Ministry for Primary Industries
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Acoustic survey of spawning hoki in Cook Strait during winter 2011

New Zealand Fisheries Assessment Report 2012/17

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ISSN 1175-1584 (print)
ISSN 1179-5352 (online)
ISBN 978-0-478-38845-9 (online)

May 2012

New Zealand Government

Growing and Protecting New Zealand

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EXECUTIVE SUMMARY

O'Driscoll, R.L. (2012). Acoustic survey of spawning hoki in Cook Strait during winter 2011.

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An acoustic survey of spawning hoki abundance in Cook Strait was carried out from the industry vessels FV *Thomas Harrison* and FV *Independent 1* from 18 July to 27 August 2011. Four snapshots were completed from *Thomas Harrison* and two snapshots were carried out from *Independent 1* in three separate voyages into Cook Strait (IND1101, THH1102, THH1103). Acoustic data collection was supervised by vessel officers, but a NIWA staff member was on board *Thomas Harrison* for one trip from 10–24 August to direct mark identification trawling. During this trip, three acoustic snapshots were carried out, and biological data were collected from 27 trawls, including 7 mark identification tows and 20 commercial tows.

All six snapshots met the criteria for estimating hoki abundance, but the first two snapshots were incomplete because stratum 5B was not surveyed in either snapshot. Acoustic data in snapshot 3 was inadvertently collected using a 2.048 ms pulse length (instead of the recommended 1.024 ms), but this was corrected for in calibration. Acoustic data in snapshot 6 were collected using a ping interval of 4 s instead of the recommended 2 s, but this should not bias abundance estimates. All snapshots were completed within the maximum of 72 hours and five (all except snapshot 2) were completed within the recommended 48 hours. All transects in strata 2 and 5A were carried out sequentially to avoid potential bias due to fish movement. All transects were carried out in suitable weather conditions, and there was no interference from other acoustic instruments.

Estimates of hoki abundance were sensitive to the length frequency data used to calculate the ratio of hoki weight to acoustic target strength. Estimates calculated using the length frequency from the 2011 commercial fishery (which was poorly sampled) ranged from 172 000 t (c.v. 23%) on 18–19 July to 478 000 t (c.v. 53%) on 20–21 August, with an average estimate over the six snapshots of 300 000 t. Estimates calculated using an average ratio of hoki weight to target strength were about 10% lower, ranging from 154 000 t to 429 000 t, with an average of 269 000 t. The survey weighting (expressed as a coefficient of variation, c.v.) for the industry survey, which includes uncertainty associated with survey timing, sampling precision, acoustic detectability, mark identification, calibration, target strength, and the missing stratum in the first two snapshots was 35%.

About 66% of the hoki biomass in Cook Strait in 2011 was from hoki schools. Commercial trawls on hoki schools caught an average of 95% hoki by weight (20 trawls sampled, range 67–100%). The remaining hoki biomass came from hoki 'fuzz' marks that also contained other species. The proportion of hoki by weight from the two successful research trawls on pelagic fuzz marks in outer Cook Strait Canyon was 85% and 98% respectively. There was also a high proportion (90–98%) of hoki and relatively high catch rates in three research trawls on bottom fuzz marks in the Narrows Basin.

Hoki from the Narrows Basin were predominantly male and were much smaller (mean length 63 cm) than hoki from the main Cook Strait Canyon (mean length 79 cm), where commercial catches were dominated by females. Gonad staging showed that fish were actively spawning on 10–24 August.

1. INTRODUCTION

The hoki fishery is New Zealand's largest finfish fishery with a total allowable commercial catch (TACC) of 120 000 t in 2010/11 increasing to 130 000 t from 1 October 2011. Although managed as a single stock, hoki are assessed as two stocks, western and eastern. The current hypothesis is that juveniles from both stocks mix on the Chatham Rise and recruit to their respective stocks as they approach sexual maturity. The western stock spawns from mid-July to late August on the west coast of the South Island (WCSI). The eastern stock spawns mainly in Cook Strait.

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 biomass estimation using acoustics. 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 inputs into hoki stock assessments for 20 years (e.g. O'Driscoll 2002a).

The 10-year Deepwater Research Plan proposes acoustic surveys of the Cook Strait hoki spawning grounds every two years to update the biomass 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.

Previous acoustic surveys of Cook Strait were carried out on research vessels annually from 1991–2008 (except in 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 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). A continuation of this approach was used in 2011 and the main fishing grounds in Cook Strait were surveyed throughout the spawning season from 15 July to 31 August. The 2011 survey described here extends the time series of Cook Strait acoustic indices used in the stock assessment (1991, 1993–99, 2001–03, 2005–09) from 16 to 17 points.

This report fulfils the reporting requirements for Objectives 1 and 2 of Ministry of Fisheries Research Project HOK2010/03A:

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 (c.v.) 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 (Figure 1). 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 biomass 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 Simrad ES60 and ES70 echosounders with a hull-mounted split-beam 38 kHz transducer, and has been used successfully to carry out research surveys of orange roughy on the Challenger Plateau in 2005, 2006, 2009, 2010, and 2011 (e.g., Clark et al. 2005), and hoki in Cook Strait in 2007, 2008, and 2009 (O'Driscoll & Dunford 2008, O'Driscoll & Macaulay 2009, 2010). *FV Independent 1* is a 45.6 m freezer trawler. *FV Independent 1* is also fitted with a Simrad ES60 echosounder and hull-mounted split-beam 38 kHz transducer, and has been 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 (O'Driscoll & Macaulay 2010), 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 during the survey period using standard scientific methods (MacLennan & Simmonds 1992). The ES60 on *Independent 1* was calibrated in Tasman Bay on 25 July 2011, and the ES70 on *Thomas Harrison* was calibrated off Cape Campbell on 15 August 2011. Calibration reports are provided as Appendices 1 and 2. Both calibrations were of good quality and indicated that the echosounders were functioning correctly. Results were also available from an earlier calibration of *Thomas Harrison* carried out on 17 July 2011, as part of the Challenger orange roughy survey. We used the mean of these two calibration values from *Thomas Harrison* (see Appendix 2) for this analysis.

2.3 Acoustic data collection

NIWA provided start and finish positions for six snapshots, each consisting of 28 random transects in the six strata (see Table 1). On two of the three trips, acoustic snapshots were carried out by vessel officers between commercial fishing operations with no scientific staff onboard.

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, sonars etc 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.
- We require some estimate of species composition, hoki size, and spawning condition in commercial catches, from an onboard observer (to estimate target strength) in addition to the requirement for targeted mark identification trawling (see Section 2.4).
- The ES60 or ES70 echosounder needs to be set-up using our scientific 'hoki' settings (key ones are power = 2000 W, pulse length = 1.024 ms, ping interval = 2 seconds, but 3 seconds is OK if you start to get 'ping interval warning' messages in deeper water, GPS position integrated into acoustic file).
- To generate a biomass index with a reasonable c.v. we need 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 seven targeted mark identification trawls were carried out on the trip on *Thomas Harrison* from 10–24 August, when the NIWA staff member was on board.

Mark identification and commercial trawls 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 cod-end was fitted for 6 of the 7 designated research tows. This is smaller than the mesh size legally required for hoki trawling (100 mm). The first research trawl and 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.

Estimated hoki length frequencies were constructed for each stratum by using all trawls within a stratum during the period of the survey, and weighting individual trawl length frequencies by the hoki catch in the trawl.

2.5 Other data collection

A Seabird SM-37 Microcat CTD datalogger (serial number 2958) was mounted on the headline of the net during the seven targeted research trawls to collect temperature and salinity data to estimate the acoustic 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}). 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)

$$w = (4.79 * 10^{-6})\, L^{2.89} \qquad (1)$$

3. using the most recent TS-length relationship for hoki (Macaulay 2006):

$$TS = 12.2 \log_{10}(L) - 63.9 \qquad (2)$$

where L 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 2011.

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

2.8 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 c.v.) used in the hoki stock assessment model are calculated for individual surveys using a Monte Carlo procedure which incorporates these additional uncertainties (O'Driscoll 2002a, 2004).

The simulation method used to combine uncertainties and estimate an overall weighting (c.v.) for each acoustic survey of Cook Strait was described in detail by O'Driscoll (2002a, 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 is created for each of the variables of interest. Second, random samples from each of the probability distributions are selected and combined multiplicatively in Monte Carlo simulations of the process of acoustic abundance estimation.

In each simulation 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 c.v., 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 c.v. was the standard deviation of the 1000 abundance (mean biomass) indices divided by their mean.

3. RESULTS

3.1 2011 Cook Strait fishery

A total catch of 11 638 t was taken from Cook Strait between 1 June and 30 September 2011, with most hoki caught between 11 July and 10 September (Figure 2). The acoustic survey was within the period of high catches. The hoki length frequency from the 2011 commercial fishery in Cook Strait based on scientific observer data and data from NIWA collected for this project is shown in Figure 3. The mean length of hoki was 79.1 cm (Table 4). Mean weight and mean backscattering cross-section (obtained by transforming the scaled length frequency distribution in Figure 3 by equations (2) and (3) and then calculating the means of the transformed distributions) were 1.63 kg and 0.0000845 m^2 (equivalent to –40.7 dB) respectively, giving a ratio, *r*, for 2011 of 19 259 kg m^{-2} (Table 4). This ratio was 15–20% higher than in recent Cook Strait surveys because the mean size of fish estimated from the commercial catch was larger (Table 4). This increase in mean length was primarily due to a decrease in the proportion of (smaller) males in the estimated catch (62% male in 2009 compared to 38% male in 2011).

There was considerable uncertainty associated with the estimated size distribution of the commercial catch from Cook Strait in 2011 because of poor observer sampling (Sira Ballara, NIWA, pers. comm.). At its meeting on 8 March 2012, the Hoki Fishery Assessment Working Group agreed to calculate two alternative series of acoustic indices for Cook Strait: one series based on annual *r* values calculated from the commercial length frequency from the year of the survey, as has been done in the past (see Section 2.6); and the other series calculated using the same *r* value for all surveys in the time-series. The assumed constant for *r* was the mean value from the individual surveys of 17 256 kg m^{-2} (Table 4).

3.2 Data collection

3.2.1 Acoustic data

Six acoustic snapshots were completed: two from *Independent 1*; and four from *Thomas Harrison* (see Table 3). Acoustic data collection was supervised by vessel officers, but a NIWA staff member (Richard O'Driscoll) was on board *Thomas Harrison* for one trip from 10–24 August to direct mark identification trawling (see Section 3.2.2). This 15-day trip was longer than the 10 days originally planned because there was a major southerly storm from 14–18 August (the 'big snow' in Wellington) and the vessel was forced to seek shelter for much of this period. During this trip, three acoustic snapshots were carried out (Table 3).

All six snapshots met the criteria for estimating hoki abundance (see Section 2.3), but the first two snapshots were incomplete because stratum 5B was not surveyed in either snapshot. This issue was not brought to our attention in two phone conversations between the vessel skipper and Richard O'Driscoll on 13 and 21 July. One line in stratum 1 (Narrows Basin) was not completed in snapshot 1 because there was a vessel in the way.

All snapshots were completed within the maximum of 72 hours and five (all except snapshot 2) were completed within the recommended 48 hours. All transects in strata 2 and 5A were carried out sequentially to avoid potential bias due to fish movement. All transects were carried out in suitable weather conditions, and there was no interference from other acoustic instruments.

Echosounder settings generally followed NIWA recommendations. Acoustic data in snapshot 3 was inadvertently collected using a 2.048 ms pulse length (instead of the recommended 1.024 ms), but this was corrected for in calibration (see Appendix 3). Acoustic data in snapshot 6 were collected using of ping interval of 4 s instead of the recommended 2 s, but this should not bias abundance estimates.

There was an 18 day gap during the peak season (24 July to 10 August) when no acoustic data were collected (see Table 3). This was because both survey vessels were fishing on the WCSI during this period.

3.2.2 Trawl data

Seven hoki midwater tows were carried out for mark identification in Cook Strait during the trip on *Thomas Harrison* from 10–24 August, but only five were suitable for estimating mark composition (Table 5, Figure 4). The trawl was tangled during tow 4 in stratum 3, so the catch was not representative. Tow 22 in stratum 6 missed the targeted mark. Of the five successful tows, three were in the Narrows Basin (stratum 1), and two in outer Cook Strait Canyon (strata 5A and 5B). Hoki made up 95% of the total catch from mark identification trawls (Table 6). Bycatch species included jack mackerels (mainly *Trachurus declivis*), spiny dogfish, ling, rattails, red cod, school shark, and rattails.

A further 20 commercial tows were also sampled, with a total catch of 174 t (see Table 5). Another 16 commercial trawls were not measured because the one NIWA person on board *Thomas Harrison* was unable to cover 24-hour operations. The original intention was that there would also be an observer on board on this trip, but this did not happen because of space limitations on the vessel.

A total of 2785 hoki were measured for length, sex and macroscopic gonad stage. Otoliths were collected from 100 hoki.

There was no observer coverage to provide biological sampling during the first two snapshots on *Independent 1*.

3.2.3 CTD data

Seven CTD profiles were obtained in conjunction with mark identification trawls. The average water temperature in Cook Strait over the entire depth range was 10.9 ºC, with an average salinity of 34.7 PSU. Estimates of sound absorption from individual CTD profiles in 2011 ranged from 8.96 to 9.30 dB km^{-1}, with an average of 9.12 dB km^{-1}. This was very similar to the average sound absorption estimated in Cook Strait in 2006 (9.09 dB km^{-1}, O'Driscoll 2007) and 2008 (9.10 dB km^{-1}, O'Driscoll 2009).

3.3 Mark identification

Marks were similar to those observed in Cook Strait in 2001–09. Example echograms of some of these mark types are shown in Figures 5–9. Further examples are provided by O'Driscoll (2002b, 2003a, 2007, 2009), O'Driscoll & Dunford (2008), and O'Driscoll & Macaulay (2009, 2010).

1. Hoki schools
Hoki schools were characterised by relatively dense marks with clearly defined edges, typically occurring in 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 the head of Cook Strait Canyon in 2011 (e.g., Figure 5), but hoki schools were also observed in outer Cook Strait Canyon (e.g., Figure 6), in Nicholson Canyon, and over the Terawhiti Sill (e.g., Figure 7). All commercial trawls were targeted at hoki schools in Cook Strait Canyon (see Figure 4) and caught an average of 95% hoki by weight (see Table 5).

2. Hoki bottom fuzz
Hoki bottom fuzz occurred as bottom-referenced layers, sometimes extending more than 50 m above the seabed, and usually in water depths shallower than 300 m. This mark type was commonly observed in the Narrows Basin (e.g., Figure 8) and over the Terawhiti Sill (e.g., Figure 7). The three mark identification trawls on bottom fuzz marks in the Narrows Basin in 2011 caught a high proportion (90–98%) of hoki (see Table 5).

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 2011, these marks were common in outer Cook Strait Canyon (e.g., Figure 6), and in the deepwater between Cook and Wairarapa Canyons (e.g., Figure 9). The proportion of hoki by weight from the two successful research trawls on pelagic fuzz marks in outer Cook Strait Canyon was 85% and 98% respectively (see Table 5).

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 2011 adjacent to Cook Strait Canyon (e.g., Figure 6). Previous research trawling on this mark type has 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 8). Previous research trawling on this mark type has caught mainly jack mackerel and few hoki.
6. Pelagic layers
Strong surface-referenced pelagic layers usually occurring from 0 to 300 m, and exhibiting strong diurnal vertical migration patterns. Pelagic layers were widespread throughout the survey areas, e.g., Figures 7 and 8), and occurred right through Cook Strait Canyon during snapshot 4 immediately following a

southerly storm (e.g., Figure 5). Targeted trawling on this mark type in the past has 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 consisting of small schools and single targets at depths of 100–200 m, above hoki schools. Midwater spiny dogfish marks are often observed in Cook Strait Canyon, but were not conspicuous during the 2011 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 has been a change in the proportion of hoki in fuzz marks over time (as was 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 10). The distribution of hoki was generally similar to that observed in previous research and industry surveys in 2001–09 (O'Driscoll 2002b, 2003a, 2006, 2007, 2009, O'Driscoll & McMillan 2004, O'Driscoll & Dunford 2008, O'Driscoll & Macaulay 2009, 2010). Hoki densities were highest in Cook Strait Canyon. Fish were concentrated in the head (northern end) of the canyon during snapshots 3 and 4 on 11–21 August, but were more spread out through the canyon in the earlier and later snapshots (Figure 10). High densities of hoki were also detected in the outer Cook Strait canyon (stratum 5A) in some snapshots (e.g., see Figure 6).

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 9) and densities in this area were relatively low (Figure 10). Acoustic densities were also generally low in the Narrows Basin (stratum 1) and over the Terawhiti Sill (stratum 6), and almost all the backscatter from these areas was from bottom fuzz marks (e.g., see Figure 8). Densities were higher over the Terawhiti Sill in snapshot 4, when some hoki schools were present in this stratum (see Figure 7). No dense marks were observed in Nicholson Canyon (stratum 3) during the 2011 survey (Figure 10). This contrasts with some earlier surveys when hoki schools were abundant in this stratum.

