NIWA

Taihoro Nukurangi

Review and revision of southern blue whiting (*Micromesistius australis*) target strength, 1994–2002

Adam Dunford

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Author	Adam Dunford
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7. Executive Summary

Southern blue whiting *in situ* target strength data collected on surveys of the Pukaki Rise, Campbell Island Rise and the Bounty Platform from 1994 to 2002 are presented in this report along with Kirchhoff modelling results from swimbladder casts scanned using a hand-held 3D laser scanner. These data are compared against the current target strength–fish length relationship, which has its origins in the relationship used for northern blue whiting and is based on measurements of tethered juvenile cod.

Both the *in situ* and the swimbladder modelling results indicate that the current relationship is no longer appropriate for southern blue whiting, and indicate a steeper slope than that currently used. A preliminary estimate of the new target strength–fish length relationship based on both sets of data has been obtained – $<TS> = 40 \log_{10}(l) - 99$. Although there is still work to be done, including investigating the tilt angle distribution used in modelling the swimbladders and the adult *in situ* target strength, there is no evidence to suggest that the results of this work will support the existing relationship. It is therefore recommended firstly that southern blue whiting target strength research continue with the aim of refining the target strength–fish length relationship and secondly, that effort be put into making it possible to automatically re-analyse the acoustic biomass time–series as the relationship is refined.

8. Objectives

This report addresses objective 2 of Ministry of Fisheries Project SBW2001/02: **"To refine estimates of acoustic target strength from *in situ* measurements"**, which includes the following activities:

1. Review and reanalyse earlier in-situ target strength results
2. Carry out swimbladder modelling studies
3. Collect *in situ* target strength data from the 2002 survey

9. Methods

9.1 Introduction

Southern blue whiting (*Micromesistius australis*, Norman 1937) (SBW) supports a significant commercial fishery. Stock assessments for SBW use acoustic surveys to estimate relative biomass, where the main uncertainty is the target strength. If the relationship between acoustic target strength (TS) and fish size could be reliably established, acoustic biomass estimates of SBW could be used as absolute estimates of abundance. The target strength variable is among the most important used in the biomass calculation, because small changes produce large differences in the biomass estimate.

The current TS–length relationship is the same as that used for blue whiting (*Micromesistius poutassou*, Risso, 1826) in the Northern hemisphere; the same relationship is also used in Argentine (Madirolas 1999) and Chilean acoustic surveys of SBW. This relationship is based on a re-analysis of historical measurements of tethered Atlantic cod (*Gadus morhua*) (Foote 1980, Nakken & Olsen 1977). Northern hemisphere *in situ* split-beam measurements, which have begun recently, indicate that the TS of blue whiting is higher than previously thought (Godo et al. 2002) and further *in situ* work is planned to allow a more definitive relationship to be determined (Olav Godo, Institute of Marine Research, Bergen, Norway, pers. comm.). In light of this it is timely to revisit SBW TS to see whether, given the body of *in situ* and swimbladder modelling results obtained so far, it is possible to move to a TS-length relationship based on southern blue whiting data.

9.2 Existing data

Early in-situ measurements of SBW target strength were made in 1994 on the Campbell Island Rise to the south of New Zealand using both deconvolution of echoes from a single-beam towed system (Macaulay 1995) and a hull mounted Simrad EK500 split-beam system (Hanchet 1994, McClatchie et al. 1998). From 1998 onwards the custom-built Computerised Research Echo Sounder Technology (CREST) system (Coombs et al. 2003) was employed (see Dunford, 2000, 2001 for a description). When using the split-beam systems 'single-target' detection algorithms were used (e.g. Dunford 2000, 2001 for a description).

Kirchhoff modelling of epoxy swimbladder casts collected during previous SBW acoustic surveys and scanned using a 3D laser scanner in this and previous projects, has given further data independent of the *in situ* TS results. Earlier Kirchhoff modelling of sectioned plaster casts and some of the *in situ* results have previously been published by McClatchie et al. (1998).

9.3 2002 *in situ* data

Six attempts were made to collect *in situ* data were made during the 2002 survey of Campbell Island Rise (Hanchet 2002) and out of these three usable sets of data were obtained. To collect *in situ* split-beam data, SBW marks were located and the towed transducer deployed 40–150 m above the marks. The marks were trawled, before and/or after the target strength work, to identify the species and to obtain an estimate of the size distribution.

To estimate target strength it is first necessary to filter out echoes that do not originate from a single fish. Echoes were considered to be from a single fish if the following conditions were met:

- The width of the echo was between 63% and 157% of the transmit pulse width at half the maximum echo amplitude (the 6dB amplitude points).
- The standard deviation of the fore/aft and port/starboard angle of arrival was less than 0.1 degrees; this is the equivalent of the EK500 phase standard deviation filter.
- The width of the four individual echoes at the 6dB amplitude points varied by less than 63% of the transmit pulse width.
- The echo peak was more than 1.125 m in range from other echoes.
- The mean and standard deviation of the difference between the echo amplitude on beam 1 and the same echo on beams 2, 3 and 4 was less than 3.0 and 1.5 dB respectively for all three comparisons.
- The estimated angle of arrival of the echo was within 3.55 degrees of the normal to the transducer face.

