Final Report to Fisheries
Research and Development Corporation

Development and use of Acoustic Techniques for the assessment of Deepwater Commercial Fish Stocks

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CSIRO
AUSTRALIA

DIVISION OF **FISHERIES**

PART ONE

SUMMARY

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INTRODUCTION

The most commercially important southeast Australian trawlfish resources are now found in deep water over the continental slope and include orange roughy, gemfish, blue grenadier, and others. Management of these fisheries in Australia and New Zealand has generally proven exceptionally difficult, largely due to problems of stock assessment. Cohort analysis has not been possible for orange roughy due to their exceptional longevity and difficylty of ageing mature fish, and catch per unit effort (CPUE) indices are generally difficult to use as estimates of stock density for highly aggregated species, such as roughy or grenadier. The value of trawl surveys alone for orange roughy and blue grenadier also seems highly questionable due to their occurrence over untrawlable ground, variable distribution in the water column (i.e. only partial accessibility to sampling gear), and saturation of the trawl when aggregated. Despite these difficulties, there is a critical need to properly manage these resources. The orange roughy seems particularly vulnerable to overfishing due to the combination of its apparent longevity (> 100 years) and massive, highly predictable spawning aggregations. Segments of the New Zealand orange roughy fishery are on the verge of collapse after only 10 years of exploitation.

With the discovery in 1989 of the first major spawning aggregation of orange roughy off St. Helens, northeast Tasmania, the catch of orange roughy (~20,800 t) more than doubled and likely exceeded the catch for all other fin fish in the Southeast Australia trawl fishery combined. Estimates of the biomass of the aggregation at the time varied by more than an order of magnitude (50,000 - >1,000,000 t), placing management of the fishery in a state of crisis, since first-order models indicate that only ~3% of virgin biomass may be removed annually on a sustainable basis (Mace et al. 1990).

The recent development of the deepwater trawl fishery off southeast Australia also highlights how little is known of Australian deepwater fishery resources. The slope region off western Australia is particularly poorly explored, which underlied CSIRO's FIRDC grant, 'Exploratory survey for deep-water fisheries resources on the continental slope of Western Australia.' A trawl survey was proposed as part of this grant, but again, trawl surveying alone is a relatively inefficient means to search for commercial fish concentrations. The use of acoustics in combination with trawl sampling would considerably enhance the ability to search for and assess the extent of potentially important concentrations of fish.

Acoustic and egg production methods for stock assessment appeared feasible and were proposed to assess the orange roughy stock that spawns off eastern Tasmania. Acoustic survey methods have been standardised (Johannesson and Mitson 1983; Shotton and Bazigos 1984) and used successfully on a world-wide basis with epipelagic, midwater and shelf fisheries (e.g. Gjosaeter and

Kawaguchi 1980; Jakobsson 1983; Karp and Traynor 1988). Quantitative acoustic echo-integration surveys are based upon use of a calibrated echo sounder, often in combination with photographic, video and/or trawl sampling for target identification and comparison of packing density estimates. The use of acoustics has recently been extended to surveying orange roughy off New Zealand (Do and Coombs 1989), but significant technical questions still remain.

Orange roughy is best suited to acoustic survey methods during the spawning period. At this time, most of the stock appears to be highly localised (the area of the aggregation off St. Helens was ~10 km^2 in area), is found from the seabed to several hundred metres into the water column, and catches indicate little admixture of other species. As a result the aggregation can be mapped and echo integration techniques applied to estimate orange roughy biomass in the water column. Once the method has been validated and analytic protocols developed, acoustics may provide a rapid assessment tool - results of the acoustic survey may be known virtually upon completion of the field work.

This study on development of acoustic techniques and a related, but independent study ("Development and use of the egg production method to assess the biomass of orange roughy off eastern Tasmania") were largely framed within the specific need to assess the biomass of orange roughy off eastern Tasmania. However, they were also designed to meet the critical long-term need for alternative survey methods for major trawl fisheries off southeast Australia. We believe that their use may be extended both to other regions (if orange roughy spawning aggregations are discovered elsewhere) and to other species, such as blue grenadier, which form reasonably localised, predictable spawning aggregations.

OBJECTIVES

To develop the techniques to provide quantitative acoustic assessment of the biomass of commercially important fish stocks in the AFZ.
To use these methods on:

a. to assess the standing stock of orange roughy off east Tasmania.
b. to assist in deepwater exploratory fish surveys off western Australia.

RESEARCH SUMMARY

EQUIPMENT DEVELOPMENT

The exploitation by commercial fishing of deep-water resources in southern Australian and New Zealand has increased substantially over the past years. One such species, orange roughy (*Hoplostethus atlanticus*) is vulnerable to over exploitation due to its aggregating behaviour, slow growth and longevity. Estimating stock size is vital for good management to maintaining orange roughy as a sustainable fishery. The acoustic method for monitoring stock size is suitable for orange roughy due to its aggregating behaviour. The depth of the fish 700-1200 m introduces problems for standard vessel mounted acoustic systems. To overcome these range and weather dependent problems, a deeply towed acoustic system is required. A deep-water towed acoustic biomass survey system was designed, built, tested and used to monitor the commercial fishing of orange roughy in Australian waters. The acoustic system is capable of conducting echo integration at a towing depth of 600m at 5-6 knots and in-situ target strength measurements at towing depths to 1000m at 2-3 knots. Several advantages of the towed transducer compared with hull mounted systems when working in deep-water where realised. These included improved signal to noise, stability in rough weather, lower pulse length and reduced dead zone. The acoustic dead zone which is a particular problem with orange roughy surveys due to the steepness of the bottom (14-17deg) was reduced by half using the towed acoustic system. The calibration of the system showed that the air backed transducer had a marked change in sensitivity over the 0-1000m depth range but has been stable over the four years of use.

ORANGE ROUGHY

BEHAVIOUR TO SAMPLING METHODS

The response orange roughy to lowering an underwater camera was monitored acoustically. Acoustic layers of the fish at 660–790 m depth dispersed rapidly at least 30–40 m when the camera was ~130 m above them. The reaction occurred day and night and prior to activation of the strobe lights, so it was presumably mediated by the low-frequency sound of the system being lowered rather than visually. Orange roughy contain a pronounced lateral line and extensive frontal sensory canal system that may be used to sense low-frequency sound. Our observations indicate that some marine species are highly sensitive even to non-capture sampling gears, so use of non-remote methods of sampling may lead to highly biased estimates of density. The avoidance response is consistent with the relatively high metabolic levels that have been reported for this species, as well as with their very low estimated rates of natural mortality. We speculate that the response has evolved to facilitate escape from large, highly-mobile predators.

TARGET STRENGTH

In-situ target strength data of fish from 600 to 1200m were collected from a spawning aggregation of orange roughy located off the east coast of Tasmania in 1992. The target strength data show many modes, none of which can be definitely and uniquely attributed to orange roughy. Dominant modes at -50 and -55dB could be attributed to myctophid fishes that contain gas-filled swim bladders that were undisturbed by the acoustic towed body. Small modes at -44dB and -31dB were attributed to the macrourid, *Coryphaenoides subserrulatus* and morid, *Halagyreus johnsonii* sp. respectfully. The swimbladder of H. johnsonii is gas-filled, whilst that of *C. subserrulatus* contains a spongy gas-matrix. No evidence of a separate peak at -36 or -41.3dB was found for the previously reported values of orange roughy target strength. Results from modeling and tethered experiments on orange roughy indicate that the possible target strength range for a 35cm standard length fish is -43 to -53 dB. The dominant peak in the in-situ data at -50dB which ranges from approximately -48 to -52dB and is associated with myctophids is likely to be masking the orange roughy targets. It is concluded that the in-situ target strength for a 35cm standard length orange roughy is likely to be in the range of -48 to -53dB; that is, from the maximum of the in-situ TS values to the lower range of the tethered measurements.

BIOMASS ON ST. HELENS SEAMOUNT

Acoustic surveys with hull-mounted and deeply towed transducers were carried out from 1990-93 on a spawning aggregation of orange roughy off the east coast of Tasmania. Echo integration was carried out to 150 m above bottom, and the data were stratified by 100 m depth strata. Species composition on the spawning ground was assessed using primarily demersal and pelagic trawl samples. The community appeared to be dominated by orange roughy (95% of individuals) at the 700-900 m depth strata and to decline at shallower and deeper depth strata. Other dominant groups included large and small myctophids, whiptails and morid cods. Acoustic backscattering declined by approximately half after 1990. Based upon the hull-mounted data, the biomass of orange roughy on the spawning ground declined from approximately 33,000 tonnes in 1990 to 14,500 tonnes in 1991 and to 12,900 tonnes in 1992-93. The hull-mounted echo integration estimates were consistently lower than the towed body by a factor of 1.6-1.8, most likely due to sampling threshold effects at the edge of the acoustic beam when sampling over large depths

BLUE GRENADIER

An echo-integration and *in situ* acoustic target strength survey of spawning blue grenadier (*Macruronus novaezelandiae*) was carried out off the west coast of Tasmania from 30 July to 8 August 1992. A SIMRAD EK500 echo-integrator and split-beam target strength analyser operating at 38 kHz was used in conjunction with pole and towed body mounted transducers. A broad-scale systematic survey of the spawning ground was followed by finer scale surveys over areas of known blue grenadier concentration. The biomass of blue grenadier on the west coast at the time of the survey was 47,600±11,600 tonnes, based on trawl estimates of species composition or 15,700± 4,700 tonnes based on acoustic estimates of species composition. The mean target strength of blue grenadier observed *in situ* during the survey was -30.3 ±0.2 dB at 38 kHz.

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TRANSFER OF RESULTS

Preliminary results of the acoustic surveys were made available to industry and management committees as soon as possible. Results have also been communicated to the scientific community at scientific meetings and will be reported in Australian Fisheries and refereed scientific journals (see Part Two for draft manuscripts).

1990

Smith, T. & T. Koslow. Biomass survey of orange roughy at St Helens.
Australian Fisheries 40 (10), 29-31.
Demersal and Pelagic Fishery Research Group (DPFRG)
Government, Industry & Technical Liaison Committee (GITLC)
Public seminar GITLC, CSIRO Marine Laboratories, Hobart

1991

GITLC meeting
DPFRG meeting

1992

GITLC meeting
DPFRG meeting

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1993

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CONCLUSIONS AND RECOMMENDATIONS

The primary objective of the project was to develop quantitative acoustic assessment techniques, the secondary objective was to use these techniques on the standing stock of orange roughy off east Tasmania. Both objectives were successfully achieved and the results have been instrumental in managing the orange roughy fishery for the past few years. The acoustic techniques have also been used on spawning blue grenadier off the west coast of Tasmania and orange roughy off the south of Tasmania. Details of the study are documented in part 2.

The initial stock assessment results for orange roughy in 1990 on the St. Helens seamount significantly reduced the huge (50-1000 thousand tonnes) uncertainty surrounding the stock size. As the stock is fished down the technique becomes sensitive to species composition with more care required in the analysis of results. The trend from acoustic surveys from 1990-93 of biomass on the hill shows a consistent decline. The target strength of orange roughy is still not precisely known due to the avoidance response of the fish to sampling gear. From our knowledge at present it is concluded that the in-situ target strength for a 35cm standard length orange roughy is likely to be in the range of -48 to -53dB; that is, from the maximum of the in-situ TS values to the lower range of the tethered measurements.

Results of the acoustic surveys were similar to those obtained from the egg survey of the same spawning aggregation in 1992, adding to confidence in the overall biomass assessment. These assessments provided the basic data for the management strategy developed for the stock. Confidence in the assessment allowed substantial quota reductions on the orange roughy to be made.

The acoustic estimates agreed well with those of the egg production method, but the statistical precision of the acoustic estimate was higher than that of the egg survey (CV = 10% cf. 35%). However there are a few non-statistical sources of error with the acoustic surveys such as the acoustic target strength of orange roughy and the species composition of acoustic marks in the vicinity of the spawning area that still present major sources of uncertainty in the absolute acoustic biomass assessment. These sources of error are less important for a relative biomass assessment and the low cost of acoustic surveys in terms of recurring ship time makes the technique a very good relative biomass tool.

The pilot study of acoustic biomass on blue grenadier stocks looks very promising with this technique being used in New Zealand to manage their stocks. The major source of non-statistical bias with our survey was the question of turn over rates on the ground. This will need to be overcome to obtain both relative and absolute biomass assessments.

In conclusion, acoustic surveys have proven to be an effective method of stock assessment for Australian deepwater fisheries. We recommend that its use be considered in long term relative and absolute biomass assessments of orange roughy and blue grenadier stocks. This is consistent with CSIRO's recent proposal, which AFMA funded, to use acoustic surveys to assess the southern hills orange roughy stocks and to construct a portable acoustic system. We also recommend that acoustic surveys be used for the continued monitoring of the east Tasmanian orange roughy. The costs of long term relative acoustic surveys are much lower than other methods.

PART TWO

DETAILS OF THE STUDY

CHAPTER ONE

AVOIDANCE OF A CAMERA SYSTEM BY A DEEPWATER FISH, THE ORANGE ROUGHY (*HOPLOSTETHUS ATLANTICUS*)

AVOIDANCE OF A CAMERA SYSTEM BY A DEEPWATER FISH, THE ORANGE ROUGHY (*HOPLOSTETHUS ATLANTICUS*)

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ABSTRACT

The response of the benthopelagic fish, orange roughy (*Hoplostethus atlanticus*), to lowering an underwater camera was monitored acoustically. Acoustic layers of the fish at 660–790 m depth dispersed rapidly at least 30–40m when the camera was ~130 m above them. The reaction occurred day and night and prior to activation of the strobe lights, so it was presumably mediated by the low-frequency sound of the system being lowered rather than visually. Orange roughy contain a pronounced lateral line and extensive frontal sensory canal system that may be used to sense low-frequency sound. Our observations indicate that some marine species are highly sensitive even to non-capture sampling gears, so use of non-remote methods of sampling may lead to highly biased estimates of density. The avoidance response is consistent with the relatively high metabolic levels that have been reported for this species, as well as with their very low estimated rates of natural mortality. We speculate that the response has evolved to facilitate escape from large, highly-mobile predators.

INTRODUCTION

Avoidance of sampling gear is a serious source of sampling bias in the collection of data on virtually all motile marine organisms from the plankton to fish. Marine organisms appear to respond to a variety of cues in avoiding sampling gears: i.e. visual, auditory, and mechanical stimuli associated with the gear (Clutter and Anraku, 1974; Wardle, 1986). Avoidance reactions by marine organisms are often considered a response to imminent gear approach, that is, a reaction within a few meters of the point of disturbance. Studies of net avoidance are often based upon video recordings or diver observations made in the vicinity of the gear (Hemmings, 1973; Wardle, 1986). Attempts to minimize or quantify avoidance have been based largely upon development of alternative non-capture (e.g. photographic) or remote sensing (e.g. acoustic) technology, and higher estimates of fish density have generally been obtained by these methods (Haedrich *et al.*, 1975; Uzmann *et al.*, 1977; Ohta, 1983). However, even non-capture oceanographic instruments may elicit avoidance (Vassière and Fredj, 1964; Grassle *et al.*, 1975; Orr, 1981).

Despite limitations of the visual field underwater, video and photographic techniques have been used increasingly in marine research, particularly in surveys of the megabenthos (Haedrich and Rowe, 1977; Ohta, 1983; Hecker,

1990) and in fisheries (Graves, 1977; Aoki *et al.*, 1986). The use of photographic techniques to study the density and spatial structure of organisms, such as fish, rests upon the assumption that the camera system does not significantly affect their behaviour and distribution. It is apparent that towed camera systems may elicit avoidance responses similar to those induced by trawls (Vassiere and Fredj, 1964). However, Ohta (1983) found that estimates of the biomass of large benthic organisms based upon photographic transects using a drifting camera suspended from a wire were an order of magnitude larger than estimates based upon a survey with a small beam trawl. In the absence of an objective standard, it is difficult to resolve questions of avoidance.

In July and August 1990, we undertook an acoustic survey of the east Tasmanian orange roughy (*Hoplostethus atlanticus*) stock during its period of aggregation and spawning on an underwater pinnacle off northeastern Tasmania, Australia (Fig. 1). Since 1989, this spawning ground has been one of two major sites for the orange roughy fishery, which is the largest finfish fishery in Australia. A trawl survey indicated that during the non-spawning period, orange roughy is the dominant species at mid-slope depths (700-1200 m) off southeastern Australia, comprising 23% of fish biomass (Koslow *et al.*, in press). Although trawl catches are heterogeneous during the non-spawning phase, orange roughy comprise 90-95% of the catch within the spawning aggregation. Trawl catches of orange roughy may exceed 10 tonnes for a several minute tow. Approximately 40,000 tonnes of orange roughy are estimated to aggregate within the 10 km^2 area of the spawning pinnacle in July and August (Koslow *et al.*, 1992).

In carrying out the acoustic survey, trawling and deepwater photography were used to identify acoustic targets. Stereo photography was also proposed as an independent means to estimate fish density. However, the use of acoustics during camera drops enabled us to monitor from a distance the response of deepwater fish to the camera system. The response of orange roughy to the camera frame, which we report here, proved so dramatic that we effectively abandoned the use of a freely-drifting camera system for deepwater fishery surveys.

METHODS

A Simrad EK500 acoustic system was used with an EDO deepwater 38 kHz transducer with 6.5^{o} beam angle to the +/- 3 dB points, which was mounted on a pole alongside the survey vessel. The acoustic traces were recorded on a colour printer and summaries of the acoustic backscattering were averaged each minute and stored on a computer data file along with data on water depth, time, and vessel position. Vessel position was monitored using Global Positioning System (GPS), which is accurate within the pass of a single satellite to approximately 10 m.

Following completion of acoustic transects, the vessel was positioned over acoustic targets, and a deepwater stereo camera system was lowered vertically to photograph them. The camera system consisted of a Photosea 2000M stereo camera within a housing, two 150 watt-second strobes, and a 50 kHz transducer to determine height above bottom. The camera was directed horizontally, and the system was mounted on a metal-bar frame of dimensions ~2x1x1 m. The system was lowered by winch on a single-conductor cable to the depth of interest, where the camera and strobes were triggered from the surface. Initially the frame was lowered at ~1.5 m/sec and subsequently maintained at a particular depth, where photographs were taken at ~30 sec intervals for a period of 15-30 min. Over flat bottom, the only movement during a series of photographs resulted from the ship's horizontal drift and its vertical pitch and roll; over sloping bottom the system was winched up or down when drift caused the camera to deviate more than 5-10 m from the desired depth above bottom.

RESULTS

On 29 July 1990, under calm conditions when ship's drift was minimal, we monitored on the echo sounder the descent of the camera system beneath the vessel and the response of acoustic targets to it. Four camera drops were carried out under these conditions in water depths of 660-790 m (Table 1; Figs. 1, 2). At these sites the aggregation of demersal fish extended from the seafloor to 50-140 m into the water column along the slope of the pinnacle from water depths of ~670-840 m (Fig. 1). The targets were composed predominantly of orange roughy, based upon both the resulting photographs and catches of the commercial fleet and a chartered commercial fishing vessel, which accompanied the acoustic survey vessel to sample the size and species composition of acoustic targets.

The orange roughy rapidly dispersed when the frame descended to within ~130 m of the top of the aggregation. The strobes on the camera frame were not activated while it was being lowered, and the drops were carried out both day and night (Table 1), so it is unlikely that the orange roughy were responding to visual cues. The head of the orange roughy contains an extensive system of sensory canals, such that they may be responding either to high-frequency sounds transmitted along the conducting cable or to the pinging of the acoustic transducer mounted above the camera frame or to the low-frequency pressure wave of the frame as it was being lowered. However, the fish also were observed to respond to a simple iron bar (approximate dimensions, 30 x 8 x 1 cm) that was dropped over the side of the vessel, while the transducer was suspended from a cable ~225 m above bottom (Fig. 2E). The layer of fish beneath the transducer dispersed when the bar was ~60 m above it. No ship noise or acoustic pinging was associated with this free-falling object, so the reaction was presumably to the low-frequency pressure wave.

The rapid dispersal of virtually the entire column of fish at the second and third sites (Figs. 2B, C) suggests that the fish lower in the water column responded to the movement of fish nearer the source of disturbance. Movement between neighboring fish is generally communicated visually or through the lateral line system, which is well-developed in the orange roughy: the scales along the lateral line are 4-6 times larger than adjacent body scales (Last *et al.,* 1983). The scale of horizontal dispersion by the orange roughy was at least 35-45 m, the radius of a 6.5^{o} acoustic beam 600-800 m below the transducer. The sphere of influence of the camera system also may be estimated from the time and distance that the ship drifted before the acoustic signals returned to initial levels. The acoustic signals did not return to pre-response levels until the ship had drifted 140-225 m over a period of 13.0-16.7 min. However, the fish distribution may still have been affected by the presence of the camera system drifting above the bottom.

Interestingly, a deep scattering layer of unknown composition between 500 and 600 m at these stations showed no apparent response to the camera as it was lowered through it (Fig. 2 b-d). Thus the reaction to the camera system appears to be species-specific.

DISCUSSION

Recent acoustic investigations have shown that fish, particularly within the upper 200 m of the water column, may respond at distances of some tens to over 100 m to the approach of a trawl or vessel. (Olsen *et al.*, 1982; Ona and Godo, 1990). The response of orange roughy to a descending camera system at distances of over 100 m indicates that fish can be sensitive to disturbance of their environment by objects far smaller than a commercial trawl. It also indicates that energetic avoidance responses are not limited to near-surface fishes.

The rapid dispersal of orange roughy from the camera system is in marked contrast to the sluggish behaviour of many deepwater species, which often display little reaction to deepwater vehicles (e.g. *Sebastolobus altivelis*, Smith and Brown, 1983). The high degree of sensitivity of orange roughy to their environment and strong avoidance reaction are consistent with their high rates of food consumption and estimated metabolism reported by Bulman and Koslow (1992) for this species relative to the rates reported for other non-migratory deepwater fishes. The marked contrast between the apparent activity levels of orange roughy and species such as *S. altivelis* raises the question whether the paradigm of markedly reduced metabolic activity in deepwater animals (Smith and Hessler, 1974; Smith, 1978; Torres *et al.*, 1979; Smith and Brown, 1983) is biased by the use of species that can be readily captured or manipulated *in situ*.

Our observations have obvious implications for the use of non-remote instruments. even those that do not depend upon actual capture, in carrying out surveys and ecological studies of motile marine organisms. Avoidance of samplers can lead to highly biased estimates of absolute density. Avoidance may be pronounced and species specific. Avoidance of samplers at distances of

~100 m also has implications for the use of so-called remote sampling gears, such as acoustics, if these are deployed at this range for routine sampling or to obtain detailed target strength measurements.

Our observation of a marked avoidance reaction from a deepwater fish raises the question of its adaptive significance. Orange roughy are exceptionally long-lived: ages of approximately 150 years are reported (Fenton *et al.*, 1991). Orange roughy thus have very low natural mortality rates ($M \simeq 0.04$ (Francis *et al.*, 1992)) and are presumably adept at avoiding predators. We have often observed sperm whales diving in the vicinity of orange roughy aggregations. It is possible that orange roughy are preyed upon either by the sperm whales themselves or by large squid, which sperm whales are reported to feed on (Matthews, 1938). We are not aware of any records of sperm whales feeding on orange roughy. However, sperm whales have been found entangled in deep sea cables at depths of 900-1100 m (Heezen, 1957) and have been reported to feed, at times predominantly, on fish of similar size and body form (e.g. *Sebastes* spp.) that live at comparable depths (Pike, 1950; Roe, 1969). We speculate that the avoidance response of orange roughy has evolved to facilitate escape from highly-mobile, deepwater predators.

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Figure 1. Bathymetric chart of the underwater pinnacle where the study was conducted showing the position of the camera stations referred to in the text. Inset shows the location of the pinnacle off northeastern Tasmania. Depths in metres.

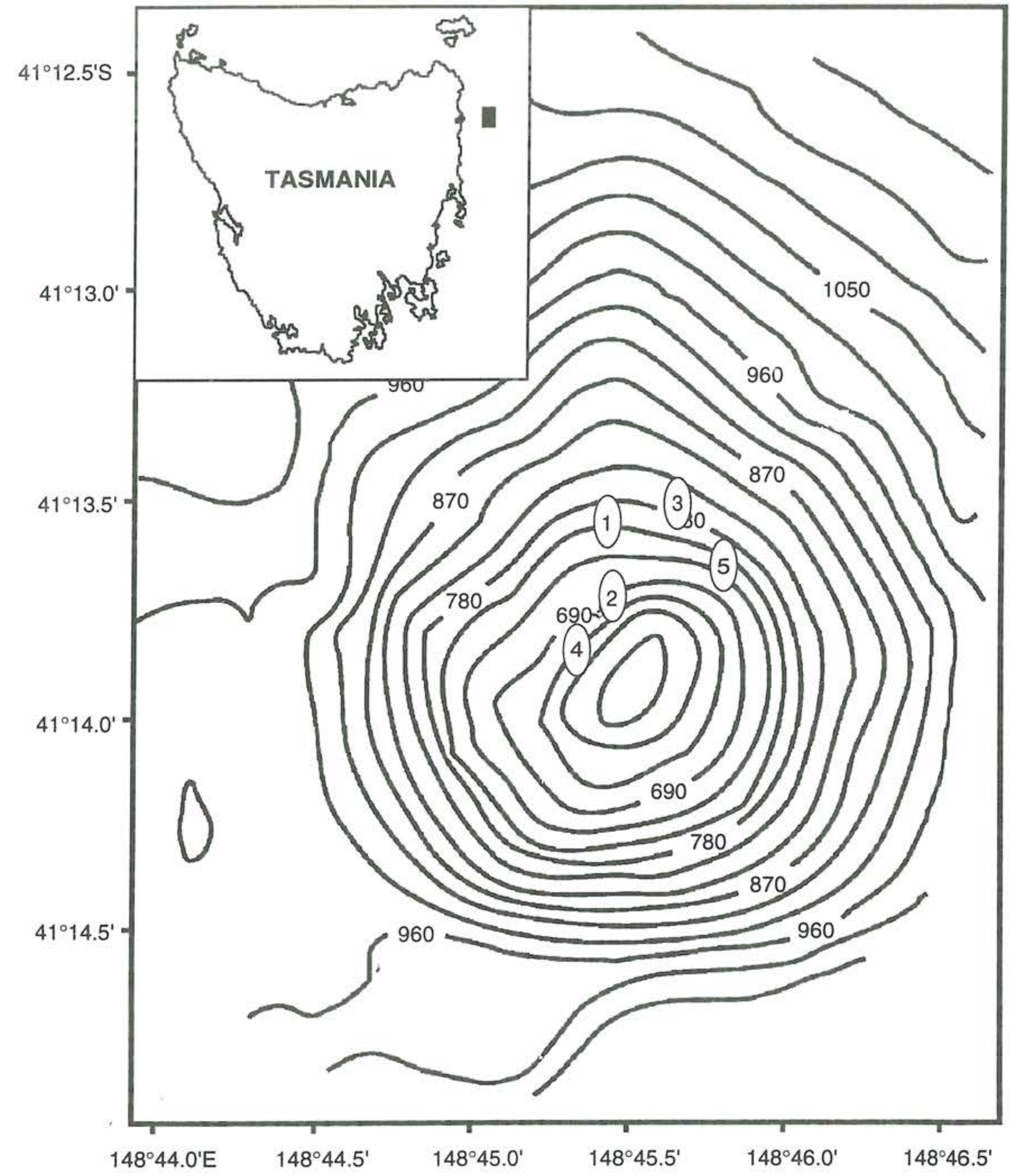
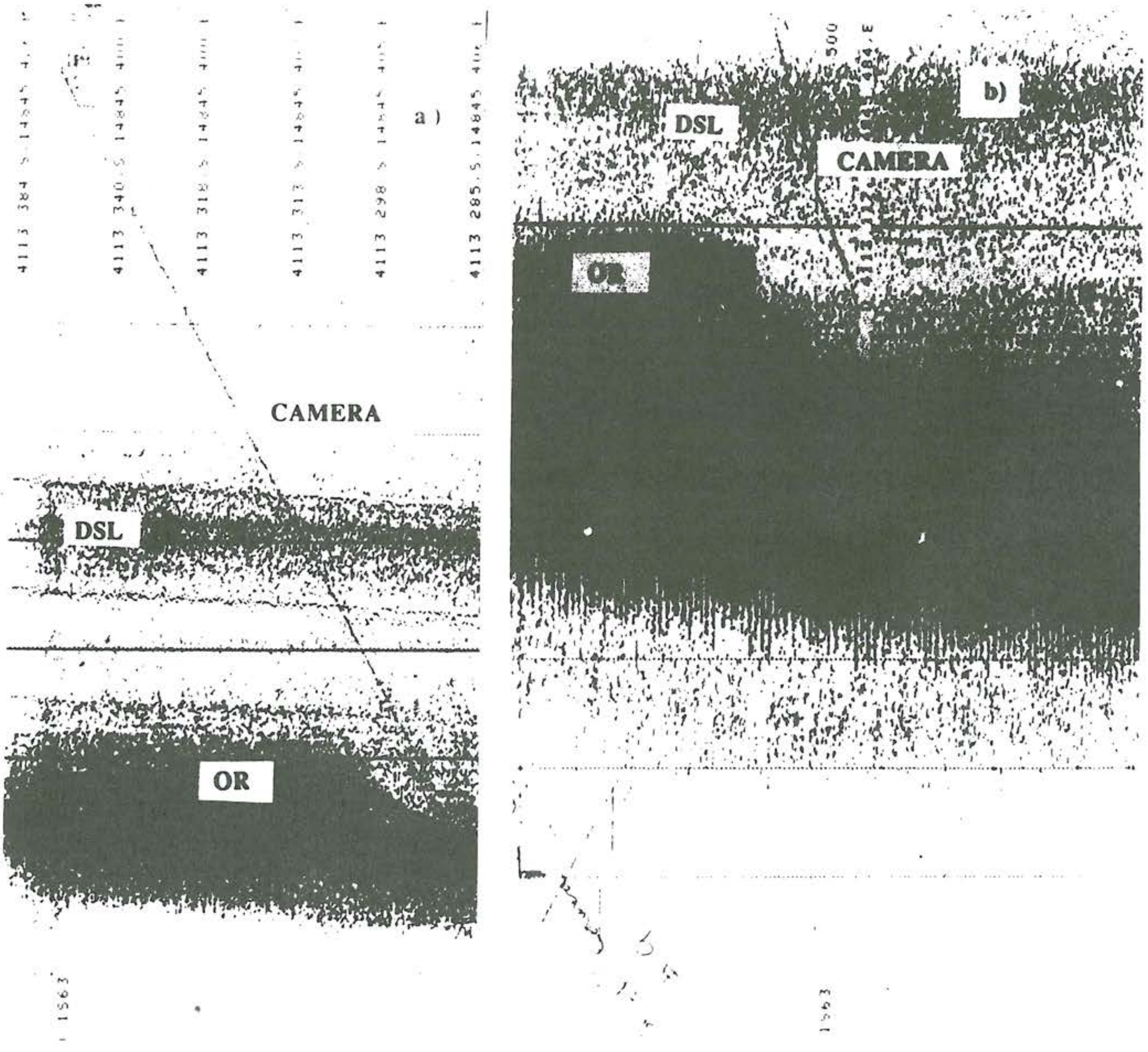


Figure 2. Echograms from four sites (A-D, which correspond to camera drops 1-4 in Table 1, respectively) showing the descent of the camera system through the water column and response of acoustic layers to it. At each site the deep scattering layer (DSL) between 500-600 m was not visibly affected by the descent of the camera (C) through it. The layer of demersal fish, presumably orange roughy (OR), scattered when the camera was approximately 130 m above it. The sea floor (SF) is indicated by the solid band in the figures. The acoustic dead zone (DZ), which is caused by reflections from the slope of the hill by side lobes of the acoustic beam, is the distinct, less-dark zone above bottom. The horizontal lines represent 100 m depth intervals. Echogram (A) extends from the surface to the bottom at 760 m; echograms (B-D) extend from 500 m to the bottom. In E), an iron bar is seen free-falling through the water. The transducer was suspended ~225 m above bottom, and the layer of fish scattered when the bar was ~60 m above it.