3.5 Hoki size and maturity

Although the number of mark identification trawls in 2011 was low (only five successful tows), there appeared to be variation in hoki length frequencies between these tows and those from commercial trawls in the main Cook Strait Canyon (Figure 11). Hoki from the Narrows Basin were predominantly male and were much smaller (mean length 63 cm) than hoki from the main Cook Strait Canyon (mean length 79 cm), where commercial catches were dominated by females. The few fish sampled from strata 5A and 5B were also mainly female, with mean length 69 cm (Figure 11).

Gonad staging showed that fish were actively spawning on 10–24 August, with the percentage of spent fish increasing during this period (Figure 12).

3.6 Hoki abundance estimates

Hoki abundance estimates by snapshot and strata are given in Table 7 and plotted in Figure 13. Estimates of hoki abundance using the value of *r* calculated for 2011 ranged from 172 000 t (c.v. 23%) in snapshot 1 on 18–19 July to 478 000 t (c.v. 53%) in snapshot 4 on 20–21 August. There was a large drop in estimated biomass between snapshot 4 and snapshot 5, only two days later (Figure 13). It is unlikely that hoki abundance decreased by a factor of two over this period, and the difference between individual snapshots probably includes variability due to transect location (sampling design) and fish behaviour (e.g., changes in TS) as well as changes in abundance. One or two very high snapshots have also been observed in previous surveys, most recently in 2006 and 2007 (Figure 14). Sampling precision (c.v.) of individual snapshots ranged between 23 and 53% (Table 7).

When results from Table 7 were averaged over all snapshots, 68% of the hoki biomass was in stratum 2, 12% in stratum 1, 8% in stratum 5B, 5% in stratum 5A, and 3% in stratum 6, and 2% in stratum 2. Hoki densities in strata 1 and 5B were generally low (see Figure 10), and the importance of these strata to the overall biomass was due to their relatively large areas. The contribution of biomass from outside Cook Strait Canyon (stratum 2) may also be overestimated because most of the estimated biomass in the other strata was from hoki fuzz marks which contain other species (Table 8).

The average proportion of the biomass from hoki schools in 2011 was 66% (Table 8). This was within the range recorded in previous surveys in the time series (30–74% of hoki in schools). Most (95%) of the hoki observed in stratum 2 were in schools (Table 8). Hoki schools were also observed in stratum 3, 5A, and 6. As in previous surveys, changes in abundance over the survey period were driven mainly by changes in the biomass of hoki schools (see Figure 13). The biomass from hoki fuzz marks remained relatively constant between 57 000 and 113 000 t throughout the survey period.

Estimates from all snapshots were averaged to obtain the overall acoustic abundance index. All six snapshots in 2011 were within the period of peak commercial catches (see Figure 2), and within the period of previous surveys (see Figure 14). There has been no obvious trend in the timing of peak biomass estimates from previous acoustic surveys to suggest that the main spawning season (plateau interval) has shifted over time (Figure 14). The sampling c.v. for the survey varied depending on which of the two methods was used to calculate variance. The average of the snapshot variances was 18%. The variance of the abundance estimates from the seven snapshots was 15%.

3.7 Survey weighting for stock assessment

The overall survey weighting estimated from the Monte Carlo simulation model for Cook Strait was 0.35 (Table 9). As in previous Cook Strait surveys (O'Driscoll 2004), timing (including uncertainties about plateau timing and residence time) and mark identification were the major sources of uncertainty (Table 9). Uncertainties due to calibration, detectability, TS, and using an estimate for stratum 5B in the first two snapshots contributed relatively little to the overall c.v. However, incorrect choice of TS and calibration coefficients do have potential to introduce bias, which is not reflected in the c.v. in Table 9 (see Section 4).

4. DISCUSSION

Six acoustic snapshots of the Cook Strait spawning grounds were completed from the industry vessels *Thomas Harrison* and *Independent 1* during winter 2011. All of these snapshots were suitable for biomass estimation, despite snapshots 1 and 2 being incomplete, and corrections being required for echosounder settings in snapshot 3. Survey timing was appropriate, although there was an 18-day gap during the peak season (24 July to 10 August) when no acoustic data were collected because of unavailability of vessels. All six snapshots were averaged to obtain the abundance index for 2011.

There was considerable uncertainty associated with the estimated size distribution of the commercial catch from Cook Strait in 2011 because of poor observer sampling. Following the recommendations of the Hoki Fishery Assessment Working Group, two alternative series of acoustic indices were calculated for Cook Strait: one series was based on annual r values using the commercial length frequency from the year of the survey; and the other series was calculated using the same r value for all surveys in the time-series (see Table 4). Both time series of acoustic indices of hoki abundance in Cook Strait are given in Table 10 and plotted in Figure 15.

The abundance index for 2011, calculated using the length frequency from the 2011 commercial fishery, was 300 000 t, which was 5% lower than the equivalent index from the 2009 industry survey, but higher than estimates from 2003 to 2008, and above average for the overall time-series (Table 10). The abundance index for 2011, calculated using a constant r value, was 269 000 t which was 19% lower than the equivalent index from 2009 and near average for the time series (Table 10). The overall c.v.s were the same for both alternative series. The c.v. of the 2011 estimate (35%) was higher than that estimated for the most recent research survey in 2008 (c.v. 30%) because of the 18-day gap in sampling during the (theoretical) peak season. However, the c.v. of the 2011 survey was at the lower end of the range estimated for previous surveys in the time series (30–91%) and lower than that estimated from the industry surveys in 2007 and 2009 (Table 10).

The survey approach in 2011, using industry vessels rather than a dedicated research vessel, required compromises between scientists and industry participants. The requirement to complete an entire snapshot within 48 hours and to run all transects in the main Cook Strait Canyon (strata 5A and 2) involves considerable investment and commitment on the part of the vessel, 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 need to be suspended to collect acoustic data.

A major limitation of previous acoustic surveys of Cook Strait from industry vessels 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 (see Table 8), but which are not usually targeted commercially because of low fish density. This was addressed in 2011 with provision in the survey design for a limited number of mark identification trawls with a scientist present on board. 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 have differed from those in snapshots at the start and end of the spawning period. However, we believe that the risks are reduced by having at least some dedicated mark identification tows.

O’Driscoll (2009) noted that trawling on hoki fuzz mark types with a variety of gears is required to help improve estimates of species composition. Although the number of trawls in 2011 was small, it was interesting to note that the proportions of hoki in both bottom fuzz and pelagic fuzz marks with the *Thomas Harrison* midwater trawl were somewhat higher than the proportion of hoki in similar marks sampled with the smaller *Kaharoa* trawl (e.g., O’Driscoll 2009). It will be important to retain mark identification trawling on future surveys.

Very recent work by Kloser et al. (2011) on the acoustic target strength (TS) of hoki (blue grenadier) in Australia raises concern that acoustic estimates based on the TS-length relationship of Macaulay (2006) may overestimate hoki biomass. Kloser et al. (2011) collected optically verified *in situ* measurements of hoki and found that the TS was considerably higher than that predicted by equation (2). They provide a TS-to-standard length (SL) relationship for hoki of:

$$TS = 25.4 \log_{10}\mathrm{SL} - 81.5 \qquad (3)$$

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 *r* which are only 25–30% of those obtained using the TS-length relationship of Macaulay (2006) (see Table 4), and consequently a much lower hoki biomass (Table 10). Because the alternative TS-length relationships in equations (1) and (3) have different slopes, there is potential to bias relative indices of abundance where the size of hoki varies between surveys. However, the length of hoki caught in Cook Strait has been quite similar over the acoustic time-series (see Table 4), and the choice of the TS-length relationship has relatively little impact on relative indices when values of *r* are calculated annually (Figure 16), and no impact if a constant value of *r* is used for the whole series. The implication for stock assessment of adopting the new TS-L relationship of Kloser et al. (2011) would be a change in the estimate of the acoustic *q*. This would also force us to reconsider our interpretation of, and priors on, *q* because in some years (e.g., 1996, 1998) the catch from Cook Strait exceeded the acoustic abundance estimate using the Kloser et al. (2011) TS (Table 10). This would only be possible if the turnover of fish on the spawning grounds is much quicker than currently estimated (Harley 2002). Target strength experiments on hoki using the acoustic-optical system (AOS) proposed for July-August 2012 on the west coast South Island should help to reconcile the very large difference in TS estimates for hoki.

5. ACKNOWLEDGMENTS

Thanks to Justin Rillstone, Roger Connolly, and Ted Goomes and the crew of *Independent 1* and *Thomas Harrison* for their assistance. Bill Healey (Sealord) provided logistic support. Thanks also to John Cleal (Deepwater Group Ltd) who provided the 60 mm codends used for research tows and to Mike Soule (Fisheries Resource Surveys Ltd) for supplying calibration data collected as part of the Challenger orange roughy survey. This work was funded by the Ministry of Fisheries (Project HOK2010/03A). Oliver Ross reviewed a draft of this report.

6. REFERENCES

Clark, M.; O'Driscoll, R.L.; Macaulay, G. (2005). Distribution, abundance, and biology of orange roughy on the Challenger Plateau: results of a trawl and acoustic survey, June–July 2005 (THH0501). NIWA Client Report WLG2005-64 prepared for The Orange Roughy Management Company Limited, October 2005. 60 p.

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

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

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

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

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

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

Harley, S.J. (2002). Estimation of residence time for hoki on the Cook Strait and west coast South Island spawning grounds. *New Zealand Fisheries Assessment Report 2002/1*. 55 p.

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

Kloser, R.J.; Ryan, T.E.; Macaulay, G.J.; Lewis, M.E. (2011). *In situ* measurements of target strength with optical and model verification: a case study for blue grenadier, *Macruronus novaezelandiae*. *ICES Journal of Marine Science 68*: 1986–1995.

Knudsen, H.P. (2009). Long-term evaluation of scientific-echosounder performance. *ICES Journal of Marine Science 66*: 1335–1340.

Livingston, M.E. (1990). Spawning hoki (*Macruronus novaezelandae* Hector) concentrations in Cook Strait and off the east coast of the South Island, New Zealand, August–September 1987. *New Zealand Journal of Marine and Freshwater Research 24*: 503–517.

Macaulay, G.J. (2006). Target strength estimates of hoki. Final Research Report for Ministry of Fisheries Project HOK2004/03 Objective 3. 13 p. (Unpublished report held by MPI, Wellington)

MacLennan, D.N.; Simmonds, E.J. (1992). Fisheries acoustics. Chapman & Hall, London. 325 p.

McNeill, E. (2001). ESP2 phase 4 user documentation. NIWA Internal Report 105. 31 p. (Unpublished report held in NIWA library, Wellington.)

O'Driscoll, R.L. (2002a). Review of acoustic data inputs for the 2002 hoki stock assessment. *New Zealand Fisheries Assessment Report 2002/36*. 64 p.

O'Driscoll, R.L. (2002b). Acoustic survey of spawning hoki in Cook Strait during winter 2001. *New Zealand Fisheries Assessment Report 2002/37*. 35 p.

O'Driscoll, R.L. (2003a). Acoustic survey of spawning hoki in Cook Strait during winter 2002. *New Zealand Fisheries Assessment Report 2003/27*. 34 p.

O'Driscoll, R.L. (2003b). Acoustic survey of spawning hoki off the east coast South Island in September 2002. *New Zealand Fisheries Assessment Report 2003/28*. 26 p.

O'Driscoll, R.L. (2004). Estimating uncertainty associated with acoustic surveys of spawning hoki (*Macruronus novaezelandiae*) in Cook Strait, New Zealand. *ICES Journal of Marine Science 61*: 84–97.

O'Driscoll, R.L. (2006). Acoustic survey of spawning hoki in Cook Strait during winter 2005, and revision of hoki acoustic abundance indices for Cook Strait and the west coast South Island. *New Zealand Fisheries Assessment Report 2006/44*. 46 p.

O'Driscoll, R.L. (2007). Acoustic survey of spawning hoki in Cook Strait and off the east coast South Island during winter 2006. *New Zealand Fisheries Assessment Report 2007/21*. 52 p.

O'Driscoll, R.L. (2009). Acoustic survey of spawning hoki in Cook Strait and off the east coast South Island during winter 2008. *New Zealand Fisheries Assessment Report 2009/17*. 52 p.

O'Driscoll, R.L.; Bagley, N.W.; Macaulay, G.J.; Dunford, A.J. (2004). Acoustic surveys of spawning hoki off South Island on FV *Independent 1* in winter 2003. *New Zealand Fisheries Assessment Report 2004/29*. 48 p.

O'Driscoll, R.L.; Dunford, A.J. (2008). Acoustic survey of spawning hoki in Cook Strait during winter 2007. NIWA Client Report WLG2008-1 for The Deepwater Group Ltd. 44 p.

O'Driscoll, R.L.; Macaulay, G.J. (2005). Using fish processing time to carry out acoustic surveys from commercial vessels. *ICES Journal of Marine Science 62*: 295–305.

O'Driscoll, R.L.; Macaulay, G.J. (2009). Industry acoustic survey of spawning hoki in Cook Strait during winter 2008. NIWA Client Report WLG2009-8 for The Deepwater Group Ltd. 40 p.

O'Driscoll, R.L., Macaulay, G.J. (2010). Industry acoustic survey of spawning hoki in Cook Strait during winter 2009. NIWA Client Report WLG2010-13 for The Deepwater Group Ltd. 56 p.

O'Driscoll, R.L.; McMillan, P.J. (2004). Acoustic survey of spawning hoki in Cook Strait during winter 2003. *New Zealand Fisheries Assessment Report 2004/20*. 39 p.

O'Driscoll, R.L.; Nelson, R. (2010). *Tomi Maru 87* ES70 and ES60 calibrations, April 2010. NIWA Client Report WLG2010-24 for The Deepwater Group Ltd. 9 p.

Rose, G.; Gauthier, S.; Lawson, G. (2000). Acoustic surveys in the full monte: simulating uncertainty. *Aquatic Living Resources 13*: 367–372.

Ryan, T.; Kloser, R. (2004). Quantification and correction of a systemic error in Simrad ES60 echosounders. Technical note presented at the ICES WGFAST 2004, Gdynia, Poland. 9 p.

7. TABLES

Table 1: Stratum boundaries, areas and transect allocation for the 2011 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 c.v)
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
Missing stratum 5B$^{\#}$		Uniform	0.85-1.15

* 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 arose 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).

$^{\#}$ For snapshots 1 and 2 only (see Table 3). Based on the relative contribution from this stratum in snapshots in previous surveys which was between 2 and 30% of biomass.

Table 3: Summary of snapshots carried out during 2011 Cook Strait hoki acoustic survey. Times are NZST.

Snapshot	Vessel	Start time	End time	No. of transects
1	*Independent 1*	18 Jul 06:17	19 Jul 02:45	24*
2	*Independent 1*	20 Jul 19:21	23 Jul 01:25	25*
3	*Thomas Harrison*	11 Aug 06:40	12 Aug 10:45	28
4	*Thomas Harrison*	20 Aug 13:20	21 Aug 15:25	28
5	*Thomas Harrison*	23 Aug 07:50	24 Aug 07:29	28
6	*Thomas Harrison*	26 Aug 05:05	27 Aug 03:20	28

* Stratum 5B was not surveyed during the first two snapshots.

Table 4: 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 (2006), and the recently published relationship from Kloser et al. (2011) with hoki total length converted to standard length.

			Macaulay (2006)		Kloser et al. (2011)	
Year	Mean length (cm)	Mean weight (kg)	Mean TS (dB)	*r* (kg m^{-2})	Mean TS (dB)	*r* (kg m^{-2})
1991	73.1	1.25	-41.1	16 289	-35.8	4 720
1993	74.7	1.29	-41.0	16 406	-35.6	4 715
1994	76.9	1.40	-40.9	17 129	-35.3	4 755
1995	78.4	1.50	-40.8	17 931	-35.1	4 806
1996	77.4	1.46	-40.8	17 773	-35.2	4 802
1997	74.9	1.33	-41.0	16 838	-35.5	4 749
1998	75.7	1.38	-41.0	17 250	-35.4	4 776
1999	75.6	1.37	-41.0	17 090	-35.4	4 763
2001	76.9	1.43	-40.9	17 479	-35.3	4 783
2002	78.5	1.50	-40.8	17 948	-35.0	4 806
2003	76.8	1.43	-40.9	17 551	-35.2	4 789
2005	78.7	1.54	-40.8	18 323	-35.0	4 833
2006	74.7	1.34	-41.0	17 039	-35.5	4 768
2007	73.8	1.30	-41.1	16 669	-35.6	4 746
2008	72.9	1.23	-41.2	16 101	-35.8	4 706
2009	73.3	1.25	-41.1	16 281	-35.8	4 718
2011	79.1	1.63	-40.7	19 259	-35.0	4 821
Mean				17 256		4 768

Table 5: Summary and catch information from mark identification trawls and commercial tows where NIWA collected biological data during the 2011 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. - for commercial tows indicates less than 10 kg estimated catch.

