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Estimates of target strength of hake (*Merluccius australis*)

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7. Executive Summary

The target strength of hake was measured *in situ* using a split-beam echosounder during September 1999 off the west coast of the South Island, and also by modelling of hake swimbladders collected at the same time. The preliminary target strength to fork length relationships are:

$TS = 27.1\log_{10} FL - 83.5$ at 38 kHz, and

$TS = 23.8\log_{10} FL - 78.5$ at 12 kHz,

where TS is the fish target strength in dB re 1μPa at 1 m and FL is the hake fork length in centimetres.

Further research into and data on the target strength of hake is required before a definitive hake target strength to fish length relationship can be obtained. These data and research should be collected and carried out as part of any future hake acoustic surveys.

8. Objectives

To determine estimates of target strength of hake.

9. Methods

9.1 Introduction

The data analysed in this report were collected from the *Tangaroa* during a voyage off the west coast of the South Island in August/September 1999. Acoustic *in situ* target strength data were collected and casts of hake swimbladders were made.

9.2 Acoustic equipment description

Acoustic target strength data were collected using a towed split-beam 38 kHz transducer. All data were processed and stored using the NIWA *CREST* data acquisition system (Coombs, 1994). The particular *CREST* system configuration was a four channel towed system, with underwater electronics, connected to a Simrad type ES38DD split beam transducer. The equipment and operational parameters used for the target strength data collection are given in Table 1.

CREST is computer based, using the concept of a 'software echo sounder'. It supports multi-channels, each channel consisting of at least a receiver and usually also a transmitter. The receiver has a broadband, wide dynamic range pre-amplifier and serial analog-to-digital converters (ADCs) which feed a digital signal processor (DSP56002). The ADCs have a conversion rate of 100 kHz and the data from these are complex (quadrature) demodulated, filtered and decimated. The filter was a 100 tap, linear-phase finite impulse response digital filter. For target strength work the bandwidth was 4.86 kHz and the decimated frequency 10 kHz. Following decimation a 40 log R time-varied gain was applied. The results were shifted to give 16 bit resolution in both the real and imaginary terms and the complex data were stored for later processing.

The transmitter is a switching type with a nominal power output of 2 kW rms. It will operate over a wide range of frequencies (12-200 kHz). For target strength work the transmitted pulse length was 0.32 ms (12 cycles at 38 kHz). Time between transmits was 1.4 seconds. The receiver and transmitter were mounted in a flat-nosed, torpedo-shaped, 3 m long 'heavy weight' towed body.

The digital data from the receiver are sent to a control computer where they are combined with position and transect information and stored. The data are transmitted via the tow cable to the control computer on the towing vessel. All four transducer quadrants (beams) are energised simultaneously from a single transmitter but on receive, the system operates as four semi-independent echosounders. Data are processed independently on the four channels but operation is tightly synchronised by the transmit key and by using a common clock for all the ADCs. For target strength the beams are treated separately to reject multiple echoes and calculate the position of the echoes in the beam.

The acoustic systems were calibrated with the standard procedure using a 38.1 mm diameter tungsten carbide sphere as detailed in MacLennan and Simmonds (1992). The towed *CREST* system was calibrated at sea (at depths ranging from 50 to 708 m) during the night of 9 September and yielded a calibration in agreement with at sea calibrations carried out during acoustic surveys in 1998 and 1999. The towed system was also calibrated before (June 1999) and after the voyage (September 1999) in the deep tank at the NIWA Greta Point laboratories and yielded results that were consistent with previous calibrations.

9.3 Hake swimbladder collection and processing

Detailed biological measurements were taken from eighty-four hake and the trunks were frozen. Casts of swimbladders were made by injecting an epoxy resin (with filler to improve the durability of the cast) into the swimbladder of the thawed fish. After the resin had set the fish body was removed and the casts encapsulated in a block of clear epoxy resin. Hake vertebrae above the swimbladder have broad transverse processes with markedly concave ventral surfaces. The dorsal surface of the swimbladders extends into each of these cavities. As a result the dorsal surface of hake swimbladders have a very distinctive rippled form with about 20 pairs of ridges shaped by these cavities (see Figure 1). To adequately capture this shape required five slices per ridge. This resulted in at least 100 slices per swimbladder. Three casts were sectioned in this way. The resulting sections were digitised and input to in-house software that calculates the back-scattering target strength of the swimbladder using the mapping method (McClatchie *et al.*, 1996). The output was the fish target strength at 12 and 38 kHz, for tilt angles ranging from –45° to +45°. This data were convolved with a tilt angle distribution (normal distribution, mean of 0° and standard deviation of 15°) to give a tilt averaged target strength value.

Each swimbladder was scaled to simulate a set of swimbladders of length 20 to 140 cm. Scaling factors were determined by measuring, for 41 hake, the fish length and swimbladder length and width. A regression was then fitted to these data to provide a relationship for scaling the swimbladder to achieve a given hake length. These regressions were $s_l = 0.25l - 0.4$ and $s_w = 0.06l$, where s_l is the swimbladder length, s_w the swimbladder width and l the fish length. All units are centimetres. The scale factor was applied equally to all three dimensions of the swimbladder and the target strength of these simulated swimbladders was then calculated.