After filtering, the positions of the echoes remaining in the beam were calculated (Ehrenberg 1979) and the amplitudes corrected accordingly. In addition, the maximum amplitude in each echo was estimated by fitting a quadratic to the three samples that made up the peak of the echo and taking the maximum of this quadratic as the target strength value for the subsequent data analysis.

In addition to the filters discussed above, target strength data were selected only from within visually identified SBW marks on the echograms (Dunford 2000) .

9.4 Trawl data collection

Trawling during the various surveys was carried out using both bottom and mid-water trawls. Mid-water trawls used a pelagic trawl (headline height ca. 40 m). Bottom trawls used the standard NIWA fine meshed orange roughy wing trawl (headline height ca. 4.5 m). All trawls were made with a 40mm mesh liner in the cod-end.

All catches were weighed; with more detailed biological information taken from SBW and other species using *Tangaroa's* computerised wet-lab system. In trawls done as part of target strength measurements all fish, up to a maximum of 600 per species, were measured to determine a length frequency distribution.

9.5 Calculation of target strength estimates

Target strength estimates of SBW were obtained by comparing the modes in the filtered *in situ* target strength data with those in fish length data obtained from trawls. Only data from trawls that had a high percentage catch of SBW were used. For details on the 1994 deconvolution and EK500 split-beam analysis methods see McClatchie et al. and Macaulay (1995). For the CREST split-beam data, target strength – fish length pairs were obtained by using manual mode-matching with various methods being used to obtain the mean target strength and lengths.

In 1998 (Macaulay 1999), 1999 (Dunford 2000) and 2001 the length modes were essentially unimodal allowing means to be calculated. In 2000 (Dunford 2001) and 2002 the length distributions were more complex and means in the ranges 24–31 cm and greater than 32 cm corresponding to immature and adult fish were used.

In 1998 target strength modal values were estimated by eye (Macaulay 1999), while in 1999 and 2000 target strength means in the ranges -42 to -38 dB and -36 to -26 dB were matched to the length means. In 2001 the mean of a Gaussian fit to the target-strength histogram was matched to the mean length and in 2002 target strength means in the ranges -47 to -38 dB and -36 to -26 dB were used. All calculations were done in the linear domain. A summary of the methods used is given in Table 1.

The 'subjective' mode-matching used to obtain the correspondence of length and TS modal values is likely to give a similar result to more 'objective' methods based on constrained least-squares fitting, e.g. Macaulay et al. (2002). This is because in situations where the underlying TS/length data is of lower quality, either due to poorly defined modes or because the solution is under-determined, the least-squares fit is unlikely to be any more reliable. Conversely, in situations where the fit is extremely good it is likely to be similar to what would be achieved by performing manual mode matching on the sets of data.

9.6 Swimbladder collection and processing

Swimbladders for target strength modelling were collected during the 1997 survey of the Bounty Platform and Pukaki Rise, the 2001 survey of the Bounty Platform and the 2002 survey of the Campbell Island Rise (Hanchet 1997, 2001, 2002). A number of these bladders have been scanned using a hand-held laser 3D scanner (Polhemus 2000) which produced a triangular mesh representing the swimbladder surface. This replaced the sectioning and digitising used previously which was both time-consuming and error-prone. In addition, an updated version of the Kirchhoff modelling software was used. Details of the procedure can be found in Macaulay et al. (2001). The tilt angle distribution followed that used by McClatchie et al. and had a mean of 0° and standard deviation of 15°.

A total of 77 swimbladders were scanned with the 3D laser scanner. Three of these were rejected as the scanned swimbladders had large holes which affect the computed target strength. Application of the Kirchhoff modelling method (Macaulay et al. 2001) to the remaining bladders yielded 74 new target strength estimates.

The swimbladder results of McClatchie et al. were not included. These data were calculated by slicing the swimbladder casts, digitising the slices, and then reconstructing the 3D shape for calculation of the target strength. The slicing and reconstruction process was manually intensive and prone to error, and the software for calculating the target strength from the Kirchhoff-approximation model has undergone improvements and corrections since producing those results. Macaulay et al. (2002) analysed the results from several hoki casts which were both sliced and 3D scanned and found differences of 2-6 dB in the target strength.

To determine the effect of changes to the swimbladder tilt distribution, the SBW cast data were re-computed using a range of tilt angle distributions. The mean and 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 target strength regression was then fitted to the re-computed data for each distribution using the Matlab robustfit function (The Mathworks Inc. 2001), an implementation of an iteratively re-weighted least-squares regression (Holland & Welsch 1977).

10. 2002 *in situ* results

Figure 1 and Figure 2 show the target strength and fish length distributions from the three sets of data from the 2002 survey of Campbell Rise. The first two sets are of adult SBW and show the combined TS from selected echogram regions (c.f. Dunford (2001)) and the length data from the trawls associated with these measurements. The third set is from juvenile SBW. The shaded areas on the graphs indicate the target strength or length ranges averaged over to obtain the values in Table 1.

