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A revised target strength–length estimate for blue whiting (*Micromesistius poutassou*): implications for biomass estimates

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Acoustic abundance estimates of blue whiting have generally been higher than estimates based on catch data. One explanation has been that the relationship between acoustic target strength (*TS*) and length is too low and hence overestimates the number of fish. Measurements of *TS* were conducted during surveys of blue whiting in March/April 2003–2007 to the west of the British Isles from several different measurement platforms, and also during August 2005 in the Norwegian Sea. Results from these experiments confirm the view that the existing *TS*–length relationship is too low. A new *TS*–length relationship is proposed that is ~5 dB higher. Blue whiting *TS* is considerably higher than observed and modelled for a similar species, southern blue whiting (*Micromesistius australis*).

Keywords: acoustics, blue whiting, *in situ*, target strength.

Introduction

Blue whiting (*Micromesistius poutassou*; hereafter BW) is a gadoid whose distribution extends from Morocco to Spitsbergen, mainly along continental margins, penetrating into the Barents Sea, but also into the Mediterranean and the northern Atlantic Ocean. The main exploited stock is migratory and spawns west of the British Isles from February to April (Monstad, 2004), where it forms large, high-density aggregations between 300 and 500 m deep that are suitable for acoustic surveying and efficient trawling. Nursery areas appear to be along shelf edges from Morocco to northern Norway. The stock is harvested mainly west of the British Isles during the spawning season, and later in the season in the southern Norwegian Sea. The spawning stock reached a record high in 2003 as a result of strong recruitment, but has since declined as a consequence of an imbalance between exploitation and recruitment. Recruitment has been strong in all years from 1995 to 2004, but has been weaker in 2005 and 2006. The annual catch of BW has exceeded 2 million t since 2003. ICES recommendations for total allowable catch in 2007 and 2008 were not to exceed 980 000 and 835 000 t, respectively (ICES, 2008a).

Acoustic surveys of the main spawning areas have been carried out during March and April since the 1970s, with increasing cooperation and coordination in recent years between the survey efforts of individual countries (ICES, 2008b). Acoustic estimates of BW abundance have always tended to be considerably higher than those based on catch data (Godø *et al.*, 2002), probably because the target strength (*TS*) used has been too low, leading to an overestimate of the number of fish (Heino *et al.*, 2003). New *TS* measurements of BW and a resulting revision of acoustic survey results are clearly needed (Heino *et al.*, 2003), because the *TS*–length relationship currently used for BW is based on measurements of juvenile cod (Nakken and Olsen, 1977; Foote, 1980):

$$TS = 21.8 \log_{10} L - 72.8. \tag{1}$$

Seeking a new relationship, *TS* measurements were conducted during the annual BW surveys from 2003 to 2007 using different observation platforms. *In situ TS* measurements of BW were performed before (Nakken and Olsen, 1977; Robinson, 1982; Forbes, 1985), but in recent years, most work relevant to acoustic scattering from BW has been on the closely related southern blue whiting (*Micromesistius australis*; SBW). That species is found in the southern hemisphere, particularly around New Zealand and the southern part of South America (McClatchie *et al.*, 1998; Dunford and Macaulay, 2006). McClatchie *et al.* (1998) estimated the mean *TS* of SBW from the periphery of shoals using split-beam and single-beam echosounders. They also modelled the *TS* using the Kirchhoff approximation applied to manually digitized swimbladder casts. Dunford and Macaulay (2006) presented results from Kirchhoff modelling of SBW swimbladder casts scanned using a hand-held three-dimensional laser scanner.

The main objective of the present study was to provide a new *TS*–length relationship for BW based on high-quality *in situ* measurements conducted on the spawning grounds. The development of pressure-stabilized transducers and advances in platform technology during the past decade has made it possible to lower echosounders to the depth occupied by BW, and hence to obtain this goal (Kloser *et al.*, 1997; Gauthier and Rose, 2002; Dalen *et al.*, 2003; Klevjer and Kaartvedt, 2006).

