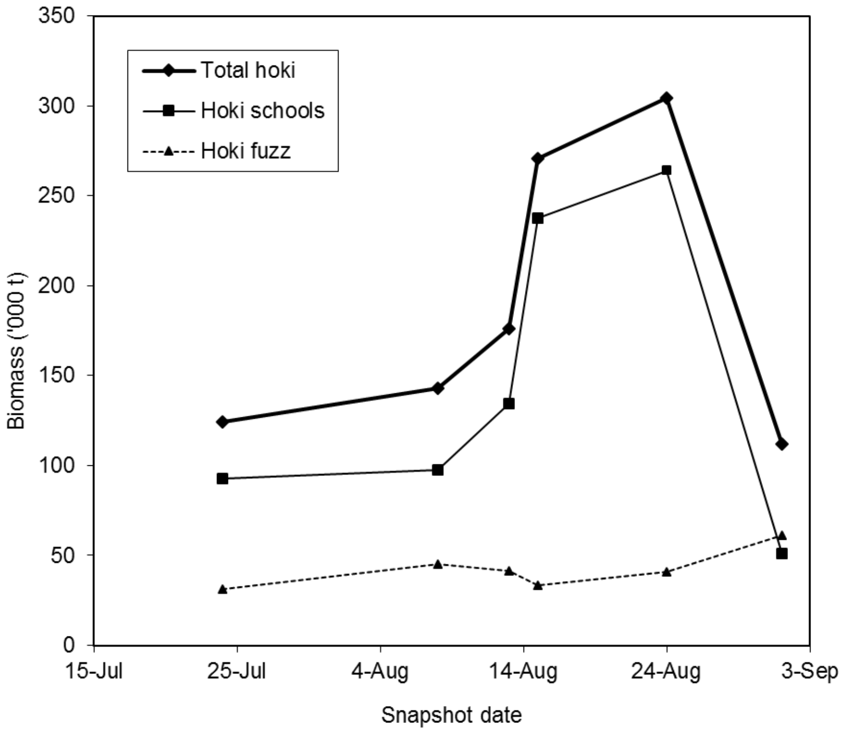


Figure 14: Estimated hoki abundance in Cook Strait by snapshot and mark type from the 2015 survey.

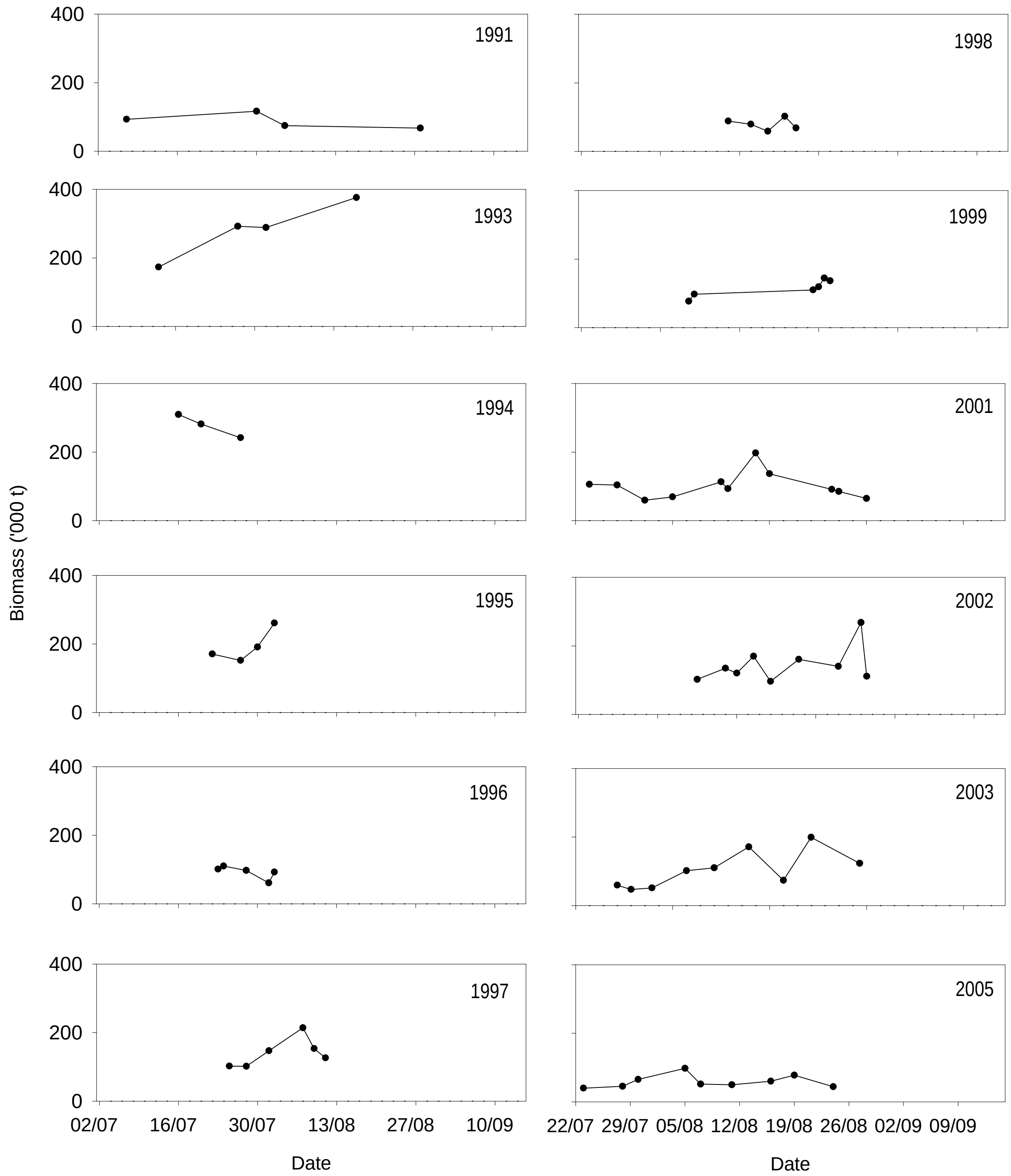


Figure 15: Estimated hoki abundance by snapshot for acoustic surveys in the Cook Strait time series from 1991 to 2005.