11. Discussion

The *in situ* results for all years are shown in Table 1, and plotted in Figure 3. The swimbladder modelling results are given in Table 2, along with the maximal target strength values which are provided as a reference for comparisons with other swimbladder modelling results. Following the justification of Macaulay et al. (2002), the swimbladder results of McClatchie et al. are not included. The swimbladder modelling results are plotted in Figure 4. Both figures include the current target strength–fish length relationship for comparison and it can be seen that neither the *in situ* or swimbladder modelling results agree very well with the current relationship.

Each of the data sets has its own limitations, for example it is possible that some of the higher value *in situ* data points in Figure 3 are contaminated by multiple echoes. This problem is generally more severe for small species like SBW that form dense schools (Madirolas 1999) where the short distances between fish makes resolving individual echoes more difficult. The use of a 'drifting frame' echosounder rather than the conventional towed body may be beneficial in this regard allowing closer and less disturbed observation. It may also be worth investigating a multi-frequency scheme such as that proposed by Demer et al. (1999) to address this problem. An alternative technique used by Madriolas (pers. comm.) is to average target strengths from selected fish tracks within an echogram.

Although the swimbladder modelling data are more numerous than the *in situ* data, they are uncertain to the extent that the swimbladder tilt angle distribution and inflation level are unknown. If it were possible to determine that some of the *in situ* data were accurate, then these could be derived using a Monte Carlo modelling method (Coombs & Barr 2003, Macaulay 2003). Another option for determining the tilt angle distribution would be to measure fish swimming angles from fish tracks obtained by drifting over a school of whiting as is being done for hoki (Macaulay pers. comm.).

The effect of different tilt angle distributions on the swimbladder data was investigated by recalculating the values using a range of distributions as described in section 9.6 above. As can be seen in Figure 5, changing the tilt angle distribution has little effect on the slope of the regression and hence, regardless of what distribution is finally adopted, it is likely that the 'true' relationship will have a higher slope than that currently used.

The current relationship is the same as is used for blue whiting, which was based on historical measurements of tethered Atlantic cod (Foote 1980, Nakken & Olsen 1977). This relationship was initially adopted due to the paucity of SBW data. Figure 6 shows *in situ* data for northern blue whiting (Forbes 1985, Godo et al. 2002) and Argentine *in situ* data for SBW (Madriolas pers. comm.) along with the current relationship. Clearly, from Figures 3, 4 and 6, this is no longer an appropriate relationship to use for SBW.

A new preliminary estimate of the relationship, of the form $\langle TS \rangle = m \log_{10}(l) + c$, where l is the fish length in cm and $\langle TS \rangle$, m and c are tilt-averaged target strength, slope and intercept respectively in dB re 1 m^2, was calculated using a weighted linear regression. There are fewer *in situ* points than swimbladder modelling points, 19 as opposed to 74, and it was decided to weight the data so that each data set contributed equally to the overall fit. Thus, the points within each data set were given a constant weighting such that the sum of the weights over each data set equalled 0.5; i.e. each *in situ* point had a weight of $\frac{0.5}{19}$ and each modelling point had a weight of $\frac{0.5}{74}$. As recommended by McClatchie (2003), no attempt was made to force the relationship slope through 20. The regression to the combined *in situ* and swimbladder modelling data was $\langle TS \rangle = 40 \log_{10}(l) - 99$, as compared to the current relationship used for stock assessment of $\langle TS \rangle = 21.8 \log_{10}(l) - 72.8$. These relationships, along with the *in situ* and swimbladder modelling are shown in Figure 7.

This preliminary relationship should not be regarded as a definitive answer. A comparison of Figure 3 and Figure 4 shows that a different relationship would be obtained by considering either the *in situ* or the modelling data in isolation – in particular fitting to the *in situ* data alone would give a higher slope. In addition, if some of the higher value adult *in situ* points in Figure 3 were assumed to be suspect due to the inclusion of multiple echoes, and hence removed or down-weighted, this would also alter the resulting fit, by reducing the slope. For these reasons it was decided to treat the *in situ* and modelling methods equally and to give equal weight to all the points within each set, as described above.

12. Conclusions

Southern blue whiting *in situ* target strength data from the Campbell Island Rise and the Bounty Platform from 1994 to 2002 are presented in this report along with swimbladder modelling results obtained using improved scanning technology and updated modelling software. The results suggest that the target strength for SBW is higher than that currently used in biomass estimation and also that the slope of the relationship may be steeper. Both swimbladder modelling and *in situ* methods indicate that the target strength-length relationship currently used in biomass estimation is no longer appropriate. It is therefore advisable that further work be done in both areas to determine allow a new relationship to be obtained for use in stock assessment. A preliminary estimate, using both *in situ* and modelling data, is $<TS> = 40 \log_{10}(l) - 99$, as compared to the current relationship $<TS> = 21.8 \log_{10}(l) - 72.8$. These regressions along with the *in situ* and swimbladder modelling data are shown in Figure 7.

