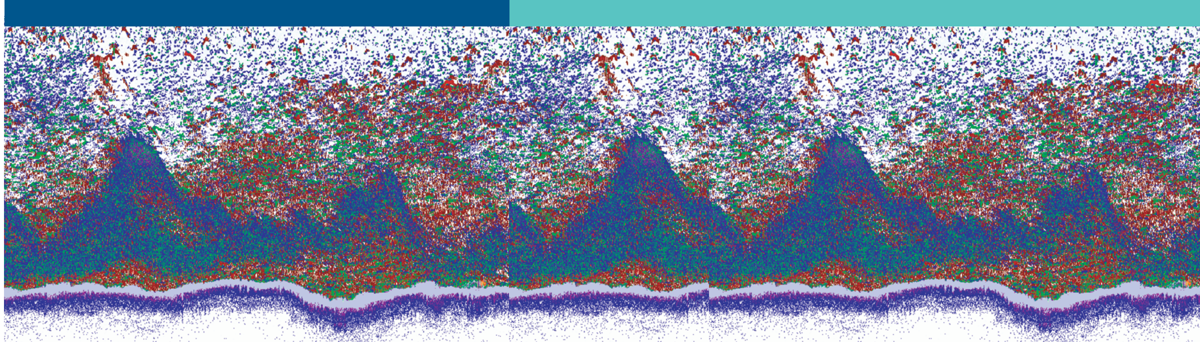
# Development and application of a combined industry/scientific acoustic survey of orange roughy in the eastern zone


R. J. Kloser
T. E. Ryan
A. Williams
M. Lewis



Final Report • December 2001

FRDC PROJECT 99/111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Development and application of a combined industry/scientific acoustic survey of orange roughy in the eastern zone – CSIRO Marine Research

# DEVELOPMENT AND APPLICATION OF A COMBINED INDUSTRY/SCIENTIFIC ACOUSTIC SURVEY OF ORANGE ROUGHY IN THE EASTERN ZONE

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# DEVELOPMENT AND APPLICATION OF A COMBINED INDUSTRY/SCIENTIFIC ACOUSTIC SURVEY OF ORANGE ROUGHY IN THE EASTERN ZONE – FRDC PROJECT – 99/111


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| **Principal Investigator** | Mr R. J. Kloser |
| **Address** | CSIRO Marine Research<br>GPO Box 1538 Hobart Tas 7001<br>rudy.kloser@csiro.au |
| **Co Investigators** | Dr Alan Williams, Dr Jeremy Prince*<br>* involved in the initial part of the project as a consultant for industry liaison |


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| | |
|---|---|
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Funding for the survey was provided by the fishing industry, FRDC, AFMA and CSIRO, and some logistical costs were met individually by the participating companies. Importantly, we note that the participation of vessel operators was voluntary.

# EXECUTIVE SUMMARY

## Objectives

- To survey the orange roughy on the Eastern Zone fishing grounds during the spawning period using industry vessel acoustics over an extended period and the CSIRO acoustic package during the anticipated peak spawning period.
- To assess how industry acoustics may be best used in the long term management of the resource.
- To compare the sensitivity and precision of acoustic surveys using scientific vessel-mounted and towed-body acoustics and industry vessel-mounted acoustics.
- To further develop the acoustic method by improving the multi-frequency technique for species identification.

## Non technical summary

### Background and need

In 1999, the orange roughy fishery remained the most valuable component of the South-East Fishery (SEF) but recent assessments indicated the Eastern Zone TAC would need to be further reduced to enable the stock to rebuild. The validity of the current estimates of stock status needed to be clarified - there had been no comprehensive survey of the spawning aggregation since 1992. Futhermore, there has been a southwards shift of the fishery from St. Helens Hill to an area known as St. Patricks Head. There were insufficient data to estimate the biomass of orange roughy on that ground with confidence.

The uncertainties associated with recent surveys can be traced to the limited spatial and temporal coverage of the scientific acoustic surveys and the lack of quantitative data from industry. This project aimed to carry out a survey during the 1999 spawning season that combined the high-precision acoustic capability of the CSIRO research vessel *Southern Surveyor* together with the knowledge of fish dynamics and extended time on the ground provided by an industry vessel. It also aimed to assess the ability of industry echo-sounders to monitor the size and dynamics of the spawning aggregations with a view to using industry vessel acoustics for long term monitoring of the resource. The opportunity to test the capability of industry vessel based surveys was possible during the 2001 spawning season because of an extension to this project. Results from that survey are also reported here.

### Methods overview for 1999 biomass assessment

From July 9th 1999, the industry vessel *Saxon Progress* completed four trips to the St. Helens Hill and St. Patricks Head fishing grounds over a month long period. The vessel completed acoustic surveys using its commercial fisheries sounder and undertook targeted demersal trawling as directed by scientists aboard the *Southern*

*Surveyor*. Mid-way through the month-long industry vessel survey, from July 16th onwards, the *Southern Surveyor* spent 16 days at the fishing grounds. At St. Helens Hill and St. Patricks Head, it carried out a series of acoustic surveys using vessel-mounted and deep-towed acoustic systems. In addition, target identification of midwater acoustic scatterers was achieved by pelagic sampling of midwater communities.