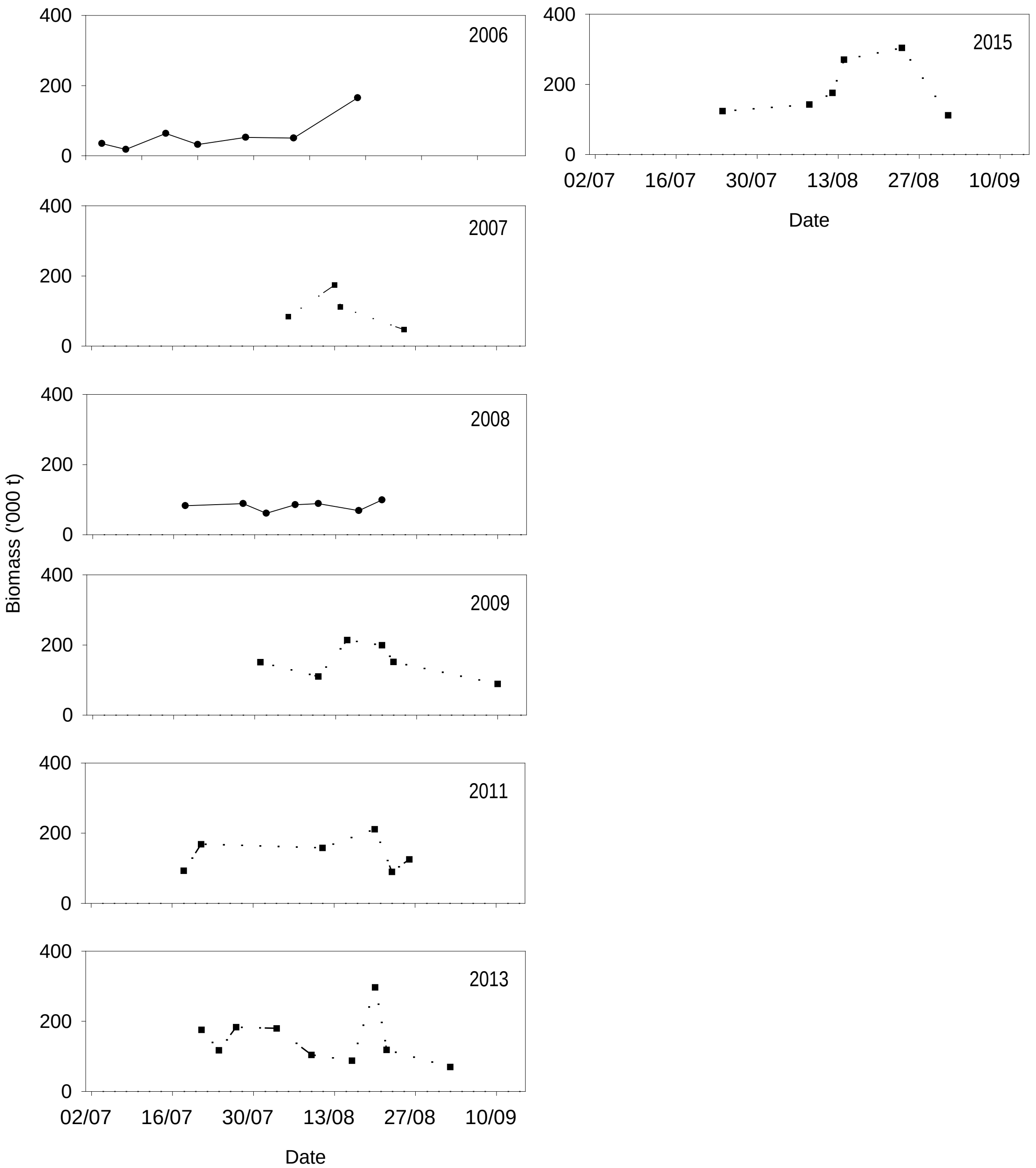


Figure 15 cntd: Estimated hoki abundance by snapshot for acoustic surveys in the Cook Strait time series from 2006 to 2015. Dotted lines show surveys carried out from commercial vessels.

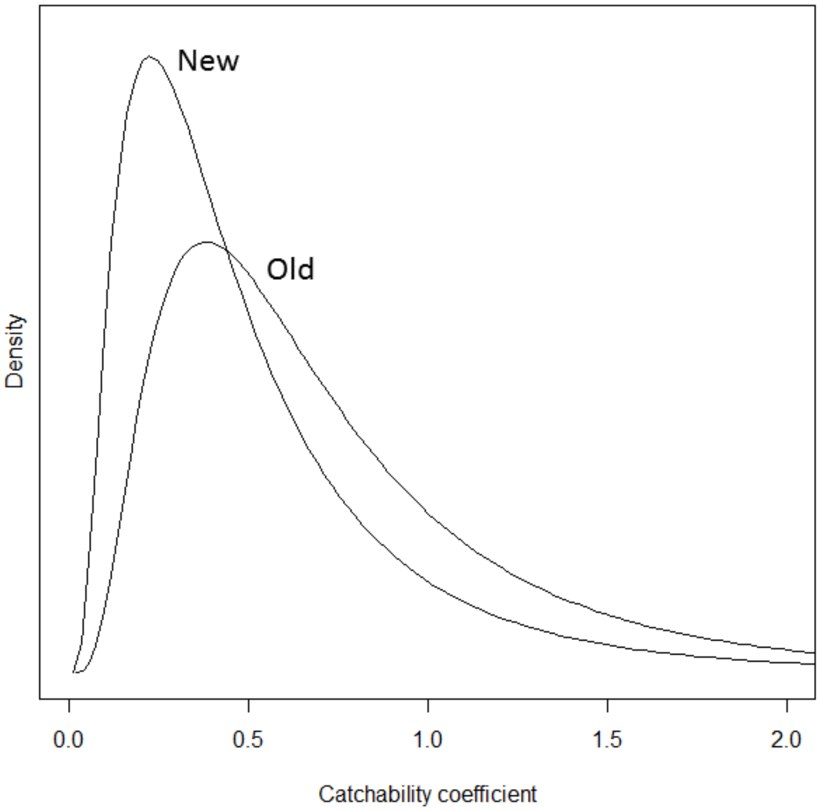


Figure 16: Estimated prior for acoustic *q* in Cook Strait estimated in this report ('New') compared to existing prior ('Old').