Although multiple echoes may have influenced some *in situ* estimates, there is insufficient evidence to determine this conclusively. It is recommended that further *in situ* data be collected to allow this to be investigated further and that further work be done on reducing the uncertainty in the swimbladder modelling data.

There remains further work to do on refining the target strength-length relationship, however this work will probably still lead to a higher slope. Currently, stock assessments of SBW use acoustic biomass estimates as relative indices and changing the slope of the target strength–length relationship will require the entire acoustic biomass time series to be recalculated, rather than simply scaling the values (since the relative contributions of adult and juvenile SBW will have changed). As a corollary, it would be desirable to set up the acoustic data so that future re-analyses are a simple matter to perform as the relationship is progressively refined.

13. Publications

None.

14. Data storage

Data collected from trawling is stored in the Ministry of Fisheries Trawl survey database. Acoustic data is stored in the Ministry of Fisheries Acoustics Database.

15. Acknowledgements

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Table 1. *In situ* target strength data for southern blue whiting collected from 1994 to 2002 on the Campbell Rise and Bounty platform. Also shown is the method of calculating the length and TS estimates.

Year	Area	Data type	Length (cm)	TS (dB)	Length method	TS method
1994	Campbell	deconvolution	27.7	-41.3	Mean	By eye
			31.0	-40.8	Mean	By eye
	Campbell	split-beam	28.0	-40.0	By eye	By eye
			29.0	-40.0	By eye	By eye
			31.0	-40.0	By eye	By eye
1998	Campbell	split-beam	40.2	-34.5	Mean	By eye
1999	Bounty	split-beam	31.7	-39.8	Mean	Mean (-42 – -38 dB)
			36.7	-31.1	Mean	Mean (-36 – -26 dB)
			37.1	-30.8	Mean	Mean (-36 – -26 dB)
2000	Campbell	split-beam	38.8	-29.9	Mean (>32 cm)	Mean (-36 – -26 dB)
			39.4	-29.7	Mean (>32 cm)	Mean (-36 – -26 dB)
			27.4	-39.9	Mean (24 – 31 cm)	Mean (-42 – -38 dB)
			28.5	-39.9	Mean (24 – 31 cm)	Mean (-42 – -38 dB)
2001	Bounty	split-beam	26.0	-40.3	Mean	Gaussian model fit
			39.5	-34.2	Mean	Gaussian model fit
2002	Campbell	split-beam	44.7	-29.6	Mean (>32 cm)	Mean (-36 – -26 dB)
			42.8	-30.3	Mean (>32 cm)	Mean (-36 – -26 dB)
			29.8	-42.5	Mean (24 – 31 cm)	Mean (-47 – -38 dB)

Table 2. Swimbladder cast target strength calculated using a tilt angle distribution of mean 0° and standard deviation 15°. Gonad stages are after Hanchet et al. (1994).

Swimbladder cast ID	Length (cm)	Weight (g)	Fish sex	Fish gonad stage	Tilt-averaged TS	Maximum TS
175	20.4	55	unknown	1	-46.9	-43.4
172	20.7	55	unknown	1	-49.4	-46.1
165	21.1	50	unknown	1	-48.5	-44.9
168	21.3	60	unknown	1	-47.1	-44.0
173	21.3	60	unknown	1	-50.3	-46.7
164	22.3	65	unknown	1	-48.1	-45.3
163	22.5	65	unknown	1	-47.5	-44.5
162	22.7	65	unknown	1	-47.4	-43.6
161	23.4	75	unknown	1	-44.7	-41.0
1	24.0	65	unknown	unknown	-41.6	-36.9
2	25.0	97	unknown	unknown	-45.3	-41.4
127	25.7	100	male	1	-46.0	-41.6
97022	26.0	95	unknown	unknown	-44.8	-40.8
126	26.6	105	male	1	-41.6	-36.9
118	26.9	120	female	1	-41.5	-36.9
97010	27.0	125	male	4	-43.4	-39.0
97014	27.0	125	male	4	-41.7	-38.1
124	27.4	115	male	1	-41.7	-37.7
97002	28.0	147	female	2	-46.2	-42.5
97003	28.0	130	female	2	-42.6	-38.8
97004	28.0	126	unknown	unknown	-41.7	-38.2
97009	28.0	135	female	1	-45.2	-41.2
97015	28.0	136	female	1	-42.5	-37.9
97016	30.0	158	female	1	-40.9	-36.5
97005	31.0	160	female	1	-41.9	-37.1
97017	31.0	190	female	1	-40.3	-37.4
97001	32.0	235	male	3	-44.7	-40.4
97027	33.0	240	female	1	-39.7	-33.1
3	35.0	238	unknown	unknown	-37.3	-32.2
97018	35.0	231	male	3	-36.2	-32.2
123	35.2	240	female	1	-37.6	-31.5
97008	36.0	362	male	4	-37.7	-32.8
97013	37.0	350	female	3	-38.7	-32.9
97019	37.0	380	male	4	-37.6	-32.0
97021	37.0	323	female	4	-38.3	-32.7
97025	37.0	315	female	3	-43.2	-37.4
122	37.2	340	female	6	-36.4	-30.4
97007	38.0	355	female	3	-38.8	-32.3
97020	38.0	393	female	4	-40.1	-34.7
97024	38.0	375	unknown	unknown	-42.4	-37.5
4	39.0	433	unknown	unknown	-37.1	-31.8
5	39.0	450	unknown	unknown	-35.7	-29.6
97006	39.0	381	female	1	-37.1	-31.5
121	39.1	390	female	1	-35.7	-29.5
97023	40.0	430	unknown	unknown	-38.1	-31.9
97028	40.0	355	female	5	-37.8	-31.5
108	41.3	490	male	6	-35.4	-29.2
102	41.4	450	female	7	-34.4	-28.1
107	41.4	470	female	6	-33.7	-27.1
6	42.0	443	unknown	unknown	-34.5	-28.2
106	43.3	605	male	6	-33.6	-28.0
101	44.4	475	female	7	-35.6	-29.9
7	45.0	565	unknown	unknown	-33.6	-28.4
8	46.0	580	unknown	unknown	-32.4	-25.3
104	47.9	815	female	6	-31.9	-26.1
129	47.9	975	female	3	-35.5	-29.8
133	48.8	800	female	3	-35.6	-32.1

