Target strength of southern blue whiting (M icromesistius australis) using swimbladder modelling, split beam and deconvolution

Sam M McClatchie, Gavin M Macaulay, Stuart Hanchet, and Roger F. Coombs


The tilt-averaged target strength, <TS>, of southern blue whiting (M. australis) at 38 kHz was measured using swimbladder modelling and two in situ methods. Split beam estimates of <TS> for southern blue whiting were carefully screened for multiple echoes, but a few useful values of <TS> were obtained from the periphery of shoals even at 150–300 m depths. We compare <TS> of southern blue whiting derived from swimbladder modelling to split beam and deconvolution estimates of <TS>. The <TS>-length regression for M. australis has similar slope but lower intercept than the published regression for blue whiting, M icromesistius poutassou. Predicted <TS> for M. australis are 2.9 to 4.3 dB lower than for M. poutassou of the same size. In contrast to the swimbladder results, split beam and deconvolution estimates of <TS> for M. australis were in line with the <TS>-length relationship for M. poutassou. The magnitude of the difference between modelling and in situ results could arise from the assumed tilt distribution of fish used in the modelling calculations and the actual, but unknown tilt distribution of the fish in situ. Acquiring information on the tilt distributions of southern blue whiting is essential to resolve the measured difference between in situ and modelled estimates of target strength.

Key words: acoustics, target strength, swimbladder, in situ, split beam, deconvolution, southern blue whiting.

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S. M McClatchie, G. J. M Macaulay, S. M. Hanchet, and R. F. Coombs: National Institute of Water and Atmospheric Research Ltd (NIWA), P O Box 14-901, Kilbirnie, Wellington, New Zealand. Correspondence to S. M McClatchie: tel: +64 04 386 0300; fax: +64 4386 0574; e-mail: smcclatchie@niwa.cri.nz

Introduction

Blue whiting (M icromesistius poutassou, Risso, 1826) are the focus of a very large fishery in the eastern North Atlantic (444 000–818 000 t between 1984 and 1993 (FAO, 1993)). The closely related southern hemisphere species, southern blue whiting, M icromesistius australis, Norman, 1937, supported a catch of 104 000–232 000 t between 1984 and 1993 on the Patagonian and Fuegian shelves, in Antarctic waters and off New Zealand (FAO, 1993). Spawning aggregations of southern blue whiting are currently the target of an 18 000 t fishery (1994–1995) in Subantarctic waters off south-east New Zealand (Annala and Sullivan, 1996). Annual landings of southern blue whiting have fluctuated widely, peaking in 1973 at 50 000 t, when they were the focus of a Soviet head and gut fishery, and again in 1991–1992 when they were targeted mainly by Soviet head and gut vessels and Japanese surimi vessels. Landings were reduced after the introduction of a 32 000 t catch limit in 1992–1993 (Annala and Sullivan, 1996). The fishery remains one of the most important in New Zealand and acoustic surveys are essential for stock assessment. During August and September southern blue whiting, form single species spawning aggregations in depths of 250 to 500 m, where their biomass can be assessed by echo integration surveys. Consequently it is vital to know the relationship between tilt-averaged target strength, <TS>, and fish size. However the best data available, until now, was a <TS>-length regression derived from blue whiting, M. poutassou (ICES, 1985; ICES, 1982; Monstad, 1992).
Ideally, we prefer to measure target strength by a number of independent methods, and use the estimated values from one method to support the results from the other methods. We estimate target strength using theoretical models for comparison with experimental measurements on dead or live fish in tanks, and in situ target strength measurements made on the fish in their natural habitat. Southern blue whiting have not been maintained alive in tanks and because they have swimbladders, experimental measurements on dead fish are probably not useful. Hence we currently have measurements of target strength from modelling and in situ measurements. For the in situ measurements we used two independent approaches. First, we collected echo ensembles using our custom-built, towed echosounder (CRFREDA, see Table 1), and estimated target strength using deconvolution to remove the beam pattern from the fish echo probability density functions (pdfs). Second, we measured target strength directly using a hull-mounted split beam transducer and an EK500 echosounder.

Recent studies demonstrate that under certain conditions the EK 500 single echo detection algorithm fails, and multiple targets are erroneously interpreted as single echoes, producing biased target strength distributions (Soule et al., 1995). This problem, which is not limited to the EK500, is particularly relevant for small, densely shoaling fish such as anchovies and pilchards and becomes more serious for targets further from the transducer (Barange et al., 1996). So far, relatively few studies have addressed this problem, but the need to examine in situ target strength data with a critical eye is clear. We used the empirical tests described by Barange et al. (1996) to determine whether the multiple echo bias was present in our data, and were able to select a few unbiased data to compare the split beam target strengths with other techniques.

