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Abstract

Relative fish densities obtained simultaneously from demersal trawls and echointegration are compared. The data was taken during a deepwater demersal trawl survey of southeastern Australian waters. Trawl catches were dominated by deepwater sharks which subsequently proved to have the main influence on the multiple regression analysis of the acoustic and catch data. Overall there was a poor correlation between trawl and acoustic data which we attribute at least partially to the high degree of heterogeneity in the species composition. There were limitations on the acoustic data, due mainly to the use of a single-beam system and a lack of any target strength information for the species concerned. However, the results suggest that it may be possible to use acoustics to both identify single species schools and to estimate the biomass of demersal deepwater fish stocks in a multispecies fishery. The results also suggest that the published mean target strength figure for orange roughy is too high.

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Contents

Introduction

Comparable acoustic and net sampling estimates of demersal fish densities from laboratory and shelf water (100 m) studies using a dual-beam transducer was reported by Dickie *et al* (1984). Species classification of schooling fish was deemed possible using acoustics in areas of low species diversity by Rose and Leggett (1988), yet differentiation between species in a multispecies fishery has yet to be determined.

A reliable comparison of acoustic and trawl based estimates of fish densities would enable researchers to better utilize acoustics in large scale deepwater fish surveys, possibly increasing the effectiveness and efficiency of the surveys. Regular sampling by trawling during the survey would still be required to obtain species composition and fish sizes.

The objective of this study was to compare the results from acoustic transects with trawl catch data obtained from demersal tows over the same area. The study was undertaken as part of the 1989 CSIRO random deepwater trawl survey for orange roughy (*Hoplostethus atlanticus* Collett 1889) on the continental slope (800 - 1199 m) in southeastern waters of Australia (Bulman *et al* 1994). The area surveyed consists of a multispecies fishery with large aggregations of orange roughy dominating the fishery in various areas and at certain times of the year.

Target strength values for the species present in this Australian multispecies deepwater fishery have yet to be obtained. Thus reliable acoustic estimation of fish density is not possible in this study. Likewise, reliable density estimates using the trawl net are subject to numerous errors in relation to the volume of water swept by the trawl gear. Wing spread and mouth opening can be monitored during a trawl but there is considerable variance in these during the tow depending on towing and bottom conditions. Catchability, or behaviour towards the trawl gear, of the deepwater species in this fishery is also unknown. Therefore in this study we aimed to standardize our sampling procedures in order to minimize the effects of some of these uncertainties, and attempted to compare estimates of relative fish densities as sampled by the two independent procedures.

Materials and Methods

Equipment

The trawling and acoustic measurements were conducted from the FRV *Soela* (Table 1). An Engel high-rise bottom trawl was used throughout the survey, rigged for rough bottoms with no lower wings (Table 2).

A Simrad EK400 scientific echo-sounder was coupled to a 38 kHz (Simrad 38-29/25-E) hull-mounted transducer and a modified BioSonics 121 echo-integrator. The system configuration is shown in Figure 1. A modified TVG amplifier was designed to cover the depths and water absorption ranges of concern in this study. A Furuno 50 kHz/75 kHz net recorder was used on all trawls, to provide information on headline height above bottom, and actual net-time on the bottom.

Survey positions

The area covered by the depth-stratified random trawl survey was from south of Kangaroo Island (136°E) to the northeast coast of Tasmania (148°E) (Figure 2). The continental slope between 800 m and 1199 m (7,165 km^2) was divided into four 100 m depth strata and survey positions were randomly allocated in each at a rate of 1 per 30 km^2. The number of positions was allocated in proportion to the area within each stratum, all ground was assumed trawlable and the abundance and degree of aggregation of fish was assumed to be the same in all strata (Bulman *et al.* 1994). Three cruises were conducted in order to complete the survey - SO1/89 (January - February), SO2/89 (March) and SO3/89 (April - May).

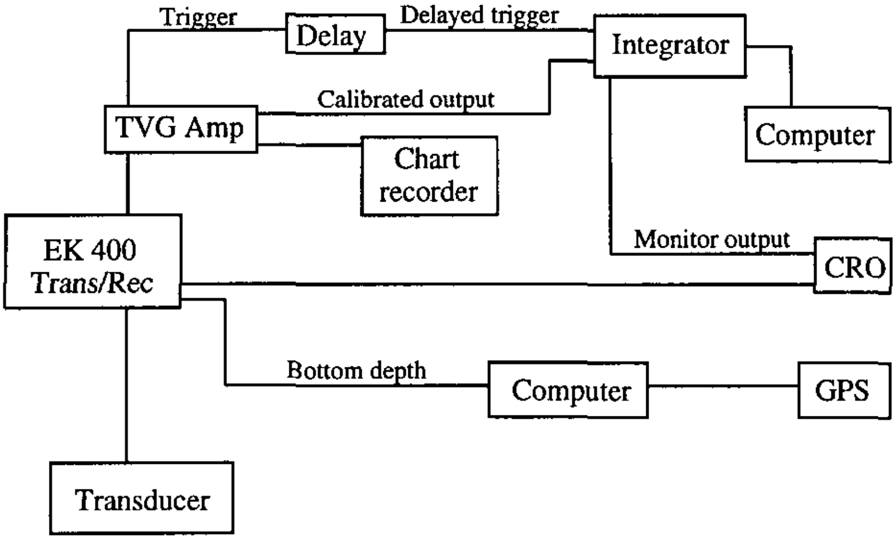

Figure 1: Configuration of acoustic system on the FRV *Soela* used during the survey.

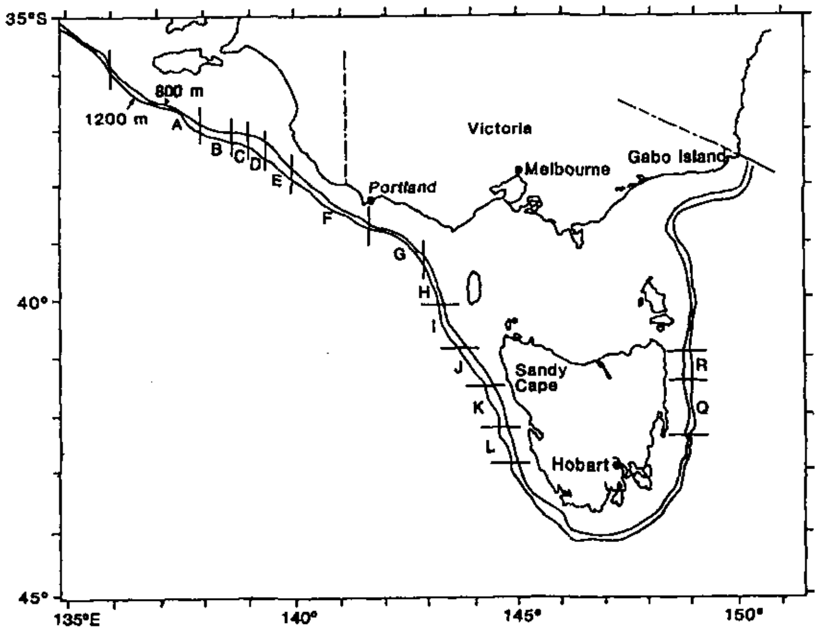

Figure 2: The South East Trawl area of Australia surveyed by the CSIRO in 1989.