Table 2. (*continued*)

153	49.2	950	female	6	-38.9	-32.4
182	49.2	825	female	8	-34.0	-28.3
136	49.5	885	female	6	-33.5	-27.2
183	50	780	female	6	-33.4	-27.4
140	50.2	1165	female	6	-33.6	-27.2
154	50.6	1070	female	6	-34.7	-28.9
132	50.8	1045	female	3	-34.2	-29.0
130	50.9	1075	female	3	-33.1	-28.2
181	51.6	990	female	6	-33.2	-27.3
152	52	1310	female	unknown	-34.7	-30.2
138	52.1	1140	female	6	-35.0	-28.2
128	52.9	1270	female	3	-33.3	-27.2
131	53	1425	female	3	-31.7	-25.4
139	53	1090	female	6	-36.0	-31.5
110	53.5	1140	female	7	-30.4	-23.1
134	56.5	1605	female	6	-32.3	-26.3
109	57.3	1815	female	6	-30.9	-26.5

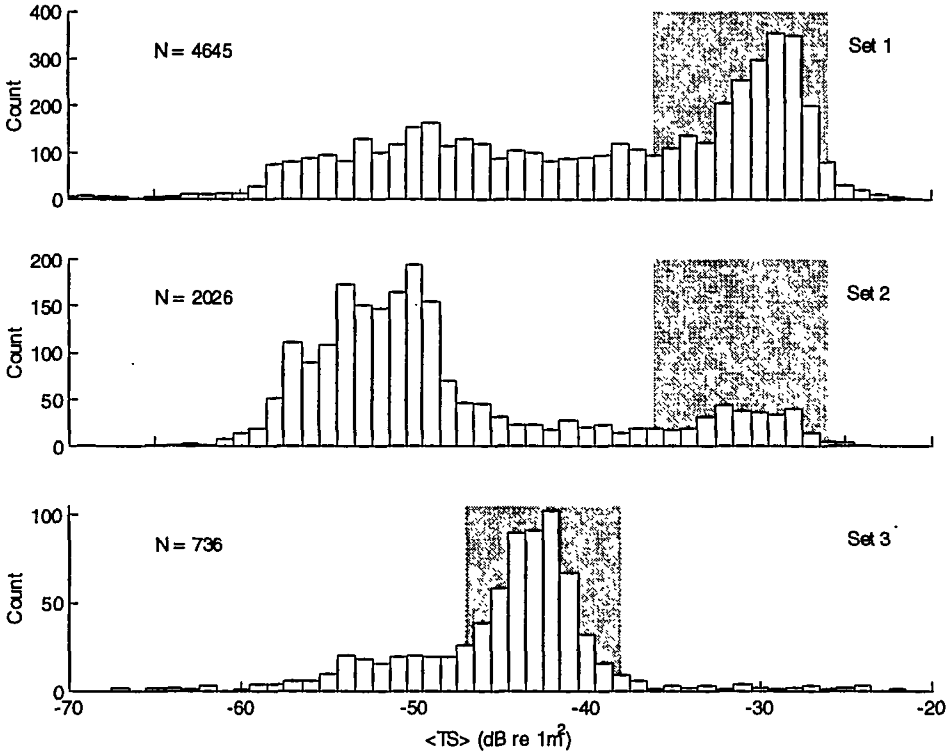

Figure 1. Target strength from three measurements in voyage TAN0212 on Campbell Rise 2002. Shaded regions show ranges over which data were averaged to produce the values in Table 1.