Material and methods

Measurements of BW *TS* were made during five cruises over the period 2003–2007. In all, 33 sets of measurements were obtained using four echosounder platforms (submersible transducer, towed body, stationary platform, *TS* probe). To achieve data of sufficiently high quality, the measurement range of the echosounder was short (50–80 m), with a high pulse-repetition rate (typically 3–4 s^{-1}). The research vessel was brought to a complete halt during each experiment, except when using the towed body. Echosounder settings are listed in Table 1 along with details of the acoustic components. All echosounder platforms used Simrad EK60 acoustic transceivers (Andersen, 2001). Some of the platforms contained a 120 kHz acoustic echosounder, but few high-quality datasets were obtained from this, so no 120-kHz results are presented here.

Acoustic equipment

The transducer was held at a constant depth above or within the BW layers during each experiment. A rudder mounted on the top of the rig ensured that the transducer held a stable and relatively constant heading. Eight measurement sets at different depths were performed, and raw echodata were stored for post-processing. The equipment is described in more detail by Ona (2003).

A large torpedo-shaped (2.14 m long, 0.51 m diameter), deep-towed body (Dalen *et al*., 2003), weighing ~620 kg in air was used in 2005. Aside from the echosounders, it was equipped with sensors to measure the pitch, roll, and depth of the towed body. During the *TS* measurements, the body was towed at 2–3 knots, and placed directly above or within the layers of BW.

The lander (i.e. the stationary acoustic platform) was basically a large frame containing flotation and instrumentation that was moored to the seabed using an anchor and acoustic release. The mooring line was of nylon 5 mm in diameter, and was not visible in the acoustic data (Johansen *et al*., 2006; Wenneck *et al*., 2008). The transducers were mounted on the underside of the frame, looking downwards. Data from a compass, inclinometer, and depth sensor were also recorded. The echosounder in the lander was configured according to the actual area and measurement situation, then deployed in areas with good acoustic registrations of BW and left for a period of up to 24 h in 2005 and 2006.

The *TS* probe is an instrument specially designed for detailed acoustic measurement of the acoustic backscattering from fish (Ona and Pedersen, 2006). The transducers were mounted on a gimballed platform, the direction of which could be controlled from the vessel. The probe depth, tilt, and roll of the transducer platform were monitored continuously, and all the data were stored for later analysis. The probe was lowered into BW layers in 2006 and 2007. A calibration sphere was positioned below the transducer in most of the experiments, to monitor the operation of the transducers during the measurements.

Acoustic calibration

All echosounders were calibrated according to recommended procedures (Foote, 1983; Foote *et al*., 1987), using a tungsten-carbide sphere 38.1 mm in diameter (WC 38.1), except the 2003 calibration of the 38-kHz system, when a 60-mm copper sphere (Cu 60) was used. Although all the transducers used in this study are pressure-stabilized, their performance does change with depth (Pedersen *et al*., 2009). Variation of the calibration with depth was measured by positioning the sphere near the acoustic axis 10–15 m below the transducers, then lowering the transducers to 500 m in steps of 50 m. This was carried out either in Bjørnafjord, south of Bergen, Norway, or in sheltered areas on the west coast of Scotland. The change in the observed *TS* of the sphere with depth was used to correct the *TS* measurements of the fish. In several of the *TS* experiments, a sphere (Cu 60 or WC 38.1) was also suspended beneath the transducer to monitor transducer performance over time. Depth calibrations were not performed in 2006 and 2007, when corrections were estimated based on measurements of the calibration sphere positioned below the transducer.

Biological sampling

Four vessels were used to carry out biological sampling of the BW aggregations: RV "G. O. Sars" (2005 and 2006), RV "Johan Hjort" (2003), MS "Libas" (2005), and MS "Eros" (2007). A pelagic trawl (Åkratrawl) 486 m in circumference with a vertical opening of 25–35 m was used to sample the fish before and/or after *TS* measurements conducted from RV "G. O. Sars" and RV "Johan Hjort". On RV "G. O. Sars", this trawl was equipped with a multisampler (Engås *et al*., 1997), with three codends that could be opened and closed remotely. A 587-m circumference Åkratrawl and a large commercial BW trawl (Egersundtrawl) were used at some stations (1200 m circumference). On both MS "Libas" and MS "Eros", a commercial BW trawl was used with a codend mesh of 22 mm.

