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In situ target strength estimates of visually verified orange roughy

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The first estimates of orange roughy (*Hoplostethus atlanticus*) target strength at 38 and 120 kHz with visual verification were obtained from a self-contained echosounder and video camera system affixed to a demersal trawl towed through dense aggregations of spawning orange roughy. Mean target strength estimates were obtained from 24 tracks of orange roughy containing 83 echoes. The mean target strength at 38 kHz was −52.0 dB with a 95% confidence interval of −53.3 to −50.9 dB for fish with a mean length of 33.9 cm. At 120 kHz the mean target strength was −47.9 dB (confidence interval of −48.8 to −46.4 dB). This work makes two significant advances: *in situ TS* measurements have been made that can be confidently attributed to orange roughy, and using a trawl to herd orange roughy past the system resolved the previously intractable problem of fish avoidance.

Keywords: Acoustic, orange roughy, target strength, video.

Introduction

The acoustic echo-integration method of estimating fish stock biomass is used in many fisheries (Simmonds and MacLennan, 2005). An important parameter for this technique is an estimate of the mean acoustic reflectivity (and its logarithmic form, mean target strength, $<TS>$) of the fish being surveyed. The accuracy and representativeness of $<TS>$ directly affects the accuracy of the resulting biomass estimate, hence reducing *TS* uncertainty as much as is practical is paramount.

Acoustic surveys have been used to estimate orange roughy (*Hoplostethus atlanticus*) biomass since 1986 (Do and Coombs, 1989) and continue to be used for several stocks, predominantly in New Zealand and Australia. Orange roughy are a long-lived bathypelagic species found worldwide in deep waters (700–1500 m). They form large dense aggregations during spawning, often associated with underwater features such as seamounts (Pankhurst, 1988; Clark, 1999), and have been commercially fished in New Zealand waters since the late 1970s (Clark, 1999). Their deep location, low target strength (due to a wax ester-, rather than gas-filled swimbladder), and occurrence in areas with poor weather make them a difficult species to survey acoustically (Kloser and Horne, 2003; Coombs and Barr, 2007), and after more than 25 years of surveys and research, several challenges remain. A particular limitation of using acoustic surveys for orange roughy stock assessment is the uncertainty associated with target strength estimates. For example, prior to this study, the New Zealand Ministry of Fisheries used two 38 kHz *TS*–length relationships for orange roughy due to a lack of evidence to support the use of one over the other. Its "high" relationship:

$$TS = 16.15\log_{10} l - 74.34,$$

where *TS* is the mean target strength (in dB) for a fish of standard length *l*, (in cm), was derived from *ex situ* measurements of live fish in a tank (McClatchie *et al.*, 1999) combined with *in situ* measurements (Barr and Coombs, 2001), and its "low" relationship:

$$TS = 16.15\log_{10} l - 77.82$$

was based on *in situ* measurements (Kloser and Horne, 2003) from which an intercept of −77.82 was used with the slope from the "high" relationship. Biomass estimates calculated from these relationships differ by a factor of 2.2.

The key issues for reducing uncertainty and bias when estimating a population's $<TS>$ include: correct identification of the species for each *TS* measure; rejection of *TS* measures that originate from more than one target (multiple echoes); avoidance or behavioural changes caused by the presence of the measuring equipment; and the requirement for direct measures of animal length, sex, condition, and orientation. Added complications are the low target strength of orange roughy relative to their size, due to the lack of a gas-filled swimbladder (Phleger and Grigor, 1990), and mixing with other organisms of similar or greater target strengths (Kloser *et al.*, 1997; McClatchie and Coombs, 2005). Adding an optical imaging sensor (such as a still or video camera) to an acoustic *TS* measuring system is a way to resolve the species identification issue (Jaffe *et al.*, 1998; Ryan *et al.*, 2009; Kloser *et al.*, 2011) and also eliminates uncertainties with trawl targeting, selectivity, and multiple echoes. However, orange roughy have a strong and long-range avoidance reaction to lowered or falling objects (Koslow *et al.*, 1995; Kloser *et al.*, 1997, 2002; O'Driscoll *et al.*, 2012) and it is difficult to place optical sensors close enough to collect target identification data without evoking the avoidance response.