Table 1: Details of FRV *Soela* used for this survey.

FRV *Soela*:	stern trawler built in 1963
LOA:	52.8 m
Beam:	9.5 m
Draft:	4.9 m
Displacement:	500 tons
Power:	2 Deutz diesel engines of 900 b.h.p. supplying power to 2 Siemens electric propulsion motors each of 515 kW; controllable pitch propeller
Winches:	2 automatic spooling winches with 2600 m of 24 mm trawl wire
Trawl doors:	Polyvalent, each door 800 kg + 200 kg
Navigation:	Trimble 10X Navigator global positioning system and Magnavox MX 1105 Satellite navigator; Taiyo TP-C10 colour course plotter, Taiyo TP-R14 data recorder and an Epson LX-86 printer.

Table 2: Details of Engel high-rise bottom trawl used throughout this survey.

Headline:	35.5 m
Footrope:	50 m, 16 m chain on each wing, bosom with rubber bobbins
Wings:	rigged flying; mesh only attached to ground rope in the bosom
Bridles:	upper and lower - 50 m wire no sweeps
Mesh size:	180 mm to 100 mm
Codend mesh size:	90 mm with 40 mm liner of knotted 400/60 twine in final 2 m
Wing spread:	av. 19 m wingtip-to-wingtip (53.5% of headline length) measured by Scanmar net monitoring system in depths of 400-500 m at vessel speed of 2.5 knots.
Net opening:	3 - 5 m (recorded by headline monitoring unit).

Station data

Station logs for each occupied survey position recorded such details as position and time at completion of paying out trawl gear, time of net reaching bottom, position and time of net leaving bottom, wind direction and force, direction and height of sea and swell, vessel speed, direction of tow, and net headline height above bottom.

Catch data

Demersal tows of 30 minutes bottom time duration were attempted at each survey position. Actual time on bottom for the net was recorded using the headline net recorder. Tows of less than 15 minutes bottom time were not included in calculations. The total catch from each tow was sorted and weighed, by nine major catch components, these being:

Roughy (*Hoplostethus atlanticus*)
Morids (e.g. *Mora moro, Halargyreus johnsonni*)
Macrourids (e.g. *Lepidorhynchus denticulatus, Coelorinchus* spp. and *Coryphaenoides* spp.)
Dories (e.g. *Neocyttus rhomboidalis, Allocyttus verrucosus*)
Eels (e.g. *Diastobranchus* sp.)
Sharks (e.g. *Deania calcea, Centroscymnus* spp.)
Slickheads (*Alepocephalus* spp.)
Other commercial species (e.g. *Macruronus novaezelandiae)*
Others.

For each station the trawl catch was standardized by conversion to a catch rate. Two catch rates were calculated - catch per time (of net on the bottom) expressed as kg per hour, and catch per swept area of the tow expressed as kg per km^2.

The swept area was calculated from:

swept area = speed of tow(knots) x 1,852 (m per nm) x tow duration (bottom time, mins) x 1/60 x 19 (ave. wing spread in m).

A biomass estimate for each catch component for the area surveyed was obtained from the product of the mean catch rate and area surveyed. It was assumed in calculating these estimates that the accessibility of the fish to the net was 100% and there was no escapement or avoidance by fish from the effective path swept by the net, which was equal to the measured wing spread.

Acoustic theory

The application of acoustic methods to abundance estimates of fish is summarized by Johannesson and Mitson (1983). An appropriate acoustic pulse is transmitted through the water column and the corresponding echo recorded. A 'time-varied-gain' (TVG) amplifier applied to each returned echo compensates for the spreading and absorption loss of the acoustic pulse in the water column. The amplitude of the returned signals therefore is independent of the range of the target from the transducer. The strength of the returned echo is termed the volume backscattering strength (Sv, in dB re 1μPa), and is defined as the proportion of incident acoustic energy reflected back towards the transducer by targets within a unit volume of water. It is related to the voltage measured across the transducer by the logarithmic equation:

$$Sv = VRT - (SL + SRT + G) - 10 \log (c\tau/2) - 10 \log\psi + (20 \log R + 2\alpha R) \qquad \mathbf{1}$$

where,

VRT = voltage measured across transducer (20 log V in dB re 1 volt)
SL = source level (dB re 1μPa)
SRT = receiving sensitivity of transducer (dB re 1 volt μPa^{-1})
G = gain constant of system
c = sound velocity (m s^{-1})
τ = pulse length (ms)
ψ= two-way equivalent beam width of transducer (steradian)
R = range from transducer to target volume (m)
α = absorption coefficient of sound in water (dB m^{-1})
(modified from Johannesson and Mitson 1983).

The values for SL, SRT and G were determined from calibration data. The absorption coefficient and the speed of sound in sea water were calculated using data obtained from CTD casts conducted at regular intervals during the survey and using the formulae of Francois and Garrison (1982a, b) for α and MacKenzie (1981) for c. The two-way equivalent beam width, ψ of the transducer was obtained from the specification sheet with a possible deviation of ± 1.1 dB. Calibration of the acoustic system was performed on three occasions (at the start, mid-way through and at the end of the survey) using a standard 60 mm copper sphere and the method described by Foote *et al.* (1987). Calibrated system parameters and EK400 settings used during the survey are presented in Table 3.