Our main objective was to provide a new \(<TS>-length regression for southern blue whiting, removing the necessity to rely on the relationship for \(M. poutassou\). We wanted to compare the results of our swimbladder modelling with in situ target strength. Last, we were interested in the performance of the Simrad

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**Table 1. Echosounder settings of the EK 500 and CRFREDA systems used in this study.**

<table>
<thead>
<tr>
<th>Simrad EK 500</th>
<th>CRFREDA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transducer</td>
<td>ES38B</td>
</tr>
<tr>
<td>Frequency</td>
<td>37.9 kHz</td>
</tr>
<tr>
<td>Nominal beam width</td>
<td>7.1°</td>
</tr>
<tr>
<td>Pulse duration</td>
<td>1 ms</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>3.8 kHz</td>
</tr>
<tr>
<td>Ping rate</td>
<td>0.5 pings s(^{-1})</td>
</tr>
<tr>
<td>Transducer gain</td>
<td>26.5</td>
</tr>
</tbody>
</table>

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Figure 1. The subantarctic region off south east New Zealand where southern blue whiting are found. Trawl and target strength data were collected on the Campbell Island Rise. The inset shows the location of the subantarctic region in relation to the 1500 m contour around New Zealand.
2 was collected over distances of 2.5 km (for CRFREDA data) and 3.5 km and target strength was measured to the nearest centimetre. The size distribution within shoals of spawning southern blue whiting tends to be homogeneous rather than forming sub-shoals within same shoals with closer than 20 m or further than 100 m from the transducer were also rejected. Rician pdfs was used to estimate the tilt-averaged target strength from the echograms because mean volume backscattering was not recorded. Fifty metre depth bins containing shoaling fish were compared to adjacent 50 m depth bins with scattered fish. We expected any multiple echoes to appear as higher target strength modes in the frequency distribution for the depth bin with shoaling fish (Barange et al., 1996).

Deconvolution of single echo ensembles

In situ target strength data (n=2) were also collected using CRFREDA with a 40 Log R TVG on the Campbell Island Rise during the 1994 acoustic survey of southern blue whiting stocks. A towed 38 kHz EDO transducer with a 3 dB beam width of 6.5° was operated with 2000 W input and a 1 ms pulse length (Table 1). Several transects over aggregations of southern blue whiting were made at 1.5–3 knots with the acoustic transducer lowered to within 40–70 m of the aggregation. The length composition of southern blue whiting in the shoals was measured from trawl samples collected from the aggregation before or after the acoustic transects.

To estimate tilt-averaged target strengths, the pdf of fish echoes, \( \omega_f(e) \), was obtained by removing the pdf of the transducer beam, \( \omega_T(b) \), from the pdf of the echoes received by the transducer, \( \omega_{e}(e) \) using deconvolution:

\[
\omega_{e}(e) = \frac{1}{\omega_T(b)} \omega_f \left( \frac{e}{b} \right) \frac{db}{b}
\]

where \( e \) is the echo level, \( b = D^2 \) and \( D \) is the normalized beam directivity (Craig and Forbes, 1969; Ehrenberg, 1972, 1983; Clay, 1983).

The raw acoustic data were filtered in order to remove any echoes that were not from single fish. The main filtering criterion was that the length of the returned echo (at half its maximum amplitude) was from 50 to 100% of the length of the transmitted pulse. All echoes closer than 20 m or further than 100 m from the transducer were also rejected. Rician pdfs (Clay and Heist, 1984) were fitted to the fish pdfs using least squares. The backscattering cross-section, \( \sigma_{bsf} \), obtained from the Rician pdfs was used to estimate the tilt-averaged target strength (\( \langle TS\rangle = 10 \log_{10} \sigma_{bsf} \)) for the modal size of fish in the trawls. Note the tilt-averaged target strength is

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**Table 2. Parameter settings used in the EK 500 single echo detection algorithm in this study.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection threshold</td>
<td>−60 dB</td>
</tr>
<tr>
<td>Minimum echo length</td>
<td>0.8</td>
</tr>
<tr>
<td>Maximum echo length</td>
<td>1.8</td>
</tr>
<tr>
<td>Maximum gain compensation</td>
<td>4 dB</td>
</tr>
<tr>
<td>Maximum phase deviation</td>
<td>2.0 phase steps</td>
</tr>
</tbody>
</table>

EK 500 as a tool for estimating target strength of southern blue whiting.