9.4 Trawl data collection

Trawling was carried out using both bottom and midwater trawls. The standard NIWA 8 seam hoki bottom trawl with a 59 m groundrope, 45 m headrope and a cod-end mesh size of 60 mm was used (net plans contained in Hurst *et al.*, 1994). Rigging included 100 m long sweeps, 50 m bridles and 12 m backstrops. Midwater trawling was carried out using the NIWA Ymuiden P/159A midwater trawl with 150 m bridles and a 60 mm cod-end. Both gear types used 6.1 m^2 Super V trawl doors.

All trawls were targeted on specific marks (or in some cases, the absence of marks) and were nominally 3 n. miles in length. All catches were weighed, with more detailed biological information taken from hake, ling, hoki and miscellaneous other species using the *Tangaroa's* computerised wet-lab system.

9.5 *In situ* target strength data collection and processing

To collect *in situ* data, marks that were expected to be hake were located and the towed transducer deployed 30–70 m above the marks. The marks were then trawled to identify the species and to obtain an estimate of the size composition.

The recorded acoustic data preserve both amplitude and phase information and allow both target position and amplitude to be calculated. To estimate target strength it is first necessary to filter out all echoes that do not originate from a single fish. To achieve this the following echo characteristics were checked:

- width of the combined beam
- relative width of the four beams
- phase stability of the combined beam
- similarity of amplitude between beams
- angle of arrival of the echo

These characteristics are based on those listed by Soule *et al.* (1995) and Soule *et al.* (1997) and from discussions with Soule. They were used to filter data to reject all echoes formed by more than one fish. The values of these characteristics that were considered indicative of echoes from single fish were set by conducting an experiment involving two spheres at constant angles in the acoustic beam, but at a range of different distances (after Soule *et al.*, 1997). Echoes were considered to be from a single fish if the following conditions were met:

- The width of the echo was between 50% and 150% of the transmit pulse width at half the maximum echo amplitude (the 6dB amplitude points).
- The standard deviation of the electrical echo phase between the 6dB amplitude points was less than 0.4 radians on the combined echoes.
- The width of the four individual echoes at the 6dB amplitude points varied by less than 63% of the transmit pulse width.
- 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 1.5 and 3.0 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.

9.6 Calculation of target strength estimates

Target strength estimates of hake were obtained by comparing the filtered *in situ* target strength data and the fish length data obtained from trawls. In all cases trawls were made before and after the collection of target strength data and if the length distributions were not significantly different, the data were combined and compared to the acoustic data. The mean of the target strength data (in linear space) were then taken to obtain an estimate of target strength.

10. Results

10.1 *In situ* target strength results

Trawls on two separate aggregations yielded sufficient hake to justify collecting *in situ* target strength data. The first occasion was on 3 September when an aggregation containing hake was found. It also contained significant amounts of hoki. Data were collected from this aggregation to provide information on a mixed aggregation, as this was a common occurrence in the area at the time of the voyage. The second occasion was from mid-morning on 8 September to mid-morning of the following day, when target strength data were collected as part of the 24 hour acoustic observation of a hake aggregation.

The target strength data collected from the first occasion consists of one transect over the same path as the associated trawl. The transect was extended well beyond the actual trawl track because large intense marks were seen with the hull mounted echosounders. However, upon reaching these marks with the towbody it was clear from the target strength data that the marks contained very few strong scatterers, and hence were likely to contain very few hake. The acoustic data collected from the trawl track gave echoes of amplitudes consistent with hoki (Macaulay & Grimes, 2000), and virtually no echoes appropriate for hake. For this reason, these data have not been analysed further.

The target strength data collected from the second occasion consists of nine transects over the same path. Four transects were carried out during daylight, and five during the night. During two of the night transects the echosounder was towed at a depth of approximately 300 m to obtain data from the hake which had appeared to migrate into midwater. For the remaining seven transects the echosounder was towed at a depth of approximately 420 m. The vertical distribution of the filtered single targets from these nine transects are given in Figure 2. The corresponding target strength distributions are given in Figure 3. Distributions from transects carried out during the day include the echoes from within 30 m of the bottom, and transects carried out at night include all echoes, regardless of the distance from the bottom. This was done because the hake length data were collected with a midwater trawl towed along the bottom with a net opening height of approximately 27 m. During the night the hake were assumed to be dispersed throughout the water column (Macaulay and Dunn, 2000) and hence all echoes were used.

The target strength data contained large numbers of low amplitude echoes with two peaks at approximately –55 and –49 dB. These echoes are too low to be from hake, and are probably from fish of length 10 to 20 cm. The target strength of hake with a length of approximately 80 cm was expected to be of the order of –31 dB (Lillo *et al.*, 1996). The target strength distribution also contained a smaller mode in the range of –45 to –39 dB. This is an appropriate range for hoki (Macaulay & Grimes, 2000); consequently all echoes greater than –38 dB were assumed to be from hake, and the mean of these data taken. The distributions and means are given in Figure 3 and Table 2 respectively. The linear mean over all means in Table 2 is –31.7 dB.