The scientific echo-sounder used was a SIMRAD EK500 (Version. 5.3) configured with a combination of 12, 38 and 120 kHz transceivers. The range of transducers used were hull-mounted or pole-mounted on the vessel, or towed at 400 and 800 m depth in the MUFTI (Multiple Frequency Towed Instrument).

### Biomass assessments for 1999

The relative biomass of orange roughy at St. Helens Hill was estimated to be 5,200 tonnes by the deep-towed 38kHz system and 3,300 tonnes by the *Southern Surveyor* vessel-mounted 38kHz system using our relative index methodology. This represents a reduction in biomass since 1996 of 45% and 50 % respectively in the towed and vessel estimates, at a time when the stock is expected to be in a rebuilding phase given current catch levels. Clearly this signals a dramatic decline in spawning orange roughy biomass on St Helens Hill. A previously untried Loop survey method using multi-frequency acoustics (MUFTI) is most likely to represent the best estimate of stock size due to improved species identification. It produced a school-based biomass estimate of 1,100 – 2,600 tonnes at St Helens Hill, but is not directly comparable with previous years surveys.

We consider the biomass on St Helens Hill has declined to a level where vessel mounted acoustics (industry and scientific) are no longer a viable method to survey orange roughy for biomass assessment. This is because the small size of the orange roughy stock makes vessel-mounted surveys very sensitive to school identification. The advantage of the deep-towed MUFTI system is its ability to distinguish orange roughy from the bycatch species and therefore echo-integrate schools confidently identified as orange roughy to establish their biomass.

A relatively large aggregation of orange roughy was consistently observed in the north west region of a prominent ridge feature at St. Patricks Head by both vessel and towed acoustic systems. The towed acoustic system also showed that scattered concentrations of orange roughy were found further south along the ridge in association with significant numbers of highly reflective bycatch species including lanternfishes (myctophids), whiptails, morid cd and oreos. Our provisional estimate (and upper bound) of the biomass of orange roughy at St Patricks Head is 14,800 tonnes, with some uncertainty due to the mixed species composition of the marks. These schools were persistent but were also spatially dynamic - both in their geographic position and density - making assessment based on school size a difficult proposition. We estimate that 37 % of the biomass on St Patrricks at the time of the survey was outside the high intensity school region at the north of the ground

### Biological sampling for 1999 and 2001 surveys

In 1999, aggregations of spawning orange roughy at St. Helens Hill were restricted to the western sector in the 800-900 m depth range. Large catches of ripe fish confirmed that a large spawning event also occurred at the northern end of the St. Patricks Head ridge in 800-1000 m depth. The overall size distribution of roughy at St. Helens Hill was not substantially different to that in previous surveys (based on data amalgamated for sex and without distinguishing aggregations from backscatter). Length and age data suggest there were proportionally more older and larger fish at St. Helens Hill than St. Patricks Head, and in fish samples from aggregations compared to backscatter. Gonad maturity stage data and large catches confirmed that the scientific acoustic survey undertaken by *Southern Surveyor* in 1999 spanned the main spawning event; spawning aggregations in both regions had dispersed within 10 days of the survey's completion.

In the 1999 survey, the combination of targeted demersal and pelagic trawling identified the dominant components of bycatch in marks at both grounds. In the deep water column around St. Helens Hill and along the ridge at St. Patricks Head these are lanternfishes, whiptails and morid cod. Prominent marks around the top of St. Helens Hill are mainly telescope cardinalfish and alfonsino. Because the gas-filled or spongy-matrix swimbladders of all these species are more reflective than the wax-ester filled bladder of orangy roughy they contribute relatively strongly to acoustic backscatter.

Several of the important biological patterns observed in 1999 were again found in the 2001 survey:

- Similar distributions of the main spawning aggregations across the two grounds and similar timing of the main spawning event.
- Markedly different sex ratios between the two grounds (more males at St Patricks Head and more females at St Helens Hill) despite a near-even overall ratio.
- Higher proportion of by-catch at St. Helens Hill (due in-part to the relatively small catches of orange roughy taken there).
- No appreciable between-year differences in mean length of the roughy population (by sex or ground).

Fish collections were used to make further investigation of two fundamental biological quantities of orange roughy: weight loss while frozen and during thawing, and the validity of the length-weight conversion formula. We found that weight loss may be substantial, meaning careful methodology is required to ensure parameters relying on fish weight are reliable. Analysis of both the 1999 and 2001 data confirm that conversion errors will result when using the historical length-weight conversion equation. This problem is the subject of ongoing work and will be presented to ORAG when completed.

