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Short communication

Progress in determining southern blue whiting (*Micromesistius australis*) target strength: results of swimbladder modelling

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Southern blue whiting target strength (TS) results from Kirchhoff modelling of swimbladder casts scanned using a hand-held 3D laser scanner are presented. The data are compared with the relationship between TS and fish length used for New Zealand stock-assessment surveys; $TS = 21.8 \log_{10}(\text{fork length}) - 72.8$, at 38 kHz. This relationship has its origins in the relationship used for blue whiting (*Micromesistius poutassou*) in the northern hemisphere, and is based on measurements on juvenile cod (*Gadus morhua*). The results indicate that the blue whiting relationship is not appropriate for southern blue whiting, and suggest a much steeper slope, with $TS = 38 \log_{10}(\text{fork length}) - 97$, at 38 kHz. Sensitivity analyses indicate that further investigations of swimbladder tilt-angle distribution and swimbladder volume are unlikely to provide evidence to support the use of the blue whiting relationship for southern blue whiting.

Keywords: acoustic target strength, Kirchhoff modelling, southern blue whiting, swimbladder.

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Introduction

Southern blue whiting (*Micromesistius australis*) support significant commercial fisheries around South America and New Zealand. During August and September, they form monospecific spawning aggregations in depths of 250–500 m on the Campbell and Bounty Plateau in the Subantarctic waters off southeastern New Zealand. Estimates of relative abundance from acoustic surveys of these aggregations are one of the primary stock-assessment tools for southern blue whiting (SBW) in New Zealand. Although the absolute value of target strength (TS) is not critical for a time-series of relative abundance estimates, changes in the slope of the relationship between TS and fish length will affect the time-series if the distribution of fish lengths changes over time.

The relationship between TS and length for SBW used in New Zealand is the same as that used for blue whiting (*Micromesistius poutassou*; BW) in the northern hemisphere. The BW TS–length relationship is also used on Argentine (Madirolas, 1999) and Chilean (S. Lillo, IFOP, Chile, pers. comm.) acoustic surveys of SBW. This relationship is based on measurements on juvenile cod (*Gadus morhua*; Nakken and Olsen, 1977) which were later re-analysed by Foote (1980) and taken to be representative of BW. Northern hemisphere *in situ* split-beam measurements of BW, which have begun recently, indicate that the BW TS is higher than previously thought (Godø *et al.*, 2002), and further *in situ* work is planned to allow a more definitive relationship to be obtained (O. Godø, Institute of Marine Research, Bergen, pers. comm.). Here we review swimbladder-modelling data collected for SBW in New Zealand waters and present a new TS–length relationship for SBW.

Swimbladder modelling is a useful adjunct to *in situ* measurements because it allows investigation of how variables such as swimbladder tilt angle impact on TS, and also gives results that are independent of *in situ* data. In this paper the Kirchhoff modelling technique (Foote, 1985; Medwin and Clay, 1998) is used to compute tilt-averaged TS values from scanned swimbladder casts. The contribution of the fish body to the target strength is neither estimated nor allowed for in this manuscript, for three reasons. First, for fish with a gas-filled swimbladder, the contribution is relatively small (estimated at 5–10% of the backscattered energy; Foote, 1985). Second, the swimbladder injection technique and subsequent scanning were devised as a fast and convenient method to obtain TS estimates, but obtaining the shape and size of the fish body made the process considerably longer and more involved. Finally, injecting the swimbladders is a destructive technique, and fish-body data would need to be obtained before injecting the fish. Unfortunately, however, the 3D scanner was unavailable during the voyages that collected the swimbladder casts.

Early *in situ* results and some earlier Kirchhoff modelling of sectioned SBW plaster swimbladder casts have previously been published by McClatchie *et al.* (1998). The swimbladder-modelling data were calculated by slicing the swimbladder casts, digitizing the two-dimensional slices, and reconstructing the 3D shape for the calculation of target strength. The slicing and reconstruction process were manually intensive, and the software for calculating the TS from the Kirchhoff approximation model had several coding problems which have been corrected since those results were produced. Because of this, the swimbladder-modelling results of McClatchie *et al.* (1998) are not included in this analysis.