The three trawls on the hake in the second aggregation gave mean lengths that were within 0.5 cm of each other (each trawl contained a few hake that were less than 40 cm in length which were not included in this comparison–see Figure 4). The length data from these three trawls were combined to give a mean length of 79 cm. As a result only one *in situ* hake target strength point was obtained.

10.2 Swimbladder cast results

Casts from three hake collected during the voyage were sectioned for target strength analysis. The lengths of the fish were 30.2, 72.0 and 110.8 cm. Target strength/fork length relationships for 12 and 38 kHz are given in Figure 5.

The scaled results exhibit pronounced dips in the target strength value at various lengths. The tilt-averaged target strength is obtained by convolving the modelled TS/tilt angle response with a tilt distribution (normal with a mean of 0° and a standard deviation of 15°). This serves to complicate any explanation of the behaviour of the TS/FL curves. By considering the TS/tilt relationship separately, a greater understanding of the behaviour of the TS/FL relationship can be obtained.

The TS/tilt relationship is characterised by a series of peaks and nulls (see Figure 6), where positive angles correspond to a head attitude of the fish. These nulls are a result of destructive interference of the scattered acoustic wave from different parts of the swimbladder. As the tilt angle changes, the vertical spacing between various parts of the swimbladder change when viewed vertically, and hence the amount of constructive and destructive interference (nulls) changes. As the size of the swimbladder varies, the position, number and intensity of these nulls vary. When nulls are present in the tilt angle range that is used in the convolution, they reduce the tilt-averaged target strength. As the fish size increases, the number of nulls increases and produces more dips in the TS/FL curve. Figure 7 contains target strength data for a range of swimbladder sizes and tilt angles, and is effectively a composite of the data from 101 Figure 6's. The nulls in the region that is used in the convolution (between the two horizontal lines) can be seen clearly in both parts of Figure 7. It is expected that for a real fish, the various contributions to the scattering from other parts of the fish (bones, flesh, etc) will reduce the severity of the nulls and produce a smoother TS/tilt curve and hence a smoother TS/FL curve.

The TS/tilt curves for 12 and 38 kHz are dissimilar. The 12 kHz curves increase smoothly, while the 38 kHz curves show a number of dips. This is due to the dependence of the target strength on the ratio of acoustic wavelength to swimbladder size. The wavelength of sound in seawater is 12.5 cm at 12 kHz, and 4.0 cm at 38 kHz, and the width of a swimbladder from a 110 cm hake is approximately 4 cm. At 38 kHz this causes the scattering from the swimbladder to depend to a large degree on the geometry of the swimbladder, and can cause the target strength to change rapidly with small changes in the size of the swimbladder (MacLennan & Simmonds, 1992, §2.5). At 12 kHz the wavelength is much larger that the swimbladder width, and the scattering is less dependent on the actual geometry of the swimbladder and more dependent on the volume of the swimbladder. If the 12 and 38 kHz curves are normalised by dividing the swimbladder length axis by the acoustic wavelength, the curves are identical.

10.3 Estimation of the fish length to target strength relationship

The swimbladder modelling and *in situ* data were combined and a linear regression in the log domain fitted. This is presented in Figure 5, and has the form:

$TS = 27.1\log_{10} FL - 83.5$ at 38 kHz, and

$TS = 23.8\log_{10} FL - 78.5$ at 12 kHz,

where TS is the fish target strength in dB re 1μPa at 1 m and FL is the hake fork length in centimetres. The 12 kHz estimate consists entirely of the swimbladder modelling results, while the 38 kHz estimate also includes the *in situ* point.

For comparison, the 38 kHz relationship for *M. australis* off the Chilean coast (Lillo *et al.*, 1996) is given in Figure 5. Note that it is limited to the fish length range for which the relationship was given (50–85 cm).

In situ target strength measurements are the preferred method for estimating target strength. However, many *in situ* points, spread over a wide fish length range are required to achieve a robust estimate. This was not achieved during the voyage, and may be difficult to achieve due to the broad uni-modal length distribution of hake off the west coast of the South Island. It is considered unlikely that the mean length of hake will change significantly in the near future, and individual year classes are rarely visible in the length data. This suggests that in the short to medium term more detailed mathematical models of hake target strength offer the best opportunity for improving knowledge of hake target strength, with the proviso that *in situ* data are still required to ground–truth the modelling.

11. Conclusions

Hake target strength data have been collected, and a preliminary target strength/fork length relationship has been derived.

The target strength of hake was been estimated from *in situ* split-beam data and mathematical models of swimbladder casts. Only one *in situ* estimate was obtained (at 38 kHz), and is consistent with the estimates from the swimbladder modelling. Regressions fitted to the data sets are:

$TS = 27.1\log_{10} FL - 83.5$ at 38 kHz, and

$TS = 23.8\log_{10} FL - 78.5$ at 12 kHz,

where TS is the fish target strength in dB re 1μPa at 1 m and FL is the hake fork length in centimetres.

Collection of larger quantities of *in situ* hake data will enable this relationship to be further improved by carrying out an analysis similar to that developed by Barr (2000). The relationships presented above are determined to a large degree by the modelling results and the development of a more detailed model will improve the accuracy of this relationship.