The catches from trawls were sorted and weighed, fish being identified to species when possible or to higher taxa where species identification was not feasible. Normally, a subsample of 50 BW were measured for total length and weight, their sex and age determined, and the maturity stage, stomach contents, parasite

Table 1. Echosounder settings and composition of TS equipment used in this study.

Parameter	2003 ES38DD	2005^a ES38DD	2005^b ES38DD	2006 ES38DD	2007 ES38DD
Frequency (kHz)	38	38	38	38	38
Power (W)	400	2000	2000	2000	2000
Transducer gain (dB)	20.9	26.4	24.0	26.8	21.8
Pulse duration (ms)	1.024	1.024	0.256	1.024	1.024
Alongship 3 dB beam width (°)	7.1	6.9	7.1	7.2	7.4
Athwartship 3 dB beam width (°)	7.1	6.9	7.1	7.1	7.3
Platform	Submersible transducer	Towed body	Lander	*TS* probe	*TS* probe
Attitude control	None	None	Gimbal	Active	Active
Transceiver location	Vessel, via tow cable	Vessel, via 1300 m tow cable	Pressure cylinder next to transducer	Vessel, via 6000 m tow cable	Vessel, via 6000 m tow cable
Additional transducer	–	120–7DD	120–7DD	120–7DD	120–7DD

The columns marked 2005^a and 2005^b show the towed body echosounder and lander echosounder settings, respectively.

load, and liver size evaluated. Length and weight were also measured from an additional sample of 50–150 BW from each trawl.

TS analysis

One of the main potential sources of bias in *TS* measurements of BW is the acceptance of multiple targets (McClatchie *et al.*, 1998). Incorrect fish *TS* estimates may be generated when there is more than one target in the acoustic sampling volume (Sawada *et al.*, 1993; Soule *et al.*, 1995, 1997). This is partly because of physical (Foote, 1996) and system limitations, so precaution was taken to avoid the problem in the current study; the transducers were lowered close to or into the BW layers, the measurements were limited to short ranges from the transducer, all *TS* data were scrutinized to reject files with too-dense fish aggregations, and all datasets with an indication of mixing with other species (such as mesopelagic fish, as caught in the trawls) were discarded.

Detections from potential BW targets were isolated using the Simrad EK60 single-target detection algorithm (Table 2), yielding estimates of *TS* and position in the beam (range, fore/aft and port/starboard angles). The angular positions were converted to angle off the acoustic axis, and a threshold was applied to remove targets that were considered to be too far off-axis. The cut-off angle was selected based on an analysis of the number of targets as a function of off-axis angle. The cut-off angle is usually set constant throughout the target depth range, and for a beam angle of 7°, this is typically 3° (Peña, 2008). This value is a compromise, though, and unnecessarily discards targets at short range and includes unwanted targets at greater range, so we estimated the cut-off angle as a function of depth separately for each experiment. The reduction in cut-off angle as range increased was calculated in steps of 0.5° to allow for losing targets through low signal-to-noise ratios in the outer parts of the acoustic beam.

A target-tracking software package (Handegard *et al.*, 2005) was used to isolate the tracks of single fish and to provide fish swimming angle, speed, and direction. Default target-tracking parameters were used (Handegard *et al.*, 2005). All statistical calculations on *TS* values were performed in the linear domain.

The precision of the estimated backscattering cross section of herring (*Clupea harengus*) depends on the number of targets accepted (Ona, 2003). Calculations show that when 500–1000 targets are available, the standard error of the backscattering cross section is <5% of the mean. This statistic was calculated for BW, and experiments containing fewer than 1000 single targets were discarded. In addition, a minimum target range of at least 5 m was set to ensure that the fish were not within the nearfield of the transducer, and that the transducer was outside the fish nearfield.