The output signal from the sounder is passed to an echo-integrator where the mean volume backscatter strength (MVBS, in dB re m^{-1}) is obtained by integrating Sv over a number of predetermined transmissions and in a number of predetermined depth layers. MVBS is proportional to the mean number of organisms in the volume insonified (n_V, in fish m^{-3}):

$$MVBS = 10 \log n_v + TS \qquad \mathbf{2}$$

where TS is the mean target strength of the individual organisms (dB re m^2). The target strength of an organism is the ratio of the reflected (echo) intensity at 1 m from the organism to the incident intensity which strikes it. The target strengths of fish are proportional to their back scattering cross-section and body length.

The relationship between target strength and fish size is a complex relationship and dependent upon fish behaviour and species specific factors such as morphology and presence or absence of a gas filled swimbladder. Two standard equations relating target strength to fish length and wavelength (l) are provided in Johannesson and Mitson (1983):

Love (1971)	TS = 19.1 log (length, m) + 0.9 log l - 23.9
McCartney and Stubbs (1971)	TS = 24.5 log (length, m) - 4.5 log l - 26.4.

Table 3: Calibrated acoustic system parameters and EK400 settings used throughout the survey. (G is gain constant)

System parameter	Symbol	Calibrated value/setting
Operating frequency		38 kHz
Beamwidth (-3 dB full angle)		8/8 uncalibrated
Ideal beam angle	$10 \log\psi$	-19.6 dB
Attenuation constant	α	9.3 dB km^{-1}
Source level	SL	194.9 dB re 1μPa at 1 m
Receiving sensitivity	SRT	-178.9 dB re 1 V (μPa)$^{-1}$
Pulse length	τ	3 ms
Receiver bandwidth		1 kHz
Power		High
Mode		Dynaline
Main range		7
Gain (Sub Bottom Gain)		6 (6)
Sound Speed		1498 m sec^{-1}
TVG		20 log R
Calibration parameters	SL+SRT+G	67.9 dB

Acoustic data

Echo-integration was performed over eight consecutive acoustic pings and in 25 two metre depth-layers above the bottom window. The bottom window is the depth interval around the last known bottom depth within which the sounder searches for the next bottom echo. A bottom window of either 4, 6 or 8 m was programmed into the integrator depending on the perceived changes between successive signals of the bottom depth; thus the depth of the bottom layer was either 2, 3 or 4 m.

Integration of the acoustic signal was performed at each survey position from the time of shooting the trawl gear to the time of hauling. A 30 minute time period (approximately 96 integrated intervals) of relatively constant vessel speed was later selected for analysis.

Ambient noise measurements were recorded with the transducer in passive mode at each station. The maximum noise measured referred to 900 m (the average bottom depth) was -85.9 dB (= 3.16 x 10^{-4} $V_{TVG}{}^2$). Maximum noise has been allowed for in all data analyses.

Two factors affecting the accuracy of the acoustic data must be considered due to the water depth and slope of the bottom experienced during the survey.
Firstly, the dead zone, caused by the geometry of the acoustic beam, which exists close to the sea bed and within which no target detection is possible.The closest point to the sea bed at which detection/estimation of fish is possible is equivalent to half the physical length of the transmitted pulse ($c\tau/2$; Johannesson and Mitson 1983), which in this study was 2.25 m. This is the minimum height of the dead zone at the axis of the transmitted beam, the height increasing with increasing angle from the axis, and with increasing slope of the sea bed. This source of error has been disregarded in the following analyses as it was variable along each station transect and there was no information available for estimating either the extent of the zone or the fish density in the zone.

The second factor concerns the elimination during data processing of false bottom echoes. This was achieved by both simultaneous visual evaluation of the echograms and the integration data, and via the following routine. Maximum change in voltage recorded between successive mid-water integrated layers was found to be less than a factor of five (in V_{TVG}^2). Bottom layer data were then discarded if there was a greater than five-fold increase in voltage between bottom layer and the layer above.

The output data from the echo-integrator consisted of the mean square value of the voltage measured at the transducer following TVG compensation (V_{TVG}^2). The average V_{TVG}^2 during the selected 30 minute interval, with noise and bottom effects removed, was then calculated for individual depth layers and for combinations of depth layers for each station; these were then converted into MVBS using Equation 1 and the system parameters shown in Table 3.

Comparison of trawl and acoustic data

Direct comparison of trawl-densities with acoustic-densities is not feasible, despite the simultaneous collection of the acoustic (hull mounted) measurements while the vessel was trawling. This is due to the problems associated with both methods as described above, and due to the uncertainty of the position of the trawl gear in relation to the vessel's path. The trawl gear when 1800 m to 2600 m of warp is paid away is likely to be out to one side of the vessel's path depending on wind, sea, current and tidal influence. Rather the relative fish density in the area as provided by each procedure is compared.

The degree of linear relationship between the acoustic data, expressed as MVBS in dB, and the trawl data, expressed as catch rate in kg/hr, was analysed using the correlation coefficient. The total catch rate and the catch rate for each catch component were analysed with the mean MVBS from individual integrated depth layers and combinations of depth layers for each station. The distribution of the catch rate data was found to violate the assumption of normality and so the data were subjected to logarithmic transformation which provided normality, i.e. normal statistics were applied to log(X) or log(1+X), where X is the observed catch rate. As each component of the catch, due to different acoustic properties in terms of target strength, was likely to have a unique effect upon the MVBS at each station the data were further analysed using a multiple regression model. This model assumes that the individual catch rates may predict more variance collectively than each could predict independently of the others. A forward stepwise regression model was also used in the analyses. This model attempts to produce the most efficient regression equation with the smallest number of variables (catch rates), while predicting as much of the variance of the MVBS as possible from the combination of individual catch rates.

Results

177 random stations were occupied during the survey; of these 153 were valid stations for this study. A valid station was one at which both a demersal tow and echo-integration of the near bottom water column were performed. Of the 24 invalid stations, 14 were due to aborted shots, gear damage, or the net fishing incorrectly, 9 had no acoustic data, and one was deleted with corrupt acoustic data due to ship movement in a swell of 3-4 m.

Trawl data

Orange roughy was the dominant species caught with a total of 13,931 kg out of a total catch of 43,338 kg from the 153 trawls (Table 4). However, 69% of this orange roughy catch was taken in only four trawls. Sharks were the dominant species group in the survey , representing a mean 23% of each catch (Table 5). The sharks were the main component in 50 tows, with the dories the main component in a further 40 (Table 6). The macrourids were the only catch component present in all tows, and were the main component in 22.