Further hake target strength data should be collected as part of any future hake acoustic surveys.

12. Publications

None.

13. 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.

14. References

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Table 1: Configuration of the echosounder used to collect target strength data

Transducer model	Simrad ES38DD
Transducer serial no.	28326
Nominal 3dB beamwidth(°)	6.9
Effective beam angle (sr)	0.0079
Operating frequency (kHz)	38.1
Transmit interval (s)	1.4
Nominal pulse length (ms)	0.32
Filter bandwidth (kHz)	4.86
Initial sample rate (kHz)	100.0
Decimated sample rate (kHz)	10.0
TVG	$40 \log R + 2\alpha R$
Nominal absorption (dB/km)	8.0
SL+SRT (dB re 1V at 1m)	61.1
Calibration valid at (m)	400
$20\log_{10}G$	49.7

Table 2: Mean target strength from the nine *in situ* transects

Transect	Mean target strength
1	–32.3
2	–31.0
3	–32.1
4	–30.7
5	–32.6
6	–30.5
7	–32.4
8	–32.5
9	–31.2

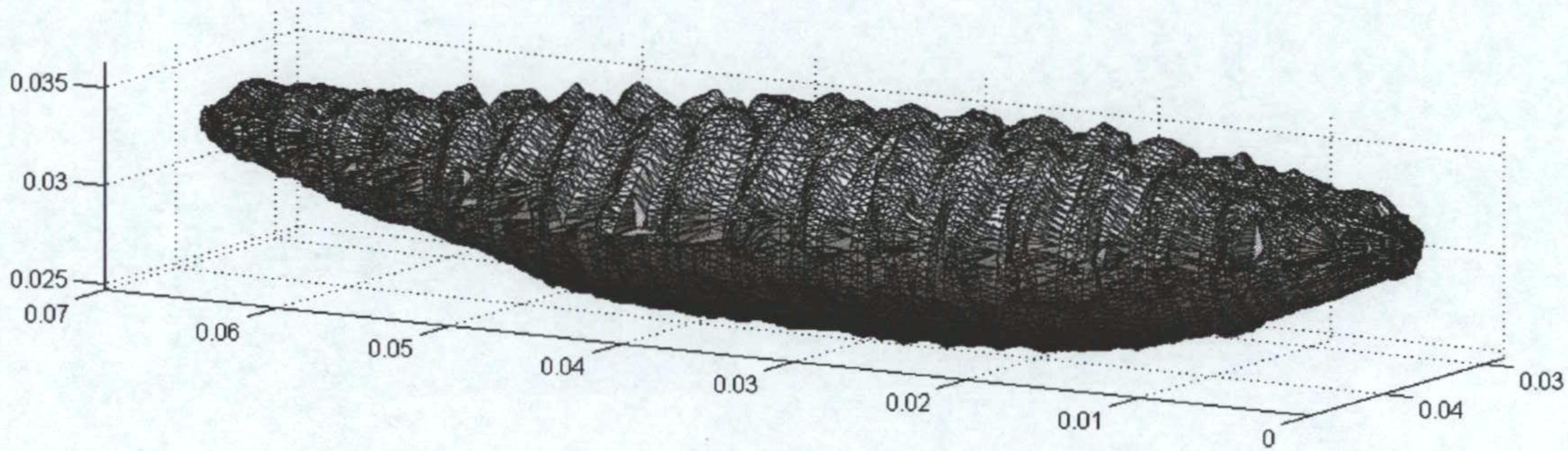

Figure 1: Three-dimensional rendering of a hake swimbladder. Axes dimensions are in metres. The swimbladder is oriented with the dorsal surface uppermost, and the front to the right.