A battery-powered, dual-frequency internally logging acoustic system was developed to make *TS* measures and investigate the species composition of deepwater ecosystems (Kloser *et al.*, 2007); this concept was extended to include a video camera and lighting, which created a combined acoustic-optical system (AOS) (Ryan *et al.*, 2009). A novel and essential part of the concept is that the AOS attaches to a conventional demersal or pelagic trawl net, providing the means to herd fish to within the operating range of the video camera while also collecting the fish in the trawl cod end. The development and performance of the AOS is documented elsewhere (Ryan *et al.*, 2009) and this paper is concerned with obtaining *TS* estimates from visually verified orange roughy, and hence reducing uncertainty in orange roughy acoustic biomass estimates.

Methods

The AOS [comprising Simrad EK60 38 and 120 kHz split-beam echosounders and transducers (Table 1), a video camera (59° field-of-view), an attitude sensor, batteries, and control and storage computers] was affixed to the headline of a rough-bottom orange roughy demersal trawl and deployed from RV "Tangaroa", a 70 m research vessel (see Ryan *et al.*, 2009, for further details). The trawl was towed at a speed of 1.2–1.7 m s^{-1} through dense orange roughy aggregations at 750–900 m depth on the Chatham Rise to the east of New Zealand in July 2007 (Figure 1). Operating the trawl in a normal demersal fishing manner would have given a headline height of 4–6 m, a range to the seafloor that was too short for effective use of the 38 kHz echosounders. Instead, the trawl was operated with the headline approximately 20 m above the bottom, with the ground rope 13 m below the headline. The width of the trawl opening was approximately 14 m.

Acoustic, video, and platform attitude data were collected by the AOS and downloaded after each deployment. A ship-mounted 38 kHz echosounder was operated during the trawls and recorded the aggregations prior to the passage of the trawl and AOS (Figure 2a).

The echosounders on the AOS were calibrated during the voyage to a depth of approximately 900 m (Ryan *et al.*, 2009). The acoustic data were processed and the depth-dependent calibration applied using Echoview 4.30 (Myriax, 2007), where single targets were detected to give time-stamped values of beam pattern compensated *TS*, range, and alongship (along the axis of the net) and athwartship (across the axis of the net) angles. These data were used as input to the Echoview fish tracking algorithm (an α-β fixed coefficient filtering model, Blackman, 1986) to yield sets of single targets from each fish track (Kloser and Horne, 2003; Kloser *et al.*, 2011).

Using the time-stamp common to both the acoustic and video datasets as a key, species and orientation were established by manual inspection of the video images that corresponded to fish tracks (Figure 2b and c, and Figure 2 of Ryan *et al.*, 2009). From inspection of the video, the behaviour of the fish was noted (drifting, swimming forwards, or swimming downwards), and their bearing and orientation coarsely estimated; the single-camera video system did not provide the means to directly measure fish orientation. Data from orange roughy that were actively diving in the acoustic and video records were excluded from the analysis as it was clear that they were reacting to the presence of the trawl and hence were not likely to be representative of an undisturbed spawning aggregation. Leaving such measures in the dataset

Table 1. AOS echosounder parameters and settings.

Parameter	Value at 38 kHz	Value at 120 kHz
Transducer model	ES38DD	ES120-7D
Beam width (degrees)	7	7
Pulse length (ms)	0.512	0.256
Bandwidth (kHz)	3.28	8.71
Power (W)	2 000	500
Ping rate (Hz)	9	9
Maximum range (m)	25	25

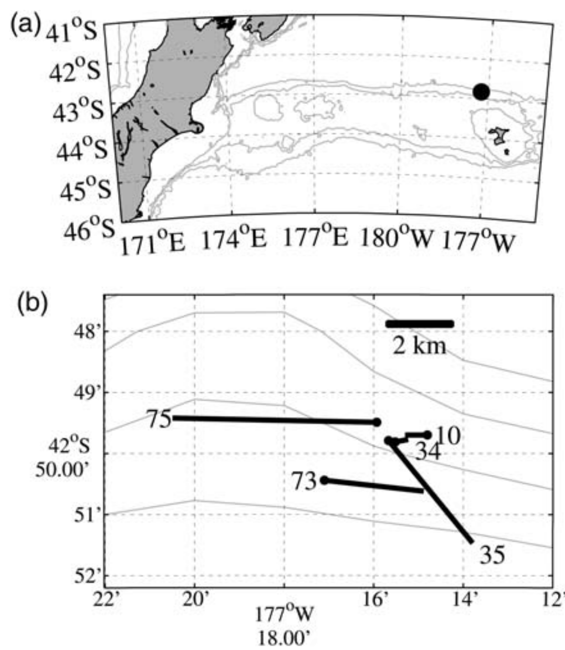

Figure 1. (a) The experimental area (filled circle) on the Chatham Rise, to the east of New Zealand. Contours are at 300, 600, and 1000 m. (b) Trawl paths with numbers indicating the trawl station (Table 2), and filled circles the start position. Contours are at 750, 800, 850, and 950 m, increasing northwards.