Reliance on commercial vessels to gather biological data with minimal observer coverage was generally successful, and contributed to the successful development of an overall industry-based survey methodology. Improvements have been identified, in particular the need for collection of length, sex and maturity stage information from a greater number of catches simultaneously at both major grounds. Collection of data separately for aggregations and backscatter, which provided interesting results in the 1999 survey, was not possible from this method of survey.

From the 2001 surveys, 576 and 968 roughy otoliths were collected at St Helens Hill and St Patricks Head respectively. These were aged at the Central Ageing Facility and the results show a general trend to younger fish between 1992 to 2001 at St Helens Hill. These new data may remove biomass uncertainty in the population model due to older than expected fish being found at St Helens Hill in 1999.

## Industry Acoustics

The ability to acquire data from industry acoustics was a major uncertainty prior to the project but was possible in 1999 after modifying the existing EchoListener equipment. In this project we demonstrated that low noise acoustic data can be collected from an industry vessel acoustic system - although factors such as sidelobe interference, signal degradation due to bad weather, and pitch/roll signal loss have the potential to significantly reduce data quality. The limited ability of any acoustic system to sample the water column adjacent to the seabed (deadzone) affects the accuracy of this kind of biomass estimation survey, but this is particularly difficult for typical commercial sounders because of their wider beamwidth and long pulse length. Absolute calibration of commercial acoustic systems is also fundamental to biomass estimation if echo-integration results are to be compared between surveys and vessels.

Data from the *Southern Surveyor's* commercial Furuno FCV 140 28kHz fisheries echosounder were digitised and logged with an Echolistener. These data were compared to the scientific acoustic data to assess the suitability of using commercial acoustic systems for quantitative surveys. Data from the *Saxon Progress*'s FCV 382, 28kHz Furuno fishery echosounder were digitised with an Echolistener and logged to a PC.

Our assessment of the industry acoustic system was also based on its use as a relative tool for obtaining a school dimension index. The major limiting factors of the wide beam 28kHz industry acoustic systems are signal degradation due to poor weather and poor resolution due to large sampling volume. To overcome this problem in-part, we developed the methodology in 2001 to acquire acoustic data from higher resolution narrow beam Simrad ES60 echosounders that are now available in the industry (e.g. on the *Petuna Explorer*). Data collection has been greatly simplified and is collected at low cost where all the equipment is owned and operated by the vessel ensuring ongoing maintenance. The split beam operation of this ES60 sounder makes it a low cost option for calibration and would enable this type of acoustic system to be routinely calibrated in future years.

Acoustic data collected in 1999 and 2001 from month-long industry vessel monitoring surveys showed no clear pattern of build-up or decline of orange roughy, or indication of a mass influx, during the spawning period at either St. Patricks Head or St. Helens Hill. This was despite other clear evidence (e.g. peaks in catch data and trends in gonad maturation) that indicated a build-up and decline had occurred with a peak abundance during the middle two weeks of the spawning season.

Industry vessel acoustic data in 1999 and 2001 were useful to confirm an absence of large aggregations of orange roughy at St. Helens Hill, but were of limited value to estimate stock size or the within season build up and decline of the spawning stock. Changes in school size that may have occurred during the survey month could not be measured with the industry acoustics at St. Helens Hill, primarily because of the difficulty in interpreting the composition and boundaries of the marks that were present. For industry acoustics to be successful at St. Helens Hill, orange roughy must be present in larger, homogeneous schools, or the acoustic system needs to be improved to give higher quality data that can enable confident interpretation of marks.

In 2001, an extensive survey by three fishing vessels at the northern end of St Patricks Head confirmed that there were orange roughy schools during the peak spawning period that again were very dynamic as seen in 1999. With modified survey designs based on 1999 sampling we were able to obtain a school size index (based on normal fishing operations) and relative biomass index (based on directed surveys) that could form the basis for an ongoing index of abundance. It has not been possible to associate measurement uncertainty for the two abundance indexes. The varying performance of the acoustic systems on the three vessels, with the Simrad ES60 system performing the best, highlights the need to ensure that ongoing data collections be based on vessels with proven acoustic capabilities. The survey in 2001 highlighted that the industry acoustic method would only be suitable for sampling the highly aggregated portion of the spawning aggregation at the northern end of St Patricks Head but unsuited to monitoring the considerable portion of the stock in the lightly aggregated region along the ridge to the south. This may reduce the usefulness of the index where it may be insensitive to large changes in biomass if school size remains constant yet surrounding biomass decreases substantially.

Despite these shortcomings, our evaluation is not limited to the prospects of industry acoustics as a means to obtain a rigorous biomass assessment or relative index. We feel that recording acoustic data from industry vessels is a worthwhile activity and it would provide information on school location and dynamics, which is a necessary part in the process of obtaining a rigorous biomass assessment. Specifically, the advantages include: (1) the low cost of equipment and data recording if performed on a voluntary basis; (2) the higher likelihood that the acoustic system will be surveying in good weather and at a time when the schools are aggregated; (3) fishers' knowledge of the grounds and inter-annual patterns in the fishery will assist with interpretation of patterns in the data; and (4) providing a recorded synopsis of fishing activity on the grounds.