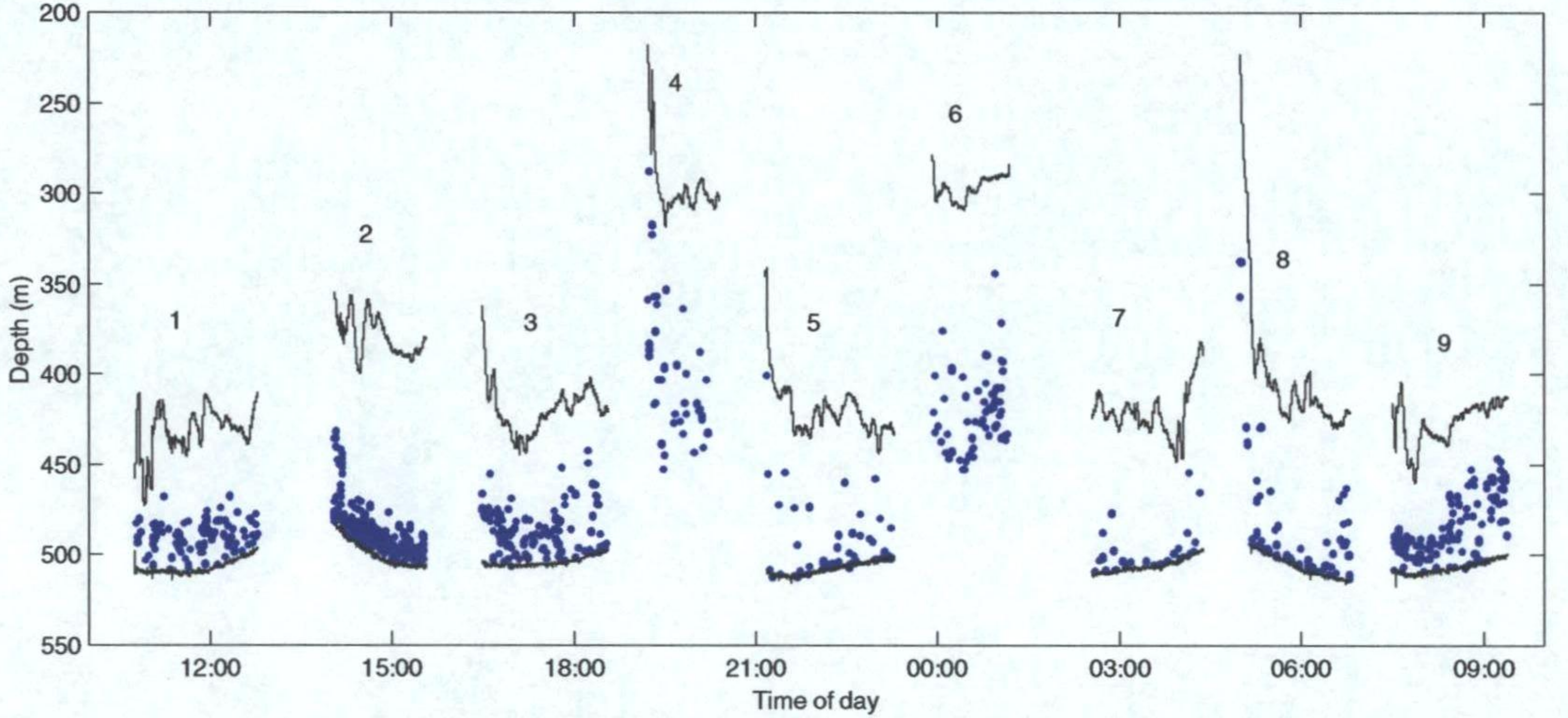

Figure 2: Vertical distribution of single target echoes from the 38 kHz towed echosounder. The upper set of lines is the depth of the echosounder, and the lower set of lines is the bottom. Single target echoes are indicated by the dots. The gaps in the data are a result of turns at the end of each transect. The numbers correspond to transects.