				Catch (kg)						
Station	Type	Stratum	Mark type	Hoki	Jack mackerel	Spiny dogfish	Ling	Rattails	Other	% Hoki
1	Research	1	BMIX	1 800	23	137	15	6	11	90
2	Research	1	BMIX	6 000	6	105	8	7	20	98
3	Research	5B	PMIX	63	0	0	0	3	8	85
4*	Research	3	PMIX	20	0	0	0	0	0	100*
5	Commercial	2	HOK	7 000	-	-	-	-	-	100
6	Commercial	2	HOK	20 000	-	800	-	-	-	96
7	Commercial	2	HOK	5 000	-	-	-	-	-	100
8	Commercial	2	HOK	3 000	-	1 500	-	-	-	67
9	Commercial	2	HOK	4 000	-	1 000	-	-	-	80
10	Commercial	2	HOK	7 000	-	-	-	-	-	100
11	Commercial	2	HOK	8 000	-	-	-	10	120	98
12	Commercial	2	HOK	10 000	-	-	-	20	110	99
13	Commercial	2	HOK	16 000	-	-	-	-	280	98
14	Commercial	2	HOK	3 000	28	-	-	-	80	97
15	Commercial	2	HOK	11 000	-	-	-	-	130	99
16	Commercial	2	HOK	6 000	-	-	-	-	115	98
17	Commercial	2	HOK	5 000	-	-	-	-	110	98
18	Commercial	2	HOK	6 000	-	-	-	-	140	98
19	Commercial	2	HOK	8 000	-	-	-	5	70	99
20	Commercial	2	HOK	12 000	-	-	-	-	180	99
21	Research	1	BMIX	1 683	1	92	0	1	7	94
22	Research	6	BMIX+	22	5	30	3	2	27	25
23	Research	5A	PMIX	1 800	5	0	0	0	27	98
24	Commercial	2	HOK	6 000	-	-	15	15	270	95
25	Commercial	2	HOK	8 000	-	-	10	-	140	98
26	Commercial	2	HOK	8 000	-	-	20	20	430	94
27	Commercial	2	HOK	15 000	-	-	-	-	170	99

* Net was tangled so retained catch was not representative.
+ Tow did not go through main mark.

Table 6: Total catch by species for the seven designated research tows carried out in the 2011 hoki acoustic survey.

Code	Common name	Catch (kg)
BAR	Barracouta	3.1
BSH	Seal shark	0.6
CBI	Two saddle rattail	15.0
CBO	Bollons's rattail	0.7
CHQ	Cranchiid squid	0.2
COL	Oliver's rattail	3.3
CSQ	Leafscale gulper shark	3.2
CYP	Longnosed velvet dogfish	3.4
EMA	Blue mackerel	1.9
EPO	Limp eel pout	0.1
EPT	Black cardinalfish	1.1
ETL	Lucifer dogfish	0.6
FRO	Frostfish	4.4
GSH	Dark ghost shark	1.5
HJO	Johnson's cod	0.2
HOK	Hoki	11 388.0
JAV	Javelinfish	0.4
JMD	Greenback jack mackerel	30.5
JMM	Slender jack mackerel	9.9
LAN	Lanternfishes	0.2
LIN	Ling	26.5
NOS	Arrow squid	1.3
RBM	Ray's bream	4.3
RCO	Red cod	25.2
RHY	Common roughy	0.5
SBK	Spineback	0.2
SCH	School shark	23.0
SKI	Gemfish	4.1
SPD	Spiny dogfish	363.2
SWA	Silver warehou	21.1
Total		11 937.7

Table 7: Hoki acoustic abundance estimates from the 2011 Cook Strait survey by snapshot and stratum.

	Stratum biomass ('000 t)						Total	Snapshot
Snapshot	1	2	3	5A	5B	6	('000 t)	c.v.
1	32	85	7	16	25*	7	172	23
2	30	209	8	36	25*	4	312	32
3	29	282	4	22	18	5	359	44
4	36	350	4	28	27	34	478	53
5	45	119	4	12	19	3	202	24
6	45	183	2	12	36	1	279	24
Mean	36	205	5	21	25	9	300	18

* Stratum 5B was not surveyed in snapshots 1 and 2, so the mean value for this stratum from the other four snapshots was assumed.

Table 8: Percentage of the hoki abundance estimate from hoki school marks in each snapshot and strata for Cook Strait. Percentages were calculated in relation to abundance estimates in Table 7.

	Percentage of biomass in schools						
Snapshot	1	2	3	5A	5B	6	Total
1	0	84	0	0	0	0	42
2	0	96	18	88	0	19	75
3	0	100	46	84	0	0	84
4	0	97	0	0	0	82	76
5	0	96	0	0	0	0	57
6	0	95	0	15	0	0	63
Mean	0	95	11	31	0	17	66

Table 9: Results of Monte Carlo simulations to determine model weighting for the 2008 Cook Strait acoustic survey (see O'Driscoll 2004 for details). The c.v. 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	0.209
+ Sampling	0.274
+ Detectability	0.275
+ Mark identification	0.330
+ Calibration	0.330
+ TS	0.339
+ Missing stratum 5B	0.350
Total	0.350

Table 10: Alternative acoustic indices of hoki abundance for Cook Strait 1988–2011. Biomass values with annual *r* use acoustic TS derived from commercial length frequency data in each survey year using the TS-length relationships of Macaulay (2006) and the recently published relationship from Kloser et al. (2011) (see Table 4). Values with constant *r* use an average ratio of hoki TS to fish weight (calculated from the mean of annual values estimated using Macaulay TS).

		Biomass ('000 t)			
Year	No of snapshots	Annual *r* Macaulay TS	Constant *r* Macaulay TS	Annual *r* Kloser TS	c.v.
1991	4	180	191	52	0.41
1993	4	583	613	167	0.52
1994	3	592	597	164	0.91
1995	4	427	411	114	0.61
1996	5	202	196	55	0.57
1997	6	295	302	83	0.40
1998	5	170	170	47	0.44
1999	6	243	245	68	0.36
2001	11	220	217	60	0.30
2002	9	320	307	86	0.35
2003	9	225	222	61	0.34
2005	9	132	124	35	0.32
2006	7	126	128	35	0.34
2007*	4	216	218	60	0.46
2008	7	167	179	49	0.30
2009*	5	315	334	91	0.39
2011*	6	300	269	75	0.35

* Surveys from industry vessels

8. FIGURES

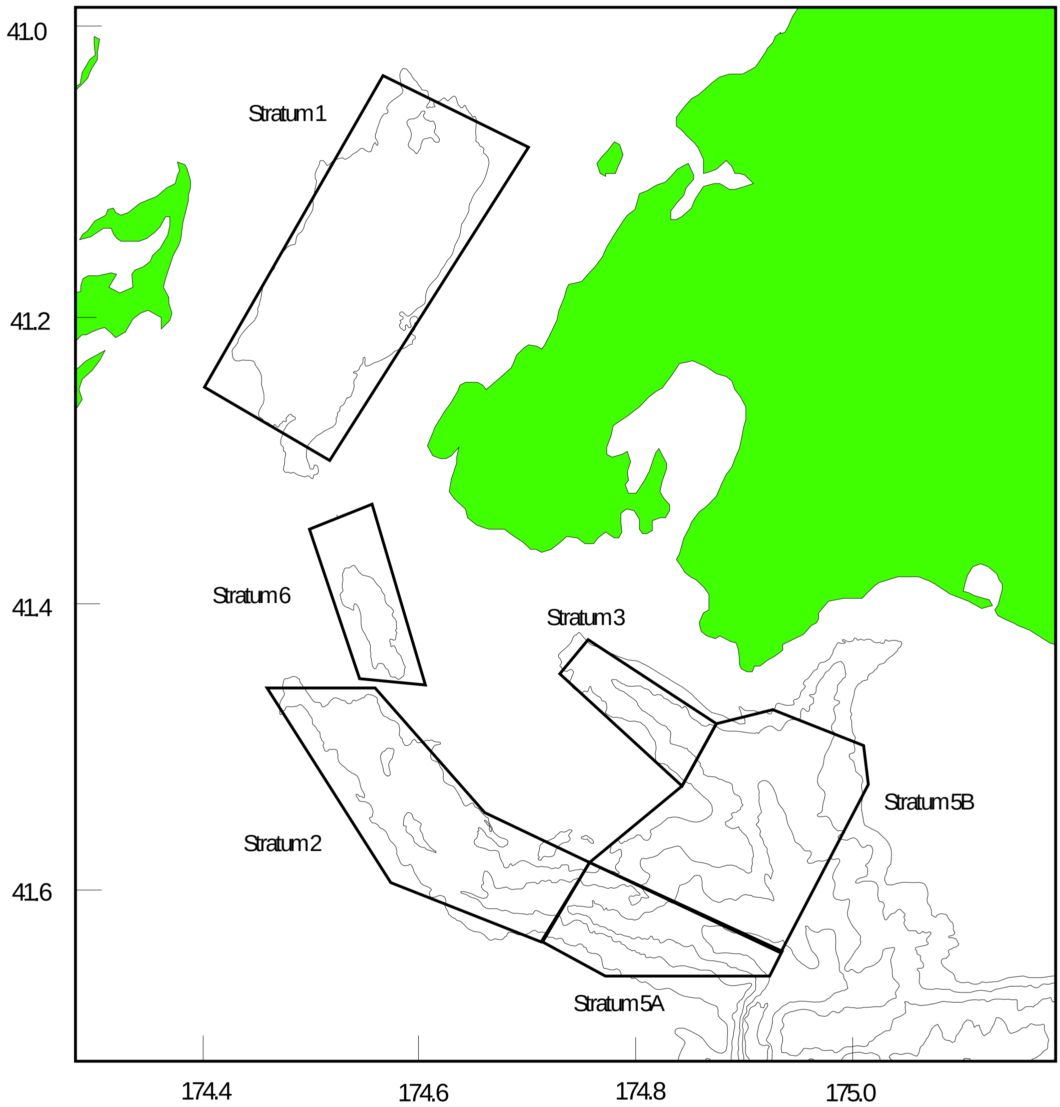


Figure 1: Stratum boundaries for the 2011 acoustic survey of Cook Strait spawning hoki: 1, Narrows Basin; 2, Cook Strait Canyon; 3, Nicholson Canyon; 5A, Cook Strait Canyon extension; 5B, Deepwater outside Nicholson and Wairarapa Canyons; 6, Terawhiti Sill. Depth contours are 250, 500, 750, and 1000 m.

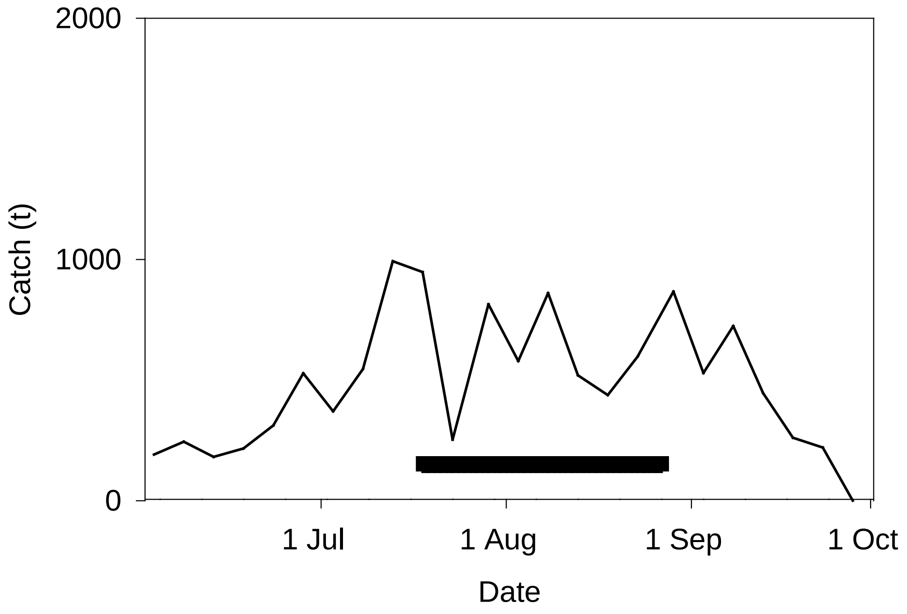


Figure 2: Timing of acoustic survey in 2011 (bar along the x axis) in relation to the commercial hoki catch from Cook Strait in 5-day periods.

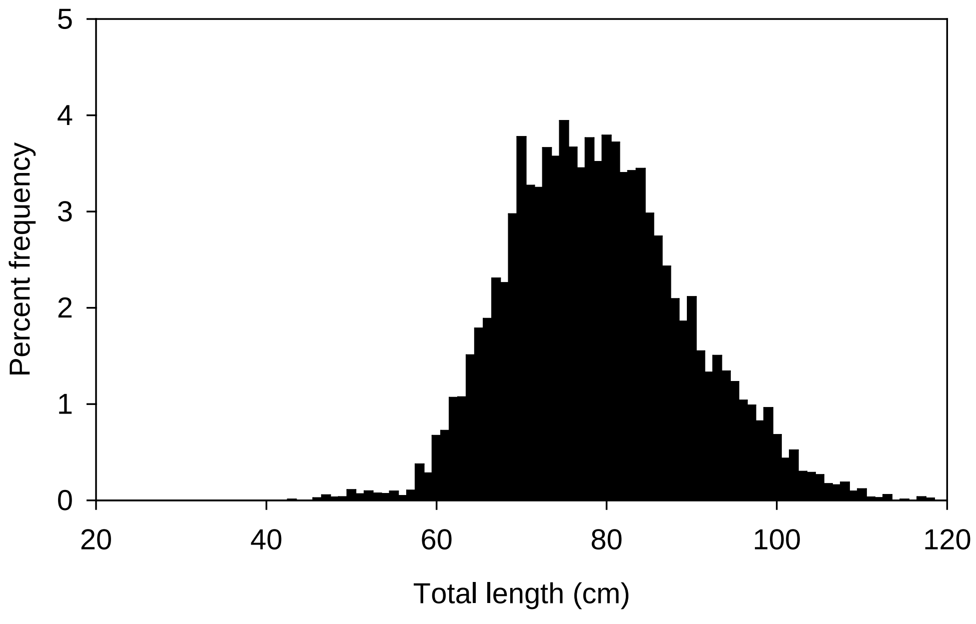


Figure 3: Scaled unsexed length frequencies of hoki caught in the commercial fishery in Cook Strait in 2011 based on at-sea observer sampling and sampling by NIWA on *Thomas Harrison*. Data were used to estimate the ratio, *r*, of mean weight to mean backscattering cross-section.

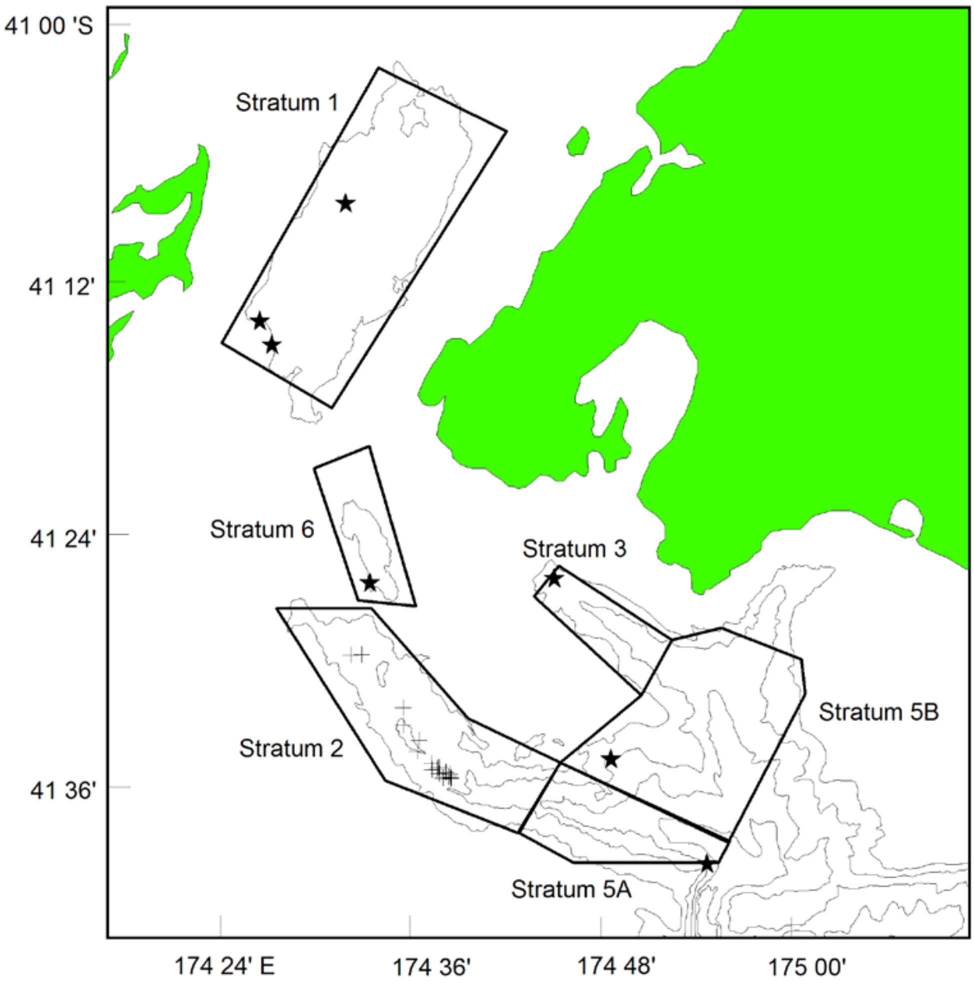


Figure 4: Location of trawls sampled on *Thomas Harrison* from 10–24 August 2011: stars show research tows; and crosses show commercial tows.