A single catch component made up more than half of the total weight in 22% of the tows. These comprised the four large catches of orange roughy, plus 15 dominated by sharks, 13 by dories and one each by eels and macrourids (Table 7). Biomass estimates for the area surveyed for each catch component and overall are shown in Table 8. The confidence limits on the total biomass estimate were 29%, while for individual catch components estimates it ranged from 83% for the orange roughy to 15% for macrourids and 21% for the sharks.

Sharks were the dominant component of the catches only in tows made in the 800 m and 900 m depths, with the dories predominating in the deeper tows (Tables 5 and 6). The sharks constituted an average of 42% of each catch in the 800 m depths and 28% in those taken in the 900 m depths, but only 8 to 11% in deeper tows. Dories made up an average of 27% of each catch in the 1,000 m depth zone and 23% in the 1,100 m zone. Eels were also more prevalent in the deeper tows comprising 22% of each catch in the 1,100 m depths. The macrourids and orange roughy were relatively consistent components of all catches at all depths (16% and 14% respectively).

Individual trawl catch rates covered three orders of magnitude, ranging between 14 to 11,250 kg per hour bottom time. Of the 153 tows, 66% had catch rates of less than 500 kg/hr, and 88% less than 800 kg/hr. 29% of catch rates were between 150 to 300 kg/hr and a further 20% between 400 to 500 kg/hr. The four highest catch rates (all > 2,000 kg/hr) were for the orange roughy dominated catches. Two other tows had a catch rate greater than 1,000 kg/hr, one dominated by a combination of dories and sharks and the other dominated by a combination of sharks and orange roughy. Of the 40 highest catch rate stations (>600 kg/hr), sharks were the main species in 19, dories in 10 and roughy in 6. The mean catch rates shown in Table 4 again demonstrate the dominance of sharks in the catches from the 800 m and 900 m depth zones, with an increase in the presence of dories and eels in the two deeper zones.

Low, but significant ($p<0.001$) correlations were found between the catch rates (with log(1+X) transformation) of the individual catch components. The highest positive correlation was 0.49 for shark and morid catch rates, with other relatively high coefficients for slickheads and eels (0.43), and sharks and roughy (0.41). A relatively high negative correlation of 0.55 was obtained for shark and eel catch rates, and 0.47 for morid and eel catch rates.

No day/night variation was observed for catch rates.

Table 4: Total catch (kg) and catch rates (kg/hr) overall and by bottom depth zone for each catch component. Bracketed figures are those when large orange roughy dominated catches are removed (four from Total, two from 800 m, and one each from 1,000 and 1,100 m).

Component	Total Catch (kg)	Catch rate (kg/hr)				
		Total	800 m	900 m	1,000 m	1,100 m
Roughy	13,931	194 (59)	462 (71)	53	121 (62)	126 (45)
Sharks	8,818	118	239	121	62	36
Dories	7,097	97	33	61	179	103
Macrourids	5,247	69	87	60	75	47
Eels	3,379	45	2	21	78	84
Morids	1,796	24	47	21	13	12
Slickheads	1,789	24	8	16	29	48
Other Comm	185	2	8	2	0	0
Others	1,096	15	16	13	15	14
Total	43,338	558 (439)	901 (514)	368	573 (492)	471 (352)
No. Stns	153	153	40	38	46	29

Table 5: Mean percentage of each catch component per trawl, overall and by bottom depth zone of the trawl.

Component	Mean percentage per trawl				
	Total	800 m	900 m	1,000 m	1,100 m
Roughy	14.9	16.4	14.0	14.3	14.7
Sharks	22.8	42.3	28.0	10.8	8.0
Dories	18.7	7.5	17.0	26.9	23.3
Macrourids	16.0	16.7	17.1	16.7	12.4
Eels	11.6	1.0	7.3	17.5	22.3
Morids	5.8	8.9	7.0	3.4	3.7
Slickheads	5.6	1.7	4.0	6.3	11.8
Other Comm	0.7	2.0	0.6	0.8	0.0
Other	4.0	3.4	5.0	3.8	3.8

Table 6: Number of trawls in which each catch component was the main component of the catch, for all stations and by bottom depth zone.

Component	Number of Trawls				
	Total	800 m	900 m	1,000 m	1,100 m
Roughy	20	5	3	8	4
Sharks	50	30	19	0	1
Dories	40	1	6	21	12
Macrourids	22	3	7	10	2
Eels	14	0	0	7	7
Morids	1	0	1	0	0
Slickheads	3	0	0	0	3
Other Comm.	0	0	0	0	0
Other	3	1	2	0	0
Total no. trawls	153	40	38	46	29

Table 7: Number of trawls dominated (> 50% of catch) by single catch component, separated by catch rate (kg/hr).

Component	Catch rate kg/hr		
	≤ 500	500 to 1,000	≥1,000
Sharks	7	6	2
Dories	6	5	2
Orange roughy	-	-	4
Eels	1	-	-
Macrourids	1	-	-

Table 8: Mean catch rates (kg/km^2) and estimated biomass (tonnes) of each catch component in the area surveyed (7,165 km^2) in 1989. 95% confidence limits expressed as percentage.

Component	Catch rate (kg/km2)		Biomass (tonnes)		
	Mean	s.e.	Mean	s.e.	95% CL
Roughy	2,099	885	15,036	6,338	83
Sharks	1,291	136	9,251	977	21
Dories	1,073	146	7,689	1,048	26
Macrourids	758	59	5,432	424	15
Eels	518	49	3,711	352	19
Morids	261	29	1,869	208	22
Slickheads	272	27	1,949	195	20
Other Comm.	28	6	200	42	41
Other	167	18	1,194	132	22
Total	6,466	947	46,331	6,786	29

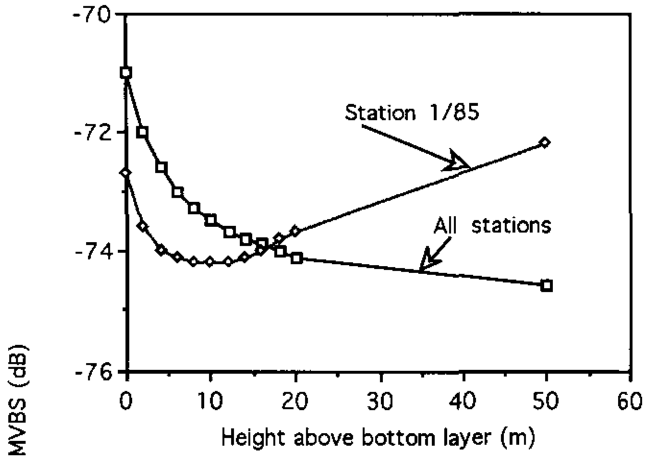

Figure 3a: Change in mean MVBS (dB) with change in water column height integrated above the bottom layer. Showing the general trend for all stations and Station 1/85, one of seven stations that differed from the general rule.

