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Pilot acoustic survey for jack mackerel on the west coast New Zealand (JMA7)

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A pilot survey for jack mackerel (*Trachurus* spp.) was carried out from 29 January to 7 February 2012 using *RV Tangaroa* (TAN1202). The main aim of the voyage was to assess the feasibility of acoustic surveys to measure relative abundance of jack mackerel on the west coast, North Island (JMA7). Twelve acoustic transects covering approximately 840 km were carried out in three strata in the South Taranaki Bight and Tasman Bay. Two diurnal experiments involving repeated transects over the same area were also carried out in regions of moderate to high jack mackerel density. Acoustic data were collected using the multi-frequency *Tangaroa* EK60 hull system operating at 18, 38, 70, and 200 kHz, and pole-mounted side-looking transducers operating at 120 kHz. Most of the jack mackerel were in small schools within 40 m of the seabed during the day which dispersed and moved towards the surface at night. Schools were scattered over a wide area. The pole-mounted side-looking acoustic system allowed us to see shallow schools out to 200 m on either side of the vessel and there was no clear evidence of vessel avoidance.

Forty nine trawls with midwater and bottom gear were carried out to identify acoustic targets and collect biological samples in support of the acoustic survey and experimental work. Mark identification trawling was complicated because of our inability to target and capture individual schools. Jack mackerel were able to evade capture in short tows with small nets during the day and were observed on video swimming out of the net during hauling. It was not possible to separate the two major jack mackerel species (*T. novaezelandiae* and *T. declivis*) acoustically. Research trawl catches usually caught a mix of both species. Other species associated with jack mackerel included barracouta, spiny dogfish, and tarakihi. Only nine specimens of *T. murphyi* (Peruvian or red-tail jack mackerel) were caught during the survey. Jack mackerel made up 68% of the midwater catch (mesopelagic and midwater trawl), but only 11% of bottom trawl catches.

Target strength (TS) measurements were attempted on five trawls using the acoustic-optical system (AOS). Three of the five AOS deployments were successful and produced TS estimates from 53 jack mackerel, 31 barracouta, and 2 squid. The mean TS at 38 kHz of the jack mackerel (mean fork length 28.5 cm) was estimated as -32.1 dB. *In situ* TS data were also collected using the hull echosounder system in a short experiment at night on 5 February. Results from the *in situ* experiment suggested a lower TS for jack mackerel of about -36 dB.

The pilot survey suggests that it is feasible to survey jack mackerel using acoustics, but that it would be very difficult to do any kind of aggregation-based acoustic survey, because there are no concentrations of fish like those seen for southern blue whiting and hoki.

1. INTRODUCTION

There are three species of jack mackerel (JMA) in New Zealand waters; *Trachurus novaezelandiae*, *Trachurus declivis*, and *Trachurus murphyi*. The three species have overlapping distributions, are all caught in varying proportions in several fisheries, and are managed together under the same quota allocation. The majority of jack mackerel landings occur from the central west coast in area JMA7, with a mean reported catch of about 28 000 t per year from 2000–01 to 2010–11 (Ministry for Primary Industries 2012). Little is known about these stocks, with the last comprehensive investigation of jack mackerel in New Zealand being a daytime trawl survey off the central west coast in February–March 1990 (Horn 1991).

Being pelagic (or semi-pelagic) species, jack mackerel appear to be good candidates for acoustic surveys (McMillan et al. 2012). However, these species have plastic behaviours that vary between regions, probably in response to prevailing local conditions and prey availability. Little is known about the vertical and horizontal movements of jack mackerel in area JMA7. This has serious implications for survey design and implementation. For example, acoustic methods work best when fish form dense aggregations away from the ocean floor. However, if fish form schools near the surface at a particular time of day, a significant proportion of the biomass may be located in the surface acoustic blind zone (typically 10 to 15 m deep on research or commercial vessels with hull-mounted transducers). Being close to the surface may also lead to strong avoidance reaction to the survey vessel (e.g., De Robertis et al. 2010). Diel changes in schooling behaviour and vertical distribution can also affect species composition within acoustic marks, thus adding to uncertainty.

The aim of this 10-day voyage was to better understand the vertical distribution and schooling behaviour of jack mackerel (and co-occurring species) in areas of high abundance, with the goal of formulating a scientifically robust acoustic survey methodology. There was no intention to provide abundance estimates from the pilot survey to be used in stock assessment

This report summarises the data collected during the pilot survey on *RV Tangaroa* from 29 January to 7 February 2012 (TAN1202), fulfilling the reporting requirements for Objectives 1–4 of Ministry of Fisheries Research Project JMA2010/01A:

1. To assess the feasibility of acoustic surveys to measure relative abundance of jack mackerel species on the west coast, North Island.
2. To collect data for determining the population age and size structure of jack mackerel and other middle depth species.
3. To collect and preserve specimens of unidentified organisms taken during the trawl survey.
4. To calibrate acoustic equipment used in the pilot acoustic survey.

2. METHODS

2.1 Survey design

The design and methodology used for the pilot survey was based on information collected during the review carried out for project JMA2010/02 (McMillan et al. 2012). The design aimed to investigate likely major areas of uncertainty in acoustic estimates of jack mackerel abundance, namely:

a) Acoustic mark identification;
b) Species composition and mixing between the three jack mackerel species;
c) Diurnal changes in vertical distribution and behaviour and impacts on acoustic detectability;
d) Potential vessel avoidance;
e) Spatial distribution and occurrence away from high density aggregations;
f) Target strength of jack mackerel and associated species.

The core approach was an area-based acoustic survey, consisting of a series of random parallel transects in areas of (historically) high jack mackerel catches to characterize mark types in the area. Small-scale experiments were also carried out where the same transect was surveyed repeatedly over 24-hours to monitor diel change in schooling behaviour and availability of fish to the acoustic sampling volume. A pole-mounted side-looking acoustic system was used to monitor vessel avoidance and near-surface schools. Mark identification tows were performed throughout the survey using three different trawls to assess species composition and fish size distribution. Acoustic target strength data were collected using the trawl-mounted acoustic-optical system (AOS) (O'Driscoll et al. 2013).

The core area was determined by examining jack mackerel catch in recent years (Figure 1) and selecting strata likely to have high jack mackerel abundance. The initial design consisted of two strata in the South Taranaki Bight at depths of 25 to 150 m, which encompassed parts of strata 12, 13, 14, 17, 18, and 19 from the 1990 trawl survey (Figure 2). We chose this survey area so that the initial (core) phase of the pilot study could be completed in approximately four days (inclusive of about 20 mark identification trawls). Stratum 3 in Tasman Bay was included at the end of the voyage when other objectives were completed ahead of schedule, and covered part of stratum 16 of the 1990 trawl survey (Figure 2).

The parallel transect approach of Jolly & Hampton (1990) was used to survey the core area. Transect locations were randomly generated using NIWA's *rtran* program, and were at right angles to the depth contours (i.e., from shallow to deep or vice versa). Transects were run at speeds of 8–10 knots with interruptions for trawls targeted on fish layers.

The best time to acoustically survey jack mackerel is uncertain. Jack mackerel have a protracted spring-summer spawning season, with many species being serial spawners. Gonad stages of *T. novaezelandiae* and *T. declivis* from the 1990 trawl survey (Horn 1991) suggest a peak spawning in December-January; work by Crossland (1981, 1982) showed jack mackerel (mostly *T. novaezelandiae*) spawning occurring from November to February in the Hauraki Gulf and east Northland. Preliminary analyses of commercial catches suggested that March would be a suitable time for surveying, with potentially a lower proportion of other species mixed in with jack mackerel schools (Cordue 2010). The survey period of 29 January to 7 February 2012 was chosen because it was thought to be at a time when jack mackerel would be aggregated. We had also hoped to carry out the survey within the period when the large commercial fishing vessels were still actively participating in the fishery (before they left the area to target squid). This would have allowed us to coordinate our research activities with the fleet and help us to find suitable aggregations for diurnal experiments. Unfortunately the fleet left the area earlier in January 2012 and, as far as we are aware, there were no large commercial vessels fishing for jack mackerel in the survey area during the survey period.

This survey immediately followed the Chatham Rise trawl survey which used similar trawl gear and acoustic equipment, thereby minimising time required for mobilisation.

2.2 Vessel and equipment

The survey was carried out from NIWA's 70-m research vessel *Tangaroa*. There were several reasons for choosing *Tangaroa* over other vessels for this survey. First, the area required to survey jack mackerel was quite large, even when focused on areas of relatively high abundance, and required a dedicated vessel. Second, to accurately monitor and assess changes in schooling behaviour required an adaptive approach that would be compromised during commercial operations. Third, catching jack mackerel requires a towing speed of 4.0–4.5 knots, which prevents the use of smaller research vessels (e.g., *Kaharoa*). Finally, *Tangaroa* is equipped with a multi-frequency acoustic system, which may help discriminate jack mackerel from other pelagic scatterers.

All core and experimental survey transects were carried out using the multi-frequency EK60 hull system operating at 18, 38, 70, and 200 kHz, and pole-mounted side-looking transducers operating at 120 kHz. The pole was positioned through the moon-pool and could be raised and lowered using the vessel crane.

The EK60 echosounder transceivers and electronics for the side-looking system were in the hydro wet-lab. The pole was on the starboard side of the vessel keel and extended approximately 2 m below the hull aperture (1 m below the keel), with two wide-beam (25° beamwidth) 120 kHz transducers mounted on the end of the pole to look sideways. The default tilt of the two transducers was 12.5° down, meaning half power points of main beam go from horizontal to 25° down. The hull and pole systems (and the bridge 12 and 27 kHz echosounders) were synchronised and the hull EK60 120 kHz echosounder was run in passive mode to avoid interference with the side-looking system.

The multifrequency hull echosounders were calibrated in Tasman Bay on 6 February 2012 (Appendix 1). This calibration showed that all five frequencies were operating correctly. Estimated calibration coefficients for the 38-kHz echosounder used for acoustic density estimation differed by less than 3% between calibrations in 2008, 2011, and 2012, and by less than 11% across all four calibrations (including 2010). The calibration coefficients for 70 and 120 kHz from the February 2012 calibration were considerably higher (equating to 15% and 24% linear decreases respectively) than those in May 2008, but very similar to the coefficients estimated for these frequencies in January 2010. The side-looking system was uncalibrated.

2.3 Trawling and biological data collection

Three different sets of trawl gear were used to sample fish marks on the seafloor and in midwater:

1. NIWA 8-seam hoki bottom trawl rigged with a 60 mm cod-end, 50 m bridles and 100 m sweeps. The original design specifications for this trawl included research sampling of jack mackerel.
2. NIWA 119 midwater trawl with a 60 mm cod-end and a vertical opening of about 40 m. This net has been designed to be towed both in midwater and along the seafloor. This net uses 150 m bridles.
3. The NIWA mesopelagic trawl with a headline height of about 12 m, which allowed us to target a narrow depth band in shallow water. This trawl has a cod-end where the mesh-size reduces along its length ending with 10 mm mesh. Early in the trip, the cod-end was tied off further up the cod-end (at 30 mm mesh) because of concerns about potential pressure waves with higher towing speeds. Later in the trip the cod-end was tied at the end (10 mm mesh) and this did not seem to affect catch rates.

At each station all items in the catch were sorted and weighed on Seaway motion-compensating electronic scales accurate to about 0.1 kg. Where possible, finfish, squid, and crustaceans were identified to species at sea. Other benthic and pelagic fauna were identified to species or (at least) family. Unusual or unidentified organisms were inventoried and then preserved (by freezing) for identification ashore (under Ministry of Fisheries contract DAE2010/01).

Biological sampling followed standardised procedures outlined by Hurst et al. (1992) for middle-depth trawl surveys. Samples of up to 200 jack mackerel (of each of the three species) and 50–200 of other important species were randomly selected from the catch to measure length, weight, sex and gonad stage. At least 20 jack mackerel (of each of the three species) from each tow were selected for more detailed biological analysis. Recorded biological information included length, fish weight, sex, gonad stage, gonad weight, and stomach state, condition and contents. Otoliths were also collected from these fish.

2.4 Target strength data collection

Knowledge of target strength (TS) is necessary for converting the backscatter attributable to jack mackerel to an estimate of biomass. Current relationships between target strength and fork length (FL) for *T. murphyi* exist in the literature (e.g., Lillo et al. 1996, Peña 2008, Peña & Foote 2008), but to our knowledge, no published relationship for *T. novaezelandiae* or *T. declivis* is available.

We carried out *in situ* TS measurements on some mark identification trawls using the acoustic-optical system (AOS) developed by NIWA and used successfully for orange roughy on the Chatham Rise in June 2010 (O'Driscoll et al. 2011), and for southern blue whiting on the Campbell Plateau in September 2011 (O'Driscoll et al. 2013). The AOS uses an autonomous EK60 38-kHz echosounder coupled to a high-definition underwater video, which can be mounted in a frame in the headline of a trawl. The trawl is used to herd fish under the AOS where visually verified estimates of TS can be made. The advantage of using the AOS to collect TS data on targeted trawls is that minimal additional time is required outside the survey framework. The AOS was calibrated down to about 80 m depth in stratum 1 on 4 February 2012 (Appendix 2).

In situ TS data were also collected using the hull echosounder system in a short experiment in stratum 1 at night on 5 February 2012. The vessel drifted slowly over the dispersed jack mackerel layer for about 3 hours. The identity and size distribution of these targets was confirmed by trawling.

2.5 Other data collection

A Seabird SM-37 Microcat CTD datalogger (bottom trawls) or RBR temperature logger (midwater trawls) was mounted on the headline of the trawl net to determine the absorption coefficient and speed of sound, and to define water mass characteristics in the area. CTD drops were also carried out in conjunction with all the acoustic calibrations (see Appendices 1–2).

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 from downward-looking echosounders were visually examined, and the bottom determined by a combination of an in-built bottom tracking algorithm and manual editing. Regions were then defined corresponding to different acoustic mark types, with a region manually drawn around each subjectively distinguished school (see Section 3.2). Backscatter at 38 kHz from regions identified as jack mackerel was then integrated to produce an estimate of acoustic density (m^{-2}). During integration acoustic backscatter was corrected for the sound absorption by seawater. The calculated sound absorption for the area based on CTD data was 8.67 dB km^{-1} at 38 kHz. Acoustic backscatter was integrated over 10-ping (vertical slices) by 10 m (horizontal slices) bins. These data were used to produce plots showing the vertical and spatial distribution of acoustic density.

Acoustic data from the side-looking system were not integrated because this system was not calibrated. Schools were identified subjectively and parameters including the minimum and maximum slant range, and across- and along-track school dimensions were extracted manually.

2.7 Target strength data analysis

Acoustic data from the AOS were processed with Echoview V5.1.34. Bottom echoes were identified and excluded using a combination of automatic bottom detection and manual editing. Echoes within the estimated near-field of 2.1 m (Macaulay et al. 2013) were also excluded. A single target detection algorithm – split beam method 2 (Myriax 2012) – with customised thresholds (Table 1) was then applied to the remaining acoustic data. Single echoes were subjected to an alpha-beta tracking algorithm (Myriax 2012) to detect fish tracks (Table 1). Acoustic data for single targets and fish tracks including ping number, time reference, angular position, range, and TS were exported.

The single target and track detections were processed with their respective video data through AOS analysis software designed in Matlab. The video metadata consisted of a configuration file containing camera timing and offsets for each video file and trawl. The acoustic metadata consisted of data identifier (e.g., trawl and track numbers). AOS alignment data was obtained from the tank calibration (Appendix 2). Using these inputs, the AOS software precisely overlaid the acoustic beam and single target positions on their respective video frames.

Optical quality was assessed for each fish track and a quality rank (0–4) was assigned (see O'Driscoll et al. (2013) for details of ranking). Only tracks with a quality rank of 3 or 4 were accepted as being "optically verified". With accurate range derived from the acoustic track and component geometry, pixel counts from the video images were used to estimate fork length of the fish (by taking the mean of three measurements). This technique was tested in the tank during calibration and could estimate the size of objects as small as the calibration sphere (diameter estimated at 40 mm). With only one camera we were not able to accurately assess the orientation of fish, so these measurements were used only as proxies of fish size, assuming their orientation was parallel to the sea-floor.

Mean TS and confidence intervals (95% CI) estimated by bootstrapping were calculated for all single targets, for means of all tracked targets, and for means of all optically verified fish tracks. Because TS (dB) is a logarithmic variable, the mean TS and confidence intervals were estimated from the equivalent linear values, the acoustic backscatter cross-section (σ_{bs} in m^2 m^{-2}). The results were then reconverted into the logarithmic form (TS) with:

$$\mathbf{TS} = \mathbf{10}\ \mathbf{log_{10}}(\sigma_{\boldsymbol{bs}}) \text{ or equivalently } \sigma_{\boldsymbol{bs}} = \mathbf{10}^{\frac{\boldsymbol{TS}}{\mathbf{10}}} \qquad (1)$$

Differences in depth, planar position and spatial displacement between single targets were used to determine swimming angles of optically verified tracks, using trigonometric functions. Angles of all single target pairs per track were calculated, after which the overall swimming angle of each track was described by taking the mean of these. Spatial displacement between single targets resulted from vessel speed and ping rate, assuming that AOS velocity is represented entirely by the speed of the vessel and no change in cable length occurred.

Echoview was also used to analyse *in situ* TS data from the hull 38 kHz echosounder. Single target detection and tracking parameters are summarised in Table 1.

3. RESULTS

3.1 Data collection

All survey objectives were completed. Because the survey immediately followed the Chatham Rise trawl survey (Ministry of Fisheries Research Project HOK2010/05A Voyage TAN1201), with no vessel crew changeover, we were able to minimise time required for mobilisation and departed Wellington ahead of schedule on 28 January. Weather conditions were good during the survey period, with only about four hours lost due to bad weather on 2 February.

Twelve acoustic transects covering approximately 840 km were carried out in three strata in the South Taranaki Bight and Tasman Bay (Figure 3, Table 2). Two diurnal experiments were carried out in areas of moderate to high jack mackerel density in stratum 1 and stratum 2 (Figure 3). The first experiment consisted of 10 transects over about 16 hours and the second experiment had 22 transects over 48 hours (Table 3). A total of 352 acoustic data files (187 hull and 165 side-looking) were recorded during the survey, constituting 16.8 GB of data.

Forty nine trawls were made to identify targets and collect biological samples in support of the acoustic survey and experimental work (Table 4, Figure 4). All three sets of trawl gear were used to sample fish marks on the seafloor and in midwater: 28 tows were carried out with the NIWA 8-seam hoki bottom trawl; 6 tows were carried out with the NIWA-119 midwater trawl; and 15 tows were carried out with the NIWA mesopelagic (fine-mesh midwater) trawl. Tow length ranged from 0.27 to 3.92 n. miles at an average speed of 4.7 knots (Table 4). Acoustic recordings were made for all trawls using the hull-mounted and side-looking transducers. Data from the net-mounted CTD and RBR showed that the water column was stratified with surface temperatures ranging between 15.3 and 18.8 °C and bottom temperatures between 13.3 and 15.9 °C.

3.2 Acoustic mark types

Jack mackerel occurred in small schools during the day, generally near the bottom, which ascended and dispersed at night (e.g., Figure 5). This was consistent with information provided to us by the fishing industry prior to the survey (McMillan et al. 2012). Bottom trawls targeted on jack mackerel schools close to the bottom during the day caught jack mackerel, with relatively high bycatch of species like spiny dogfish, barracouta, and tarakihi (e.g., Figure 6). Midwater trawls at night caught a higher proportion of jack mackerel (e.g., Figure 7). Jack mackerel made up 68% of the midwater catch (mesopelagic and midwater trawl), but only 11% of bottom trawl catches (see Table 4).

Mark identification trawling was complicated because of our inability to target and capture individual schools. Jack mackerel were able to evade capture in short tows with small nets during the day, and were observed on the AOS system swimming out of the net during hauling. To effectively catch jack mackerel required longer tows with larger nets, but this integrated across many small schools or layers so that it was uncertain which fish were coming from which marks. Consequently, it was not possible to separate the two major jack mackerel species (*T. novaezelandiae* and *T. declivis*) acoustically. Research trawl catches usually caught a mix of both species (Figure 8).

Strong midwater layers along the western (deeper) boundary of stratum 2 were associated with mesopelagic fish. A mesopelagic trawl (tow 7) on these marks caught small pearlside (*Maurolicus australis*) and no jack mackerel (Figure 9). ‘Fuzzy’ layers close to the bottom occurred throughout the survey area and were associated with a range of demersal species, particularly spiny dogfish and tarakihi. These species were abundant in bottom trawls in the vicinity of jack mackerel marks, but were seldom caught in midwater (Table 4). Numerous schools were observed on both the hull and side-looking acoustic systems in water shallower than 50 m on transect 3A in eastern Tasman Bay, and these were found to be pilchards (e.g., Figure 10).

3.3 Acoustic transect data

A total of 221 schools tentatively classified as jack mackerel were identified from the 12 acoustic transects. Almost all identifiable schools were detected during daylight hours (05:00 to 21:00 NZDT) (Figure 11). At night jack mackerel schools ascended and dispersed (Figure 12). Because it was often difficult to distinguish dispersed jack mackerel from other species at night, we recommend that future acoustic surveys be carried out in daytime only.

Most schools were relatively small with an average vertical extent (height) of 17 m. We did not encounter any large aggregations and there were certainly no concentrations of fish like those seen for spawning southern blue whiting and hoki. Schools were scattered over a wide area from 40 to 140 m water depth (Figure 13). The schools were mostly within 10–50 m off the bottom during the day, regardless of the water depth (Figure 13), but we did encounter some daytime schools close to the surface on 1 and 4 February.

About 32% of the total backscatter observed in the survey area was attributed to jack mackerel. We did not attempt to estimate acoustic biomass, but estimated densities of jack mackerel were highest along transects in stratum 3 (mean acoustic backscatter, σ_{bs} = 3.17 m^2 km^{-2}), lowest in stratum 2 (σ_{bs} = 0.63 m^2 km^{-2}) and intermediate in stratum 1 (σ_{bs} = 1.38 m^2 km^{-2}). The spatial distribution of backscatter attributed to jack mackerel (Figure 14) was consistent with the spatial pattern of trawl catch rates (see Figure 8).