**Methods**

**Trawl data**

Trawl samples were collected from the same areas on the Campbell Island Rise where target strength data were recorded (Fig. 1). Fish were sampled using a P159A Y midden midwater trawl with a 35 m headline height and a 60 mm cod end mesh, towed for ~30 min at ~4.5 knots. Catches were sorted to fish species and measured to the nearest centimetre. The size distribution within shoals of spawning southern blue whiting tends to be homogeneous rather than forming sub-shoals with distinct size structures. The lack of size sorting is supported by similarity in size distributions of commercial catches (Hanchet, unpublished data). Consequently, it is reasonable to relate the size distribution of fish to the target strength distribution, even though the fish were collected over distances of ~3.5 km and target strength was collected over ~0.5 km (in the case of the EK 500 data) and ~5.5 km (for CRFREDA data).

**Target strength from split beam**

Target strengths were recorded with a Simrad EK 500 echosounder connected to a 38 kHz, hull mounted split beam transducer using 40 Log R TVG. Echosounder specifications and settings are given in Table 1. The settings used for single echo detection were the same as the manufacturer defaults, except for the detection threshold, which was set to −60 dB instead of the default −50 dB (Table 2). Since undetected multiple echoes may bias in situ target strength recorded by any echosounder (Soule et al., 1995), target strengths were extracted from a subset of the data that could be carefully screened to avoid multiple echoes interpreted as single echoes. We started with target strength distributions from each 50 m depth bin between the surface and the bottom. Target strength data were selected from areas where targeted trawling caught enough southern blue whiting to give a reliable size distribution. From this dataset we chose echoes in depth bins that spanned southern blue whiting marks on the echogram but excluded the near bottom echoes where larger swim-bladder fish occur (e.g. ling, Genypterus blacodes). Finally we narrowed the selection to adjacent 50 m depth bins where the mark on the echogram showed one bin covering the core of a fish shoal and the adjacent bin covered the periphery of the same shoal (n=4).

To detect bias due to multiple echoes, we compared the frequency distribution of target strengths from the periphery and the core of southern blue whiting shoals, following the procedure used by Barange et al. (1996). The periphery and core of shoals was judged from echograms because mean volume backscattering was not recorded. Fifty metre depth bins containing shoaling fish were compared to adjacent 50 m depth bins with scattered fish. We expected any multiple echoes to appear as higher target strength modes in the frequency distribution for the depth bin with shoaling fish (Barange et al., 1996).
Figure 2. Fork length distribution of southern blue whiting caught in five trawls. Tow 25 and tow 26 are associated with the acoustic data used in the deconvolution analyses.

Target strength of southern blue whiting (Micromesistius australis)
actually target strength of the averaged acoustic cross-section and that all averaging is done in the linear domain.

Swimbladder models

The methods and models are described in McClatchie et al. (1996). Swimbladders of southern blue whiting are cigar-shaped and are easily modelled by a simplified cylinder shape. The equicylinder model and the deformed cylinder model (McClatchie et al., 1996) gave similar results but both these models produced higher tilt-averaged target strengths than the mapping method. The mapping method is likely to be more accurate because it involves less approximation in the shape of the swimbladder. Results of the mapping method applied to 27 fish are presented here.

Results

Trawl data

The size distribution of fish from which the in situ <TS> estimates were obtained was narrow. The narrow size range of the samples makes them quite suitable for matching with estimates of <TS>. Trawl tows 25 and 28 were made in depths of 350–380 m on the edge of the Campbell Island Rise. Research over the past 3 years has shown that this depth range on the Campbell Island Rise is dominated by immature (2 year old) southern blue whiting 25–30 cm long (Hanchet and Ingerson, 1996). Tows 26 and 27 were made amongst spawning adults in depths of 400–480 m on the Campbell Island Rise. The commercial fishery during 1994 and 1995 has been dominated by the very strong 1991 year class that ranged from 28–34 cm in 1994 at the time of the target strength work (Hanchet and Ingerson, 1996). Tow 11 was carried out further north on the Pukaki Rise in depths of 350–400 m. The size distribution from the commercial fishery data included a range of modes of different sized fish at 20, 30 and 50 cm (Hanchet and Ingerson, 1996), a fact that becomes important for interpreting an outlying target strength measurement (see Discussion section).