## Multi-frequency acoustics

We refined our multi-frequency acoustic system (MUFTI) and methodology to survey the small schools of orange roughy observed at St Helens Hill and St Patricks Head fishing grounds. The instrument was deployed over the grounds and identified regions of high orange roughy concentration by mixing the three frequencies. We judge that visualisation of the three-frequency MUFTI data enables a vastly superior interpretation of echograms when compared to the other (vessel mounted) systems. Our visualisation method of separating dominant species groups is supported by a simple resonant scattering model of the dominant fishes. The resolution of the vessel-mounted systems were unable to distinguish orange roughy at St Helens Hill and was limited to one intense school at St Patricks Head. Using the MUFTI system, a biomass assessment could be calculated with high confidence due to improved species composition. Our results show that the biomass of schooling orange roughy at St Helens Hill using multi-frequency species identification methods were 1,100 to 2,600 tonnes compared to the normal single frequency deep water surveys of 3,500 to 7,000 tonnes. A positive bias of a factor of 6.4 can occur in biomass assessments if species composition is not accurately assessed. Our results also show that the biomass at St Helens has continued to decline from 1996 to 1999 despite population models indicating it should be increasing (assuming steady recruitment).

### Future development and recommendations

This project has significantly contributed to the development and application of acoustic methods for the sustainable management of the orange roughy resource, and has applications to other fisheries based on schooling species, as well as to collection of environmental data and mapping seabed habitats. However, several areas require ongoing development of both the acoustic method and its application. These are:

1. Multi-frequency species identification is in its infancy; we have applied three frequencies to describe the major species-groups that occur with orange roughy. Further development of this methodology to improve the remote identification of nekton and micronekton species or species-groups will include detailed fish scattering models to predict optimal frequencies and using additional frequencies of similar sampling volumes, as well as wide-band methods. *We recommend that this work be continued as part of any future acoustic-based fishery assessment of orange roughy or other species, such as blue grenadier, that form spawning aggregations*.

2. Development of a low cost method for generating an index of school abundance using calibrated industry echo sounders over at least a three-year time frame would enable the index to be incorporated into the population model and its long-term usefulness to be assessed. This low-cost data collection should be supplemented with higher resolution, deep-towed multi-frequency surveys at multi-year intervals, primarily to ensure species composition and biomass in the lightly scattered portion of the spawning aggregation are not overly biasing the results. After establishing a first data point with an initial deep-towed multi-frequency survey the regularity of these surveys should be determined by the population model uncertainty or based on changes in the fishery observed with the industry acoustic data. *We recommend that industry logging occur for at least the next three years*, *preferably with calibrated echosounders, in the Eastern Zone and Cascade fisheries*. *Further, to provide a best-estimate reference point for a time series of industry acoustic biomass estimates, a complementary deep-towed multi-frequency survey should be carried out within this three year time period in the Eastern Zone and Cascade fisheries.*

3. Modelling of the acoustic data on schools and estimation of detection thresholds and error would assist in the interpretation of the school data and its

long-term utility in fishery assessments. School dynamics and industry sampling methods introduce large sampling variances and biases in the school index data. Understanding the links between school size variability and factors such as school density, location and sampling design would greatly improve the precision of the index for long term monitoring. Further work needs to be done to understand the minimum detection limits of the various techniques/platforms. When stock sizes are small, as is now the case at St. Helens and possibly the South Tasman Rise, knowing the minimum detection limit of the technique is particularly important when deciding which monitoring technique to adopt. *We recommend that advances in this methodology are a focus for outcomes from ongoing industry data logging*.

4. The low-cost and high quality acoustic data collected in this study has opened the possibility of using such data for understanding deep water environmental variability, including influences on the distribution and biomass of forage fishes and crustaceans in the micronekton. The ability to collect acoustic data throughout the water column at low-cost from multiple platforms represents a valuable opportunity. Coupling any derived index, for example of micronekton abundance, with indices on current circulation, surface temperature and ocean colour from satellite data would enable surface data to be more reliably extrapolated to depth. The environmental variability being observed at depth in several areas such as the South Tasman Rise, Cascade Plateau, Southern Hills and the blue grenadier grounds could be explored, and better population models and harvest strategies for sustainable management of the fisheries realised. *We recommend that research be conducted into developing low-cost acoustic logging from fishing vessels and coupling this with other environmental data such as ocean circulation modelling to develop environmental indices suitable for inclusion into population models.*

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# 1 INTRODUCTION

## 1.1 Background and need

### 1.1.1 Background

In 1999, the orange roughy fishery remained the most valuable component of the South-East Fishery (SEF). Following a series of egg and acoustic surveys of the spawning stock off St. Helens, Tasmania from 1990-1993, and an international review in 1994, it was concluded that the fish-down of the stock had been completed and SETMAC adopted a TAC that would enable the stock to rebuild to 30% Bo by 2004. However, following data reanalysis and increasing emphasis on the combined stock hypothesis in the 1996-98 assessments, it appears that TACs would need to be further reduced to enable the stock to rebuild to 30%Bo by 2004. This would be a major loss of revenue to industry. The validity of the current estimates of stock status therefore need to be clarified.