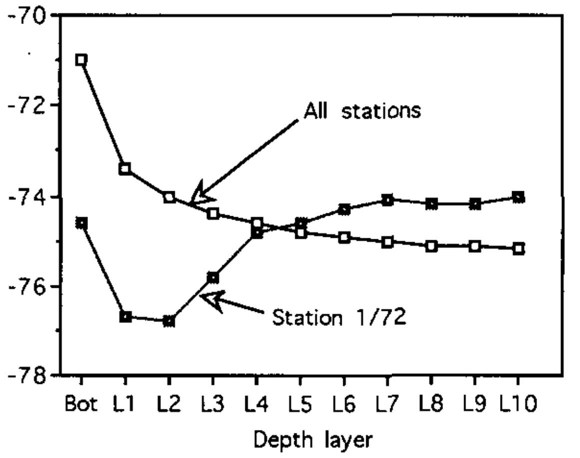

Figure 3b: Change in mean MVBS (dB) for each individual depth layer from the bottom up to 20 m above the bottom layer. Showing the general trend for all stations and Station 1/72, an example of the seven that differed to the general trend.

Bot - Bottom layer, L1 to L10 - 2 m depth intervals above the bottom layer.

Acoustic data

The highest MVBS value per integrated depth layer at all but seven stations was for the bottom layer. The other seven stations had maximum values for midwater layers such as Layer 10 (20 m above the bottom layer); there was nothing significant about the catches from these seven stations. The general trend, however, was for a decrease in mean MVBS with increasing water column height integrated above the bottom, as shown in Figures 3a and 3b. Stations at which sharks were the main component of the trawl returned significantly (ANOVA, $p = 0.0001$) higher mean MVBS than other stations. This difference was more pronounced in the midwater layers, rather than close to the bottom. Of the 30 stations with the highest MVBS values for the total depth integrated (56 m), 90% had sharks as the main component of the catch. For the 31 stations with the highest MVBS values in depths from the bottom up 20 m, only 64% had sharks as the main component, 18% had macrourids and 14% dories. Whilst of the 28 stations with highest MVBS in depths from the bottom up 4 m, only 54% had sharks as the main component, 16% had macrourids and 10% orange roughy.

The mean MVBS at each station, for the total depth integrated, ranged from -85.0 dB to -68.0 dB, with 41% of the stations having values between -77.9 dB and -75.0 dB. The mean V_{TVG}^2 for the total depth integrated for the 153 stations was 0.008496 (s.e. ± 0.000535), which converts to a mean MVBS of -74.6 dB (s.e. ± 0.3 dB). Other mean MVBS values for varying integrated depths are:

Bottom to layer 2 (8 m)	-72.6 (± 0.3) dB
Layers 1 to 2 (4 m)	-73.7 (± 0.2) dB
Bottom to layer 4 (12 m)	-73.3 (± 0.2) dB
Layers 1 to 4 (8 m)	-74.1 (± 0.2) dB
Bottom to layer 10 (24 m)	-74.1 (± 0.2) dB
Layers 1 to 10 (20 m)	-74.6 (± 0.3) dB
Layers 1 to 26 (52 m)	-74.9 (± 0.3) dB.

The mean V_{TVG}^2 at each station, for the entire depth integrated (56 m), was found to decrease with increasing bottom depth of the station (Table 9).

Table 9: Comparison of mean values (± s.e.) of trawl data (kg/hr) and acoustic data (Mean V_{TVG}^2, and MVBS, dB) by trawl depth strata. Acoustic data is for the total integrated depth to 56 m above the bottom.

Depth stratum	No Stations	Trawl data kg/hr	Acoustic data V_{TVG}^2	MVBS
800 m	40	900.9 ± 294.1	0.0141 ± 0.0013	-72.4 ± 0.4
900 m	38	368.2 ± 42.1	0.0092 ± 0.0010	-74.3 ± 0.4
1000 m	46	573.1 ± 91.5	0.0057 ± 0.0004	-76.3 ± 0.3
1100 m	29	470.7 ± 122.6	0.0041 ± 0.0006	-77.8 ± 0.5

Comparison of acoustic and trawl data

Correlation

Significant but low correlations (<0.35, $p<0.01$) were obtained between the mean acoustic values and the trawl catch rates per station, for any depth interval considered, and with log transformation of the data. The highest values recorded were for the greatest depth integrated.

The only relatively large correlation coefficient was for the correlation between the mean MVBS and shark component catch rates. The correlation coefficient for the MVBS of the total depth integrated and shark catch rate (with log(1+X) transformation) was 0.63, suggesting approximately 39% of the variance in the MVBS may be explained. The linear regression model (F = 98.35; DF = 1, 151; p = 0.0001) is:

$$\text{MVBS} = 3.30 \text{ Log}(1+ \text{Shark catch rate}) - 81.46.$$

The correlation between shark catch rate and MVBS increased with the depth off the bottom integrated. For example for the integrated depth from the bottom to 4 m above the bottom layer a coefficient of 0.42 was obtained, while for the depth from the bottom to 20 m above the bottom layer the coefficient was 0.57.

Figure 4 shows the general trend for an increase in total catch rate with increase in MVBS. Such a positive trend was shown by the individual catch rates of sharks (Figure 5a), morids and macrourids, while a negative slope was obtained for the catch rates of eels (Figure 5b) and slickheads. Catch rates for dories and orange roughy showed no variation with MVBS.