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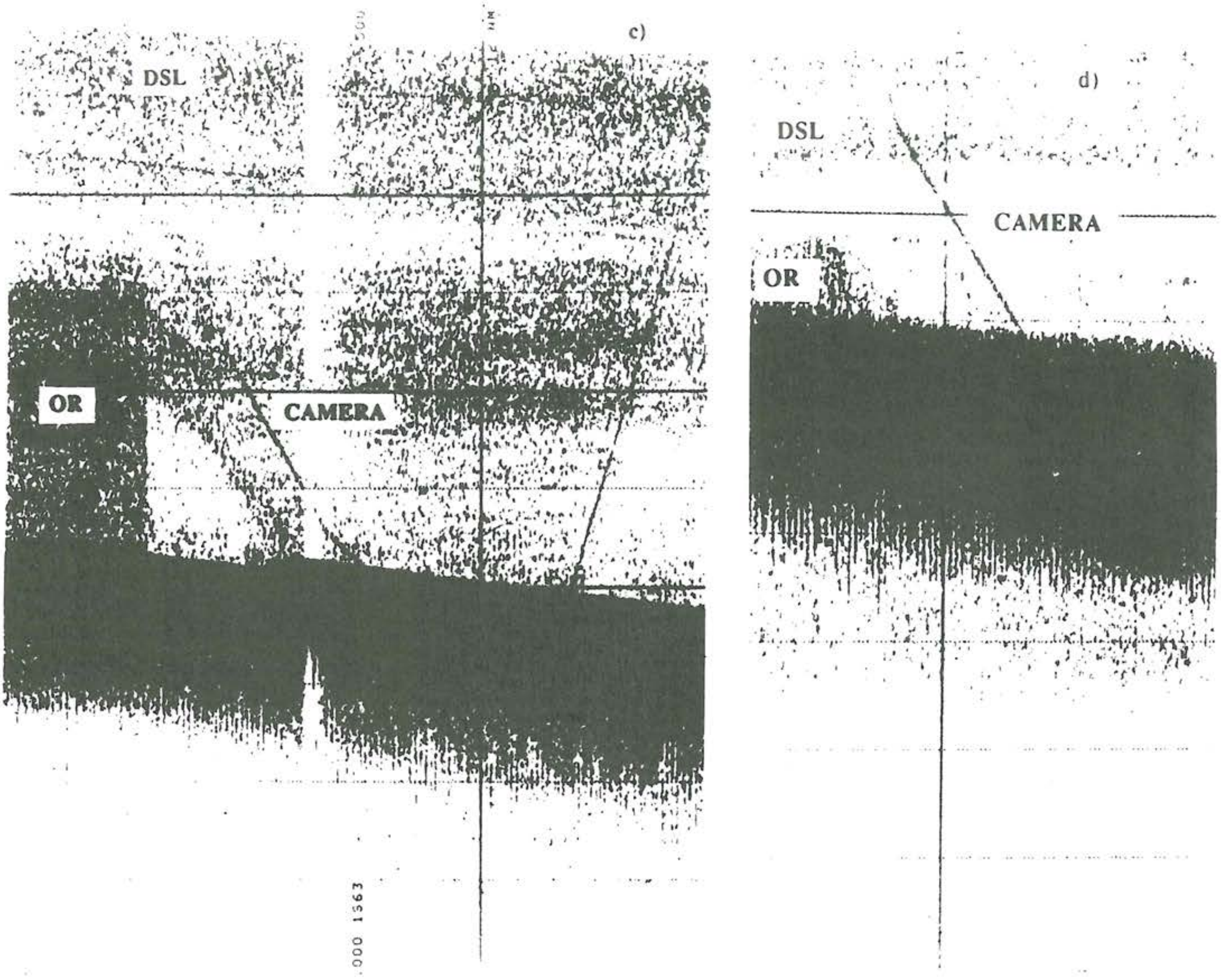

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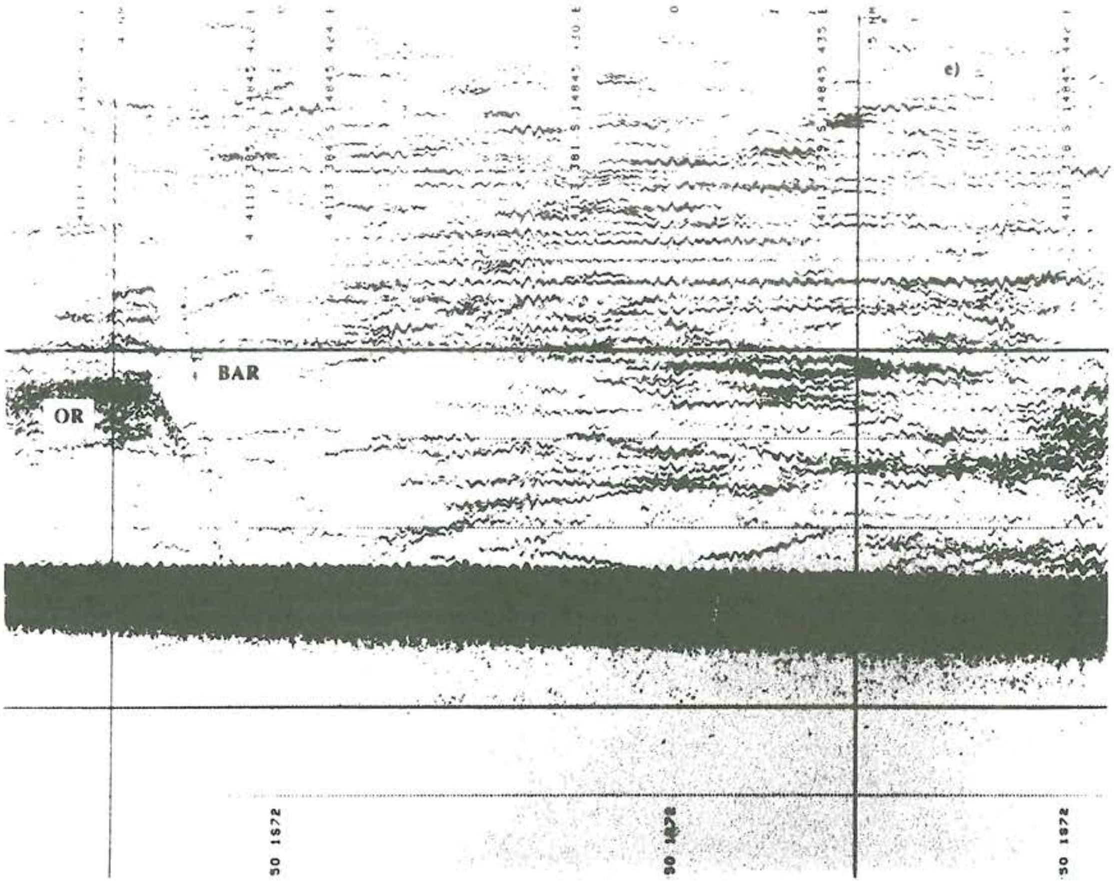

Table 1. Summary of information on camera drops. All depths and distances are in meters. NA: not available.

Drop	Local time (hr)	Water depth	School depth range	Camera depth at time of response	Response distance	Depth above bottom of photos	Time to return to original density (min)	Distance to return to original density
1	1350	760	680 - 760	550	130	4-8	13	140
2	1515	690	610-690	580	130	10-50	16.5	NA
3	2100	790	640-790	NA	NA	NA	Drop aborted	NA
4	2130	660	610-660	475	135	3-5	16.7	225

CHAPTER TWO

THE ACOUSTIC TARGET STRENGTH OF A DEEPWATER FISH, ORANGE ROUGHY (*HOPLOSTETHUS ATLANTICUS*), BASED ON MODELLING AND *IN SITU* MEASUREMENTS ON SCHOOLS AND TETHERED FISH

split beam transducers in shallow water. The split beam algorithms in the Simrad EK500 were adjusted to ensure that the TS of the sphere was correct when moved up to 3 degrees off the centre of the beam. Further, the towed transducer was calibrated from 100 - 1000 m to correct for depth dependant changes in transducer sensitivity and to examine any change in the beam pattern. This was performed by suspending a sphere 10m under the towed body and lowering it through the water column. The seawater propogation parameters of absorption (α) and sound velocity (c) were calculated from temperature and salinity profiles obtained from a Neil Brown conductivity-temperature-depth recorder (CTD) on the survey ground. This was achieved using the formulae of Francois and Garrison (1982b) for α and MacKenzie (1981) for c. Table 1 shows the calibration and parameter settings of the Simrad EK500 for *in situ* TS measurements.

IN SITU TS DATA

Two methods were used when *in situ* TS data were recorded from the split beam towed transducer during an acoustic survey on St Helens seamount in 1992. The first was to tow the transducer on the same transect line at several depths. The second was to lower the transducer vertically onto aggregations of orange roughy and other target species. Target strength data corrected for depth were logged on a personal computer. To improve data quality only targets less than 2 degrees off axis were processed, which were binned into 20m depth ranges and 1dB bins. Probability density functions (PDF) were produced for targets at each depth and these modes were assigned to species based on trawling information and historic TS data (MacLennan & Simmonds 1992).

TS OF TETHERED ORANGE ROUGHY

Orange roughy have a wax ester filled swim bladder (Sargent et al. 1983) which in principle enables TS measurements to be made on dead specimens in shallow water. A frame was constructed (Fig. 2) to suspend a fish 6m below the 38kHz split beam towed body transducer in shallow water. Five orange roughy were tested ranging in size from 21cm to 48cm. The specimens were treated with detergent to reduce bubble adhesion and care was taken to expel air in the cavities on deployment into the water. The mean TS of each fish in the on-axis position was obtained from a linear average of the data.

SIMPLE TS MODEL

To further investigate the expected value of orange roughy TS a simple model based on fish shape was constructed. The shape of the body allows the adoption of a classical model (Urick 1983) for determination of on-axis TS.

$$TS = 10 * \log \frac{(a_1 * a_2) * R}{4}$$

where a_1 and a_2 (Fig. 3) are the respective radii of the snout to tail and the side to side curvatures and R is the impedance ratio of the fish flesh and the water surrounding it. The radius a_1 is calculated from the standard length (Sl) which is approximately 0.8 times total length. An adjustment of 0.92 for the Sl is required because it extends past the circle for which the dorsal surface forms an arc. Using standard trigonometry

$$a_1 = \frac{(\frac{0.92 * S_l}{2})^2 + (\frac{d_v}{2})^2}{d_v}$$

where d_v = 24.58 +0.34 Sl.

BIOLOGICAL SAMPLING

Biological samples were collected by trawling on fish traces identified by the echosounder. Large demersal trawl nets (headline length ~35 m) were used to catch bottom fishes while a pelagic trawl system, which permitted depth-specific sampling, was used to collect mid-water samples. Accurate target trawling of fish traces was possible using Scanmar acoustic sensors to monitor the geometry and position of the fishing gear in the water column. The pelagic trawl system combined a a multiple opening/ closing cod-end apparatus, based on the design of Pearcy et al. (1977), attached to a larger and strengthened version of the International Young Gadoid Pelagic Trawl (IYGPT) net. The system was able to take four samples per deployment from known depths.

Fishing was targeted at a range of specific sounder marks or regions of topographic features to build a composite picture of the mid-slope assemblages of which orange roughy are part. Demersal fish data were obtained primarily from scientific observers aboard commercial vessels. The CSIRO Division of Fisheries research vessel, FRV *Southern Surveyor*, completed all pelagic trawl stations and three demersal trawls in addition to acoustic transects. Demersal trawling was carried out down the sides and around the base of the seamount where orange roughy aggregate to spawn.

Pelagic trawling took discrete samples from the layered marks visible around the seamount (Fig. 4) and from broad depth strata over adjacent flat ground in the depth range where orange roughy occur. It was possible to fish the pelagic gear within 30 m of the seamount in depths between ~700–1000 m.

The composition of each catch was identified to species where possible; the numbers and weights of all fishes, crustaceans and squid were recorded. Large catches processed aboard commercial vessels were subsampled. A simple classification of swimbladder type was developed to allocate the large number of fish species into three groups for analysis. Swimbladder types were identified by dissection and with reference to Marshall (1960); the categories were: 1) gas-filled, 2) fat-invested, or 3) absent. Total length (mm) and weight (g) were recorded for representative numbers (up to 200 individuals per species per trawl) of all abundant species. Sample numbers and weights were standardised as catch rates per $1000m^3$. The volume of water filtered was calculated from the duration of fishing, vessel speed and net mouth-area (wingspread x headline height as measured by sensors). Length and weight data were pooled for all taxa within each swimbladder type category. Mean population weights for each category were calculated from total weight/ total numbers. Length frequency data, standardised by volume filtered, were rounded up to 1 cm length intervals, pooled within swimbladder categories and stratified by depth.

RESULTS

BIOLOGICAL SAMPLING

The distribution of research vessel trawl effort and catch data is summarised in Table 2. Successful trawl catches were taken over and around the base of the spawning seamount. Commercial vessel catch data, provided by the Tasmanian Department of Sea Fisheries, were summarised by Koslow et al. (1992). Pelagic trawls caught a high number of mesopelagic taxa which were dominated in numbers by myctophids and sergestid prawns (Table 3). Demersal trawls caught predominantly bottom living fishes and, whilst fewer taxa were represented, catch rates, numbers and weights, were greater. Dominant benthopelagic fishes, notably the morid, *Halagyreus johnsonii*, and the macrourid, *Coryphaenoides subserrulatus*, were taken regularly by both gears. Probably due to their sensitivity to disturbance (Koslow et al. in press) orange roughy are not taken by pelagic trawling (scientific or commercial fishing) but are effectively 'herded' and caught on the bottom by demersal gear.

A large number of fish and crustacean taxa were caught along with orange roughy from mid-slope assemblages (Table 2). Squid were rare, with only two *Teuthonia pellucida* and two *Iridioteuthis* sp. taken. Several of the taxa enumerated were genera and families representing multiple species; their incomplete taxonomic description put species differentiation beyond the scope of this work. None, however, were abundant.

Based on swimbladder characteristics, taxa were grouped for in situ TS analysis using a simple classification with three principal categories: present or absent and, if present, gas-filled or fat-invested. These categories were more practical than alternatives based on anatomical and physiological features which are diverse in deepwater fishes (Marshall 1960). Most fishes, including the dominant myctophids (*Diaphus danae*, *Hygophum hanseni*, *Lampanytus australis* and *Lampichthys proceros*) and the abundant morid, *Halagyreus johnsonii*, possessed gas-filled swimbladders. Less numerous taxa in this category included species from the Anguilliformes (eels), Notocanthidae (spiney eels), Opisthoproctidae (barreleyes), Photichthyidae (lighthousefishes), Sternoptychidae (hatchetfishes), Moridae (morid cods), Macrouridae (rattails), Melamphaeidae (crustheads) and Oreosomatidae (oreos). The 'swimbladder absent' group contained many species of crustaceans, including the abundant sergestid, *Sergia potens*, but no abundant fishes; minor taxa in this group were from the Squalidae (dog sharks), Scyliorhinidae (cat sharks), Bathylagidae (deepsea smelts), Stomiiformes (dragon fishes), Alepocephalidae (slickheads), Lophiiformes (angler fishes) and Centrolophidae (trevallas). The 'fat-invested' swimbladder group comprised two principal species and two minor groups: orange roughy with a swimbladder containing wax ester (Sargent et al. 1983), the macrourid, *Coryphaenoides subserrulatus* , in which the organ is a spongy matrix of unknown composition, and *Stomias* spp. (Stomiidae) and *Cyclothone* spp. (Gonostomatidae) where investment is with connective adipose tissue (Marshall 1960).

Plots of fish length frequencies from pelagic catches over the St Helens seamount and over adjacent flat bottom showed distinct modes (Figs. 5, 6 respectively). Catch rates, and therefore relative frequencies, were higher around the seamount than over flat bottom Figs. 5, 6). In both areas, small fishes with gas-filled swimbladders were most abundant and formed modes around 3–5 cm and 7–8 cm. *Hygophum hanseni*, *D. danae* and juvenile *L. australis* were most numerous in the shorter-length mode whereas *L. australis* and *L. proceros* contributed most numbers to the longer mode. A variety of small crustaceans formed modes at lengths <10 cm. *Coryphaenoides subserrulatus* formed a mode around 32–34 cm whereas the lengths of the other dominant fish, *H. johnsonii*, were spread over a wide range. The length mode of *H. atlanticus* was around 36cm (Fig. 7).

IN SITU TS ANALYSIS

In situ TS data were obtained by vertically lowering the towed body over schools of orange roughy observed on the hull-mounted echo-sounder. Difficulties were experienced in obtaining *in situ* TS data of orange roughy in schools due to an avoidance reaction (Koslow et al. in press). The schools reacted to the low frequency sound emitted by the towed transducer up to 150 m away by tightly packing, making *in situ* detection difficult. Other species on the seamount appeared to be undisturbed by the towed transducer and *in situ* TS' values of these species were easily obtained. Thirteen vertical drops (Fig. 8) around the seamount that ranged from transducer depths of 550 to 900m and bottom depths of 630 to 1050m were collected in 1992. Dominant modes in the data were identified by visual inspection at -31dB, -44dB, -50dB and -55dB. A summary of all the TS data is given in Table 4 with the PDF for TSs for each vertical drop given in Fig. 9.

To isolate orange roughy targets, investigations were conducted on TS data in and around schools observed to be displaying an avoidance reaction and compared to diffused single fish above the school. TS data were used from both vertical drops and towing the split-beam transducer over the schools. Examples of echograms with an associated PDF of TS data in and out of the schools is shown in Fig. 11a and b. Very little TS data were obtained in the schools primarily due to the packing density and the range to the low TS targets. The TS distributions in the schools show many modes with no clear peak that can be associated to orange roughy. The low number of high TS values may be derived from multiple targets within the schools.

The dominant modes in the *in situ* TS data at ~ -50dB and -55dB occurred throughout the water column from 600m to 1000m. These modes were associated with deep mesopelagic assemblages dominated by myctophids with air-filled swim bladders. Myctophids caught in pelagic trawls in depths of 650 to 900m had mode lengths of approximately 5 and 8cm. The expected TS of myctophids can be compared with *in situ* measurements from North Sea herring (Reynisson 1993) due to their similar shape and air filled swim bladder. The relationship of TS to standard length for herring is $TS = 20^* \log l - 67.1$ where the length of the fish (l) is in cm. Applying this relationship to these data yields -53.1 and -49dB for the 5 and 8 cm myctophids which is close to the observed modes. A change in the relative TS of herring and myctophids is expected due to the different depth habitats, but this change is expected to be small at 38kHz. A small peak in the *in situ* data was also found at -43 to -44 dB. This was at first attributed to orange roughy but is more likely to be the abundant macrourid, *C. subserrulatus* which has an gas/wax ester-filled swimbladder and was caught from 650-900m. The mean total length of a *C. subserrulatus* is ~33cm. Using a model of blue grenadier TS from Do and Surti (1990) ($TS=20^*\log l - 72.7$ where the length, l, is the total length of the fish in cm) the estimated TS of a whiptail is -42.3 dB, this is very close to the *in situ* peak at -44dB. Another small peak was found at -31dB and in predominantly deeper water. This large target is likely to be *H. johnsonii* which has a gas-filled swimbladder and was caught in demersal and pelagic trawls in the deepwater.

To observe changes in the TS results with depth the data were grouped with non-overlapping windows centred on the modes observed and represented as a percentage of the total number of detections for each drop, table 4. The change in proportions of the various species groups with depth is shown in Fig. 10. No major change in TS distribution with depth was found that might indicate a separate peak for orange roughy or a major change in species composition.

INDIRECT TETHERED TS

Results of tethered dead specimen tests yielded an on-axis TS for a 35cm orange roughy to be -44.4dB. This result was very sensitive to the time the orange roughy was immersed in the water. A 5-8dB difference in TS was found comparing data obtained just after immersion to data from fish left overnight. This change in TS was attributed to air bubbles entrapped in the numerous cavities of the orange roughy's head. Therefore we have little confidence in these results. Because small air bubbles are compressed and dissolve under pressure, a 35cm orange roughy was rigidly suspended under the towed body along with a calibration sphere and lowered to a depth of 750m. The TS of the orange roughy at 700m was -53dB, and the mean values ranged from -50.1 to -53.5dB for depths 200-750m. The precise pitch/roll position of the orange roughy was not monitored throughout the experiment although it was rigidly fastened in an on-axis position.

MODEL RESULTS

Orange roughy shape for 150 fish of standard length 30-40 cm was entered into the model with an on-axis change in TS of only 1.4dB for this size range. The TS response is quite flat and is due in part to the side to side curvature for on-axis orange roughy through the size range of 33-39.5 cm being constant at 2.25 cm. This agrees well with the tethered experiment results that yield a TS change of 1.5dB for the 30-40cm size range. To obtain an absolute TS value from the model requires a value for the fish flesh reflectivity R. No measures of R were available for orange roughy but for demersal fish this value ranges from 0.04 to 0.01 (Shibata 1970) which for a 35cm fish yields an on axis TS range of -43.1 to -49.1 dB.

DISCUSSION

No obvious peak in the *in situ* data was found for 35cm orange roughy that coincided with reported values based on in-direct measurements of -36dB (Do and Coombs 1989) and -41.3dB (Elliott and Kloser 1993). To establish the bounds for the expected value for orange roughy TS, extrapolation by weight of *in situ* data from other fish that do not have swim bladders such as Atlantic mackerel (*Scomber scombrus*) has been investigated by MacLennan and Simmonds (1992). Applying this principal here, the quantity 10log(Ow/Mw) is added to the mackerels TS. Here Ow(1.5kg) is the mean weight of a 35cm orange roughy and Mw (287g, 244g) is the mean weight of a mackerel with a TS of -54.6dB and -59.0dB respectively. This yields a TS of orange roughy to be in the range of -47.4 to -51.1dB. The indirect methods of estimating orange roughy TS reported here lead to a minimum value of -53dB which overlaps the *in situ* TS of large (8cm) myctophids at -50dB. The *in situ* TS of orange roughy encountered in the dispersed phase may be masked by the TS of these large myctophids. Examination of the *in situ* data in and around the orange roughy schools that exhibited a scare reaction gave similar modes at -50dB.

From our observations it is plausible that the TS of orange roughy is in the range of *in situ* TS values -48 to -52dB where the large myctophid peak is found. It is possible to seperate two species with the same TS but different size and swimbladder characteristics based upon the standard deviation of tracked single fish. A small fish with a gas-filled swimbladder and a large fish without a gas-filled swimbladder may have different directivity patterns. Tracking single fish over a large range of pitch and roll angles and observing the standard deviation of the TS should enable separation of different species. The echo-traces of individual fish recorded from the vertical drop data were analysed in this way. A fish was analysed if it was tracked for 3 or more pings. The mean TS and standard deviation were computed using a software program supplied by Ona and Hansen (1991). A plot of the mean TS verses standard deviation does not show any distinguishable groups of targets in the -45 to -55 dB range (Fig. 12). This analysis is not conclusive due to the narrow beam (6.5deg.) of the echo sounder and the small range of pitch/roll angles that the data was collected over. Further work with a wider beam angle (20deg.) split-beam transducer is proposed and should provide better discriminatory power. The differences in the myctophid and orange roughy size and swim bladder types could also be detected using multi-frequency methods. The different backscattering responses could help in identification of individual fish and schools.

CONCLUSION

A summary of all the TS data from the various methods is shown in figure 13. The large range can be narrowed by the upper bound for the range of *in situ* measurements at -48dB and the lower bound of the tethered measurements at -53dB. Further experimentation is required to distinguish orange roughy from large myctophids *in situ* which may be possible using wide angle split-beam transducers or a multi-frequency approach at 12kHz, 38kHz and 120kHz.