Methods

Swimbladder casts for TS modelling were collected during the 1997, 2001, and 2002 SBW acoustic surveys off southern New Zealand. To assess the amount of resin to inject into each swimbladder, a number of fish were weighed in water, taking care to remove any trapped air bubbles. This weight, corresponding to the force required to make the fish neutrally buoyant, gives the volume of the swimbladder, and hence the volume of resin required. In all, 74 fish with lengths in the range 19–58 cm were measured in this way, and a relationship between fish length and buoyancy was derived and used to calculate the amount of resin to inject into each fish.

Swimbladder casts were collected from a second group of 78 fish (length range 16–58 cm) by injecting the swimbladder with epoxy resin while still in the body cavity of the fish and dissecting it out after the epoxy had cured. The casts were scanned using a hand-held, laser, 3D scanner (Polhemus, 2000), which produced a triangular mesh representing the swimbladder surface. Five casts were rejected because they contained scanning artefacts (large holes) that affect the computed TS. Using the Kirchhoff-approximation model (Foote, 1985; Medwin and Clay, 1998), the TS at 38 kHz was calculated at angles of $-40°$ to $+40°$ in steps of $1°$. These data were convolved with a fish tilt-angle distribution having a mean of $0°$ and standard deviation of $15°$ (McClatchie *et al.*, 1998) to obtain a tilt-averaged TS estimate for each fish.

A new TS–length relationship, of the form $<TS> = m\log_{10}(l) + c$, where l is the fork length in cm and <TS>, m, and c are tilt-averaged target strength, slope, and intercept, respectively, in dB re 1 m^2, was calculated using a least-squares regression. As recommended by McClatchie *et al.* (2003), no attempt was made to force the relationship slope through 20.

The two main unknowns in modelling swimbladders are the tilt-angle distribution and the inflation level. The sensitivity of the tilt-averaged TS to changes in the tilt distribution was investigated by re-computing the TS for each swimbladder using a range of tilt-angle distributions. The mean and the standard deviation of the tilt-angle distribution were varied from $-10°$ to $10°$ and $5°$ to $25°$, respectively, in steps of $5°$. A length-to-TS regression was then fitted to the re-computed TS for each tilt distribution using the Matlab least-squares fitting function (The Mathworks Inc., 2000).

A similar process was used to investigate the effect of inflation levels on TS. All three dimensions (length, width, and height) of each swimbladder were scaled by a constant factor. The range of size-scaling factors was determined by comparing the volume required for buoyancy and the actual swimbladder volume. This suggested that the swimbladder volume and the "true" volume could be different by up to a factor of two, so a size-scaling factor range of $\sqrt[3]{1/2}$ to $\sqrt[3]{2}$ was used. For each size-scaling factor, the TS of all swimbladders was re-computed, using the tilt-angle distribution of McClatchie *et al.*, (1998; mean $0°$, s.d. $15°$), and a length-to-TS regression obtained.

Results and discussion

The swimbladder-modelling results for SBW are not consistent with the BW relationship (Figure 1). These results are tabulated in the Appendix to provide a reference for comparison with other data sets. The regression fit to our swimbladder data was $<TS> = 38\log_{10}(l) - 97$, compared with the BW relationship of $<TS> = 21.8\log_{10}(l) - 72.8$.

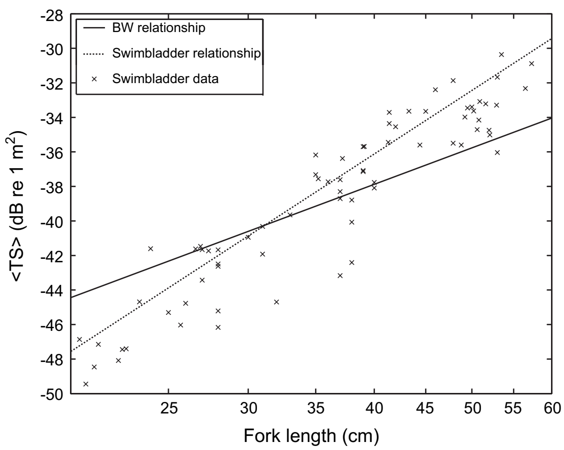

Figure 1. Southern blue whiting swimbladder-modelling data. The data points are tilt-averaged target strength (<TS>) calculated using a tilt-angle distribution of mean $0°$ and s.d. $15°$. The solid line shows the blue whiting relationship currently used for southern blue whiting stock assessment and the dotted line shows the relationship obtained from the swimbladder data.