Table 2. Parameter settings used in the EK60 single-echo detection algorithm in this study.

Detection threshold	−60 dB
Minimum echo length	0.8
Maximum echo length	1.8
Maximum phase deviation	8
Maximum gain compensation	6 dB
Minimum echo spacing	1

Results and discussion

The most successful *TS* measurements were made using "stationary" platforms (submersible transducer, *TS* probe, and lander). The towed body tended to be unstable in rough weather and also caused a greater avoidance reaction (fish packing more densely or diving) than the stationary platforms. This behaviour has been observed for SBW on the Campbell Plateau south of New Zealand (GJM, pers. comm.), as well as for other deep-water species (Kloser *et al.*, 1997). Another issue with the towed body was that it took more time to deploy and bring to desired depth than most of the stationary platforms. Several lander experiments were also unsuccessful because the aggregations had moved on before the lander reached its programmed operating depth. Other measurements were discarded because of either mixed catch or too high a fish density to permit reliable measurement of *TS*. Only information collected during the first hour of lander experiments was used, because the biological sampling was done at the same time as landers were deployed.

In all, 15 experiments met all the criteria given in the Methods section and were used in the analysis; they are detailed in Table 3. All measurements were performed west of the British Isles during the spawning season, except those using the lander deployed from MS "Libas" in 2005. That experiment was conducted off the Norwegian coast (63°48′N 5°29′E) in August 2005.

Results from the depth calibrations of the transducers revealed that the observed *TS* of the sphere (Cu 60) at 38 kHz was higher than the nominal value (at 1490 m s^{-1} sound speed and no depth effect on the transducer) of −33.6 dB re 1 m^2 down to ~25 m, then dropped to a minimum at around 150 m (Figure 1). Below that minimum, the measured *TS* rose and approached the nominal value. The results from these calibrations were used to correct BW *TS* for transducer depth. *In situ* measurements of the WC 38.1 sphere (deeper than 350 m) showed a mean *TS* deviation of −0.5 to 0.02 ± 0.1 dB from the nominal value (−42.2 dB).

Mean length of the BW sampled ranged from 21.4 to 28.1 cm, and mean weight from 53.9 to 105.7 g (Table 3). Figure 2 is an example of the length and *TS* distribution of BW from measurements in 2003, and it illustrates the unimodal nature of both *TS* and length measurements in this measurement set.

Significant correlation was found between BW *TS* and depth ($r^2 = 0.3$, $p < 0.05$), but there was also a significant correlation between depth and fish length, if the two shallowest measurements are excluded ($r^2 = 0.7$, $p < 0.05$). If those two measurements are included, the correlation is not significant ($r^2 = 0.07$, $p < 0.05$). The correlations between *TS* and time of day and between swimming angle and time of day were not significant.

Based on the *in situ* measurements here, a new *TS*–length relationship ($TS = a \log_{10} L + b$) is presented:

$$TS = 17.4 \log_{10} L - 61.6. \tag{2}$$

The rather limited mean fish length range (21.4–28.1 cm) results in good confidence intervals (*CI*s) for both *a* (±23.2 dB) and *b* (±32.7 dB), so it may be better to fix the slope and estimate the intercept. For example, if *a* is fixed at 20 (as is common; McClatchie *et al.*, 2003), we obtain

$$TS = 20 \log_{10} L - 65.2. \tag{3}$$

Table 3. Experiment details and results.