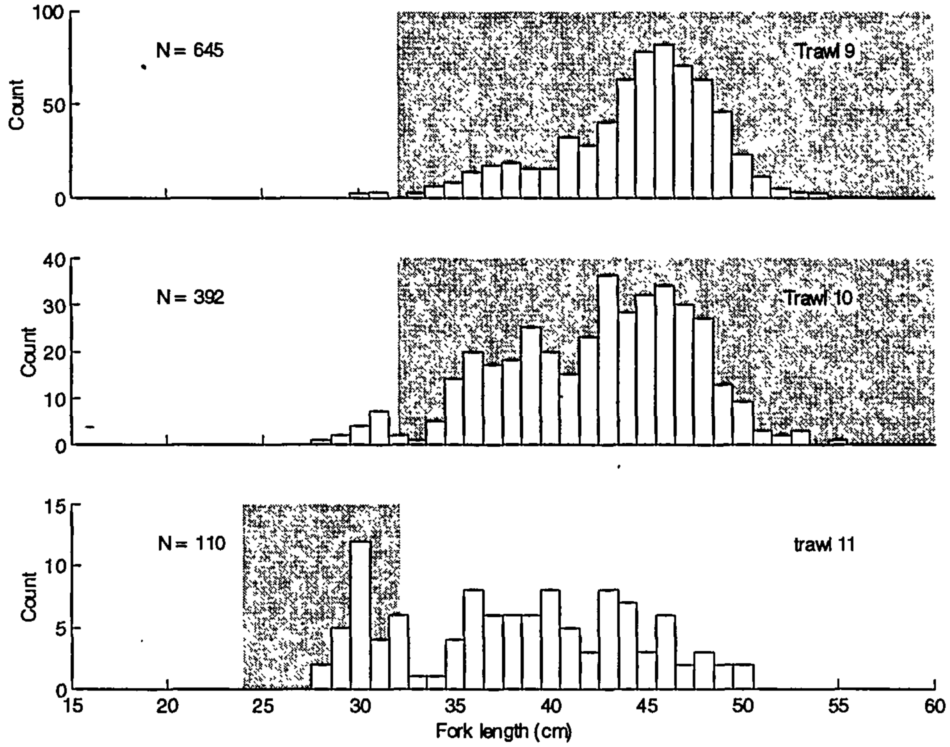

Figure 2. Fish length corresponding to the target strengths in Figure 1. Shaded regions show ranges over which data were averaged to produce the values in Table 1.

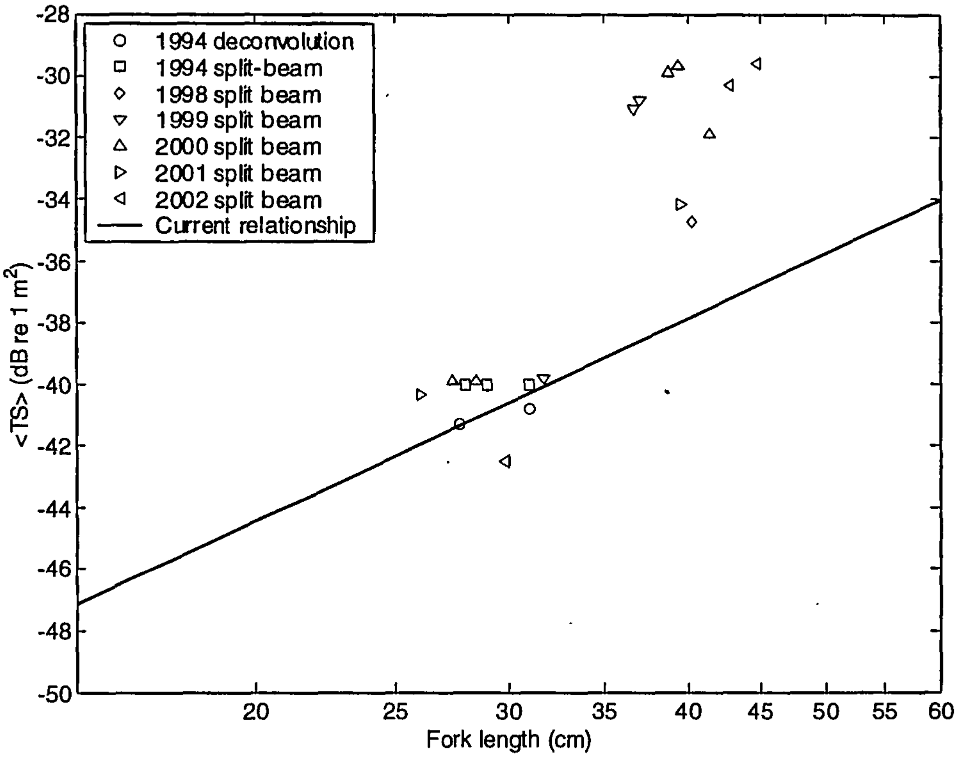

Figure 3. Southern blue whiting *in situ* target strength data from 1994 to 2002. Further details can be found in the text. The relationship currently used for stock assessment is shown for comparison.