ACKNOWLEDGMENTS

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Fig. 1. Block diagram of acoustic system used on-board the research vessel *F.R.V. Southern Surveyor.*

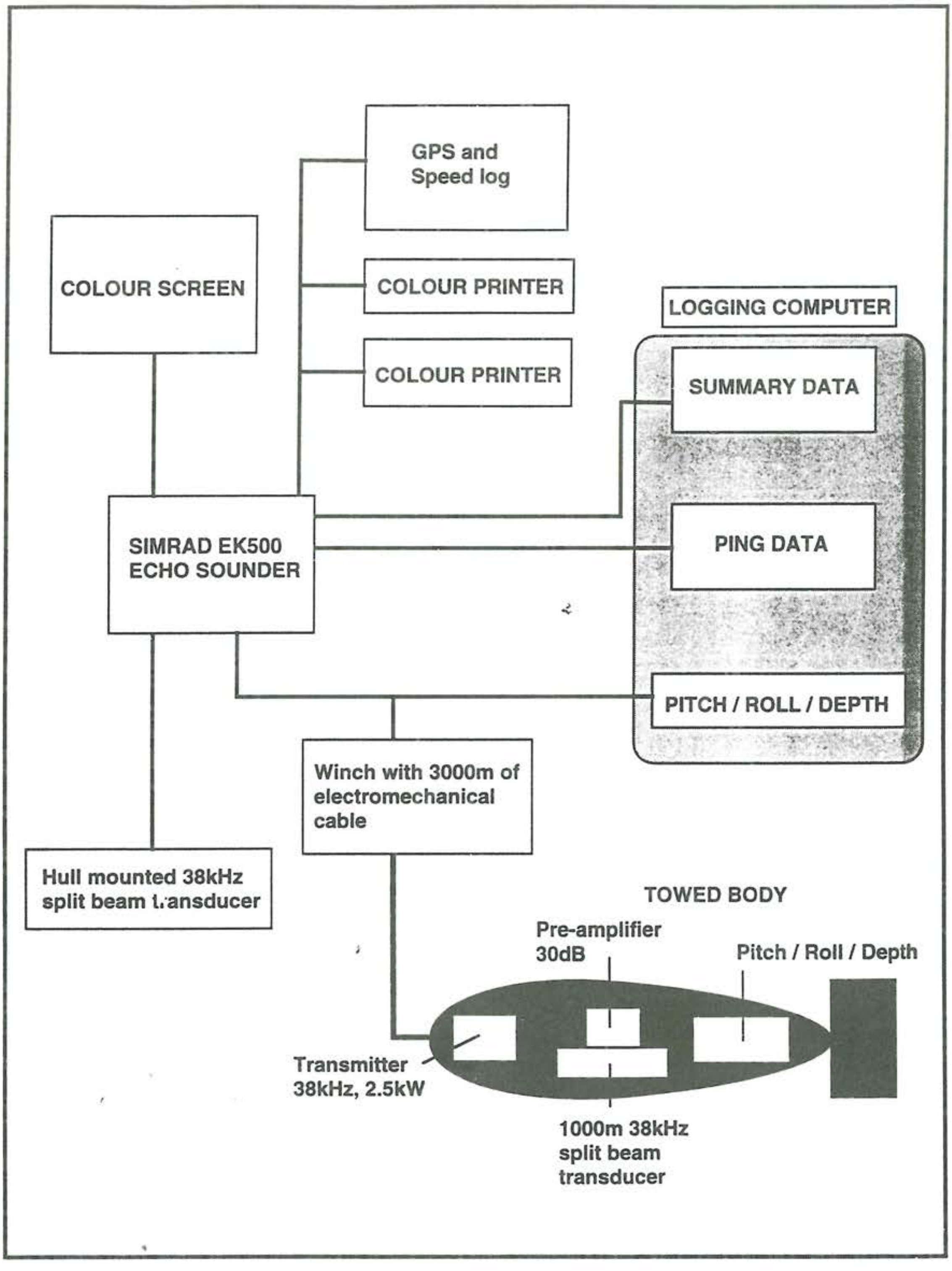

Fig. 2. Set up for tethered orange roughy experiment.

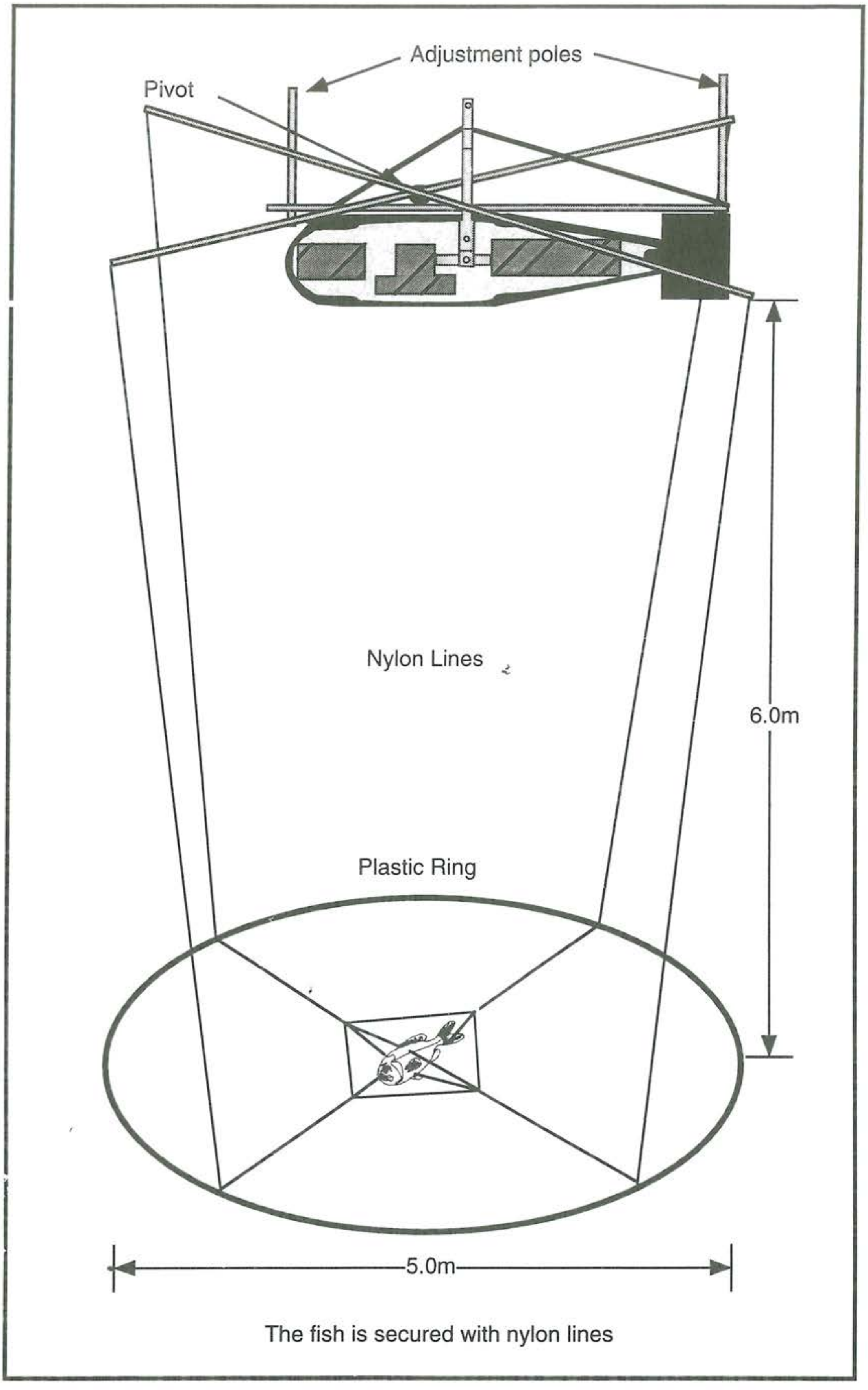

Fig. 3. Simple model parameters

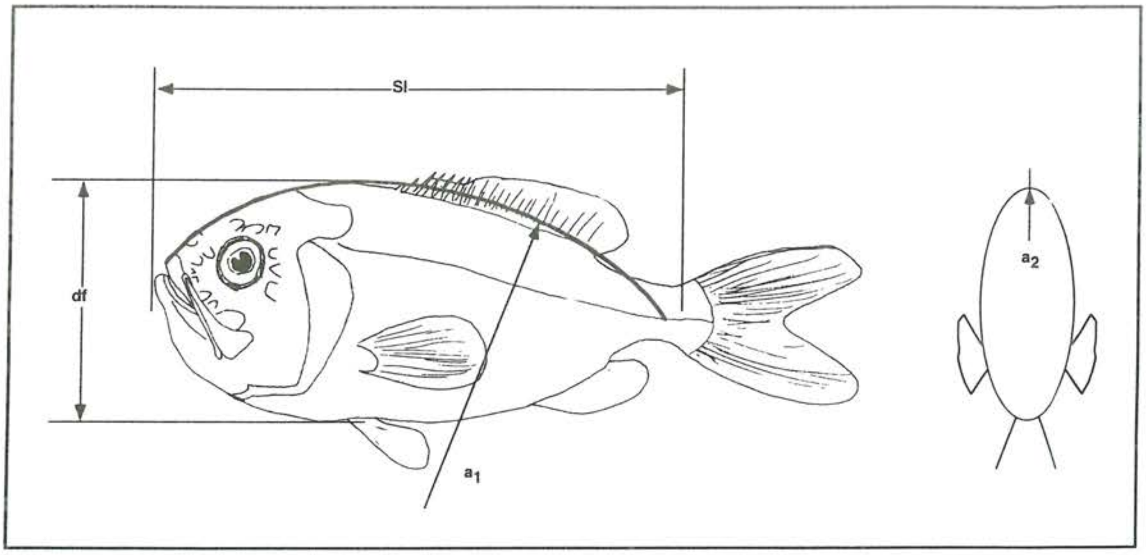

Fig. 4. Echogram of St Helens seamount showing examples of the layered marks targeted by pelagic trawls.

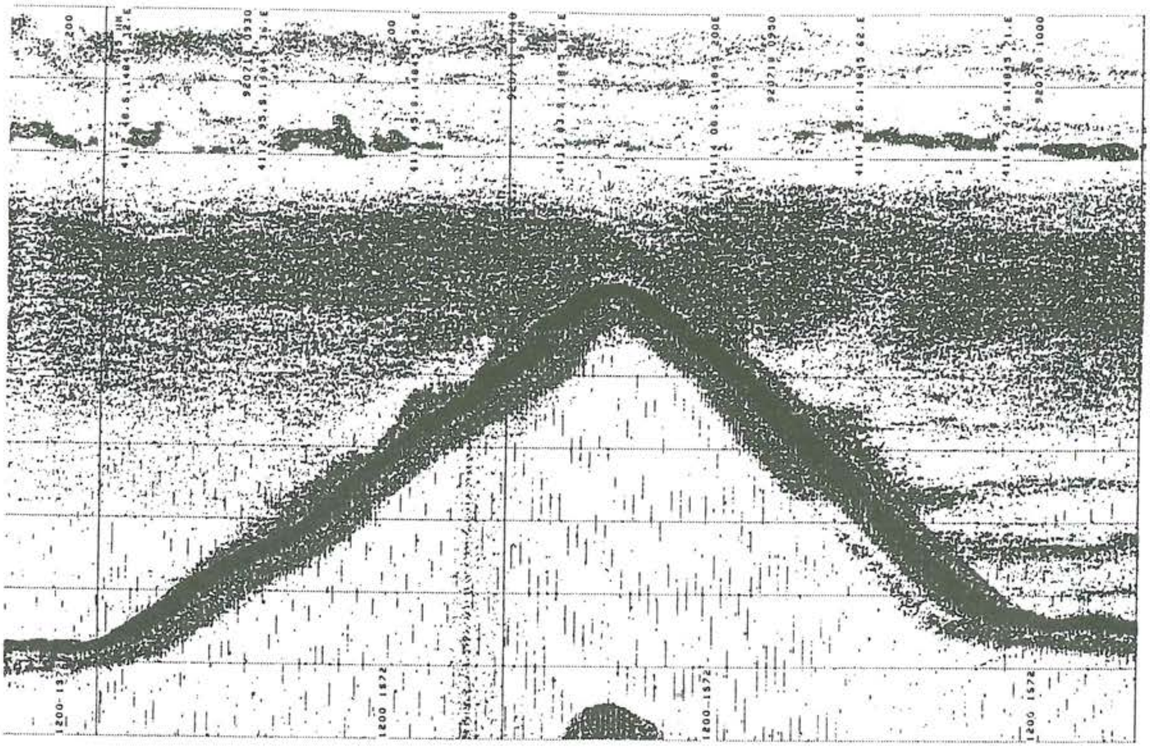

Fig. 5. Fish lengths combined by swimbladder category for pelagic trawls over St Helens seamount (relative frequency data are standardised for volume filtered).

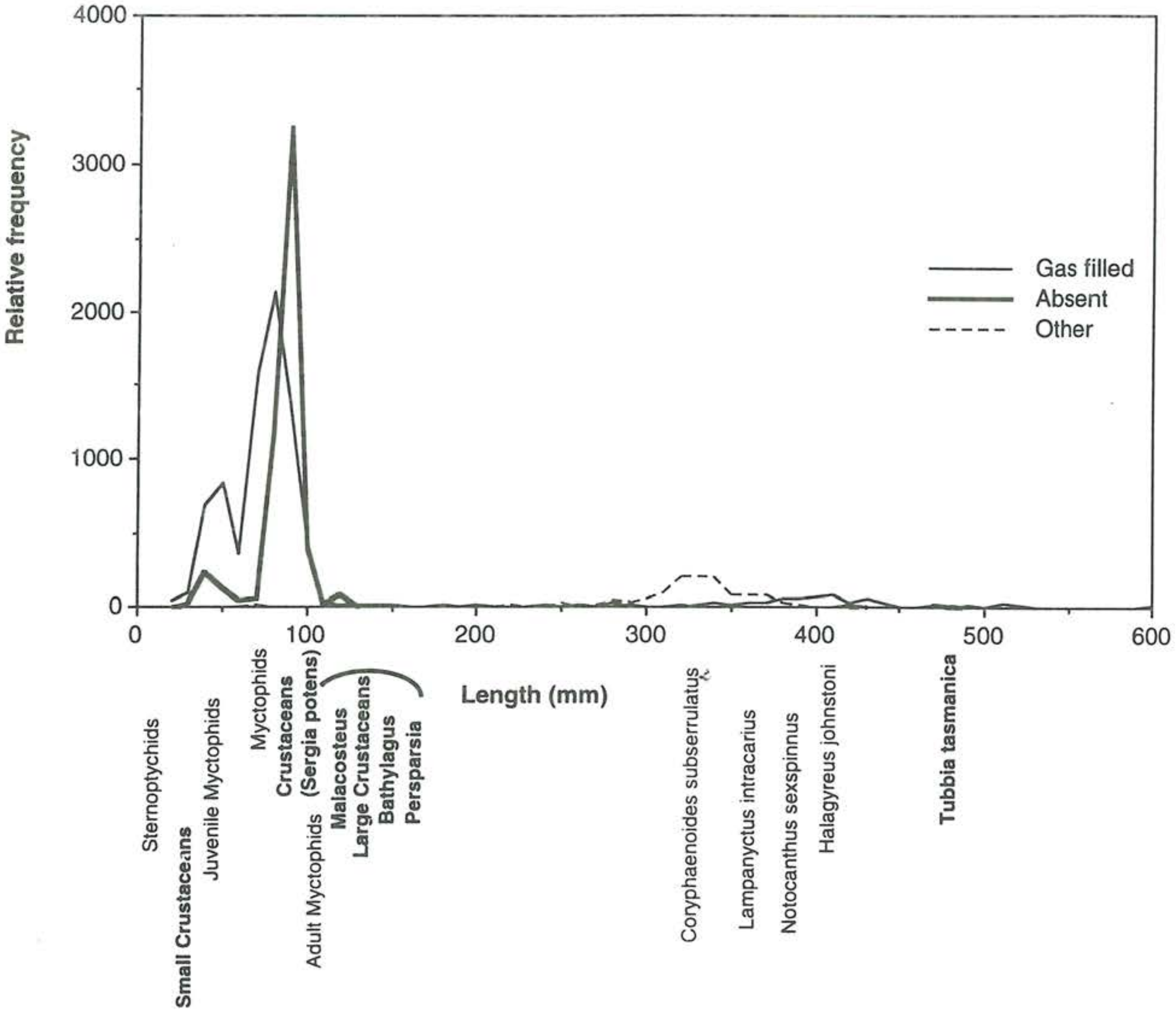

Fig. 6. Fish lengths combined by swimbladder category for pelagic trawls over flat bottom commercial orange roughy fishing grounds (relative frequency data are standardised for volume filtered).

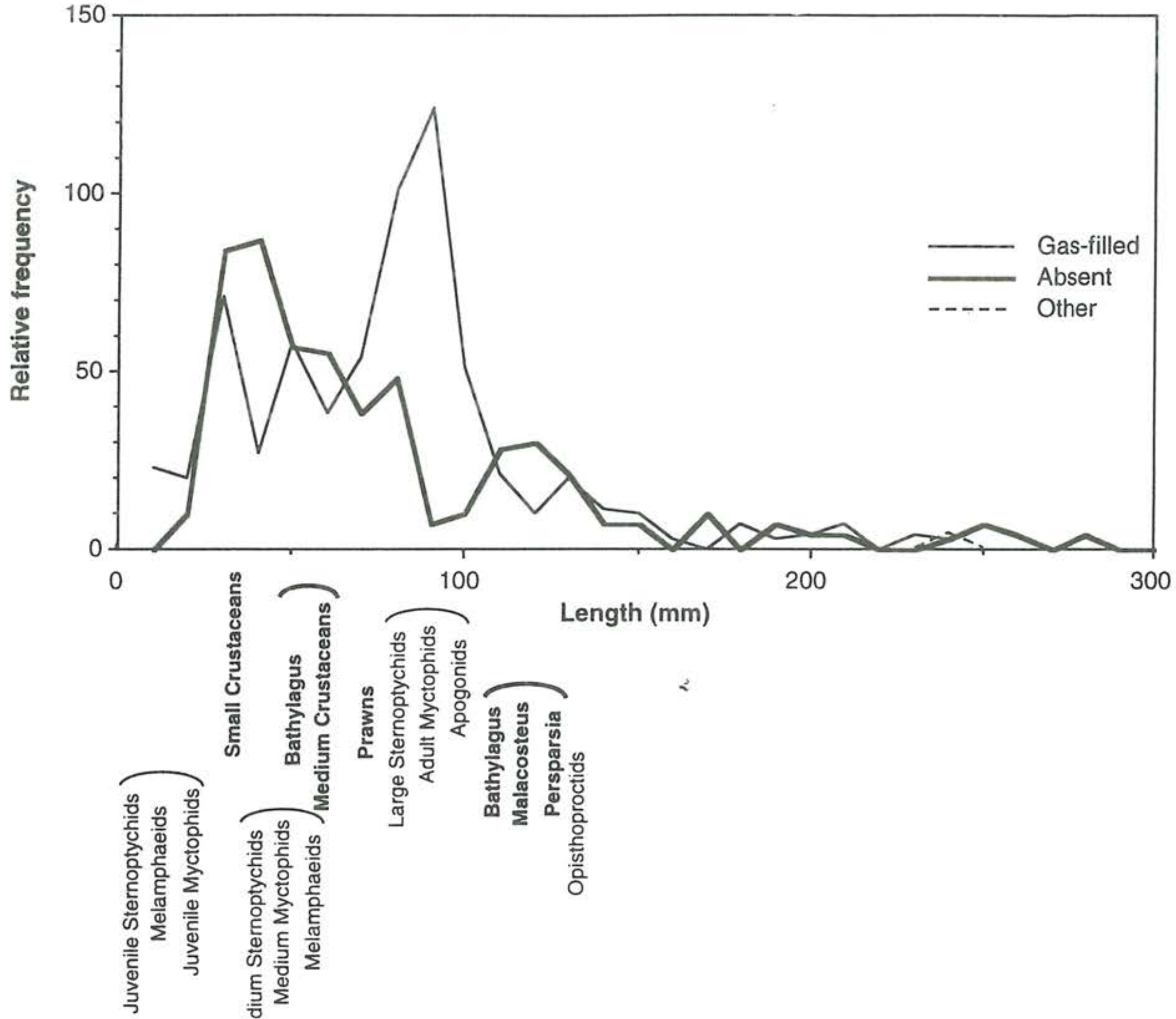

Fig. 7. Lengths of major species from demersal trawls on St Helens seamount: orange roughy (H. atlanticus), morid cod (H. johnsoni) and whiptail (C. Subserrulatus).

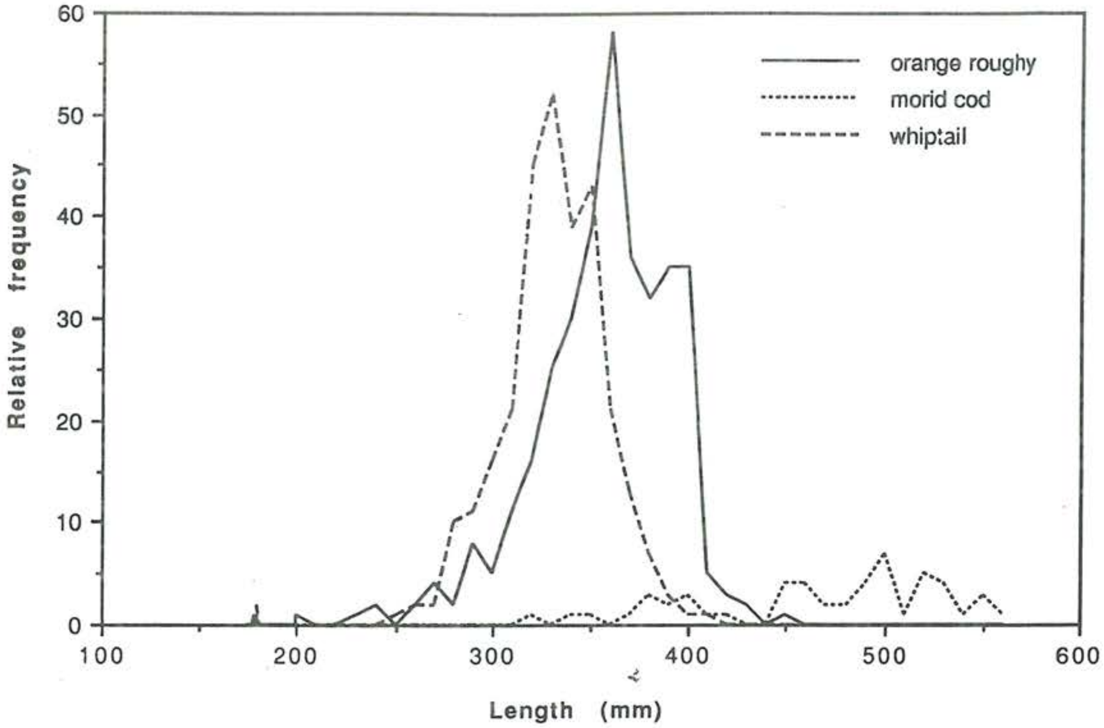

Fig. 8. Location of vertical drops on St. Helens seamount

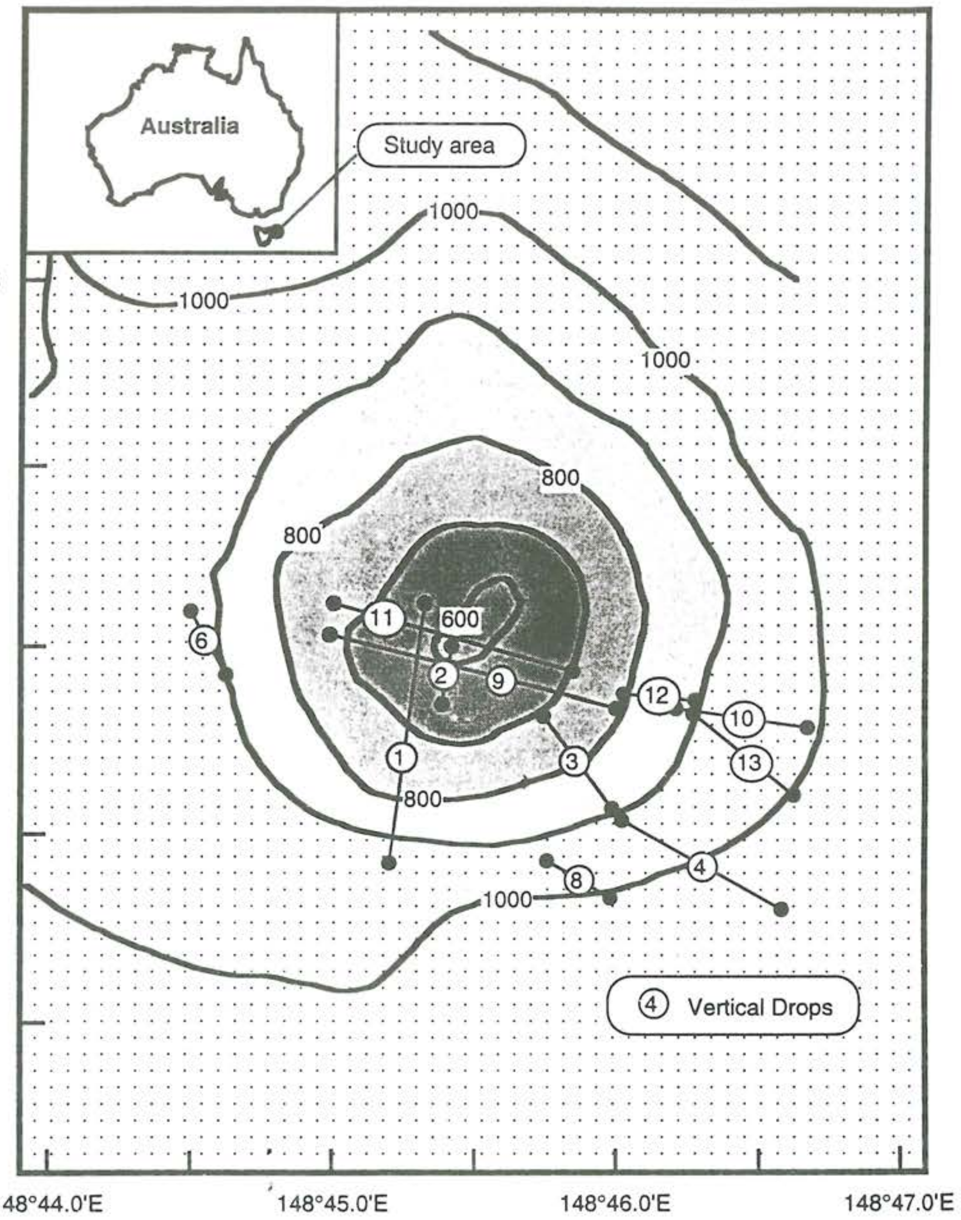

Fig. 9. Probability density functions for each vertical drop.

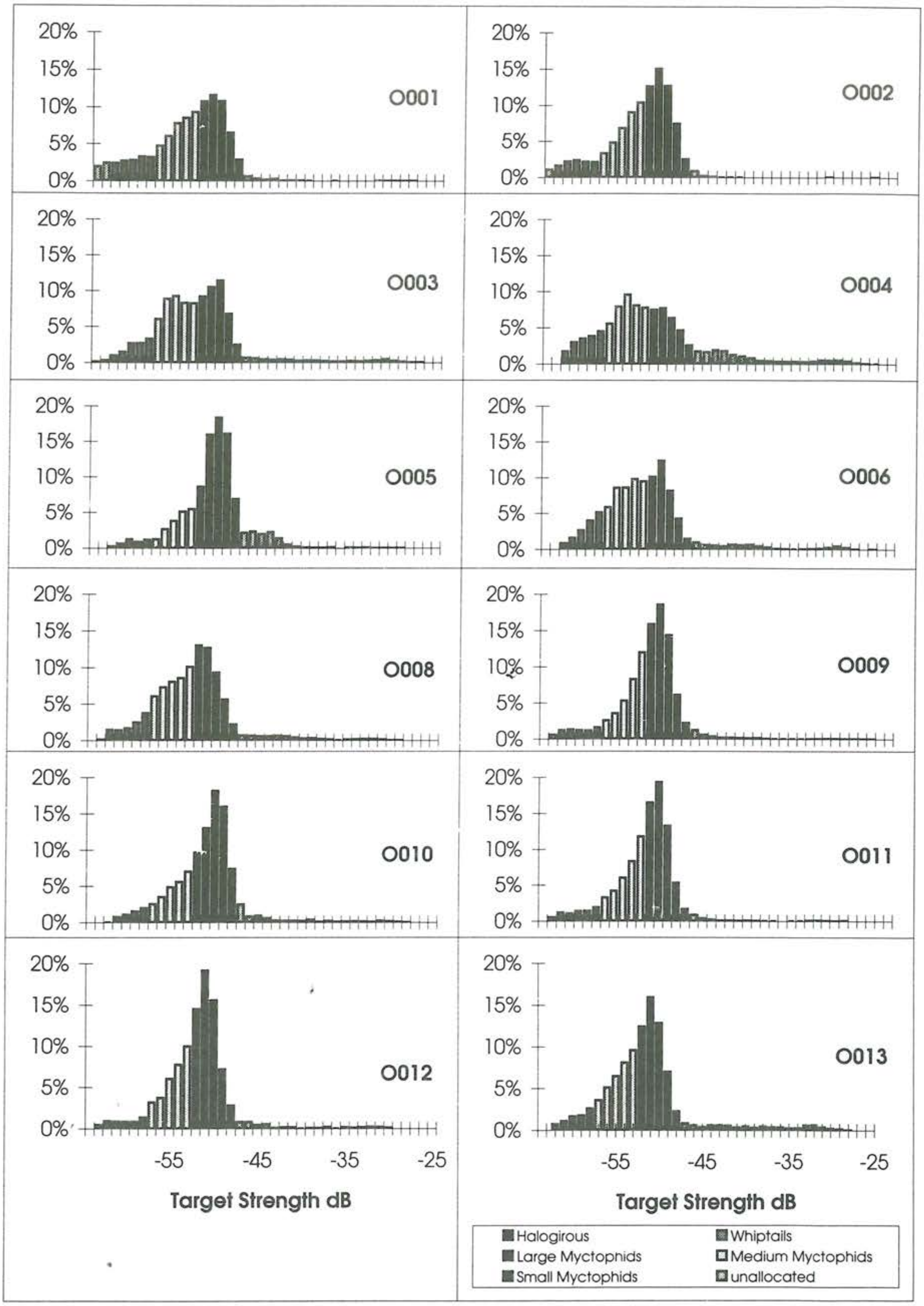

Fig. 10. TS groups represented by average bottom depth.