Date	Time	Vessel	Platform	Depth (m)	Length (cm)	Weight (g)	*TS* (dB)	θ (°)
17.04.2003	14:00	JH	ST	450	24.6 ± 2.3	67.5 ± 15.8	−38.3 ± 0.1	−11.9 ± 22.4
17.04.2003	20:59	JH	ST	400	24.9 ± 1.9	70.4 ± 15.4	−39.1 ± 0.1	−3.0 ± 15.1
21.04.2003	20:26	JH	ST	420	25.7 ± 2.3	84.2 ± 25.0	−37.9 ± 0.2	0.3 ± 9.6
25.04.2003	00:19	JH	ST	380	21.4 ± 2.7	53.9 ± 21.4	−37.2 ± 0.5	−12.5 ± 23.9
30.03.2005	19:53	GOS	TB	500	27.1 ± 2.0	105.7 ± 27.8	−36.7 ± 0.2	−0.4 ± 10.4
03.04.2005	14:17	GOS	TB	450	26.0 ± 2.0	79.9 ± 20.4	−37.3 ± 0.2	1.8 ± 10.8
11.08.2005	10:42	LIBAS	LA	250	25.9 ± 3.1	90.3 ± 29.2	−37.5 ± 0.1	1.1 ± 12.2
19.03.2006	14:30	GOS	TSP	480	26.0 ± 1.9	79.1 ± 16.1	−35.8 ± 0.1	−0.1 ± 10.9
22.03.2006	17:30	GOS	TSP	470	26.0 ± 1.9	84.3 ± 18.3	−35.3 ± 0.1	−0.9 ± 12.1
25.03.2006	16:20	GOS	TSP	460	27.5 ± 2.8	102.3 ± 31.8	−35.0 ± 0.1	−6.1 ± 13.1
14.04.2006	07:00	GOS	TSP	410	23.9 ± 3.3	72.2 ± 31.0	−38.3 ± 0.1	−6.5 ± 20.1
14.04.2006	16:02	GOS	TSP	430	26.0 ± 2.4	97.4 ± 25.5	−36.3 ± 0.2	−6.5 ± 17.0
15.04.2006	10:02	GOS	TSP	400	23.4 ± 3.4	70.1 ± 32.1	−37.7 ± 0.1	−2.8 ± 18.2
09.04.2006	11:33	GOS	LA	310	27.5 ± 2.2	95.7 ± 29.4	−38.7 ± 0.1	−4.1 ± 11.6
30.03.2007	08:41	EROS	TSP	520	28.1 ± 2.0	104.5 ± 24.4	−35.3 ± 0.1	−0.4 ± 22.7

Vessel codes are JH (RV "Johan Hjort"), GOS (RV "G. O. Sars"), LIBAS (MS "Libas"), and EROS (MS "Eros"). Platform codes are ST (submersible transducer), TB (towed body), LA (lander), and TSP (*TS* probe). Depth indicates the mean operating depth of the echosounder transducer, and length and weight the mean length and weight of the BW caught in associated trawls. The *TS* is the mean and is shown with 95% bootstrap *CI*s of the mean (1000 bootstrap runs). Also shown are estimated swimming angles (θ) from target-tracking with the standard deviations.

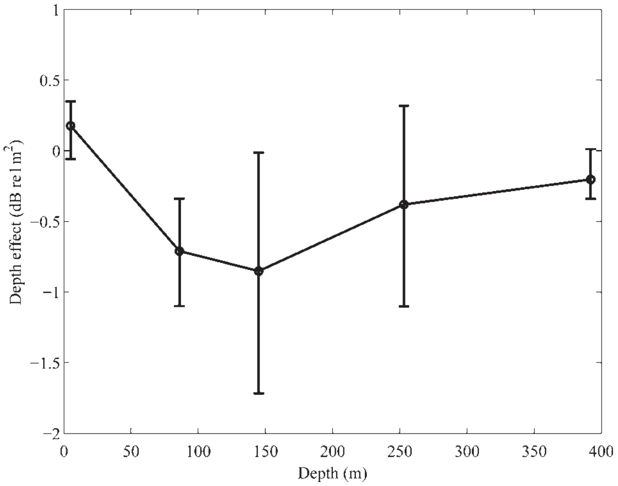

Figure 1. Difference between measured and theoretical calibration sphere (Cu 60) *TS* with depth, including 95% *CI*s.