3.4 Day-night experiments

The two day-night experiments confirmed the diurnal pattern observed on transects (see Figure 6), with both the total acoustic backscatter and the jack mackerel schools being concentrated close to the bottom during the day and migrating into the surface 10–50 m at night (Figure 15). The number of detected jack mackerel schools decreased at night as the fish dispersed. A proportion of the total backscatter remained close to the bottom at night (Figure 15) and this may have been mainly demersal species such as spiny dogfish and tarakihi.

Diurnal experiments also showed that there was a lot of variability between the number of schools and the backscatter observed between consecutive transects on the same line (Figure 16). In the more extensive second experiment, the total backscatter observed at night was higher on transects during the night (defined as 21:00 to 05:00 NZDT) (number of transects, n = 5, mean acoustic backscatter, σ_{bs} = 6.97 m^2 km^{-2}) than during the day (n = 17, σ_{bs} = 5.57 m^2 km^{-2}), but only 38% of the total backscatter was attributed to jack mackerel at night compared to 48% during the day. This suggests that there may be a diurnal bias in acoustic estimates due to our inability to distinguish dispersed jack mackerel at night, or from increased backscatter in the water column as demersal fish move away from the seabed at night, or both. Therefore, as noted in Section 3.3, we recommend that future acoustic surveys be carried out in daytime only. The high variability between consecutive transects (Figure 16) also suggests that individual schools are moving relatively quickly, and are ephemeral in time and space. The small (kilometres) scale distribution of jack mackerel is certainly not stationary.

3.5 Side-looking sonar

The pole-mounted side-looking acoustic system allowed us to see shallow schools out to 200 m on either side of the ship (e.g., Figure 17), although data quality was strongly influenced by the weather. In winds greater than about 15 knots there was a lot of interference on the side-looking system from surface waves.

A total of 247 schools were detected using the side-looking sonar on the 12 survey transects (and joining legs), with a further 119 schools detected during the two day-night experiments. No attempt was made to categorise schools by species, so detected schools included pilchards and other pelagic species as well as jack mackerel.

Figure 18 shows the minimum slant range to each of 366 detected schools. A higher proportion of schools (58%) than expected were detected on the starboard (right) side of the vessel. This may be because the port (left) transducer was looking under the vessel and therefore suffered more interference due to the ship noise and wake (see Figure 17), thereby reducing detectability. The decline in schools detected beyond 100–120 m slant range is also likely to be a function of effective range (signal-to-noise ratio) of the instrument. There was no clear evidence of vessel avoidance, as similar proportions of schools were detected at all ranges from the vessel out to 100 m. This differs from the findings of O'Driscoll & McClatchie (1998) who found that schools of barracouta and jack mackerel in shallow water (30 m deep) off Otago avoided the vessel, and that there was clear range dependence in detectability at ranges from 0 to 30 m.

The spatial distribution of schools detected on side-looking sonar (Figure 19) was broadly similar to the distribution of jack mackerel backscatter derived from the downward looking echosounder (see Figure

14) and trawl catches of jack mackerel (see Figure 8) suggesting that most of the detected schools were jack mackerel. However, the schools detected in the southern part of stratum 3 (Tasman Bay) and around D'Urville Island (Figure 19) were likely to have been pilchards or other small pelagic fish.

3.6 Biological data

The total trawl catch was 10 705 kg (Table 5). This was made up of 86 species or species groups. The most abundant species were spiny dogfish (29% of catch by weight), jack mackerel (both NZ species combined 17%), and barracouta (13%). Only nine specimens of *T. murphyi* (slender, South Pacific, or red-tail jack mackerel) were caught.

A random sample of all quota, commercially important, and selected non-commercial species were measured from all stations. A total of 10 052 fish and squid of 41 different species were measured (Table 6). Of these, 2329 fish were also individually weighed (Table 5), and 996 sets of jack mackerel otoliths were collected for ageing (539 *T. declivis*, 448 *T. novaezelandiae*, and 9 *T. murphyi*). Samples of 257 *T. novaezelandiae* otoliths and 301 *T. declivis* otoliths were subsequently aged (Horn 2012). Unidentified benthic invertebrates were collected and frozen at sea to be identified by experts ashore.

Length frequency distributions of the two major species of jack mackerel are shown in Figure 20. *Trachurus declivis* had three length modes centred at 21, 32, and 42 cm, while most *T. novaezelandiae* were between 30 and 35 cm. Length frequencies for the two species did not differ markedly from those in the 1990 survey (Horn 1991, 2012). For *T. novaezelandiae*, the survey appears to sample the adult population, but peaks and troughs in the age frequency only poorly matched those in data from the 2010–11 commercial fishery (Horn 2012). For *T. declivis*, most of the population appears well sampled, but research catches were dominated by young fish (Horn 2012). Gonad staging showed that almost all *T. novaezelandiae* were pre-spawning (89% of females maturing). *Trachurus declivis* females were immature (33%), resting (17%) and pre-spawning (49% maturing). Very few individuals of either species were in spawning condition (ripe or running ripe).

3.7 Target strength

Target strength (TS) measurements were attempted on five trawls using the acoustic-optical system (AOS) (see Table 4). Only three of the five AOS deployments were successful. The deployment on trawl 10 was unsuccessful because the microprocessor controller did not switch on the echosounder and camera. The deployment on trawl 41 failed because of a leaky connector.

The three successful AOS deployments yielded images and acoustic data from jack mackerel, barracouta, and squid (Figure 21). A total of 15 732 acoustic single targets were detected (Table 7). Of these 942 fish were tracked (comprising 13 297 single targets). Only 86 of these tracks met our quality control criteria (quality rank 3 or 4) to be considered as "optically-verified" targets. Fifty three of these tracked fish (898 single targets) were identified as jack mackerel, 31 (466 single targets) were barracouta and two (11 single targets) were squid. The TS distributions for all single targets, tracked targets, and optically-verified targets for jack mackerel and barracouta are compared in Figure 22. The mean TS from of all distributions was similar (-32.08 to -33.62 dB), however optically-verified targets had a lower proportion of values less than -55 dB.

Target strength was highly variable between the optically-verified tracks for both jack mackerel and barracouta (Figure 23). However, two data clusters were apparent in the distribution of jack mackerel TS (Figure 23b), corresponding to fish above and below a fork length of 30 cm. Therefore TS for all "small" (below 30 cm) and "large" (below 30 cm) jack mackerel were estimated separately in Table 7. The mean TS of all jack mackerel was estimated as -32.08 dB. The 23 tracks from small jack mackerel had mean TS of -32.99 dB and the 30 tracks from large jack mackerel had mean TS of -31.49 dB (Table 7). Tracks from barracouta produced a mean TS of -32.47 dB (Table 7) and tracks from squid resulted in a mean TS of -57.24 dB (95% CI -58.47 dB, -56.29 dB).

Mean fish lengths for barracouta and jack mackerel estimated from pixel counts were about 11% higher than mean measured fish length from catch (Table 7). The length histograms for catch and pixel counts (Figure 23a,d) indicate that the tracked specimen did not represent the catch distribution or vice versa. On average, fish of optically verified tracks were swimming relatively horizontal with mean swimming angles for all tracks of 1.2° (standard deviation 6.8°) (Figure 24).

A logarithmic least-squares fit through the mean target strength values of small and large jack mackerel resulted in a 'optically verified' TS-length relationship of:

$$TS = 11.28 \log_{10} FL - 49.0 \qquad (2)$$

Many single targets were observed on the hull echosounder during the *in situ* experiment on 5 February (e.g., Figure 25). The identity and size distribution of these targets was confirmed by trawling (trawl 43 in Table 4). Figure 26 shows the distribution of mean TS for all detected fish tracks along with the length frequency distributions of jack mackerel in the catch. There were two distinct modes. The first and strongest mode is visible near about -59 dB and the second mode at about -36 dB. The latter mode matches exactly those values published by Peña (2008) for jack mackerel of length 31 cm while the former mode at lower intensities is likely to be caused by euphausids present in the water column. The mean TS estimated from the *in situ* experiment is strongly dependent on the minimum threshold used when averaging. The mean TS of all values greater than -45 dB was about -35 dB. Interpretation of results from the *in situ* experiment is also confounded by the presence of the two jack mackerel species which had very different size distributions (Figure 26).

Figure 27 compares TS estimates from AOS and *in situ* experiments from this voyage with those published in the literature. Estimates from the *in situ* experiment were consistent with earlier TS-FL relationships, but results from the AOS suggested a higher TS for jack mackerel (Figure 27). Our recent results should be interpreted with caution because of the relatively small sample sizes, concerns that the size frequency derived from the trawl may not be representative of the measured population, and uncertainty associated with the natural orientation of the fish. As discussed by Ryan et al. (2009), the disadvantage of AOS measurements of TS is that the behaviour of the fish has been altered by the trawl gear, so they are not in their natural orientation. Actual tilt angle values could not be estimated in our experiments, but swimming angles had a mean of 1° (see Figure 24), suggesting that the fish had near-dorsal incidence, and therefore maximal TS. No information exists on the natural *in situ* orientation of jack mackerel, but if the fish have more variable natural orientation, then we would expect lower TS.

4. CONCLUSIONS

The pilot study showed that jack mackerel in JMA7 could be potentially surveyed using acoustics. The fish formed small schools during the day, which could be distinguished from associated species. Aggregation-based surveys are not appropriate as fish are widespread (at least in February) and schools were ephemeral in time and space. Therefore we recommend that a wide-area survey would be required to cover the distribution of the stock at this time of year. The size of the survey area would be likely to need to be similar to that surveyed in the 1990 trawl survey, 68 800 km^2 (Horn 1991). Acoustic transects would need to be run during the day when fish are in schools to avoid a diurnal bias in acoustic estimates due to our inability to distinguish dispersed jack mackerel at night. This would require a dedicated vessel and a relatively long survey period, so there would need to be detailed analysis of the relative costs and benefits of carrying out such an acoustic survey, compared to a trawl survey, and/or alternative fishery-based monitoring.

Most jack mackerel were immature or in pre-spawning condition at the time of the survey. Fish may be more aggregated when actively spawning, although this may not be the case if spawning occurs serially over several months, as has been suggested for these species (Crossland 1981, 1982). The exact timing of spawning in JMA7 remains unknown.

There did not appear to be major issues with boat avoidance or occurrence of fish close to the surface during the voyage. However, mark identification (particularly discrimination between jack mackerel species) was problematic because individual schools could not be targeted with a trawl. It is therefore unlikely that an acoustic survey could provide separate abundance indices for the three jack mackerel species. Alternative approaches to mark identification, for example using a purse-seine vessel, could be considered.

One potential survey approach for monitoring jack mackerel (all species combined) may be to use a dedicated acoustic research vessel (e.g., *Kaharoa*) in association with a larger, more powerful catcher vessel, which could tow at the speeds necessary to catch jack mackerel, as well as process the resulting catch.

The survey produced useful biological data, which has already been used to estimate the age structure of jack mackerel in JMA7 (Horn 2012). Research catches suggest that the South Pacific species (*T. murphyi*) is no longer a major component of the JMA7 stock.

Further work is required on jack mackerel TS to reconcile differences between estimates derived from AOS, *in situ*, and swimbladder model estimates.

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8. TABLES

Table 1: Single target and fish track detection properties used in Echoview to analyse TS data from AOS and hull 38 kHz echosounder.

Analysis Parameters	AOS	Hull
Single target detection criteria		
Beam compensation model	Simrad LOBE	Simrad LOBE
Lower TS threshold (dB)	-60	-63
Pulse length determination level (dB)	6.0	6.0
Minimum normalized pulse length	0.4	0.6
Maximum normalized pulse length	2.0	1.8
Maximum beam compensation (dB)	12.0	12.0
Maximum standard deviation of angles (degrees)	0.6	2.0
Fish track detection properties		
Alpha	0.7	0.7
Beta	0.5	0.5
Exclusion distance – major and minor axis (m)	2.0	8.0
Exclusion distance – depth (m)	0.3	0.8
Major and minor axis weight (%)	20	20
Range weight (%)	40	40
Target strength weight (%)	20	20
Minimum number of single targets in track	2	8
Maximum gap between single targets (pings)	3	4

Table 2: Summary of transects carried out during the 2012 pilot acoustic survey of JMA7. Transect locations are shown in Figure 3 and trawl locations in Figure 4.

Stratum	Name	Depth boundary	Area (km^2)	No. of transects	No. of trawls
1	South Taranaki Bight	25–75 m	11 270	5	16
2	Offshore	100–150 m	5 029	4	9
3	Tasman Bay	50–75 m	4 544	3	7
Total			20 843	12	32

Table 3: Summary of transects carried out in day-night experiments. Times are NZDT. Location of experimental areas are shown in Figure 3.

Experiment	Stratum	Start time	End time	No. of transects	No. of trawls
DN1	2	30 Jan 16:45	31 Jan 08:34	10	5
DN2	1	2 Feb 22:52	4 Feb 21:49	22	6
Total				32	11

Table 4: Trawl station details and catch of the main species during the during the 2012 pilot acoustic survey of JMA7. Tow positions are plotted in Figure 4. Species: JMD, *Trachurus declivis*; JMN, *T. novaezelandiae*; SPD, spiny dogfish; BAR, barracouta; FRO, frostfish.

Tow	Date	Time (NZST)	Gear type	Stratum	Start Latitude (°S)	Start Longitude (°E)	Tow depth (m)	Tow length (n. mile)	Catch (kg) JMD	JMN	SPD	BAR	FRO	Total
1	29-Jan-12	922	Bottom	2	40 11.87	172 47.00	105	1.7	9	0	116	4	2	183
2	29-Jan-12	1233	Bottom	2	40 12.00	172 28.80	148	1.53	8	0	25	0	0	99
3	29-Jan-12	1558	Bottom	2	39 59.73	172 48.04	129	1.08	7	0	3	226	0	336
4	29-Jan-12	1813	Bottom	2	39 59.94	173 03.89	116	1.46	20	0	51	37	5	318
5	29-Jan-12	2233	Bottom	2	39 50.94	173 21.42	103	1.53	18	0	23	2	3	113
6	30-Jan-12	108	Mesopelagic	2	39 50.99	173 07.38	52	1.56	1	2	0	0	0	3
7	30-Jan-12	355	Mesopelagic	2	39 50.94	172 49.71	63	1.44	0	0	0	0	0	1
8	30-Jan-12	704	Bottom	2	39 40.91	172 55.46	133	1.06	10	10	32	16	13	247
9	30-Jan-12	853	Bottom	2	39 40.78	173 04.25	121	1.49	192	54	177	51	32	597
10	30-Jan-12	1359	Bottom	AOS	39 40.82	173 02.99	123	0.95	0	0	0	0	0	0
11	30-Jan-12	1452	Bottom	AOS	39 40.79	173 05.39	121	1.5	49	9	504	100	0	897
12*	30-Jan-12	1915	Bottom	AOS	39 40.75	173 12.04	109	3.15	0	0	0	0	0	0
13	30-Jan-12	2110	Bottom	DN1	39 40.80	173 05.45	119	1.56	6	0	78	3	10	205
14	30-Jan-12	2334	Mesopelagic	DN1	39 40.81	173 08.32	50	1.54	8	3	0	0	0	11
15	31-Jan-12	358	Mesopelagic	DN1	39 40.58	173 11.46	104	1.42	5	2	5	0	1	14
16	31-Jan-12	800	Mesopelagic	DN1	39 40.80	173 08.50	100	1.7	0	0	0	0	0	0
17	31-Jan-12	914	Bottom	DN1	39 40.88	173 11.50	110	1.41	18	4	88	60	1	232
18	31-Jan-12	1412	Bottom	1	40 03.07	173 33.92	81	1.54	9	3	115	34	4	245
19	31-Jan-12	1658	Bottom	1	39 50.36	173 44.69	89	1.49	0	16	80	27	54	228
20	31-Jan-12	1924	Mesopelagic	1	39 43.87	173 50.67	54	1.62	11	0	0	0	90	102
21	1-Feb-12	133	Mesopelagic	1	39 59.99	174 04.41	50	1.92	7	2	0	4	0	22
22	1-Feb-12	329	Mesopelagic	1	40 04.38	174 00.78	44	2.43	9	9	0	1	0	19
23	1-Feb-12	549	Mesopelagic	1	40 09.85	173 56.57	83	1.52	9	0	0	2	0	14
24	1-Feb-12	745	Bottom	1	40 16.19	173 51.47	98	1.44	26	23	20	15	5	215
25	1-Feb-12	1125	Bottom	1	40 28.09	174 01.61	101	1.56	26	9	130	13	60	342

*Tow with codend open or poor gear performance.

Table 4 cntd: Trawl station details and catch of the main species during the during the 2012 pilot acoustic survey of JMA7.

Tow	Date	Time (NZST)	Gear type	Stratum	Start Latitude (°S)	Start Longitude (°E)	Tow depth (m)	Tow length (n. mile)	Catch (kg) JMD	JMN	SPD	BAR	FRO	Total
26	1-Feb-12	1327	Bottom	1	40 17.55	174 09.92	96	1.36	4	11	44	13	3	171
27	1-Feb-12	1655	Bottom	1	39 59.63	174 24.23	52	1.57	0	0	30	1	0	397
28	1-Feb-12	2147	Mesopelagic	1	40 08.09	174 43.37	55	1.01	0	0	0	2	0	4
29	2-Feb-12	710	Bottom	1	40 08.40	174 42.99	68	1.47	0	0	7	121	35	441
30	2-Feb-12	847	Bottom	1	40 14.60	174 37.66	91	1.5	0	0	80	76	0	411
31	2-Feb-12	12	Bottom	1	40 21.67	174 44.49	93	1.54	11	5	65	18	0	213
32	2-Feb-12	1432	Bottom	1	40 10.76	174 53.07	55	1.53	3	1	0	3	0	781
33	2-Feb-12	2335	Mesopelagic	1	40 06.89	173 48.85	49	1.8	5	9	0	0	0	15
34	3-Feb-12	823	Bottom	DN2	40 14.68	173 52.42	95	1.52	3	7	255	5	21	364
35	3-Feb-12	1737	Midwater	DN2	40 18.17	173 44.86	67	3.92	65	0	0	0	0	67
36*	3-Feb-12	2126	Midwater	DN2	40 12.26	173 54.44	60	0.42	0	0	0	0	0	0
37	4-Feb-12	2236	Midwater	DN2	40 12.48	173 55.13	72	3.13	121	107	0	5	0	242
38*	4-Feb-12	241	Midwater	DN2	40 13.56	173 53.22	69	2.38	6	4	1	0	0	12
39*	4-Feb-12	854	Midwater	DN2	40 17.28	173 50.46	80	1.26	4	0	0	0	0	5
40	4-Feb-12	1159	Bottom	AOS	40 21.00	173 47.93	74	3.15	112	210	855	84	3	1359
41*	4-Feb-12	1700	Bottom	AOS	40 15.45	173 51.84	97	0.27	0	0	0	0	0	0
43	5-Feb-12	100	Midwater	TS	40 11.61	173 57.21	60	2.47	119	17	1	2	0	143
44	5-Feb-12	659	Bottom	3	40 25.26	173 39.91	71	1.61	37	14	74	33	0	259
45	5-Feb-12	932	Bottom	3	40 41.02	173 40.02	56	1.48	21	41	12	11	0	176
46	5-Feb-12	1155	Bottom	3	40 53.17	173 40.03	44	0.8	0	10	241	326	0	671
47	5-Feb-12	1651	Mesopelagic	3	40 52.12	173 39.67	30	1.83	0	5	0	116	0	220
48	5-Feb-12	2112	Mesopelagic	3	40 32.65	173 24.05	47	1.64	41	37	2	2	0	88
49	6-Feb-12	26	Mesopelagic	3	40 14.11	173 23.97	36	2.34	158	22	0	0	0	179
50	6-Feb-12	346	Mesopelagic	3	40 31.56	173 11.91	40	2.14	12	24	5	2	0	48

*Tow with codend open or poor gear performance.

Table 5: Total catch by species for species contributing more than 5 kg during the 2012 pilot acoustic survey of JMA7.

Code	Common name	Scientific name	Catch (kg)
SPD	Spiny dogfish	*Squalus acanthias*	3 121
BAR	Barracouta	*Thyrsites atun*	1 413
JMD	Greenback jack mackerel	*Trachurus declivis*	1 168
POP	Porcupine fish	*Allomycterus jaculiferus*	836
JMN	Yellowtail jack mackerel	*Trachurus novaezelandiae*	669
SCH	School shark	*Galeorhinus galeus*	543
TAR	Tarakihi	*Nemadactylus macropterus*	364
FRO	Frostfish	*Lepidopus caudatus*	343
ONG	Sponges	Porifera (Phylum)	303
GSH	Dark ghost shark	*Hydrolagus novaezealandiae*	267
SDO	Silver dory	*Cyttus novaezealandiae*	205
JDO	John dory	*Zeus faber*	197
SNA	Snapper	*Pagrus auratus*	188
LEA	Leatherjacket	*Meuschenia scaber*	137
NSD	Northern spiny dogfish	*Squalus griffini*	110
PIL	Pilchard	*Sardinops neopilchardus*	91
SPO	Rig	*Mustelus lenticulatus*	79
RSK	Rough skate	*Zearaja nasuta*	70
GUR	Gurnard	*Chelidonichthys kumu*	67
HAP	Hapuku	*Polyprion oxygeneios*	64
CAR	Carpet shark	*Cephaloscyllium isabellum*	54
SSK	Smooth skate	*Dipturus innominatus*	51
ASQ	Arrow squid	*Nototodarus* spp.	42
WAR	Common warehou	*Seriolella brama*	40
SWA	Silver warehou	*Seriolella punctata*	36
SPE	Sea perch	*Helicolenus* spp.	26
MOK	Moki	*Latridopsis ciliaris*	22
KAH	Kahawai	*Arripis trutta*	21
WOD	Wood	Wood	20
SEV	Broadnose sevengill shark	*Notorynchus cepedianus*	18
SCG	Scaly gurnard	*Lepidotrigla brachyoptera*	18
STA	Giant stargazer	*Kathetostoma* spp.	14
HOK	Hoki	*Macruronus novaezelandiae*	13
JMM	Slender jack mackerel	*Trachurus murphyi*	12
TRE	Trevally	*Pseudocaranx georgianus*	11
THR	Thresher shark	*Alopias vulpinus*	8
MAK	Mako shark	*Isurus oxyrinchus*	8
SKI	Gemfish	*Rexea* spp.	7
ERA	Electric ray	*Torpedo fairchildi*	6
CUC	Cucumber fish	*Chlorophthalmus nigripinnis*	5
HTH	Sea cucumber	Holothurian unidentified	5
EMA	Blue mackerel	*Scomber australasicus*	5
Total			10 705

Table 6: Numbers of fish for which length, sex, and biological data were collected.