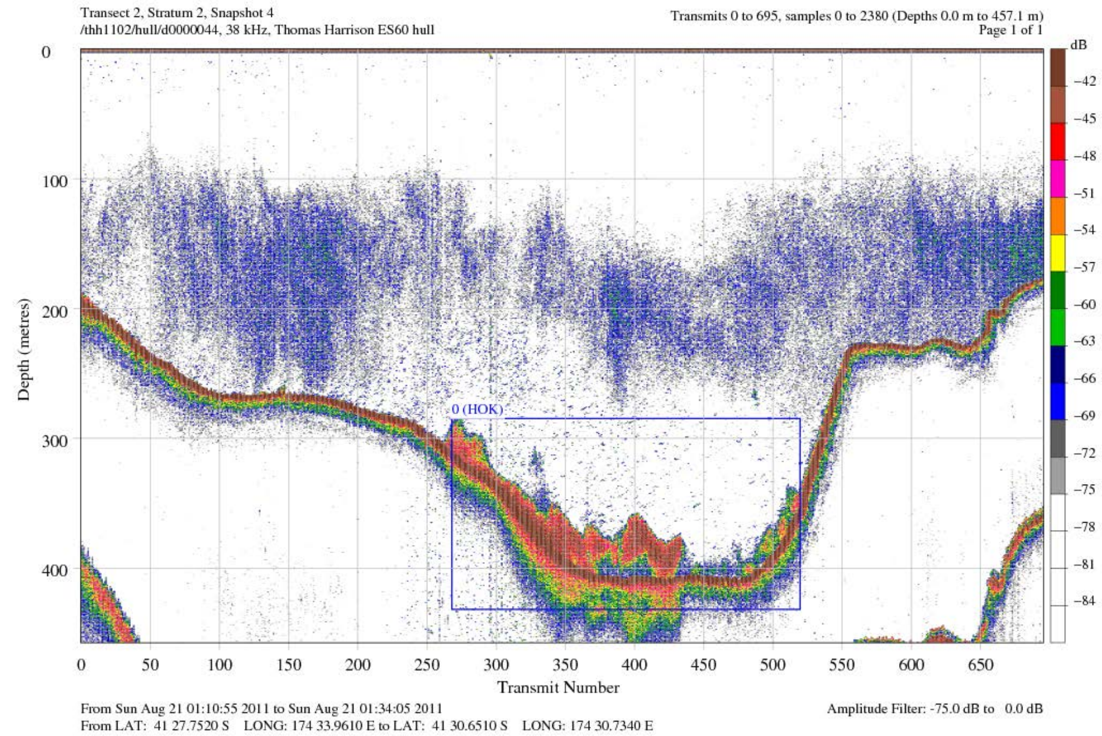


Figure 5: Acoustic echogram from Cook Strait Canyon (stratum 2) during snapshot 4 showing a dense hoki school close to the bottom at night. The dispersed layer from 130 to 250 m is probably mesopelagic fish.

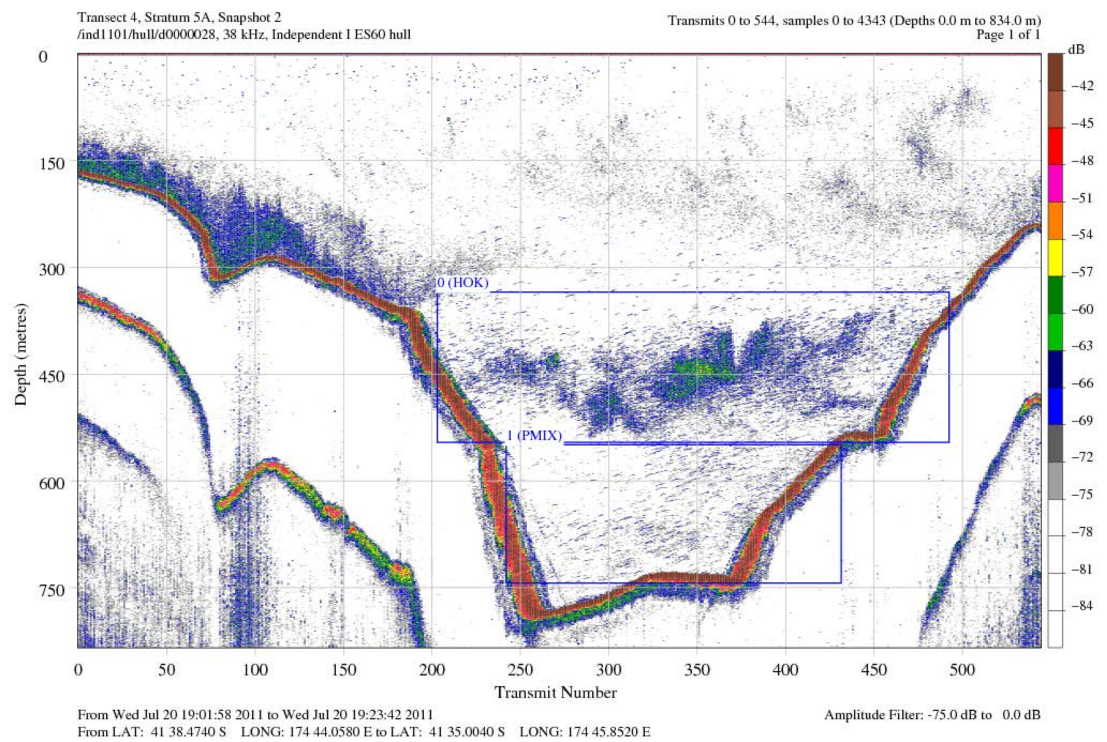


Figure 6: Acoustic echogram from outer Cook Strait Canyon (stratum 5A) snapshot 2 showing hoki schools in midwater with pelagic fuzz below. The layer close to the bottom between 150 and 300 m water depth is probably not hoki.

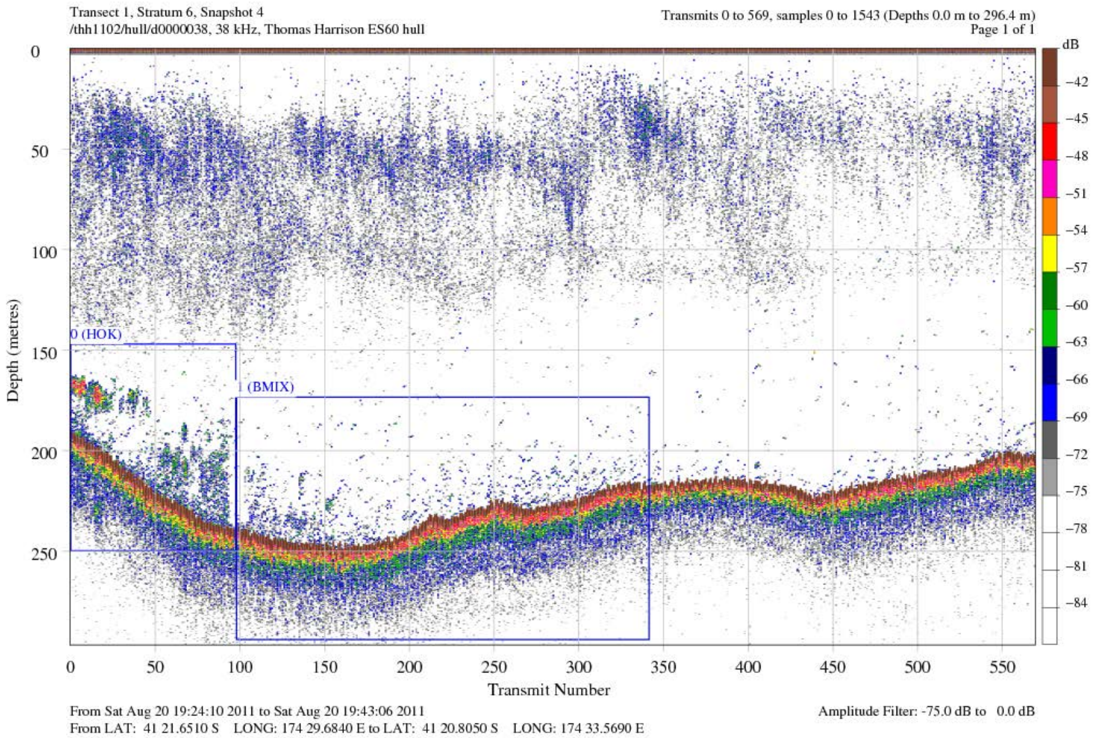


Figure 7: Acoustic echogram from Terawhiti Sill (stratum 6) during snapshot 4 showing hoki schools adjacent to hoki bottom fuzz marks. There is a pelagic layer between 20 and 150 m.

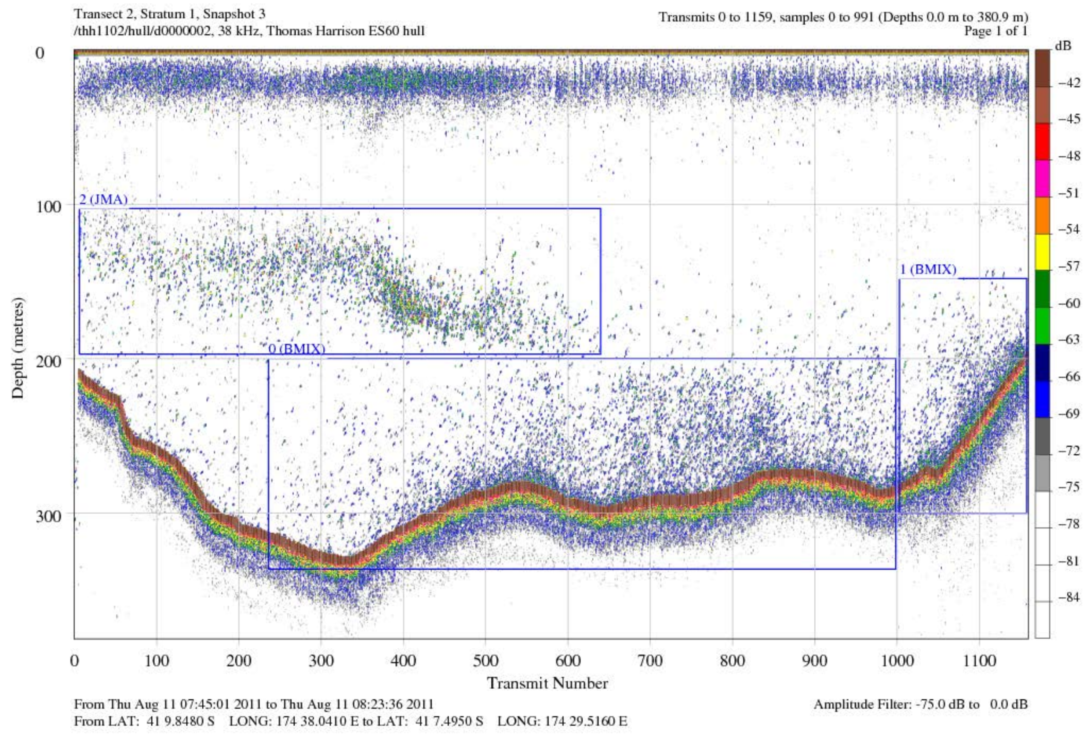


Figure 8: Acoustic echogram from Narrows Basin (stratum 1) during snapshot 3 showing hoki bottom fuzz within 100 m of the bottom and jack mackerel above at 100–200 m. There is a pelagic layer within 50 m of the surface.

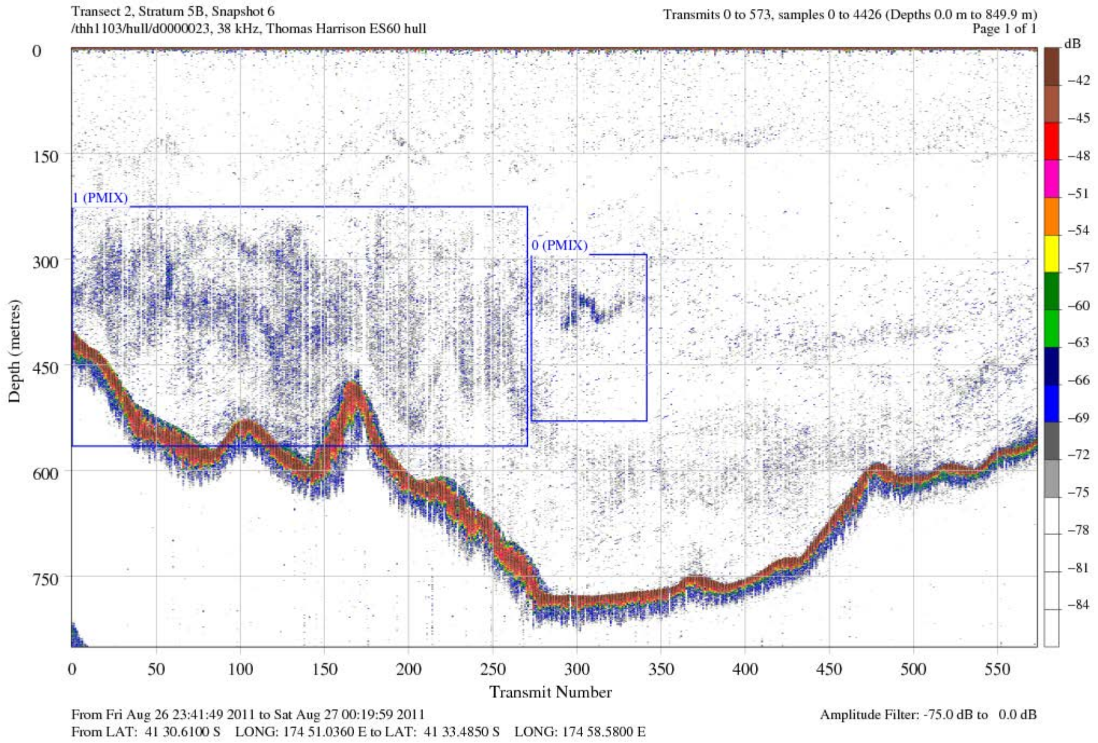


Figure 9: Acoustic echogram from the deepwater between Cook Strait and Wairarapa Canyons (stratum 5B) during snapshot 6 showing dispersed hoki pelagic fuzz marks.

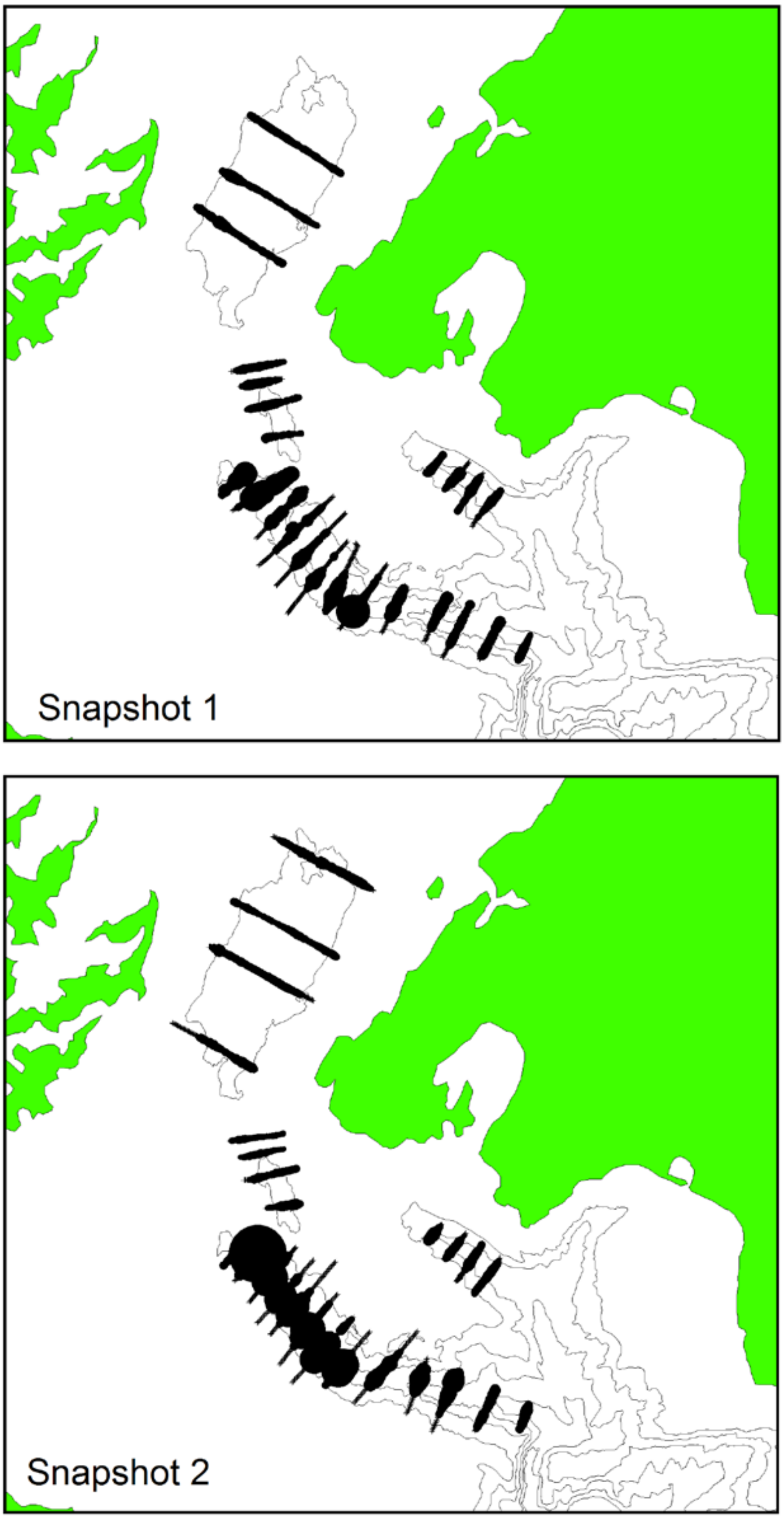


Figure 10: Spatial distribution of hoki acoustic backscatter plotted in 10 ping (~100 m) bins for snapshots 1–2 of Cook Strait. Symbol size is proportional to the log of the acoustic backscatter.