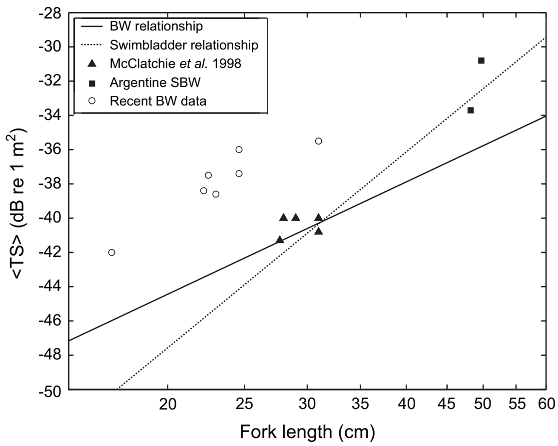

Figure 2. Southern blue whiting TS relationships compared with southern blue whiting and blue whiting *in situ* data. The solid line shows the blue whiting relationship currently used for southern blue whiting stock assessment and the dotted line shows the relationship obtained from the swimbladder data.

Figure 2 shows the *in situ* data of McClatchie *et al.* (1998) and Argentine *in situ* data for SBW (A. Madirolas, pers. comm.) which agree reasonably well with our swimbladder-modelling relationship. In addition, Figure 2 shows recent BW *in situ* data (Forbes, 1985; Godø *et al.*, 2002; Heino *et al.*, 2003), which do not agree with our relationship.

A number of factors can affect TS and may not be adequately captured by swimbladder modelling, for example, changes in TS with gonad stage or feeding, changes with depth, and changes caused by behaviour. For a species with an air-filled swimbladder, such as SBW, many of these effects can be modelled by changing either the tilt distribution used in calculating the TS or the volume of the swimbladder.

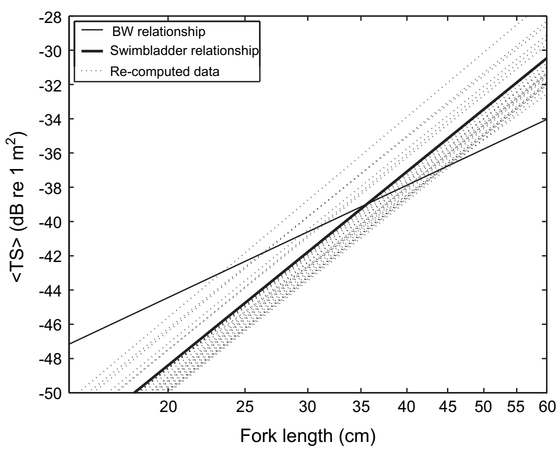

Figure 3. Southern blue whiting modelling data showing the effect of changing the tilt-angle distribution used for computation. The thin solid line shows the blue whiting relationship currently used for southern blue whiting stock assessment and the dotted lines show the regression to the re-computed data. The thicker solid line is for a mean/s.d. of 0°/15°.

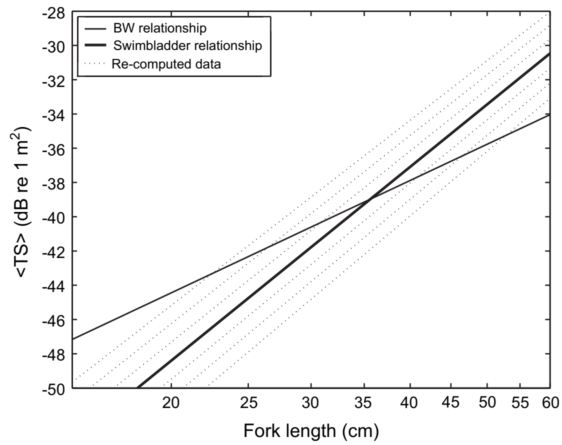

Figure 4. Southern blue whiting modelling data showing the effect of varying inflation levels. The swimbladders were "inflated" by scaling in each dimension by a constant factor. The thin solid line shows the blue whiting relationship currently used for southern blue whiting stock assessment and the dotted lines show the regression to the re-computed data for each scaling factor. The thicker solid line is for a scaling factor of 1.