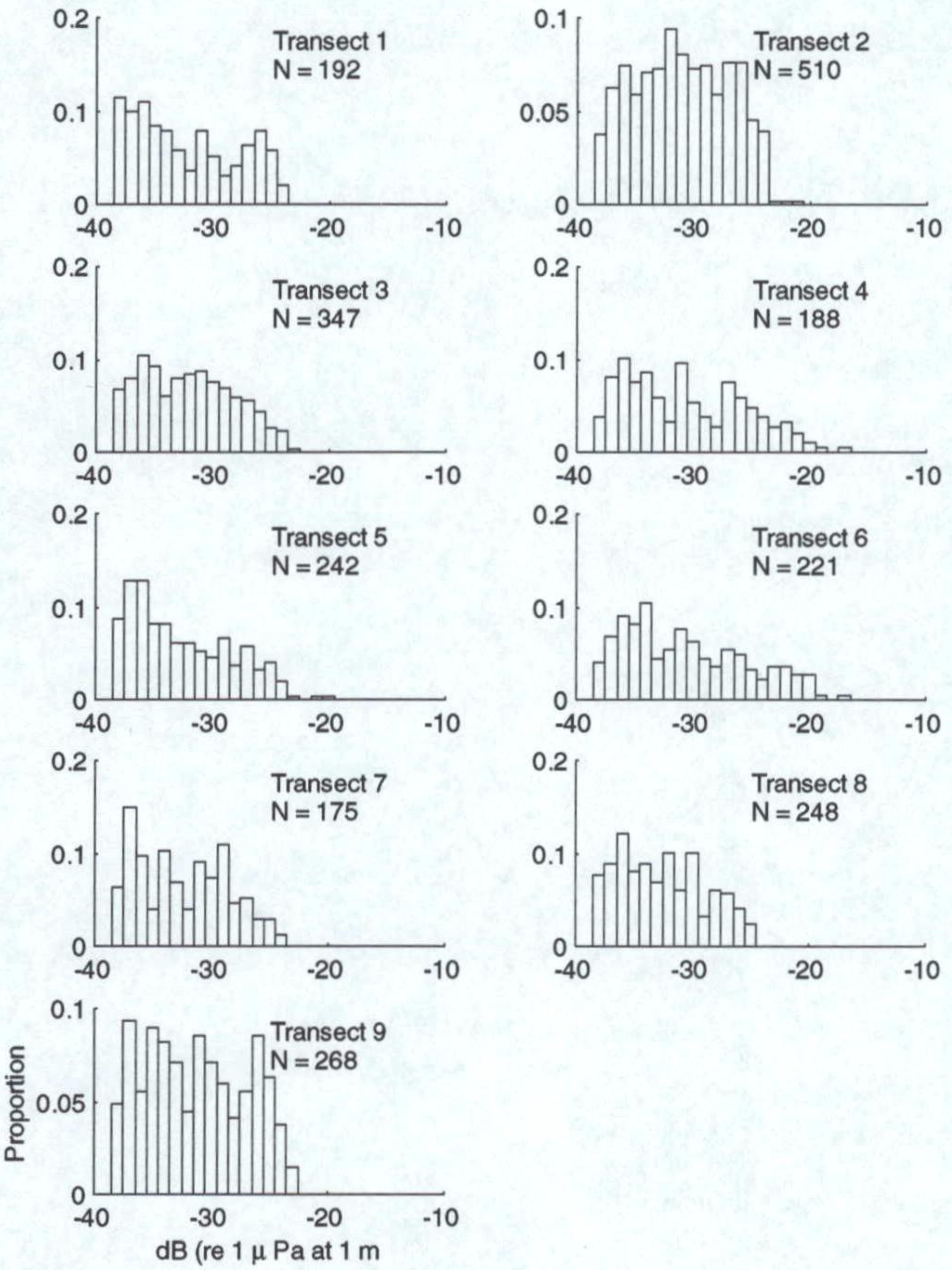

Figure 3: Target strength distributions from the nine transects shown in Figure 2.

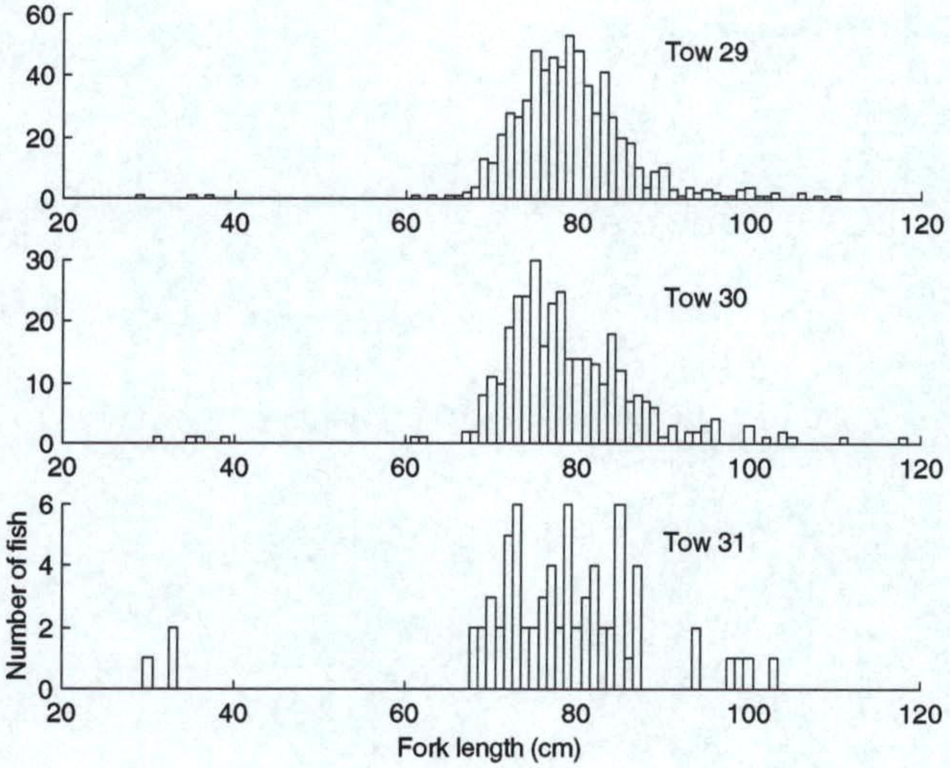

Figure 4: Hake length distribution from the three tows carried out on the spawning hake aggregation. Tows 29 and 30 used a bottom trawl, while tow 31 used a midwater trawl, all towed along the bottom.