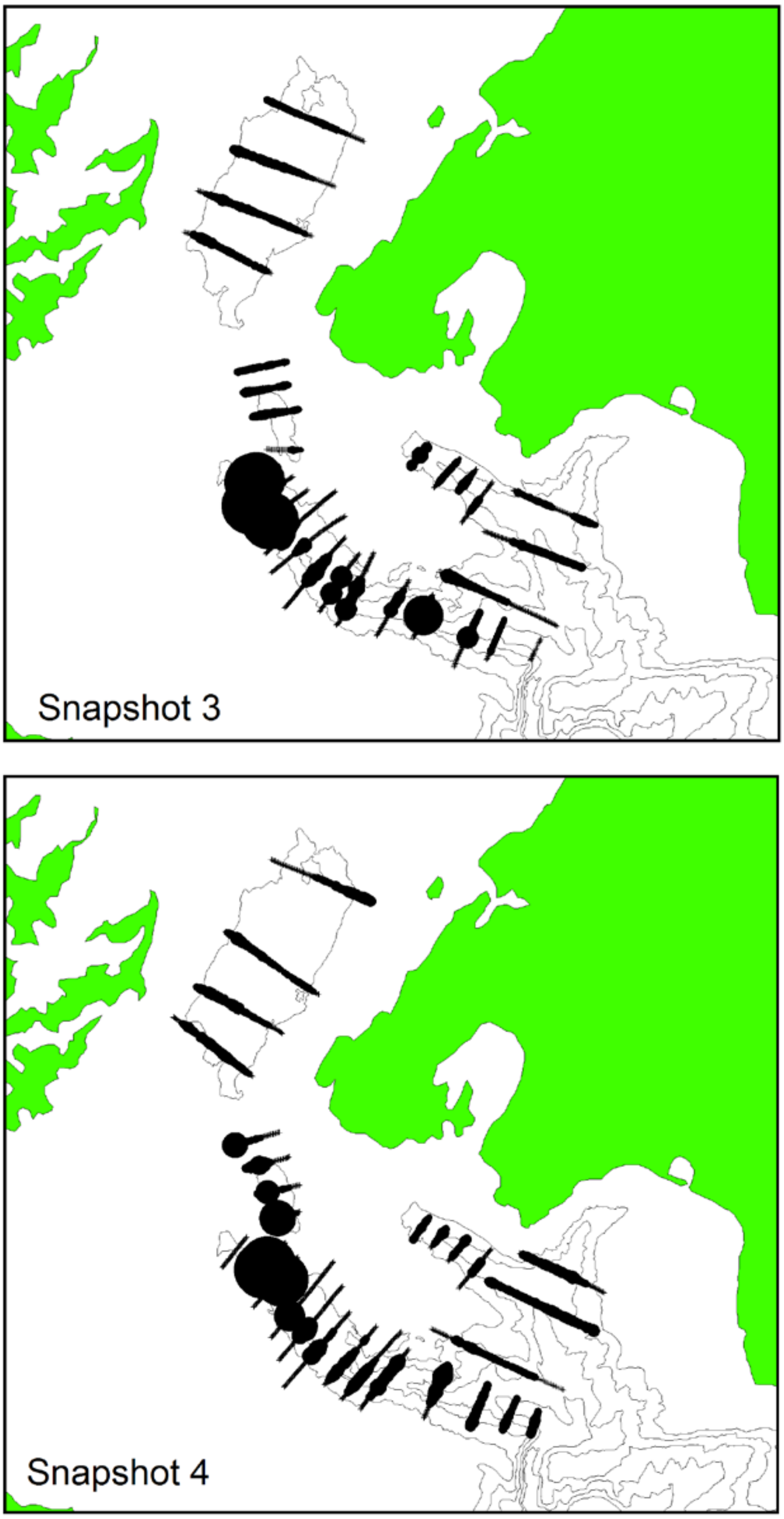
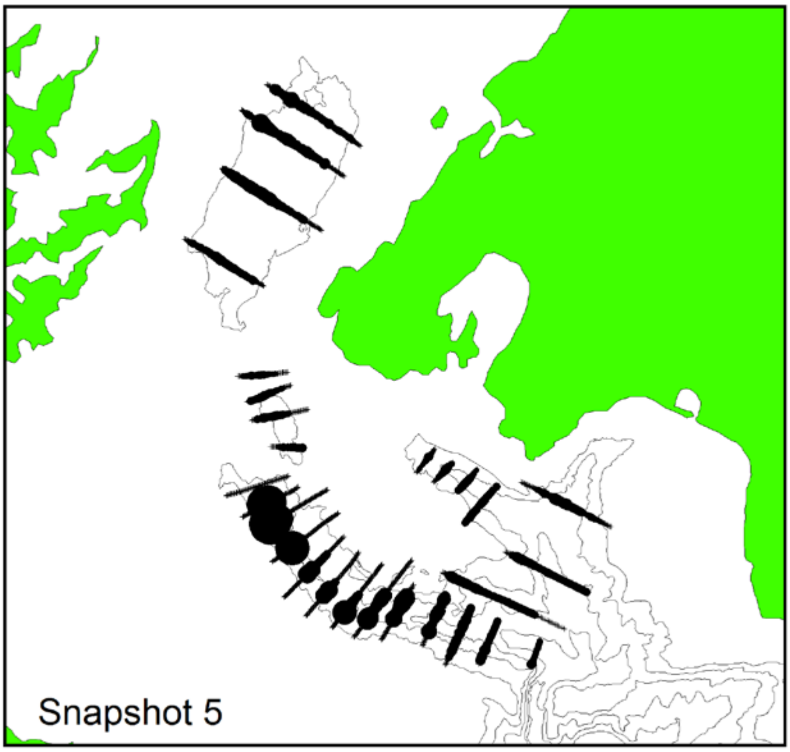


Figure 10 cont: Spatial distribution of hoki acoustic backscatter plotted in 10 ping (~100 m) bins for snapshots 3–4 of Cook Strait. Symbol size is proportional to the log of the acoustic backscatter.



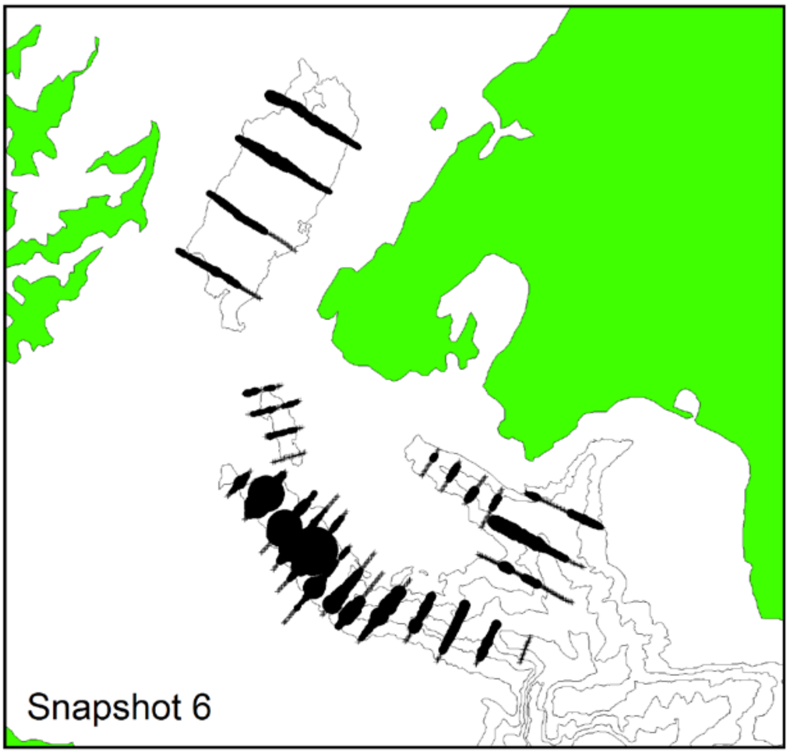


Figure 10 cont: Spatial distribution of hoki acoustic backscatter plotted in 10 ping (~100 m) bins for snapshots 5–6 of Cook Strait. Symbol size is proportional to the log of the acoustic backscatter.

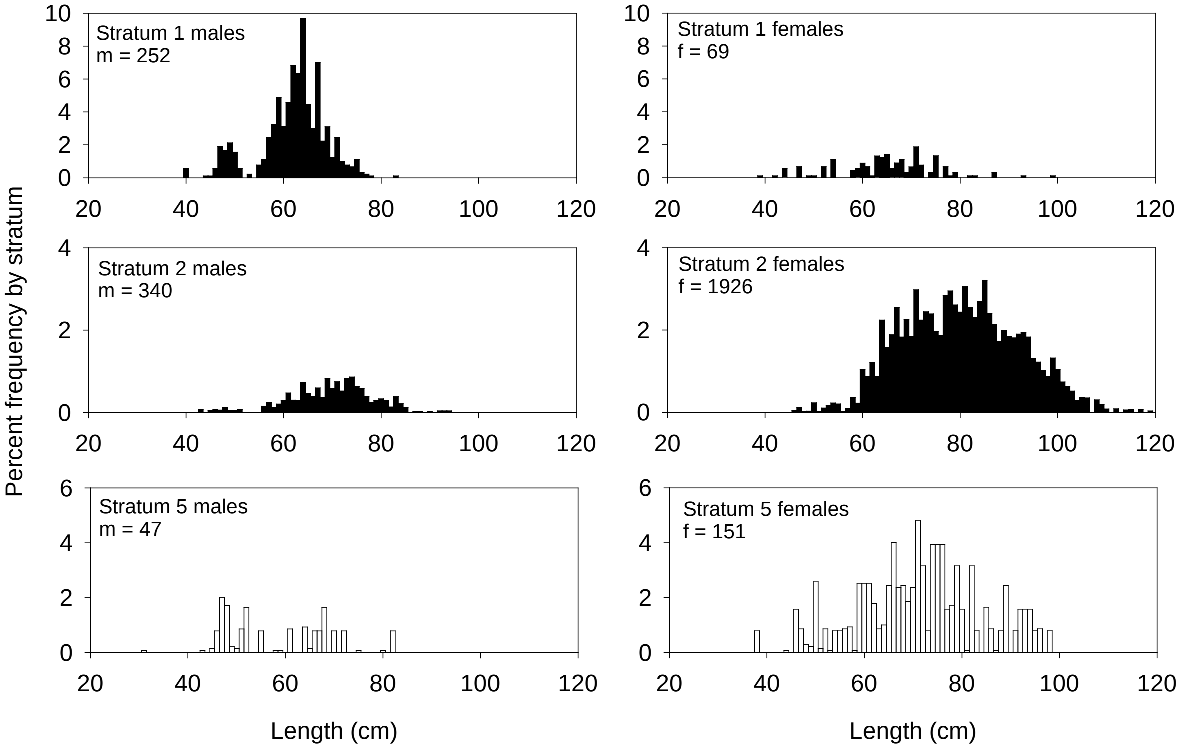


Figure 11: Scaled length frequencies of male and female hoki by stratum from trawls in Cook Strait by *Thomas Harrison* in winter from 11–23 August 2011. Length frequencies for each stratum are expressed as a percentage of the total hoki catch in that stratum. m (male) and f (female) values refer to the numbers of fish measured. Tows in strata 1 and 5 were research mark identification trawls. Tows in stratum 2 were commercial trawls (see Figure 4).

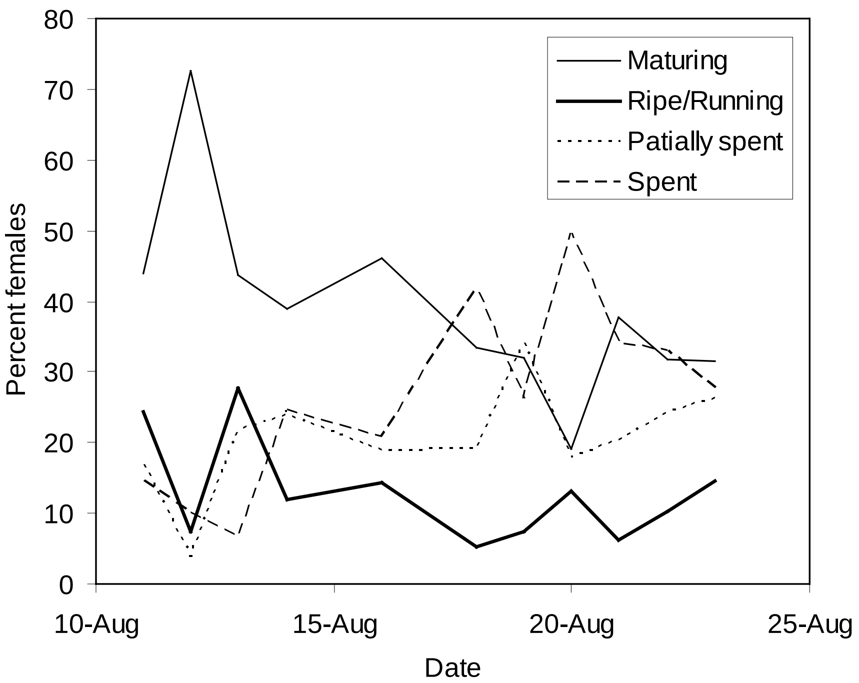


Figure 12: Proportion of female hoki in different maturity states from fish sampled on *Thomas Harrison* 11–23 August 2011.

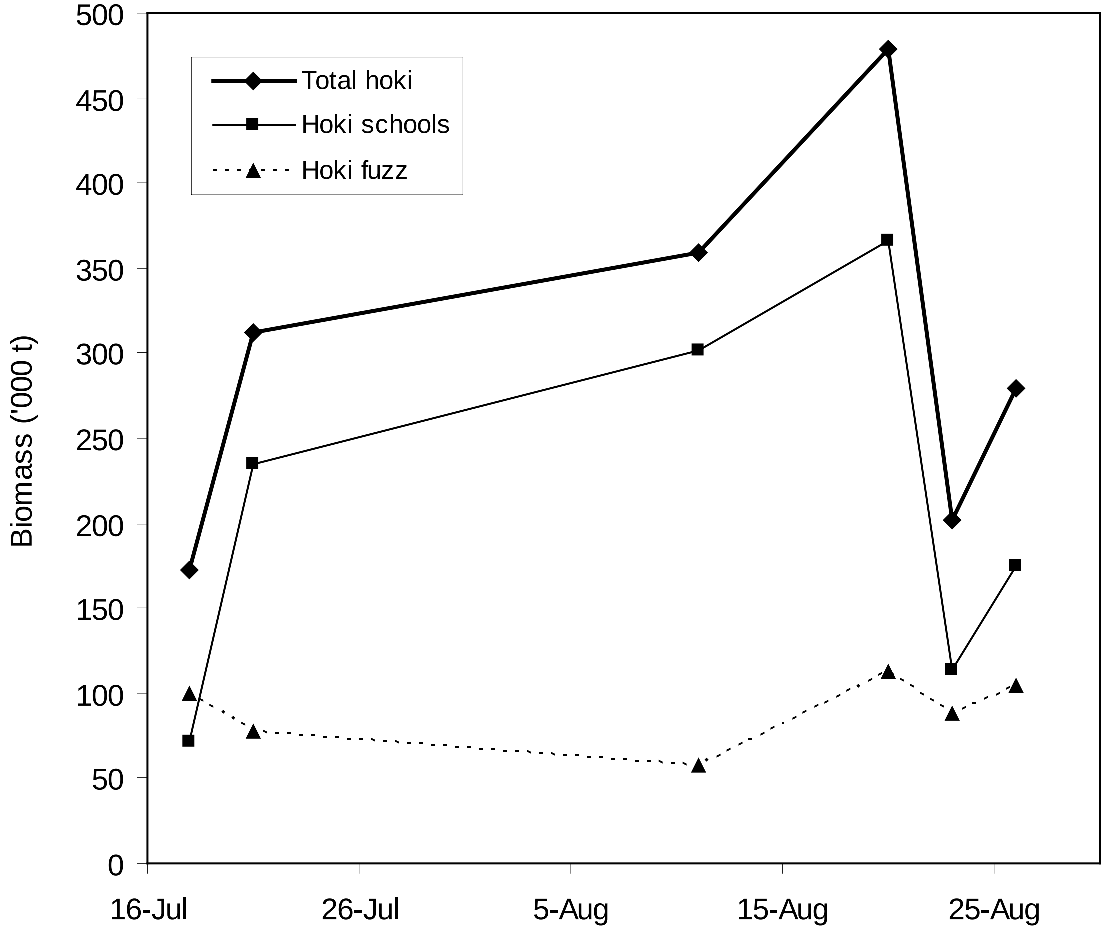


Figure 13: Estimated hoki abundance in Cook Strait by snapshot over the 2011 survey period.