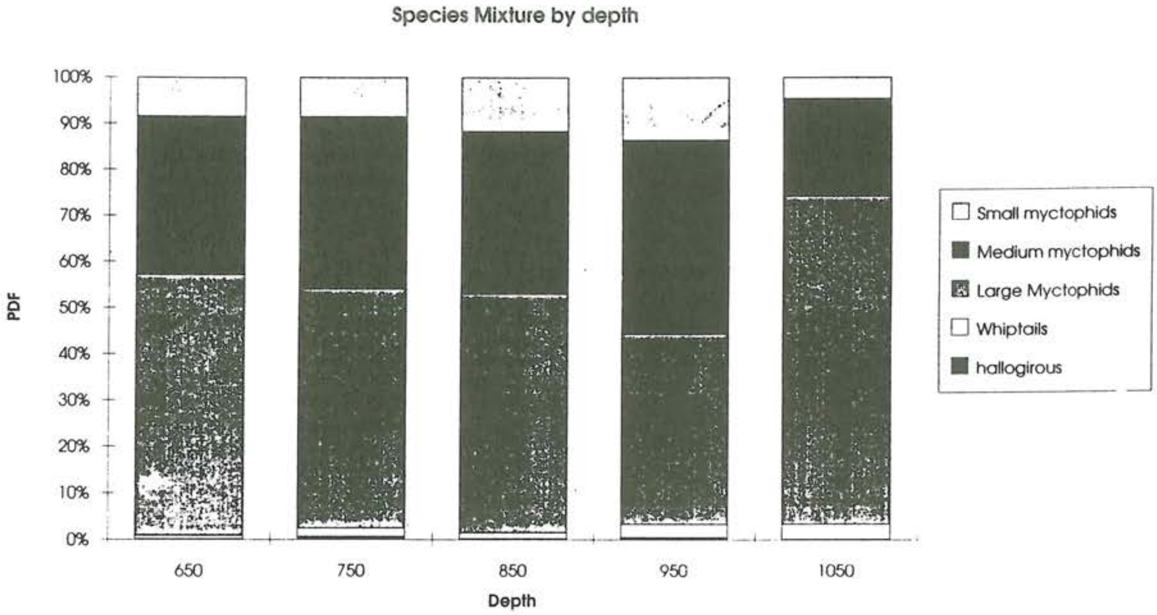

Fig. 11a. Typical example of *in situ* TS measurements inside and outside a dense orange roughy school. Outside the school a large number (793) of targets are resolved with dominant modes at approximately -55 and -50dB. In the school very few targets are resolved, 26 for S1 and 21 for S2. These school targets are generally of higher values and due to the density of fish may be multiple targets.

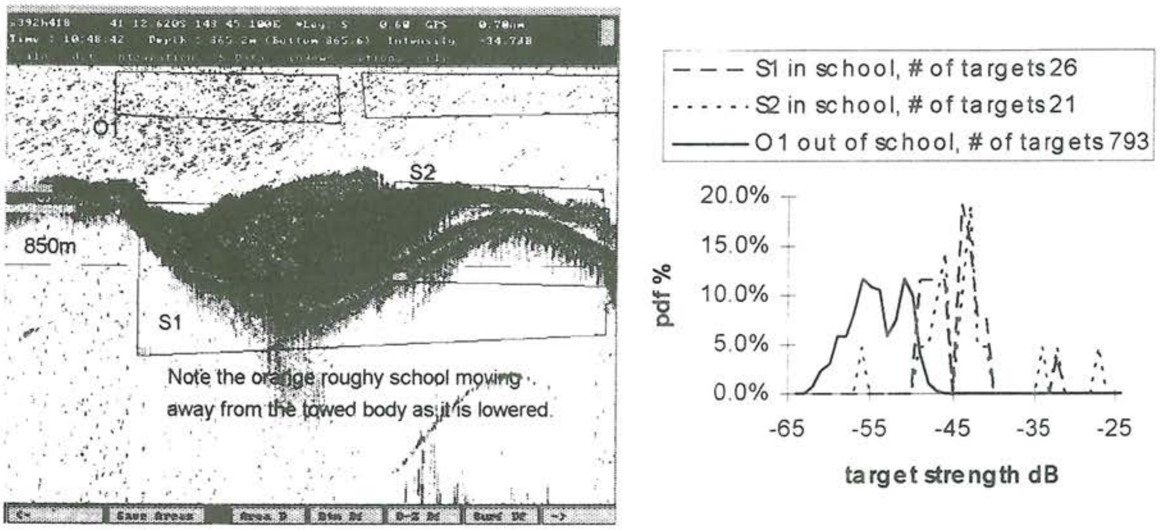
Note the orange roughy school moving away from the towed body as it is lowered.

Fig. 11b. An example of *in situ* TS measurements inside and outside a medium density fish concentration of orange roughy and myctophids. Outside the school a large number (1441) of targets are resolved with dominant modes at approximately -50dB. Near the bottom where the chance of finding orange roughy is higher only 50 targets are resolved in zone S1. These targets have modes at -55, -50dB and -30dB. The lower value modes are beleived to be from myctophids and orange roughy whilst the upper mode could be from multiple targets.

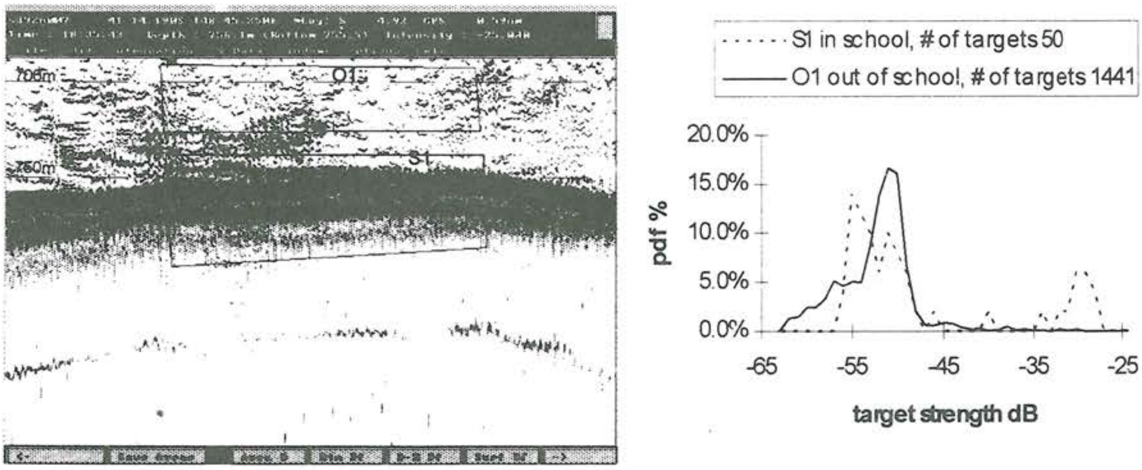

Fig. 12 TS vrs log of standard deviation for tracked fish with 3 or more pings.

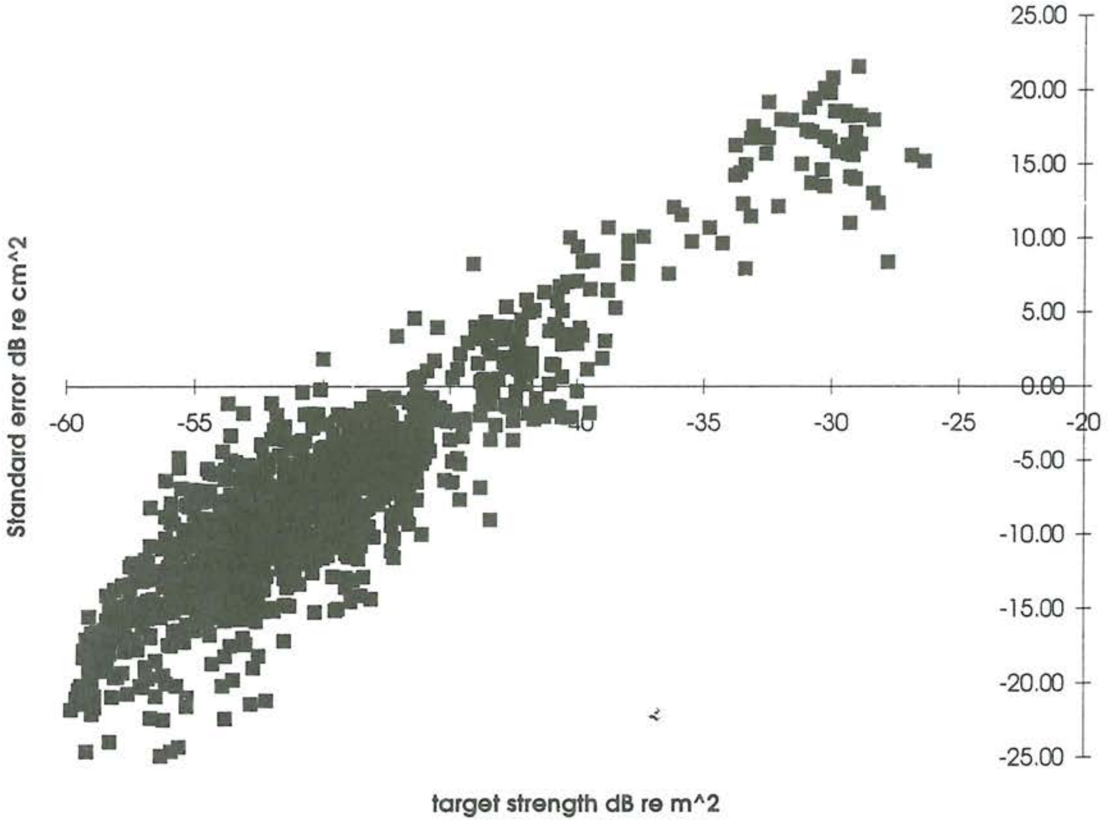

Fig. 13 Summary of different methods for determining orange roughy TS at 35cm standard length.

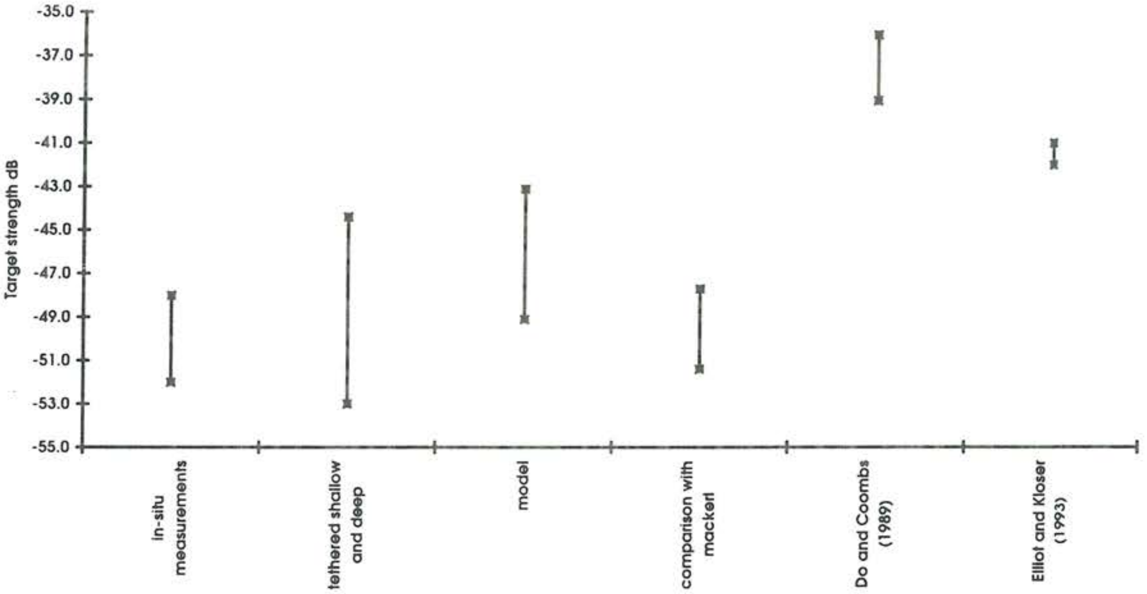

Table 1. Calibration parameters and equipment settings for collection of *in situ* TS data.

Parameter	*Towed Body*
Echo Length Min.	0.8
Echo Length Max.	1.8
Gain Compensation	4 dB
Phase deviation	2 degrees
Minimum Value	-60 dB
Pulse Length	0.3 mS
Bandwidth	3 kHz
year	92
Angle sensitivity	24.5
TSc @600m	29.6
Beam width	6.5 degrees
Angle offsets	
Alongships	-0.2 degrees
Athwartships	0 degrees
Trransducer depth sensitivity from 500-900m	
where dTS = slope * depth + constant	
slope	-0.0037
constant	5

Table 2. Summary of the distribution of trawl effort and catch data.

Target assemblage	Mid-water, adjacent to seamount	Mid-water, over flat ground	Near bottom, combined seamount sides and base
Fishing method	Pelagic	Pelagic	Demersal
No. samples	38	10	3
Total no. fish caught	1508	1236	1553
Total wt. fish caught (kg)	36	3.9	767
No. taxa	58	57	20
No. measured	1075	733	757

Table 3. Summary of catch composition of dominant species. Pelagic and demersal catch data are shown separately; rank order and % composition are for standardised catch data treating fish and crustacea separately.

	PELAGIC				DEMERSAL			
	Rank nos	% of total nos	Rank wt	% of total wt	Rank nos	% of total nos	Rank wt	% of total wt
Myctophidae								
D. danae	3	9	10	1	–	0	–	0
H. hanseni	5	4	17	<1	–	0	–	0
L. australis	1	34	4	7	–	0	–	0
L. proceros	2	26	7	4	–	0	–	0
Macrouridae								
C. subserrulatus	4	9	2	17	1	60	2	10
Moridae								
H. johnsonii	9	4	1	47	3	3	3	6
Trachichthyidae								
H. atlanticus	–	0	–	0	2	33	1	70
Total % fish catch	–	86	–	77	–	96	–	86
Sergestid prawns								
S. potens	1	86	1	97	–	0	–	0

Table 4. Summary of vertical drop *in situ* TS data.

FILE	O001	O002	O003	O004	O005	O006	O008	O009	O010	O011	O012	O013
time 1	1337	1514	1543	1557	1628	1735	1859	1957	2036	2155	2230	2236
lat deg 1	41	41	41	41	41	41	41	41	41	41	41	41
lat min 1	13.8	13.89	14.14	14.4	14.65	13.89	14.59	13.94	14.24	13.86	14.19	14.26
lon deg 1	148	148	148	148	148	148	148	148	148	148	148	148
lon mim 1	45.45	45.32	45.84	46.09	46.82	44.48	45.76	45.03	46.26	45.01	46.05	46.27
time 2	1406	1540	1557	1622	1637	1747	1907	2032	2047	2223	2233	2252
lat deg 2	41	41	41	41	41	41	41	41	41	41	41	41
lat min 2	15.22	14.13	14.4	14.57	14.8	14.11	14.72	14.24	14.31	14.12	14.22	14.37
lon deg 2	148	148	148	148	148	148	148	148	148	148	148	148
lon min 2	45.17	45.78	46.09	46.69	47.03	44.63	45.95	46.06	46.66	45.86	46.15	46.63
Calibration	2.954	2.842	2.563	2.284	1.737	2.4704	2.5076	2.954	2.582	2.954	2.72	2.396
Pulse Length	short	short	short	short	short	short	short	short	short	short	short	short
Bottom Z 1	270.65	110.5	143.32	241.03	217.05	264.96	263.8	143.95	246.7	80.447	181.72	255.245
Average bottom (z1+ av	820.65	690.5	798.32	971.03	1094.05	944.96	933.8	693.95	896.7	630.447	794.72	955.245
TB depth 1	550	580	655	730	877	680	670	550	650	550	613	700
TB depth 2	550	580	655	730	877	680	670	550	650	550	613	700
Average TB depth	550	580	655	730	877	680	670	550	650	550	613	700
Number of Targets	4230	10324	7245	9861	2635	4973	4321	22062	5407	13866	2299	6413
Target Density	61	397	518	152	293	414	90	294	492	204	766	401

Frequency of detection for TS range in dB with alloted species												
-25 to -26 unalocated	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
-27 to -34 Halagyreus johnsonii	0.0%	0.1%	1.0%	1.0%	0.1%	0.0%	0.3%	0.1%	0.5%	0.4%	0.3%	0.7%
-35 to -39 oreos	0.0%	0.0%	0.8%	0.6%	0.2%	0.3%	0.4%	0.1%	0.4%	0.1%	0.3%	0.9%
-40 to -45 macrourids	0.8%	0.2%	2.0%	3.4%	3.1%	3.2%	2.1%	1.2%	1.4%	0.7%	1.3%	1.9%
-46 to -47 unalocated	1.0%	1.2%	1.3%	2.1%	3.4%	1.3%	1.0%	1.8%	1.3%	1.3%	1.7%	1.4%
-48 to -52 large myctophids	42.7%	50.6%	41.1%	29.9%	68.3%	36.2%	42.7%	57.4%	56.9%	56.0%	59.6%	52.0%
-53 to -57 medium myctophids	36.6%	34.6%	41.6%	44.1%	20.5%	44.2%	42.1%	32.1%	31.4%	33.8%	31.3%	34.7%
-58 to -62 small myctophids	14.5%	10.6%	11.5%	18.9%	4.4%	14.8%	11.1%	6.8%	8.1%	7.1%	5.0%	8.3%
-62 to -64 unallocated	6.8%	3.6%	1.5%	2.0%	0.3%	0.9%	1.6%	1.9%	0.8%	1.7%	1.4%	0.8%

CHAPTER THREE

ACOUSTIC BIOMASS ASSESSMENT OF A SPAWNING AGGREGATION OF ORANGE ROUGHY (*HOPLOSTETHUS ATLANTICUS*) OFF SOUTHEASTERN AUSTRALIA FROM 1990-93

ACOUSTIC BIOMASS ASSESSMENT OF A SPAWNING AGGREGATION OF ORANGE ROUGHY (*HOPLOSTETHUS ATLANTICUS*) OFF SOUTHEASTERN AUSTRALIA FROM 1990-93

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ABSTRACT

Acoustic surveys with hull-mounted and deeply towed transducers were carried out from 1990-93 on a spawning aggregation of orange roughy off the east coast of Tasmania. Echo integration was carried out to 150 m above bottom, and the data were stratified by 100 m depth strata. Species composition on the spawning ground was assessed using primarily demersal and pelagic trawl samples. The community appeared to be dominated by orange roughy (95% of individuals) at the 700-900 m depth strata and to decline at shallower and deeper depth strata. Other dominant groups included large and small myctophids, whiptails and morid cods. Acoustic backscattering declined by approximately half after 1990. Based upon the hull-mounted data, the biomass of orange roughy on the spawning ground declined from approximately 28,000 tonnes in 1990 to 14,500 tonnes in 1991 and to 12,900 tonnes in 1992-93. The hull-mounted echo integration estimates were consistently lower than the towed body by a factor of 1.5-1.7, most likely due to sampling threshold effects at the edge of the acoustic beam when sampling over large depths.

INTRODUCTION

Echo integration techniques have been widely applied to assess the biomass of fish stocks over the continental slope and in epipelagic waters. The theory and methods are well established (Johannesson and Mitson 1983; McLennan and Simmons 1992). Recently these techniques have been applied to deep water species, such as orange roughy (*Hoplostethus atlanticus*) (Do & Coombs 1989, Elliott & Kloser 1992) that occur widely in the mid-slope region 700 - 1200m around New Zealand and southeastern Australia (Koslow et al. 1994).

Approximately half the Australian orange roughy fishery has been obtained historically from a single spawning aggregation that forms from early July to early August around a small seamount (area: ~ 10 km^2) off the northeast coast of Tasmania. The seamount, known as St. Helens Hill, rises from approximately 1000 m to 600 m depth. The aggregation was first commercially fished in 1989. The orange roughy typically occur in large aggregations around the hill and range from the bottom to as much as 150 m into the water column. Several factors limit the usefulness of hull-mounted or near-surface deployed acoustic systems for the acoustic assessment of deepwater fish. The major factor, which arises from the association of orange roughy with steep bottom topography, is the large acoustic dead-zone caused when the acoustic beam reverberates off the side of the hill, such that fish at greater depths within the beam cannot be distinguished from the bottom echo (Mitson 1982). Other factors include acoustic attenuation from near-surface bubbles, which varies with sea conditions (Dalen & Lovik 1981); the effects of ship motion (Stanton 1982); uncertainties in the sound absorption constant (Fisher and Simmons 1977; Francois and Garrison 1982) and beam threshholding (Foote 1991). These factors may be largely or entirely alleviated by deploying the acoustic transducer on a deep towed body (Fig. 1).

Through use of a deep towed-body acoustic system with split-beam transducer, single acoustic targets can be resolved and their size measured. Target strength is directly proportional to the biomass of acoustic targets, so it is a critical parameter in an absolute estimate of biomass. The size-frequency distribution of *in situ* targets also ostensibly provides independent data on community composition. However, such data contain potential biasses and require careful interpretation, due to beam thresholding (Foote 1991) and the effects of target density and distance from the transducer on target identification. Assessment of the proportion of orange roughy within a community appears particularly susceptible to bias, because the species has a marked avoidance reaction to the towed body within the range where individual acoustic targets may be resolved (Kloser et al. in prep.; Koslow et al. in press). Furthermore, due to the lack of an air-filled swim bladder in orange roughy, their target strength appears to be within the range of that of many myctophids and other relatively small midwater fishes that have air bladders; it has not yet been possible to resolve these two classes of targets *in situ* . As a result, it has not yet proved possible to use *in situ* target strength data to assess the composition of acoustic marks containing orange roughy (Kloser et al. in prep.). This is unfortunate, because trawl sampling, the commonly-accepted basis for assessing species composition, also contains major biasses due to net escapement and avoidance and the relatively small proportion of the water column that trawls, particularly demersal trawls, sample. These biasses are particulary problematic with orange roughy, which is only caught with demersal trawls, but which apparently extends into the water column up to 150 m above bottom.

This paper describes a 4 year study of the biomass of orange roughy on the St Helens Hill using both hull-mounted and towed transducers. Absolute estimates of orange roughy stock size obtained from the acoustic surveys are compared with an estimate from an egg survey of the spawning stock carried out in 1992 and with an estimate of stock size obtained from treatment of the acoustic estimates as a relative biomass index.

MATERIALS AND METHODS

The acoustic surveys were carried out on the research vessel *FRV Southern Surveyor* using a Simrad EK500 echo sounder connected to both a standard Simrad 38kHz (7 degrees full angle) split-beam hull-mounted transducer and an EDO Western 38kHz (6.5 degrees full angle) split-beam transducer rated to 1000 m mounted in a towed body. The towed body was built in-house to perform echo integration surveys to 500m depth at 6 knots and *in-situ* target strengths measurements down to 1000m at 3 knots with 2000 m of cable out. The towed body was a dead-weight type (750 kg weight) that housed the transducer, transmitter, pre-amplifiers and a monitoring package. The pitch, roll, depth and operating voltage of the transducer were monitored and displayed continuously. The towed body was connected to the vessel by 3000 m of electromechanical cable that consisted of 5 single conductors required for power, trigger and monitoring signals, and 4 twisted shielded pairs that carried the pre-amplified split-beam acoustic signals. The acoustic and GPS navigational data were logged on a PC connected to the Simrad EK500 by ethernet. A block diagram of the acoustic system is provided in Figure 2.

The acoustic equipment was calibrated at the beginning of each cruise using a standard -36dB, 60mm copper sphere to obtain the on-axis echo integration constant (Foote 1982, Simrad 1992) . This technique combines the electrical and acoustic constants of the system, such as transmitter power, the transmit and receiving efficiency of the transducer, and receiver gain. The only further parameter required to specify the system, the ideal beam angle is measured by the manufacturer of the transducer. The towed transducer was also calibrated from 100 - 1000 m to correct for depth dependent changes in transducer sensitivity and to test for change in beam pattern. A calibration sphere was suspended fore and aft 10m under the towed body and was lowered through the water column. Four deep-water calibrations were carried out to obtain the calibration constants provided in Table 1. The survey parameters of absorption (α) and sound velocity (c) were calculated using the formulae of Francois and Garrison (1982) and MacKenzie (1981), respectively, based upon temperature and salinity profiles obtained on the survey ground with a Neil Brown conductivity-temperature-depth recorder (CTD).

In 1991-93, acoustic echo integration data were recorded from each ping simultaneously from hull-mounted and towed transducers. The values were recorded for 2 m depth intervals over a range of 1000 m and logged on an IBM-compatible personal computer (PC). The volume reverberation (Sv) values were corrected for depth and the system calibration constants. Typically 3 Mbytes of data were collected on a transect.

To analyse the data a program was developed, ECHOX, that enabled the acoustic data to be displayed and edited on a PC. The acoustic data were displayed as an echogram with 16 colour levels, each level separated by 3 dB. The dB scale is logarithmic to the base 10, so 3 dB represents an approximate doubling of intensity. The program permitted setting of background and spike noise thresholds, corrections for calibration and absorption changes, and editing of bottom and dead-zone levels.

The background Sv noise (commonly -85dB) was measured each transect by obtaining the average Sv value below the bottom signal at 800m where no acoustic reverberation signal existed and subtracting this value from all Sv data. Spike Sv noise occurred at very high values (commonly > -25 dB) due mainly to unsychronised sounders for the hull mounted data or occasional high vibration and electrical noise associated with the towed body system. Spike Sv noise greater than the threshold was replaced by the Sv value immediately above in the water column.

Bottom editing was required where the automatic depth tracking in the Simrad EK500 could not predict the bottom signal due to the slope of the hill. These high bottom signal values could potentially corrupt the acoustic data. Using ECHOX, the acoustic bottom line could be redrawn with a mouse. The dead-zone line or true bottom depth was set on the highest acoustic bottom signal; the dead-zone height was then estimated as the difference between the two lines. Backscattering within the dead zone was extrapolated from the mean Sv in the 10 m above it.

In 1990, only hull-mounted bottom-locked summary acoustic data were available every 0.1nm along the cruise track. The output consisted of Sa values for every 2 m of water depth, extending from the bottom to 200m above. Dead-zone height was directly estimated from the colour echogram, and backscattering within the dead zone was extrapolated as for the 1991-93 data.

SURVEYS

The spawning aggregation of orange roughy on St. Helens Hill was surveyed from 1990-1993 during the approximate peak of spawning. Transects were spaced every 0.5 minutes of longitude in a north-south direction and at 0.5 minutes of latitude in an east-west direction. The timing of the surveys and the transects undertaken is shown in Table 2. A bathymetric plot shows the extent of the transects (Fig. 3). The acoustic returns were integrated from 0 to 150 m above the bottom. The acoustic data were subsequently stratified for analysis by 100 m bottom depth intervals due to differences in species composition and levels of echo returns with depth. For the 1991-93 data, the calibrated Sv values were summed each ping vertically over 75 2-m intervals (d_n) of depth (D) and averaged horizontally for m pings (p_m) to give the mean area backscattering coefficient, Sa, for a given length of acoustic transect data:

$$Sa = \frac{\sum_{p=1}^{m} *(D * \sum_{d=1}^{n} 10^{\frac{Sv_{p,d}}{10}})}{p_m} \times 4\Pi \times 1852^2 \quad m^2/nm^2$$

For the 1990 data 75 of the 2 m Sa values were summed, plus the dead-zone correction for each log interval. The weighted arithmetic mean Sa_j and variance s_j^2 of the Sa_i values for each depth interval area j were obtained by weighting the Sa_j values by segment length L_i expressed as:

$$\overline{Sa_j} = \frac{1}{n} * \sum_{i=1}^{n} W_i * Sa_i \quad \text{where} \quad W_i = \frac{L_i}{L_j} \quad \text{and} \quad \sigma_j^2 = \frac{1}{n-1} * \frac{\sum_{i=1}^{n} W_i * (Sa_i - \overline{Sa_j})^2}{\sum_{i=1}^{n} W_i}$$

The biomass for a given species i in an area j is expressed as a function of the mean backscattering in the region, Sa_j (m^2/nm^2); the proportion of the species in numbers, F_i; their target strength, TS_i; individual fish weight, W_i in kg; and area of the region, A_j, in nm^2 by:

$$\text{Biomass}_{ij} = F_i \times \frac{Sa_j}{\sum_{i=1}^{n}(F_i \times 4\Pi \times 10^{TS_i/10})} \times W_i \times A_j \quad \text{kg}$$

The species composition of each 100 m depth stratum was estimated primarily with data from depth-stratified, targeted trawling using both pelagic and demersal gear. The pelagic trawl, an International Young Gadoid Pelagic Trawl (IYGPT) (wingspread: 11 m; mean headline height: 6-7 m) used a multiple opening and closing cod-end system that enabled four discrete depths to be sampled during each tow. The demersal trawls were carried out on both the research vessel and commercial vessels. Trawl gears were broadly comparable with mouth openings of approximately 100 m^2 (20 m wingspread and 5 m headline height). Mouth opening dimensions were measured with Scanmar net sensors on board the research vessel.

RESULTS

SPECIES AND SIZE COMPOSITION.