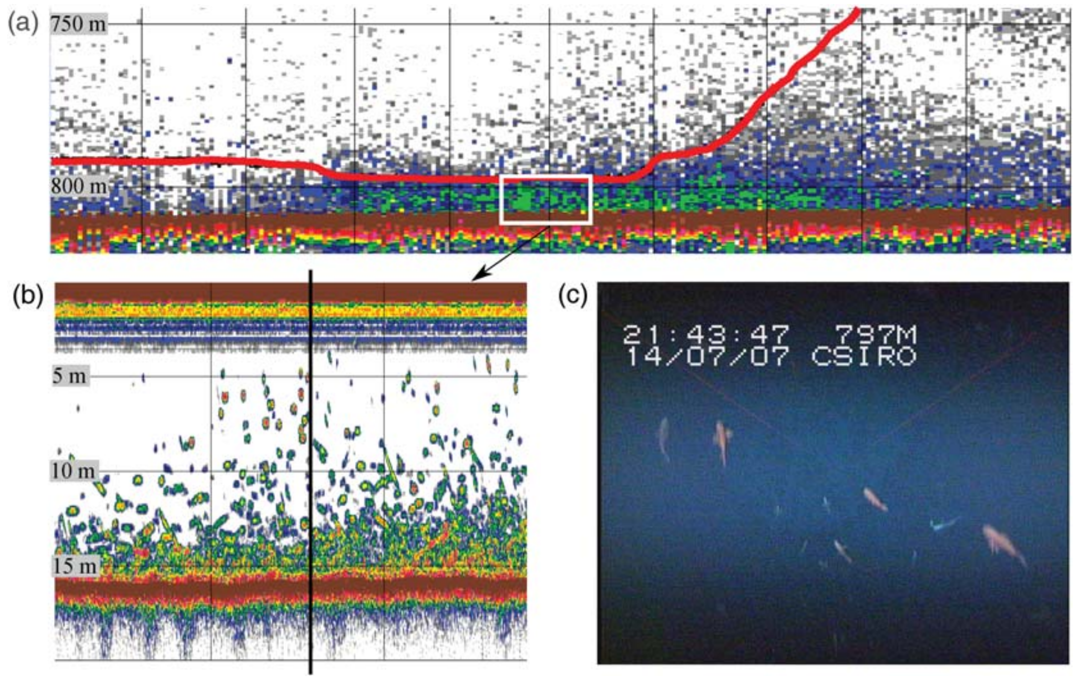

Figure 2. (a) Hull-mounted 38 kHz echogram from Station 73 (Table 2) showing the path of the trawl headline and AOS (red curve) passing through a spawning orange roughy aggregation (blue/green region above the brown coloured seafloor). Vertical lines are every 250 m and horizontal lines indicate the depth below the sea surface. Echogram colours represent S_v with a −70 dB threshold. (b) AOS echogram at 38 kHz for the region indicated in white in (a). Individual fish echoes are visible from 4 to 12 m and more dense regions of fish from 12 to 15 m. Vertical lines are every 30 s and horizontal lines indicate the depth below the AOS transducers. (c) Video frame corresponding to the time indicated with the vertical black line in (b).

Table 2. Details of AOS deployments and trawls.

Station	Vessel	Start (NZST)	Trawl duration (min)	Notes
34	RV "Tangaroa"	11 July 2007 17:39	5	Cod end closed. 5 560 kg of orange roughy and 50 kg of other species were caught
35	RV "Tangaroa"	11 July 2007 20:12	48	Cod end open
73	RV "Tangaroa"	15 July 2007 09:07	41	Cod end open
10	FV "San Waitaki"	15 July 2007 12:50	6	39 000 kg of orange roughy and 13 kg of other species were caught. No AOS
75	RV "Tangaroa"	15 July 2007 16:48	62	Cod end open

Trawl duration refers to the time that the trawl was at the desired depth and position.

could have introduced bias to the target strength estimates due to the large tilt-angle of the fish.