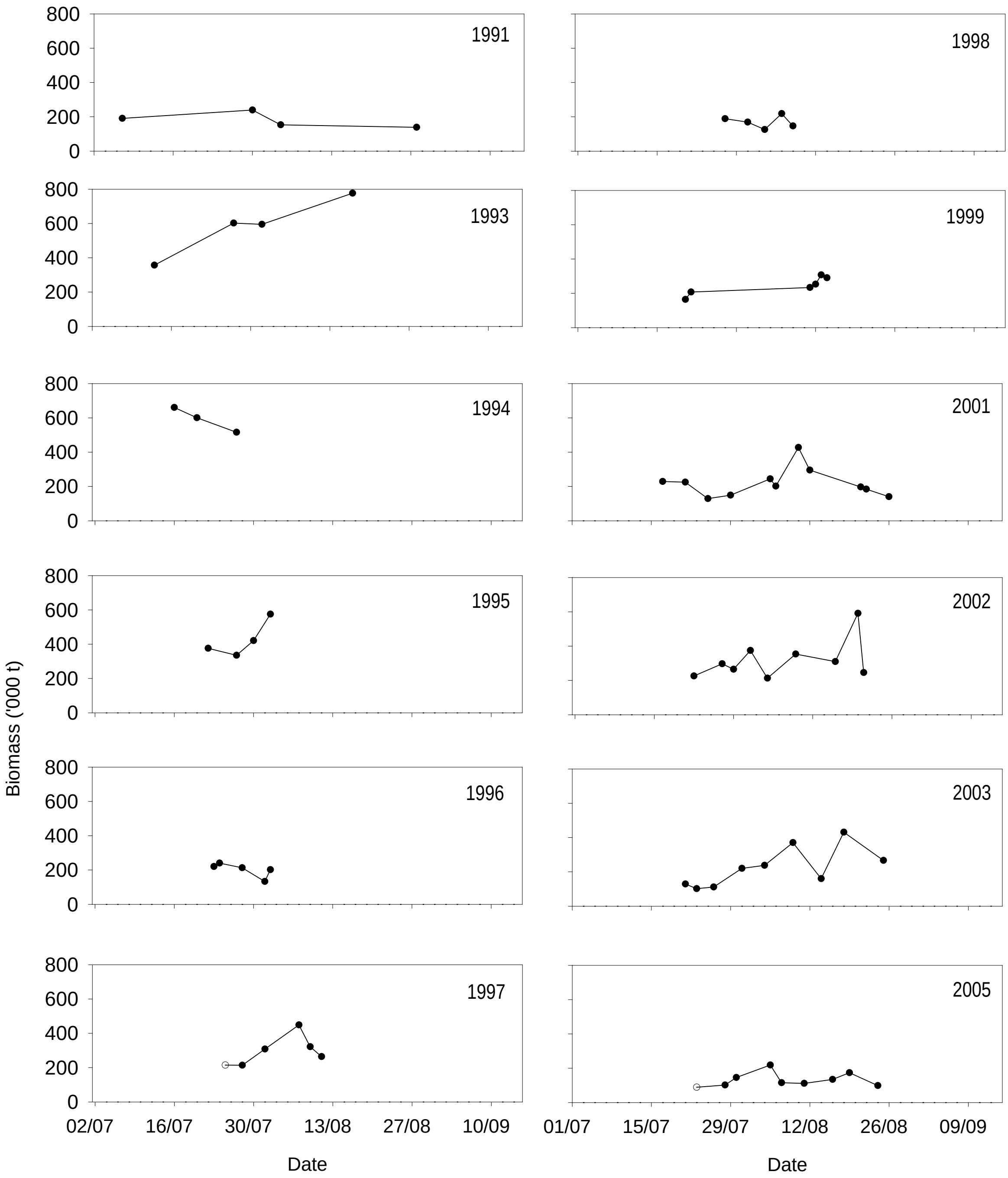


Figure 14: Estimated hoki abundance by snapshot for acoustic surveys in the Cook Strait time series from 1991 to 2005.

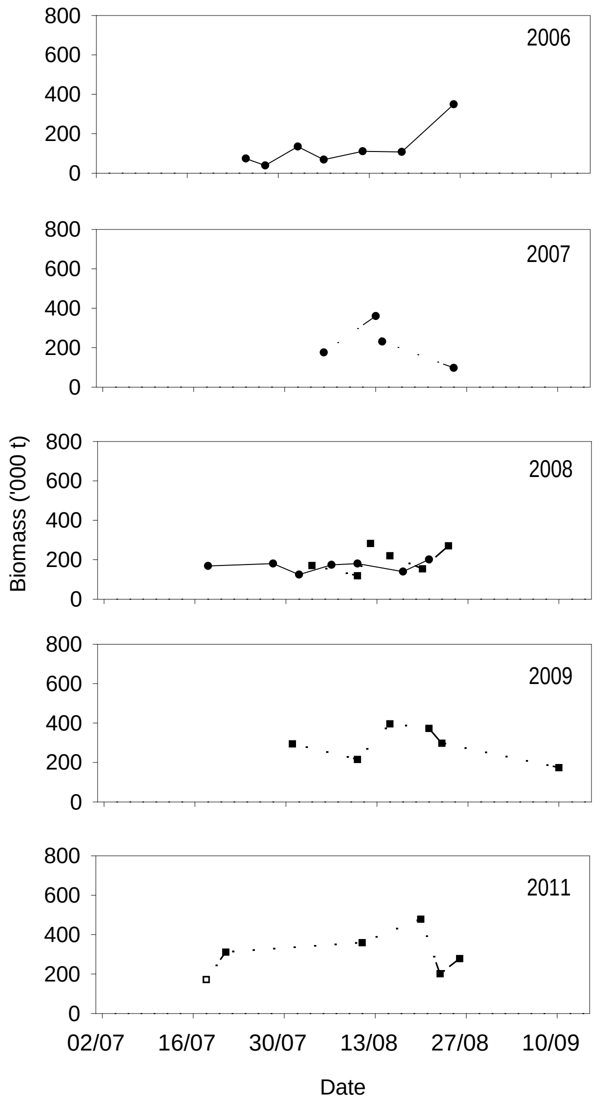


Figure 14 cont: Estimated hoki abundance by snapshot for acoustic surveys in the Cook Strait time series from 2006 to 2011. Dotted lines show surveys carried out from commercial vessels.

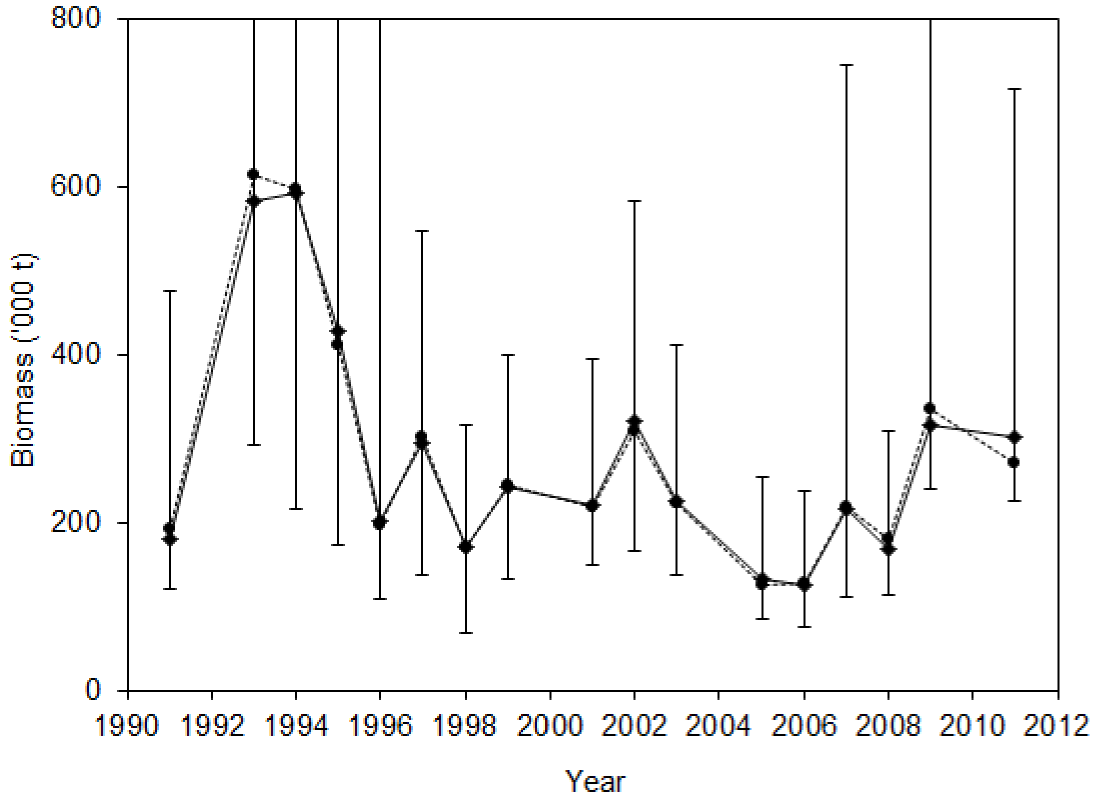


Figure 15: Relative time series of acoustic abundance estimates for spawning hoki in Cook Strait. Diamonds (with 95% confidence intervals based on Monte Carlo estimates of uncertainty) connected by solid line show indices calculated using annual estimates of ratio of hoki weight to acoustic target strength (*r*) from commercial length frequency data. Circles connected by dashed line show indices calculated using a constant *r*.

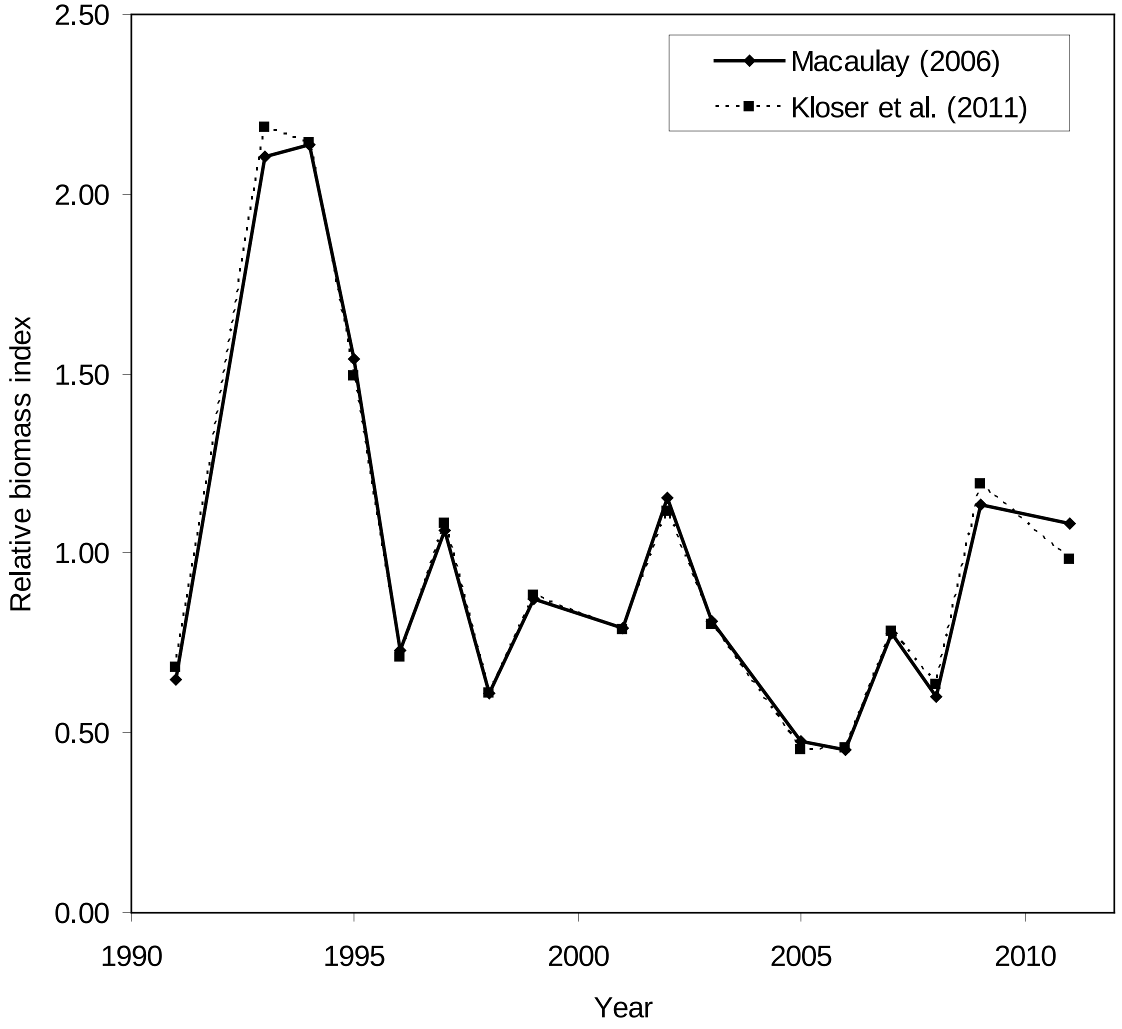


Figure 16: Comparison of relative time series of acoustic abundance estimates for spawning hoki in Cook Strait estimated with the TS-length relationship of Macaulay (2006) and the new TS-length relationship proposed by Kloser et al. (2011).

APPENDIX 1: Calibration Report *Independent 1*

Calibration of the Simrad ES60 echosounder on *Independent 1* took place in Tasman Bay (41° 00.49' S 173° 09.44' E) on 25 July 2011. Water depth was about 25 m (below the transducer). This was the fourth time that the ES60 on this vessel has been calibrated by NIWA, with the most recent previous calibration on 6 August 2009. The many calibrations carried out on this vessel as part of the Oman fisheries survey were with an EK60 connected to the transducer and are not directly comparable to the ES60 calibrations. The calibration was conducted broadly as per the procedures in MacLennan & Simmonds (1992).

Richard O'Driscoll was picked up from the Sealord Rescue Centre in Nelson by the vessel's MOB boat about 10:25 NZST and was on board *Independent 1* by 11:00. The vessel then steamed out into Tasman Bay to find shelter and deeper water. The ES60 was configured to recommended settings (2000 W power and 1.024 ms pulse) and the time of the ES60 was adjusted to the GPS. No keyboard was on board so a USB keyboard was installed. Acoustic data collected in the first two snapshots of Cook Strait on 18–19 and 20–23 July were copied to a USB hard drive.

The calibration started at 12:10 NZST. A weighted line was passed under the keel 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 also deployed about 2 m below the sphere to steady the arrangement of lines. The starboard line became entangled in something on the keel and was stuck fast. However it was still possible to manipulate the sphere in the beam by shifting the port forward line to the starboard side and then physically moving the attachment point of this line as well as manipulating the port aft line.

The weather was moderate with a 15 knot southwest wind, no swell, and choppy whitecaps of about 1 m. The vessel was allowed to drift, and the drift speed was up to 1.0 knot.

The sphere was first located in the beam at 12:36 NZST. Data quality was extremely poor with both the sphere and bottom echo breaking up. This is symptomatic of signal loss due to bubble attenuation. After discussion with vessel officers it became apparent that the propeller was turning in reverse when at 0% pitch. When a slight forward pitch was applied the data quality improved. The sphere was centred in the beam to obtain data for the on-axis calibration at 13:08. 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 a single ES60 raw format file (L0001-D20110725-T003039-ES60.raw). Raw data are stored in the NIWA Fisheries Acoustics Database. The ES60 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 water column was essentially unstratified, with a temperature of 11.6º at the surface, increasing slightly to 12.4º at 29 m. The temperature at the depth of the sphere (13 m) was 11.7º. 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 14:10 NZST. The vessel steamed towards Nelson and the MOB boat took Richard O'Driscoll ashore to the Sealord Rescue Centre at 15:45.

The data in the ES60 files were extracted using custom-written software. There were several instances where the ES60 lost contact with the General Purpose Transceiver (GPT) during the latter part of the calibration (from pings 25 000 to 30 000). This was interpreted as a Mode Change by the calibration software and the Matlab functions had to be modified to allow the data to be read. 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 or where the ES60 had lost contact with the GPT 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 data (Ryan & Kloser 2004) was also applied as part of the analysis. The estimation of the zero ping offset was based on the first 25 000 pings only, so that the estimation algorithm was not influenced by the missing data caused by losing contact with the GPT.

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. The estimated beam pattern and sphere coverage are given in Figure A1.1. The symmetrical nature of the pattern and the zero centre of the beam pattern indicate that the transducer and ES60 transceiver were operating correctly. The fits between the theoretical beam pattern and the sphere echoes is shown in Figure A1.2 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 0.22 dB (Table A1.3), indicating that the calibration was of good quality (less than 0.4 dB is poor, less than 0.3 dB good, and less than 0.2 dB excellent).