Using the same a as the current survey equation results in

$$TS = 21.8 \log_{10} L - 67.8. \tag{4}$$

The 95% *CI* in both cases is ±0.7 dB. All mean *TS* measurements from the current experiments, along with Equation (3), are shown in Figure 3 and compared with the current BW survey equation and the modelled SBW result (Dunford and Macaulay, 2006).

The *in situ TS* estimates obtained for BW differ from the measured and modelled SBW *TS* estimates. Model *TS* estimates for SBW in McClatchie *et al*. (1998) are 2.9–4.3 dB lower than for BW of the same size, and *in situ* estimates of SBW are consistent with the current *TS*–length relationship for BW [Equation (1)]. Dunford and Macaulay (2006) calculated a lower *TS*–length regression intercept and a steeper slope for SBW than the BW *TS*–length relationship. Nakken and Olsen (1977) measured the *TS* of ten dead BW with lengths ranging from 31 to 35 cm, and obtained a mean *TS* of 32.0 ± 1.8 dB. Robinson (1982) estimated an *in situ TS* of -31.1 ± 1 dB kg^{-1} at 29.3 kHz, for a BW of 31 cm mean length.

The *TS*–length relationship for SBW yields unrealistically high biomass estimates for BW (Figure 4). We cannot provide a robust explanation as to why the *TS* is so different between what appear to be similar species, but it is likely to include physiological and behavioural differences between the two species. Differences in swimbladder inflation and stages in diel migration, and factors such as fat content, may contribute to differences in *TS*. Johnsen and Godø (2007) analysed acoustic recordings from the Norwegian surveys of BW, and showed that the acoustic density was ~20% higher by day than by night. The diel bias varied considerably by year, though, and acoustic density in shallow water was in general highest at night. Possible differences in orientation will have an influence on *TS*, but Dunford and Macaulay (2006) found that the estimated slope in the *TS* relationship for SBW was higher than for BW, irrespective of tilt-angle distribution (using a 0° mean).

The methodology for length measurement is different for BW and SBW; total length (TL; without the lobes compressed along the midline) is used for BW, and fork length (FL) is used for SBW (the procedure in New Zealand is to smooth down the tail so that it forms a clear fork, then measuring from the tip of the snout to the tip of the middle caudal fin rays). TL and FL measurements were taken from 114 SBW (S. Hanchet, NIWA, pers. comm.), then used to derive a conversion: TL = 1.06 FL − 0.28 (cm), so all the measurements presented herein are either TL (for BW) or estimated TL (for SBW). Note that the TL measurement technique used for SBW was to compress the lobes along the midline, so is not exactly the same as used for BW. However, we believe that the difference in length will be small.

Some data on swimbladder length and TL do exist. Figure 5 shows a plot of TL on swimbladder length using data from Dunford and Macaulay (2006) and Jacobsen *et al*. (2002). The data indicate that the BW swimbladder is longer than the SBW swimbladder for a given fish TL. This will potentially contribute to a higher *TS* for BW, but a thorough comparison of SBW and BW is still needed because the *TS* of a swimbladder is determined by more than just its length.