The proportions of major species and species groups from the demersal and pelagic trawls are shown in Tables 3 and 4. The demersal trawl samples from 700-900 were virtually entirely composed of orange roughy. This is consistent wtih commercial catches from St. Helens Hill, which are predominantly from this depth range and contain little bycatch. There are few samples from the very top of the Hill or at its base, where uncertainty regarding species composition is greatest. It is difficult to trawl on the peak of the seamount, due to the restricted area; also, successful trawling for orange roughy seems to depend upon 'herding' the fish down the slope of the Hill. However, although orange roughy may not be entirely lacking at this depth range, several species with shallower depth ranges are commonly caught at this depth, such as cardinal fish (*Epigonus telescopus*), blue grenadier (*Macruronus novaezelandiae*), and blue-eye trevalla (*Hyperoglyphe antarctica*). The single trawl from the base of the hill at 1000-1100 m contained only 7 fish. It is included because the species composition is consistent with the community composition observed on the flat ground in a broad-scale survey of trawlable ground at these depths: a community dominated by a mix of orange roughy, macrourids, sharks, morid cods, and several other species (Koslow et al. 1994).

The data from the pelagic trawls are notable for the complete lack of orange roughy. Orange roughy display a strong avoidance reaction (Koslow et al. in press), and the large commercial catches with demersal trawls appears to be due in part to the effect of 'herding' the fish to the bottom, where they can then be caught.

The pelagic catches were predominantly of large and small myctophids, but with an appreciable admixture of benthopelagic fishes, such as the morid cod, *Halagyreus johnsoni*, and the macrourid whiptail, *Coryphenoides subserrulatus*, particularly at deeper depth strata. These fishes apparently extend well into the water column.

The estimate of community composition that was used in the biomass assessment is shown in Table 5. The community at depths of 700-900 m, the region that is best-sampled, is assessed to be strongly dominated by orange roughy, consistent with the results of demersal trawling. There are few samples from shallower or deeper strata, but available data indicate that the proportion of orange roughy declines on either side of the depth preferendum, where most commercial trawl activity has occurred. The high proportion of '*H. johnsoni*,' at 600-700 m reflects catches at this depth of several additional fishes with similar high target strengths: cardinalfish, trevalla, and grenadier. At depths greater than 900 m, domination by orange roughy declines, leading to a community with a more balanced mix of orange roughy, macrourids, myctophids and morids.

The total catch of orange roughy from the hill was estimated to be 21,096, 11,456, 14,817, and 4,768 tonnes for 1990-93, respectively (A.D.M. Smith, pers. comm.). The mean weight of orange roughy was assumed to be 1.5 kg. The mean size of fish in the landings has been stable over the period of the fishery.

SURVEYS AND BIOMASS ASSESSMENT

Acoustic surveys were conducted with near-surface transducers from 1990-93; in 1991-93, data were recorded simultaneously from a transducer mounted in the deep towed body. The dates of the cruises, shown in Table 2, were comparable between years. The cruises were conducted in relatively calm weather, so there was no noticeable degradation of the acoustic signals from the hull-mounted transducer data due to surface bubbles or ship motion. However, a typical echogram (figure 4) displaying the raw data from both transducers shows the difference in resolution and the width of the dead zone and bottom signal between the two systems.

Acoustic estimates of biomass for major fish groups around St. Helens Hill based upon near-surface and deep-towed transducers are shown in Tables 6 and 7, respectively. There is a large decline in biomass between 1990 and succeeding years but little trend after 1991. The estimated mid-season adult stock biomass of orange roughy from 1990-93 is shown in Figure 5. The data are from the near-surface deployed transducer, but it is assumed that these data are biassed downward by a factor of 1.7. It is also assumed that 90% of spawners were within the survey area at the time of the surveys; that there is a 50:50 sex ratio; and that 90% of mature males spawned each year but only 54% of mature females in 1990 and 72% in 1991-93.

DISCUSSION

PRECISION OF THE ESTIMATES

The coefficients of variation (CV) of the survey estimates were generally between 11-15%. If one assumes that factors, such as species composition, did not vary significantly between years, this is the error that may be placed around each point treated as a relative index of stock abundance. This index may then be used to estimate original stock size based upon stock reduction analysis. However, there are a number of additional sources of potential error and bias, which are difficult to quantify, if the results were used as absolute estimates of stock abundance. Species composition is notably difficult to ascertain. If one assumed that 100% of all targets were orange roughy, the estimate for biomass on the spawning ground in 1993 would be 2.7 - 3.2 times higher than the present estimate based upon the hull-mounted and towed-body data, respectively. Due to the relatively low target strength of orange roughy, absolute estimates of its abundance are sensitive to error in estimates of community composition, particularly of the proportion represented by species with relatively high target strengths, such as macrourids and morid cods. The estimate of the proportion of spawners within the survey area at the time of the surveys is also open to question.

Values for Sa from the deep-towed transducer were higher than those from the near-surface transducer by a factor of 1.5 - 1.7 (1.8 - 2.3 dB) for the three surveys from 1991-93. Because the two transducers were recording data over the same ground, the consistency of this difference indicates a constant source of bias in one of the data sets. The difference is unlikely to be due to instrument error, because the transducers were calibrated each year at their depth of operation. The most likely source of error is from the acoustic sampling volume changing with depth (Foote 1991). Due to threshold effects, the effective sampling volume of the near-surface transducer may be effectively less than would be estimated from simple extrapolation of beam geometry through the water column. However, another possible source of error is the absorption of sound in sea water. The Francois and Garrison (1982) formula, which we use, results in backscattering approximately 1.5-2 dB higher than that of Fisher and Simmons (1977) over the depth range of this survey: i.e. the difference would be approximately double if we used Fisher and Simmons' formulation. Sound attenuation may be greater than estimated by Francois and Garrison, but there is insufficient data here to separate out the effects of changing sampling volume and sound absorption.

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Figure 1. Cartoon showing differences between acoustic surveys for deepwater fish with hull-mounted deep-towed transducers. Note in particular the reduced dead zone resulting from use of the towed body.

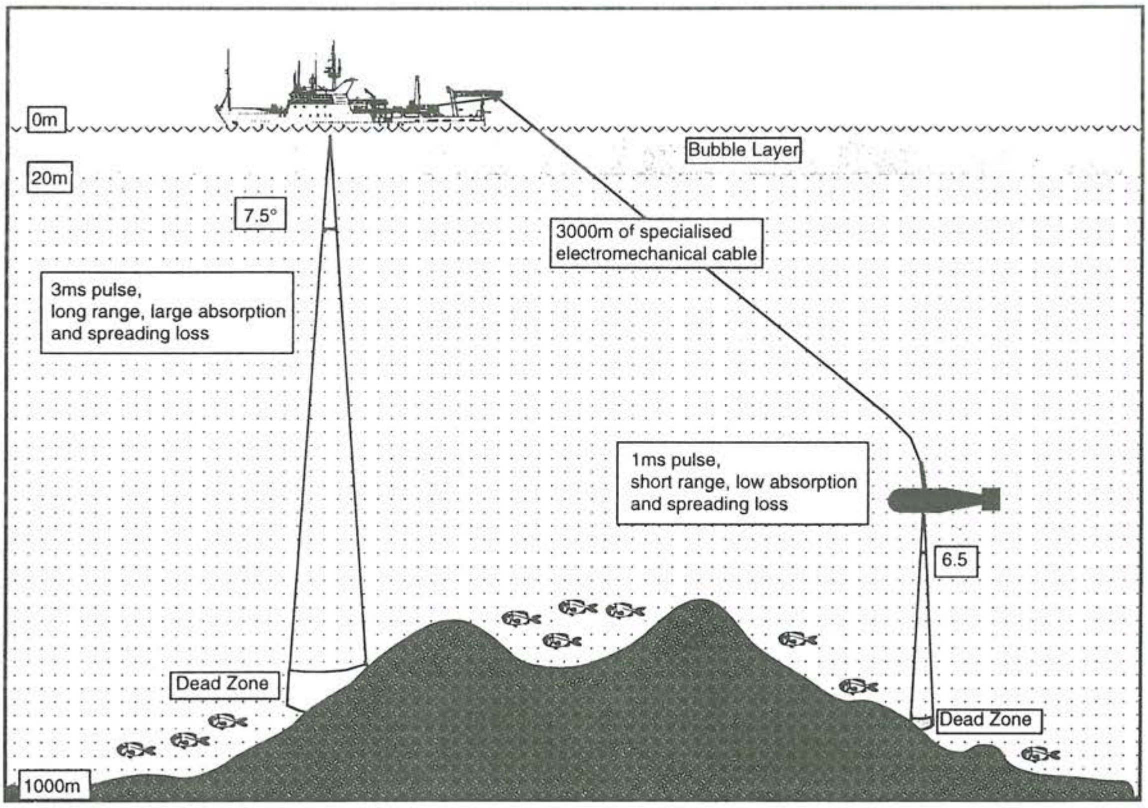


Figure 2. Schematic of the acoustic system used in surveys of orange roughy aboard FRV *Southern Surveyor*.

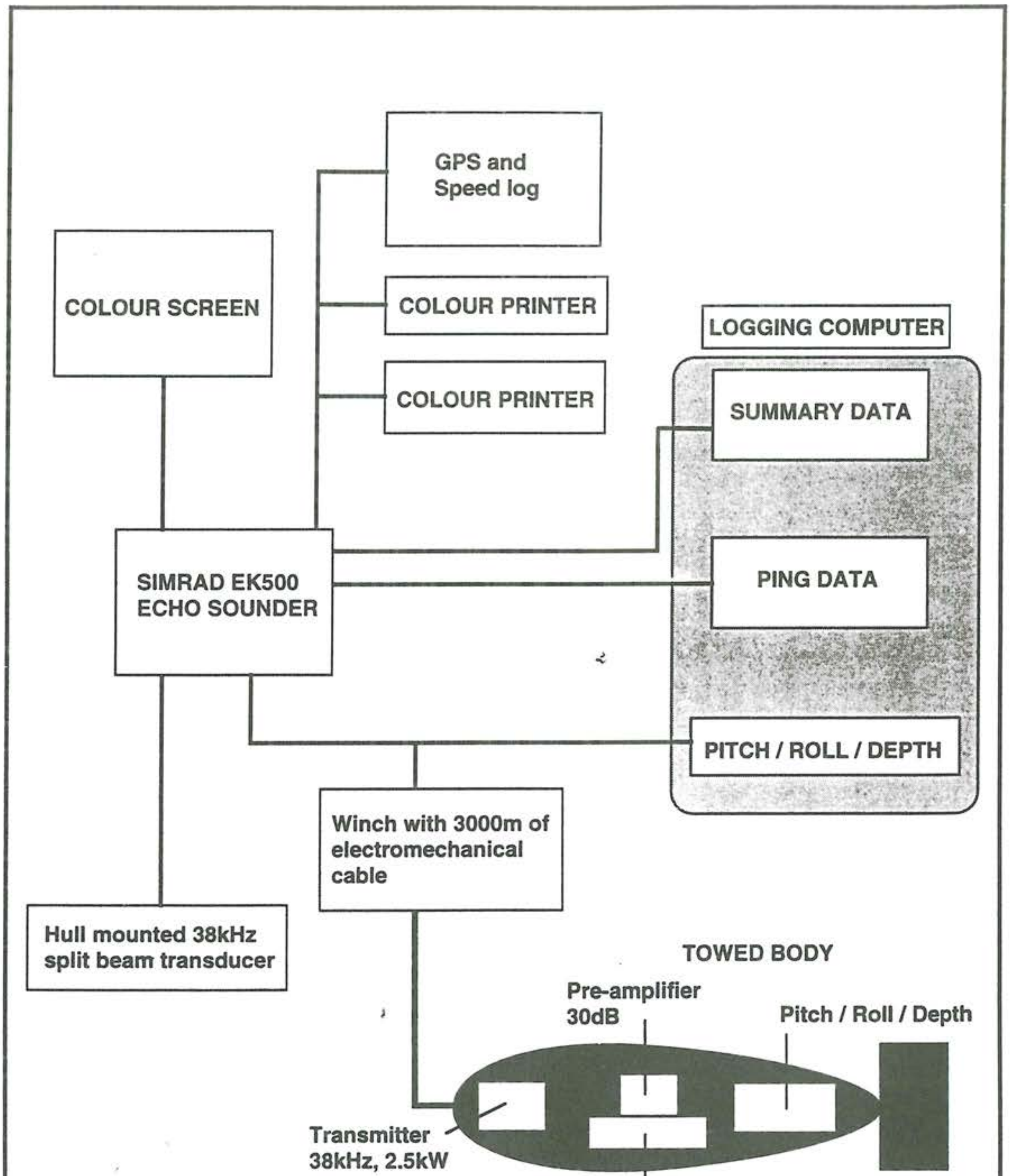


Figure 3. Chart showing location of surveys, bathymetry of St. Helens Hill, and the location of transects used during surveys from 1990-93.

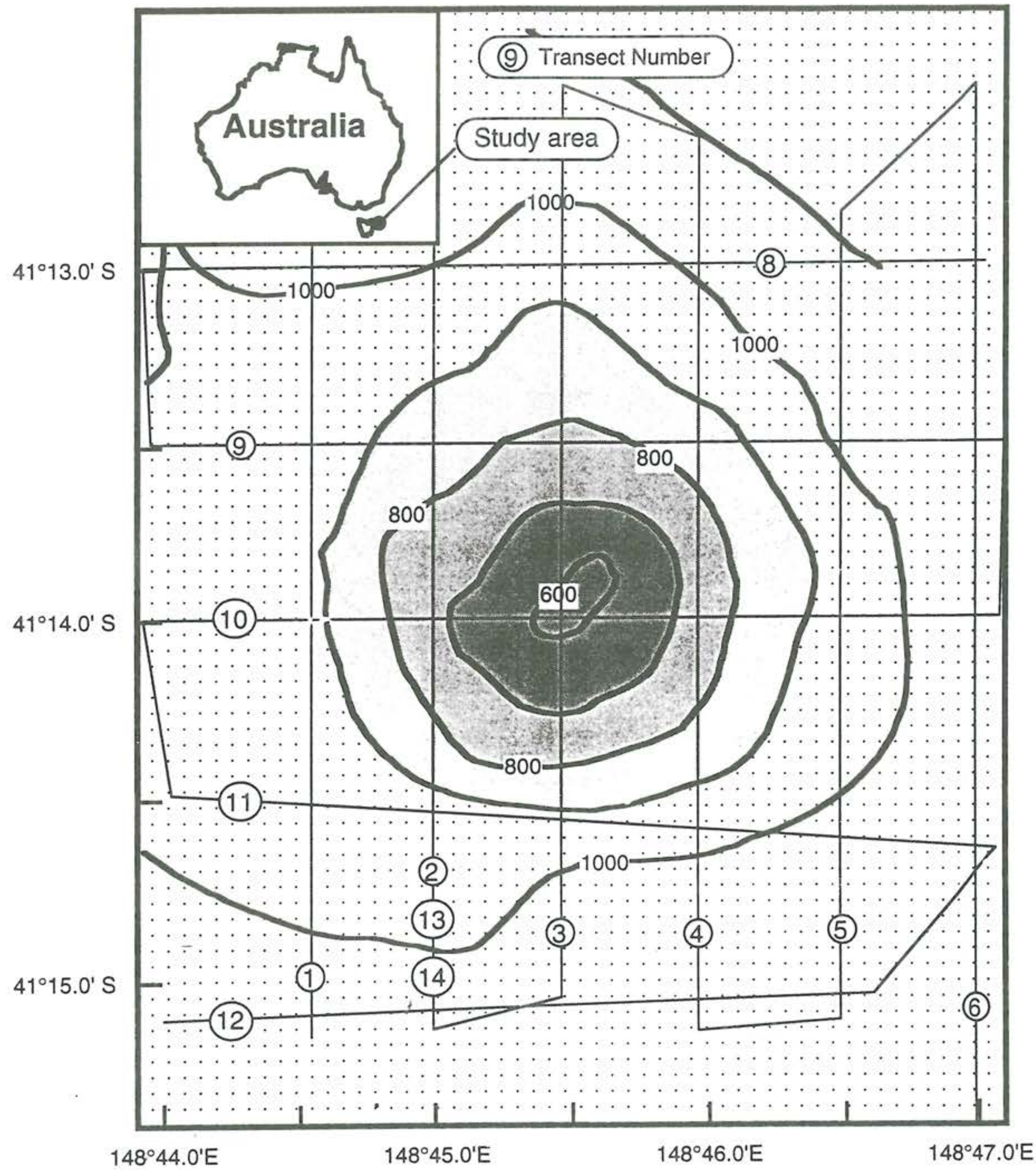
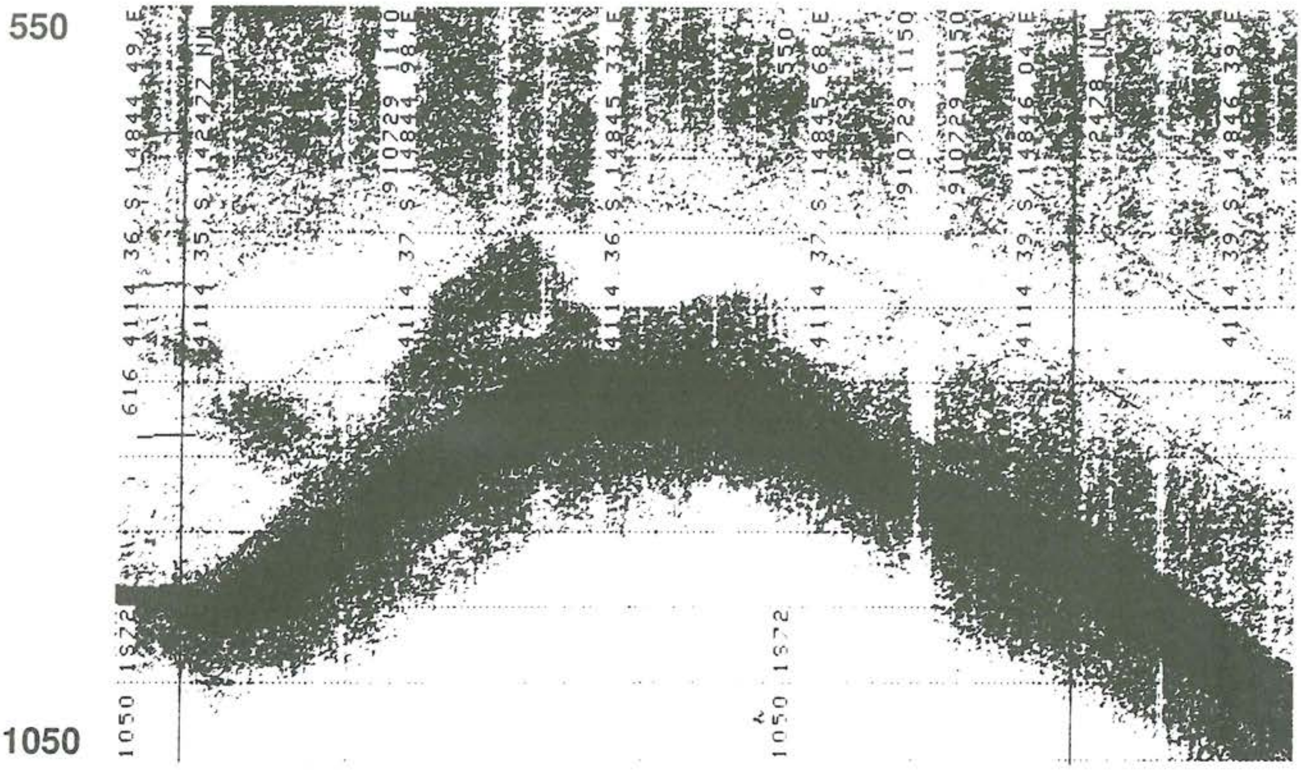


Figure 4. Echogram from hull-mounted (top) and towed transducers (bottom). They are of the same ground. Note the greater definition of the acoustic marks from the deep-towed transducer and the diminished dead zone.

Depth (metres) **Hull mounted transducer**



Depth (metres) **Towed body transducer at 500 metres deep**

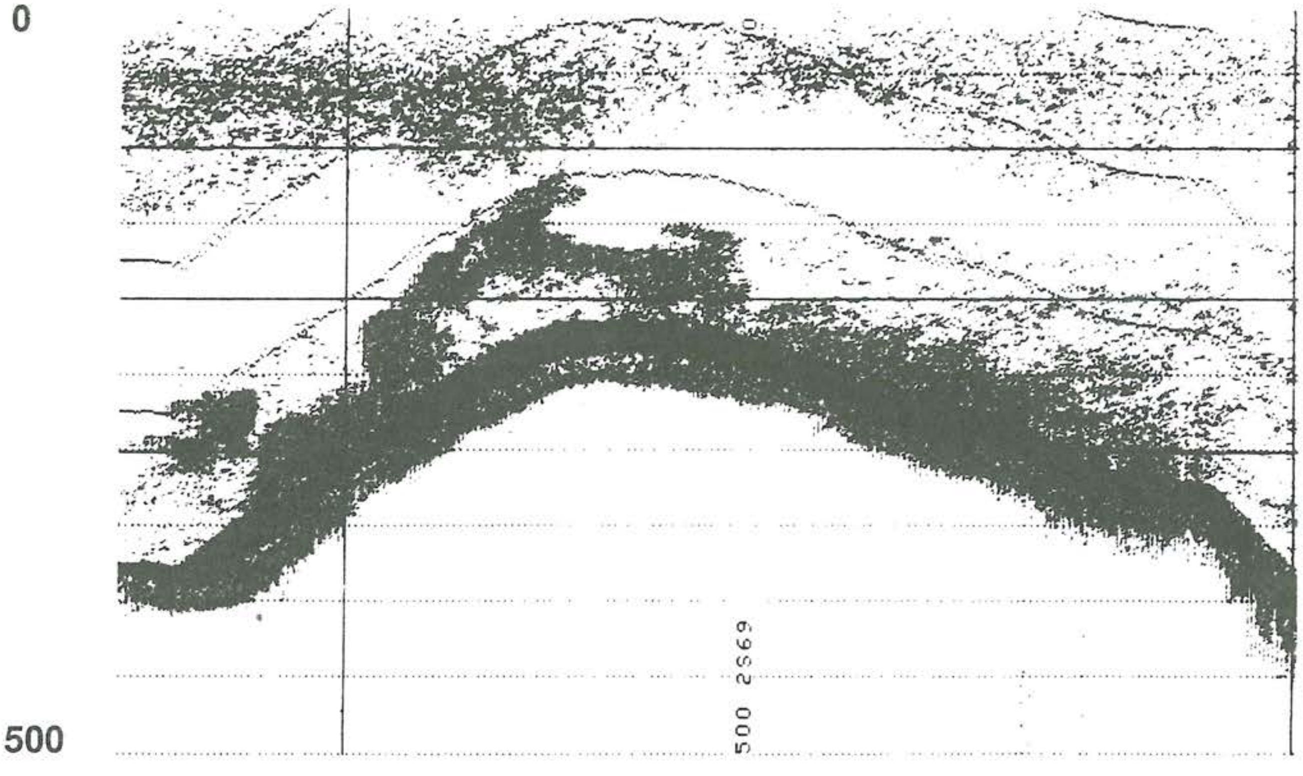


Figure 5. The estimated mid-season biomass and 95% confidence limits of orange roughy adult stock biomass from 1990-93 based upon data from the hull-mounted transducers. It is assumed that 90% of spawners were within the survey area at the time of the surveys; that 90% of mature males spawned each year but 54% of females in 1990 and 72% in 1991-93; and that there was a 1.7-fold downward bias in the hull-mounted transducers.

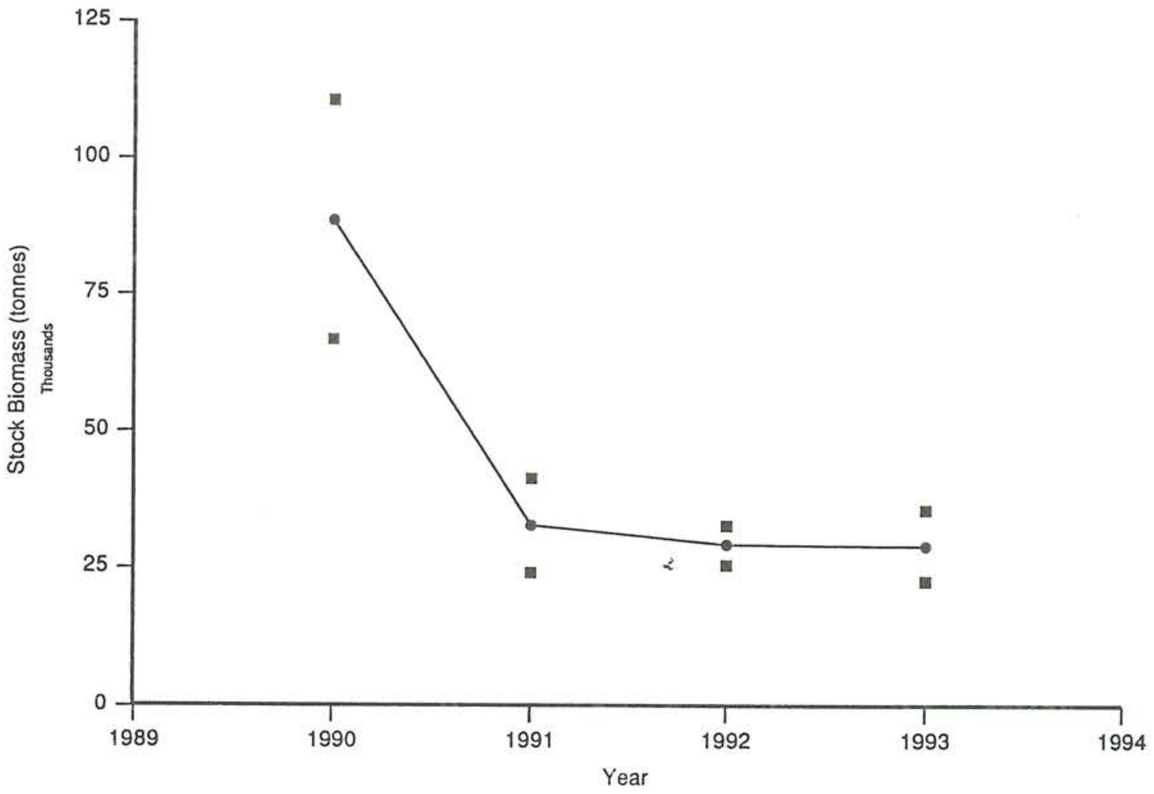


Table 1. Calibration parameters for echo integration.

PARAMETER	HULL	TOWED	UNITS
Pulse Length	3	1	ms
Bandwidth	1	3	kHz
Ideal Beam Angle			
90	-20.0	N/A	dB
91	-20.7	-21.1	dB
92	-20.7	-21.1	dB
93	-20.7	-21.1	dB
Sv Gain		@600m	
90	27.4	N/A	
91	27.7	31.0	
92	27.7	31.4	
93	27.8	30.8	
Absorption 800m	9.6	9.3	dB/km
Sound velocity 800m	1498	1490	m/s

Table 2. The dates and transects (see Figure 3) of surveys of the spawning aggregation of orange roughy off northeastern Tasmania.

	TOWED BODY			HULL MOUNTED			
Year	**91**	**92**	**93**	**90**	**91**	**92**	**93**
Date	30-Jul	19-Jul	25-Jul	16-Jul	26-Jul	17-Jul	25-Jul
Start time	10:40	16:32	3:50	1:30	3:00	20:42	3:50
Stop time	23:50	5:10	8:50	6:10	12:13	4:02	8:50
# of transects	8	12	7	8	10	12	7
		N-S transects along			**N-S transects along**		
	148:44.5	148:44.5	148:44.0	148:44.0	148:44.5	148:44.5	148:44.0
	148:45.0	148:45.0	148:44.5	148:44.5	148:45.0	148:45.0	148:44.5
	148:45.5	148:45.5	148:45.0	148:45.0	148:45.5	148:45.5	148:45.0
	148:46.0	148:46.0	148:45.5	148:45.5	148:46.0	148:46.0	148:45.5
	148:46.5	148:46.5	148:46.0	148:46.0	148:46.5	148:46.5	148:46.0
		148:47.0	148:46.5	148:46.5	148:47.0	148.47.0	148:46.5
			148:47.0		148:47.5		148:47.0
		E-W transects along			**E-W transects along**		
	41:13.5	41:12.5		41:14.0	41:13.5	41:12.5	
	41:14.0	41:13.0		41:13.5	41:14.0	41:13.0	
	41:14.5	41:13.5			41:14.5	41:13.5	
		41:14.0				41:14.0	
		41:14.5				41:14.5	
		41:15.0				41:15.0	

Table 3. Catch composition in per cent by numbers on St. Helens Hill from demersal trawls taken during the spawning season from 1990-92. The data are stratified by 100 m depth intervals based upon the mean depth of the tow. Only fishes represented by $\geq$ 1% of the catch are shown.