The estimated peak gain (G_0) in 2011 was 0.20 dB higher than that estimated in 2009 and the sa correction was 0.04 dB lower (Table A1.3). This is equivalent to a 7% change in calibration coefficients in the linear domain.

Table A1.1. ES60 transceiver settings and other relevant parameters during the calibration of *Independent 1*.

Parameter	Value
Echosounder	ES60
ES60 software version	1.5.2.77
Transducer model	ES38B
Transducer serial number	Not recorded
ES60 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)	0.3192
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 A1.2. Auxiliary calibration parameters derived from depth/temperature measurements.

Parameter	Value
Mean sphere range (m)	12.8
S.D. of sphere range (m)	0.3
Mean sound speed (m/s)	1 496
Mean absorption (dB/km)	9.32
Sphere TS (dB re $1m^2$)	–42.41

Table A1.3: Calculated echosounder calibration parameters for *Independent 1*.

Parameter	2011	2009	2003	2002
Transducer peak gain (dB)	25.63	25.43	25.43	25.17
Sa correction (dB)	-0.70	–0.66	–0.78	–0.68
Beamwidth (°) alongship/athwarthship	6.8/6.9	7.3/7.2	7.1/6.9	7.0/7.0
Beam offset (°) alongship/athwarthship	0.00/0.00	-0.00/0.00	0.0/0.1	0.0/0.2
RMS deviation	0.22	0.16	0.27	0.39
Echoes used to estimate the beam shape	9 636	25 146	333	143

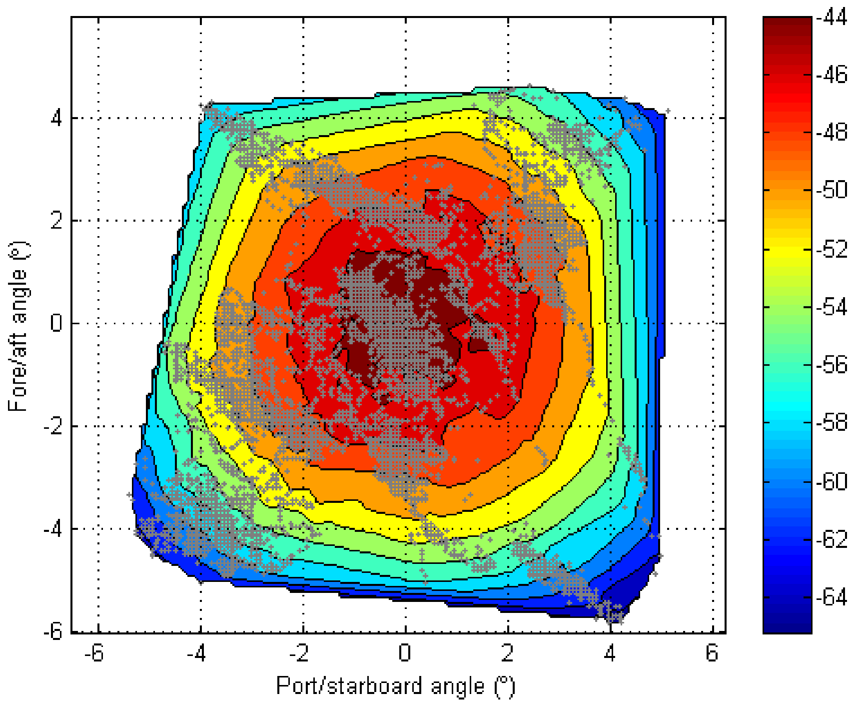


Figure A1.1. The estimated beam pattern from the sphere echo strength and position for the calibration of *Independent 1*. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

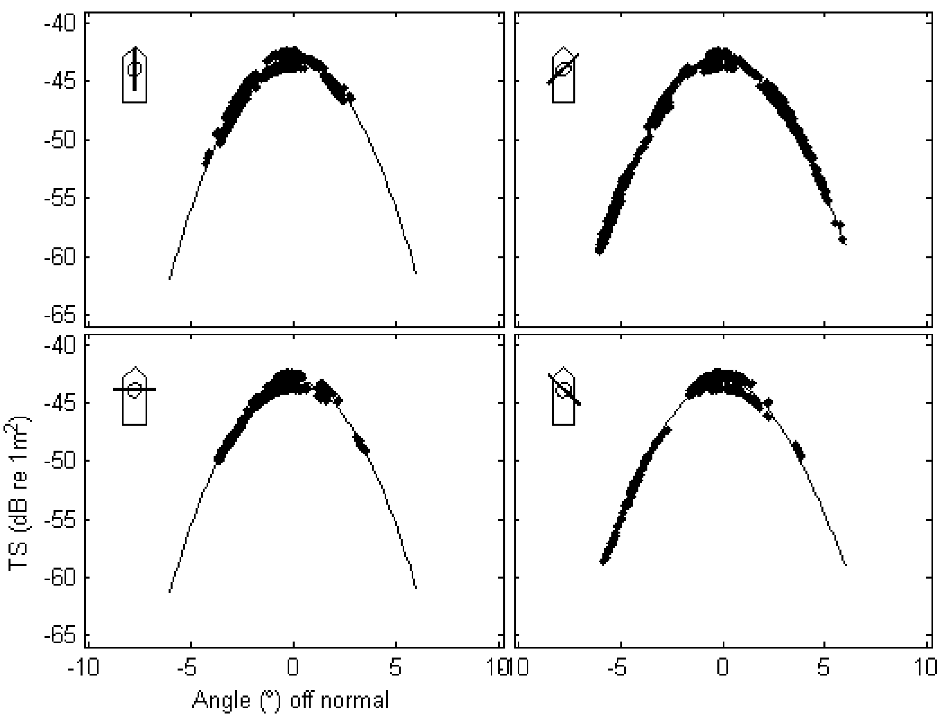


Figure A1.2. Beam pattern results from the calibration analysis for *Independent 1*. The solid line is the theoretical beam pattern fit to the sphere echoes for four slices through the beam.

APPENDIX 2: Calibration Report *Thomas Harrison*

Two calibrations of the Simrad ES70 echosounder on *Thomas Harrison* were carried out by Richard O'Driscoll during the 2011 Cook Strait hoki survey (10–24 August 2011). This was the ninth 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 (O'Driscoll & Nelson 2010). All calibration was conducted broadly as per the procedures in MacLennan & Simmonds (1992).

The first calibration attempt took place in deep water (378 m) in Cook Strait (41° 34.18' S 174° 37.82' E) on 13 August 2011. 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 this first calibration was calm with no wind but a 1 m southeast swell. The vessel was allowed to drift, and the drift speed was about 0.5 knots. The sphere was located in the beam at 13:51 NZST. Calibration data were recorded into a single ES70 raw format file (thh1102-D20110813-T015113.raw). Prior to the calibration, the ES70 was configured to recommended survey settings (2000 W power and 1.024 ms pulse) and the time of the ES70 was adjusted to the GPS. However when the recording range was reduced to 50 m during the calibration, the echosounder automatically reduced the pulse length to 0.256 ms (the auto adjustment box was checked). The transceiver settings in effect during the calibration are given in parentheses in Table A2.1. This first calibration has no relevance to the hoki survey (which was carried out with a 1.024 ms pulse) so the calibration was repeated. However, results are included here for interest and because they provide additional information about the beam pattern.

The second calibration took place off Cape Campbell (41° 40.99' S 174° 16.92' E) on 15 August 2011 while the vessel was sheltering from a storm. Water depth was about 30 m. The same pole arrangement and procedures were used. The weather was dreadful with a 25–30 knot southerly wind, sleet, and snow. Despite being on a lee shore there was a 1 m swell and whitecaps. The vessel was allowed to drift, and the drift speed was 1.5–2.0 knots. Because of the adverse conditions the calibration was carried out at a shorter range than normal (about 10 m) as this allowed more control over the sphere. The sphere was located in the beam at 12:02 NZST. The wind increased further to 40 knots and the calibration was stopped at 12:45 NZST. Calibration data were recorded into a single ES70 raw format file (thh1102-D20110814-T235306.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.

Water temperature measurements were taken using an RBR-2050 temperature depth probe, serial number 11817. The water column was unstratified, with a temperature of 9.3º at the surface, increasing slightly to 9.4º at 20 m. The salinity at the calibration site was not measured but was estimated as 34.8 PSU from CTD data collected in Cook Strait. 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 files from both calibrations 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 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 for the first calibration with 0.256 ms pulse length are given in Table A2.3. The estimated coefficients are not relevant to the hoki survey. However, the symmetrical nature of the estimated beam pattern (Figure A2.1) 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 A2.2) 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 3.6° off axis was 0.16 dB (Table A2.3), indicating that this calibration was of excellent quality (less than 0.4 dB is poor, less than 0.3 dB good, and less than 0.2 dB excellent).

The calibration results for the second calibration (with 1.024 ms pulse length) are given in Table 4 and the estimated beam pattern in Figures A2.3 and A2.4. The RMS of 0.21 dB indicated that this calibration was of good quality. The estimated calibration coefficients were very similar to those from the NIWA calibration in 2010: peak gain (G_0) in 2011 was 0.06 lower than that estimated in 2010, and the Sa correction was 0.07 dB higher (Table A2.4). This is equivalent to a 0.4% change in calibration coefficients in the linear domain.

Note that the calibration coefficients in Table 4 for NIWA calibrations from 2009–2010 differ from those published in previous reports (Table A2.5). This was because a bug was found in December 2010 in the part of the Matlab calibration software that corrects for the ES60 triangle wave error. The problem was that the code was converting the +0.5 to -0.5 dB error to a ratio (about 0.95 to 1.05) and dividing the backscatter by that ratio. However, because backscatter values are in decibels, the correct thing to do was to subtract the decibel version of the error. This error tended to make the sphere target strength (TS) more variable that it should have been (rather than removing the triangle wave error, it was exaggerating it). The increased variability in the sphere TS caused another filter in the code to come into effect (one that discarded all sphere echoes more than 0.75 dB off the expected sphere TS). Since the exaggerated ES60 triangle wave correction was larger than 0.75 dB, this resulted in more than two-thirds of the sphere echoes being rejected. The bug caused small (less than 0.5 dB) errors in the calculated coefficient parameters. The bug affected all ES60 calibrations carried out by NIWA from March 2008 to December 2010. The values in Table A2.4 were all recalculated in August 2011 using corrected code.

Comparison with other 2011 calibrations

Two calibrations of the echosounder on *Thomas Harrison* were carried out by Fisheries Resource Surveys (FRS) as part of the 2011 survey of Challenger orange roughy. The ES70 was calibrated on 25 June. As for the first NIWA calibration on 13 August, the echosounder had automatically reverted to a short pulse length (0.256 ms). The calibration was repeated on 17 July using the ES60 echosounder connected to the same transducer with the correct pulse length (1.024 ms). However data during this second calibration was only on-axis and did not fully map the beam pattern. Both calibrations were carried out with a copper sphere.

Raw data from both calibrations were provided to NIWA by Mike Soule (FRS), along with calibration parameters estimated from the Simrad Lobe calibration software. Calibration parameters were re-estimated for both calibrations using the NIWA Matlab software.

Results are compared in Table A2.6 (0.256 ms pulse) and Table A2.7 (1.024 ms pulse). Reassuringly both Lobe and the NIWA Matlab software gave similar results from the same dataset (Table A2.7). However both NIWA calibrations gave values of G_0 which were higher than the equivalent values from the FRS calibrations: by 0.31 dB for 0.256 ms pulse (Table A2.6) and by 0.24 dB for 1.024 ms pulse (Table A2.7). These differences were too large to be explained by differences in calibration methodology, but it seems unlikely that the calibration shifted over a two-month period. After much discussion, NIWA and FRS agreed to use the average of the two calibrations at 1.024 ms pulse for analysis of both the 2011 Challenger orange roughy survey and the 2011 Cook Strait hoki survey. The agreed values were G_0 = 24.50 dB, and sa correction = -0.54 dB.

There has been a trend of declining G_0 for this transducer and GPT since the new transducer was installed in 2008 (Figure A2.5). 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).

Table A2.1. ES70 transceiver settings and other relevant parameters during the calibration of *Thomas Harrison*. Values in parentheses for bold parameters are from the first calibration attempt when the echosounder automatically adjusted the pulse length.

Parameter	Value
Echosounder	ES70
ES70 software version	1.0.0
Transducer model	ES38B
Transducer serial number	n/a
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 (0.256)**
Transducer peak gain (dB)	**26.5 (24.0)**
Sa correction (dB)	0.0
Bandwidth (Hz)*	**2425 (3675)**
Sample interval (m)*	**0.192 (0.048)**
Two-way beam angle (dB)	–20.60
Absorption coefficient (dB km^{-1})	9.43
Speed of sound (m s^{-1})	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

* Data during snapshot 3 of the survey were inadvertently collected with 2.048 ms pulse length, 1448 Hz bandwidth, and 0.384 m sample interval (see Appendix 3).

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

Parameter	1.024 ms pulse	0.256 ms pulse
Mean sphere range (m)	9.9	21.0
S.D. of sphere range (m)	0.6	1.1
Mean sound speed (m s^{-1})	1 488	1 492
Mean absorption (dB km^{-1})	9.64	9.43
Sphere TS (dB re $1m^2$)	–42.4	-42.4

Table A2.3: Calculated echosounder calibration parameters for *Thomas Harrison* with 0.356 ms pulse length. These values are not applicable to survey data.

Parameter	0.256 ms pulse
Mean TS within 0.21° of centre	-44.89
Std dev of TS within 0.21° of centre	0.15
Max TS within 0.21° of centre	-44.55
No. of echoes within 0.21° of centre	34
On axis TS from beam-fitting	-44.51
Transducer peak gain (dB)	22.93
Sa correction (dB)	-0.48
Beamwidth (º) alongship/athwarthship	6.85/6.77
Beam offset (º) alongship/athwarthship	0.00/0.00
RMS deviation	0.16
Number of echoes	11 227

Table A2.4: Calculated echosounder calibration parameters from NIWA calibrations of *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	15 Aug 11	24 Jun 10	7 Aug 09	25 Jun 09
Mean TS within 0.21° of centre	-46.52	-46.64	-45.06	-45.32
Std dev of TS within 0.21° of centre	0.35	0.24	0.11	0.31
Max TS within 0.21° of centre	-46.14	-46.05	-44.93	-44.46
No. of echoes within 0.21° of centre	14	176	119	2 742
On axis TS from beam-fitting	-46.39	-46.46	-44.81	-45.20
Transducer peak gain (dB)	24.62	24.68	25.24	25.48
Sa correction (dB)	-0.52	-0.59	-0.60	-0.64
Beamwidth (º) alongship/athwarthship	6.90/6.81	7.07/6.98	6.68/6.69	6.94/7.04
Beam offset (º) alongship/athwarthship	0.00/0.00	0.00/0.00	-0.05/-0.00	0.00/0.00
RMS deviation	0.21	0.18	0.18	0.17
Number of echoes	3 613	22 728	18 221	34 909

Table A2.5: Comparison of echosounder calibration parameters for calibrations in 2009 and 2010 re-calculated in 2011 (NEW) with values previously published (OLD). OLD values were estimated using a version of the Matlab calibration software that contained a bug (see text for details).

Parameter	24 Jun 10		7 Aug 09		25 Jun 09	
	NEW	OLD	NEW	OLD	NEW	OLD
Transducer peak gain (dB)	24.68	25.04	25.24	25.25	25.48	25.02
Sa correction (dB)	-0.59	-0.59	-0.60	-0.61	-0.64	-0.64
Beamwidth (º) alongship/athwarthship	7.1/7.0	6.6/7.0	6.7/6.7	6.9/6.9	6.9/7.0	7.1/7.3
Beam offset (º) alongship/athwarthship	0.0/0.0	0.0/0.0	-0.0/-0.0	0.0/0.0	0.0/0.0	0.0/0.0
RMS deviation	0.18	0.21	0.18	0.24	0.17	0.22
Number of echoes	22 728	4 677	18 221	4 040	34 909	6 627

Table A2.6: Calculated echosounder calibration parameters for *Thomas Harrison* with 0.256 ms pulse length comparing data collected in 2011 by FRS and NIWA. All parameters estimated using Matlab.

Parameter	FRS	NIWA
Date	25 Jun 2011	13 Aug 2011
Sphere type	Copper	Tungsten carbide
Sphere TS	-33.6	-42.4
Mean TS within 0.21° of centre	-36.39	-44.89
Std dev of TS within 0.21° of centre	0.05	0.15
Max TS within 0.21° of centre	-36.35	-44.55
No. of echoes within 0.21° of centre	2	34
On axis TS from beam-fitting	-36.06	-44.51
Transducer peak gain (dB)	22.62	22.93
Sa correction (dB)	-0.37	-0.48
Beamwidth (º) alongship/athwarthship	6.99/6.93	6.85/6.77
Beam offset (º) alongship/athwarthship	-0.03/0.02	0.00/0.00
RMS deviation	0.09	0.16
Number of echoes	1 021	11 227

Table A2.7: Calculated echosounder calibration parameters for *Thomas Harrison* with 1.024 ms pulse length comparing data collected in 2011 by FRS and NIWA. Parameters for FRS data estimated using both Matlab and Lobe.