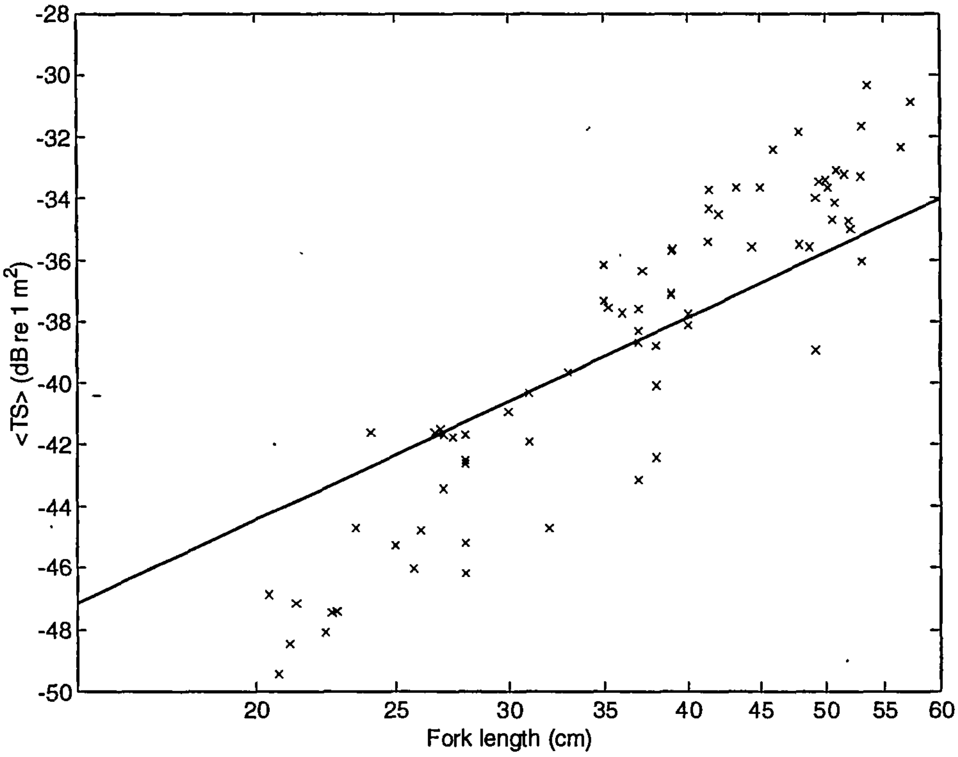

Figure 4. Southern blue whiting swimbladder modelling data. Further details can be found in the text. The relationship currently used for stock assessment is shown for comparison.

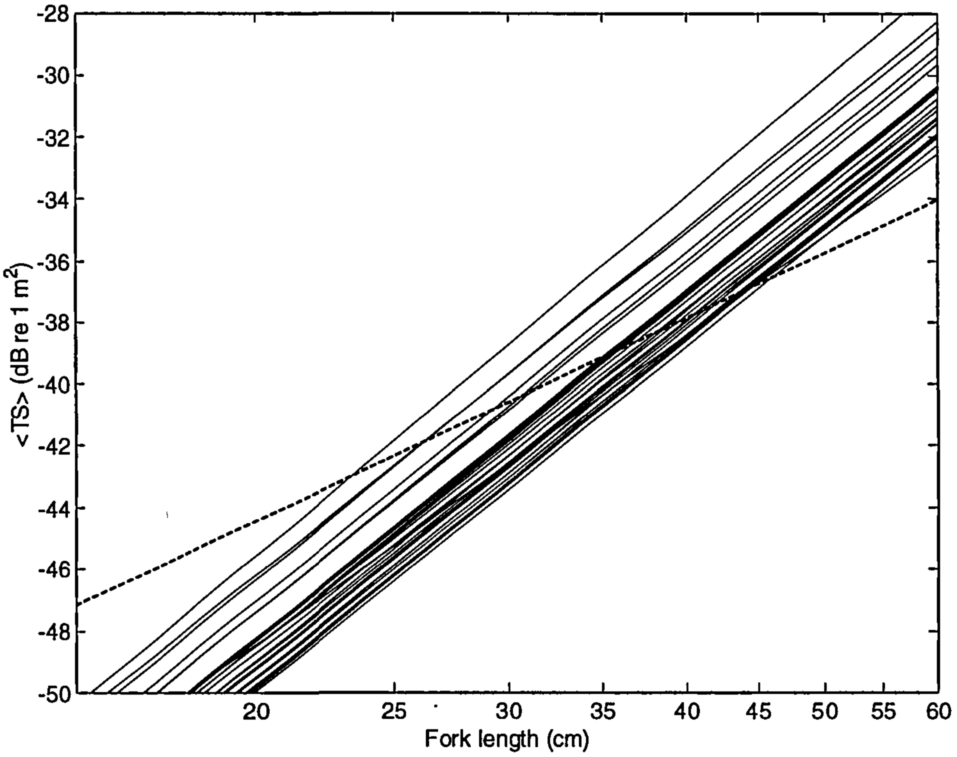

Figure 5. Southern blue whiting modelling data showing the effect of changing the tilt angle distribution used for computation. The dashed line shows the current relationship while the solid lines show the regression to the recomputed data. The thicker solid line is for a mean/standard deviation of 0°/15°, which are the values used in this report.