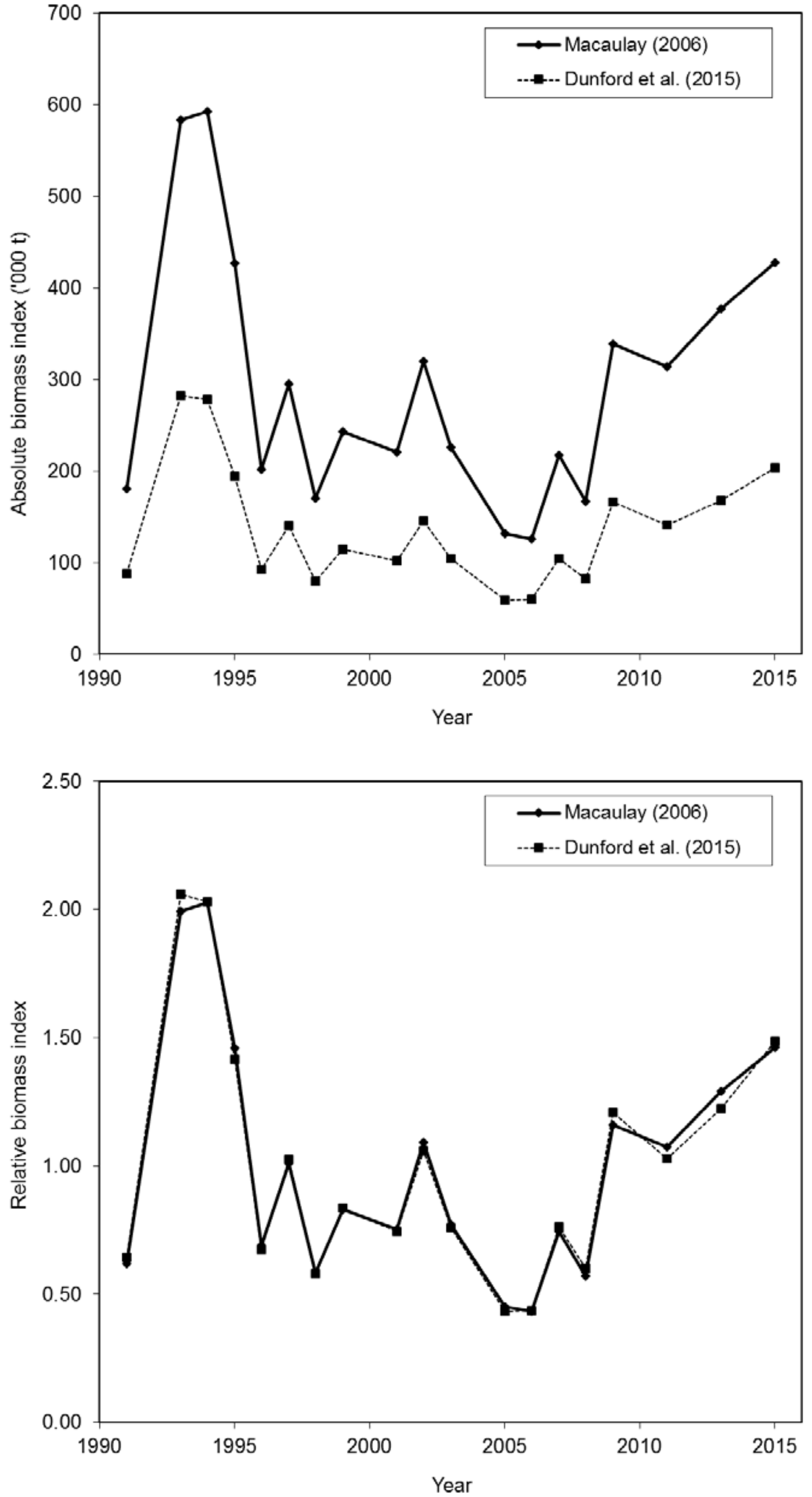


Figure 17: Comparison of absolute (upper panel) and relative (lower panel) time series of acoustic abundance estimates for spawning hoki in Cook Strait estimated with the TS-length relationship of Macaulay (2006) and the new TS-length relationship derived from AOS data (Dunford et al. 2015).

APPENDIX 1: Calibration Report *Thomas Harrison*

Calibration of the Simrad ES70 echosounder on *Thomas Harrison* was carried out by Yoann Ladroit and took place in Tasman Bay on 10 August 2015. This was the twelfth time that the Simrad echosounder on this vessel has been calibrated since 2005, but the first four calibrations were with an older transducer (which failed in 2008). A new ES70 computer and software were installed on *Thomas Harrison* in December 2010 and connected to the same 38-kHz GPT and transducer as the ES60 used previously. Because the ES60 and ES70 use the same hardware, the calibrations with the two software systems are identical within the measurement uncertainty. In 2014 two other ES70 38 kHz were installed looking at about 30 degrees angle on port and starboard, to complement the downward-looking 38 kHz and 18 kHz echosounders. The only echosounder calibrated here was the downward-looking 38 kHz echosounder used to collect survey data. The calibration was conducted broadly according to the procedures in Demer et al. (2015).

The calibration took place in Tasman Bay (41° 05.87’ S 173° 18.17’E) in about 30 m of water. The vessel left Nelson at 14:50 NZST and was on calibration site at 16:10 NZST. A weighted line was passed under the keel to facilitate setting up the three lines and calibration sphere. The transducer on *Thomas Harrison* is located near the bow, and a 5 m long pole was used to place one of the lines forward of the transducer position. The sphere and associated lines were immersed in a soap solution prior to entering the water. A lead weight was also deployed about 2 m below the sphere to steady the arrangement of lines. The sphere was centred in the beam to obtain data for the on-axis calibration, and was then moved around the beam to obtain data for the beam shape calibration.

The weather during the calibration was excellent – the wind was variable 5 knots, with flat sea. The shaft was unclutched during calibration, the vessel was allowed to drift. Drift speed was about 0.2 knots. The sphere was first located in the beam at 16:45 NZDT, and the recording was stopped at 17:25 NZST, before it got dark (sunset at 17:35 NZST). Calibration data were recorded into a single ES70 raw format file (D20150810-T163256). The ES70 transceiver settings in effect during the calibration are given in Table A1.1.

Water temperature measurements were taken using an RBR-2050 temperature depth probe, serial number 11817. The salinity at the calibration site was assumed to be 35 PSU. An estimate of acoustic absorption was calculated using the formulae in Doonan et al. (2003) and an estimate of sound speed was calculated using the formulae of Fofonoff & Millard (1983).

The data in the ES70 file were extracted using custom-written Matlab 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 Sa correction was calculated from:

$$S_{a,corr} = 5\log_{10}\left(\frac{\sum P_i}{4P_{\max}}\right),$$

where P_i is the sphere echo power measurement 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 $S_{a,corr}$.

A correction for the triangle wave error in ES60/ES70 data (Ryan & Kloser 2004) was also applied as part of the analysis.

Results

The mean range of the sphere and the sound speed and acoustic absorption between the transducer (about 6 m deep) and the sphere are given in Table A1.2.

The calibration results are given in Table A1.3 along with the results from previous NIWA calibrations. The symmetrical nature of the estimated beam pattern (Figure A1.1) centred on zero indicates that the transducer and ES70 transceiver were operating correctly. The fits between the theoretical beam pattern and the sphere echoes (Figure A1.2) also confirms that the transducer beam pattern is correct. The RMS of the difference between the Simrad beam model and the sphere echoes out to 3.4° off axis was 0.17 dB (Table A1.3), indicating that this calibration was of excellent quality (≥0.4 dB is poor, <0.3 dB good, and <0.2 dB excellent).

There has been a trend of declining G_0 for this transducer and GPT since the new transducer was installed in 2008 (see Figure A1.3), but this seems to have stabilized.

Table A1.1. ES70 transceiver settings and other relevant parameters during the calibration of *Thomas Harrison*.

Parameter	Value
Echosounder	ES70
ES70 software version	1.0.0
Transducer model	ES38B
Transducer serial number	30884
ES70 GPT serial number	GPT-Q38(4) 1.0 0090720179e5
GPT software version	040120
Sphere type/size	tungsten carbide/38.1 mm diameter
Operating frequency (kHz)	38
Transducer draft setting (m)	0.0
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^{-1})	9.7
Speed of sound (m s^{-1})	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 A1.2. Auxiliary calibration parameters derived from depth/temperature measurements.

Parameter	Value
Mean sphere range (m)	21.6
S.D. of sphere range (m)	0.6
Mean sound speed (m/s)	1495
Mean absorption (dB/km)	9.39
Sphere TS (dB re $1m^2$)	–42.41

Table A1.3: Calculated echosounder calibration parameters for *Thomas Harrison*. Calibrations prior to 2008 are not reported here as the transducer was found to be faulty during the 2008 calibration and replaced prior to the 2009 calibrations.

Parameter	10 Aug 15	15 Nov 13	27 Mar 13	15 Aug 11	24 Jun 10	7 Aug 09	25 Jun 09
Mean TS within 0.21° of centre	-47.12	-47.28	-47.79	-46.52	-46.64	-45.06	-45.31
Std dev of TS within 0.21° of centre	0.32	0.12	0.22	0.35	0.24	0.11	0.31
Max TS within 0.21° of centre	-46.69	-47.19	-47.12	-46.14	-46.05	-44.93	-44.45
No. of echoes within 0.21° of centre	1 432	67	277	14	176	119	2 738
On axis TS from beam-fitting	-47.02	-47.33	-47.55	-46.39	-46.46	-44.81	-45.19
Transducer peak gain (dB) (mean)	24.14	24.07	23.81	24.41	24.39	25.17	25.05
Sa correction (dB)	-0.61	-0.58	-0.55	-0.52	-0.59	-0.60	-0.64
Beamwidth (°) alongship/athwarthship	6.90/6.70	6.95/6.95	7.05/7.05	6.90/6.81	7.07/6.98	6.68/6.69	6.94/7.04
Beam offset (°) alongship/athwarthship	0.00/0.00	0.00/0.00	-0.01/0.01	0.00/0.00	0.00/0.00	-0.05/-0.00	0.00/0.00
RMS deviation	0.17	0.09	0.18	0.21	0.18	0.18	0.17
Number of echoes	5 146	8 692	16 825	3 613	22 728	18 221	34 909