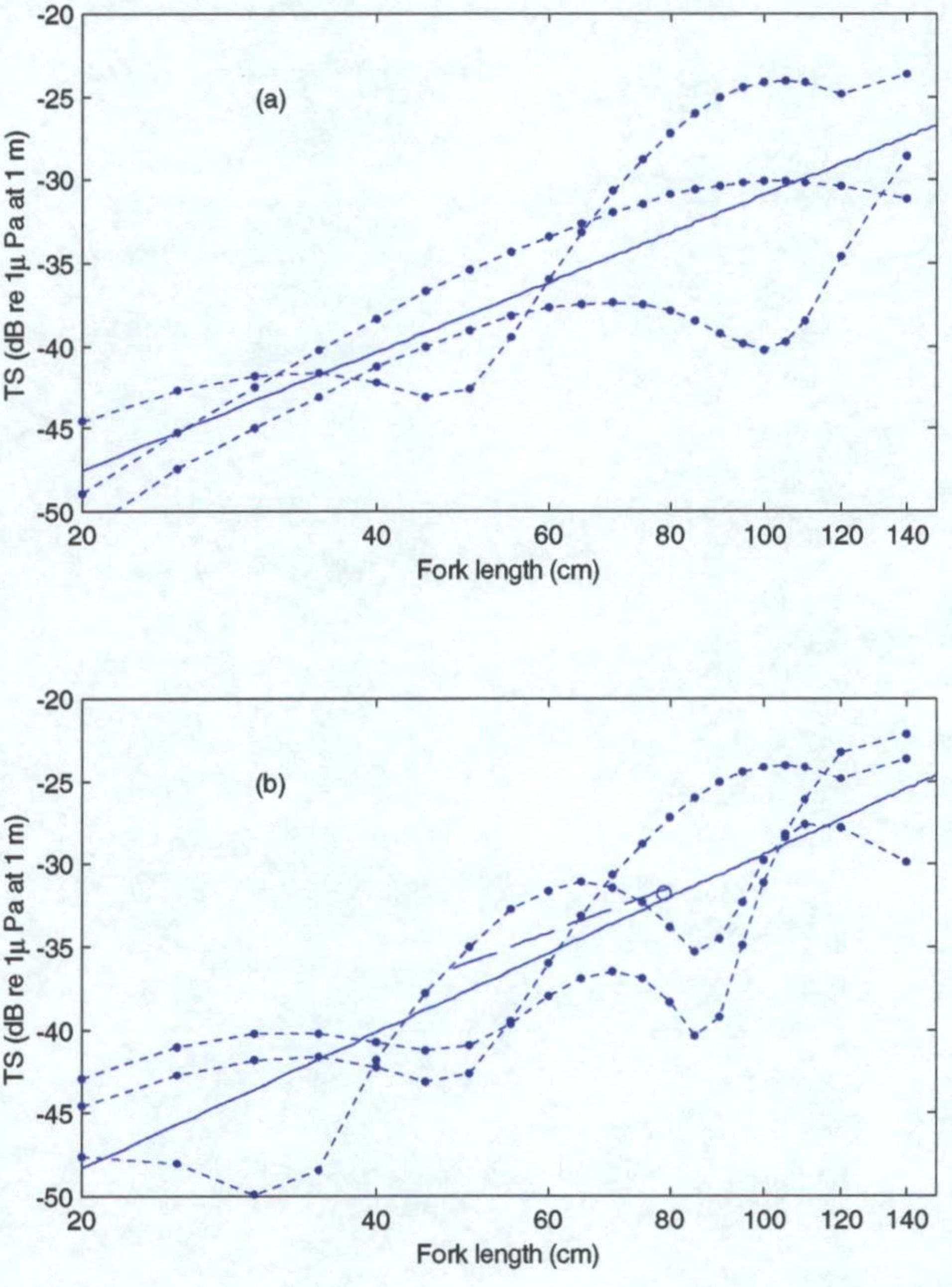

Figure 5: The target strength/fork length data obtained from swimbladder modelling and *in situ* data. The dashed curves and dots are from scaled swimbladders. The dashed line is from Lillo (1996), and the circle is the *in situ* point. The solid lines are regressions fitted to the swimbladder and *in situ* data. Part (a) contains results for 12 kHz, and (b) contains results for 38 kHz.

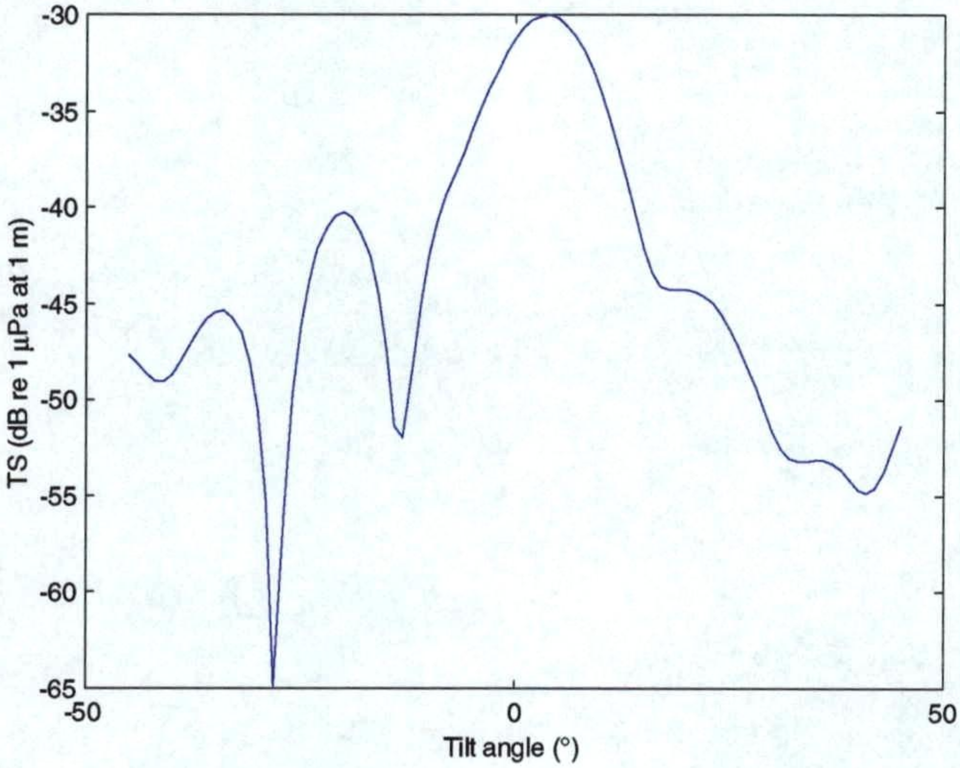

Figure 6: An example of the TS/tilt relationship obtained from the hake swimbladder modelling. Positive tilt angles correspond to a fish head up attitude.