Species group	**Depth (m)** **600-699**	**700-799**	**800-899**	**900-999**	**1000-1100**
Number of samples	2	5	9	3	1
Orange roughy	0	96	99.2	84	14
Small myctophids (and other small midwater fishes)	0	0	0	0	14
Large myctophids	30	0	0	0	0
Whiptails (predom. *Coryphenoides subserrulatus)*	30	4	0.1	12	29
Sharks	1	0	0	0	29
Large fish with air-filled swimbladders (predom. *Halagyreus johnsoni)*	35	1	0.4	3	14
Other	5	0	0.3	1	0

Table 4. Catch composition of major groups of fishes in per cent by numbers on St. Helens Hill from depth-stratified pelagic trawls taken during the spawning season from 1990-92. The data are stratified by 100 m depth intervals based upon the mean depth of the tow. Only fishes represented by ≥ 1% of the catch are shown.

Species group	**Depth (m)** **600-699**	**700-799**	**800-899**	**900-1000**
Number of samples	5	9	13	3
Small myctophids (<70 mm)	36.9	23.3	20.0	1.5
Large myctophids (>70 mm)	58.0	63.6	59.6	40.8
Halagureus johnsoni	0.0	2.8	7.2	2.3
Coryphenoides subserrulatus	0.0	0.5	7.7	41.0
Other	5.1	9.8	5.5	11.5

Table 5. The per cent composition of community around St. Helens Hill employed in analysis of acoustic surveys, 1990-93. The estimated target strength (TS) of each group is shown in parentheses in dB units.

Species group (TS in dB)	Depth (m) 600-699	700-799	800-899	900-1000	> 1000
Orange roughy (-50)	60.0	95.0	95.0	50.0	35.0
Large myctophids (-50)	10.0	4.0	2.4	20.0	15.0
Small myctophids (-55)	5.0	0.8	2.4	1.0	6.0
Whiptails (-44)	15.0	0.1	0.1	25.0	40.0
Halagyreus and other large fishes (-31)	10.0	0.1	0.1	4.0	4.0

Table 6. Acoustic biomass assessment for orange roughy in spawning aggregation around St. Helens Hill, 1990-93 based upon near-surface deployed transducers. The integrated acoustic backscattering from bottom to 150 above bottom is shown (Sa in units of m^2) and the estimated biomass of orange roughy (in tonnes) based upon the estimate of community composition and target strengths given in Table 5. The areas of the depth strata (in m) are shown in units of nm^2. The standard error of the total biomass is shown in parentheses.

	Depth					
	600-699	**700-799**	**800-899**	**900-1000**	**> 1000**	**Total**
Year Area	0.25	0.45	0.7	1.9	2.6	5.9
Sa						
1990	430	778	2065	1707	761	5742
1991	289	854	431	481	192	2247
1992	341	658	399	634	974	3005
1993	244	679	362	1151	455	2891
Biomass						
1990	331	8148	21840	2076	597	32991 (4091)
1991	222	89841	4558	584	151	14456 (1885)
1992	262	6887	4215	771	764	12900 (794)
1993	188	7111	3828	1400	357	12883 (1403)

Table 7. Acoustic biomass assessment for orange roughy in spawning aggregation around St. Helens Hill, 1991-93 based upon deep-towed transducers. The integrated acoustic backscattering from bottom to 150 above bottom is shown (Sa in units of m^2) and the estimated biomass of orange roughy (in tonnes) based upon the estimate of community composition and target strengths given in Table 5. The areas of the depth strata (in m) are shown in units of nm^2. The standard error of the total biomass is shown in parentheses.

	Depth **600-699**	**700-799**	**800-899**	**900-1000**	**> 1000**	**Total**
Year Area	0.25	0.45	0.7	1.9	2.6	5.9
Sa						
1991	662	1053	863	854	376	3808
1992	357	1275	893	1053	824	4402
1993	403	764	591	1606	1402	4766
Biomass				1		
1991	509	11027	9125	038	295	21993 (2690)
1992	274	13349	9447	1280	647	24998 (3743)
1993	310	7999	6251	1953	1100	17613 (5023)

CHAPTER FOUR

AN ACOUSTIC SURVEY OF SPAWNING BLUE GRENADIER BIOMASS AND TARGET STRENGTH OFF WESTERN TASMANIA DURING WINTER 1992

AN ACOUSTIC SURVEY OF SPAWNING BLUE GRENADIER BIOMASS AND TARGET STRENGTH OFF WESTERN TASMANIA DURING WINTER 1992

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ABSTRACT

An echo-integration and *in-situ* acoustic target strength survey of spawning blue grenadier (*Macruronus novaezelandiae*) was carried out off the west coast of Tasmania from 30 July to 8 August 1992. A SIMRAD EK500 echo-integrator and split-beam target strength analyser operating at 38 kHz was used in conjunction with pole and towed body mounted transducers. A broad-scale systematic survey of the spawning ground was followed by finer scale surveys over areas of known blue grenadier concentration. The biomass of blue grenadier on the west coast at the time of the survey was 47,600±11,600 tonnes, based on trawl estimates of species composition or 15,700± 4,700 tonnes based on acoustic estimates of species composition. The mean target strength of blue grenadier observed *in situ* during the survey was -30.3 ±0.2 dB at 38 kHz.

INTRODUCTION

Blue grenadier (*Macruronus novaezelandiae*) in eastern Australia are fished on their winter spawning ground off the west coast of Tasmania from June through August and are fished more widely in south eastern Australia during the non-spawning season. There has been an ~5000 tonne total allowable catch (TAC) for blue grenadier, which has been based primarily upon a swept-area estimate of their abundance from demersal trawl surveys (Wilson 1984). The catchability of blue grenadier is particularly difficult to estimate because blue grenadier are often found well above the bottom. Wilson assumed a catchability of 0.5 for all species including blue grenadier so his estimates of grenadier stock size (39,500 tonnes in winter and 66,800 tonnes in summer) is probably conservative.

Acoustic surveys are a suitable method to estimate blue grenadier stocks. The fish is generally found above the bottom where it can be detected acoustically; it is often dispersed and has an air- filled swim bladder so its target strength (TS) is large; and it is reasonably aggregated within a limited area during the spawning season. Blue grenadier have been surveyed acoustically around New Zealand, but these surveys have provided only relative biomass indices, partly due to the lack of empirical TS estimates.

Several factors complicate any attempt to obtain an absolute biomass estimate. The primary factor is that during the long spawning season there is likely to be a substantial turnover on the spawning ground. This is difficult to quantify, particularly because the distribution of the larger spawners is not known outside the spawning period. An estimate of spawning stock biomass equal to the acoustically estimated biomass would therefore be conservative. Other complicating factors include estimating the proportion of blue grenadier in the local fish community and the statistical uncertainties inherent in any survey of biomass.

A two phase survey design was selected for this initial survey of blue grenadier on their spawning ground; the first phase to examine the broad-scale distribution of the fish, and the second to intensively survey known areas of particularly high fish density.

METHODS

A SIMRAD EK500 echo-sounder operating at 38 kHz was used in conjunction with both a pole mounted transducer and a transducer mounted in a towed body. The towed body could be deployed at any depth between the surface and over 700 m. The system was calibrated at Great Taylors Bay with a 60 mm copper sphere, according to the standard target method (Foote, 1982). The system was also calibrated with the towed body at a number of depths between the surface and 1000 m to account for the sensitivity of the transducer to pressure. The default settings and calibration corrections for the system are given in Table 1.

Acoustic data for echo integration were recorded from the EK500 ETHERNET port (single ping Sv data) for post cruise analysis. These data are of sufficient resolution to digitally reconstruct echograms and to allow arbitrary echo-integration layers to be set during post-cruise analysis.

The survey was a two phase stratified design with an initial broad scale survey over the known spawning distribution of blue grenadier followed by a number of fine scale surveys over geographic locations reported by local fisherman to have regular concentrations of blue grenadier. During the first phase, 33 transects were surveyed along lines of latitude every five nautical miles throughout the survey area between the shelf break (250 m depth) and 700 m depth (Figure 1). The starting point of the survey was chosen arbitrarily but not randomly. During the second phase, finer scale surveys were carried out in areas of known blue grenadier concentration.

DATA VERIFICATION AND ESTIMATION OF NOISE

Echograms were displayed on a computer monitor and edited using the CSIRO program "echox". The echox program uses the default bottom signal from the EK500 to estimate the bottom contour and the lower limit of the acoustic "dead zone". These need visual verification and, in many cases, editing where the program is unable to correctly interpret the features of the echogram. Accurate determination of the bottom contour is critical because echoes from the sea bed are orders of magnitude greater than fish echoes and their inclusion in integration layers would cause significant bias in the results.

Echoes from the sea bed were excluded form the integration layers by shifting the bottom contour vertically four metres followed by visual inspection and editing where necessary. Editing of the bottom contour was particularly necessary where the weather had been rough and there were large apparent waves in the bottom echo. No estimate was made of fish numbers in the acoustic dead zone because blue grenadier are not in general bottom-dwelling fish. Parts of some aggregations were observed close to the bottom but this was not generally the case. The resulting error in estimated biomass is therefore considered to be small.

Background acoustic noise contributes to mean volume backscattering strength (Sv) and thus to the estimated biomass unless it is corrected for. The strength of the background acoustic noise was estimated at a depth of approximately 475 m (the nominal mid-point of the integration range) and all integration intervals were corrected for this level of noise.

Spikes are another source of noise caused by the ship pitching, wave slap and the like. Spikes are strong apparent echoes that appear to increase in strength with depth and to last in time for only one or two pulses. Spikes were excluded from the data by setting an upper threshold on valid Sv's. This threshold was determined by viewing the echograms with a display threshold of -35 dB and determining the strength of the weakest part of any visible spikes.

ECHO INTEGRATION

Backscattering area per unit horizontal area or "Sa" (m^2/nm^2) was calculated by echo integration along each transect for seven 50 m deep layers between 300 and 650 m below the sea surface with a reset at intervals of 0.1 nm. A mean Sa for each transect of the broad and fine-scale surveys over the depth range 300 to 650 m was calculated. The density ($Density_{bg}$) of blue grenadier in units of tonnes per square nautical mile was calculated for each transect from Sa using the following relationship

$$\text{Density}_{\text{bg}} = P_{bg} \bullet \frac{Sa}{4\pi\sum_{i=1}^{4}\left(P_i \bullet 10^{TS_i/10}\right)} \bullet \frac{\text{Weight}_{\text{bg}}}{1000}$$

where

TS_i are the target strengths of the four principal species including blue grenadier,

P_{bg} ,P_i are the proportions (by number) of blue grenadier and other species in the surveyed population,

Weight_{bg} is the mean weight in kilograms of adult blue grenadier caught in the trawl survey ($\text{Weight}_{bg} = 2.15$ kg).

The biomass and standard error of biomass of blue grenadier within a survey area was estimated by the mean and standard error of the transect densities (weighted by transect length) multiplied by the survey area. Survey area was calculated as the area of the smallest polygon surrounding the survey transects and drawn through the start and end points of the transects.

IN SITU TARGET STRENGTHS

The EK500 uses the split beam method (Ehrenberg 1983) to determine the target strength of targets that meet a set of criteria defining a "single target" (Table 1). The probability density function (PDF) of TS was determined for each of 12 target strength transects from all single targets detected within 2° of the acoustic axis, between 25 m and 300 m from the transducer and deeper than 250 m.

Peaks in the target strength PDFs were identified with the most probable target species. The peak associated with blue grenadier was identified from transects through aggregations occurring at geographic locations known to have significant numbers of blue grenadier. The observed blue grenadier TS is compared with predictions based on modelling.

The widths of the four principal peaks in the TS PDFs were estimated at the midpoints between the peaks so that all detections would be included in the TS range associated with one of the peaks. The width of the blue grenadier peak was subsequently narrowed to reduce the influence of the tail of the large whiptail group on the calculated blue grenadier TS when the number of detections in the blue grenadier peak was small. For two transects (B201 and CS09) where the blue grenadier peak was shifted to lower dB's in comparison to the other transects no gap was allowed between the blue grenadier peak and the large whiptail group peak (Figure 4).The mean TS of fishes under each peak was calculated from the mean scattering cross section of all detections under the peak. The mean TS for blue grenadier was estimated by a weighted mean of the mean blue grenadier transect for each of the 12 transects, where the number of blue grenadier detections on a transect was used as the weighting factor. For the other species groups the mean TS was estimated from the (unweighted) mean scattering cross section of the same species group in each of 12 transects.

COMMUNITY COMPOSITION

The *in situ* TS data were used to estimate the community composition on each transect by calculating the proportion of detections in each of the four TS peaks. There is a distinct cut off depth below which targets of a given strength cannot be detected by the EK500 (Figure 2). To correct for the targets that were not detected because of this threshold the number of detections in each species group was multiplied by the ratio of the depth range over which blue grenadier could be detected to the depth range over which the species group could be detected. The multiplying ratios were 1.0, 1.96, 3.06, and 3.77 for blue grenadier, the large whiptail group, the small whiptail group and for very small fishes respectively. No estimate was made of the number of targets with target strengths less than the minimum TS criteria of -60 dB (-55 dB on transect B207).

The community composition was also estimated from the proportions of the principal species in the trawl catch. Trawls were undertaken during the acoustic survey, by two commercial fishing boats Petuna explorer and Petuna endeavour using demersal and combined demersal/pelagic nets.

RESULTS

TARGET STRENGTH

Twelve target strength transects undertaken during the broad and aggregation surveys have been analysed. The principal peaks in the TS frequency distributions (Figures 3a-l) occur within the target strength ranges -29 to -31 dB, -40 to -47 dB, -48 to -53 dB and -54 to -59 dB. The principal peaks, however, are not present on every transect and in addition other minor peaks can be identified on some transects. A large and distinct peak with greater than 600 counts at about -30 to -31 dB was present on three of the aggregation transects (RT05, RT06 and PR07). Two of the aggregation transects (CS07 and CS09) showed less distinct peaks (with about 30 counts) at -32 or -34 dB and one aggregation transect showed no peak and only 5 counts greater than -34 dB. Trawls were not undertaken in conjunction with every TS transect, and so there is no direct evidence that significant numbers of blue grenadier were actually present on the transects that did not show a substantial peak at -30 to -34 dB. Targets with TS's around -30 to -34 dB were only seen at depths greater than about 250 m, which is also consistent with their being blue grenadier. The evidence from these transects strongly suggests that the -30/-31 dB peak and probably the -32/-34 dB peaks are due to the presence of blue grenadier in the water column.

The mean TS's for blue grenadier and other species for six aggregation transects and six broad-scale transects are presented in Table 2. The mean TS of blue grenadier was estimated to be -30.3 dB with 95% confidence limits (based on twice the standard error in the mean scattering cross section, assuming the 12 transects to be independent and weighting the transect means by the number of blue grenadier detections on the transect) of -30.5 to -30.1 dB. There was little variation in the mean TS for the other three species groups between the transects. No significant difference was observed between blue grenadier TS on day and night surveys.

The primary groups of fishes other than blue grenadier found in abundance in the area were large and small whiptails and very small midwater fish, such as myctophids. The peaks in TS around -43 dB, -50 and -57 dB are presumably associated with these groups. The TS of each group of similar-sized fish was estimated as the mean TS of all targets within the TS ranges -47.5 to -36.5 dB (large whiptails), -53.5 to -47.5 dB (small whip tails) and -70.5 to -53.5 dB (very small fish). The final estimate of blue grenadier biomass is not sensitive to small changes in these ranges.

COMMUNITY COMPOSITION

Community composition in the survey area was estimated from both the *in situ* TS data by counting the proportion of detections in the target strength ranges associated with the four species groups and from trawl data. The *in situ* TS data (Table 3) show an apparent difference between the community composition on the aggregation transects and the broad-scale transects. The aggregations have a higher proportion of blue grenadier and very small fish groups and a lower proportion of the large and small whiptail groups.

The average composition of trawls by number was 15% blue grenadier, 55% large whiptails and juvenile grenadier, 15% were small whiptails and 15% other fishes. Very small fishes such as myctophids were not retained due to the large mesh size of the commercial nets. To estimate community composition the trawl composition was adjusted by assuming that the "other fishes" could be distributed equally between the large and small whiptail groups and by adjusting for the loss of very small fishes by assuming that 50% of the community was very small fishes. The 50% figure for very small fishes is based on the *in situ* TS data.

BIOMASS ESTIMATION

Mean Sa per transect and the overall mean Sa and standard error for the four survey areas were calculated (Tables 4a-d). The standard errors were calculated assuming the transects were independent. The time of day (Day day time, Night = night time, Twilight = twilight) of the start of each transect is indicated. There was no apparent difference between the Sa's recorded on day and night transects within the broad survey. The assumption of independent transects is unlikely to hold for the fine-scale aggregation surveys, however the bias in the calculated standard error is not likely to be large compared to the (unestimated) errors associated with factors such as community composition.

To estimate the total biomass in the survey area the biomass in the aggregations from the fine-scale surveys was added to the broad-scale survey biomass because the fine-scale surveys were conducted in geographically distinct areas known to fishermen to have large blue grenadier concentrations. The fish aggregations in the canyon like features were highly localised, and there was no evidence of heightened fish concentrations in their vicinity from the broad-scale survey.

The fish biomass was partitioned between blue grenadier and other species using three scenarios for community composition (Table 5). The three scenarios were; 1) 100% of target is blue grenadier (highly unrealistic), 2) the trawl survey estimate of community composition and 3) the *in situ* TS estimate of community composition determined for the broad and fine scale surveys and applied to the respective surveys. There is an approximate three fold range from 15,700 tonnes to 47,600 tonnes in the biomass estimated using trawl and TS community composition scenarios (Table 6).

DISCUSSION

The shape of the TS frequency distribution is determined by the length frequency distribution of the scatterers, the behaviour of the animals (probability density function of tilt angle) and the density distribution of the scatterers in the water column. The *in situ* split-beam technique is an empirical technique that in theory measures the actual distribution of the target animals depending only on proper calibration and the assumption that the TS peaks are correctly matched with peaks in the trawl catch composition. In practice the density distribution of the scatterers in the water column can bias the measured distributions because some scatters cannot be seen as single targets. If the resolvable fishes on the edge of dense aggregations are representative of fishes within the aggregation this bias may not be large. We assume that the mean TS of the detected blue grenadier is the mean TS of blue grenadier in the water column.

There are no other published *in situ* blue grenadier target strength data. Our results can therefore only be compared with the results of modelling blue grenadier target strength. Do and Surti (1989) modelled sound scattering from blue grenadier and obtained the TS to length relationship TS = 20log(l) -72.7, where TS is the mean TS of a blue grenadier of length l cm assuming a normal tilt angle probability density function (PDF) with mean 0° and standard deviation 15°. A changed tilt angle PDF (mean 11.8°, standard deviation 29.1°) based on in situ camera observations results in the relation ship TS = 22.32 log(l) - 79.84 (P. Condue, NZMAF, pers. comm.). The expected mean TS of blue grenadier with the length frequency distribution of fish sampled during this survey (Figure 4) for the two relationships above is -34.5 dB and -37.2 dB respectively. These are approximately 4 dB and 6 dB lower than the TS we have estimated using *in situ* techniques. No peak was observed in the vicinity of -37 dB and only one transect (CS07) showed a peak near -34 dB during this survey. In fact most transects show a distinct minimum in the TS frequency distribution at -34 to -36 dB with the next peak at approximately -45 dB. Furthermore the average proportion of targets in the -45 dB peak is lower for the fine-scale transects in known area of blue grenadier concentration than for broad-scale survey transects, providing evidence that this peak is unlikely to be blue grenadier.

TS estimates based on modelling embody important assumptions regarding the nature of scattering from swim bladders and fish bodies, the *in situ* shape and size of swim bladders and the behaviour/orientation of fish. Sizeable errors in the predicted TS can result from deviations from these assumptions. Do and Surti (1989) for example, show that changes of greater than 1 dB in the predicted TS can be caused by small changes in either the mean or the standard deviation of the assumed tilt angle probability density function. We have no data on the tilt angle PDF of blue grenadier observed acoustically in this study. No other large fish were caught in appreciable numbers that might have a target strength of -30/-31 dB, and there was no peak in TS near the model's predicted TS. Consequently we have a high degree of confidence in the *in situ* results.

There were considerable differences in the estimates of fish community composition based on the trawl and *in situ* TS data sets. There are several possible reasons for this difference.

The trawl only samples within several metres of the sea floor, and factors affecting the catchability of different species (ie. losses through the meshes, differential escape and herding responses) may bias estimates of species composition even within this stratum. A crude correction for the loss of very small fishes from the trawls was made by assuming that 50% of the community by number was myctophids and other very small fishes. The 50% figure is based on the proportion of very small fishes in the *in situ* TS estimate of community composition. In addition most trawls were not random, rather they were aimed at acoustic marks.

The EK500 TS analyser can only detect single targets over the entire TS range of interest (greater than -60 dB) over a depth range of approximately 25 to 80 m from the transducer (Figure 2). Single blue grenadier targets can be detected to a maximum depth of approximately 270 m. To estimate the species composition of the fish community over the depth range 25 to 300 m from the number of single targets detected it is necessary to assume that the composition is uniform with depth and to either extrapolate the composition measured in the depth range 25 to 80 m over the range 25 to 300 m or to use all single targets detected over the range 25 to 300 m and correct for the depth threshold on the detection of each species group. The second method is considered superior because it is based on the greatest amount of information (all collected single target data) and because, at least for blue grenadier, single detections are counted over almost the entire depth range of 25 to 300 m. This method assumes that there is an equal probability of detecting fish of a given TS over the entire depth range over which fish of that TS can be detected and that there is an equal probability of detecting fish of all TS's (that can be detected) at any given depth. In addition the TS analyser cannot detect single targets when the density of targets of a given TS within the acoustic beam is above some threshold, ie single targets cannot be detected within dense schools. It has thus been assumed, particularly for the aggregation transects that single targets detected outside schools are representative of the fish within observed dense aggregations. The extent biases due to these assumptions have not been quantified.

Thus estimates of species composition from both the trawl samples and *in situ* TS data may contain significant bias. The survey results are, however, robust to even substantial variation in estimates of species composition because blue grenadier have a large target strength. Thus there is a fourteen-fold difference between the trawl and in situ estimates of the proportion of blue grenadie in the fish community sampled in the broad survey, but only a three-fold difference in the estimate of blue grenadier biomass on the spawning ground.

CONCLUSION

A biomass of blue grenadier of 60,500 tonnes (±14,800 tonnes), estimated assuming 100% of the acoustic target is blue grenadier (scenario 1) is an upper bound on the possible biomass of blue grenadier that must be unrealistically high. Biomass estimates of 47,600 tonnes (±11,600 tonnes) assuming a community composition based on trawl data (scenario 2) and 15,700 tonnes (±4,600 tonnes) assuming the acoustically determined community composition (scenario 3) must be considered equally likely without more information on the extent of biases in the two methods of estimating species composition.

The mean target strength at 38 kHz of blue grenadier observed *in situ* during the survey was -30.3 dB (±0.2 dB). Substantial bias in this estimate is not expected. The mean length of blue grenadier associated with this TS was not estimated because of the loose association between trawl catches and the blue grenadier detected as single acoustic targets.

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Foote, K.G. (1982). Optimising copper spheres for precision calibration of hydroacoustic equipment. J. acoust. Soc. Am.; 71:742-747.

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Table 1. Default settings and calibration corrections for the EK500.

	Transducer		
	Towed body (TS mode)	**Towed body (integration)**	**Pole mounted (integration)**
Pulse length	0.3 ms	1 ms	3 ms
Equivalent 2-way solid beam angle (ψ)	dB	dB	dB
Sv gain	dB	dB	dB
TS gain	dB	dB	dB
Attenuation constant (As)	9.0 dB/km	9.0 dB/km	9.0 dB/km
Single target detection criteria			
TS minimum	-60 dB	-	-
Minimum echo length	0.8	-	-
Maximum echo length	1.8	-	-
Maximum gain compensation	4 dB	-	-
Maximum phase deviation	2	-	-

EK500 Calibration Data

Gain constant (G_c)	5	2.8	-0.7
Gain slope (G_s)	-.0037	-.0035	0.0
Measured attenuation constant (A_m)	9.6	9.6	9.6

$$TS = TS_m - (G_c + G_s{*}\text{Transducer depth}) - 2{*}\frac{(A_s - A_m)}{1000}{*}\text{range}$$

where TS = calibrated target strength, TS_m is the measured target strength, transducer depth is the depth of the transducer relative to the sea surface and range is the distance from the transducer to a single target.

Table 2. Mean target strength of blue grenadier on each of 12 transects and overall mean target strength for blue grenadier calculated from transect means.

Transect	Transect time	Target Strength (dB)			
		Blue grenadier	Large whiptail group	Small whiptail group	Very small fishes group
(Aggregations)					
RT05	Night	-30.4	-42.2	-50.2	-56.5
RT06	Night	-30.4	-42.3	-50.1	-56.6
RT21	Night	-32.2	-43.6	-49.8	-56.9
PR07	Night	-30.1	-41.6	-50.5	-56.0
CS07	Day	-32.5	-42.3	-50.0	-55.7
CS09	Night	-30.5	-41.3	-50.3	-55.4
(Broad survey)					
B201	Night	-33.7	-43.5	-49.7	-57.0
B306	Day	-29.8	-44.5	-50.5	-58.4
B207	Day	-29.2	-44.6	-50.2	no data
B224	Night	-30.9	-41.4	-50.0	-56.3
B228	Day	-30.1	-43.2	-50.4	-56.4
B230	Night	-31.1	-42.6	-50.2	-56.3
Mean		**-30.3**	**-42.6**	**-50.2**	**-56.5**
Upper 95% conf. limit		-30.5	-	-	-
Lower 95% conf. limit		-30.1	-	-	-
Number of detections		3383	21020	14966	25501

Table 3. Community composition by transect and mean compositions for the six aggregation and six broad survey transects.

	Proportion of Single Target Detections by species group (%)				Number of detections (corrected for detection thresholds)
	Blue grenadier	Large Whiptail group	Small whiptail group	Very small fishes group	
Aggregation transects					
RT05	2.8	19.3	22.0	55.9	22170
RT06	1.8	18.4	18.7	61.1	33575
RT21	0.0	23.2	19.5	57.3	16576
PR07	5.7	14.6	18.7	61.0	27510
CS07	1.2	55.4	22.4	21.0	2653
CS09	2.1	30.5	42.7	24.8	4154
Mean	**2.7**	**19.7**	**20.5**	**57.0**	**106638**
Broad transects					
B201	1.2	19.6	26.6	52.6	5692
B306	2.1	8.8	17.8	71.3	5896
B207	0.4	12.0	40.5	no data, assume 47.1	9656
B224	0.5	37.5	25.4	36.5	33494
B228	0.1	16.1	32.2	51.6	19191
B230	0.3	16.4	26.9	56.4	10188
Mean	**0.5**	**24.0**	**28.4**	**47.1**	**84117**

Table 4a. Mean Sa per transect and overall mean Sa and standard error for the Broad survey.

Broad Survey Transects

Survey Date	29-July-92 to 1-Aug-92
Area (nm^2)	428

Transect	File name	Day/Night	Length	Sa 300-650 m
1	s392b101	N	1.78	1276
2	No Data			
3	s392b1p3	N	2.24	551
4	s392b1p4	N	2.02	562
5	s392b1p5	T	1.60	657
6	s392b206	D	2.47	852
7	s392b107	D	2.39	723
8	s392b208.xls	D	2.09	469
9	s392B109	D	2.25	555
10	s392b110	T	2.33	369
11	s392b111	N	2.54	389
12	s392b112	N	2.45	334
13	s392b113	N	2.97	545
14	s392b114	N	2.46	631
15	s392b115	N	2.90	1711
16	s392b116	N	2.26	1135
17	s392b117	N	2.40	685
18	s392b118	T	2.59	683
19	s392b119 and s392bt20	D	3.72	876
20	s392b120	D	3.98	318
21	s392b121	D	7.41	592
22	s392b122	D	7.91	345
23	s392b223	T	1.54	1225
24	s392b124 TB	N	4.79	1006
25	s392b125.xls	N	5.73	733
26	s392b126	N	3.75	1228
27	s392b127	N	2.24	689
28	s392b128	D	4.30	782
29	s392b129	D	4.44	1675
30	s392b130	N	3.21	590
31	No Data			
Mean Sa				754
Standard Error				78

Table 4b. Mean Sa per transect and overall mean Sa and standard error for the Cape Sorell survey.

Survey Date	6-Aug-92
Area (nm^2)	7.14

Transect	File name	Day/Night	Length	Sa 300-650 m
1	s392cs01	D	1.24	1070
2	s392cs02	D	2.89	434
3	s392cs03	D	3.36	371
4	s392cs04	D	3.38	512
5	s329cs05	D	4.49	525
Mean Sa				515
Standard Error				64

Table 4c. Mean Sa per transect and overall mean Sa and standard error for the Pieman River survey.