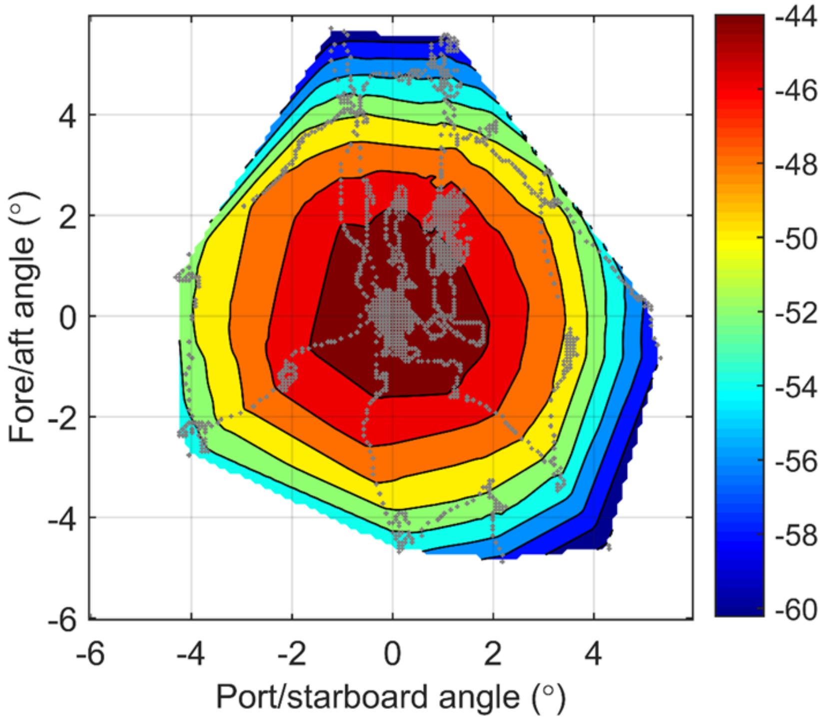


Figure A1.1. The estimated beam pattern from the sphere echo strength and position for the calibration of *Thomas Harrison*. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

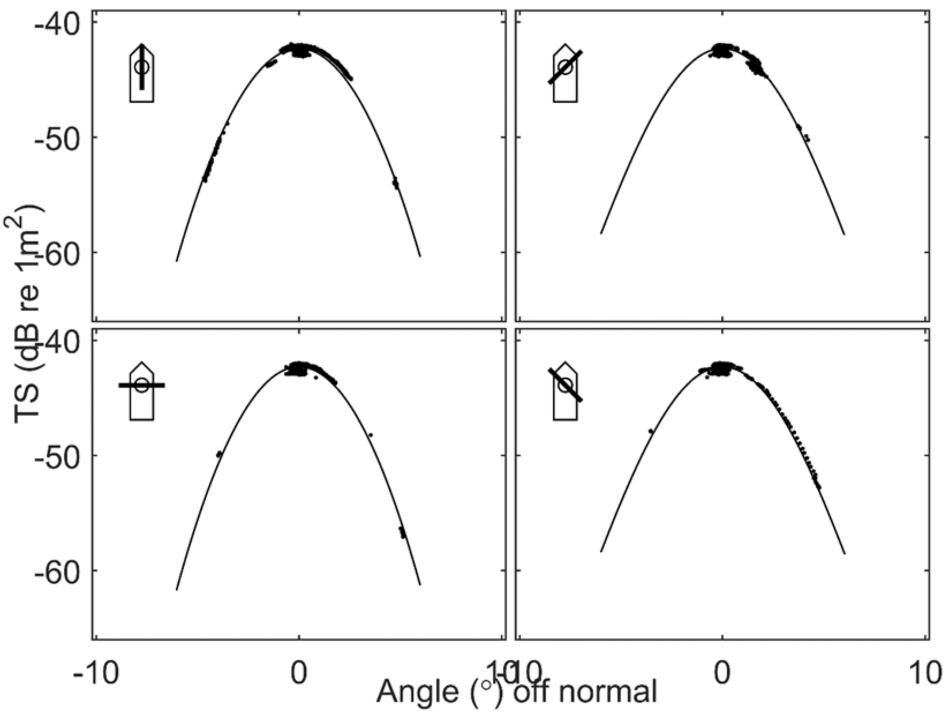


Figure A1.2. Beam pattern results from the calibration analysis for *Thomas Harrison*. The solid line is the theoretical beam pattern fit to the sphere echoes for four slices through the beam.

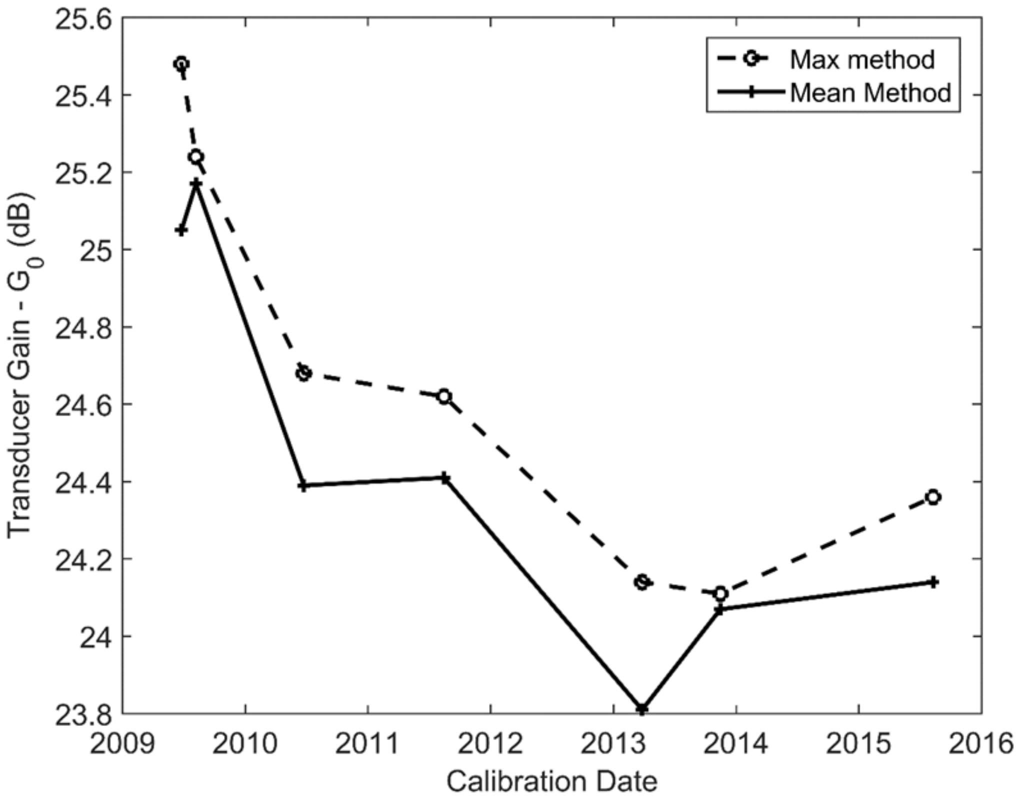


Figure A1.3. The trend in transducer gain (G_0) for the Simrad ES38B transducer installed on *Thomas Harrison*. For comparability only calibrations carried out and analysed by NIWA are shown.