Plots of the tracks of each visually verified fish at 38 kHz and 120 kHz were used to visualize the quality and accuracy of the acoustic data, with an emphasis placed on fish that maintained a relatively constant depth below the AOS and had a rate of movement that was consistent with the AOS and fish swimming speeds (Figure 3). A first pass analysis was made followed by a review by two of the authors (RJK and TER) of decisions made for each fish. Particular care was taken to ensure that small gas-bearing organisms (such as myctophids and syphonophores) with little visibility on the camera system were not included.

Sets of *TS* measures at both 38 and 120 kHz from positively identified fish were then produced and exported for further analysis. For each AOS trawl, *TS* data were also exported for detected tracks from regions where high orange roughy concentrations had been recorded by the video system. Tracks that came from regions of high track density were removed prior to analysis, leaving only clearly separated tracks. These were taken to be visually unmatched estimates of orange roughy target strength, having higher target identification uncertainty than the estimates with visual-verification.

The *TS* values from visually verified orange roughy were filtered further by only accepting echoes that were 4–10 m in range from the transducers. These ranges were determined by the acoustic near-field region of the transducer and fish, and by the inability to positively identify a fish as an orange roughy in the video at larger ranges. The effect of target position and range on *TS* was tested using a linear regression.

The extent of the acoustic near-field of the main lobe of the transducers was calculated from A/λ (Clay and Medwin, 1977), where A is the area of the active elements in the transducer and

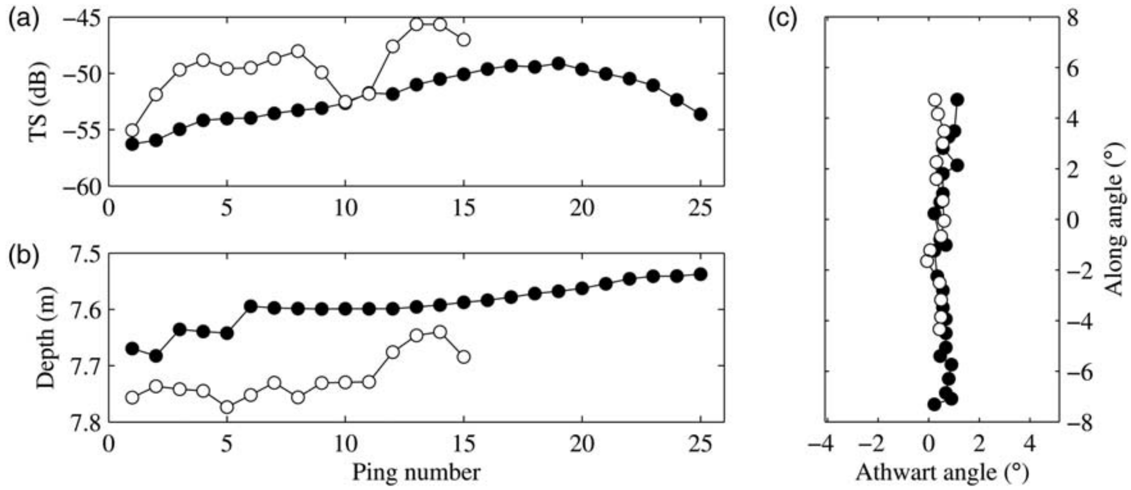

Figure 3. The location and *TS* of a visually verified orange roughy as it passed under the AOS at 38 kHz (filled circles) and 120 kHz (open circles) prior to filtering: (a) variation in *TS* as a function of ping number; (b) variation in depth; (c) position in the acoustic beam. First appearance was at the upper end of the shown track.

λ the acoustic wavelength [$\lambda = c/f$, f is frequency (Hz), and c was set to 1470 m s^{-1}], and used to check that the minimum fish acceptance range was in the far-field of the transducer. The radius of the active elements was estimated from

$$r = \frac{1.6}{k \sin\left(\frac{\theta_{\mathrm{BW}}}{2}\right)},$$

where k is the acoustic wavenumber and θ_{BW} the beamwidth at the -3 dB points and the active area calculated as πr^2 (Sherman and Butler, 2007). The near-field of the acoustic scatter from a fish is much less understood (e.g. Dawson *et al.*, 2000; Gerlotto *et al.*, 2000; Moszynski and Hedgepeth, 2000). Thus, in the absence of a better method it was assumed that the near-field of orange roughy backscatter was similar to that of a elliptical transducer with a major axis the same length as mean orange roughy standard length and a width 20% of the standard length (McClatchie and Ye, 2000, Figure 1; Barr, 2001, Table III).