The length frequency distributions for tows 25 and 28 were dominated by immature age 2+ fish (25–30 cm) with a small mode of 1+ fish (~20 cm) (Fig. 2). All other tows were dominated by 3+ fish (28–34 cm). Tows 26 and 27 were the only samples with fish older than 5 years (40–55 cm fork length), but the distribution was still dominated by 3+ fish (Fig. 2). Each tow was dominated by southern blue whiting but occasionally single specimens of hoki (M acuru ronous novaezeelandiae), hake (M erlucius australis), ling (G enypterus blacodes) or deafi sh (T rachypteridae, probably T rachypterus trachypterus) were caught (Table 4).

Target strength from Simrad EK 500

Within the southern blue whiting shoals, the bias due to multiple echoes can be seen with depth. Returns from deeper into the shoal give higher target strengths (Fig. 3), which we interpret as being due to multiple echoes rather than to any size stratification of fish within.

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Trawl depth, m</th>
<th>TS depth, m</th>
<th>Pulse volume, m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>350–400</td>
<td>250–300</td>
<td>405–583</td>
</tr>
<tr>
<td>25</td>
<td>350–380</td>
<td>250–300</td>
<td>405–583</td>
</tr>
<tr>
<td>27</td>
<td>400–480</td>
<td>150–250</td>
<td>146–405</td>
</tr>
<tr>
<td>28</td>
<td>350–380</td>
<td>150–250</td>
<td>146–405</td>
</tr>
</tbody>
</table>

Table 4. Species composition of catches from a Ymuiden midwater trawl fished in the same area for which target strength data were collected (see Table 3). A total number of fish caught are given, with the percentage composition of southern blue whiting in parentheses for each trawl. Species codes are: API, Aleriticthys blacki; CAS, Caelorinchus aspercephalus; DEA, Trachipterus trachypterus; HAK, M erlucius australis; HOK, M acurus novaezeelandiae; LIN, Genypterus blacodes; PIG, Congiopodus leucopaecilus; SBW, M icromesistius australis; SSI, Argentina elongata; SQX, squid (not identified to species).

<table>
<thead>
<tr>
<th>Tow</th>
<th>API</th>
<th>CAS</th>
<th>DEA</th>
<th>HAK</th>
<th>HOK</th>
<th>LIN</th>
<th>PIG</th>
<th>SSI</th>
<th>SQX</th>
<th>SBW</th>
</tr>
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<tbody>
<tr>
<td>11</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>350 (97.8%)</td>
</tr>
<tr>
<td>25</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>340 (96.6%)</td>
</tr>
<tr>
<td>26</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2361 (99.9%)</td>
</tr>
<tr>
<td>27</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>1435 (98.4%)</td>
</tr>
<tr>
<td>28</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>202 (97.1%)</td>
</tr>
</tbody>
</table>
the shoals. We know from commercial vessel catches that the size distribution of fish in the aggregations is homogeneous. Dense shoals of southern blue whiting tend to be overlain by lower target strength organisms, assumed to be small fish such as myctophiids or dense plankton.

Comparisons of the target strength frequency distributions from the periphery and centre of southern blue whiting shoals were made to test for bias due to multiple echoes. The mode of target strength frequency distributions associated with tows 11, 25, and 27 shifted ~2 dB to higher target strengths from the periphery to the centre of shoals. This indicates that multiple echoes were accepted by the EK 500 as single echoes in the centre of shoals. In contrast, the target strength data associated with tow 28 showed no evidence of multiple echo bias.

Target strength modes on the periphery of southern blue whiting shoals, free of multiple echo bias, were -34 dB (tow 11), -40 dB (tows 25, 27 and 28) (Fig. 4). The echosounder system parameters and the depth range for these measurements are given in Tables 2 and 3 respectively. The pdfs for backscattering cross-sections calculated from these target strength data show the characteristic exponentially declining shape indicating that scattering was due to individual scatterers where

![Figure 3. Frequency distribution of target strengths moving down through the water column into a large shoal of southern blue whiting (SBW) extending from 150 m deep to the bottom at ~380 m. Low target strengths are due to small fish, possibly myctophiids (non-SBW). Higher target strengths due to multiple echoes become common in the deeper and most dense part of the shoal. 100-150 m (---); 150-200 m (-- --); 250-300 m (· · ·); 300-350 m (· · ·).](image)

![Figure 4. Probability density functions (pdf) for target strength of southern blue whiting estimated using the EK 500 echosounder in the region of 4 midwater trawls. Species composition of the trawl catch is given in Table 4. Depth ranges for the target strength estimates and echosounder system parameters are respectively given in Table 3 and Table 2.](image)
Echoes do not overlap (Stanton and Clay, 1986). The exponential pattern in the distribution is especially clear for data associated with tows 11, 25 and 28 (Fig. 5) and lends additional support to our assertion that the target strength data we present are from individual fish.