Very low (but significant, $p<0.01$) correlation coefficients between trawl and acoustic data were obtained for individual catch components when stations were grouped by depth interval; the highest catch component correlations per depth zone were:

800 m	40 stations	Sharks = 0.50
900 m	38 stations	Sharks = 0.61
		Orange Roughy = 0.54
1,000 m	46 stations	Macrourids = 0.36
1,100 m	29 stations	Macrourids = 0.49

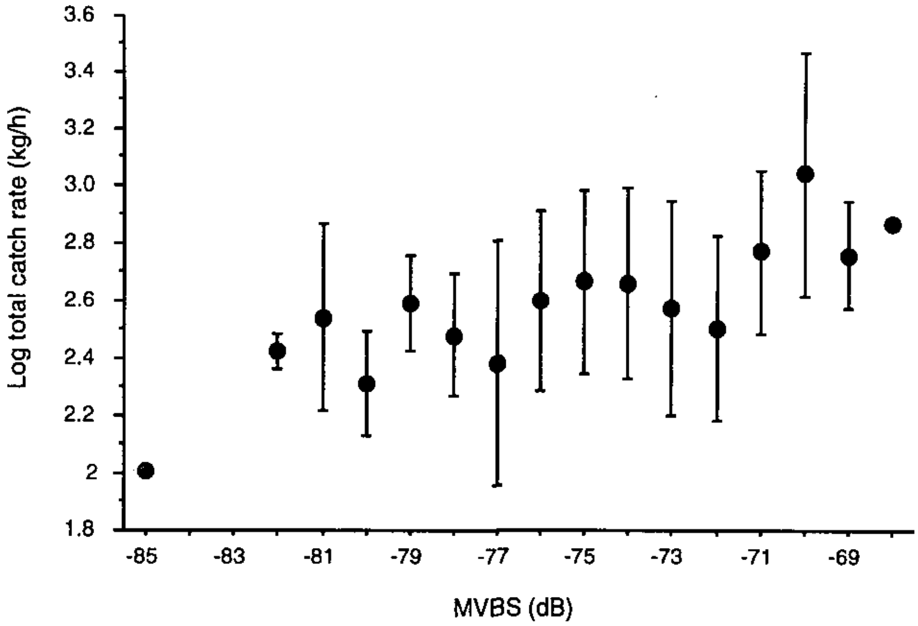

Figure 4: Change in log total catch rate (kg/hr) with change in MVBS (dB) for total volume integrated (56 m), showing mean and one standard deviation for each one dB range for all 153 stations.

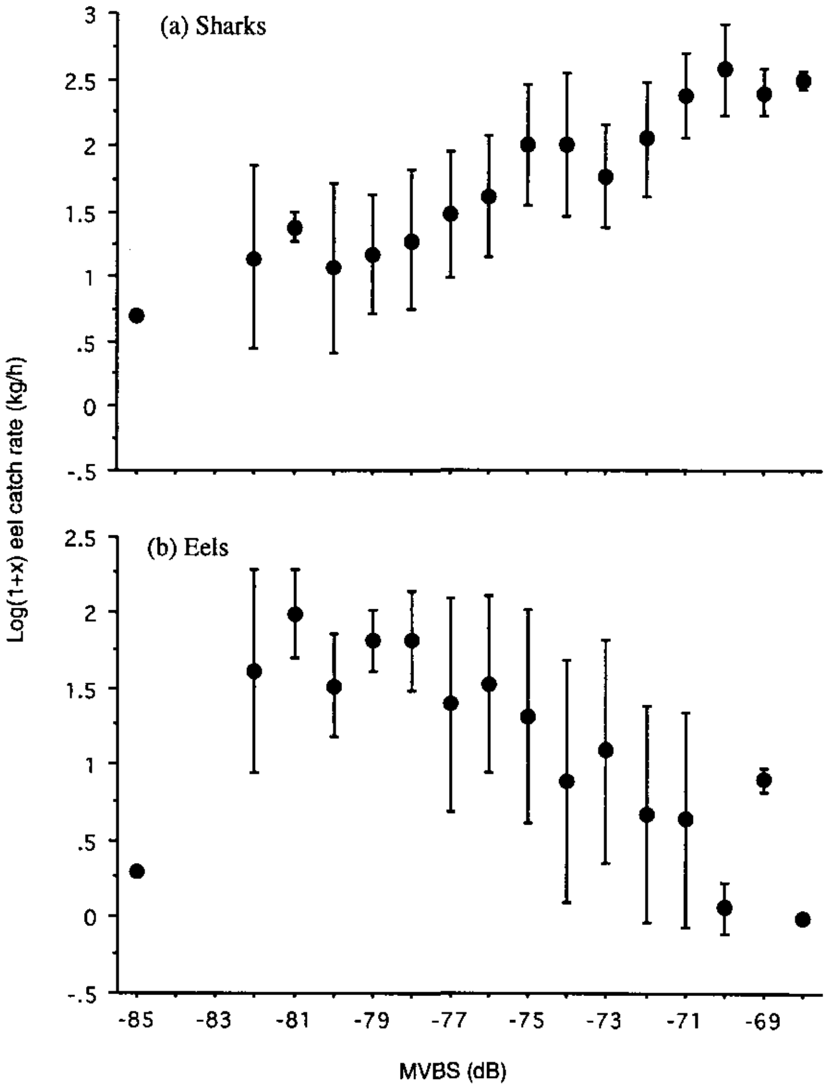

Figure 5: Change in individual catch component catch rates (kg/hr) with change in MVBS (dB), for a) sharks and b) eels. Mean and one standard deviation per one dB range shown for all 153 stations.

Multiple regression model

The multiple regression model for the individual catch rates (log(1+X) transformed) of the nine catch components with the mean MVBS for the full depth integrated (56 m) accounted for a statistically significant portion of the variance (F = 18.53; DF = 9, 143; p = 0.0001). The adjusted R-squared value indicated approximately 51% of the variance was accounted for by the regression model. Whilst the mean MVBS for the other combinations of integrated depth layers returned significant (p = 0.0001) multiple regression models, the proportion of variance accounted for was not as high as that returned for the full depth integrated; the proportion accounted for increased with the depth integrated. For example, compared to full depth integrated:
MVBS bottom to Layer 2 (Bottom layer plus 4 m), F = 5.04;
DF = 9, 143; P = 0.0001; adj. R-squared = 0.19.
MVBS bottom to Layer 10 (Bottom layer plus 20 m), F = 12.23;
DF = 9, 143; P = 0.0001; adj.R-squared = 0.40.

For the mean total (depth integrated 56 m) MVBS multiple regression model the following component catch rate (log(1+X) transformed) coefficients were significant:

Sharks	p = 0.0005
Eels	p = 0.0044
Dories	p = 0.0075
Morids	p = 0.0104.

The general regression equation from the model was:

$$\begin{aligned} \text{MVBS} = {} & 1.64Sh - 1.08E + 0.85D + 1.06Mo + 0.06R + \\ & 1.06Mac + 0.69C - 0.46Sl + 0.10Ot - 81.33 \end{aligned}$$

where: Sh = sharks, E = eels, D = dories, Mo = morids, R = roughy,
Mac = macrourids, C = other commercial, Sl = slickheads, and Ot = others.