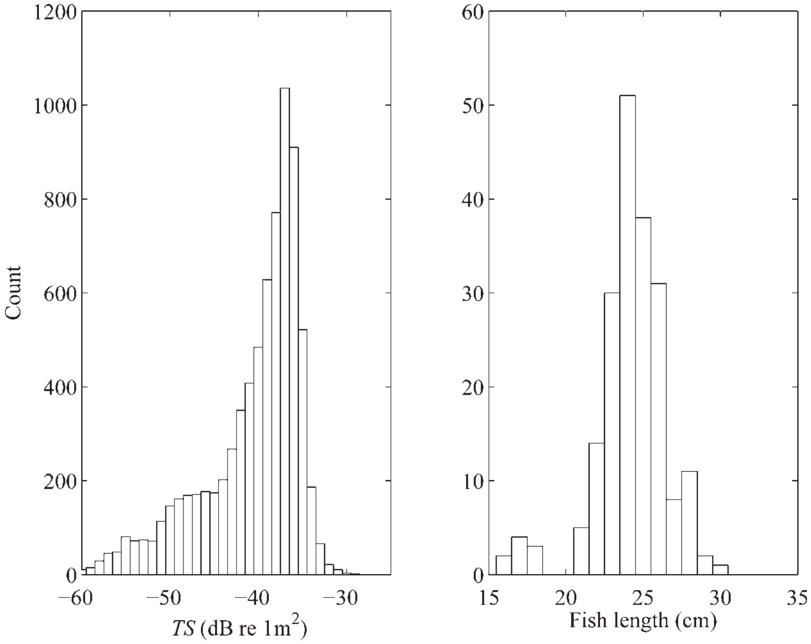

Figure 2. An example of observed *TS* and a length distribution of blue whiting (17 April 2003; row 1 of Table 1).

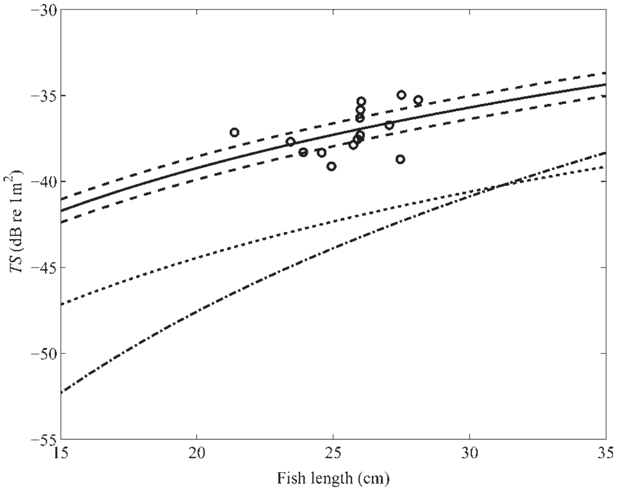

Figure 3. Three *TS*–length relationships; new blue whiting relationship 20 $\log_{10}$ length − 65.2 (solid line) with 95% *CI*s (dashed lines), survey equation for blue whiting (dotted line), and new southern blue whiting relationship (dashed–dotted line). The circles show the mean *TS* from each experiment.

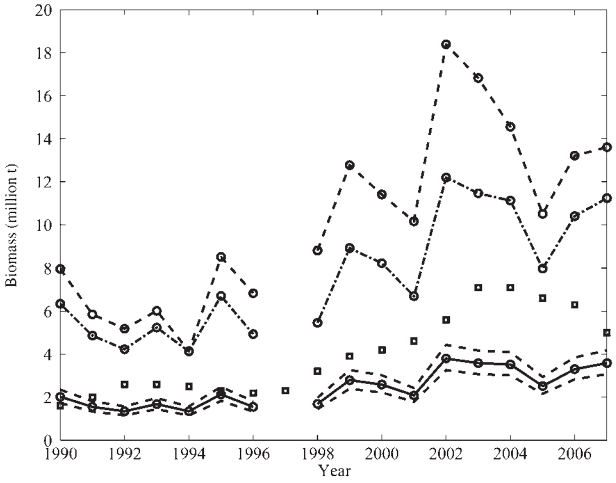

Figure 4. Estimated biomass from blue whiting cruises from 1990 to 2007 (dashed–dotted line), the Norwegian spawning ground survey (1990–2004), and the international blue whiting spawning ground survey (2004–2007). The solid line shows the abundance scaled by the new *TS*–length relationship (20 $\log_{10}$ length − 65.2) using the mean fish TL and weight for each survey. The dotted line shows the same approach, but using the southern blue whiting relationship from Dunford and Macaulay (2006). The squares indicate assessment results (ICES, 2008a).

All but one experiment took place during the spawning period (March/April), and insufficient data exist to estimate annual variations in *TS* that might exist because of changes in gonad size, fat content, etc. However, because the surveys are conducted during the spawning season, the *TS* at that time is most relevant.