Deconvolution of single echo ensembles

Two echo ensembles corresponding to separate aggregations of southern blue whiting (tows 25 and 26) were selected for analysis because the fish size distributions in the associated targeted trawls showed well defined modes (Fig. 2). The filtered echoes collected by the CRFRED A system, corresponding to tow 25 and tow 26 are given in Figure 6. The deconvolved fish pdfs for the same data (converted to target strength) are given in Figure 7. The fish pdf for tow 26 has two peaks. The larger peak at $-40.8$ dB corresponds to the main mode in Figure 7. A very small “peak” at $-34.5$ dB was attributed to noise in the input data but could have arisen from fish larger than southern blue whiting. The southern blue whiting of length 40 to 50 cm caught in tow 26 (Fig. 2) were not evident in the deconvolved results, most likely due to the small number present when compared to the fish at the mean length of 31 cm.

Target strength–length relationship

The target strength–length relationship derived from M. poutassou and currently used for biomass estimation of southern blue whiting in New Zealand is:

$$<TS> = 21.72 \log_{10} FL - 72.80$$

where $<TS>$ is the tilt-averaged target strength (dB) and FL is the fish fork length (cm). We present a target strength–length regression for M. australis based on our swimblader modelling results using the mapped model (Fig. 8):

$$<TS> = 25.05 \log_{10} FL - 81.35$$

This is based on a robust least trimmed regression (Statistical Sciences, 1995) rather than a least squares regression. Examination of residuals from the least squares fit showed that errors were normally distributed and there was no obvious trend, but that the spread of the residuals was quite wide relative to the fitted values and there were some outliers that were influencing the regression slope. By using the robust regression we minimized influence of outliers. Relationships between

Figure 5. Probability density functions (pdf) for scattering cross-sections of southern blue whiting estimated using the EK 500 echosounder in the region of four midwater trawls. Species composition of the trawl catch is given in Table 4. Depth ranges for the target strength estimates and echosounder system parameters are respectively given in Table 3 and Table 2.
In contrast to the swimbladder modelling results, our in situ target strengths were closely aligned with the published in situ target strengths of *M. poutassou* (Fig. 8). The reason for this is not clear. The magnitude of the difference between the in situ and swimbladder modelling results is 2.34 dB. We have insufficient in situ data (n=5) to determine whether this observed difference is consistent for all sizes of southern blue whiting.

**Discussion**

We recognize that bias against small targets is important and must be corrected for when the size distribution of fish or frequency distribution of target strengths is wide. The target strength distribution could be wide for a narrow size range of fish if, for example, the range of fish orientations was great. If a Ricean model is fitted to the distribution of scattering lengths, and mean scattering length is obtained from the model parameter, the mean will be biased to the degree that small targets are below the threshold. One way around this problem is to truncate the measured distribution at the lower threshold, append the tail of a theoretical distribution, and then fit a model to the new distribution (Foote et al., 1986). We did not do this because our size distributions were so narrow. The primary size mode was between ~25 to 35 cm (Fig. 2) which represents target strengths in the range of ~40 to ~46 dB (see Fig. 8). We simply estimated the modal target strength by eye from the frequency distributions. The threshold for the EK 500 was set at ~60 dB (see Table 2). This threshold is far below the expected range of target strengths for the sizes of southern blue whiting that we encountered.

The severity of multiple echo bias in target strength data depends on both species and behaviour, becoming significant for tightly shoaling small fish far from the transducer (Barange et al., 1996). Even within a species the spacing between fish varies with time of day, whether fish are escaping from predators (Pitcher, 1986), feeding, migrating or spawning (Rose, 1993). Different species shoal at varying densities and the spacing between fish is generally related to fish size. A large data set for gadoids and herring (Pitcher and Partridge, 1979) shows a linear relationship between fish size and the distance between fish in a shoal (Fig. 10). Using a relationship calculated from these data, distance between fish in cm = 5.156 + 0.559 fork length (Pitcher and Partridge, 1979, Table 1), we predict that southern blue whiting of 25–35 cm long will generally be ~19–25 cm apart in the centre of schools. In contrast, anchovies 11–14 cm long are predicted on average to be ~11–13 cm apart. A considerable amount of variability is related to the swimming velocity, because shoals tend to pack more tightly as...
velocity increases (Pitcher and Partridge, 1979). The multiple target problem for southern blue whiting is probably considerably less severe than for anchovies at close ranges. However, the 3 dB beamwidth of the acoustic beam at several hundred metres is to the order of 20 to 40 metres so target strengths still need to be measured on the periphery of southern blue whiting shoals. The reverberation volumes are quite large for our measurements (see Table 3). Nevertheless, the pdfs for scattering cross-sections (Fig. 5) show that in 3 out of 4 cases the pdfs approximate the Rayleigh distribution that is expected from single echoes (Stanton and Clay, 1986). By carefully screening our data we are confident that we removed any multiple echo bias.