The 1996 survey of orange roughy indicated a continuing decline of fish on the spawning ground off St. Helens, Tasmania. However, in 1996 the fishery shifted significantly to an area known as St. Patricks Head, 30 km south of St. Helens Hill, such that catches and effort were approximately equal at the two sites. Although several acoustic transects were carried out across Paddy's Head, they were not sufficient to estimate the biomass of orange roughy on that ground with confidence. The industry also indicated that the fish at St. Helens Hill built up after the surveys were performed, although no further fishing was carried out. Given these uncertainties in the 1996 acoustic biomass survey, the 1997 assessment could only use the data in the form of several alternative hypotheses. In effect there has been no comprehensive survey of the spawning aggregation since 1992 (the 1993 survey was an opportunistic survey undertaken as the research vessel passed St. Helens Hill and did not include biological sampling, so the identity of fish marks has remained in question). In 1997 fishers observed large marks at the spawning hill but the acoustic data were not logged, and videos and photographs of the soundings are difficult to interpret.

In summary, the uncertainties associated with recent surveys can be traced to the limited spatial and temporal coverage of the scientific acoustic surveys and the lack of quantitative data from industry. It is proposed to obtain explicit industry input in the survey design and analysis phases of the survey, and to carry out the survey using an industry vessel together with the CSIRO research vessel to combine, respectively, broad spatial and temporal coverage of the spawning event with scientific precision. If successful, spawning aggregations in the South Tasman Rise and Cascade Plateau fishery could also be surveyed using the same techniques.

### 1.1.2 Need

The primary need is to remove the uncertainty surrounding the status of the orange roughy stock of the Eastern zone. This will be addressed by performing a survey during the 1999 spawning season that combines the high-precision acoustic capability of the CSIRO research vessel together with the knowledge of fish dynamics and extended time on the ground provided by an industry vessel.

The second need is to assess the ability of industry echo-sounders to monitor the size and dynamics of the spawning aggregations. Industry monitoring of the stock could prove less costly than high precision scientific surveys. However, a number of questions remain unanswered regarding industry vessel acoustics precision and sensitivity. Clearly industry-based surveys need to be carried out with calibrated sounders and to conduct biological sampling of fish marks with fine-mesh liners in the codends. However, it is also necessary to determine what precision can be obtained from vessel-mounted systems that are susceptible to sea-state, vessel noise and stability.

To test the capability of the industry sounders for assessment purposes requires a controlled experiment. This can be achieved by conducting acoustic surveys simultaneously with the common 28 kHz industry sounders and the scientific 38 kHz vessel-mounted and towed systems. This was attempted in 1996 in an opportunistic manner. However, in that year a logger borrowed from the industry and set up on the *Southern Surveyor's* 28kHz echo sounder failed after a short time of operating so no useful data were collected. A more rigorous attempt to incorporate industry acoustics is required.

## 1.2 Objectives

The objectives of the study are:

1) To survey the orange roughy on the Eastern Zone fishing grounds during the spawning period using industry vessel acoustics over an extended period and the CSIRO acoustic package during the anticipated peak spawning period.

2) To assess how industry acoustics may be best used in the long term management of the resource.

3) To compare the sensitivity and precision of acoustic surveys using scientific vessel-mounted and towed-body acoustics and industry vessel-mounted acoustics.

4) To further develop the acoustic method by improving the multi-frequency technique for species identification.

## 1.3 Voyage Outline

Two vessels participated in the survey. Starting from the 9$^{th}$ of July, the industry vessel *Saxon Progress* completed four trips to the St. Helens Hill and St. Patricks Head fishing grounds over a month long period (Table 1.1). The vessel was used to commercially trawl for its own quota as well as a limited amount of research trawl quota, perform targeted demersal trawls as directed by scientists aboard the *Southern Surveyor* and run acoustic surveys using its commercial fisheries sounder according to specified survey designs.

Mid-way through the month-long industry vessel survey, from July 16$^{th}$ onwards, the *Southern Surveyor* spent 16 days at the fishing grounds (Figure 1.1). At St. Helens Hill and St. Patricks Head the *Southern Surveyor* carried out a series of acoustic surveys using vessel and deep-tow acoustic systems. In addition, target identification of midwater acoustic scatterers was achieved by pelagic sampling of midwater communities.

We also took this opportunity to conduct the first survey of seabed habitat at St. Helens Hill using a towed underwater video array and a benthic sled. The results will be reported in a future publication. They are not reported here because that work was funded separately by CSIRO and were not objectives of this project.