To limit transducer beam compensation errors, all echoes that were $> 4^\circ$ off axis were excluded. All echoes with a $TS < -70$ dB were also excluded to eliminate noise bias at the start and end of tracks. The echo location from the split-beam echosounders (range, alongship, and athwartship angles) was transformed to Cartesian coordinates relative to the respective transducers and compared (Demer *et al.*, 1999). The 38 and 120 kHz transducers were aligned along the athwartship axis and offset by 0.4 m in the alongship axis, so echoes were rejected if the position discrepancy between the 38 and 120 kHz transducers was outside ± 0.15 m athwartship and ± 0.10 m alongship (based on a review of positional accuracy and visual checking of targets and their associated tracks). The linear mean of the remaining *TS* values for each fish track was then calculated and a weighted linear mean of the track means calculated to give an estimate of mean orange roughy target strength, $<TS>$. The weights were the number of echoes in each fish track. A weighted 95% bootstrap confidence interval of $<TS>$ (10 000 samples, bias corrected and accelerated percentile, DiCiccio and Efron, 1996) at 38 and 120 kHz was estimated from the final set of fish track means and from the visually unmatched track means. The number of echoes in each fish track were used to determine the probability of selecting a particular track mean in the bootstrap procedure so that tracks with more echoes had a greater chance of being selected.

Catch data were obtained from the first AOS deployment, but the cod end was left open thereafter to allow for longer deployments without catching large quantities of fish (Table 2). However, a fishing vessel (FV "San Waitaki") was operating in the same area at the time and recorded biological data from a trawl on the spawning aggregation. The mean length and standard deviation for orange roughy, normalized by catch weight, was calculated. Individual fish weights were measured from the FV "San Waitaki" catch and the mean fish weight estimated. Fish weights were not measured from the RV "Tangaroa" catch, but a length to weight relationship was calculated from all other trawls on the voyage where weights were measured, and used to estimate the mean weight for the first AOS deployment.

Results

Acoustic and video data were successfully obtained from four trawls on spawning orange roughy aggregations (Table 2). Fish dove down in response to the trawl – this was clearly visible in the video data and can be inferred from the acoustic data via the layer of overlapping fish echoes in the 2–3 m above the seafloor (Figure 2b), with isolated fish above, in contrast to the echogram from the vessel which shows a 10–15 m high layer (Figure 2a).

At 38 kHz there were 45 tracks comprising 296 echoes that could be unequivocally identified as orange roughy from the video and be confidently paired with corresponding acoustic measures. Selecting only echoes that were visible at 38 kHz and 120 kHz yielded 37 tracks (162 valid echoes), and then using the geo-location of the 38 and 120 kHz target positions gave 24 tracks (83 echoes) with mean target strengths of -52.0 dB and -47.9 dB at 38 kHz and 120 kHz respectively (Figure 4). The 95% bootstrapped confidence interval of $<TS>$ was estimated to be -53.3 to -50.9 dB at 38 kHz and -48.8 to -46.4 dB at

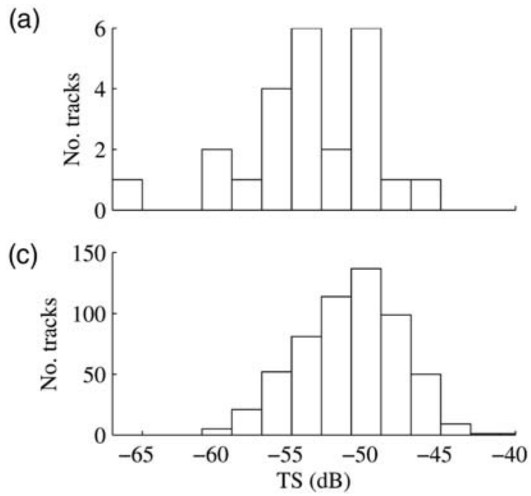

Figure 4. Distribution of orange roughy track <*TS*> at 38 kHz (a) and 120 kHz (b) with visual verification, and visually unmatched track <*TS*> at 38 kHz (c) and 120 kHz (d).