APPENDIX 2: Calibration Report *Aukaha*

Calibration of the Simrad ES70 echosounder on FV *Aukaha* (46 m trawler owned by Sealord Group Limited) took place in Tasman Bay (41° 03.26' S 173° 11.32' E) on 18 September 2015. Water depth was about 27 m (below the transducer). This vessel was formerly known as *Independent 1*, and this was the sixth time that the echosounder on this vessel has been calibrated by NIWA, with the most recent calibration on 27 June 2013. The many calibrations carried out on *Independent 1* as part of the Oman fisheries survey were with an EK60 connected to the transducer and are not directly comparable to the ES60/ES70 calibrations. The calibration was conducted broadly according to the procedures in Demer et al. (2015),

The calibration was carried out using divers as an earlier attempt to calibrate *Aukaha* on 26 August 2015 was unsuccessful, due to calibration lines fouling on the hull. Problems with lines fouling were also encountered in 2011 and 2013, but successful calibrations were still achieved with some effort. Given the importance of a calibration for analysis of Cook Strait hoki survey results, the added expense of diver support was justified.

Richard O'Driscoll (NIWA) left Nelson at 10:15 NZST on the New Zealand Diving Services (NZDS) vessel *Topline* with Bruce Lines and two other NZDS staff. The team met *Aukaha* at the calibration position in Tasman Bay at 11:15 NZST. The ES70 was configured to recommended settings (2000 W power and 1.024 ms pulse). The time of the ES70 PC was not adjusted to the GPS, but was noted to be out by about 8 minutes. A keyboard was available (installed on the wall under the bridge console).

The divers entered the water at about 11:55 NZST to facilitate setting up the three lines and calibration sphere. The sphere and associated lines were immersed in a soap solution prior to entering the water. A lead weight was deployed about 4 m below the sphere to steady the arrangement of lines. Difficulty was experienced getting the sphere in the echosounder beam using the standard configuration of rods. There is an anode on the keel on the port side which fouled the port forward line (and was responsible for the earlier unsuccessful attempt on 26 August). To avoid this anode the port forward rod was moved further aft on the foredeck and the port aft rod was moved forward (to just ahead of the workboat). This gave less separation between port rods, but avoided the anode and other obstructions on the hull. No photographs were taken of the new rod positions.

With the new rod positions, the sphere was first observed in the beam at close range at 12:58. The sphere was lowered in 5 m increments, but was moving around considerably and disappeared from the beam at ranges greater than 15 m. No echo from the lead weight was visible during the calibration and when the lines were recovered it was discovered that this had broken off sometime during the set-up, meaning that the lines were not as steady as usual. The sphere was first centred to obtain data for the on-axis calibration at 13:10. After on-axis data were collected, the sphere was then moved around the beam to obtain data for the beam shape calibration. Calibration data were recorded into two ES70 raw format files (Aukaha-D20150917-T005050.raw and Aukaha-D20150917-T012945.raw). Raw data are stored in the NIWA Fisheries Acoustics Database. The ES70 transceiver settings in effect during the calibration are given in Table A2.1.

The weather was good at the start of the calibration attempt with a variable wind and 1 m swell, but a 15–20 knot northwesterly wind developed from 13:00, with a 1 m chop. The propeller was de-clutched and the vessel was allowed to drift, and the drift speed was about 0.6 knots.

Water temperature measurements were taken using an RBR-duet temperature depth probe, serial number 82704. The water column was weakly stratified, with a temperature of 12.5º at the surface, decreasing to 12.0º at the depth of the sphere (19 m). The salinity was not measured and was assumed to be 35 PSU. An estimate of acoustic absorption was calculated using the formulae in Doonan et al. (2003) and an estimate of sound speed was calculated using the formulae of Fofonoff & Millard (1983).

The calibration was completed at 14:15 NZST. Richard O'Driscoll disembarked from *Aukaha* at 14:50 and *Topline* arrived back in Nelson at 15:30.

The data in the ES70 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. 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 Sa correction was calculated from:

$$S_{a,corr} = 5\log_{10}\left(\frac{\sum P_i}{4P_{\max}}\right),$$

where P_i is the sphere echo power measurement 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 $S_{a,corr}$.

A correction for the triangle wave error in ES60 data (Ryan & Kloser 2004) was also applied as part of the analysis.

Results

The mean range of the sphere and the sound speed and acoustic absorption between the transducer (about 6 m deep) and the sphere are given in Table A2.2.

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 ES70 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 root mean square (RMS) of the difference between the Simrad beam model and the sphere echoes out to 3.6° off axis was 0.21 dB (Table A2.3), indicating that the calibration was of good quality (≥0.4 dB is poor, <0.3 dB good, and <0.2 dB excellent).

Calibration coefficients in 2015 were about 0.5 dB lower than those obtained in the three *Aukaha* calibrations from 2009–13 (Table A2.3), suggesting a decline in echosounder sensitivity since 2013. Other long-term time series of echosounder calibrations have also observed gradual declines in peak gain, possibly as a function of transducer ageing (Knudsen 2009). The Sa corrections estimated from the four most recent calibrations were all within 0.06 dB (Table A2.3).

Table A2.1. ES70 transceiver settings and other relevant parameters during the calibration of *Aukaha*.

Parameter	Value
Echosounder	ES70
ES70 software version	1.1.0.0
Transducer model	ES38B
Transducer serial number	Not recorded
GPT serial number	GPT 38 kHz 009072033fc2 1 ES38B
GPT software version	Not recorded
Sphere type/size	tungsten carbide/38.1 mm diameter
Operating frequency (kHz)	38
Transducer draft setting (m)	0.0
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 (º) alongship/athwartship	7.10/7.10
Angle offset (º) alongship/athwartship	0.0/0.0

Table A2.2. Auxiliary calibration parameters derived from depth/temperature measurements.

Parameter	
Mean sphere range (m)	12.3
S.D. of sphere range (m)	0.4
Mean sound speed (m s^{-1})	1 498
Mean absorption (dB km^{-1})	9.25
Sphere TS (dB re $1m^2$)	–42.41

Table A2.3: Calculated echosounder calibration parameters for *Aukaha*. Transducer peak gain was estimated from mean sphere TS using version 7045 of ExCal Matlab calibration code.

Parameter	2015	2013	2011	2009
Mean TS within 0.21° of centre	-45.97	-44.87	-44.61	-45.02
Std dev of TS within 0.21° of centre	0.43	0.35	0.36	0.36
Max TS within 0.21° of centre	-45.34	-44.31	-44.15	-44.55
No. of echoes within 0.21° of centre	21	112	97	33
On axis TS from beam-fitting	-45.98	-44.61	-44.79	-44.82
Transducer peak gain (dB)	24.72	25.55	25.63	25.43
Sa correction (dB)	-0.67	-0.71	-0.70	–0.66
Beamwidth (º) alongship/athwarthship	6.93/7.09	6.86/6.67	6.83/6.93	7.30/7.24
Beam offset (º) alongship/athwarthship	0.11/0.14	0.00/0.00	0.00/0.00	-0.00/0.00
RMS deviation	0.21	0.21	0.22	0.16
Echoes used to estimate the beam shape	7 326	12 076	9 636	25 146