**Table 1.1 Voyage dates for four *Saxon Progress* survey legs.**

| Leg | Start Date | End Date |
|---|---|---|
| 1 | 9-Jul-99 | 14-Jul-99 |
| 2 | 18-Jul-99 | 21-Jul-99 |
| 3 | 25-Jul-99 | 29-Jul-99 |
| 4 | 9-Aug-99 | 11-Aug-99 |

## 1.4 Voyage Objectives

The stated objectives of the *Southern Surveyor* and *Saxon Progress* voyages were:

1) To assess the biomass of orange roughy based on acoustic surveys on the Eastern Zone fishing grounds (St. Helens Hill and St. Patricks Head) during the spawning period using industry vessel acoustics over an extended 4 week period and the CSIRO acoustic package during the anticipated peak spawning period.

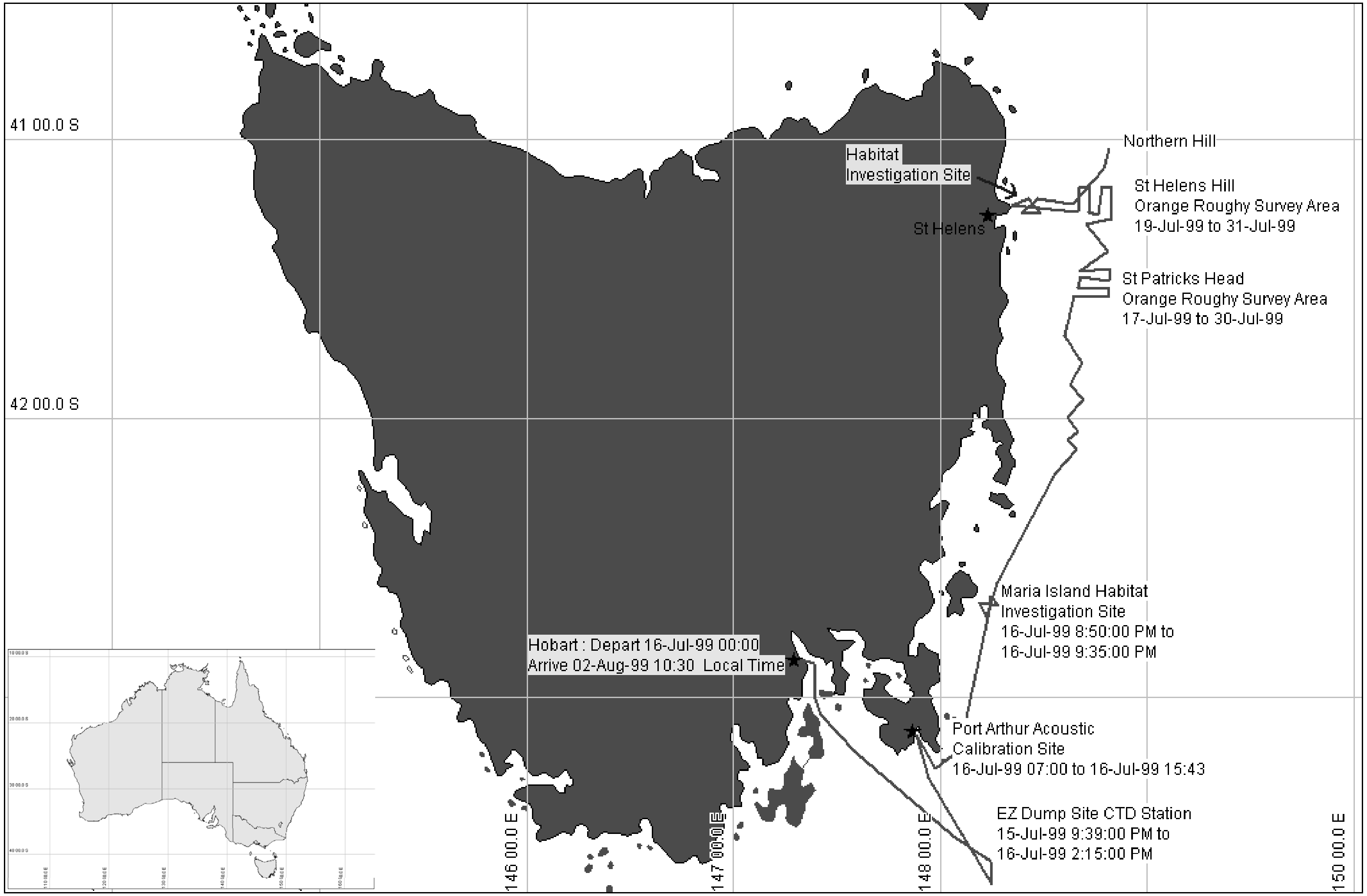
2) To compare the sensitivity and precision of acoustic surveys using scientific vessel-mounted and towed-body acoustics and industry vessel-mounted acoustics at various frequencies.

3) To further develop the acoustic method by improving the multi-frequency technique for species identification, sound absorption coefficient and in-situ target strengths.