The stepwise regression model for total MVBS and the nine component catch rates (log(1+X) transformed) gave the following results:

Step 1. variable entered - Sharks adj. R-squared = 0.39
F = 98.35 DF = 1, 151 p = 0.0001
Regression equation:
MVBS = 3.30Sh - 81.46

Step 2. variable entered - Eels adj. R-squared = 0.45
F = 63.03 DF = 2, 150 p = 0.0001
Regression equation:
MVBS = 2.55Sh - 1.19E - 78.68

Step 3. variable entered - Macrourids adj. R-squared = 0.48
F = 47.98 DF = 3, 149 p = 0.0001
Regression equation:
MVBS = 1.96Sh - 1.50E + 1.64Mac - 80.04

Further steps did not explain significantly any more of the variance.

Single catch component stations

While shark and dory dominated stations (i.e. > 50 % of catch) had similar catch rates (mean ± se, 578.3 ± 68.8 kg/hr and 666.6 ± 118.6 kg/hr, respectively), the dory dominated stations had significantly (p = 0.0001) lower total MVBS values (mean ± s.e.: -72.1 ± 0.5 dB and -76.7 ± 0.9 dB respectively) (Figure 6). Figure 6 also shows that the four roughy dominated stations had catch rates an order of magnitude higher (mean ± se, 6.133.7 ± 1733.1 kg/hr), yet the MVBS values (mean ± s.e. -73.5 ± 1.3 dB) were not significantly different to those for the shark dominated stations, and only significantly higher than dory dominated stations at p = 0.03.

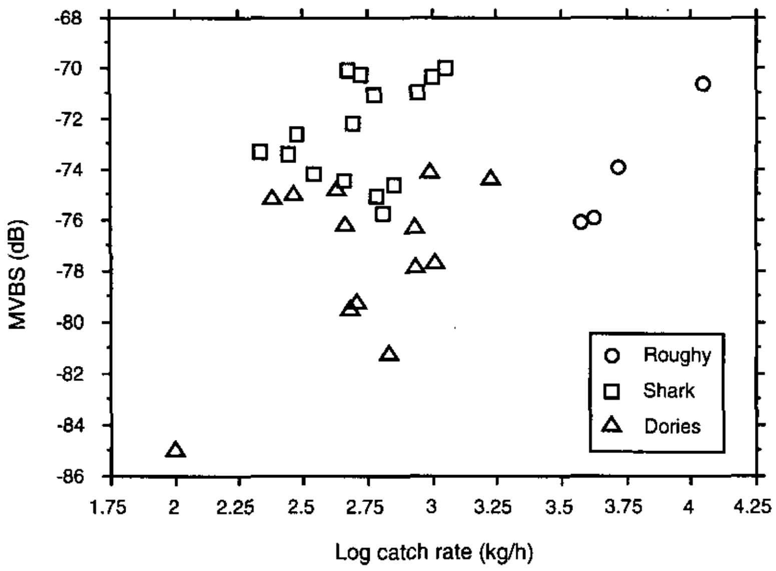

Figure 6: Mean MVBS values (dB) and catch rates (kg per hour) for the single species dominated stations, showing the differentiation between the three species. (sharks, dories, and orange roughy)

Target strengths

Orange roughy

Orange roughy made up 95% and 96% of the total catch from two stations in this survey. An estimate of the density of orange roughy at each of these two stations (assuming 100% orange roughy) was obtained by applying a mean target strength for orange roughy of -36 dB (Do and Coombs 1989) and the mean MVBS obtained at each of these two stations into equation 2 above (MVBS = 10 log n + TS). Such estimates (fish m^{-3}) using various integrated depths, as well as the trawl based estimates of density in kg m^{-3} and fish m^{-3} at the two stations are presented in Table 10. The trawl based estimates in fish m^{-3} were obtained using a mean weight per orange roughy, as measured from these two trawl catches, of 1.6 kg. The ratios of fish density as measured by the trawl to that measured by acoustics are also shown in Table 10.

Whilst the acoustically obtained fish densities are lower than the trawl based densities, they do show an equivalent ratio between the two stations. The closest estimate of fish density between the two procedures was obtained using the entire integrated depth of 56 m, and assuming the trawl sampled with 100% efficiency a depth equal to 56 m above its swept area. Even then there is a factor of four difference.

To increase the acoustic densities, either the mean target strength must be lower or the mean MVBS higher. Two factors were noted above that may influence the mean MVBS calculations, however both would tend to increase the value rather than decrease it. Therefore it appears that the mean target strength of -36 dB for the orange roughy suggested by Do and Coombs (1989) may be too high.

Of course two other possibilities also exist in that the fish were predominantly near the bottom and within the dead zone, and/or the fish were within an area sampled by the trawl gear but not passed over by the acoustic equipment.

A mean target strength value for the fish at a particular station can be obtained by applying the trawl based density and MVBS (for the full 56 m integrated) for that station into equation 2 above (TS = MVBS - 10 log n). The results for the two stations with 95% and 96% orange roughy, provided mean target strengths for this species of -41.4 dB and -42.1 dB, respectively. These calculations assume the efficiency and swept volume of the trawl as discussed above, the catch was 100% orange roughy and an average weight per fish of 1.6 kg.

Table 10: Comparison of density estimates of orange roughy obtained from trawl and acoustic data for two stations in which orange roughy dominated the catch. Four volumes of assumed trawl influence are examined. Average weight per fish, measured from trawl catches, is 1.6 kg. Ratio T/A is the ratio of fish density measured by the trawl to that measured by acoustics.