The results obtained here differ from the established *TS*–length relationship used in BW acoustic surveys, and would significantly reduce the resultant biomass estimates. Figure 4 shows the BW biomass estimated by acoustic survey from 1990 to 2007 using the existing *TS* relationship [Equation (1)], the revised relationship [Equation (3)] with 95% *CI*s on *b*, and the SBW relationship from Dunford and Macaulay (2006). Also included in that figure are BW, the biomass estimates reported by the ICES Working Group on Widely Distributed Stocks (ICES, 2008a), calculated using commercial catch-at-age data (1981–2007) along with data from three acoustic survey series. Mean fish TL and weight for each survey has been used in the scaling process, but this is a simplification and gives an approximation of the biomass, because the 17 surveys depicted in Figure 4 have not been reprocessed with the new equation. The biomass value from the revised relationship is consistently lower than the stock assessment value; the greatest deviations are found for the past decade.

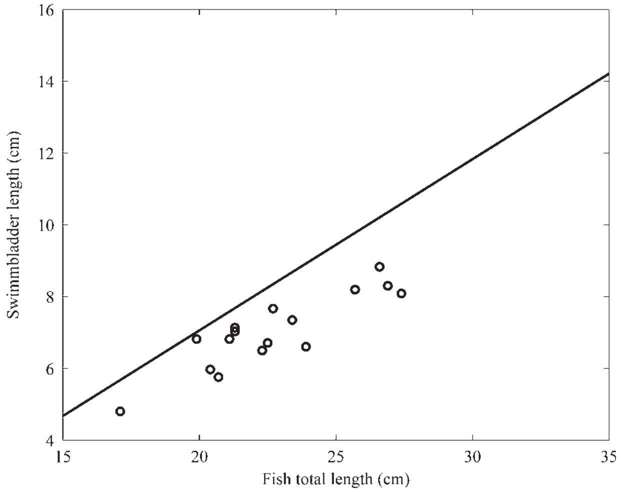

Figure 5. Swimbladder length as a function of fish *TL* for blue whiting (solid line; Jacobsen *et al.*, 2002) and southern blue whiting (circles, Dunford and Macaulay, 2006) in the fish TL range 15–35 cm. The measured FL of southern blue whiting has been converted to total TL using the relationship TL = 1.06 FL − 0.28 (cm). Note that the TL measurement technique used for southern blue whiting was to compress the lobes along the midline, so is not exactly the same as that used for blue whiting.

The mean difference in estimated biomass between the revised relationship results and the stock assessment (ICES, 2008a) is −0.9 ± 0.4 million t for the years before 1998, but −2.9 ± 1.2 million t after 1998. If the biomass using the existing *TS* relationship is compared with the stock assessment, the difference is 2.8 ± 1.1 million t for the years before 1998, and 3.9 ± 2.1 t from 1998 on.

Because of the lack of *TS* estimates for smaller and larger fish in this work, the slope of Equation (2) might not be correct for BW, and our opinion is that Equation (3) or (4) is preferable. Equation (3), rather than Equation (4), has been used to illustrate the impact on biomass estimates, however, because it has some basis in scattering physics (McClatchie *et al.*, 2003) and avoids having the new *in situ* relationship affected by the existing relationship, which was not derived from BW. The relationships obtained here should, however, not be applied to BW outside the length range analysed because of its restricted range and the resulting assumption of a slope of 20°. *TS* measurements of smaller and larger BW are clearly required to determine a relationship that spans other lengths in the fishery.

Conclusions

Based on *in situ TS* measurements conducted from BW (2003–2007), new *TS*–length relationships are presented [Equations (2)–(4)]. The use of Equation (3) to analyse spawning BW acoustically, within the fish length range observed, is likely to result in a more accurate estimate of the stock size of BW. The measured *TS* of BW, and the resulting *TS*–length relationship, differ significantly from that of SBW (McClatchie *et al.*, 1998; Dunford and Macaulay, 2006). A thorough acoustic and biological comparison of the two closely related species is, however, required to explain the relatively large difference in *TS*.

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