	Length frequency data				Length-weight data	
	No. of fish measured			No. of	No. of	No. of
Species	Total †	Male	Female	samples	fish	samples
Anchovy	38	0	0	2	-	-
Barracouta	924	421	351	34	388	24
Blue cod	2	0	2	1	-	-
Butterfly perch	1	0	0	1	-	-
Two saddle rattail	5	0	5	1	-	-
Cucumber fish	58	0	0	4	-	-
Blue mackerel	3	2	1	2	3	2
Frostfish	313	94	82	19	166	13
Dark ghost shark	194	66	127	16	-	-
Gurnard	123	50	35	19	-	-
Hapuku	10	7	3	4	10	4
Hoki	143	4	4	2	-	-
John dory	142	39	90	23	9	1
Greenback jack mackerel	2 281	1 061	925	38	1 023	38
Slender jack mackerel	9	5	4	5	9	5
Yellowtail jack mackerel	1 345	773	527	32	536	32
Kahawai	9	3	4	4	7	3
Leatherjacket	329	9	7	6	-	-
Ling	3	0	0	2	-	-
Pearlside	100	0	0	1	-	0
Moki	4	4	0	1	4	1
Arrow squid	154	23	39	16	7	1
Northern spiny dogfish	31	4	27	6	-	-
Pilchard	355	0	1	2	42	1
Ray’s bream	2	1	1	1	2	1
Redbait	25	0	0	3	19	1
Red cod	8	2	3	5	-	-
Scaly gurnard	159	0	0	6	-	-
School shark	13	6	7	2	-	-
Silver dory	847	0	0	12	-	-
Gemfish	1	0	1	1	1	1
Snapper	75	34	41	11	70	8
Spiny dogfish	1 305	429	870	29	-	-
Sea perch	86	15	11	6	-	-
Rig	13	9	3	5	-	-
Silverside	128	0	0	6	-	-
Giant stargazer	3	0	0	2	-	-
Silver warehou	265	3	4	8	-	-
Tarakihi	487	134	172	22	31	1
Trevally	3	0	3	2	2	1
Common warehou	56	26	16	6	-	-
				0	-	
Grand Total	10 052	3 224	3 366	44	2 329	43

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

Table 7: Summary of *in situ* TS data collected with the AOS.

Biological data	Barracouta		Jack mackerel	
Number measured	127		735	
Mean fork length ± s.d. (cm)	50.61 ± 19.9		28.46 ±7.6	
Optically verified	Barracouta	Jack mackerel	Jack mackerel below 30cm	Jack mackerel above 30cm
Samples	466	898	429	469
Tracks	31	53	23	30
Mean target strength (95% CI) in dB	-32.47 (-34.98, -30.41)	-32.08 (-33.36, -30.93)	-32.99 (-34.18, -32.14)	-31.49 (-33.41, -30.0)
Mean fork length (95% CI) in cm	55.81 (54.01, 57.5)	31.57 (30.17, 32.88)	26.24 (25.39, 26.98)	35.65 (34.88, 36.49)
Tracked targets				
Samples	13 297			
Tracks	942			
Mean target strength (95% CI) in dB	-33.0 (-33.21, -32.87)			
Single targets				
Samples	15 732			
Mean target strength (95% CI) in dB	-33.62 (-33.83, -33.42)			

9. FIGURES

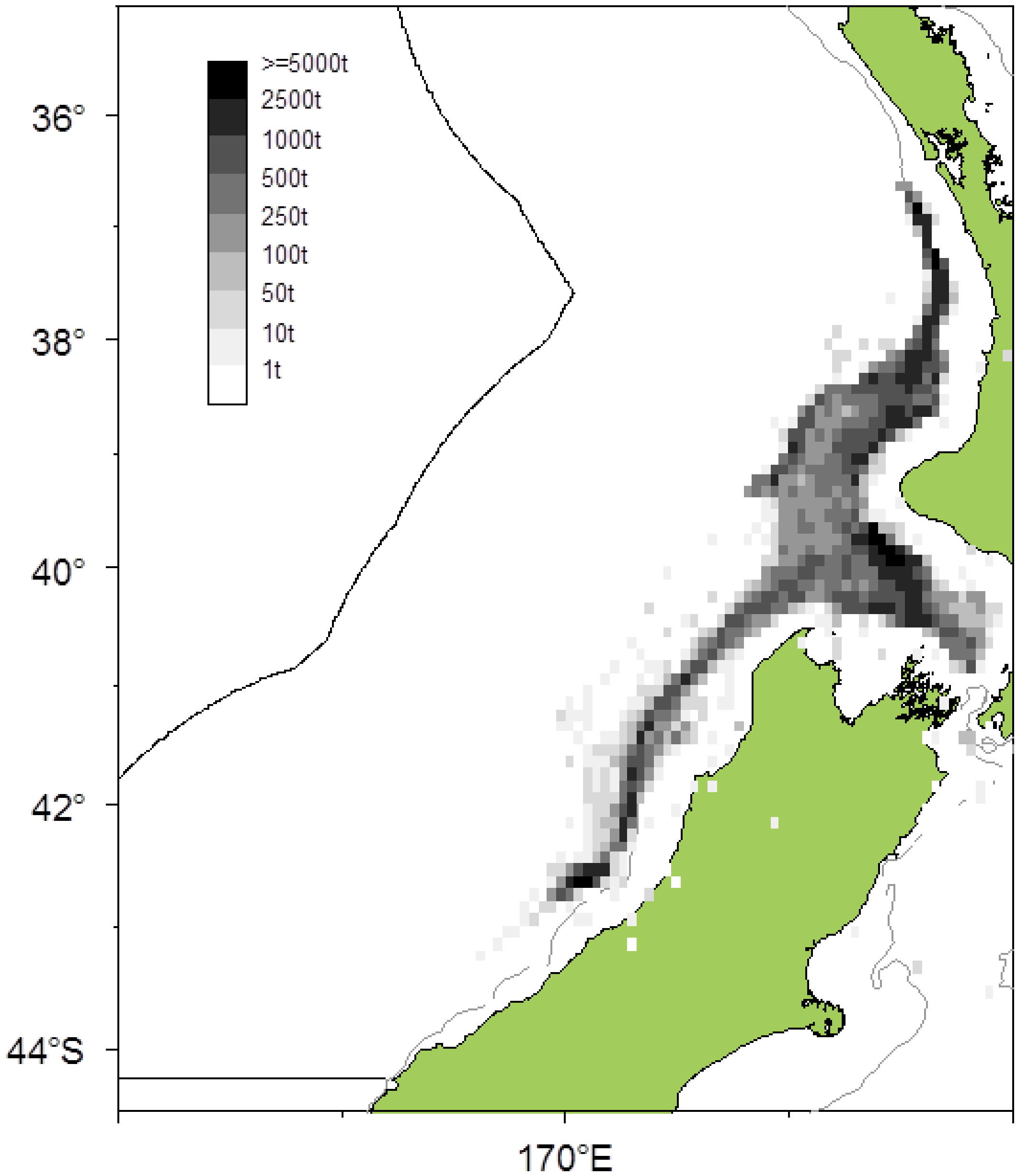


Figure 1: Midwater trawl catches of jack mackerel in JMA7 1990–2009.

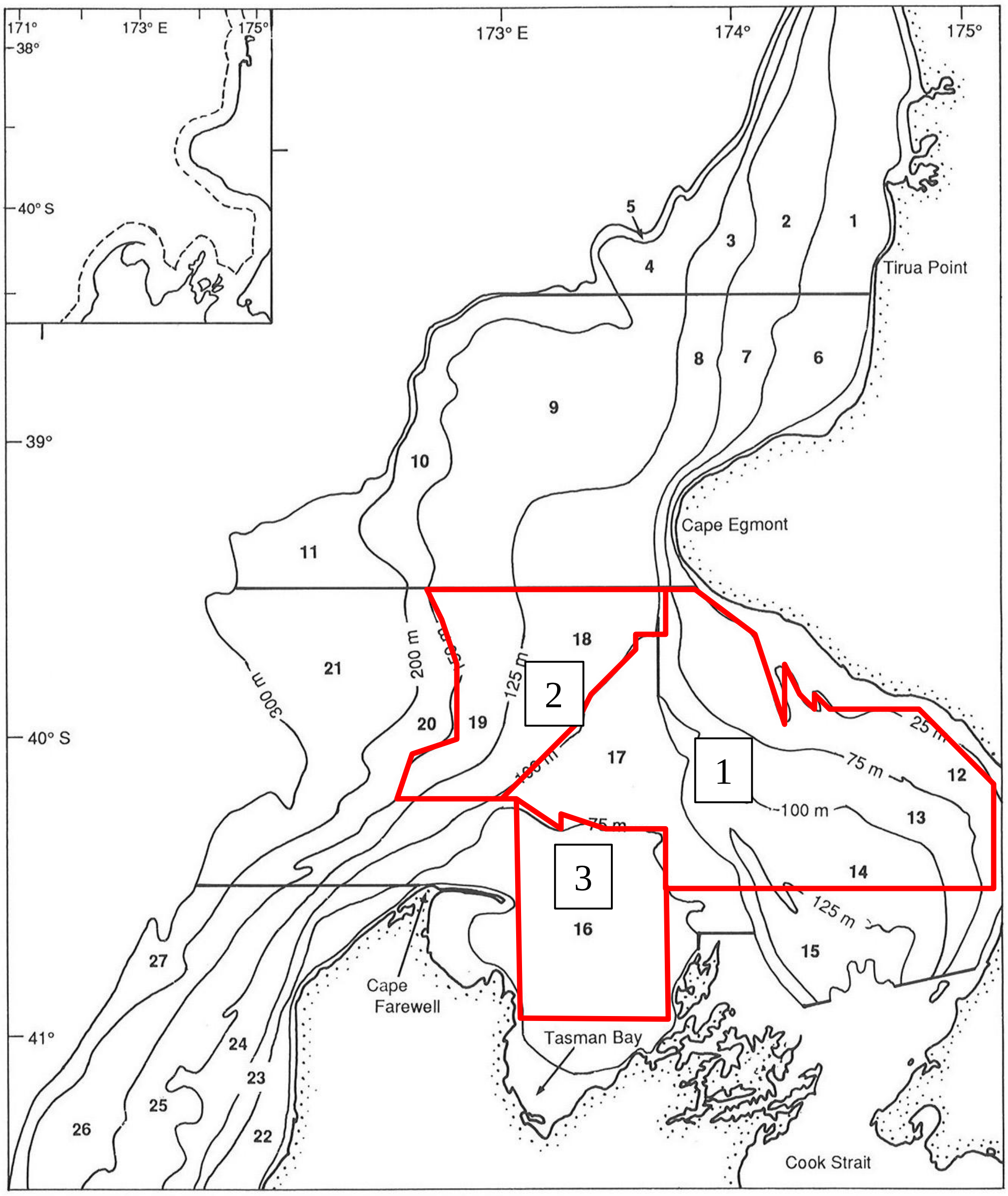


Figure 2: Survey strata (outlined in red and numbered in boxes) compared to stratification from the previous trawl survey in 1990 (from Horn 1991).

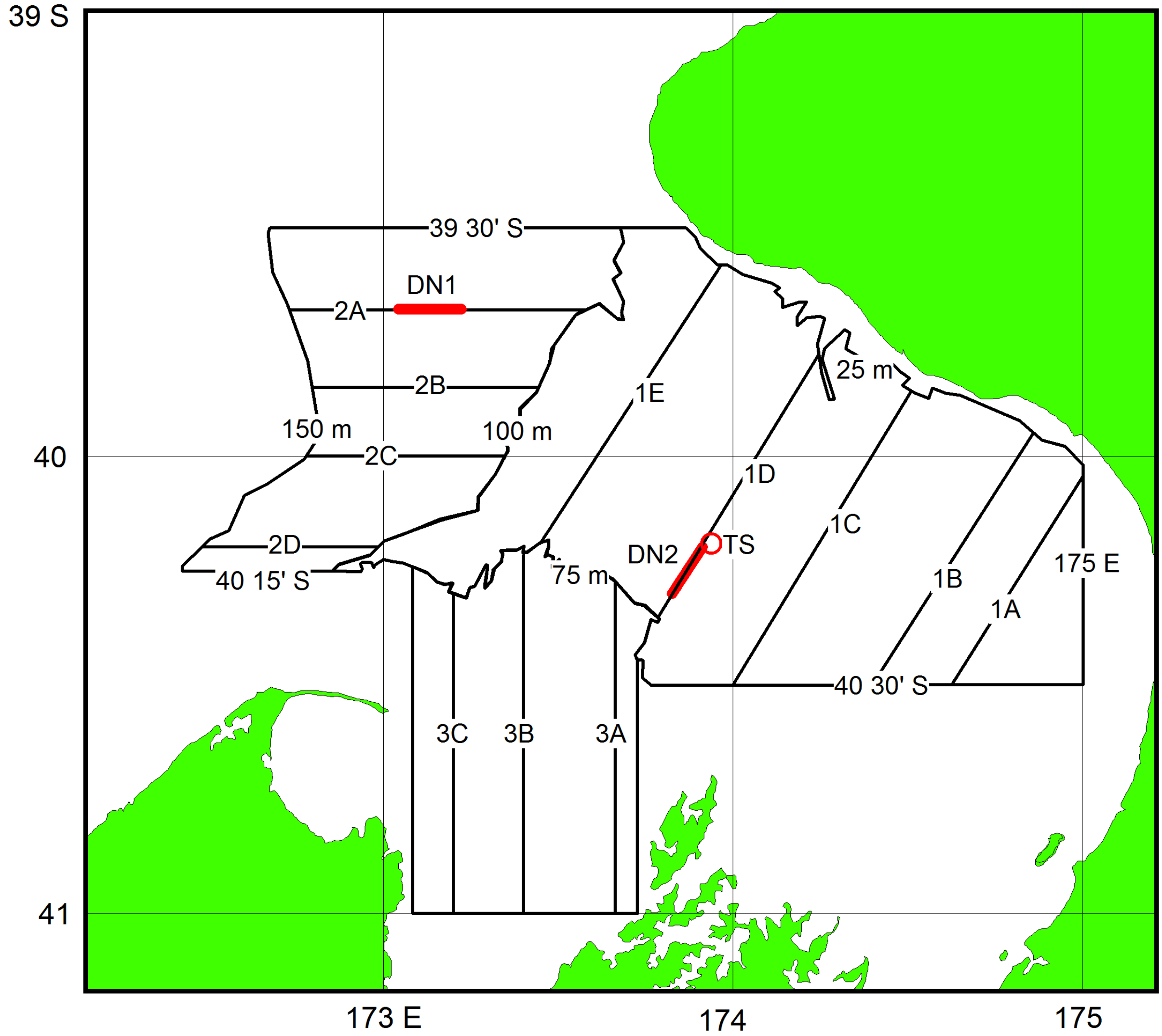


Figure 3: Stratum boundaries and approximate location of transects during the 2012 pilot acoustic survey of JMA7. The two areas where day-night experiments were carried out are indicated as thick red lines labelled DN1 and DN2. The red circle shows the location of the *in situ* target strength (TS) experiment.

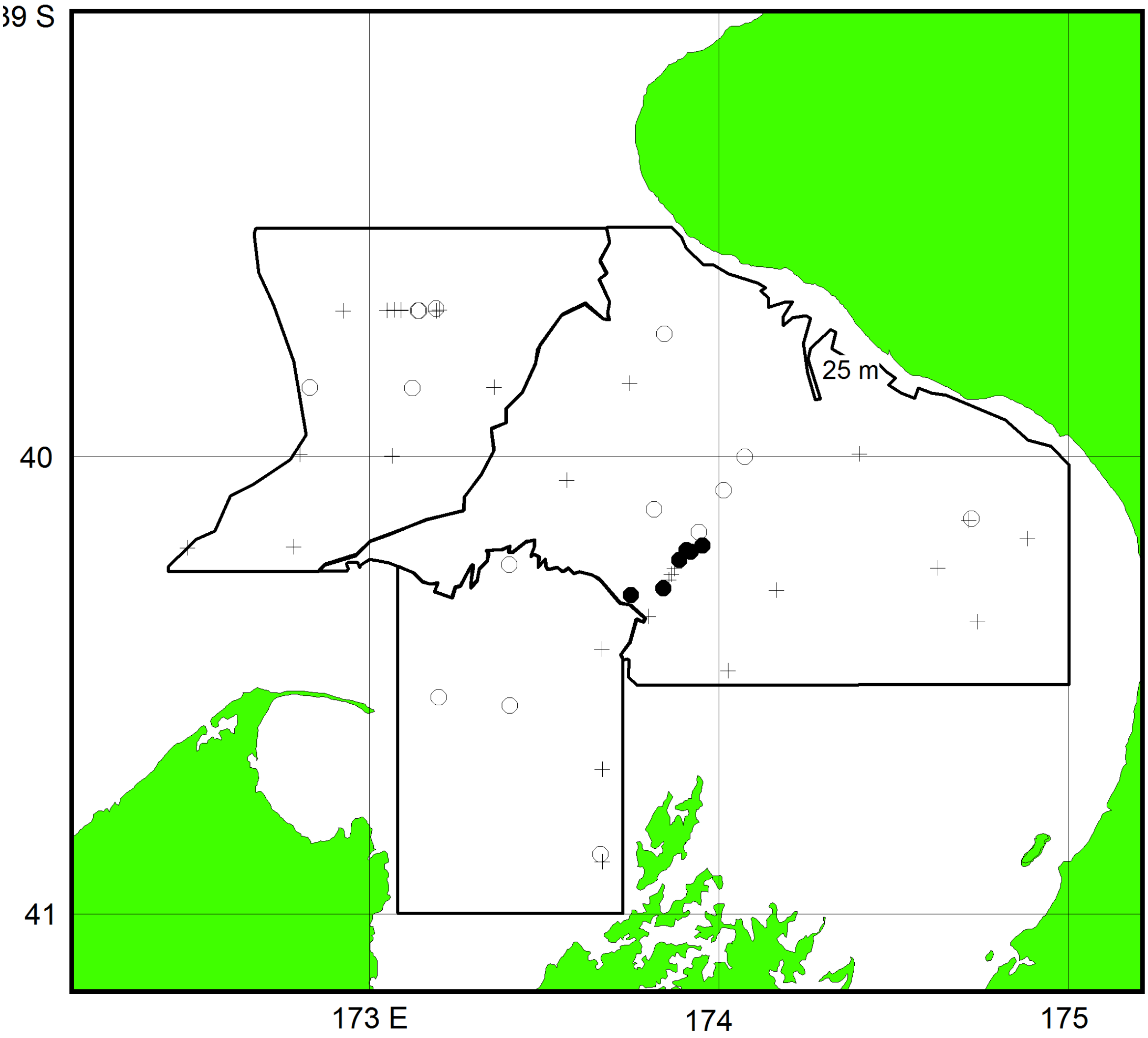


Figure 4: Location of trawls during the 2012 pilot acoustic survey of JMA7. Crosses indicate bottom trawls, open circles are mesopelagic (fine-mesh midwater) trawls, and closed circles are midwater trawls.

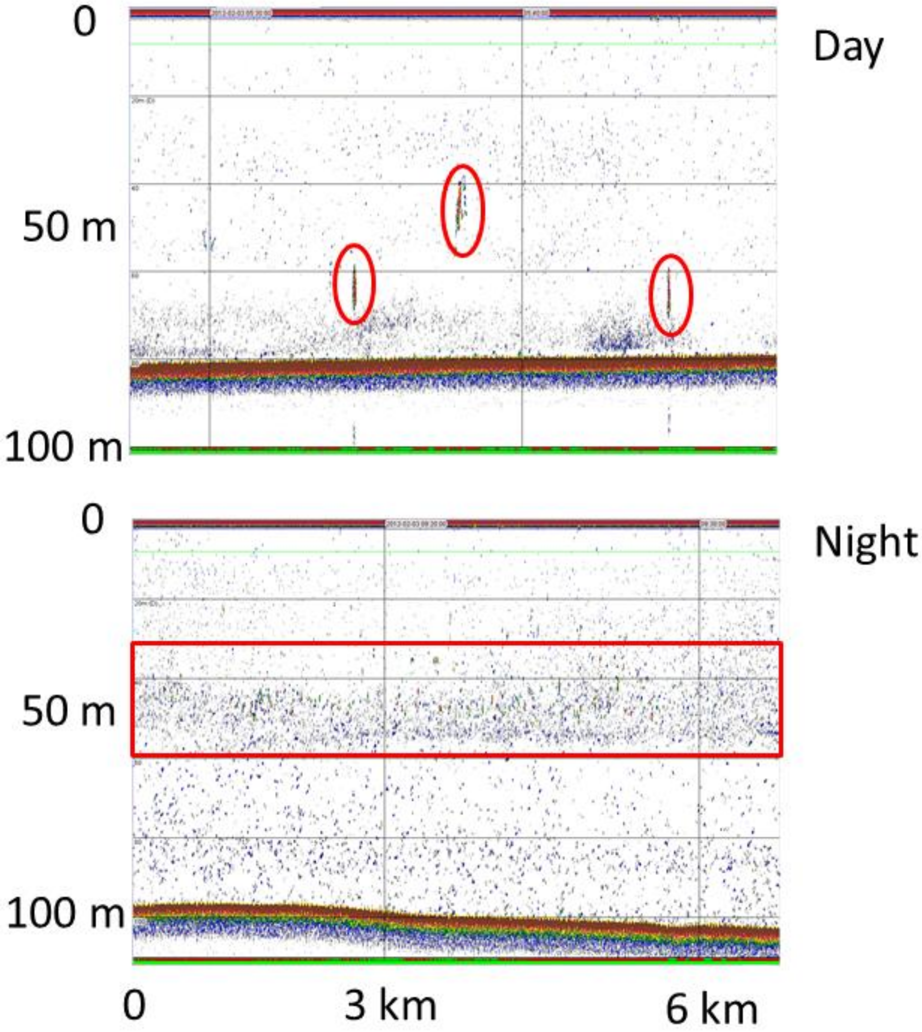


Figure 5: Annotated example echograms showing jack mackerel in schools during the day (red circles) and in a dispersed layer centred around 50 m depth at night (red rectangle) during the day-night experiment (DN2) in stratum 1 on 3 February. Echograms are from hull-mounted 38 kHz echosounder.