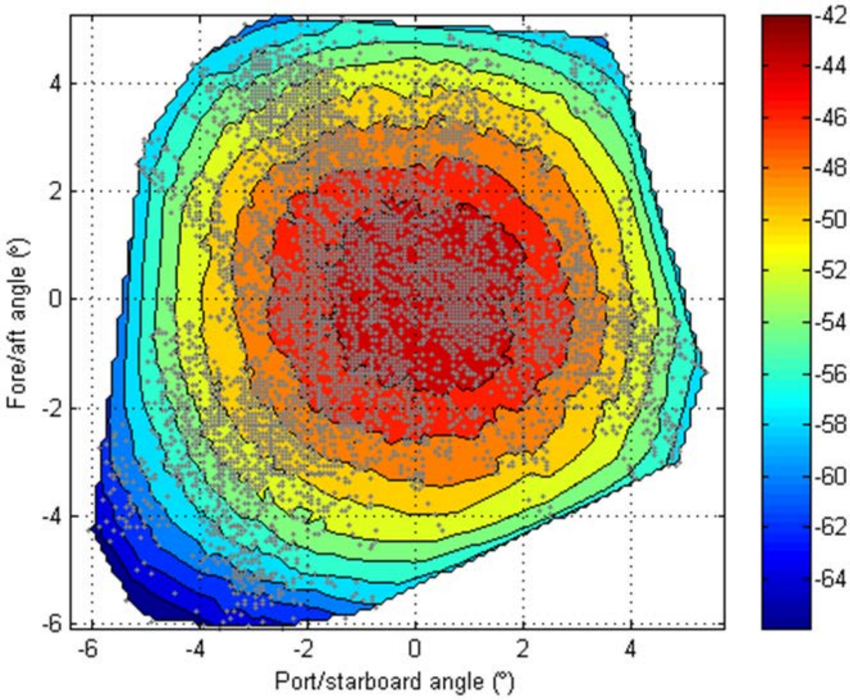


Figure A2.1. The estimated beam pattern from the sphere echo strength and position for the calibration of *Aukaha*. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

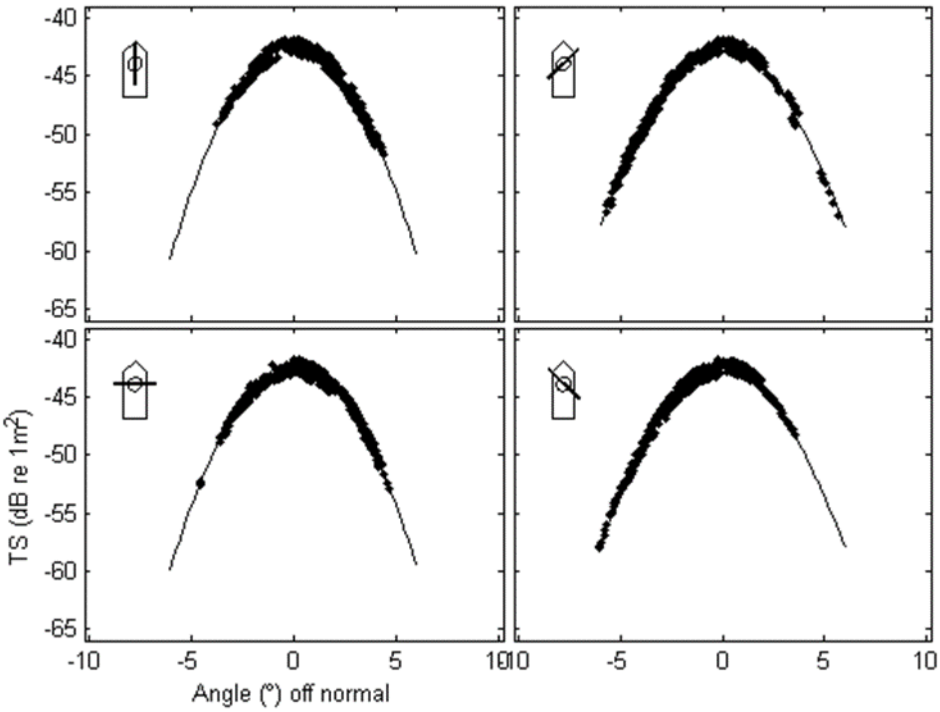


Figure A2.2. Beam pattern results from the calibration analysis for *Aukaha*. The solid line is the theoretical beam pattern fit to the sphere echoes for four slices through the beam.

APPENDIX 3: Update of WCSI acoustic time-series and *q* prior

Three different acoustic methodologies were used to estimate abundance of hoki from the 2013 west coast South Island (WCSI) hoki acoustic survey: 1) 'old'; 2) 'revised'; and 3) 'new' (O'Driscoll et al. 2015b).

The 'old' method follows O'Driscoll (2002a). It is based on the methods of Cordue (2002) updated using the target strength of Macaulay (2001) and using consistent stratum areas. This is the method currently used to calculate the WCSI time series used in recent hoki stock assessments (e.g., McKenzie 2015).

The 'revised' method updated WCSI acoustic abundance indices from 1988–2013 for changes in sound absorption, more accurately estimated stratum areas, and used the target strength to total length (TS-TL) relationship of Dunford et al (2015), derived from combined Australian and New Zealand data:

$$TS = 30.7 \log_{10}(TL) - 95.3 \qquad (A1)$$

The revised series was not accepted by the Hoki Fishery Assessment Working Group (HFAWG) in 2013 because the update ignored the effect of changing the hoki TS-TL relationship on the species decomposition of acoustic backscatter before 2000. This criticism is applicable to both the 'old' and 'revised' methods, because the TS-TL 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-TL relationship (Dunford et al. 2015) gave similar estimates of hoki TS to that of Coombs & Cordue (1995), and therefore the effect on decomposition is likely to be insignificant (O'Driscoll et al. 2015b).

The 'new' method followed current best practice based on estimating hoki composition and TS values for each sub-stratum based on research trawls. 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 estimated using the 'new' acoustic methods (O'Driscoll et al. 2015b).

At its meeting on 16 November 2015, the Deepwater Fishery Assessment Working Group agreed to adopt the TS-TL relationship of Dunford et al. (2015), derived from New Zealand only data for acoustic surveys of hoki in Cook Strait:

$$TS = 24.5 \log_{10}(TL) - 83.9 \qquad (A2)$$

Equations (1) and (2) give slightly different estimates of TS for the WCSI (Table A3.1). To ensure that the same TS-TL relationship is used for all surveys of New Zealand hoki, the 'revised' indices for the WCSI given in O'Driscoll et al. (2015b) were updated here (Table A3.2). Absolute estimates of abundance using the most recent hoki TS-TL relationship of Dunford et al. (2015) (Equation A2) were about 50% lower than those obtained using the TS-TL relationship of Macaulay (2001) (Figure A3.1). However, the choice of the TS-length relationship has relatively little impact on relative indices (Figure A3.1).

The implication for stock assessment of adopting 'revised' WCSI estimates based on the new TS-TL relationship of Dunford et al. (2015) (Table A3.2) is a change in the estimate of the acoustic q. The current prior on the WCSI acoustic survey q is lognormal with a mean (in natural space) of 0.57 and CV of 0.68 (McKenzie 2015). This was derived by O'Driscoll et al. (2002) based on the estimated bounds on each of six factors influencing the acoustic q: plateau height and timing; target strength; calibration; mark identification and species mix; acoustic availability; and areal availability (Table A3.3).

The prior on q was re-calculated in this report. Estimated bounds on three of the six factors were the same as those used by O'Driscoll et al. (2002) and assumed uniform priors on calibration, acoustic availability, and areal availability (Table A3.3). Revision of the bounds on TS was required due to the change in TS-length relationship. As for Cook Strait, TS was further divided into two contributing factors: uncertainty and tilt angle. Target strength uncertainty was the uncertainty in the fit to the TS-L relationship from bootstrapping of the hoki AOS data. This was estimated based on Dunford et al. (2015) as a uniform distribution with bounds of about ±1.5 dB (70–160% in linear space). Target strength tilt angle was the estimated bias due to the difference between the tilt angle distribution of hoki as they pass through the trawl under the AOS (approximately horizontal) and that of free-swimming hoki *in situ*. This uncertainty was derived from swimbladder models comparing the relative TS estimated using the orientation of hoki measured on the AOS (mean tilt 3° s.d. 14°) with the estimated TS from hoki with tilt angles observed *in situ* on the WCSI by Dunford et al. (2015) (mean tilt -1° s.d. 26°) and in Cook Strait by Coombs & Cordue (1995) (mean tilt 12° s.d. 29°). The estimated TS was 2.9 dB lower for the tilt distribution observed by Dunford et al. (2015) and 4.0 dB lower for the tilt distribution of Coombs & Cordue (1995). We assumed a uniform uncertainty distribution with a range of 0–6 dB (25–100% in linear space), and a 'best guess' of 3 dB (50% in linear space) (Table A3.3). Rather than using the bounds and assuming uniform distribution for plateau height and timing and mark identification and species mix, the distributions from simulations of uncertainty from all previous surveys (Figure A3.2) were re-sampled directly to generate the prior.