The concept that spawning southern blue whiting form single species aggregations is an acceptable approximation as far as we can tell from the midwater trawl catches (see Table 4). However, we currently lack the equipment to sample fast swimming adult fish at fine spatial scales. Our midwater trawl descends open and is retrieved open, although it probably does not fish effectively on the descent. Target identification with trawls is limited unless an opening-closing mechanism can be applied to the net. We can confidently identify southern blue whiting marks on echograms and have limited our analyses to recognizable marks. It appears from target strength distributions that smaller fish of other species often occur above the southern blue whiting marks and we know from bottom trawls that southern blue whiting are mixed with large swimbladder fish such as ling near the bottom. These areas were carefully excluded when selecting the split beam data for analysis of target strength.

The $<TS>$-length regressions for southern blue whiting ($M. australis$) and blue whiting ($M. poutassou$) differ by 2.9 to 4.3 dB depending on the size of the fish (Fig. 8). The regression slope for $M. poutassou$ ($b=21.72$) is close to a quadratic dependence on fish size (i.e. slope=20 where target strength is proportional to surface area). The slope for $M. australis$ ($b=25.05$) deviates more from quadratic dependence and so we have not standardized the regression equations by forcing the slope through 20 (see McClatchie, 1996). The two blue whiting species are morphologically very similar (Cohen et al., 1990). Consequently, we expected fish of the same size from the two species to have similar target strengths, assuming that their orientation distributions are also similar. Our in situ $<TS>$ results are very close to the in situ results for $M. poutassou$ but we have a very small sample. The difference between our swimbladder modelling target strengths and our in situ target strengths could arise from different orientation distributions. Unfortunately there are no data on the orientation of $Micromesistius$ spp.

We regard the split beam data associated with trawl 11 as an obvious outlier. This sample was collected on
the Pukaki Rise in contrast to all the other in situ data that were from the Campbell Island Rise (see Fig. 1). The length distribution of commercial catches on the Pukaki Rise shows a broader range of modes than the other region, with peaks at 20, 30 and 50 cm (Hanchet and Ingerson, 1996). The size distribution from commercial catches differs from the research trawl catch (see Discussion section). This sample was collected on the Pukaki Rise in contrast to all the other in situ data that were from the Campbell Island Rise. Residuals for the robust regression show no strong trends, but considerable variation.

Figure 8. Target strength–length relationships for southern blue whiting. <TS> is tilt-averaged target strength. The dotted line is the regression for blue whiting, *Micromesistius poutassou* (<TS> = 21.72 \log_{10} \text{fork length, cm} – 72.80) (ICES, 1982; ICES, 1985; Monstad, 1992). The solid line shows the robust regression for southern blue whiting target strength based on swimbladder modelling: <TS> = 25.05 \log_{10} \text{fork length, cm} – 81.35 (see text). Solid circles = swimbladder model data; open circles = deconvolution data; triangles = split beam data. Outlying split beam data from trawl 11 are omitted (see Discussion section). This sample was collected on the Pukaki Rise in contrast to all the other in situ data that were from the Campbell Island Rise. Residuals for the robust regression show no strong trends, but considerable variation.

Four target strength estimates for *M. poutassou* are available (Forbes, 1985; MacLennan and Forbes, 1987) that were not included in the published <TS>-length regressions (ICES, 1982; ICES, 1985; Monstad, 1992). Two of these estimates fall close to the published...
regression, but the other two are ~5 dB higher than the regression would predict. There is one more set of data (Nakken and Olsen, 1977) that also differs from the published regression by as much as 6–10 dB, but these measurements were made in experiments on dead fish, so they may not be representative. More information is required on the in situ target strength for a wider size range of both species, and the orientation distribution of the fish in nature needs to be described before the target strength of these species can be definitively quantified.

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