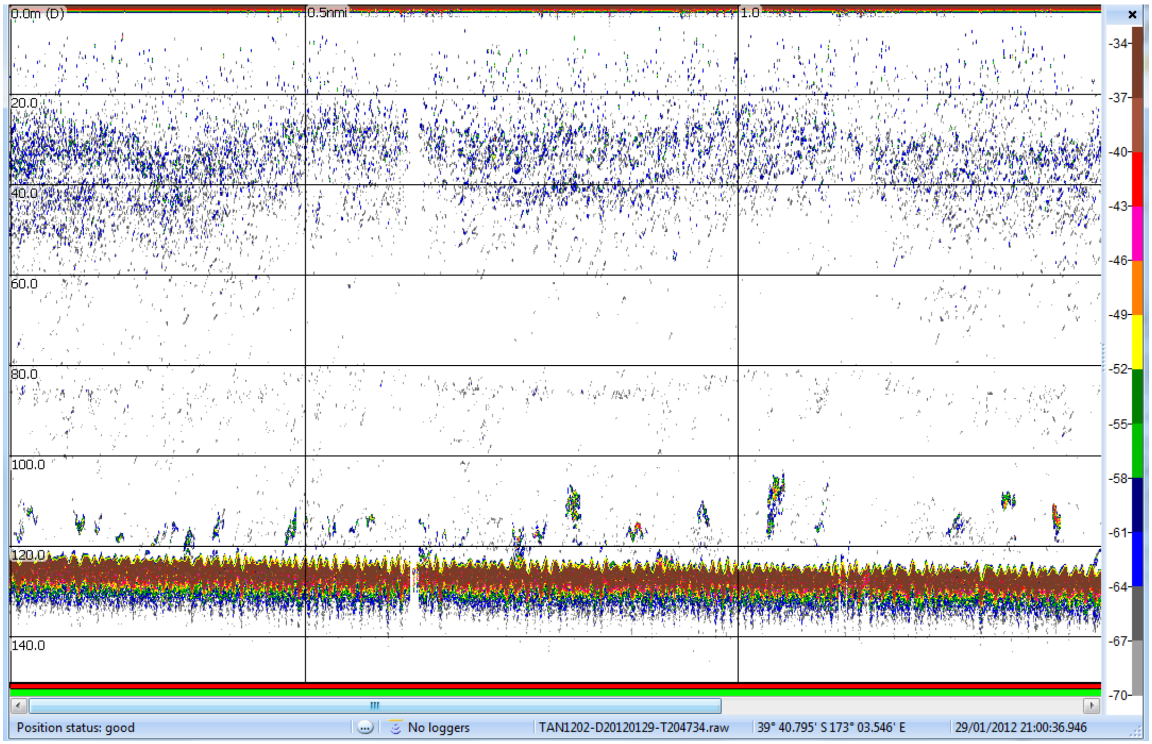


Figure 6: Echogram recorded during trawl 9 in stratum 2 at 09:00 NZDT on 30 January 2012 showing daytime jack mackerel schools close to the bottom. A bottom trawl on this mark caught 41% jack mackerel by weight, with bycatch of spiny dogfish and barracouta (see Table 4).

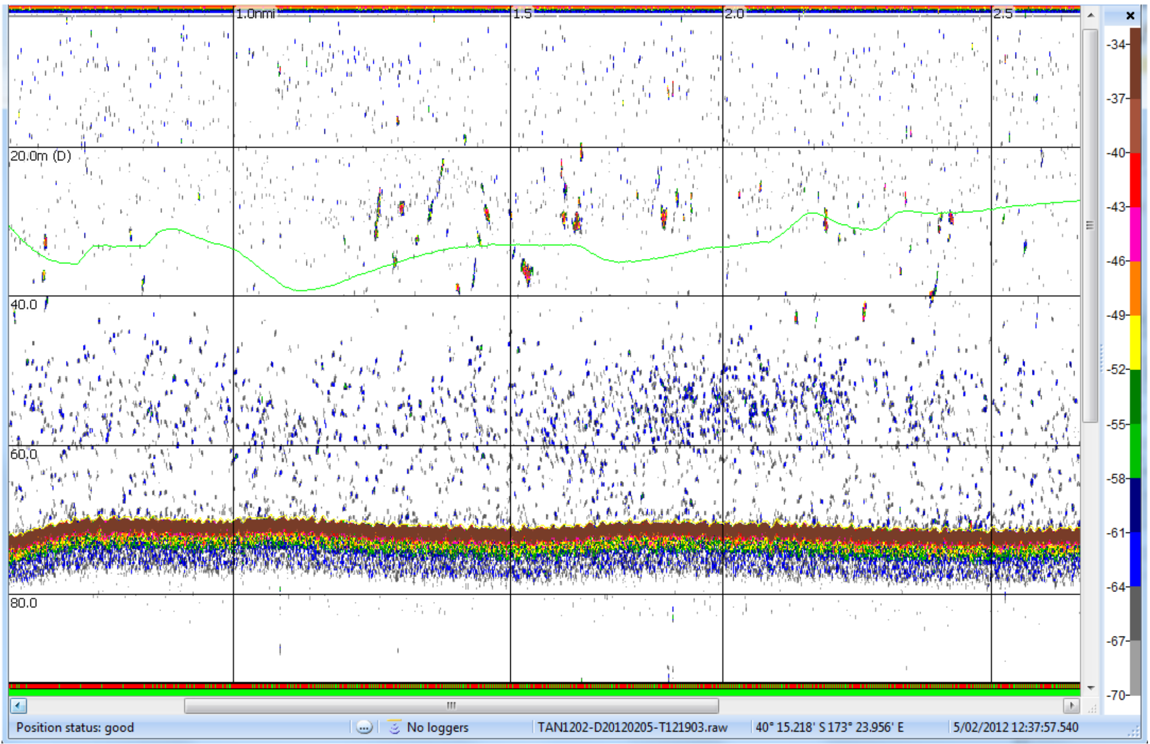


Figure 7: Echogram recorded during trawl 49 in stratum 3 at 00:37 NZDT on 6 February 2012 showing night-time jack mackerel schools in a band from 20–40 m. A mesopelagic trawl on this mark (trawl path shown by green line) caught 100% jack mackerel by weight (see Table 4).

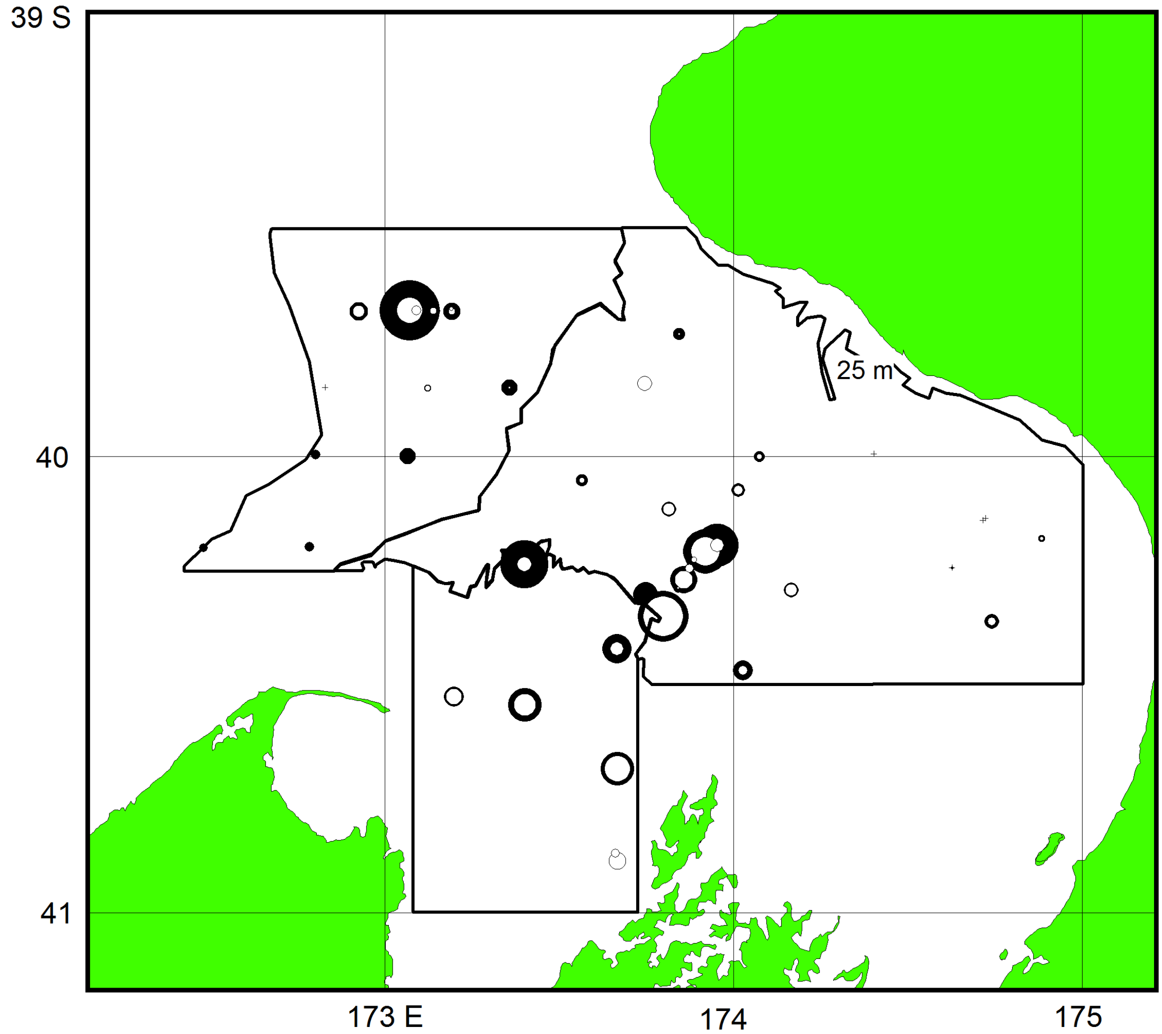


Figure 8: Catch rates of *Trachurus declivis* and *T. novaezelandiae* during the 2012 pilot acoustic survey of JMA7. Circle area is proportional to catch of the two species combined, with the catch of *T. novaezelandiae* shown as the white portion of the circle and the catch of *T. declivis* as the black portion.

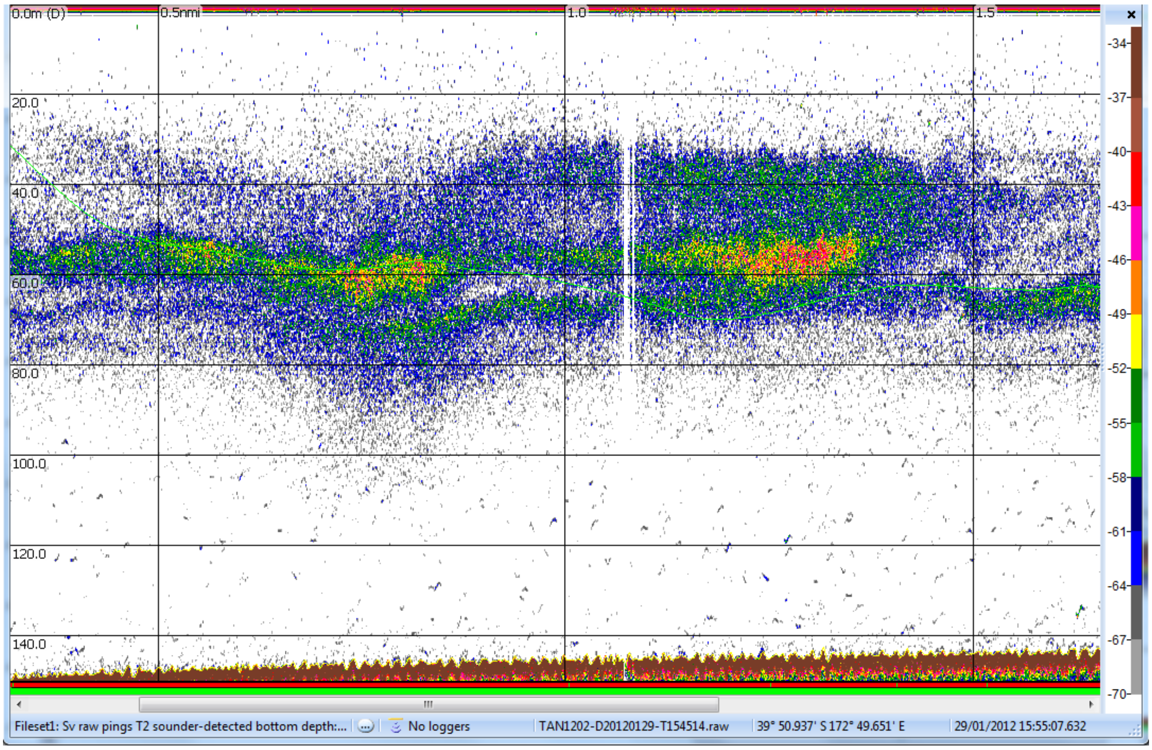


Figure 9: Echogram recorded during trawl 7 in stratum 2 at 03:55 NZDT on 30 January 2012 showing marks from mesopelagic fish at 30–80 m. A mesopelagic trawl on this mark (trawl path shown by green line) caught mainly pearlside and no jack mackerel (see Table 4).

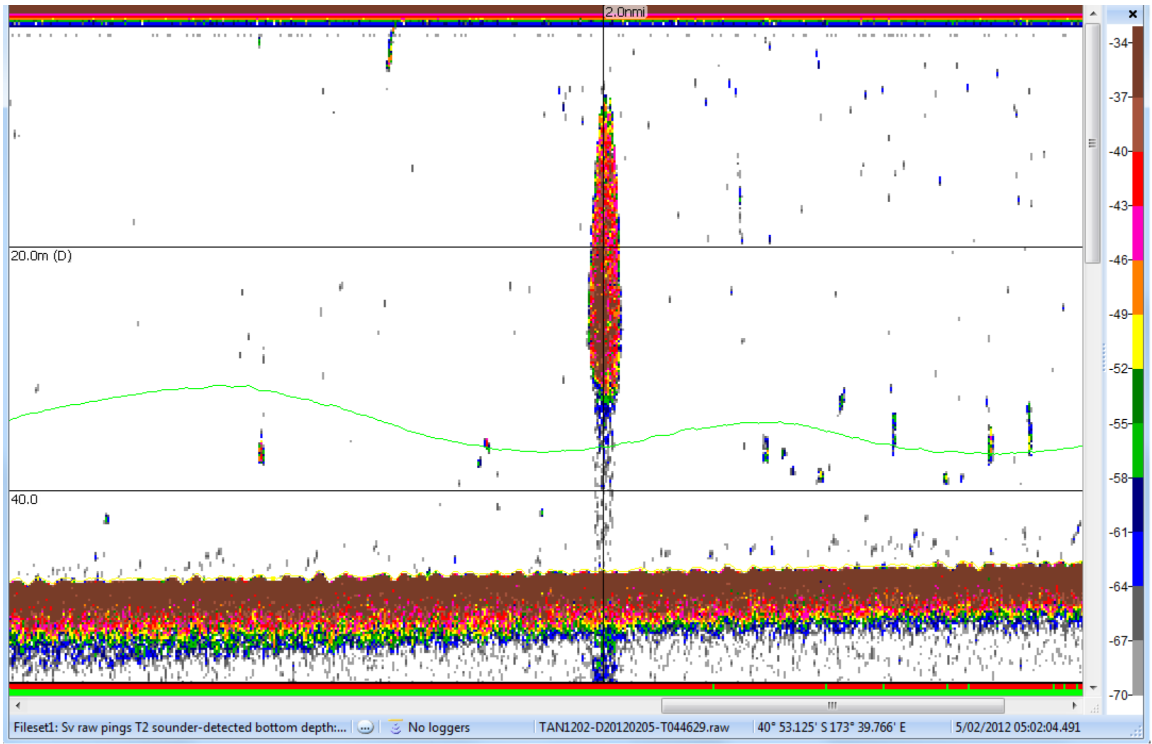


Figure 10: Echogram recorded during trawl 47 in stratum 3 at 17:02 NZDT on 5 February 2012 showing a large school of pilchards. A mesopelagic trawl on this mark (trawl path shown by green line) caught 88 kg of pilchards, 116 kg of barracouta, and only 5 kg of jack mackerel (see Table 4).

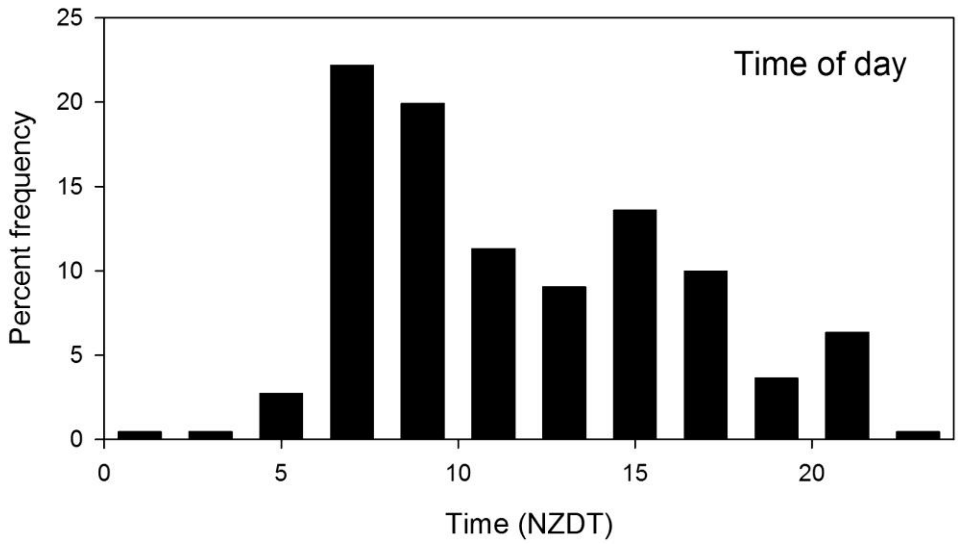


Figure 11: Frequency histograms showing distribution of schools detected on the hull-mounted echosounders during acoustic transects in relation to time of day.

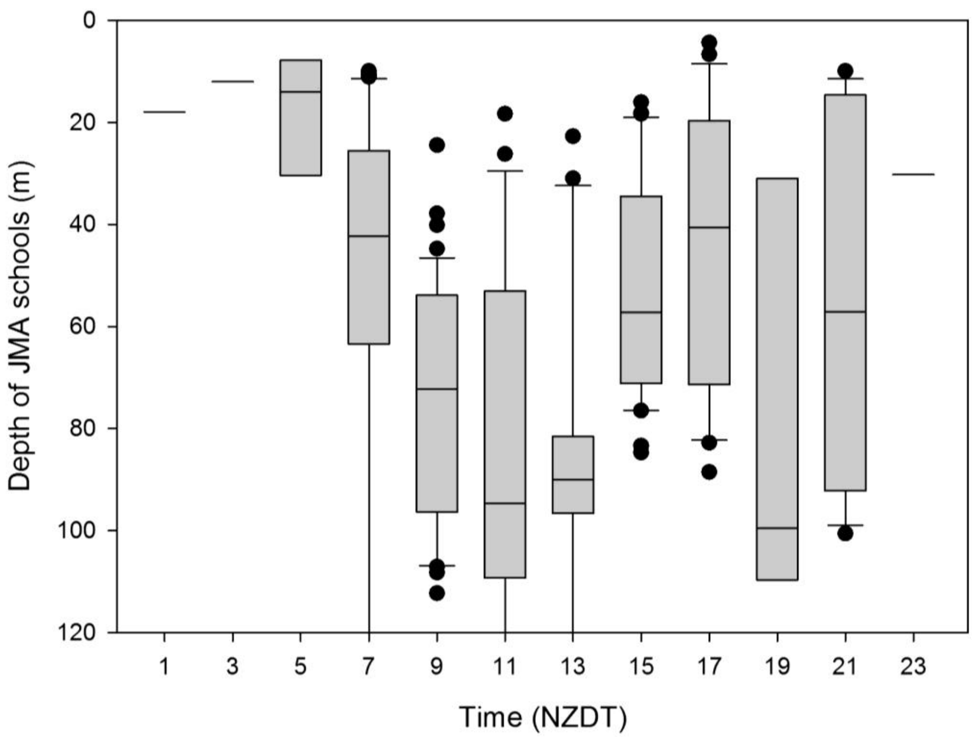


Figure 12: Boxplots showing diurnal pattern in vertical distribution of schools detected on the hull-mounted echosounders along acoustic transects. Bars are 25th to 75th percentiles divided by the median. Whiskers are 5th to 95th percentiles, with outliers shown as dots.