The 'best guess' estimates for each factor were derived as the medians from simulations (e.g., for plateau height and timing) or from other prior information. Uncertainties were combined to create the prior on *q* using the basic procedure of Cordue (1996) as implemented in R.

The re-calculated prior for the WCSI acoustic *q* had lognormal parameters with a mean of 0.39 and CV of 0.77. The new prior is plotted and compared to the previous prior in Figure A3.3.

Table A3.1: Estimates of the ratio *r* for converting hoki acoustic backscatter to biomass using acoustic TS derived from commercial length frequency data using the TS-length relationships of Macaulay (2001) and Dunford et al. (2015) (Equations A1 and A2). Estimates based on Macaulay (2001) were used to generate the 'old' time-series of hoki abundance estimates currently used in assessment. Estimates based on Dunford et al. (2015) Equation A1 (combined New Zealand and Australian AOS data) were used to generate the 'revised' time-series by O'Driscoll et al. (2015b). Estimates based on Dunford et al. (2015) Equation A2 (New Zealand AOS data only) were used to generate the 'revised' series in Table A3.2

			Macaulay (2001)		Dunford et al. (2015) Equation A1		Dunford et al. (2015) Equation A2	
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	-36.5	7 367	-37.0	8 272
1989	81.6	1.67	-39.5	15 006	-36.5	7 372	-36.9	8 263
1990	81.9	1.69	-39.5	15 073	-36.4	7 365	-36.9	8 279
1991	80.5	1.63	-39.6	14 967	-36.5	7 370	-37.0	8 261
1992	79.3	1.54	-39.8	14 600	-36.8	7 403	-37.2	8 175
1993	78.2	1.49	-39.9	14 400	-37.0	7 421	-37.4	8 128
1997	74.1	1.31	-40.3	13 861	-37.6	7 458	-37.9	8 016
2000	80.3	1.59	-39.7	14 763	-36.7	7 390	-37.1	8 211
2012	75.4	1.37	-40.1	14 090	-37.4	7 438	-37.7	8 070
2013	79.1	1.56	-39.8	14 728	-36.8	7 388	-37.2	8 209

Table A3.2: Recalculated acoustic abundance indices for WCSI. Indices using the 'old' method are those currently used in assessment. Indices using the 'revised' method are based on O'Driscoll et al. (2015b) but updated using the hoki TS of Dunford et al. (2015) Equation A2 instead of Equation A1.

	'Old'		'Revised'	
Year	Abundance ('000 t)	CV	Abundance ('000 t)	CV
1988	417	0.60	266	0.60
1989	249	0.38	165	0.38
1990	255	0.40	169	0.40
1991	341	0.73	227	0.73
1992	345	0.49	229	0.49
1993	549	0.38	380	0.38
1997	655	0.60	445	0.60
2000	397	0.28	263	0.28
2012	412	0.34	283	0.34
2013	357	0.35	233	0.35

Table A3.3: Estimated bounds on factors influencing acoustic *q* for the WCSI Lower and upper bounds from O'Driscoll et al. (2002) used in the old prior are given in parentheses. Target strength parameters were changed due to the change to a new TS-length relationship based on AOS measurements (see text for details). Bounds on plateau height and timing and mark identification and species mix were based on 95% confidence intervals of distributions from simulations from all previous WCSI surveys (see Figure A3.2). "Best guess" estimates are medians based on simulations or other prior knowledge.

Factor	Lower bound	Upper bound	Best guess
Plateau height and timing	0.19 (0.25)	0.98 (1.00)	0.78
Target strength: uncertainty	0.70 (0.50)	1.60 (2.00)	1.00
Target strength: tilt angle	0.25	1.00	0.50
Calibration	0.88 (0.88)	1.12 (1.12)	1.00
Mark identification and species mix	0.64 (0.60)	2.23 (1.60)	0.99
Acoustic availability	0.80 (0.80)	0.95 (0.95)	0.90
Areal availability	0.60 (0.60)	0.90 (0.90)	0.80
Product (overall bounds)	**0.01 (0.03)**	**3.35 (3.10)**	**0.28**