Parameter	FRS		NIWA
	Lobe	Matlab	Matlab
Date		17 Jul 2011	15 Aug 2011
Sphere type		Copper	Tungsten carbide
Sphere TS		-33.6	-42.4
Mean TS within 0.21° of centre	-38.06	-37.97	-46.52
Std dev of TS within 0.21° of centre	0.11	0.12	0.35
Max TS within 0.21° of centre	-37.92	-37.83	-46.14
No. of echoes within 0.21° of centre	165	146	14
On axis TS from beam-fitting	N./A	-37.96	-46.39
Transducer peak gain (dB)	24.27	24.38	24.62
Sa correction (dB)	-0.56	-0.57	-0.52
Beamwidth (º) alongship/athwarthship	7.3/6.9	7.16/7.07	6.90/6.81
Beam offset (º) alongship/athwarthship	-0.09/-0.06	0.03/-0.04	0.00/0.00
RMS deviation		0.06	0.21
Number of echoes		950	3 613

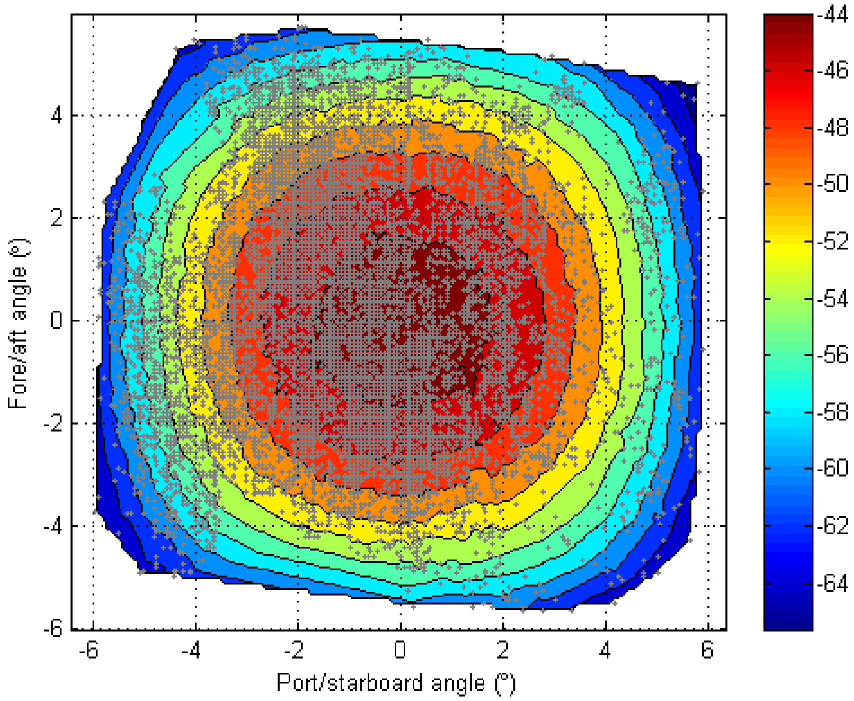


Figure A2.1. The estimated beam pattern from the sphere echo strength and position for the calibration of *Thomas Harrison* with 0.256 ms pulse length. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

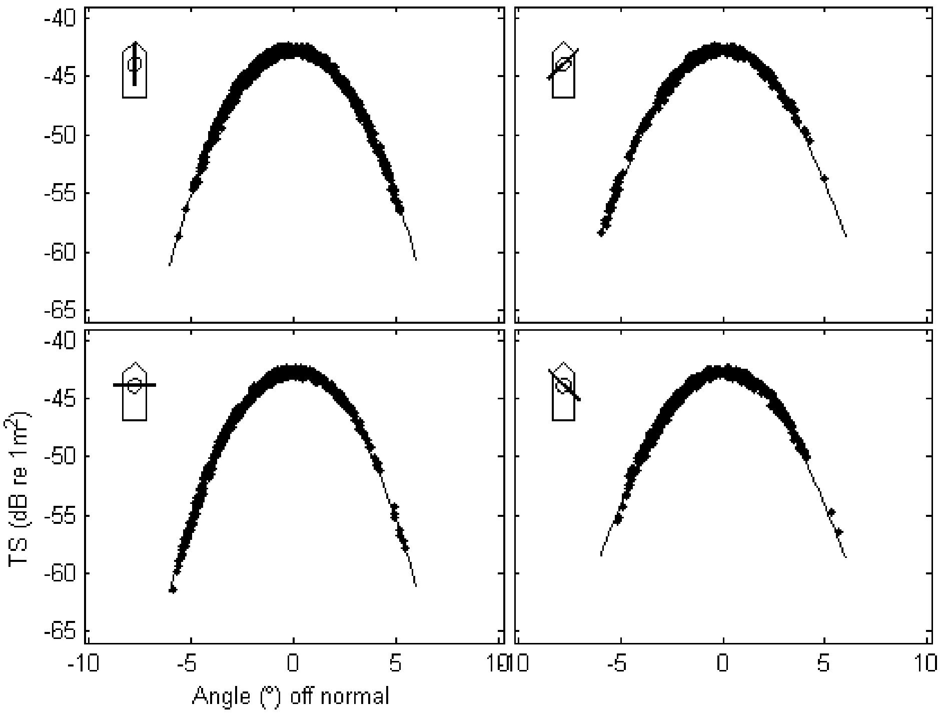


Figure A2.2. Beam pattern results from the calibration analysis for *Thomas Harrison* with 0.256 ms pulse length. The solid line is the theoretical beam pattern fit to the sphere echoes for four slices through the beam.

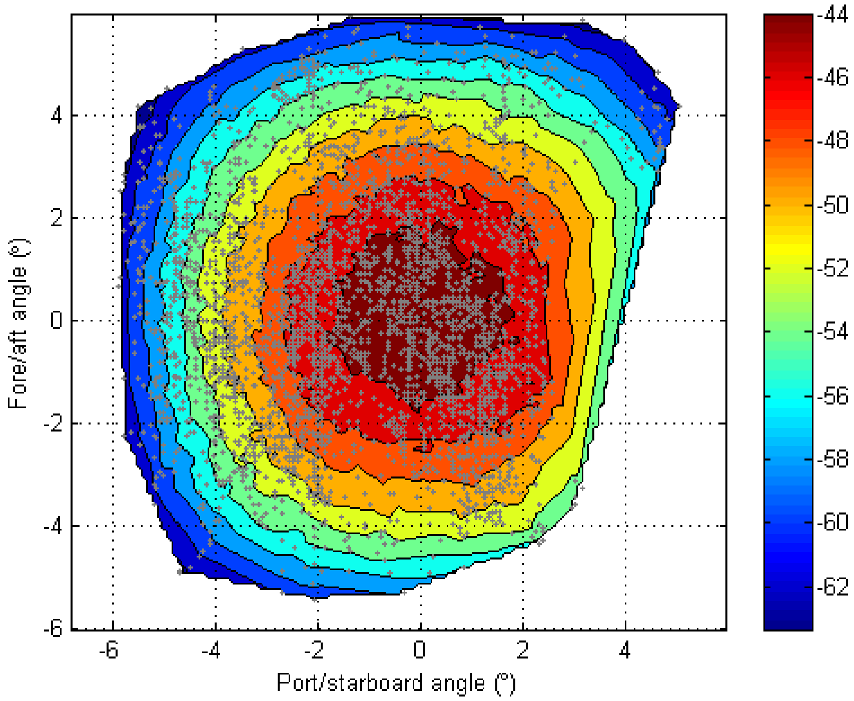


Figure A2.3. The estimated beam pattern from the sphere echo strength and position for the calibration of *Thomas Harrison* with 1.024 ms pulse length. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

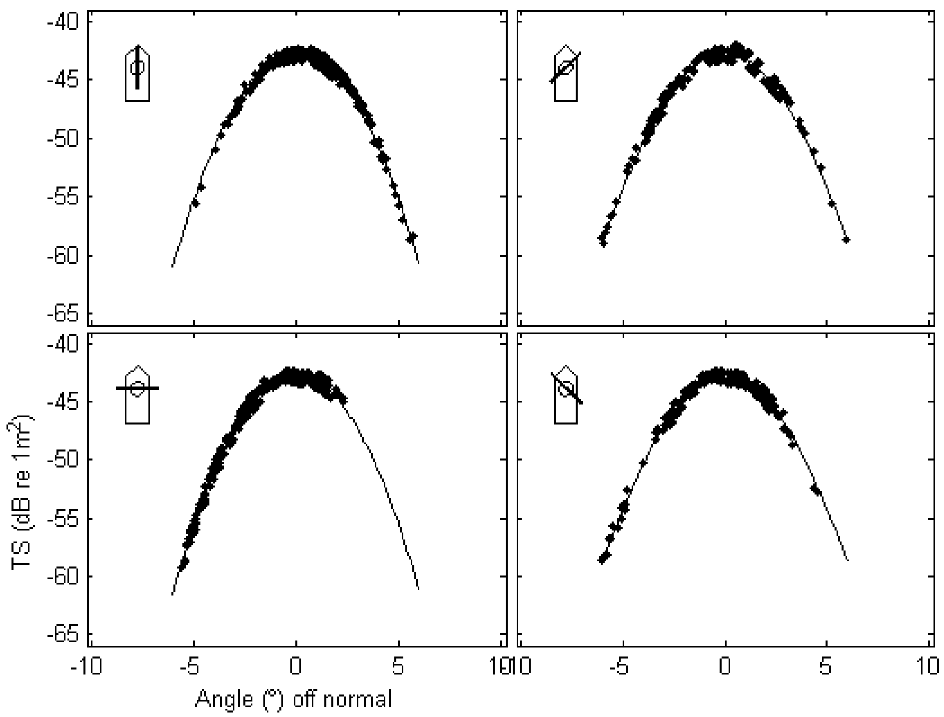


Figure A2.4. Beam pattern results from the calibration analysis for *Thomas Harrison* with 1.024 ms pulse length. The solid line is the theoretical beam pattern fit to the sphere echoes for four slices through the beam.

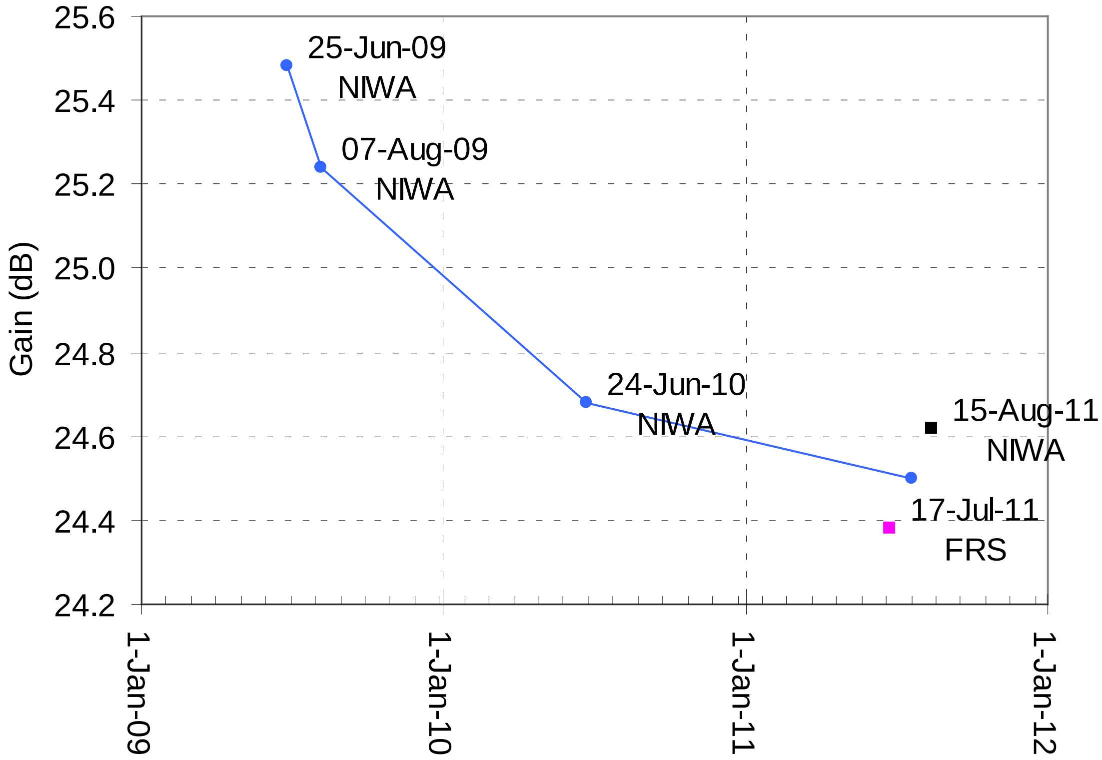
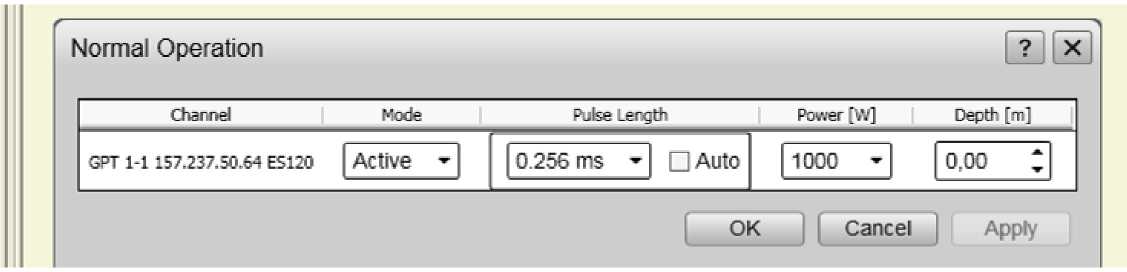


Figure A2.5: Comparison of calibration results (G_0) for calibrations of *Thomas Harrison* from 2009 to 2011.

APPENDIX 3: Pulse length correction for Snapshot 3

Acoustic data were collected from *Thomas Harrison* using a Simrad ES70 and the software was unfamiliar to both the vessel crew and the NIWA scientist onboard. When the system was first set up after sailing on 10 August, the ES70 was configured to recommended survey settings (2000 W power and 1.024 ms pulse) and the time of the ES70 was adjusted to the GPS. However, the auto adjustment box for pulse length in the operation menu (see below) was checked which meant that the echosounder was automatically adjusting the pulse length depending on the depth settings. This feature does not exist on the ES60 or on the scientific version of the echosounder, the EK60. Furthermore, when the auto adjustment box is checked, the value shown in the adjacent box is *not* the current pulse length setting, but rather the value last set manually. This meant that, although the displayed pulse length in the operation menu was 1.024 ms, the actual pulse length being used was different (and not displayed anywhere).



This issue was detected after the first calibration on 13 August (see Appendix 2) and the auto adjustment box was unchecked. However, on subsequent analysis of acoustic data from snapshot 3 (the first snapshot carried out from *Thomas Harrison*), it was discovered that data from this snapshot had been collected with a 2.048 ms pulse.

The chosen pulse length affects the calibration parameters because (in simple terms) more sound is put into the water with a longer pulse. No calibration data were available for the echosounder on *Thomas Harrison* with a 2.048 ms pulse. Instead we calculated a calibration correction for snapshot 3 based on comparable calibrations of an ES60 echosounder on the Sealord vessel *Rehua* where data were collected at both 1.024 ms and 2.048 ms pulse lengths in 2010 and 2011. Analysis of calibration coefficients from these paired calibrations gave a correction factor (backscatter from target sphere measured with 1.024 pulse divided by backscatter from target sphere with 2.048 ms pulse) of 0.85 in 2010 and 0.76 in 2011 (Table A3.1). We used the average of these correction factors (0.80) to scale acoustic data collected during snapshot 3 by *Thomas Harrison*.

Table A3.1: Calculated echosounder calibration parameters for *Rehua* with 1.024 ms and 2.048 ms pulse length used to estimate correction factor for snapshot 3 carried out by *Thomas Harrison*. Calibrations carried out with a tungsten carbide sphere (TS = -42.4 dB). All parameters estimated using Matlab calibration software version 6818.

Parameter	28 Sep 2010		29 Sep 2011	
Pulse length (ms)	1.024	2.048	1.024	2.048
Mean TS within 0.21° of centre	-44.41	-44.00	-44.03	-43.78
Std dev of TS within 0.21° of centre	0.29	0.12	0.06	0.20
Max TS within 0.21° of centre	-44.06	-43.65	-43.91	-43.29
No. of echoes within 0.21° of centre	200	28	27	244
On axis TS from beam-fitting	-44.29	-43.74	-44.15	-43.98
Transducer peak gain (dB)	25.67	25.87	25.75	36.06
Sa correction (dB)	-0.61	-0.45	-0.70	-0.41
Beamwidth (º) alongship/athwarthship	6.83/7.20	6.84/6.63	6.80/6.80	6.77/6.65
Beam offset (º) alongship/athwarthship	0.00/0.00	0.00/-0.00	-0.02/-0.12	0.00/0.00
RMS deviation	0.18	0.16	0.22	0.20
Number of echoes	22 466	5 919	16 256	8 686
Correction factor (1.024 ms / 2.048 ms)		0.85		0.76