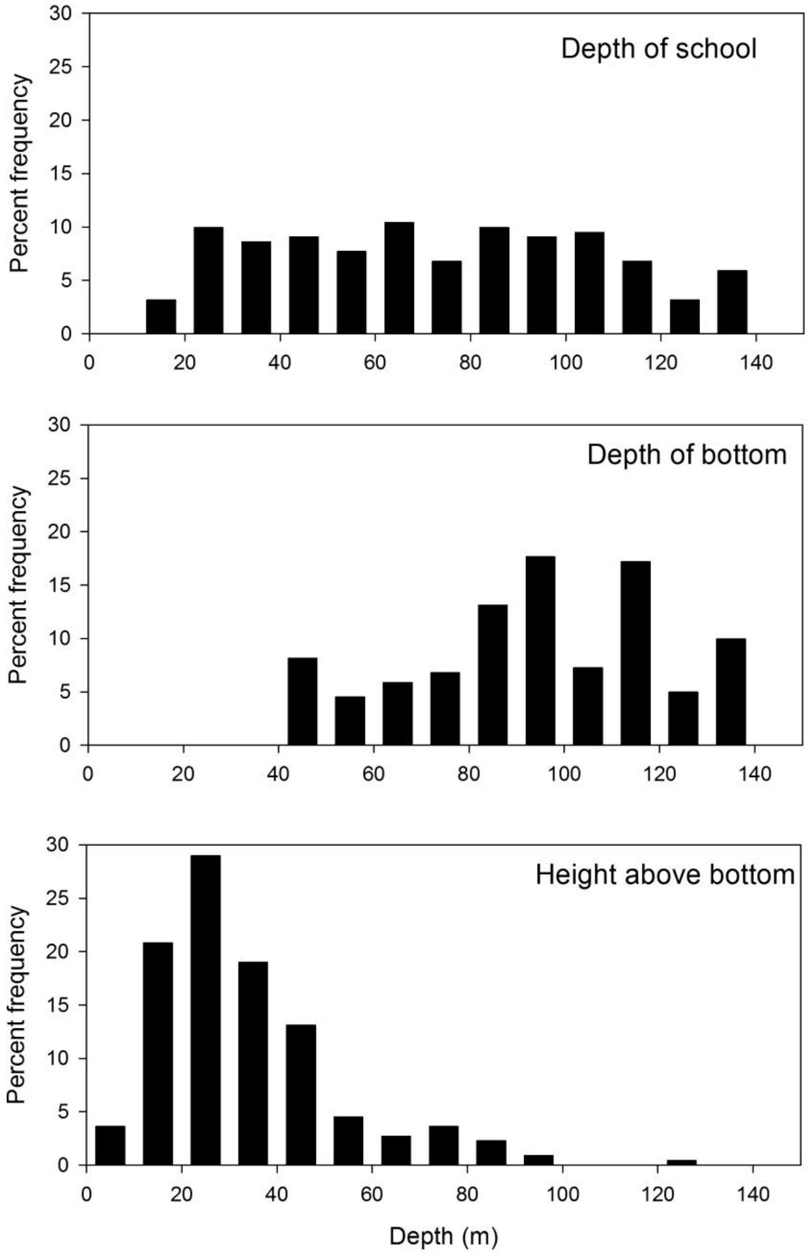


Figure 13: Frequency histograms showing distribution of schools detected on the hull-mounted echosounders during acoustic transects in relation to school depth (from surface), bottom (seabed) depth, and height of school above bottom.

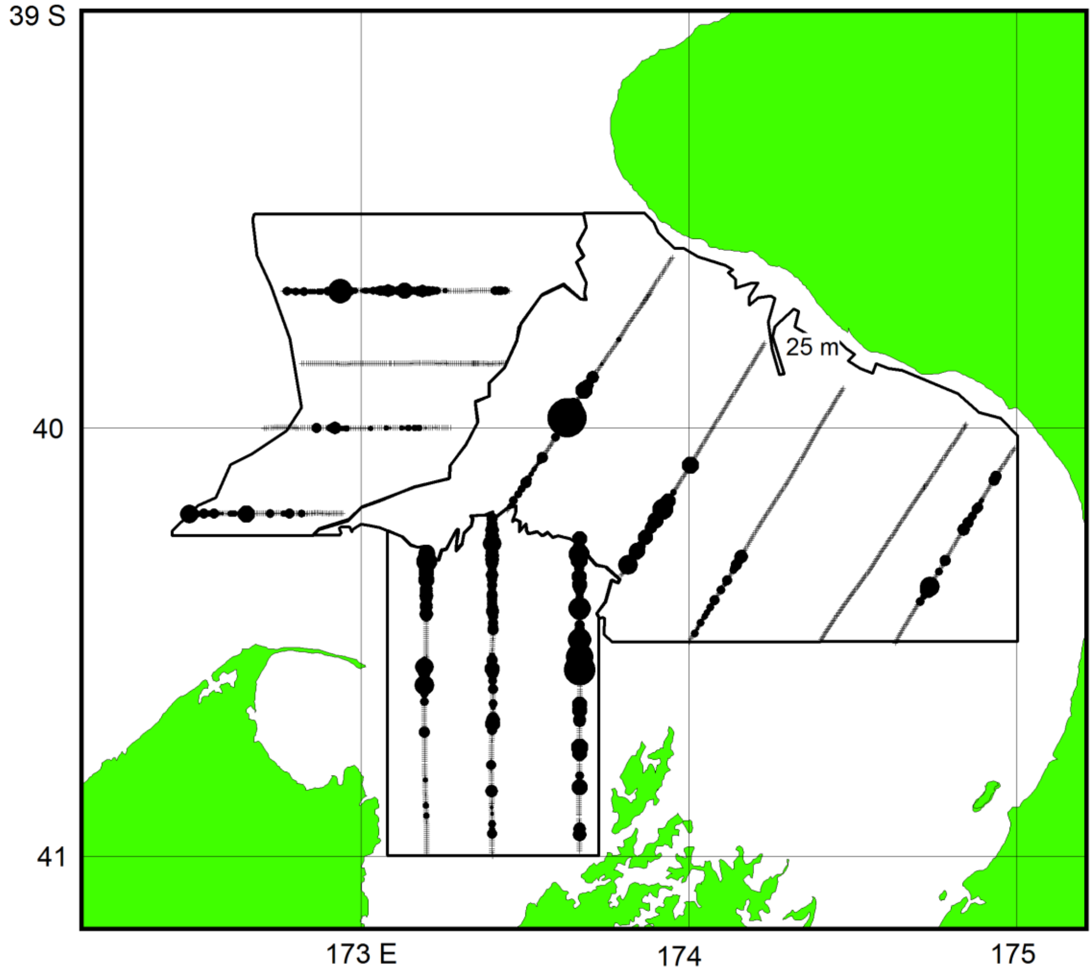


Figure 14: Spatial distribution of acoustic backscatter attributed to jack mackerel plotted in 10 ping (approximately 100 m) bins. Circle area is proportional to the log of the acoustic backscatter, scaled to the maximum backscatter recorded in the survey.

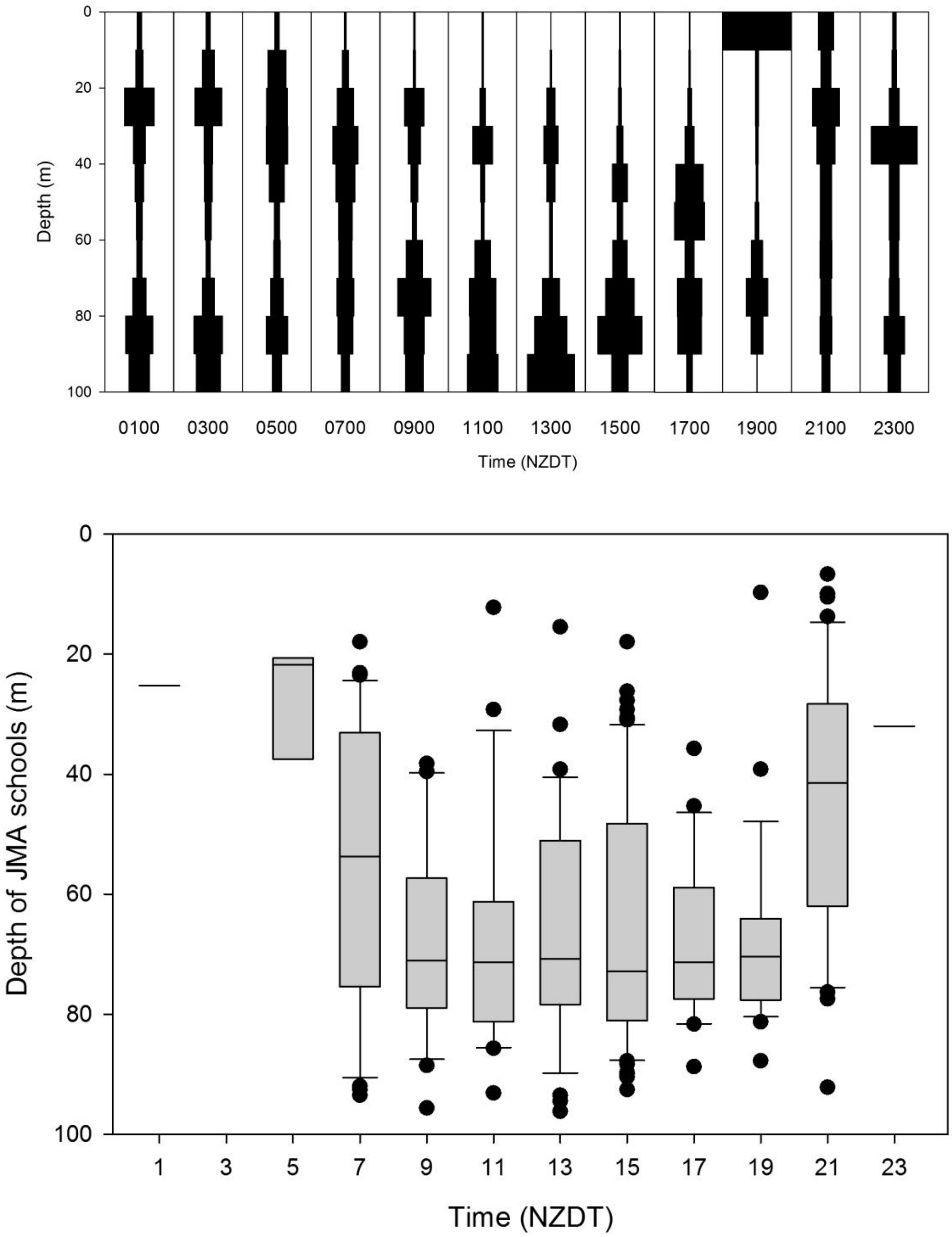


Figure 15: Diurnal pattern in vertical distribution of total backscatter (upper panel) and jack mackerel schools (lower panel) during the second day-night experiment on 2–4 February 2012 (see Table 3). Width of bars in the upper panel is proportional to the total acoustic backscatter in 10 m depth bins. Bars in the lower panel are 25th to 75th percentiles divided by the median. Whiskers are 5th to 95th percentiles, with outliers shown as dots.

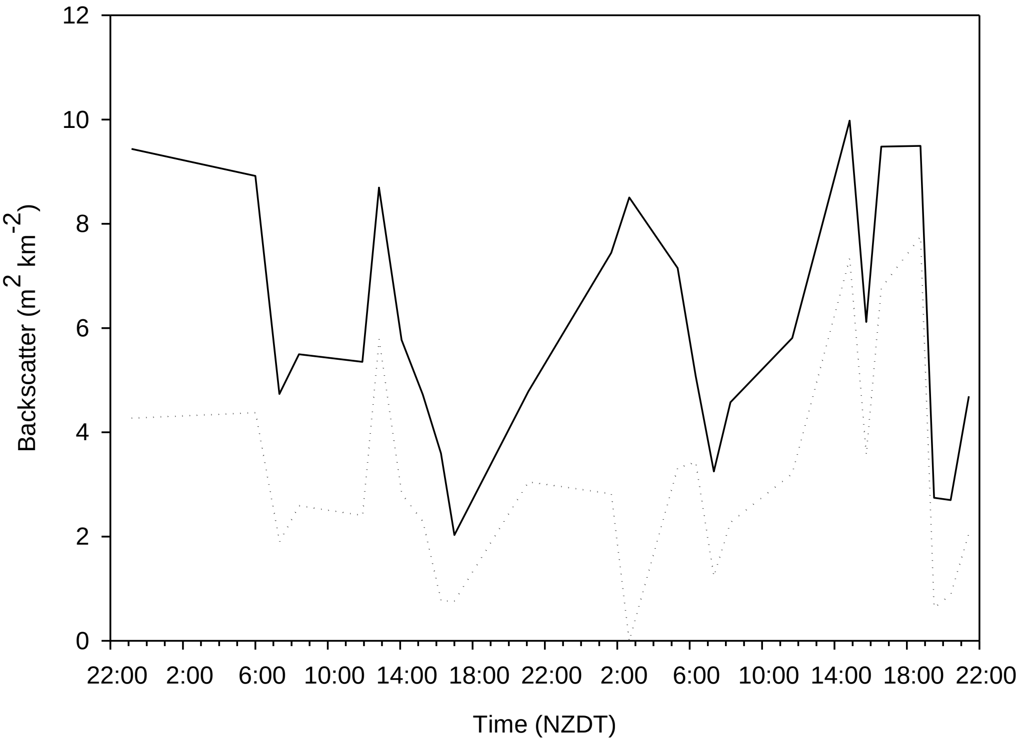


Figure 16: Temporal changes in total acoustic backscatter (solid line) and backscatter attributed to jack mackerel (dotted line) during the second day-night experiment on 2–4 February 2012 (see Table 3).

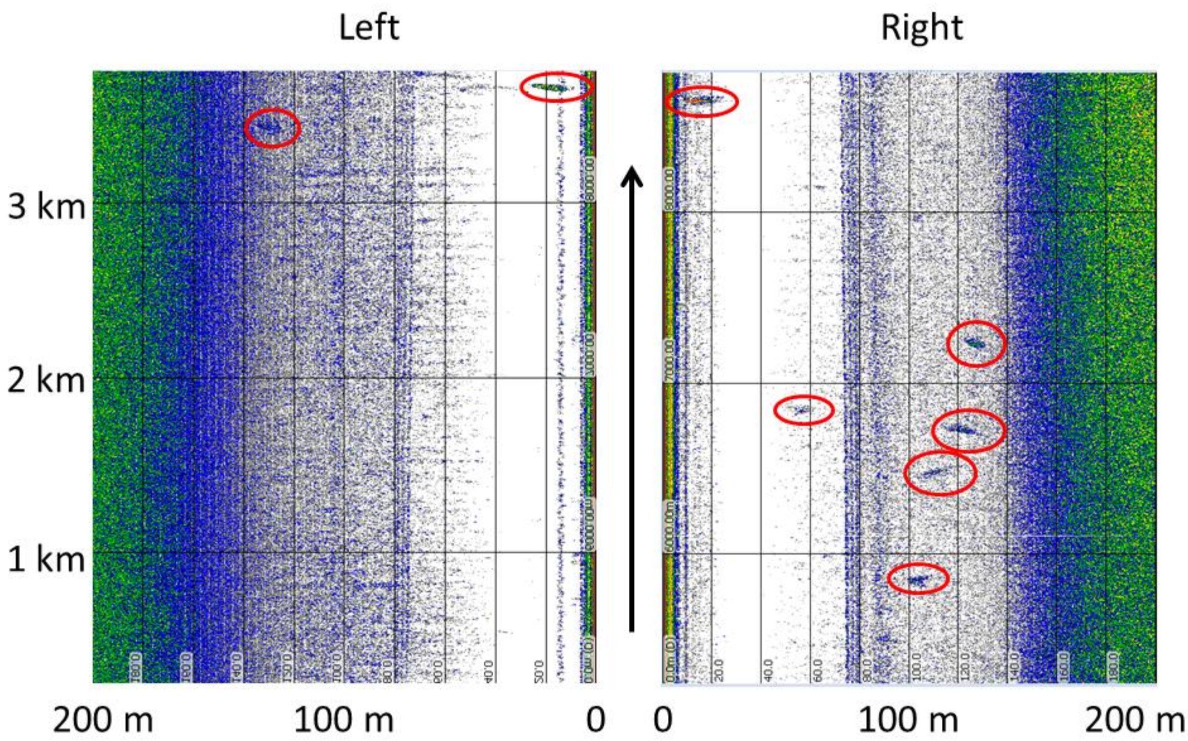


Figure 17: Annotated example echograms from side-looking 120 kHz acoustic system showing jack mackerel schools (circled) during the day on transect 1E on 31 January. Echograms have been rotated so direction of travel is up the page.

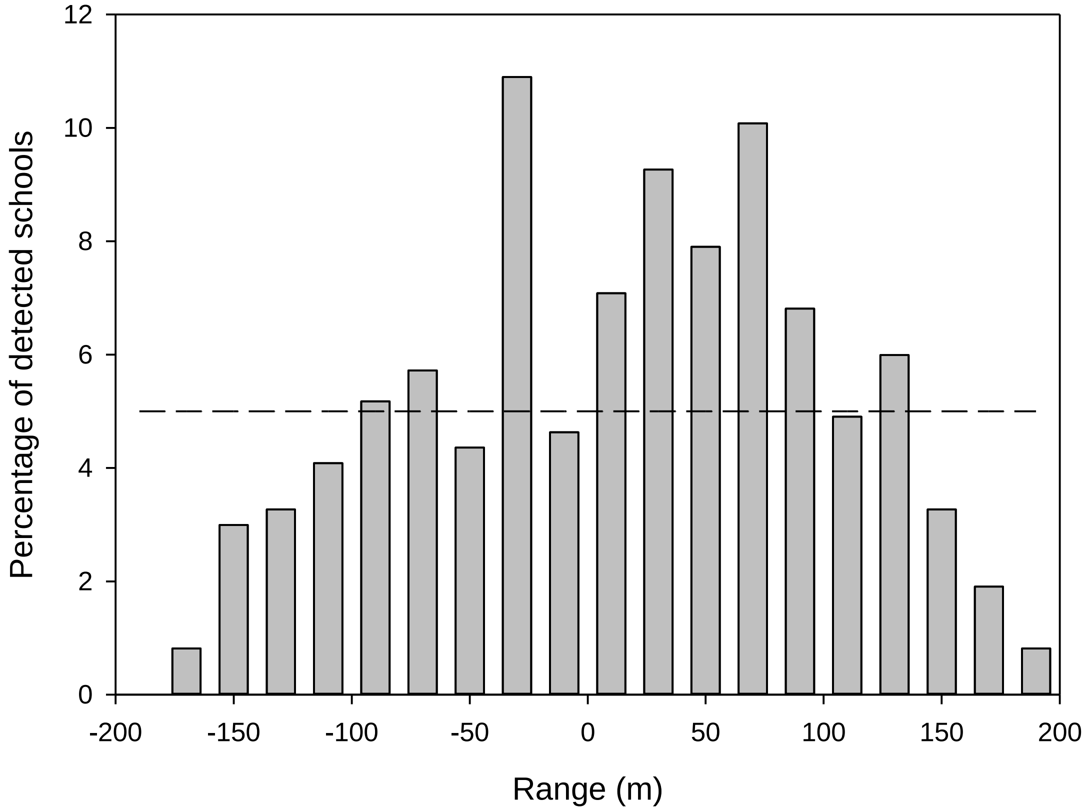


Figure 18: Frequency histogram showing minimum slant range to schools detected on side-looking sonar. Negative values are from the transducer pointing to port (left of the vessel) and positive values are to starboard (right). Dotted line shows the expected frequency if there was no range dependence.

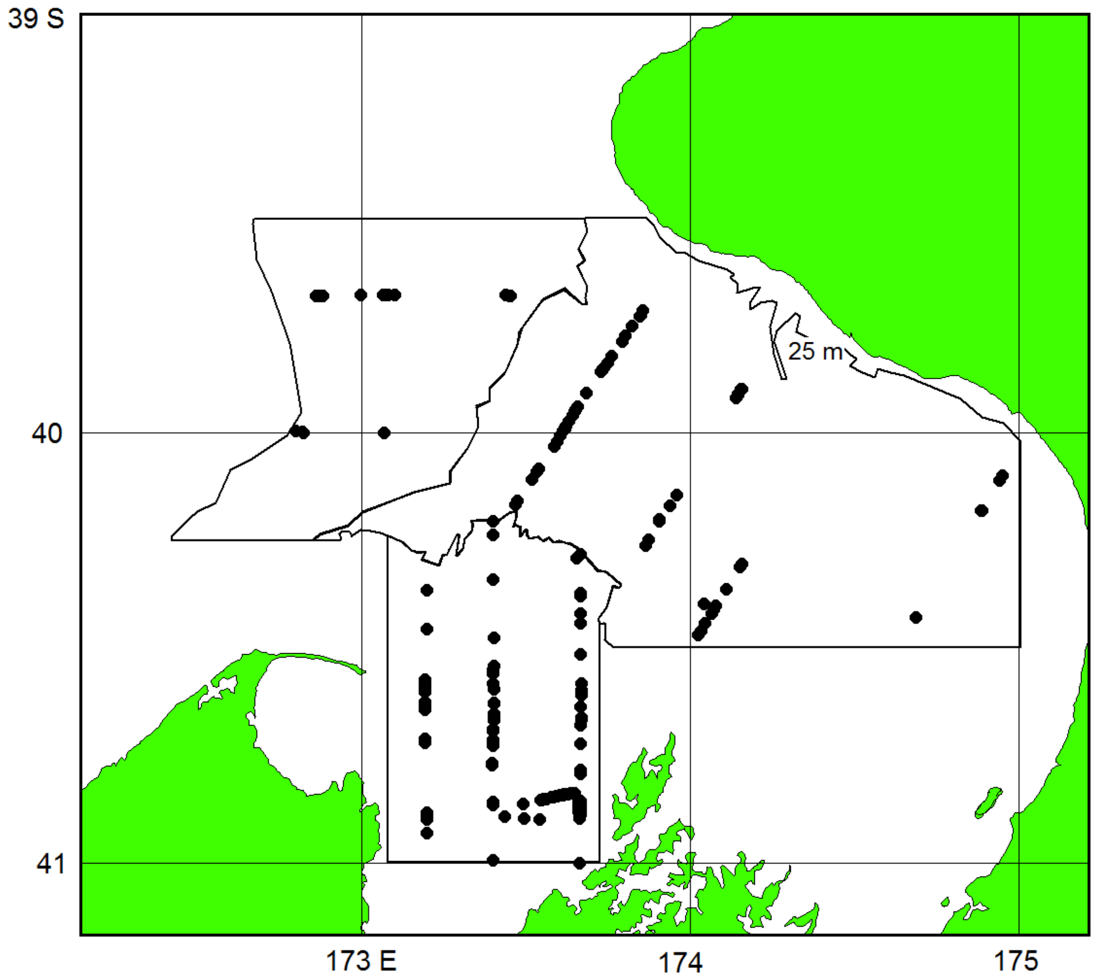


Figure 19: Spatial distribution of schools detected on side-looking sonar. No attempt was made to categorise schools by species.