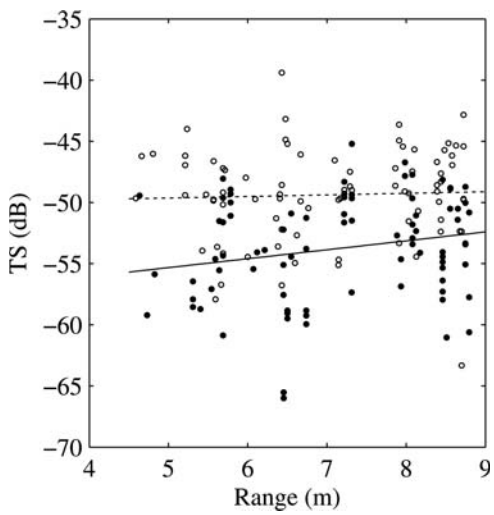

Figure 5. Orange roughy *TS* with visual verification plotted against range from the AOS transducers at 38 kHz (filled circles) and 120 kHz (open circles) and linear regressions (38 kHz solid line, $F_{1,81} = 3.6$, $p = 0.06$, $r^2 = 0.04$; 120 kHz dashed line, $F_{1,81} = 0.14$, $p = 0.71$, $r^2 = 0.0$).

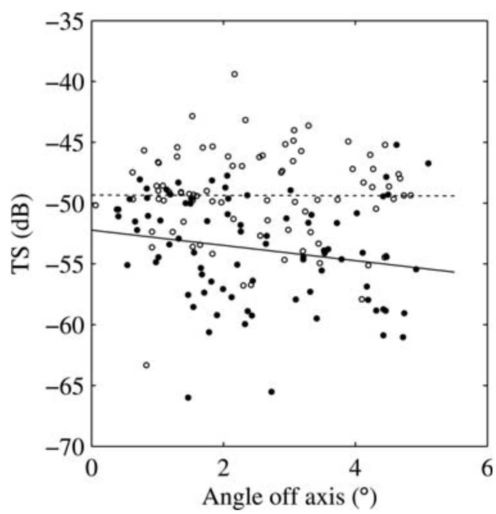

Figure 6. Orange roughy *TS* with visual verification plotted against angle off the central axis of the AOS transducers at 38 kHz (filled circles) and 120 kHz (open circles) and linear regressions (38 kHz solid line, $F_{1,81} = 3.2$, $p = 0.08$, $r^2 = 0.04$; 120 kHz dashed line, $F_{1,81} = 0.0$, $p = 0.97$, $r^2 = 0.0$).

120 kHz for the final set of 24 tracks. At 38 kHz there were 570 tracks from the visually unmatched dataset comprising 4226 echoes (Figure 4) with a <*TS*> of −49.9 dB and a 95% bootstrapped confidence interval of −50.1 to −49.5 dB. At 120 kHz there were 982 tracks comprising 6749 echoes (Figure 4) with a <*TS*> of −49.4 dB and a 95% bootstrapped confidence interval of −49.8 to −49.4 dB.

The mean standard length of orange roughy from the RV "Tangaroa" trawl was 34.2 cm (s.d. 2.5) and 33.6 cm (s.d. 2.9) from the FV "San Waitaki" trawl. The combined mean length was 33.9 cm (s.d. 2.8). The mean orange roughy weight from the RV "Tangaroa" and FV "San Waitaki" trawls was 1.3 kg in both cases.

There was no significant trend in orange roughy *TS* with range from the transducer for 38 kHz ($F_{1,81} = 3.6$, $p = 0.06$, $r^2 = 0.04$) or 120 kHz ($F_{1,81} = 0.14$, $p = 0.71$, $r^2 = 0.0$), Figure 5. There was also no significant trend in *TS* with angle off the transducer axis ($F_{1,81} = 3.2$, $p = 0.08$, $r^2 = 0.04$) or 120 kHz ($F_{1,81} = 0.0$, $p = 0.97$, $r^2 = 0.0$), Figure 6.

The near-field of the main lobe of the transducers was estimated to be 2.1 and 0.7 m for the 38 kHz and 120 kHz transducers, respectively. The near-field range of a 33.9 cm standard length orange roughy was estimated to be 0.5 and 1.5 m at 38 kHz and 120 kHz, respectively.