Changing the tilt-angle distribution has little effect on the slope of the regression (Figure 3), so regardless of what distribution is finally adopted, it is likely that the "true" relationship will have a higher slope than the BW relationship. Similarly, scaling of swimbladder dimensions has little effect on the slope of the relationship (Figure 4).

The major sources of error in swimbladder modelling arise from the difference between the "true" swimbladder tilt-angle distribution and inflation level and those used in the calculations. As the sensitivity analyses have shown, it is unlikely that further investigations will provide evidence to support the use of the BW relationship for SBW. For an average SBW of 45 cm (Paul, 2000) the TS from the BW relationship and that based on the swimbladder data are −36.8 dB and −34.2 dB, respectively. For a population with mean length 45 cm, adoption of the swimbladder-modelling relationship would reduce acoustic biomass estimates by approximately 45%.

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Appendix

Length (cm)	Weight (g)	Fish sex	Tilt-averaged TS	Maximum TS
20.4	55	—	−46.9	−43.4
20.7	55	—	−49.4	−46.1
21.1	50	—	−48.5	−44.9
21.3	60	—	−47.1	−44.0
21.3	60	—	−50.3	−46.7
22.3	65	—	−48.1	−45.3
22.5	65	—	−47.5	−44.5
22.7	65	—	−47.4	−43.6
23.4	75	—	−44.7	−41.0
24.0	65	—	−41.6	−36.9
25.0	97	—	−45.3	−41.4
25.7	100	M	−46.0	−41.6
26.0	95	—	−44.8	−40.8
26.6	105	M	−41.6	−36.9
26.9	120	F	−41.5	−36.9
27.0	125	M	−43.4	−39.0
27.0	125	M	−41.7	−38.1
27.4	115	M	−41.7	−37.7

Appendix (*continued*).

Length (cm)	Weight (g)	Fish sex	Tilt-averaged TS	Maximum TS
28.0	147	F	−46.2	−42.5
28.0	130	F	−42.6	−38.8
28.0	126	—	−41.7	−38.2
28.0	135	F	−45.2	−41.2
28.0	136	F	−42.5	−37.9
30.0	158	F	−40.9	−36.5
31.0	160	F	−41.9	−37.1
31.0	190	F	−40.3	−37.4
32.0	235	M	−44.7	−40.4
33.0	240	F	−39.7	−33.1
35.0	238	—	−37.3	−32.2
35.0	231	M	−36.2	−32.2
35.2	240	F	−37.6	−31.5
36.0	362	M	−37.7	−32.8
37.0	350	F	−38.7	−32.9
37.0	380	M	−37.6	−32.0
37.0	323	F	−38.3	−32.7
37.0	315	F	−43.2	−37.4
37.2	340	F	−36.4	−30.4
38.0	355	F	−38.8	−32.3
38.0	393	F	−40.1	−34.7
38.0	375	—	−42.4	−37.5
39.0	433	—	−37.1	−31.8
39.0	450	—	−35.7	−29.6
39.0	381	F	−37.1	−31.5
39.1	390	F	−35.7	−29.5
40.0	430	—	−38.1	−31.9
40.0	355	F	−37.8	−31.5
41.3	490	M	−35.4	−29.2
41.4	450	F	−34.4	−28.1
41.4	470	F	−33.7	−27.1
42.0	443	—	−34.5	−28.2
43.3	605	M	−33.6	−28.0
44.4	475	F	−35.6	−29.9
45.0	565	—	−33.6	−28.4
46.0	580	—	−32.4	−25.3
47.9	815	F	−31.9	−26.1
47.9	975	F	−35.5	−29.8
48.8	800	F	−35.6	−32.1
49.2	825	F	−34.0	−28.3
49.5	885	F	−33.5	−27.2
50	780	F	−33.4	−27.4
50.2	1 165	F	−33.6	−27.2
50.6	1 070	F	−34.7	−28.9
50.8	1 045	F	−34.2	−29.0
50.9	1 075	F	−33.1	−28.2
51.6	990	F	−33.2	−27.3
52	1 310	F	−34.7	−30.2
52.1	1 140	F	−35.0	−28.2
52.9	1 270	F	−33.3	−27.2
53	1 425	F	−31.7	−25.4
53	1 090	F	−36.0	−31.5
53.5	1 140	F	−30.4	−23.1
56.5	1 605	F	−32.3	−26.3
57.3	1 815	F	−30.9	−26.5