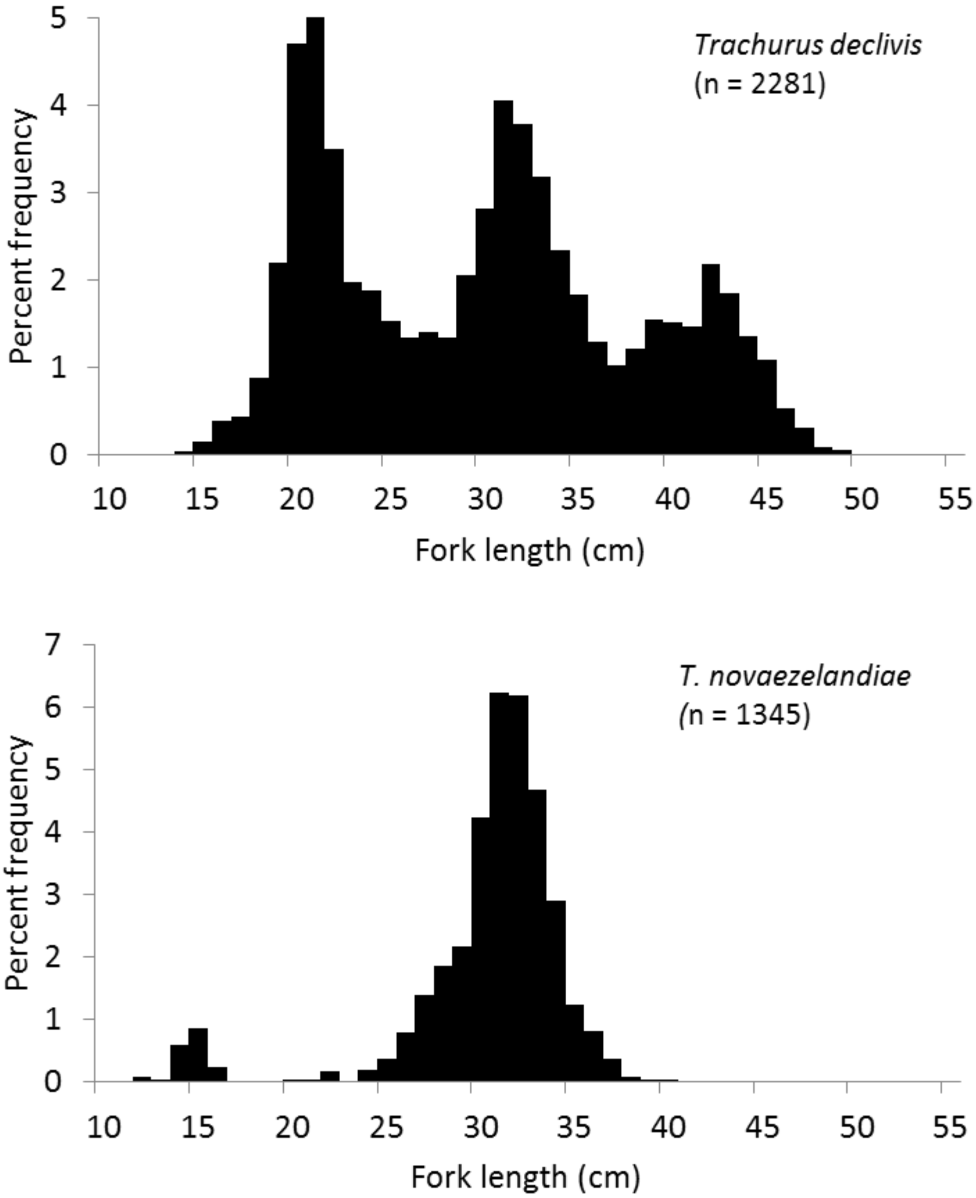


Figure 20: Scaled length frequency distributions for the two NZ species of jack mackerel caught during the survey.

Figure 21: Compilation of images recorded on the video camera attached to the acoustic-optical system (AOS) showing clockwise from top right: jack mackerel close to the camera; school of jack mackerel swimming out of the net on hauling; school of squid; barracouta.

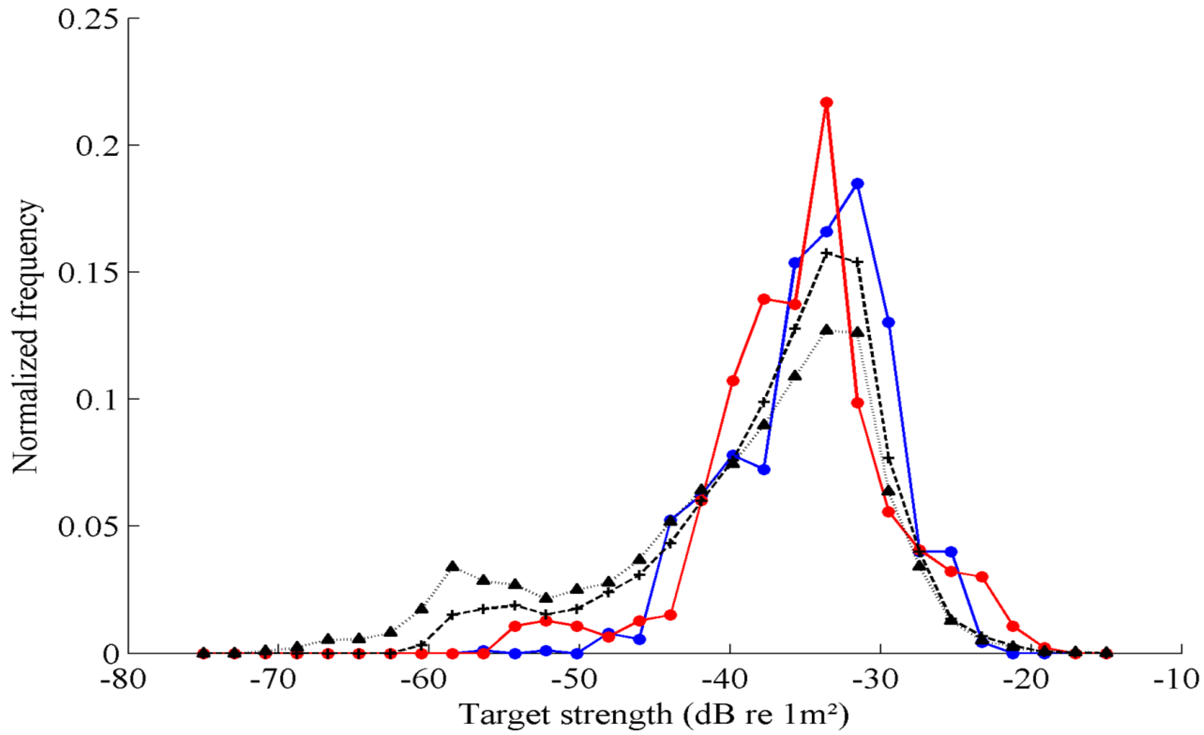


Figure 22: Target strength distribution of all single targets (triangles dotted line), tracked targets (crosses dashed line) and optically-verified targets for jack mackerel (blue line) and barracouta (red line).

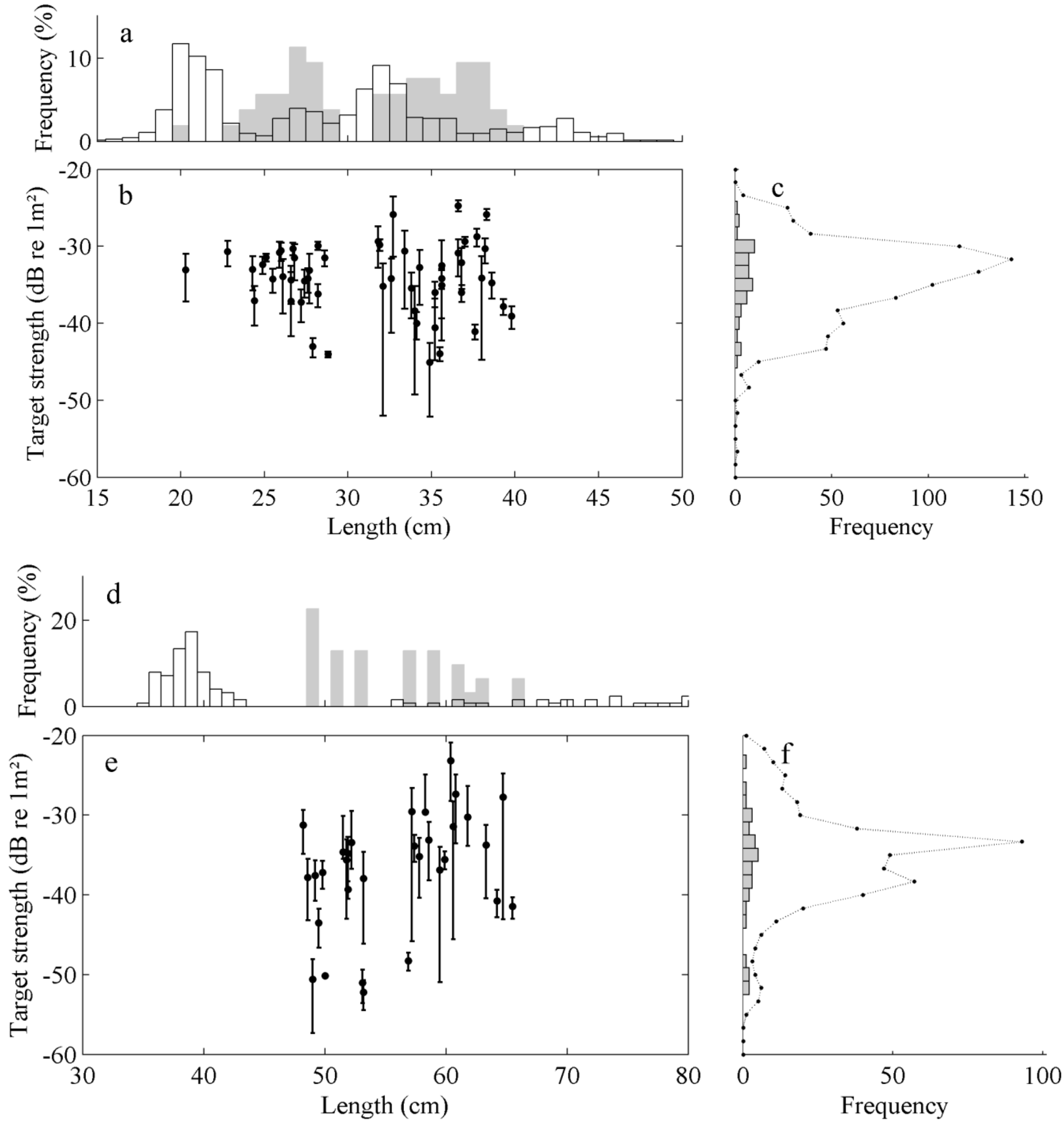


Figure 23: Optically-verified species TS as function of fork length, along with histograms of fish length (left) and TS (right). Data in panels a) to c) are from jack mackerel and panels d) to f) are data from barracouta. Length histograms (panels a) and d)) compare percentile frequency of fish length estimates from pixel counts (grey bars) with measured FL from the catch (transparent bars). TS histograms (panels c) and f)) show mean TS for each track, while dots represent values from individual echoes within accepted tracks.

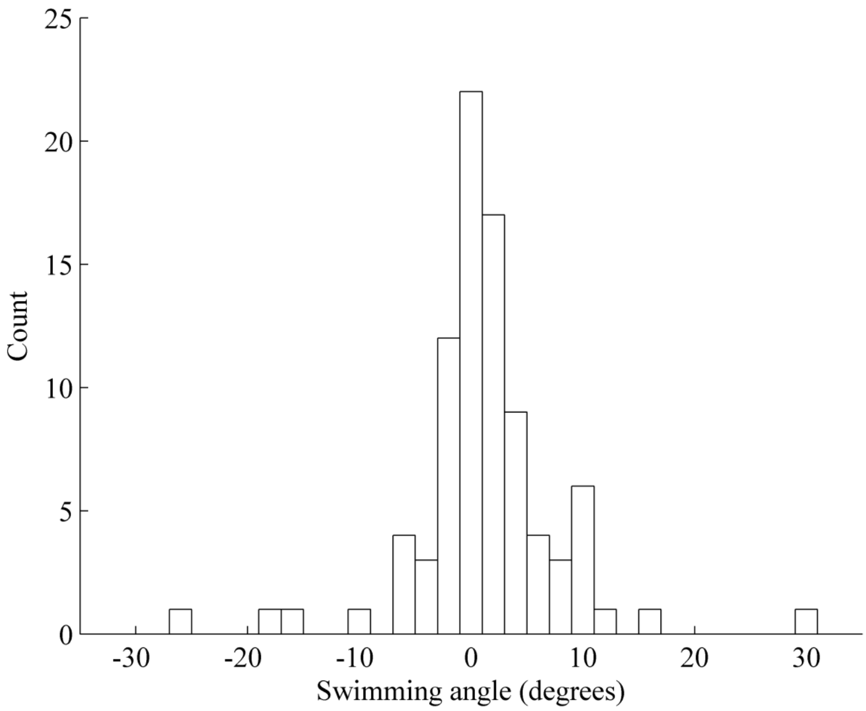


Figure 24: Swimming angles of derived from optically verified fish tracks.

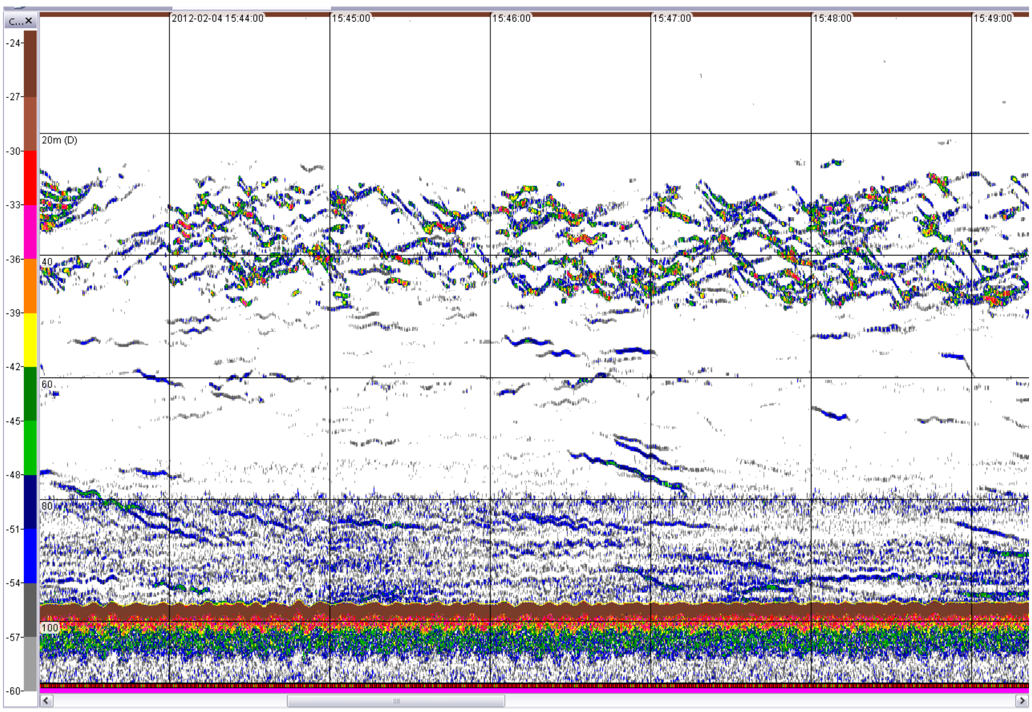


Figure 25: Example of 38 kHz acoustic echogram collected while making *in situ* TS measurements on jack mackerel at night in stratum 1 on 5 February. The red and green coloured squiggles between 30 and 50 m are believed to be individual jack mackerel.

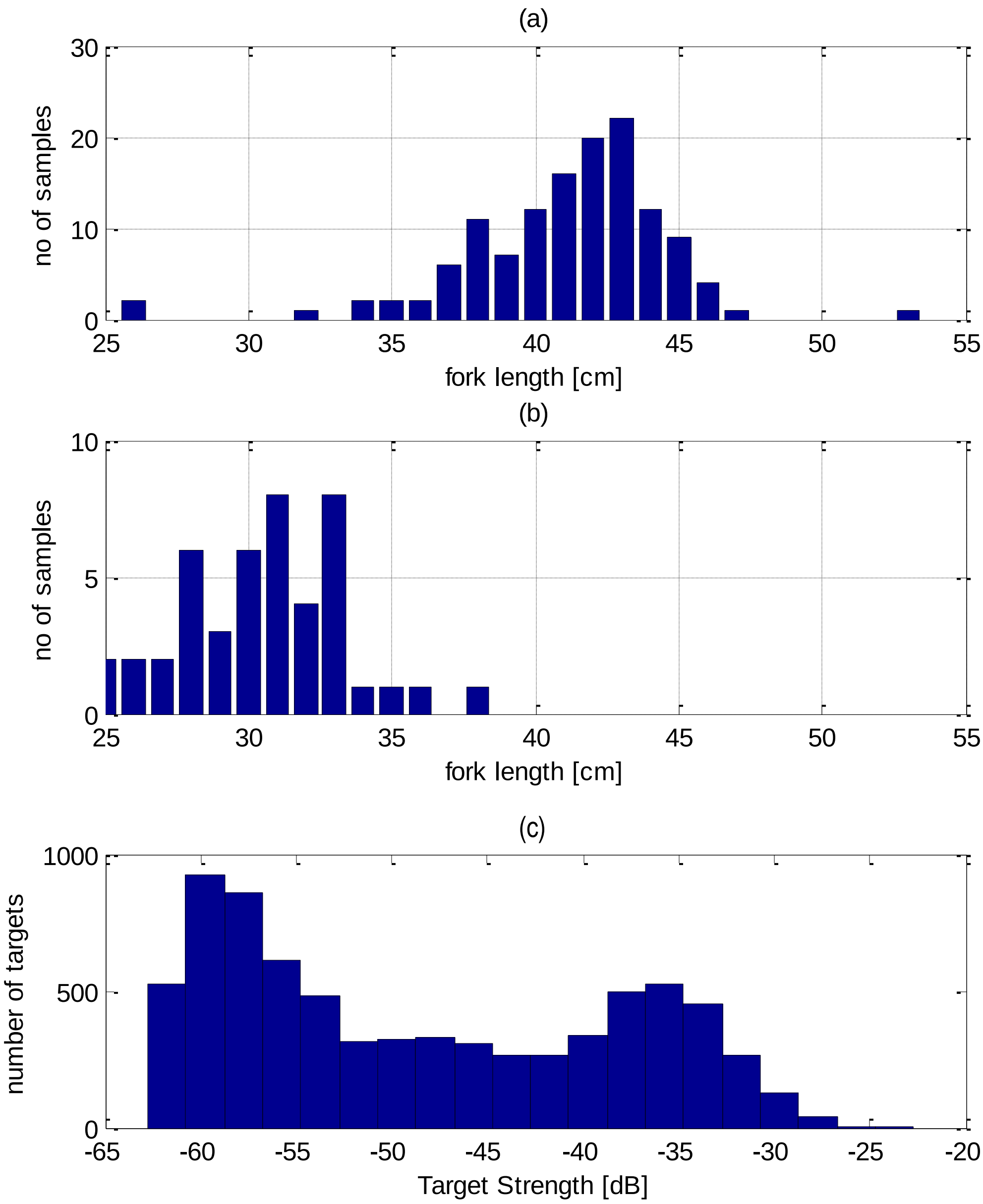


Figure 26: Results from the *in situ* TS experiment: length frequency distributions of (a) *Trachurus declivis* and (b) *T. novaezelandiae* in trawl 43; and (c) histogram of the average target strength for the identified fish tracks.