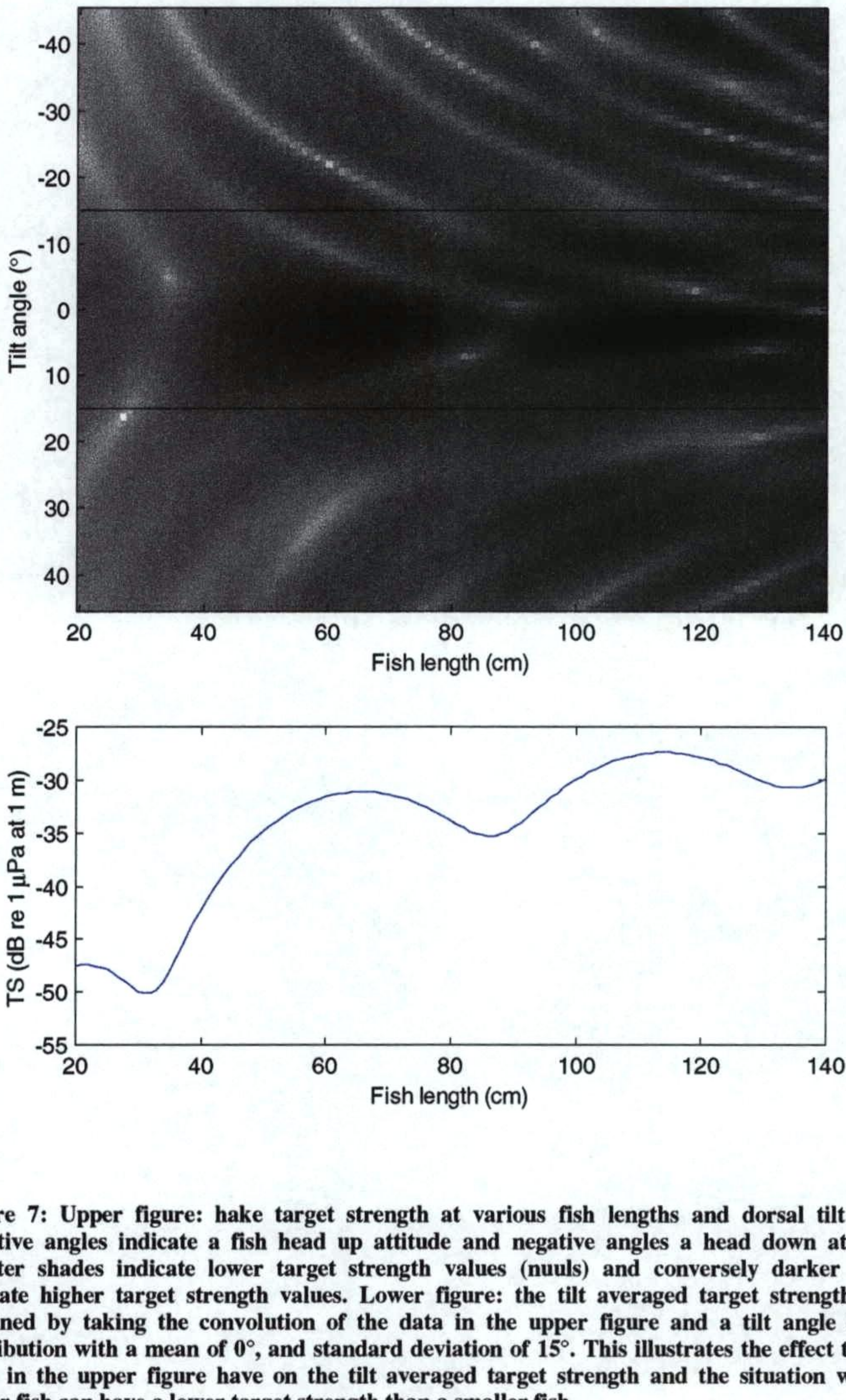

Figure 7: Upper figure: hake target strength at various fish lengths and dorsal tilt angles (positive angles indicate a fish head up attitude and negative angles a head down attitude). Lighter shades indicate lower target strength values (nuuls) and conversely darker shades indicate higher target strength values. Lower figure: the tilt averaged target strength curve obtained by taking the convolution of the data in the upper figure and a tilt angle normal distribution with a mean of 0°, and standard deviation of 15°. This illustrates the effect that the nulls in the upper figure have on the tilt averaged target strength and the situation where a larger fish can have a lower target strength than a smaller fish.