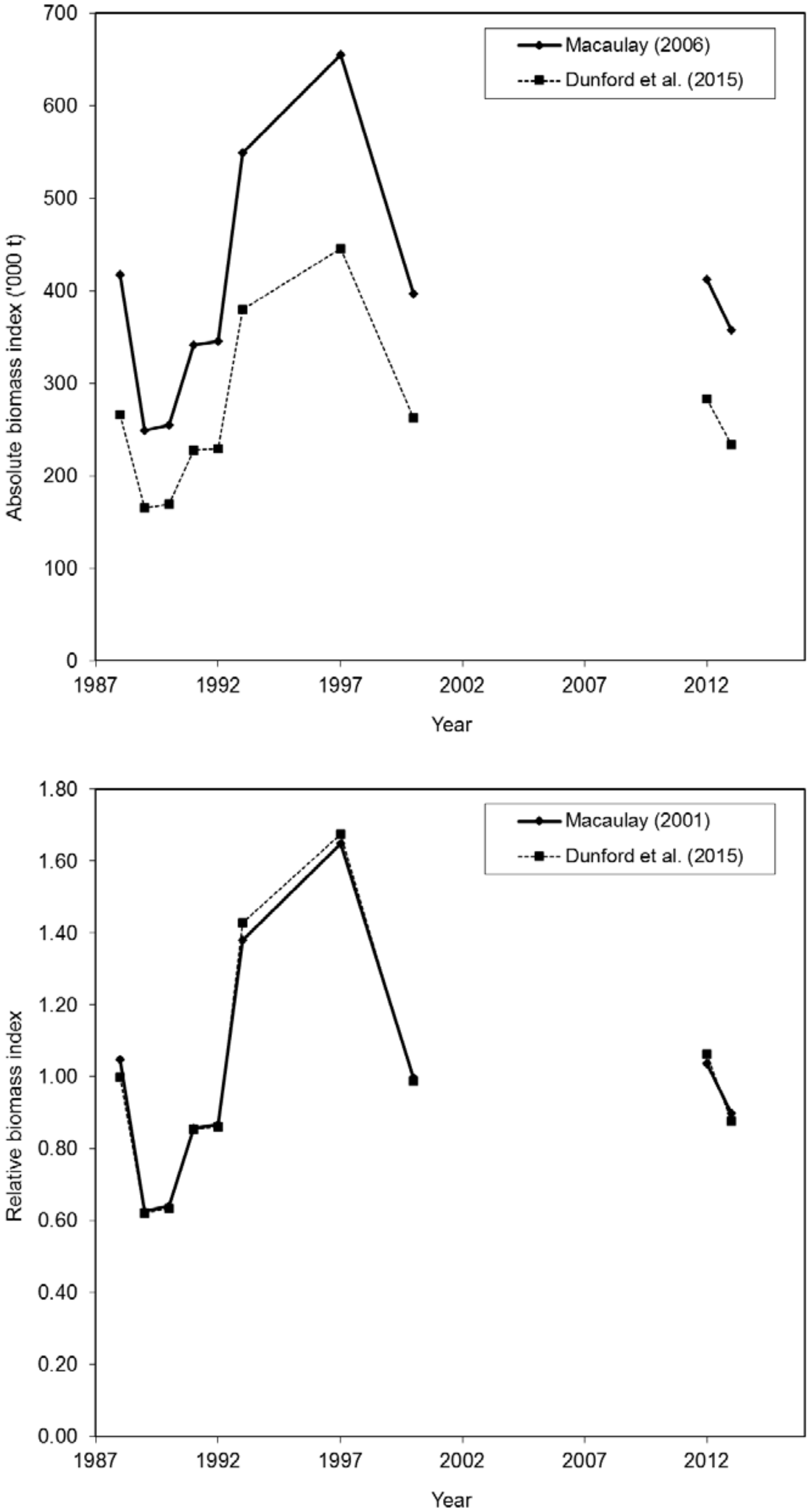


Figure A3.1: Comparison of absolute (upper panel) and relative (lower panel) time series of acoustic abundance estimates for spawning hoki on the WCSI estimated with the TS-length relationship of Macaulay (2001) and the new TS-length relationship derived from New Zealand AOS data (Dunford et al. 2015).

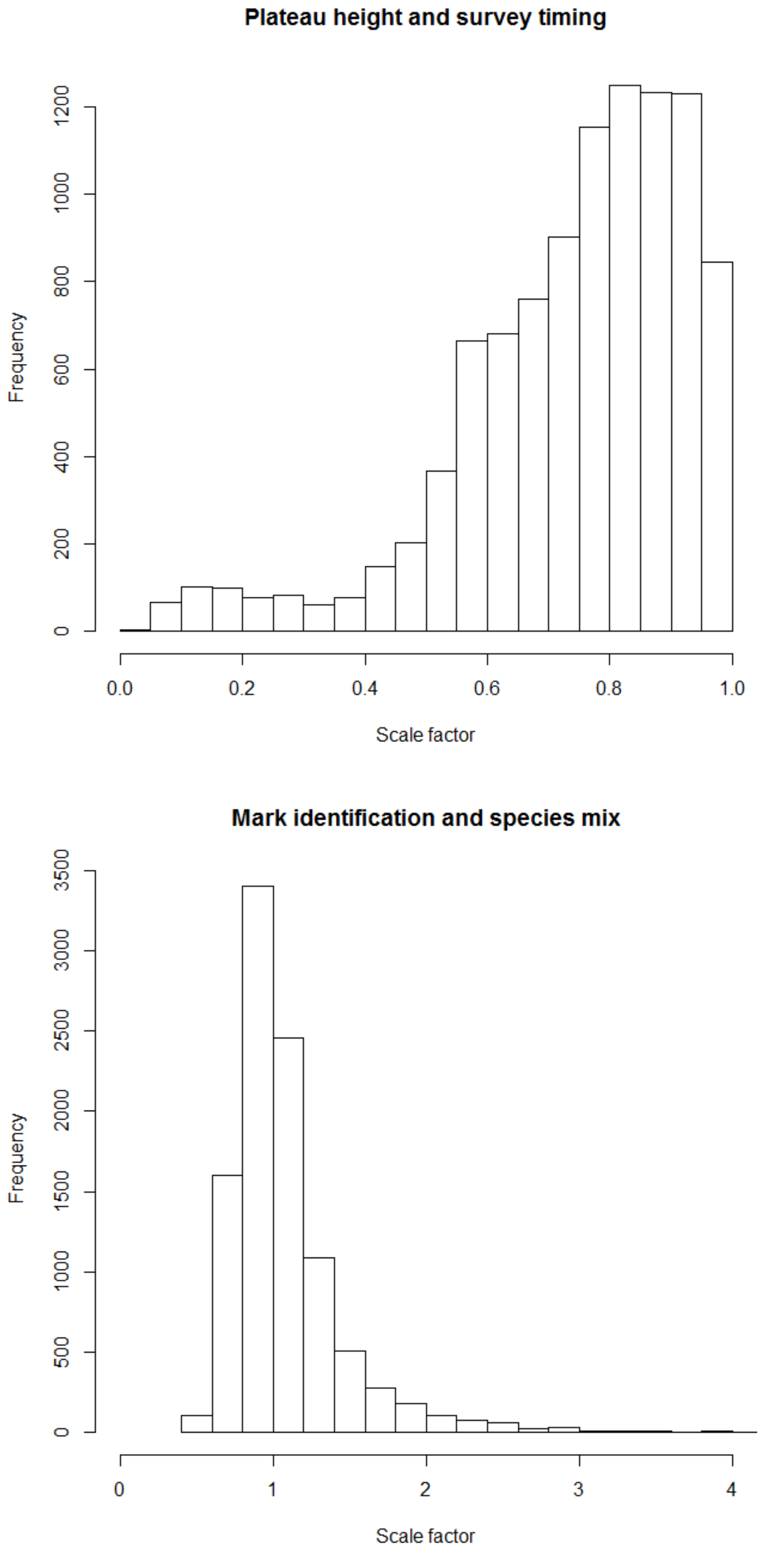


Figure A3.2: Distributions of survey scale factors associated with plateau height and survey timing and mark identification and species mix estimated from simulations of uncertainty from all previous WCSI surveys surveys. These distributions were used to generate priors on acoustic *q* (see Table A3.3)

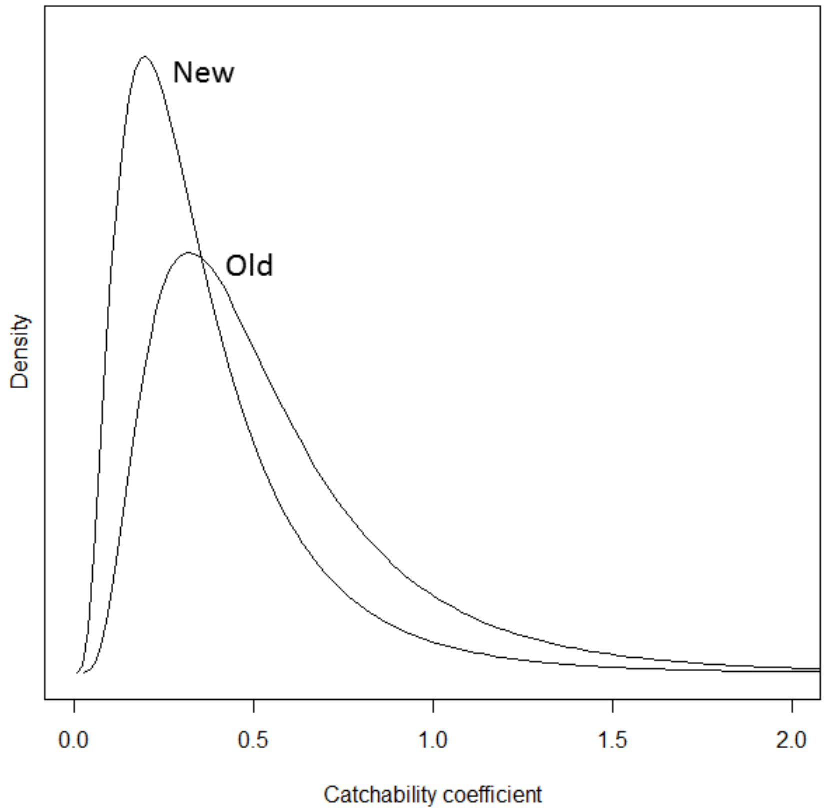


Figure A3.3: Estimated prior for acoustic *q* in WCSI estimated in this report ('New') and compared to the existing prior ('Old').