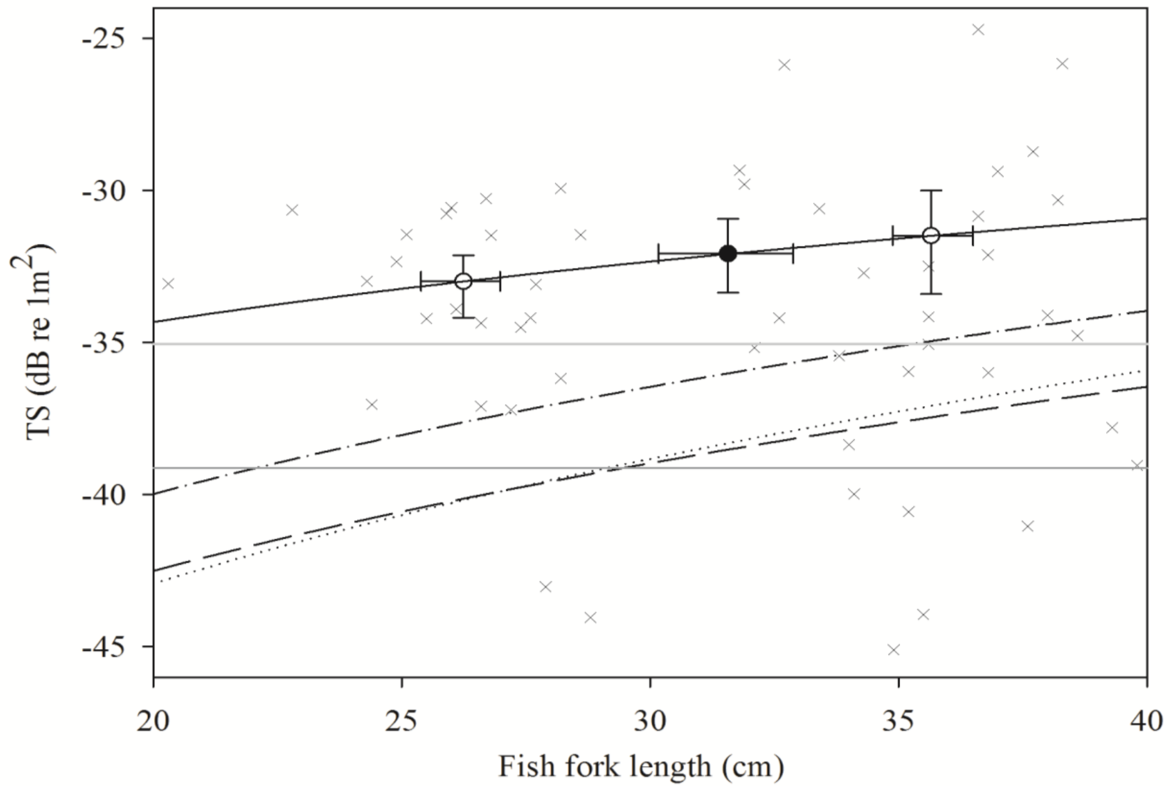


Figure 27: Comparison of different TS-length relationships for jack mackerel. Filled circle shows mean TS for pooled and transparent circles show mean TS for small and large jack mackerel from AOS measurements (Table 7). Error bars indicate 95% CI in optically verified mean fish length and mean TS. Solid line shows our new 'optically verified' relationship of TS=11.28 $\log_{10}$ FL-49.0. The horizontal lines represent results from the *in situ* TS experiment on this voyage (see Figure 26), where the upper grey line equals the mean TS of all *in situ* data and the lower grey line the mean TS of data greater than -45 dB. Two other *in situ* relationships for jack mackerel by Lillo et al. (1996, dotted line) and Peña (2008, dashed-dotted line) and one relationship from swimbladder modelling by Peña & Foote (2008, dashed line) are also shown.

APPENDIX 1: Calibration Report: *Tangaroa* 6 February 2012

The 18, 38, 70, 120, and 120 kHz EK60 echosounders on *Tangaroa* were calibrated on 6 February 2012 in Tasman Bay, at the end of the pilot acoustic survey of jack mackerel in JMA7. The calibration was conducted broadly following the procedures in MacLennan & Simmonds (1992).

The previous calibration on 30 August 2011 (TAN1112) used divers because of difficulties with calibrating *Tangaroa* in the past and uncertainty about whether the installation of the dynamic positioning system would affect our ability to drag a line from the bow of the vessel. This calibration was achieved without divers, but once again there were considerable difficulties with calibration lines fouling on the anodes and bilge keels. We recommend that, where possible, future calibrations of *Tangaroa* use divers to minimise set-up time.

The vessel was allowed to drift in about 32 m of water in Tasman Bay (41˚ 04.23' S, 173˚ 21.73' E). The calibration started at 10:00 NZDT. A weighted line was passed under the keel to facilitate setting up the three lines and calibration sphere. Long (3.8 m) fibreglass calibration poles were used in place of our standard 1 m poles in an attempt to help keep the calibration lines clear of the hull. Initial pole locations were the same as those for the previous calibration in August 2011. The sphere and associated lines were immersed in a soap solution prior to entering the water. A lead weight was also deployed about 2 m below the sphere to steady the arrangement of lines.

The weather during the calibration was reasonable, with 10–15 knots of south-easterly wind, a wind-chop, and no swell. The vessel was drifting at an average speed of about 0.7 knots.

The port line fouled on the bilge keel and it was not possible to get the sphere far enough aft for it to appear in the main lobe of the transducers. To achieve this, it was necessary to move the starboard aft pole back about 15 m to the aft end of the cutaway. The sphere was first located in the beam at 11:12 NZDT. The sphere was then centred in the beam of the 38 kHz transducer to obtain data for the on-axis calibration and moved around to obtain data for the beam shape calibration. Due to the close proximity of all five transducers, a number of echoes were recorded across all frequencies. After the 38 kHz calibration, the sphere was moved to ensure on-axis calibration of the other frequencies. To get the sphere centred in the beam of the higher frequencies (70, 120, and 200 kHz) it was necessary to shorten the sphere range to about 10 m.

The calibration data were recorded in two EK60 raw format files (TAN1202-D20120205-T212608.raw and TAN1202-D20120206-T002951.raw). These data are stored in the NIWA *acoustics* database. The EK60 transceiver settings in effect during the calibration are given in Table A1.1. The calibration was completed at 14:29 NZDT.

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

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

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

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

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

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

Results

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

The calibration parameters resulting from the calibration are given in Table A1.3, along with results from previous calibrations. It is important to note that the 38 kHz and 70 kHz systems were calibrated in the Ross Sea in February 2008, where the water temperature was -1.44 °C, considerably lower than during the subsequent calibrations. The effect of water temperature on transducer parameters and performance is not precisely known, but has been reported to have a significant effect at some frequencies (Demer & Renfree 2008) and any large differences between the two sets of results should not be taken as a permanent shift in system performance. Also, the 70 kHz transducer was in a different location during the voyage to the Ross Sea and this can also affect transducer performance. Despite this, results for all frequencies are relatively consistent (usually within 0.5 dB) across all calibrations. We have observed greater variability in our calibrations at higher frequencies (70, 120, and 200 kHz) and this was again observed in this calibration. The linear change (which can be interpreted as the percentage change in estimated biomass) between the calibration in May 2008 used for default settings and the calibration in February 2012 ranged between -24% (for 120 kHz) and +3% (for 38 kHz). The calibration coefficients for the 38-kHz echosounder most often used for abundance estimation differed by less than 3% between calibrations in 2008, 2011, and 2012, and by less than 11% across all four calibrations (Table A1.3). The calibration coefficients for 70 and 120 kHz from the February 2012 calibration were considerably higher (equating to 15% and 24% linear decreases respectively) than those in May 2008, but very similar to the coefficients estimated for these frequencies in January 2010 (Table A1.3). However, the results from this 120 kHz calibration should be treated with caution because coefficients were calculated from only three echoes close to the beam centre. Coverage of the other frequencies in February 2012 was better with 133 (18 kHz), 101 (38 kHz), 26 (70 kHz), and 12 (200 kHz) sphere echoes close to the origin.

The estimated beam patterns, as well as the coverage of the beam by the calibration sphere, are given in Figures A1.1–A1.10. The symmetrical nature of the beam patterns and the centering on zero indicates that the transducers and EK60 transceivers were operating correctly. The root mean square (RMS) of the difference between the Simrad beam model and the sphere echoes out to the 3 dB beamwidth was 0.14 dB for both 18 and 38 kHz, 0.18 dB for 200 kHz, 0.19 dB for 120 kHz, and 0.21 dB for 70 kHz (Table A1.3), indicating good or excellent quality calibrations on all frequencies (<0.4 dB is acceptable, <0.3 dB good, and <0.2 dB excellent).

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

Parameter					
Frequency (kHz)	18	38	70	120	200
GPT model	GPT-Q18(2)-S 1.0 009072058c476	GPT-Q38(4)-S 1.0 00907205c463	GPT-Q70(1)-S 1.0 00907205ca98	GPT-Q120(1)-S 1.0 009072058148	GPT-Q120(1)-S 1.0 009072058148
GPT serial number	652	650	674	668	692
GPT software version	050112	050112	050112	050112	050112
ER60 software version	2.1.2	2.1.2	2.1.2	2.1.2	2.1.2
Transducer model	ES18-11	ES38	ES70-7C	ES120-7C	ES200-7C
Transducer serial number	2080	23083	158	477	364
Sphere type/size	tungsten carbide/38.1 mm diameter (same for all frequencies)				
Transducer draft setting (m)	0.0	0.0	0.0	0.0	0.0
Transmit power (W)	2000	2000	1000	500	300
Pulse length (ms)	1.024	1.024	1.024	1.024	1.024
Transducer peak gain (dB)	22.96	25.81	26.43	26.17	24.96
Sa correction (dB)	-0.81	-0.57	-0.35	-0.36	-0.25
Bandwidth (Hz)	1574	2425	2859	3026	3088
Sample interval (m)	0.191	0.191	0.191	0.191	0.191
Two-way beam angle (dB)	–17.0	–20.6	–21.0	–21.0	–20.7
Absorption coefficient (dB/km)	2.67	9.79	22.79	37.44	52.69
Speed of sound (m/s)	1494	1494	1494	1494	1494
Angle sensitivity (dB) along/athwartship	13.90/13.90	21.90/21.90	23.0/23.0	23.0/23.0	23.0/23.0
3 dB beamwidth (°) along/athwartship	10.8/10.8	7.0/7.0	6.6/6.6	6.5/6.6	6.8/6.9
Angle offset (°) along/athwartship	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0

Table A1.2. CTD cast details and derived water properties. The values for sound speed, salinity and absorption are the mean over water depths 6 to 25 m.

Parameter	
Date/time (NZDT, start)	6 February 2012 15:10
Position	41˚ 03.12 S 173˚ 19.98 E
Mean sphere range (m)	13.5 (18 kHz), 13.3 (38), 13.2 (70), 12.7 (120), 13.0 (200)
Mean temperature (ºC)	17.8
Mean salinity (psu)	34.7
Sound speed (m/s)	1513.8
Water density (kg/m^3)	1025.4
Sound absorption (dB/km)	2.00 (18 kHz) 8.20 (38 kHz) 22.28 (70 kHz) 42.94 (120 kHz) 71.43 (200 kHz)
Sphere target strength (dB re 1m^2)	–42.49 (18 kHz) –42.41 (38 kHz) –41.60 (70 kHz) –39.68 (120 kHz) –38.85 (200 kHz)

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

		Feb 2012	Aug 2011	Jan 2010	May 2008	Feb 2008
18 kHz						
	Transducer peak gain (dB)	22.81 (+1%)	22.78	23.36	22.96	
	Sa correction (dB)	-0.69	-0.69	-0.76	–0.81	
	Beamwidth (º) along/athwartship	10.7/10.9	10.9/11.1	11.1/11.3	10.8/10.8	
	Beam offset (º) along/athwartship	0.00/-0/.00	-0.02/0.08	0.00/0.00	0.00/0.00	
	RMS deviation (dB)	0.14	0.08	0.14	0.26	
38 kHz						
	Transducer peak gain (dB)	25.75 (+3%)	25.75	25.98	25.81	25.85
	Sa correction (dB)	-0.57	-0.58	-0.58	–0.57	–0.53
	Beamwidth (º) along/athwartship	6.8/6.8	6.8/6.9	6.9/7.0	7.0/7.0	7.0/7.0
	Beam offset (º) along/athwartship	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	–0.04/0.04
	RMS deviation (dB)	0.14	0.08	0.10	0.16	0.13
70 kHz						
	Transducer peak gain (dB)	26.78 (-15%)	26.23	26.78	26.43	26.58
	Sa correction (dB)	-0.35	-0.32	-0.30	–0.35	–0.28
	Beamwidth (º) along/athwartship	6.3/6.1	6.5/6.6	6.3/6.4	6.6/6.6	6.7/6.6
	Beam offset (º) along/athwartship	0.00/0.00	-0.00/0.00	0.00/0.00	0.00/0.00	–0.03/0.00
	RMS deviation (dB)	0.21	0.10	0.14	0.25	0.15
120 kHz						
	Transducer peak gain (dB)	26.80 (-24%)	25.96	26.79	26.17	
	Sa correction (dB)	-0.38	-0.39	-0.35	–0.36	
	Beamwidth (º) along/athwartship	6.0/6.0	6.4/6.6	6.1/6.4	6.5/6.6	
	Beam offset (º) along/athwartship	0.00/0.00	-0.13/0.11	0.00/0.00	0.00/0.00	
	RMS deviation (dB)	0.19	0.17	0.17	0.35	
200 kHz						
	Transducer peak gain (dB)	25.16 (-10%)	25.25	25.35	24.96	
	Sa correction (dB)	-0.21	-0.29	-0.36	–0.25	
	Beamwidth (º) along/athwartship	6.2/6.2	6.3/6.7	6.7/6.7	6.8/6.9	
	Beam offset (º) along/athwartship	0.08/-0.08	0.00/0.00	0.00/0.00	0.00/0.00	
	RMS deviation (dB)	0.18	0.21	0.18	0.39	

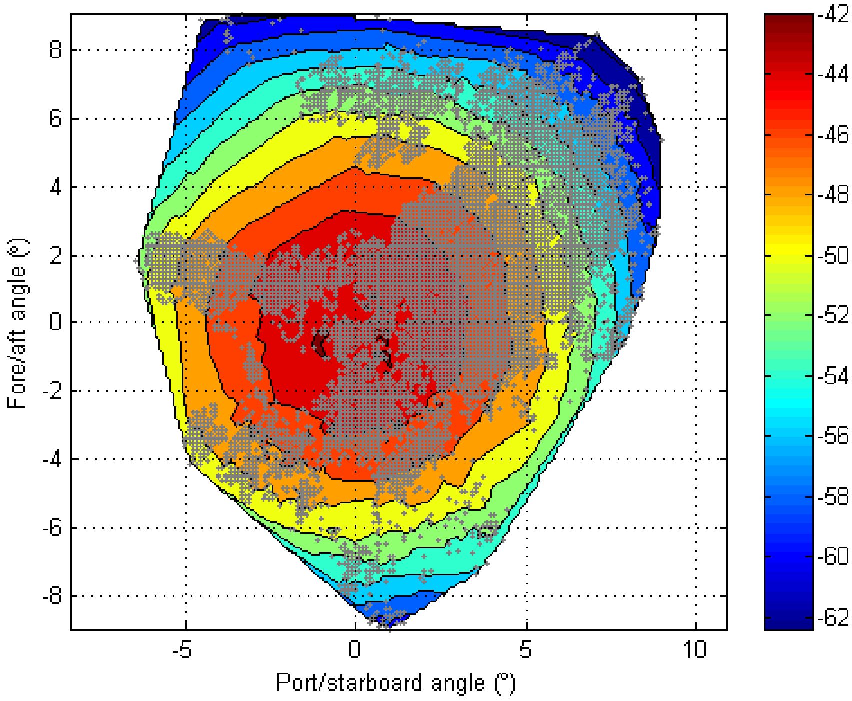


Figure A1.1. The 18 kHz estimated beam pattern from the sphere echo strength and position. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

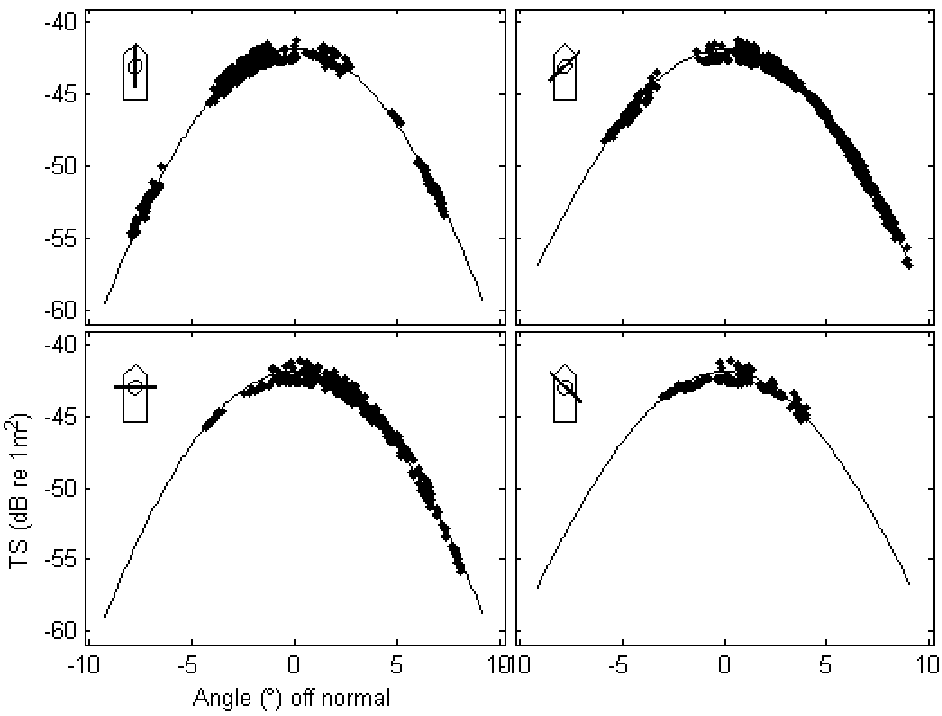


Figure A1.2. Beam pattern results from the 18 kHz analysis. The solid line is the ideal beam pattern fit to the sphere echoes for four slices through the beam.

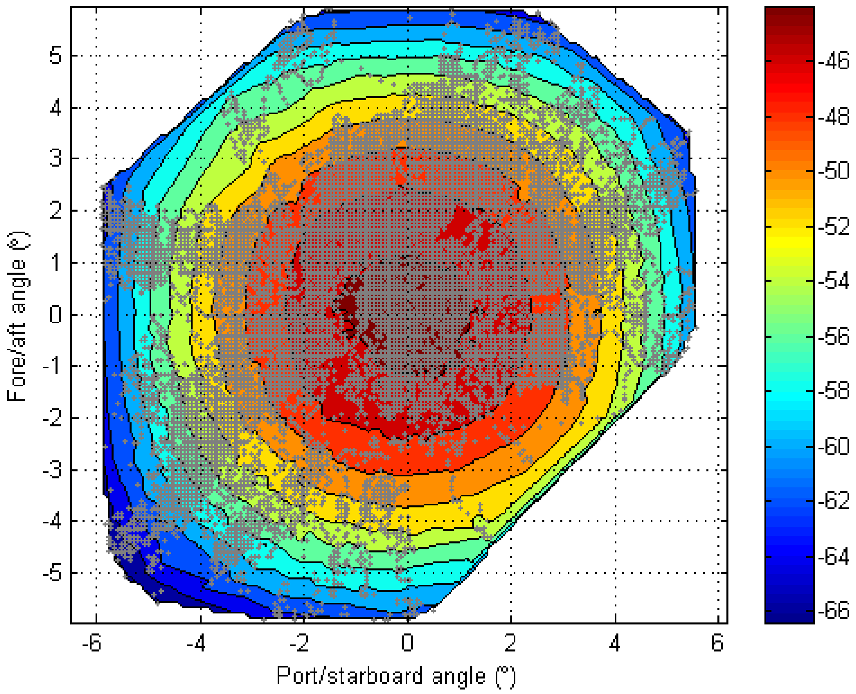


Figure A1.3. The 38 kHz estimated beam pattern from the sphere echo strength and position. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

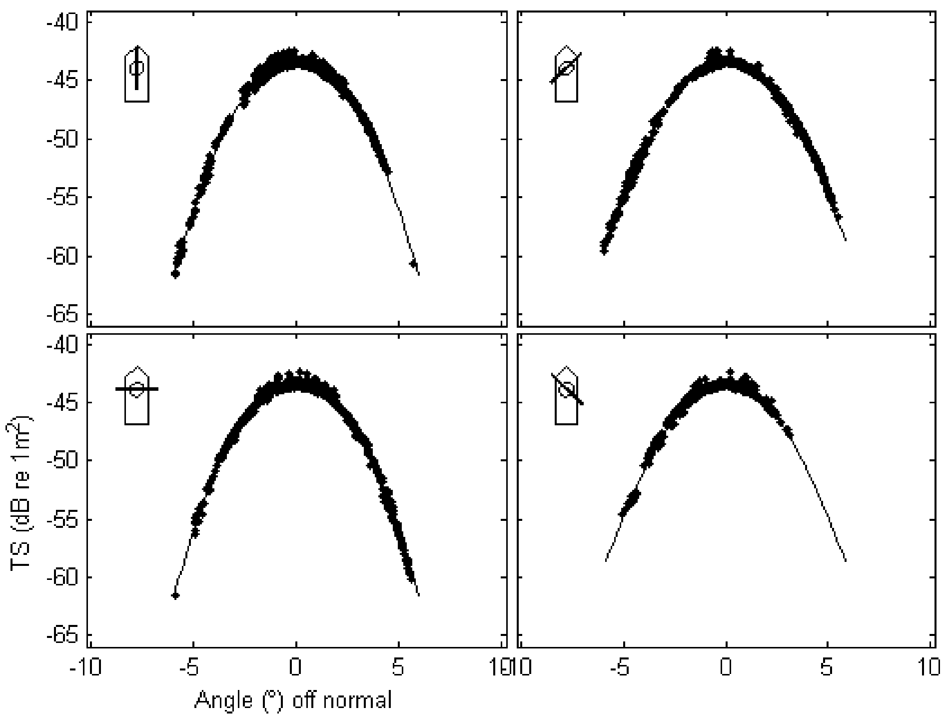


Figure A1.4. Beam pattern results from the 38 kHz analysis. The solid line is the ideal beam pattern fit to the sphere echoes for four slices through the beam.