Discussion

As discussed by Ryan *et al.* (2009), the *in situ* data obtained from the trawl-affixed AOS represents two significant improvements over previous orange roughy *in situ* estimates: (i) avoidance reaction of orange roughy to lowered equipment was circumvented by using the trawl to herd the fish into the working ranges of the video camera and echosounders, and (ii) the camera was used to eliminate any uncertainty over the species of the acoustic echoes recorded by the echosounders.

The visually verified dataset of 24 trawl-herded fish gave a 38 kHz <*TS*> of −52.0 dB for fish of mean length 33.9 cm and, due to the visual verification and lack of active avoidance behaviour, is the most robust estimate available. This value is lower than the visually unverified New Zealand Ministry of Fisheries Deepwater Working Group's "high" relationship (−49.6 dB for a 33.9 cm fish) and higher than its "low" relationship (−53.1 dB for a 33.9 cm fish). The bootstrapped confidence interval from the 24-track dataset includes the "low" estimate but not the "high" estimate (Figure 7). Our result is lower than the −49.3 dB (for a 35 cm fish) obtained using the rate of change of echo phase target selection method (Coombs and Barr, 2007), but is within the −52.9 to −51.0 dB range for orange roughy identified using *TS* differences at 38 and 120 kHz (Kloser and Horne, 2003). All previous *in situ* estimates were derived from single targets either on the periphery or in the general vicinity of orange roughy aggregations and lack visual attribution of acoustic echoes to species.

While the new target strength estimates have no target identification uncertainty, additional work is required to establish that the *TS* measurements are sufficiently representative of the surveyed fish length, sex, spawning condition, and orientation. For example, the visually verified measurements were from herded fish with a mainly horizontal attitude (Ryan *et al.*, 2009) while moored video measurements of unherded orange roughy show a slight head-down attitude with a range that exceeds ±30° (O'Driscoll *et al.*, 2012). The fish size distribution may also differ between herded fish and an undisturbed aggregation (e.g. fish are oriented differently in different parts of a spawning plume, the sex ratio varies throughout the plume, reaction to the trawl is fish-size-dependent), making it difficult to determine how representative these new measurements may be of the surveyed population and how best to use them in stock assessments. Similar questions of representativeness are present in all previous orange roughy *TS* estimates and this experiment was not intended to address those questions; the primary objective was to obtain target strength estimates of orange roughy without target identification uncertainty. To this end, while there were many thousands of video observations of orange roughy and dual-frequency *TS* measures from the AOS, we have concentrated on acoustic echoes and tracks that could be, with absolute certainty, identified as orange roughy at both 38 kHz and 120 kHz.

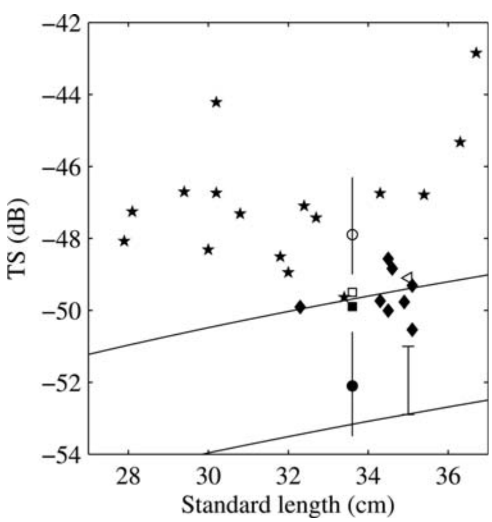

Figure 7. Comparison of current and past orange roughy target strength estimates at 38 kHz and 120 kHz. *In situ* <*TS*> with visual verification (38 kHz, filled circle; 120 kHz open circle) and 95% confidence interval of <*TS*> (extent of vertical line); visually unmatched <*TS*> (38 kHz, filled square; 120 kHz, open square; 95% confidence interval of <*TS*> not shown for clarity, but is less than ±0.3 dB for both frequencies). Kloser & Horne (2003) tracked *in situ* <*TS*> range at 38 kHz (vertical line with whiskers) and single estimate for 120 kHz (open triangle); Coombs & Barr (2007) *in situ* (filled diamonds); McClatchie *et al.* (1999) *ex situ* (filled pentagrams). Upper continuous line is the New Zealand Ministry of Fisheries "high" relationship and the lower line the "low" relationship, both for 38 kHz.