Survey Date	3-Aug-92
Area (nm^2)	10.27

Transect	File name	Day/Night	Length	Sa 300-650 m
1	s392pr01	N	1.38	3935
2	s392pr02	N	1.13	2513
3	s392pr03	N	2.50	1376
4	s392pr04	N	3.55	598
5	s392pr05	N	3.09	761
Mean Sa				1390
Standard Error				486

Table 4d. Mean Sa per transect and overall mean Sa and standard error for the Sandy Cape survey.

Survey Date	2-Aug-92
Area (nm^2)	12.1

Transect	File name	Day/Night	Length (nm)	Sa 300-650 m
1	s392rt01	N	3.95	1379
2	s392rt02	N	1.76	3586
3	s392rt03	N	2.94	595
4	s392rt04	N	5.04	807
7	s392rt07	N	3.71	132
8	s392rt08	N	3.76	795
Mean Sa				995
Standard Error				312

Table 5. Three scenarios of community composition; 1) 100% of target is blue grenadier, 2) the trawl survey estimate of community composition and 3) the *in situ* target strength estimate of community composition.

	Scenario 1 **100% blue grenadier**		**Scenario2** **Trawl community composition**		**Scenario 3** **In situ community composition**	
Survey section	Biomass (tonnes)		Biomass (tonnes)		Biomass (tonnes)	
	Mean	SE	Mean	SE	Mean	SE
Broad	55029	5715	43276	4494	12114	1258
Cape Sorell	675	84	531	66	437	54
Pieman River	2618	915	2059	720	1694	592
Sandy Cape	2208	692	1737	544	1429	447
Total	**60530**	**7405**	**47603**	**5824**	**15674**	**2352**

Table 6. Blue grenadier biomass observed in the broad, Cape Sorell, Pieman River and Sandy Cape survey areas and total blue grenadier biomass estimated for three scenarios of community composition.

Species	Target strength	Scenario 1 100% blue grenadier		Scenario2 Trawl community composition		Scenario 3 In situ community composition	
		broad	aggregations	broad	aggregations	broad	aggregations
Blue grenadier	-30.3	100%	100%	7.5%	7.5%	0.5%	2.7%
Large whiptails or juvenile grenadier	-42.6	0%	0%	31.3%	31.3%	23.3%	19.1%
Small whiptails and other small fish	-50.2	0%	0%	7.5%	7.5%	27.6%	20.7%
Other very small fish	-56.5	0%	0%	50.0%	50.0%	48.7%	56.9%

Figure 1. Broad survey transects and the approximate locations of blue grenadier aggregations off the west coast of Tasmania.

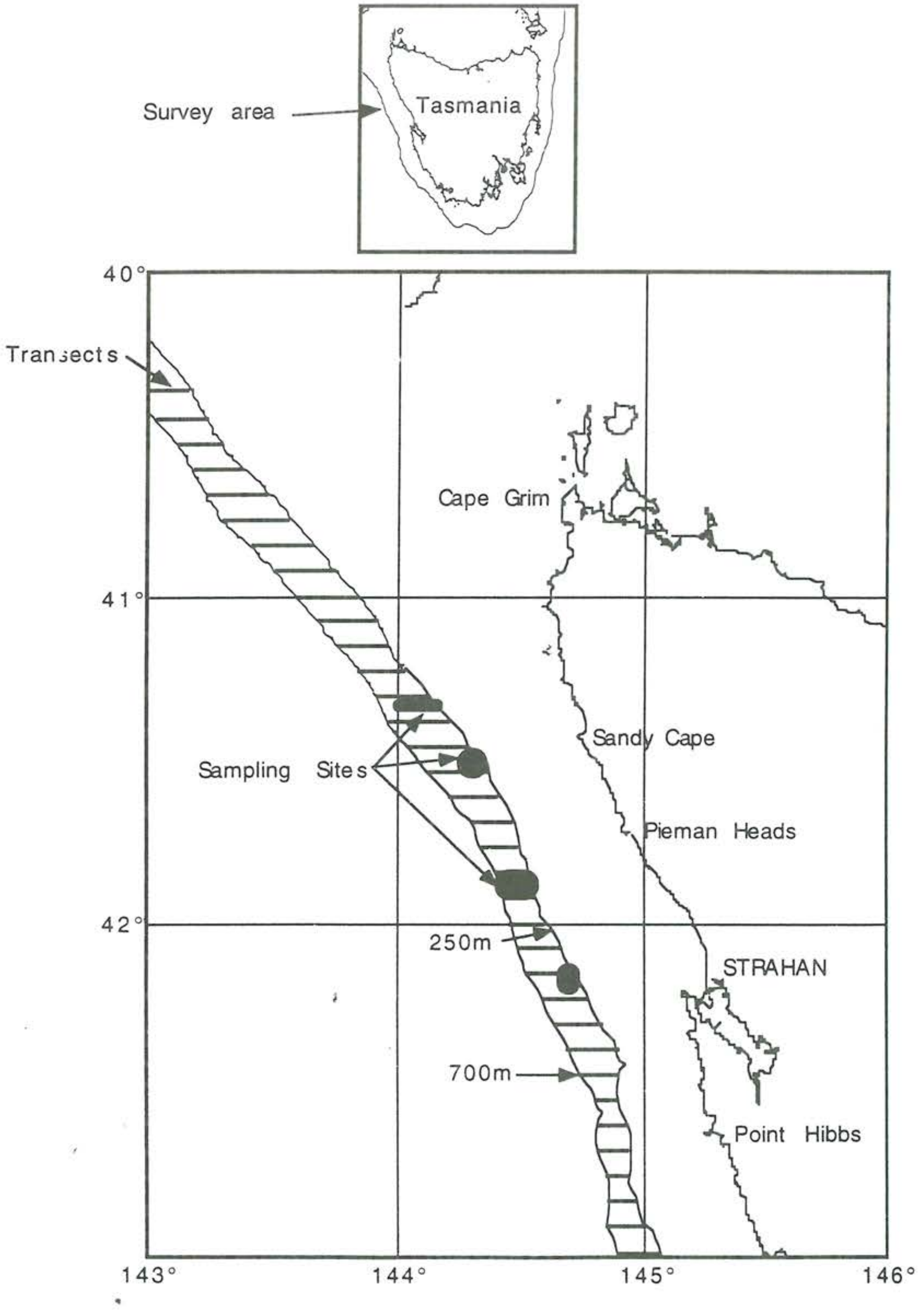


Figure 2. Scatter plot of the target strength of single targets against range from transducer showing the distinct depth threshold below which single targets are not detected. The step function drawn over the scatter plot indicates the ranges over which four species groups were detected.

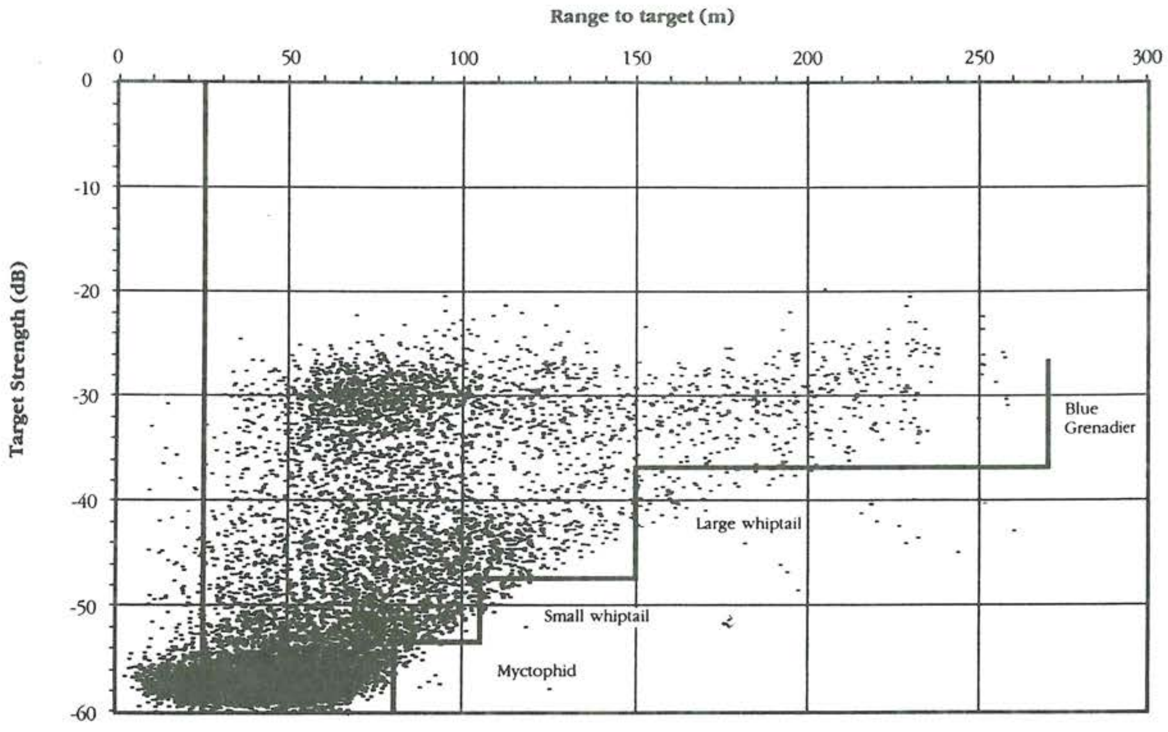


Figure 3a. Target strength probability density function for transect RT05 (Sandy Cape).

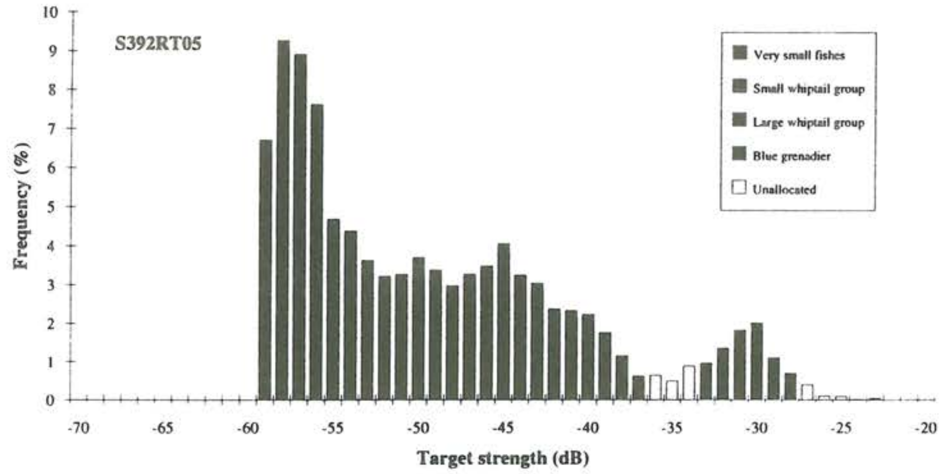


Figure 3b. Target strength probability density function for transect RT06 (Sandy Cape).

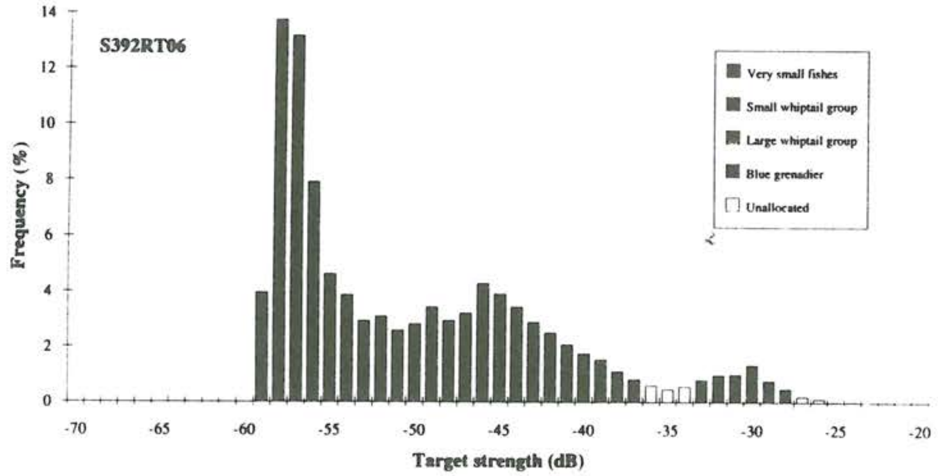


Figure 3c. Target strength probability density function for transect RT21 (Sandy Cape).

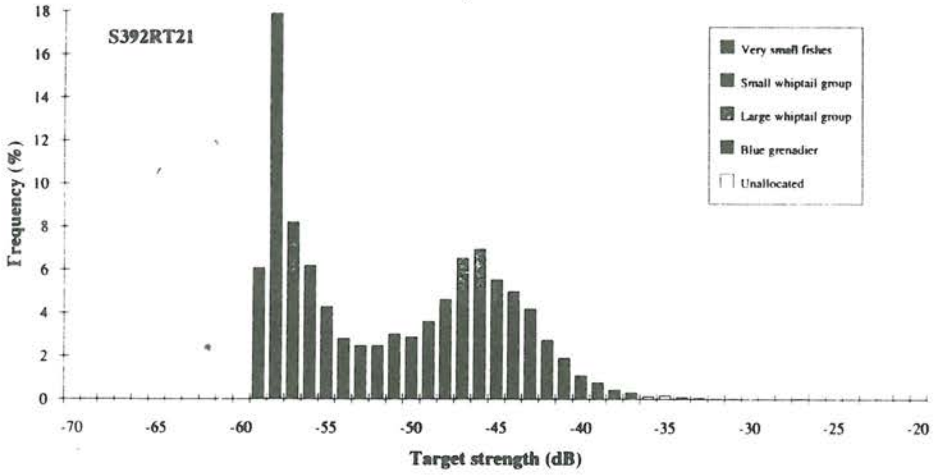


Figure 3d. Target strength probability density function for transect PR07 (Pieman River).

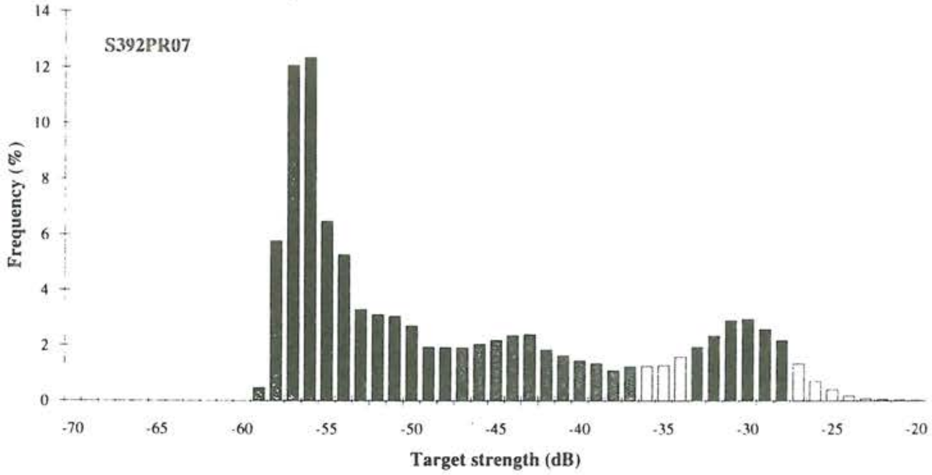


Figure 3e. Target strength probability density function for transect CS07 (Cape Sorell).

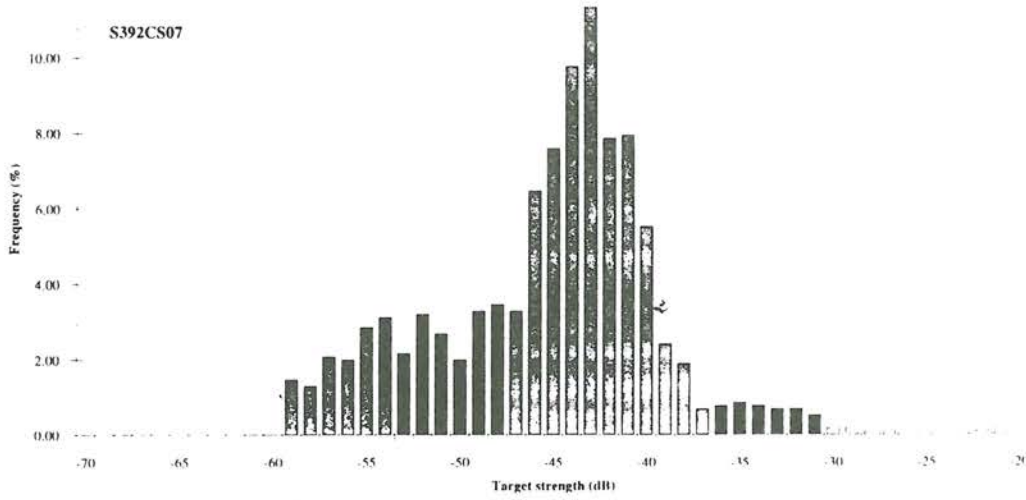


Figure 3f. Target strength probability density function for transect CS09 (Cape Sorell)

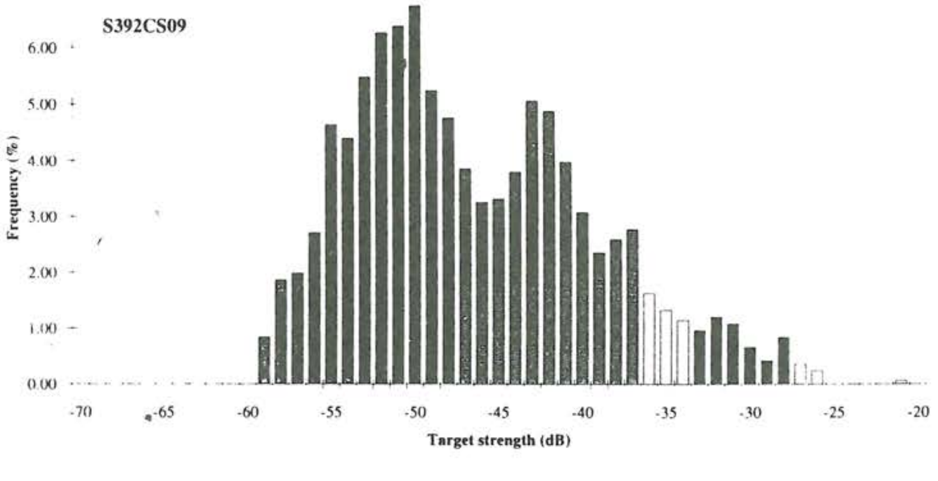


Figure 3g. Target strength probability density function for transect B201 (Broad survey).

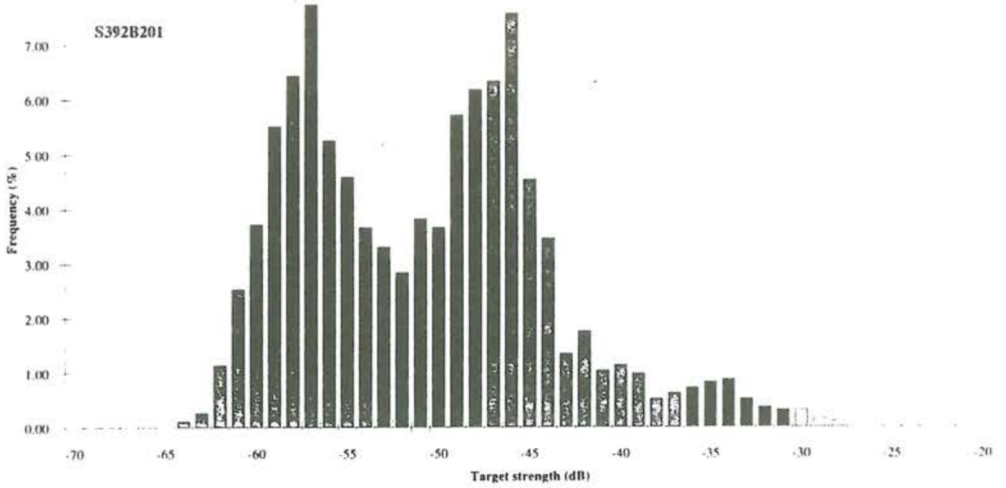


Figure 3h. Target strength probability density function for transect B306 (Broad survey).

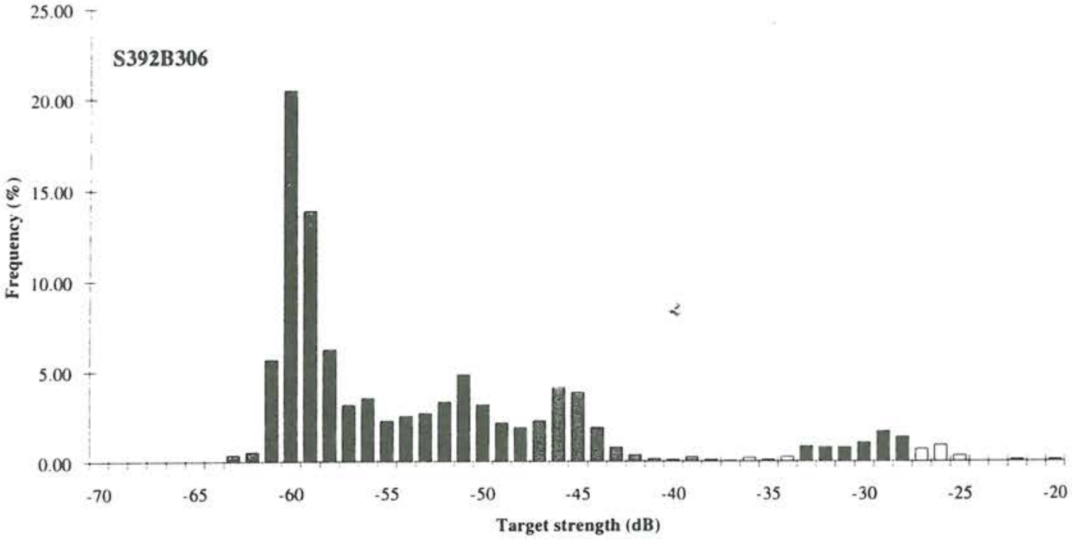


Figure 3I. Target strength probability density function for transect B207 (Broad survey).

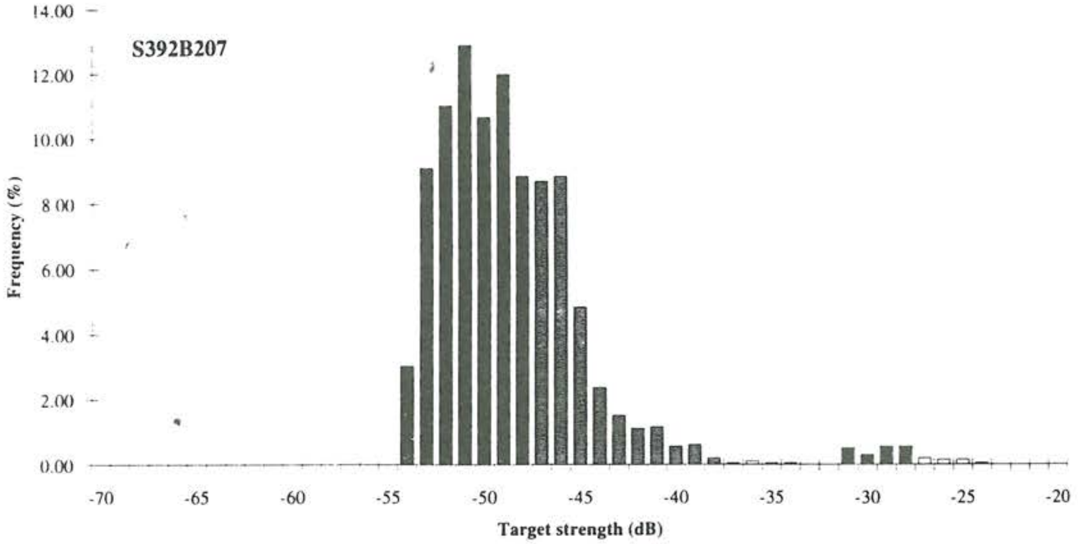


Figure 3j. Target strength probability density function for transect B224 (Broad survey).

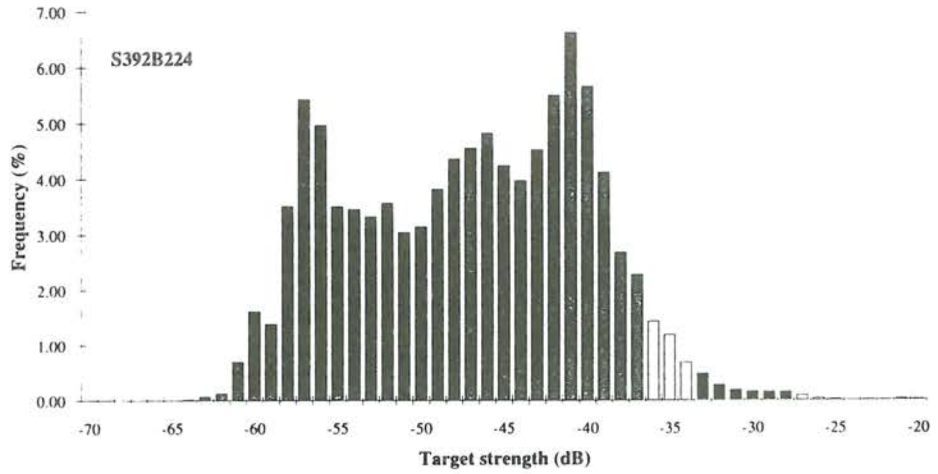


Figure 3k. Target strength probability density function for transect B228 (Broad survey).

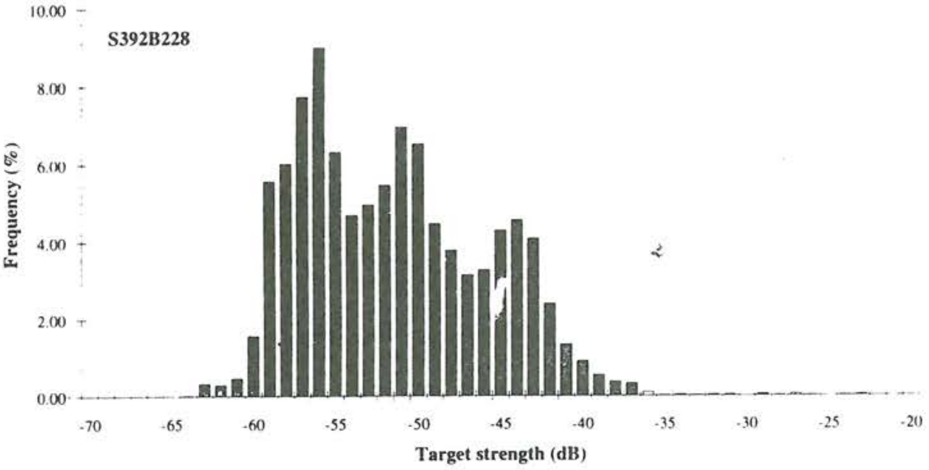


Figure 3l. Target strength probability density function for transect B230 (Broad survey).

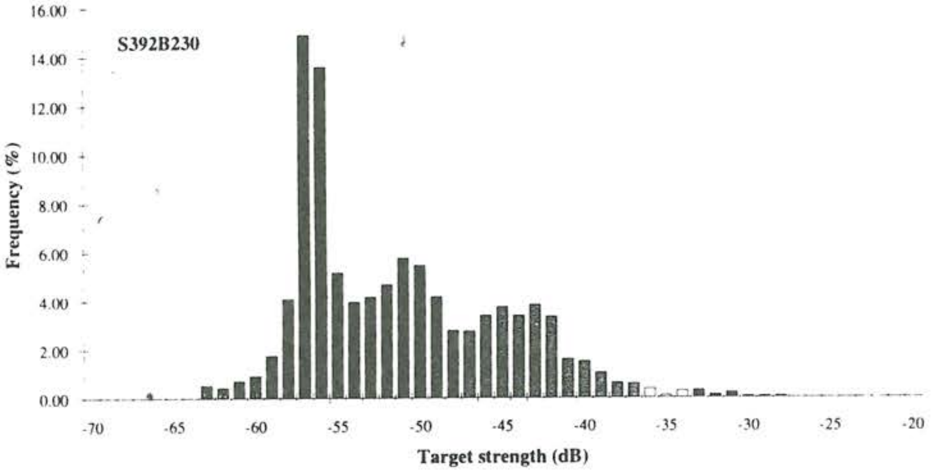
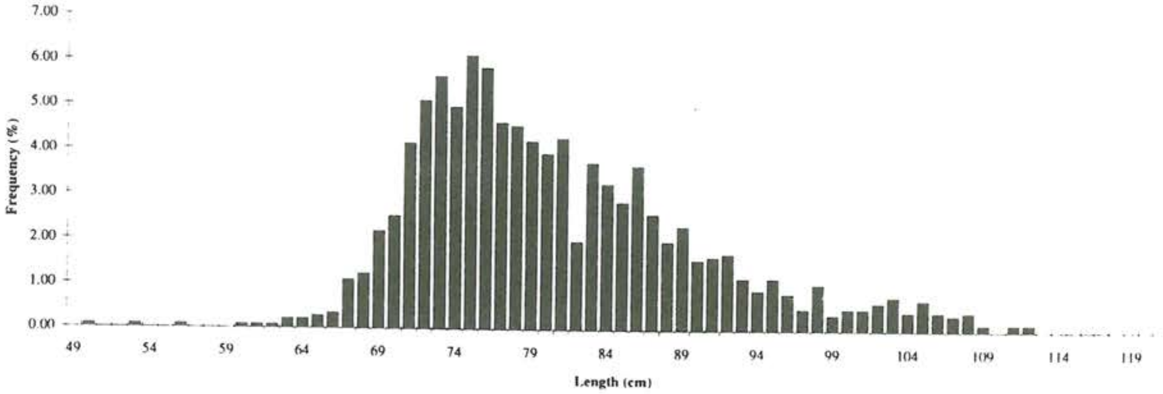


Figure 4. Length-frequency distribution of adult blue grenadier caught during the trawl survey.