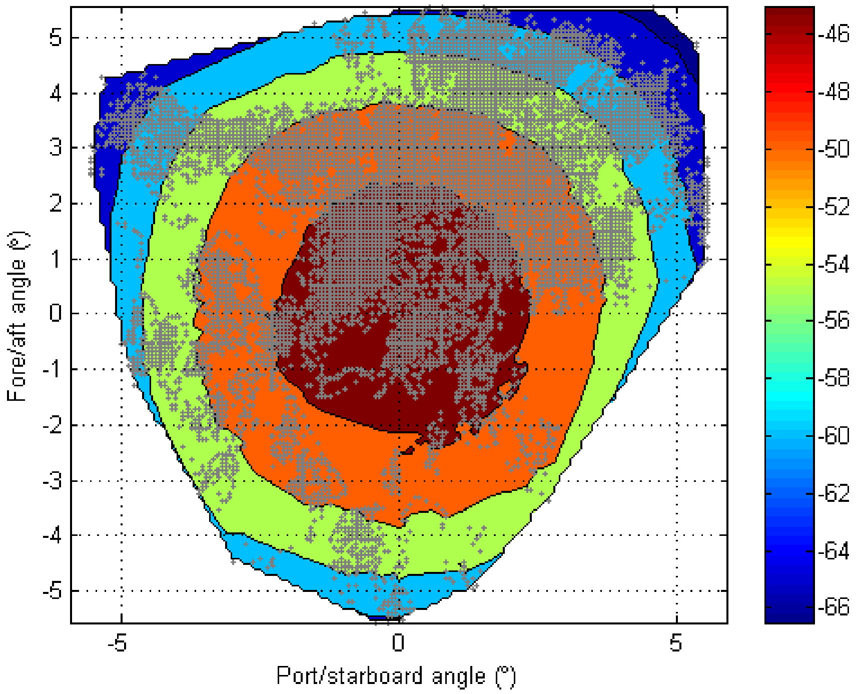


Figure A1.5. The 70 kHz estimated beam pattern from the sphere echo strength and position. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

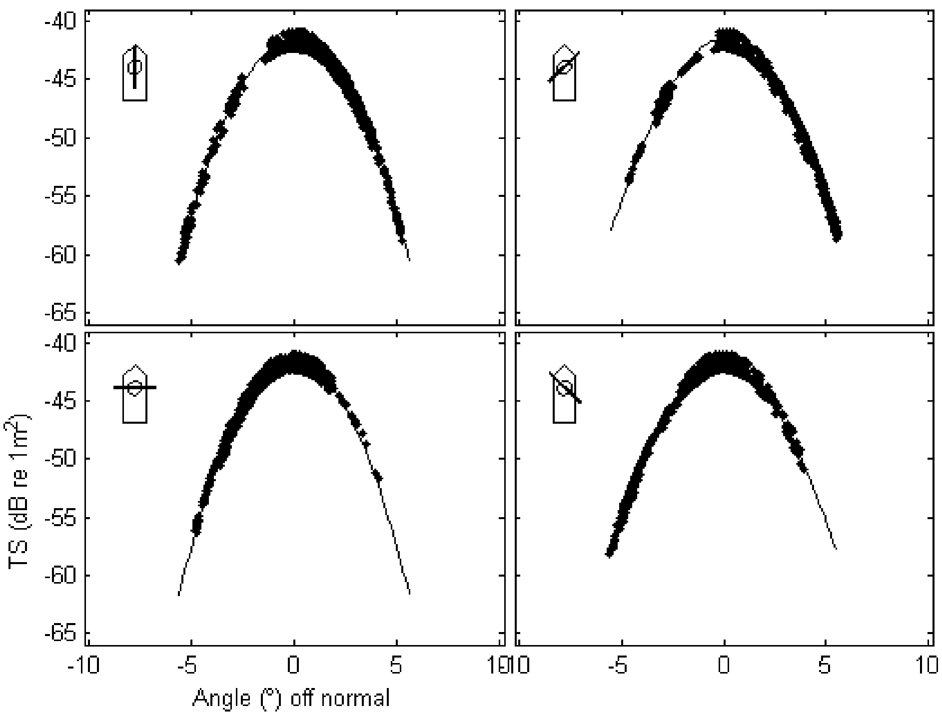


Figure A1.6. Beam pattern results from the 70 kHz analysis. The solid line is the ideal beam pattern fit to the sphere echoes for four slices through the beam.

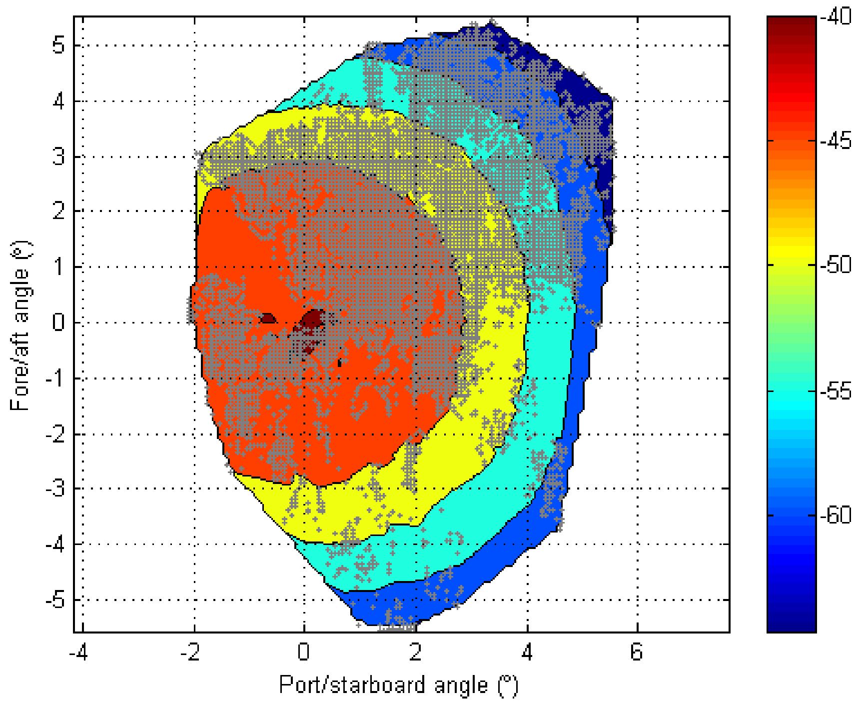


Figure A1.7. The 120 kHz estimated beam pattern from the sphere echo strength and position. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

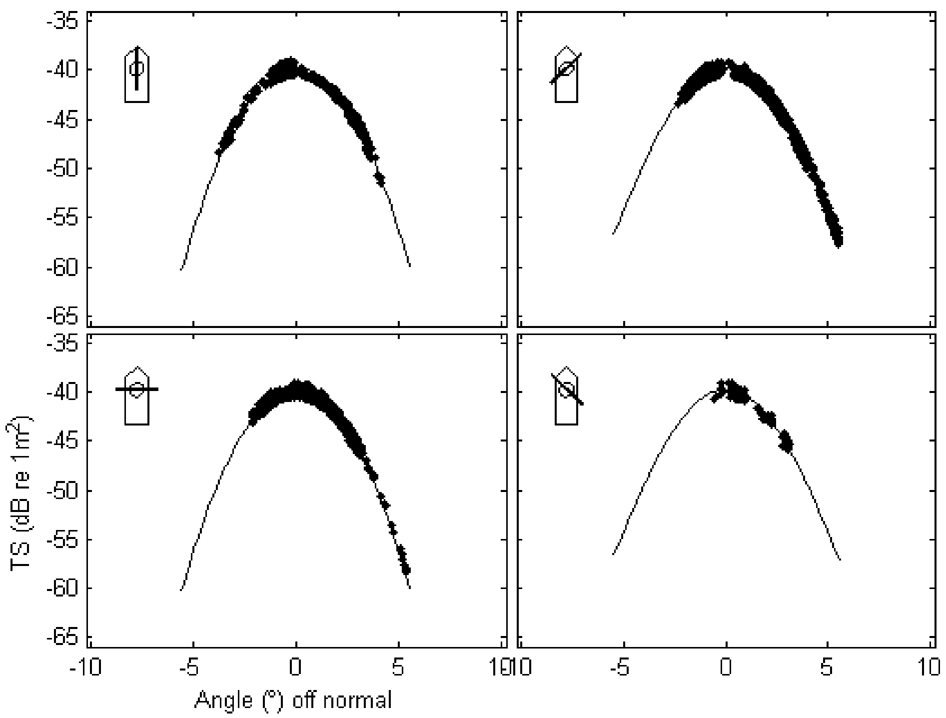


Figure A1.8. Beam pattern results from the 120 kHz analysis. The solid line is the ideal beam pattern fit to the sphere echoes for four slices through the beam.

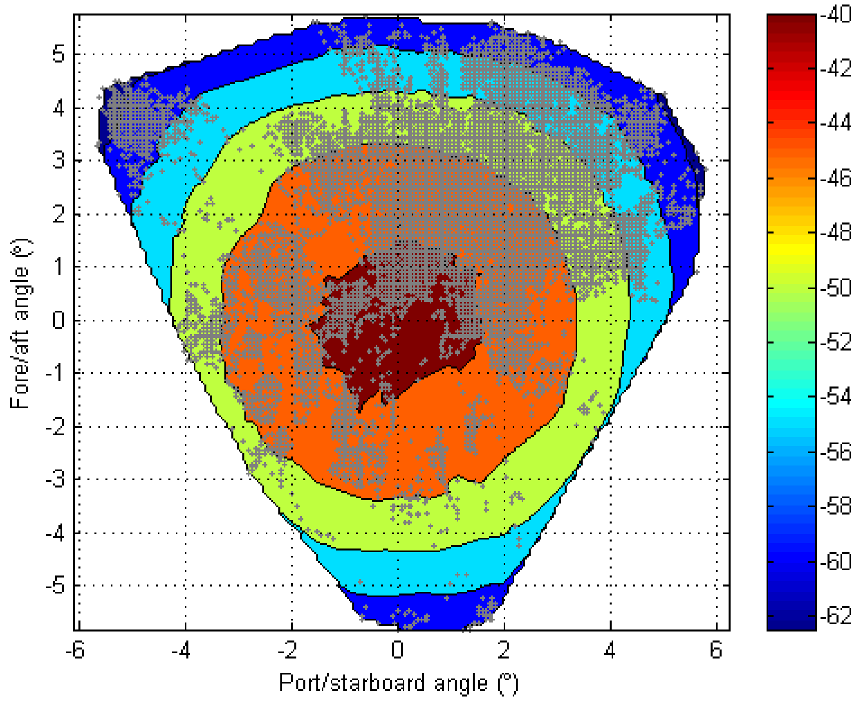


Figure A1.9. The 200 kHz estimated beam pattern from the sphere echo strength and position. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

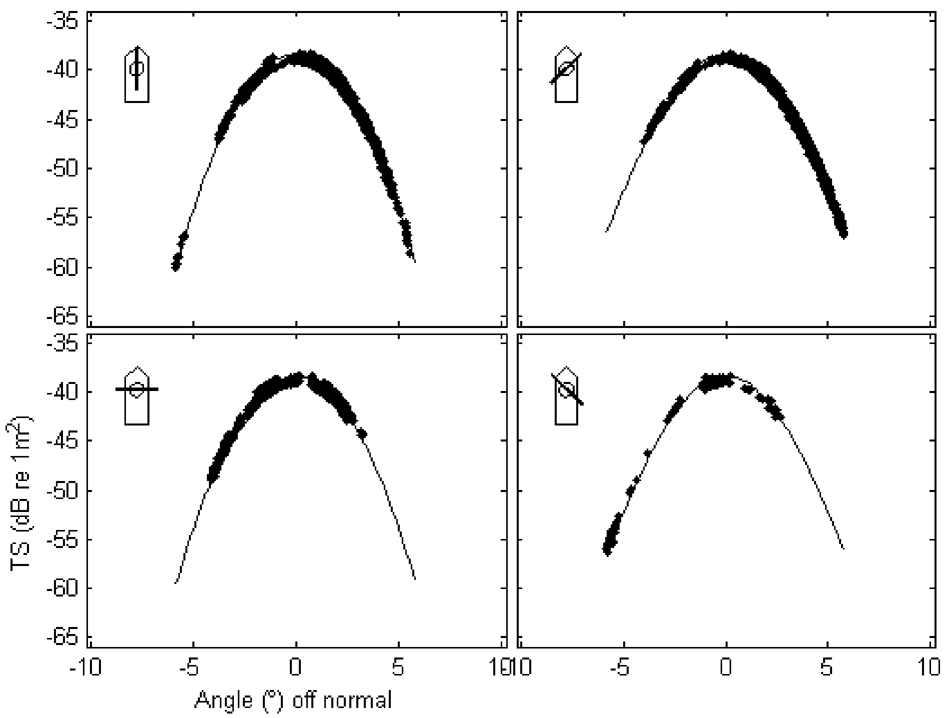


Figure A1.10. Beam pattern results from the 200 kHz analysis. The solid line is the ideal beam pattern fit to the sphere echoes for four slices through the beam.

APPENDIX 2: Calibration Report: AOS

The AOS 38 kHz echosounder was calibrated to 76 m depth during the voyage on 4 February 2012. A 38.1 mm diameter tungsten carbide sphere was suspended 25 m below the transducer's axis from a fitted frame on the AOS and the system was lowered down to 76 m (for 5 min) stopping for the same amount of time at 10 m (on the way down and the way up). Calibration parameters are listed in Table A2.1. For these three intervals the system gain (G_0) was independently estimated using the mean of on axis target strength compensated by beam fitting with customised Matlab functions. A Seabird SM 37 Microcat CTD datalogger was mounted on the AOS during this calibration to measure conductivity, depth, temperature and pressure. The pressure and temperature profile was used along with mean salinity to estimate the sound velocity and density (Fofonoff & Millard 1983), absorption coefficient (Doonan et al. 2003), and the sphere theoretical target strength (MacLennan 1981) at each depth interval.

An alignment of the AOS video and acoustic components was assessed after the voyage in NIWA's deep water tank at Greta Point on 9 March 2012 (Table A2.1). The temperature was measured and the salinity assumed to calculate the sound velocity and density (Fofonoff & Millard 1983) and absorption coefficient (Doonan et al. 2003). All of the AOS components were in the same configuration as during the voyage. The physical displacement of camera and sounder was measured. A 38.1 mm diameter tungsten carbide target sphere was placed firstly in the centre of the sounder beam and secondly in the centre of video at a fixed range and acoustic data was recorded. Then the relative position of the sphere from the video centre with respect to the sounder centre was measured. These measurements along with the physical displacement were used to geometrically determine the relative orientation of the sounder with respect to the camera using customised Matlab functions. A further calibration of the AOS echosounder was also performed in the tank. During the day, targets from all over the beam pattern were recorded in order to calculate precise beam angles. To measure an accurate G_0 in the tank (that was not influenced by ambient noise) data was recorded overnight (sample interval 10 s).

Results

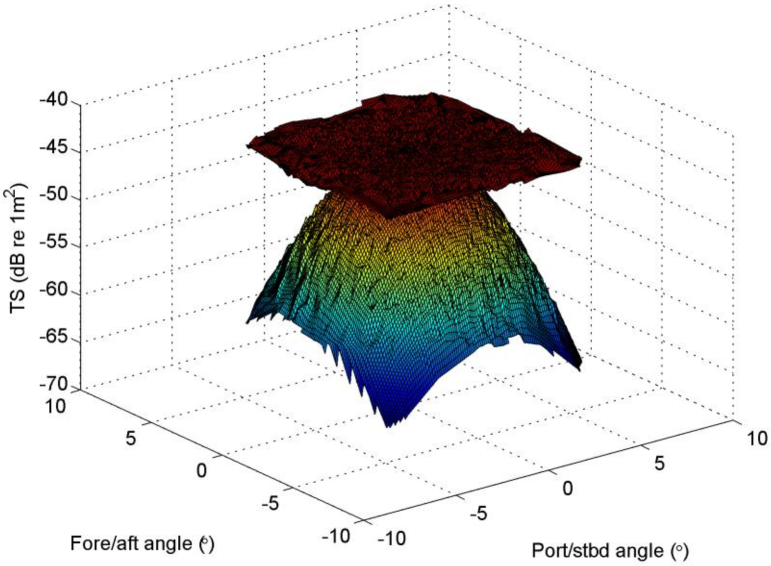
The calibration parameters are listed in Table A2.2. During this voyage the AOS was deployed at depths ranging around 100 m, therefore estimates of the deep voyage calibration are the most accurate. Hence a G_0 of 23.97 dB was used for the analysis. Because data from the voyage calibration were not sufficient to estimate beam angles, estimates of 7.179º (along) and 7.188º (athwart) from the tank calibration were used for the analysis (Table A2.2). Figure A2.1 shows a three dimensional contour plot (a) of the beam and the beam pattern (b) along the different axes from the voyage calibration. Graphical alignment of acoustic and video data (Figure A2.2) proves that acoustics and optics are overlapping well for a broad depth range.

Table A2.1. EK60 transceiver settings and environmental details for the deep water tank experiment. The values for sound speed, salinity and absorption are for water depth of 2 m.

Parameter	Value
Transceiver settings	
Transducer model	Simrad ES38D
ER60 software version	2.1.2
Sphere type	38.1 mm diameter tungsten-carbide
Transmit power (W)	2000
Pulse length (ms)	0.512
Bandwidth (Hz)	3280
Sample interval (m)	0.096
Two-way beam angle (dB)	–20.60
Absorption coefficient (dB/km)	9.79
Speed of sound (m/s)	1494
Angle sensitivity (dB) alongship/athwartship	21.90/21.90
Tank experiment details	
Date/time (NZST, start)	09 March 2012, 11:30
Position	Greta Point deep water tank
Mean sphere range (m)	4.0 (lateral)
Mean temperature (ºC)	17.9
Mean salinity (psu)	35
Sound speed (m/s)	1515.6
Water density (kg/m3)	1025.3
Sound absorption (dB/km)	8.44
Frequency (kHz)	38

Table A2.2: Estimates for G_0 and beam width from calibrations performed during voyage and after the voyage in the deep water tank.

	Depth (m)	G_0 (dB)	Beam width (º) along/athwart
Voyage calibration			
Way down	12.4	24.65	-
Deep	78.3	23.97	-
Way up	11.1	24.61	-
Tank calibration			
Day time (beam angles)	2	25.04	7.179/7.188
Night time (G_0)	2	24.51	-



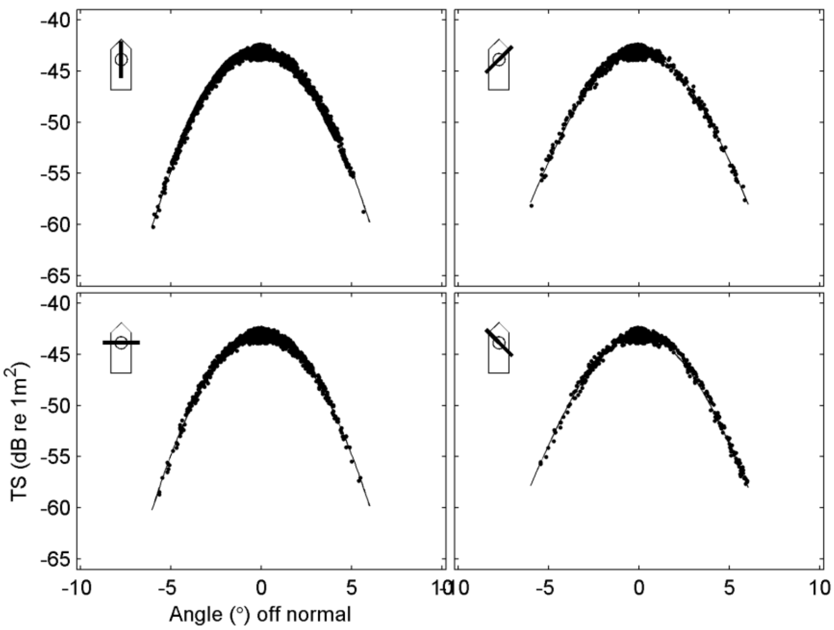


Figure A2.1. The 38 kHz estimated 3D contour plot of the beam (a) from the sphere echo strength and position. Beam pattern results (b) from the 38 kHz analysis. The solid line is the ideal beam pattern fit to the sphere echoes for four slices through the beam.

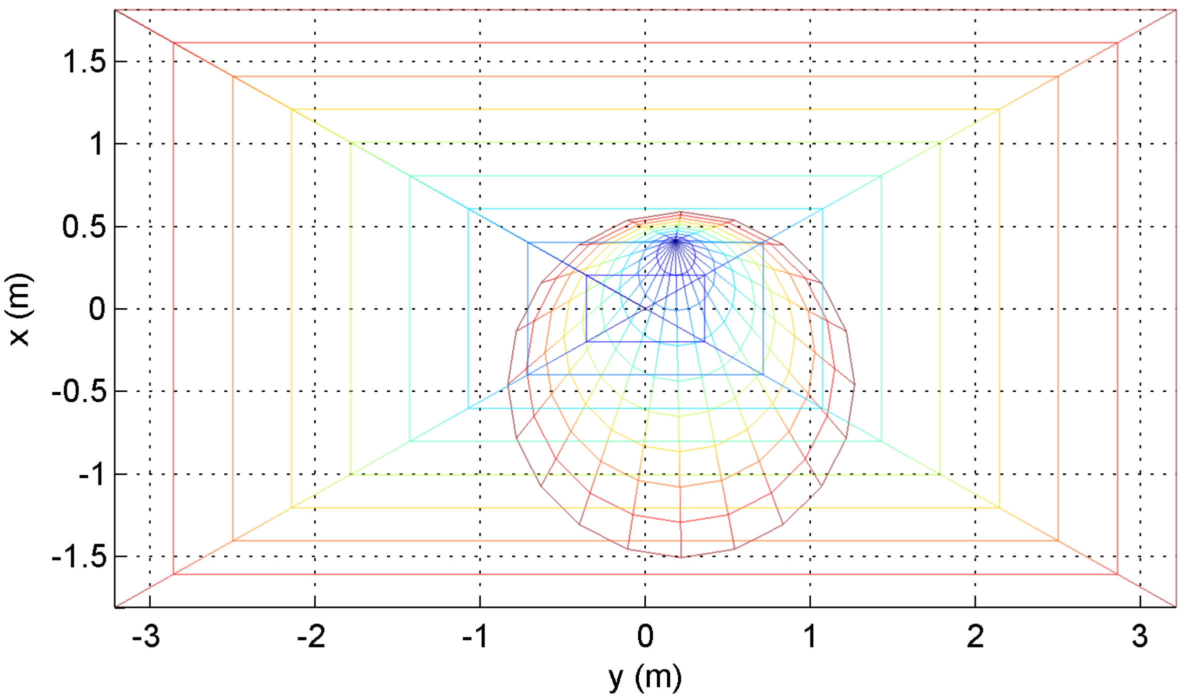


Figure A2.2: Plot of the AOS alignment, where circles represent acoustic beam and squares video frame at different depth according to colours.