A first step towards assessing the representativeness of herded target strength measurements with visual verification has been described (Kloser *et al.*, 2011) for a deep-water fish, blue grenadier (*Macruronus novaezelandiae*). This method integrated a model of fish scattering with target strength and associated stereo optical measurements of fish size and orientation and verification of species.

The 2.4 dB range in the 38 kHz <*TS*> sampling confidence interval is moderate – a biomass estimate derived using −52.0 dB would change by a factor of 0.8 or 1.3 at the limits of the 95% confidence interval. For example, the 2010 estimate of orange roughy stock size in the main New Zealand fishing grounds (43 300 t in area ORH3B, Ministry of Fisheries Science Group, 2011) could vary from 33 000 t to 57 000 t.

The <*TS*> estimate at 120 kHz (−47.9 dB) lies within the interval reported by Kloser and Horne (2003) (−49.1 dB with a s.d. of 6.6 dB) and the frequency difference, 38 kHz minus 120 kHz, of the ensemble targets (−4.1 dB) is within the range reported for spawning orange roughy aggregations (−2 to −5 dB, Kloser *et al.*, 2002). Acoustic biomass estimates of orange roughy have primarily used 38 kHz, but backscatter differences between 38 and 120 kHz can be used to estimate species composition (Kloser *et al.*, 2002), and if 120 kHz was used as the main survey frequency the 2–5 dB higher *TS* could reduce the problems of surveying a low-*TS* species in mixed species aggregations (Kloser *et al.*, 1997; McClatchie and Coombs, 2005). However, other consequences of using a higher frequency may be detrimental to the echo-integration technique, such as the shorter working range of a 120 kHz system, and the tendency for target strength variability with tilt angle to increase at higher frequencies (Horne and Jech, 1998).

The visually unmatched <*TS*> estimates are outside the 95% confidence intervals of the visually verified estimates at 38 and 120 kHz (Figure 7), although the range of track <*TS*> is comparable (Figure 4). The verified dataset is a subset of the unmatched dataset and the difference in <*TS*> is hence a consequence of the objective exclusion of tracks when deriving the verified dataset. The visually verified and visually unmatched 99% <*TS*> confidence intervals at 38 and 120 kHz also do not overlap, indicating that they are statistically different at the $p = 0.01$ level. Several reasons for this difference can be postulated, such as behavioural or spatial variations in orange roughy *TS* with respect to the AOS in combination with the filtering that selects on range and fish density. It is also possible that organisms other than orange roughy were present in the regions of visually high orange roughy density (Ryan *et al.*, 2009) and highlights the potential for a bias in conventional *in situ TS* measurements of spawning orange roughy – it cannot be confidently assumed that all echoes from an area of high orange roughy density are actually from orange roughy (as noted by Ryan *et al.*, 2009, smaller and darker fish, such as small swimbladder-bearing mesopelagic fish with target strengths broadly similar to that of orange roughy, were not detected by the AOS camera). Of note is that the visually unmatched <*TS*> at 38 kHz is consistent with *in situ* estimates from earlier visually unverified orange roughy estimates (Coombs and Barr, 2007) and suggests that those results may include echoes that are not from orange roughy. In contrast, the <*TS*> at 38 kHz is consistent with echoes selected from regions with a 38–120 kHz *TS* difference thought to originate from orange roughy (Kloser and Horne, 2003), and suggests that selecting echoes based on the 38–120 kHz frequency difference may be a more reliable method of identifying orange roughy than from echo phase change (Coombs and Barr, 2007). However, it should be noted that these statements are based on 83 echoes and a larger number of observations would allow for more certainty in these statements.

TS estimates should be unbiased from technical aspects of calibration; the calibration of the AOS echosounders has been shown to vary by ±0.25 dB at 38 kHz and ±0.7 dB at 120 kHz over multiple depth-parameterized calibrations (Ryan *et al.*, 2009) and hence will not markedly affect the *TS* results and comparisons. The correction to *TS* for position in the acoustic beam was shown to be appropriate, with no significant trend in fish *TS* with angle off the transducer axis.

The short fish acceptance range (4 m) raised the possibility of near-field effects from either the transducer or fish degrading the accuracy of the target strength measurements. However, the estimates of transducer and fish near-field range were all considerably less than 4 m, indicating that near-field effects should not be a concern, and this is supported by the lack of a significant trend in target strength with range from the transducers (Figure 5).

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