	Station 3/16	Station 3/27
Total catch (kg)	2630	5625
% orange roughy	95	96
Swept area (m^2)	52,782	43,985
Area density (kg m^{-2})	4.98×10^{-2}	12.79×10^{-2}
Depth integrated - 56 m (bottom window plus 26 layers)		
Mean MVBS (dB)	-73.9	-70.6
Acoustic density (fish m^{-3})	1.62×10^{-4}	3.47×10^{-4}
Trawl density (kg m^{-3})	8.90×10^{-4}	2.28×10^{-3}
Trawl density (fish m^{-3})	5.56×10^{-4}	1.43×10^{-3}
Ratio T/A	3.43	4.12
Depth integrated - 6 m (bottom window plus layer 1)		
Mean MVBS (dB)	-70.9	-68.9
Acoustic density (fish m^{-3})	3.24×10^{-4}	5.13×10^{-4}
Trawl density (kg m^{-3})	8.30×10^{-3}	2.13×10^{-2}
Trawl density (fish m^{-3})	5.19×10^{-3}	1.33×10^{-2}
Ratio T/A	16.02	25.93
Depth integrated - 12 m (bottom window plus 4 layers)		
Mean MVBS (dB)	-72.1	-69.2
Acoustic density (fish m^{-3})	2.46×10^{-4}	4.78×10^{-4}
Trawl density (kg m^{-3})	4.15×10^{-3}	1.07×10^{-2}
Trawl density (fish m^{-3})	2.60×10^{-3}	6.66×10^{-3}
Ratio T/A	10.57	13.93
Depth integrated - 24 m (bottom window plus 10 layers)		
Mean MVBS (dB)	-72.7	-69.1
Acoustic density (fish m^{-3})	2.14×10^{-4}	4.89×10^{-4}
Trawl density (kg m^{-3})	2.08×10^{-3}	5.33×10^{-3}
Trawl density (fish m^{-3})	1.30×10^{-3}	3.33×10^{-3}
Ratio T/A	6.08	6.81

Table 11: Estimated mean target strengths (TS) for dories and sharks obtained from seven stations in which the single catch component represented over 70% of the total catch. Percentage composition of catch attributed to the main single species are also shown. Estimation assumes single component is 100% of catch. The average weight per fish used for dories was 1.5 kg and for sharks 3.0 kg.

Component	% of catch	Main species	% of catch	Mean TS
Dories	71.5	*A. verrucosus*	71.5	-37.3 dB
Dories	75.4	*A. verrucosus*	75.4	-39.3 dB
Dories	86.2	*A. verrucosus*	86.2	-35.0 dB
Sharks	70.1	*C.crepidater*	49.0	-28.8 dB
		D.calcea	17.5	
Sharks	74.6	*D.calcea*	65.3	-31.6 dB
Sharks	76.8	*D.calcea*	37.7	-26.8 dB
		C.crepidater	32.6	
Sharks	86.3	*C.crepidater*	54.8	-28.9 dB
		D.calcea	26.3	

Dories and sharks

The mean target strengths for dories and sharks were estimated using similar assumptions, apart from the average weight per fish, with seven stations that had over 70% of their catch as one catch component (Table 11). These estimates of target strength appear reasonable given that dories have air-filled swim bladders and the sharks represent sizeable acoustic targets. Average weight per fish for dories was taken as 1.5 kg and for sharks 3.0 kg. In any of these calculations an increase in the average weight per fish would increase the estimated mean target strength obtained.

Average TS and fish density

Estimates of the mean target strength for fish from the entire survey area were obtained by applying a guesstimate of average fish length of 30 cm to the target strength equations of Love (1971) and McCartney and Stubbs (1971). These target strengths were then converted to mean fish densities using equation 2 and the mean total MVBS from the survey area of -74.6 dB:

	Love	McCartney and Stubbs
mean TS	-35.2 dB	-32.9 dB
density (fish m^{-3})	11.48×10^{-5}	6.78×10^{-5}

To convert these fish densities to biomass values (kg m^{-3}) equivalent to those obtained from the trawl results would require an average fish weight from the survey of 1.0 kg and 1.7 kg respectively; neither of which are that unrealistic.

Day/night variation

The only day/night variation with MVBS values compared to catch rate was a possibly lower acoustic return per catch rate at night (i.e. higher catch rates per acoustic return) for dory dominated catches; dory dominated stations were too few however for results to be conclusive.

Discussion

The lack of a strong correlation between the acoustic data and trawl data is not unexpected when one considers the high degree of heterogeneity in the families and size of fish caught. Most catches consisted of a wide range of acoustic targets from the macrourids to sharks to orange roughy. Such factors prevent an accurate estimation of the acoustic conversion factor (TS in equation 2) necessary for transforming acoustic data into fish density. This is a general feature of single-beam acoustic surveys, but can be greatly improved upon using a dual or split beam approach (Dickie *et al* 1984). Had size distribution data been collected, there is still the basic problem that there is no information on in-situ target strength relationships for any of the species located in this survey.

A biomass estimate based on the acoustic data would not be reliable without an acoustic estimate of fish sizes and numbers. The target strength, and thus the conversion factor, is very complex and dependent on many factors beyond the scope of this study, such as species difference, fish behaviour and density at each station, and so using a mean value would not provide an accurate estimate of fish density. However, with these limitations in mind and the assumptions previously outlined, the density estimates obtained using the two general equations for mean target strength are not unrealistic compared to the trawl results.

Our results, in light of the findings of Dickie *et al* (1984) and Rose and Leggett (1988), suggest that it may be possible to both estimate the biomass of deep-water demersal fish stocks and to classify aggregations of single species using acoustics. Acoustic data obtained from a dual or split beam system will enable estimates of both size and number of fish to be obtained. Rose and Leggett (1988) found that an array of discriminators from the acoustic signal can be used to discriminate single species schools. Such discriminators included standardized peak to trough distance, mean distance between voltage peaks, target strengths and such features as distance of target from the bottom. The results from the few single catch component dominated stations obtained in this survey suggest that with such additional information it would be possible to distinguish between the three main components of this fishery - orange roughy, sharks and dories.

The catchability of the trawl gear is just one of a number of assumptions made when estimating biomass indices from trawl surveys. Very little is known about the behaviour of the gear or of the many species found at the depths of this survey. However, our results indicate that the influence of the trawl gear, in terms of the volume swept, extends well above the net headline, possibly extending as high as or above 50 m.

The dissimilar distribution of mean MVBS and catch rates between stations highlights the difference between these two estimation techniques in that the acoustics is dependent, among other things, upon the number and length of the fish rather than the total weight as is trawl data. Therefore in future comparisons of these techniques more emphasis should be placed upon size distribution of the catch components.

The mean target strength for orange roughy presented by Do and Coombs (1989) of -36 dB does appear from our results to be too high. There are of course limitations to the accuracy of our figures yet it would appear that a target strength of ca. -42 dB may be closer to the mean value. In-situ measurements are required to verify this, as there are inherent problems in performing measurements on dead specimens, as conducted by Do and Coombs, in depths and temperatures dissimilar to the norm, particularly with the deepwater orange roughy that has a swim bladder filled with wax esters rather than gas.

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