4) Identify the composition of distinct bio-acoustic scattering layers with underway multi-frequency acoustic data and target sampling with a pelagic trawl capable of depth stratified sampling.

5) Map significant deep-water seabed habitats using the towed deep-water video camera and towed acoustic system and further develop the technique with experiments in shallow water.

**Figure 1.1** ***Southern Surveyor*** **voyage track showing areas of operation and dates of activities**



# 2 ACOUSTIC SURVEY EQUIPMENT AND CALIBRATION 1999 SURVEYS

Tim Ryan

## 2.1 Introduction

There is a range of specific needs for acoustic and biological survey of orange roughy because of the great depth at which they live, and because they have a low acoustic target strength relative to many other deepwater species. Foremost, the acoustic system must have low signal to noise and a large dynamic range to effectively measure the return signal. The spatial and behavioural dynamics of the orange roughy and their relatively low target strength make this particularly challenging. There needs to be precise calibration of sample data, the towed instruments and their data need to be precisely geo-located and of the highest quality. In addition, the sampling platform needs to be sufficiently large to accommodate a large winch housing a long tow-wire and provide stability in offshore conditions. All these needs are met by the acoustic and other sampling systems aboard *Southern Surveyor:* the various items of equipment used during this survey are described below and shown (Figure 2.1).

## 2.2 Description of sampling systems

### 2.2.1 *Southern Surveyor* Sampling Systems

#### Acoustic systems

The scientific echo-sounder used was a SIMRAD EK500 (Version. 5.3) configured with a combination of 12, 38 and 120 kHz transceivers; the frequencies used depended on the survey mode. The range of transducers used were hull-mounted or pole-mounted on the vessel, or towed at depth in the MUFTI (Multiple Frequency Towed Instrument) system; their specifications and locations are outlined (Table 2.1).

The Pole system comprises a 38kHz split-beam narrow beam-width transducer attached to a rigid steel pole that can be lowered 3.5 metres below the vessels' hull to significantly reduce signal loss and noise due to aeration of the near surface bubble layer.

The MUFTI system is a custom built towed body that houses 12, 38 and 120kHz transducers. Typically, it is towed between 400 and 800 m depth to reduce or remove many of the factors that degrade the performance of the surface systems (Kloser 1996). Towing the MUFTI system at great depth also allows the limited range 120kHz channel to be brought within a working distance of the orange roughy thus enabling simultaneous recording of three-frequency acoustic data. The great advantage of multi-frequency data is that it can effectively discriminate between the echo returns of orange roughy and bycatch species (Kloser et al 1998 and see also Chapter 7).

It is necessary to record both the vessel's motion and an acoustic trigger pulse to compensate for transducer motion. The motion of the vessel and MUFTI were collected at a rate of 10 Hz with an associated trigger pulse registration. Processed and raw acoustic data were logged via ECHO - a custom UNIX based acoustic data manipulation program developed by CSIRO to scrutinise, analyse and post-process acoustic data (Waring et al 1994).

Data from the *Southern Surveyor's* Furuno FCV 140 28kHz fisheries echosounder was digitised and logged with an Echolistener. The data were compared to the scientific acoustic data as part of the assessment of the suitability of using commercial acoustic systems for quantitative surveys (see Chapter 5).