APPENDIX

ORIGINAL PROPOSAL

FIRDC 1989 NEW APPLICATION GRANT

FISHING INDUSTRY RESEARCH AND DEVELOPMENT COUNCIL
1989 NEW APPLICATION GRANT 1989

1. TITLE OF PROJECT

Development and use of acoustic techniques for the assessment of deepwater commercial fish stocks

2.KEYWORDS

Acoustics, deepwater commercial fish stocks, stock assessment, orange roughy, southeast Australia, western Australia

3.OBJECTIVES

- To develop the techniques to provide quantitative acoustic assessment of the biomass of commercially important fish stocks in the AFZ.
- To use these methods a) to assess the standing stock of orange roughy off east Tasmania, and b) to assist in a deepwater exploratory fish survey off western Australia.

4. JUSTIFICATION

The most commercially important southeast Australian trawlfish resources are now found in deep water over the continental slope and include orange roughy, gemfish, blue grenadier, and others. Management of these fisheries in Australia and New Zealand has generally proven exceptionally difficult, largely due to problems of stock assessment. Cohort analysis has not been possible for orange roughy due to inability to age the mature fish, and catch per unit effort (CPUE) indices are generally difficult to use as estimates of stock density for highly aggregated species, such as roughy or grenadier. The value of trawl surveys alone for orange roughy and blue grenadier also seems highly questionable due to their occurrence over untrawlable ground, variable distribution in the water column (i.e. only partial accessibility to sampling gear), and saturation of the trawl when aggregated. Despite these difficulties, there is a critical need to properly manage these resources. The orange roughy seems particularly vulnerable to overfishing due to the combination of its apparent longevity (~75 years) and massive, highly predictable spawning aggregations. Segments of the New Zealand orange roughy fishery are on the verge of collapse after only 10 years of exploitation.

With the discovery last year of the first major spawning aggregation of orange roughy off St. Helens, northeast Tasmania, the catch of orange roughy (~20,800 t) more than doubled and likely exceeded the catch for all other fin fish in the Southeast Australia trawl fishery combined. Estimates of the biomass of the aggregation vary by more than an order of magnitude (50,000 -

>1,000,000 t), placing management of the fishery in a state of crisis, since first-order models indicate that only ~3% of virgin biomass may be removed annually on a sustainable basis (Mace et al. in press).

The recent development of the deepwater trawl fishery off southeast Australia also highlights how little is known of Australian deepwater fishery resources. The slope region off western Australia is particularly poorly explored, which underlies CSIRO's FIRDC grant, 'Exploratory survey for deep-water fisheries resources on the continental slope of Western Australia.' A trawl survey is proposed as part of this grant, but again, trawl surveying alone is a relatively inefficient means to search for commercial fish concentrations. The use of acoustics in combination with trawl sampling would considerably enhance our ability to search for and assess the extent of potentially important concentrations of fish.

The following proposal and a related, but independent proposal ("Development and use of the egg production method to assess the biomass of orange roughy off eastern Tasmania") are largely framed within the specific need to assess the biomass of orange roughy off eastern Tasmania. However, they are also designed to meet the critical long-term need for alternative survey methods for major trawl fisheries off southeast Australia. We believe that their use may be extended both to other regions (if orange roughy spawning aggregations are discovered elsewhere) and to other species, such as blue grenadier, which form reasonably localized, predictable spawning aggregations. Finally, this proposal is intended to enhance our ability to explore the potential deepwater fishery resources of the AFZ (e.g. off western Australia). This proposal builds directly upon developing expertise at CSIRO in the use of acoustics for deepwater fisheries (FIRDC grant 1987/129).

Acoustic survey methods have been standardized (Johannesson and Mitson 1983; Shotton and Bazigos 1984) and used successfully on a world-wide basis with epipelagic, midwater and shelf fisheries (e.g. Gjosaeter and Kawaguchi 1980; Jakobsson 1983; Karp and Traynor 1988). Quantitative acoustic echo-integration surveys are based upon use of a calibrated echo sounder, often in combination with photographic, video and/or trawl sampling for target identification and comparison of packing density estimates. The use of acoustics has recently been extended to surveying orange roughy off New Zealand (Do and Coombs 1989), but significant technical questions still remain.

Orange roughy is best suited to acoustic survey methods during the spawning period. At this time, most of the stock appears to be highly localized (the area of the aggregation off St. Helens was ~10 km^2 in area), is found from the seabed to several hundred metres into the water column, and catches indicate little admixture of other species. As a result the aggregation can be mapped and echo integration techniques applied to estimate orange roughy biomass in the water column. Once the method has been validated and analytic protocols developed, acoustics may provide a rapid assessment tool - results of the acoustic survey may be known virtually upon completion of the field work.

However, there are still several significant technical issues to be resolved in the use of acoustics to obtain absolute biomass estimates for a benthopelagic fish at mid-slope depths.

- Even within spawning aggregations, a significant fraction of the orange roughy population may be distributed near the bottom, where it is not possible to reliably estimate fish biomass due to an acoustic 'dead zone' and possible acoustic artifacts in the near-bottom layer, particularly in steep, rugged environments. Estimates of the near-bottom portion of the population will be obtained by comparison of data for the near-bottom layer when the acoustics are towed at varying depths from the bottom; as well as comparison of the results from acoustics with those from trawl sampling and photographic sampling of the near-bottom layer. Again, this problem can be minimized by towing the acoustic system at depth, but the depth at which the system can be safely towed in the vicinity of pinnacles is clearly limited.

- There is serious question concerning the target strength of orange roughy. Do and Coombs' (1989) target-strength estimate was based upon the average backscattering from dead orange roughy, which were rotated 30°.to either side of the dorsal aspect in the pitch and roll planes. The resulting target-strength estimate was a factor of two higher than the value obtained if the orange roughy were rotated only 5°. In other words, use of Do and Coombs' target strength value could lead to a two-fold underestimate of orange roughy biomass. Furthermore, the in situ target strength of orange roughy may differ from that obtained in the laboratory due to a possible phase change at surface pressure and temperature in the wax esters that roughy use for buoyancy and energy storage (Yayanos et al. 1978). Measurements are therefore required of the target strength of orange roughy in the field. Such measurements would take account of the fish's behavioral aspect, as well as ensuring against possible physical/chemical artifacts. Photographic assessment of the in situ vertical aspect of orange roughy is also desireable.

The target strength of other major benthopelagic fishes should be determined as well to lay the groundwork for possible acoustic discrimination among species. This would significantly enhance the use of acoustics for deepwater fishery surveys. Unlike most macrourids and oreo/dories at these depths, which have gas-filled swimbladders, orange roughy have a swimbladder filled with wax esters. Orange roughy therefore present a weaker acoustic target. Given ancillary information (i.e. from trawls or photography) about the overall composition of the mid-slope benthopelagic community in an area, it may be possible to distinguish acoustically between orange roughy and other species, when the fish are dispersed so individual targets may be recorded. Acoustic discrimination has been successfully achieved for several species in the North Atlantic (Rose and Leggett 1988). Such discrimination would greatly expand the possible range for application of acoustic survey methods, since several species generally co-occur with orange roughy when the roughy are either dispersed or in non-spawning aggregations: e.g. summer aggregations of orange roughy off southern Tasmania (Maatsuyker), which co-occur with dories and other species.

Funds are requested for three year's field work. The validity of the methods needs to be tested by comparing results of the biomass assessments over two field seasons. Results of the first year's (1990) orange roughy survey will prove provisional, due to lack of a suitable vessel (i.e. the FRV 'Southern Surveyor'), from which the towed body may be deployed. Development of acoustic methods will be carried out largely on summer cruises, when, in particular, multispecies discrimination can be best examined. A workshop is proposed to be held in Hobart at the end of the first year, when results of the initial survey will be available. It will be particularly valuable to assess our use of acoustic and stereo photographic techniques at this time. Members of the acoustic and stereo photographic groups at the New Zealand MAFFish Fisheries Research Centre and Antarctic Division (Hobart) will be invited, along with outside experts: J. Osborn, University of Tasmania on use of stereo photographic techniques, and an acoustician from a major European or North American laboratory. Funds are requested to meet the expenses of bringing in this latter individual.

In summary, the information to be gained from this project is critical to the present management needs of the southeast trawl fisheries and to development of deepwater fisheries in western Australia. When the technical issues related to the use of acoustics for deepwater fishes are resolved, acoustic methods can be used routinely to assess orange roughy in other areas and can be extended to assess other segments of Australian trawl fisheries (e.g. blue grenadier, gemfish). Aspects of the proposal were presented to the 1989 Orange Roughy Workshop (Taroona, Tasmania) and discussed with the DPFRG and GITLC during their 1989 meetings. The final performance of the project should be judged primarily on our ability to successfully develop the acoustic survey technology and to apply it to assessment of the orange roughy resource off east Tasmania and exploratoration of deepwater fish resources off Western Australia. In the longer term the project should be judged based upon the successful transfer of the technology to the routine assessment of orange roughy and other deepwater resources.

5. PROPOSAL IN DETAIL

METHOD OF PROCEDURE

OBJECTIVE: DEVELOPMENT OF ACOUSTIC METHODOLOGY.

The acoustic sampling system was designed and constructed under FIRTA Grant 87/129 (see Appendix 1) to address problems encountered when applying acoustic methods to deep sea resources. The acoustic system will be deployed and fishery surveys conducted from the first year of this proposed study, within the constraints of the available survey vessel. (See Table 1: Project timetable.) However, interpretation of the acoustic data will be subject to several potentially significant sources of bias. An experimental program must be carried out in parallel with the survey program to resolve these issues. Based upon results of these experiments, provisional biomass estimates from surveys in years 1 and 2 may be revised at the conclusion of the project. The following experimental program is required to refine the use of acoustics for deepwater fish biomass estimation:

- Target strength measurements will be made on orange roughy and other deepwater fishes that are of potential commercial importance (e.g. blue grenadier, gemfish, oreo/dories). Acoustic measurements will be made on dead fish in the laboratory, where the size and aspect (i.e. pitch and roll), as well as the species, can be precisely controlled. In the field, this work will involve, first, in situ measurements using the split beam transducer to determine the mean target strength of individual fish within aggregations, in particular of orange roughy. Secondly, acoustic measurements will be related to the size and species composition of targets by comparing results of acoustic and trawl sampling of particular areas and depth strata. Of particular concern are the layers of acoustic traces often found well above the bottom in regions where orange roughy are obtained with demersal trawls. An opening-closing cod-end net system (Pearcy 1980) is requested in order to sample discrete strata through the water column. Opening-closing systems for midwater trawls, a basic and widely used tool for studying deepwater fisheries, have not yet been used in Australian waters. Finally, we will compare estimates of fish type, size, and density from acoustic and stereo photographic profiles, which will be obtained by simultaneously lowering these systems through the water column. Data on the packing density, length composition, and behavioral aspect of fish in the water column can be obtained from stereo photographs (Klimley and Brown 1983; Aoki et al. 1986, and references therein). Stereo photographs will be analyzed with an Adams Technology analytical stereoplotter available through J. Osborn, University of Tasmania.

- We will examine the influence of the acoustic near-bottom/dead zone on biomass estimates for orange roughy. This question will be approached several ways: 1) comparison of acoustic returns from the near-bottom layer when the towed body is deployed at varying depths over the bottom and when the acoustic system is switched between the hull-mounted and towed transducers; and 2) comparison of acoustic and both trawl and photographically-based estimates of fish abundance in the near-bottom layer. This work will be repeated over several bottom types, since the extent of the dead zone is a function of bottom slope and roughness.

OBJECTIVE 2: FIELD SURVEYS

Two forms of acoustic (echo-integration) surveying will be carried out to estimate the biomass of an orange roughy spawning aggregation: namely, small scale biomass surveys of the spawning aggregation itself and a coarser scale survey of the dispersed population outside the main spawning aggregation to estimate the proportion of the stock that is either non-reproductive or moving to and from the spawning area. Both surveys will involve extension of standard acoustic (echo-integration) survey methods (Johannesson and Mitson, 1983; Shotton and Bazigos, 1984) to deep water (see Appendix 1 for details of the theory of acoustic biomass estimation).

The area occupied by the main spawning aggregation of orange roughy off northeast Tasmania was relatively small in 1989 (~10 km^2) and therefore lends itself to repeated intensive acoustic surveying. Likewise, the size and species composition was homogeneous (J. Lyle, J.A. Koslow, unpublished data from 1989 spawning aggregation), which facilitates the use of echo-integration for biomass estimation. The survey will be based upon a series of parallel and orthogonal acoustic transects over the aggregation, which will be completed within a single Global Positioning System (GPS) 'window' (~8 h) and repeated several times during the spawning period. The actual size and species composition of acoustic targets will be determined from commercial catch sampling, demersal and midwater trawling using the opening-closing net, and stereo camera profiles. The packing density of the fish will be determined:

- from data on in situ target strength of orange roughy (and other dominant fishes) obtained by use of a calibrated acoustic system with split-beam transducer, which enables individual targets to be positioned; and
- from a series of vertical acoustic and photographic profiles, which will be obtained simultaneously by lowering the towed body with both acoustics and stereo camera through the water column.

In addition to the survey of the spawning aggregation itself, a survey will be conducted along the northeast coast of Tasmania to determine the distribution and abundance of orange roughy outside the spawning aggregation (Fig. 1). This will enable us to estimate during the spawning season the proportion of fish that are .a) non-reproductive (non-maturing gonads), which was estimated at 17% of the adult stock in 1988 (Bell 1989)) or b) in pre- or post-spawning condition and presumably en route to the spawning aggregation or dispersing from it. Gonad material will be examined histologically to differentiate between atretic (i.e. non-reproductive) and spent fish. If possible, fish will also be sampled from the commercial catch prior to the spawning migration (i.e. in March), when the proportion of non-reproductive fish relative to the mature population can be best estimated. This survey will be carried out within the area 55 km north and south of the spawning aggregation and will be based upon a series of zig-zag acoustic transects between 800 to 1500 m depth (Fig. 1). When fish traces are found, the towed split-beam transducer and stereo camera will be lowered to identify targets and determine packing density acoustically and photographically through the water column. Trawl samples will be obtained where possible to determine species composition. Additional trawl samples will be taken systematically within 100 m depth strata along the acoustic track to estimate background levels of fish abundance. Thus in combination with trawl and stereo photographic sampling, acoustics will be used outside the spawning aggregation to enhance the search for orange roughy, examine their vertical and horizontal distribution, and estimate abundance.

We will examine the possibility of surveying mixed species aggregations in the second or third year of the project, after target strength measurements have been made on dominant benthopelagic fishes. This work will likely be carried out on orange roughy in non-spawning aggregations (e.g. Maatsuyker off southern Tasmania), where fishermen report mixed-species catches. The transducer's split beam capability would be used to examine the frequency distribution of the strength of individual targets. Assuming that the orange roughy present relatively weak acoustic targets, due to their lack of a gas-filled swimbladder, it should be possible to distinguish them from dories and several other species. Again, acoustic results will be compared with samples obtained from trawling with the opening-closing net and photographic profiles of the water column.

The acoustic system will also be used as part of the exploratory fishing program that FIRDC has funded for the slope waters off Western Australia. A series of zig-zag acoustic transects will be carried out from ~20° S to 35° S at depths from 200-1300 m. A trawl survey was proposed to carry out this program, but trawling alone is an inefficient means to search for fish aggregations. The use of acoustics in combination with trawl sampling would considerably enhance our ability to search for and assess the extent of potential commercial concentrations of fish.

Field surveys to assess the biomass of an orange roughy spawning aggregation will be carried out on a cruise during the winter spawning period of each year. Ancillary acoustic experimentation and testing, work with mixed-species aggregations, and the combined acoustic/trawl exploratory fishing survey on the slope off Western Australia will be conducted during cruises in the non-spawning period.

FACILITIES AVAILABLE

Field work will be carried out aboard the newly outfitted CSIRO FRV 'Southern Surveyor' after August, 1990. The vessel contains laboratory space with electronic balances for wet laboratory fish work. CSIRO has the following equipment required for field and experimental work: Engel High LIft (rough bottom) commercial demersal trawls (19 m long mouth opening; headrope 10 m high maximum) (an additional net is requested for replacement purposes); Engel 152 commercial midwater trawl, which can be fitted to the requested opening-closing codend system; a Simrad EK500 scientific sounder system with tow body and faired conducting cable to tow it at several hundred meters and lower it to 1000 m; a Photosea stereo camera.system that can be lowered to 2000 m; computers and software required for data analysis.

Histological examination of the gonads of orange roughy captured outside the spawning aggregation will be carried out at the laboratory of J. Bell (Fisheries Research Institute, NSW Agriculture & FIsheries), which is fully equipped for this work.

The 'Southern Surveyor' will not be available in 1990 in July, when the orange roughy spawned in 1989. A chartered vessel, such as the FRV "Bluefin' will be required to carry out the survey. The slip-ring winch required for the towed body (weight: ~750 kg) and 2500 m of conducting cable cannot be removed from 'Southern Surveyor', so we will be limited to deploying the transducer near the surface. Photographic and trawl sampling will not be affected by use of the chartered vessel. Funds have been requested from the Government-Industry Technical Liaison Committee (GITLC) for vessel charter and approval is expected. If funds are not forthcoming from the industry, a supplementary application will be made to FIRDC.

SUPPORT DATA

Staff have been actively involved as part of FIRDC Grant 1987/129 in carrying out trawl surveys and biological investigations of orange roughy (Bulman and Elliot 1988; Bulman et al. 1989) and development of the deepwater acoustic and stereo photography systems.

6. RESEARCH PRIORITY

The proposed study is directly related to the Council's first priority, fish resource assessment, i.e. to develop and implement use of a survey method to assess the orange roughy resource off east Tasmania. It is expected that these methods can be extended to other aggregations of orange roughy as discovered, as well as to other southeast trawl fisheries.

7. TRANSFER OF RESULTS TO INDUSTRY

Results of this project are of critical importance to the proper management of the developing orange roughy fishery off southeast Australia. Survey results will be presented in a timely manner to committees and agencies responsible for management of the fishery (i.e. DPFRG, SETMAC, AFS, BRR, GITLC) at annual meetings and as requested. Results will also be presented at national and international scientific meetings and published in the scientific journals in order to receive critical review and contribute to the development of fishery science. Developments will also be published in the industry literature (e.g. Australian Fisheries).

8. COMMENCEMENT AND COMPLETION DATE

Commencement date: July 1, 1990
Completion date: June 30, 1993.

9. REQUESTED BUDGET

	1990/91	1991/92	1992/93
Salaries and Wages	209,753	190,779	190,663
Operating Expenses	67,350	51,750	31,750
Travel Expenses	7,900	2,900	2,900
Capital Items	38,000	-	-
TOTAL	323,003	245,429	225,313

10. FUNDS SOUGHT FROM OTHER SOURCES

1990: Vessel charter (RV Bluefin), 4 weeks: $108,000.
Funds sought from the Government-Industry Technical Liason Committee (GITLC).

11. FINANCIAL CONTRIBUTION OF APPLICANT

SALARIES

	1990/91	1991/92	1992/93
Dr. P. Young SPRS max (15%)	9,300	9,700	10,200
Mr. C. Liron STOF 1/max (35%)	11,300	11.900	12,500
Ms. S.Wayte ES 3/2 (20%)	7,500	7,900	8,200
Mr. M. Sherlock ES 2/max (30%)	10,440	10,950	11,550
Mr. J. Cordell TOF 2/3 (30%)	8,750	9,250	9,650
Subtotal	**47,290**	**49,700**	**52,100**
Salary oncosts and overheads x 1.1	52,020	54,670	57,310
Salary total	**99,310**	**104,370**	**109,410**

OPERATING COSTS

Full operating costs for FRV Southern Surveyor for 5 weeks at sea, port and harbour dues, normal crew airfares and fuel costs	787,500	827,500	870,000
Laboratory facilities and research support	63,000	66,000	70,000
TOTAL FUNDS **provided by applicant**	**949,810**	**997,870**	**1,049,410**
TOTAL FOR 3 YEARS:			$2,997,090

Contribution of NSW Agriculture and FIsheries

Salary

	1990/91	1991/92
Dr. J. Bell, RS (10%)		

12. BUDGET IN DETAIL

	1990/91	1991/92	1992/93
Salaries			
J.A. Koslow, SRS 4 (50%)	22,850	22,850	22,850
R.J. Kloser, ES 1/max (100% Yr 1; 75% Yr 2; 50% Yr 3	30,363	22,772	15,182
C. Stanley ES 3/max (50%)	20,063	20,063	20,063
Exp scientist ES 3/max (50%)	20,063	20,063	20,063
Tech asst TA 2/max (50%)	12,057	12,057	12,057
Tech asst TA 2/max (25%) (supervised by J. Bell, NSW FRI)	6,029	6,029	-
Administrative Assistant			
ASO 1 20,466	20,466	20,466	
Computer Programmer ES 2/1	8,000	-	-
Sub-total	**139,891**	**124,300**	**110,681**
Superannuation 18.4%	25,740	22,871	20,365
Comcare 2.5% 3,497	3,108	2,767	
Leave loading 2,125	2,000	1,750	
Accrued leave		16,600	
Marine Survey allowance & overtime 5 sea wks @$1100/wk x 7 staff	38,500	38,500	38,500
Total Salaries ($)	**209,753**	**190,779**	**190,663**

Operating expenses

Engel trawl (replacement)		20,000	
Ropes, shackles, deepwater floats	3,000	3,000	3,000
Histological supplies, preservatives 3,000	3,000	3,000	
Spare parts for EK500, towbody[1] 39,600			
Electronic supplies, maintenance: acoustics	5,000	10,000	10,000
Computer software, updates	1,000	1,000	1,000
Film, processing supplies	3,500	3,500	3,500
Stereo photographic analysis[2]	12,250	11,250	11,250
Total operating expenses ($)	**67,350**	**51,750**	**31,750**
Travel expenses			
Orange roughy workshop (e.g. Sydney) 2 staff	2,400	2,400	2,400
Incidentals, staff at sea, @$8/d x 30 d x 2 staff	500	500	500
CSIRO/MAFFish workshop[3]	5,000		
Total travel expenses	**7,900**	**2,900**	**2,900**
Capital items			
Opening/closing codend system for mid-water trawl, cod-ends, travel for consultant to set-up	38,000		
Total capital items		38,000	
Budget total	**323,003**	**245,429**	**225,313**

Notes to budget

1) The EK500 is new and there is no record of which spares are essential. Spares are not available in Australia and would have to be ordered from Norway. A breakdown in mid-cruise would therefore likely entail loss of the cruise and field season. Items recommended by Simrad as spares for EK500:

38 kHz transceiver	4,300	
Interface I/O	6,500	
Digital interface	2,700	
Signal processor	4,900	
Display processor	5,500	
Control processor	5,200	
Spare connectors for towed body	3,000	
Spare retermination kit for cable	1,500	
Storage cases, electronic & towed body equipment		2,000
TOTAL:	**$39,600**	

2) Photographic analysis based on use of Adams Technology analytical stereoplotter at University of Tasmania (J. Osborn). Initial setup and training: $1,000. Thereafter the cost for use of the machine is ~$15/stereo pair (machine time: $50/hr; ~3 pairs analyzed/hr). ~750 stereo pairs will be analysed per year: ~500 from within the aggregation (10 profiles, 50 shots/profile); ~250 stereo pairs from outside the aggregation.

3) A joint workshop on acoustic and stereo photographic techniques is planned for December 1990 in Hobart between CSIRO, MAFFish (New Zealand) and the Antarctic Division (Hobart) which at that time will all have initial results from work with stereo photography, the EK500 and/or deepwater fishery surveys. There may be considerable benefit in comparing and evaluating our use of these techniques at this time, and by opening them to external review. Funds are requested to meet the costs of bringing in an outside acoustic expert. MAFFish will meet its own costs.

13. ORGANIZATION

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14. PROJECT SUPERVISOR

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15. STAFF QUALIFICATIONS AND ROLE

J.A. Koslow, Ph.D. (50%) SRS 4	**Project supervisor:** Overall responsibility for project planning and execution; data analysis, interpretation, write-up, and reporting
R.J. Kloser, BE (100%, Yr 1; 75% Yr 2; (50% Yr 3) ES 1	**Acoustics, electronic engineer:** development, use, and maintenance of acoustic system; participation in all acoustic surveys and experiments; collaboration on acoustic data analysis & report writing.
C.A. Stanley, Ph.D. (50%) ES 3	**Stereo camera:** development, use, and maintenance of stereo camera system; participation in all cruises; supervision of analysis of stereo photographs; analysis & interpretation of these data; presentation of results
Experimental Scientist (to be named) (50%)	**Collection, analysis & interpretation of** biological data (e.g. trawl sampling); participation in field program; collaboration with R. Kloser in analysis of acoustic survey and experimental data & write-up of results.
Technical assistant (50%) (to be named)	**Field & laboratory technician** Assistance in collection of biological & photographic field data; analysis of stereo photographs
Technical assistant (25%) (to be named)	**Reproductive biology** Histological sectioning and analysis of gonadal material to determine reproductive stage

Computer programmer (3 months).	**Development of software/graphics** Initial processing and graphic presentation of acoustic data
Administrative	Assistance in servicing this grant and others presently managed from the Hobart Laboratory. The problem of overheads has been discussed in Council.

16. ADMINISTRATIVE CONTACT

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Table 1: Project Timetable

Dates:	Win '90	Sum '90	Win '91	Sum '91	Win '92	Sum '92
Cruises: (vessel)	Charter	1) SS 2) SS	SS	SS	SS	SS
Program	OR	1) WA 2) Exp	OR	Exp	OR	Exp

Mile- Provisional
stones: assessments
[______] [_______]
WA exploratory
fishing completed
[________]
System tested;
Initial experiments
[________________]
Experimental
work completed
[________} [________]
OR assessment
completed
[_______]
Data analysis/
write up completed
[________________]

Notes: SS: CSIRO's FRV 'Southern Surveyor'
OR: Orange roughy acoustic assessment, SE Australia
WA: Western Australia exploratory fishing cruise
Exp: Acoustic experimentation and development cruise

APPENDIX 1 ACOUSTIC THEORY AND SAMPLING SYSTEM

THEORY

Following is a brief introduction to the theory of echo-integration assessment of fish biomass. Further details can be obtained from Johannesson and Mitson (1983). The standard acoustic equation is:

$$S_V = VRT - (SL + SRT) - 10 \log (0.5C\tau) - 10 \log \psi + TL$$

where,

S_V = volume backscatter strength - the proportion of incident acoustic energy reflected back towards the transducer by targets;

VRT = measured voltage across transducer

SL = source level

SRT = sensitivity of transducer as a receiver

C = sound velocity in sea water

τ = pulse length

ψ = equivalent beam width of transducer

TL = transmission loss due to absorption and spreading, dependent upon depth, and absorption coefficient of sound in seawater.

Standard calibration techniques will provide the values for (SL + SRT), ψ and τ.

The echo integrator receives the output signals from the echo sounder and calculates the mean volume backscatter strength (Sv) by integrating S_V over a defined number of pulses of the sounder and distance along a transect. The integration is performed in a number of predetermined depth layers.

The mean volume backscatter strength;h is proportional to the density of fish in the target volume (P_V, fish/m^3) and the mean target strength (TS) of the fish:

The TS is defined as the ratio of the reflected acoustic energy at one metre from the fish, divided by the intensity of the energy which strikes the fish:

$$S_V = 10 \log p_V + TS$$

The TS is defined as the ratio of the reflected acoustic energy at one metre from the fish, divided by the intensity of the energy which strikes the fish. The value can determine using either split or dual beam transducers which compensate for the position of the target within the intensity-varying acoustic beam.

Hence with a calibrated echosounder and measured target strengths the mean number of targets (fish) in the integrated volume can be determined.

Acoustic sampling system (purchased from FIRDC Supplementary Grant 1987/129)

- Simrad EK500 Scientific sounder with software for split beam and echo integration
- 38 kHz transceiver for EK500
- Tow body and 2500 m of special faired cable