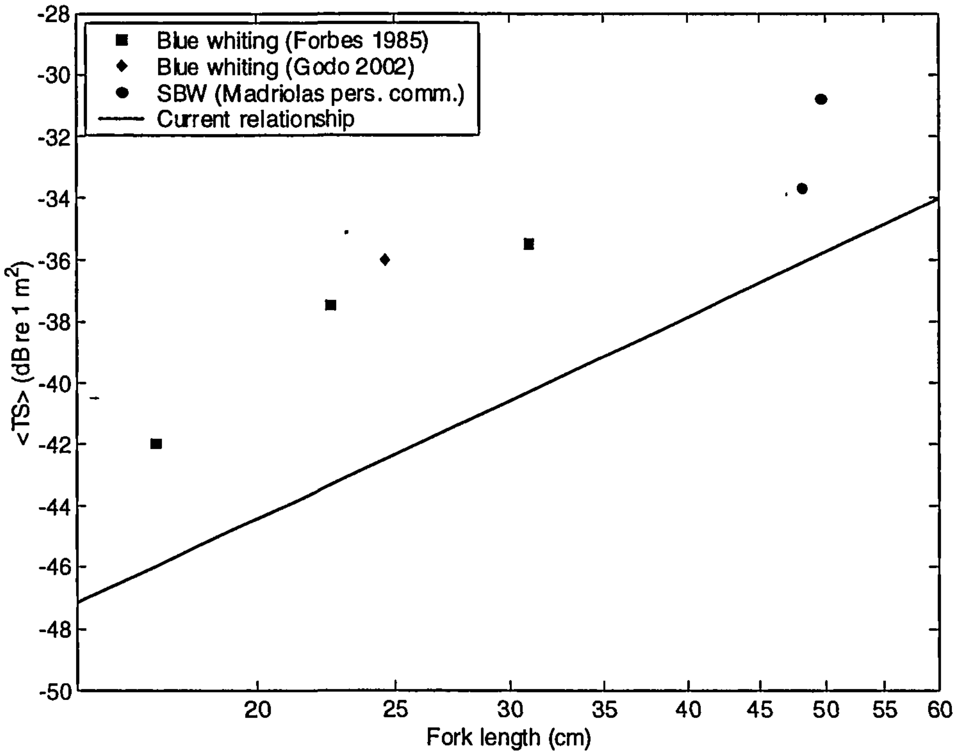

Figure 6. North atlantic blue whiting *in situ* data from the literature (Forbes 1985, Godo et al. 2002) and Argentine southern blue whiting (Madriolas pers. comm.) compared to the current relationship. This same relationship is used for assessments of blue whiting and also for southern blue whiting in Argentina and Chile.

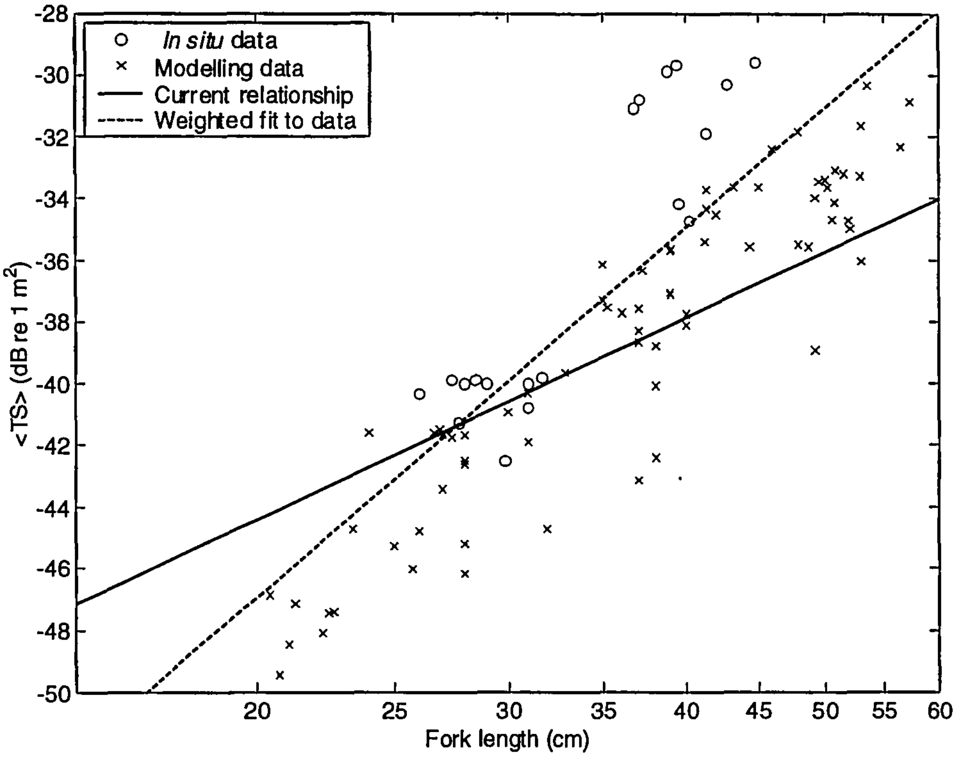

Figure 7. Southern blue whiting *in situ* and swimbladder modelling TS estimates, the current relationship (solid line), and a weighted fit to the combined *in situ* and swimbladder data.