**Figure 2.1 Sampling systems used for the July 1999 Orange Roughy Survey**

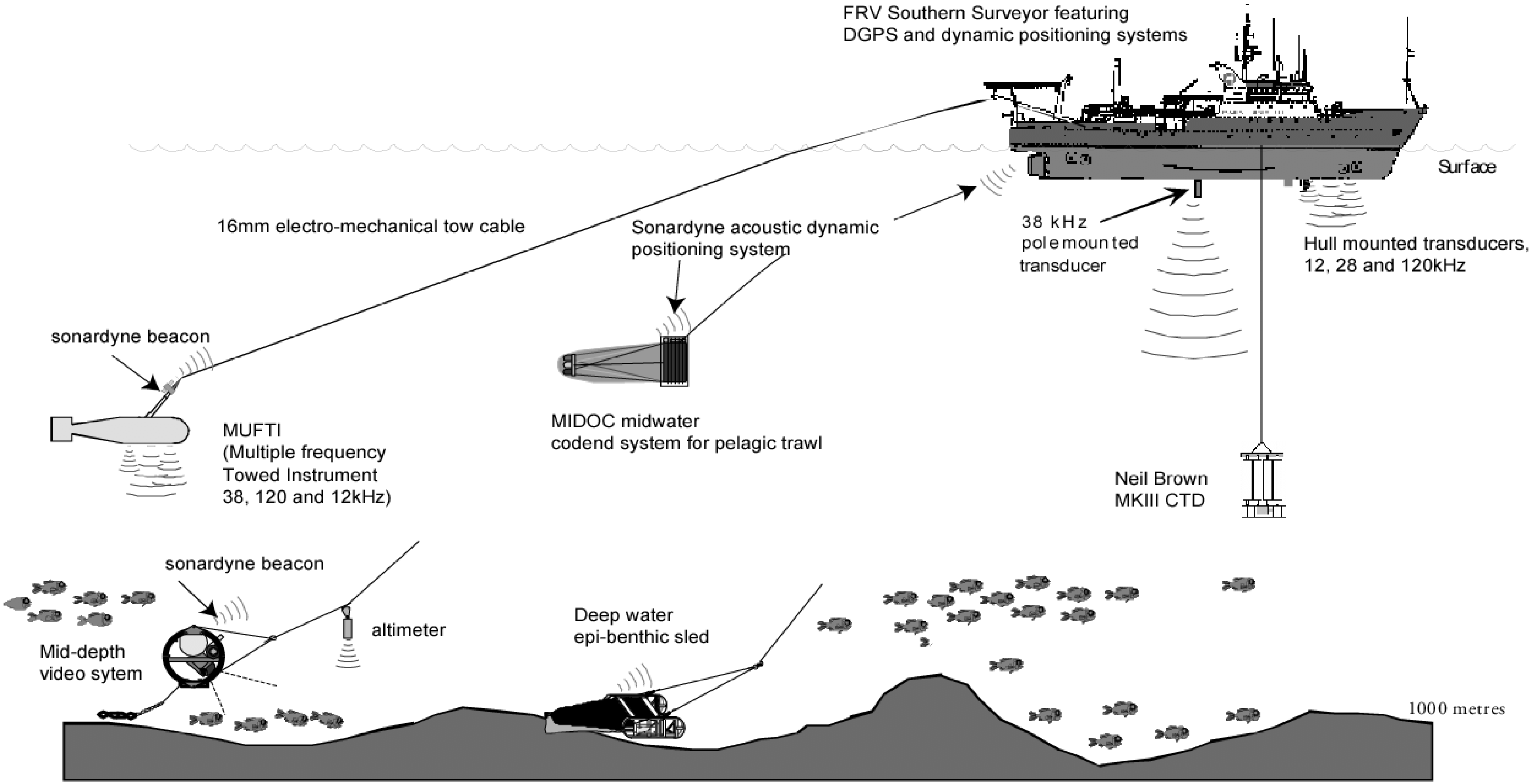


**Table 2.1. Transducer Information**

| Transducer | Manufacturer | Locations | Equivalent Beamwidth (dB re 1 steradian) | Beamwidth (degrees) |
|---|---|---|---|---|
| 120kHz | Simrad | MUFTI | -20.6 | 7 |
| 38Khz | EDO western | MUFTI | -21.1 | 6.5 |
| 12kHz | MASA | MUFTI | -10 | 40 |
| 38kHz | Simrad | Pole | -20.7 | 7.3 |
| 38kHz | Simrad | Hull | -20.7 | 7.1 |
| 28kHz | Furuno | Hull | Unknown | 14 (estimated) |

**Biological and other sampling systems**

The mid-water trawl gear is detailed in Chapter 3, while the seabed sampling equipment (epibenthic sled, video array) will be covered in a future report of the habitat structure. Temperature and salinity profiles for acoustic calibration were obtained with a Neil Brown MKIIIB conductivity-temperature-depth recorder (CTD).

### 2.2.2 *Saxon Progress* Acoustic Sampling System

Data from the vessel's FCV 382, 28kHz Furuno fishery echosounder was digitised with an Echolistener and logged to a PC. A Racal differential GPS system was used to record the vessel position giving an accuracy of approximately ± 10 metres.

## 2.3 *Southern Surveyor* Acoustic System calibration

The *Southern Surveyor's* acoustic equipment was calibrated at Port Arthur on July the 16th. A standard 38.1.mm tungsten carbide sphere was used with all the transducers to obtain the on-axis echo integration constant $S_{vc}$ (Foote et. al. 1987; Simrad software version 5.3, 1996). This technique combines the electrical and acoustic constants of the system, such as transmitter power, the transmitting and receiving efficiency of the transducer, and receiver gain. The manufacturer of the transducer measured the equivalent beam angle; tests on this value were confirmed for the towed system with a special calibration rig (Kloser et al 1998). The split-beam, deep-tow transducers were also calibrated on three occasions during the voyage to correct for changes with depth in transducer sensitivity and to test for changes in beam pattern (Kloser et al 1996). The calibration sphere was suspended 15 m directly under the centre of the towed body and the system lowered through the water column.

The seawater propagation parameters of absorption and sound velocity were calculated from the formulae of Francois and Garrison (1982) and MacKenzie (1981) respectively based upon temperature and salinity profiles (Figures 2.2 and 2.3). Three running mean scenarios of the seawater propagation parameters of sound absorption and speed were calculated assuming a pole transducer depth of 6 m and nominal towed body depths of 400 m and 600 m.

**Figure 2.2. Depth vs seawater sound absorption for July 1999 cruise based on three CTD casts**

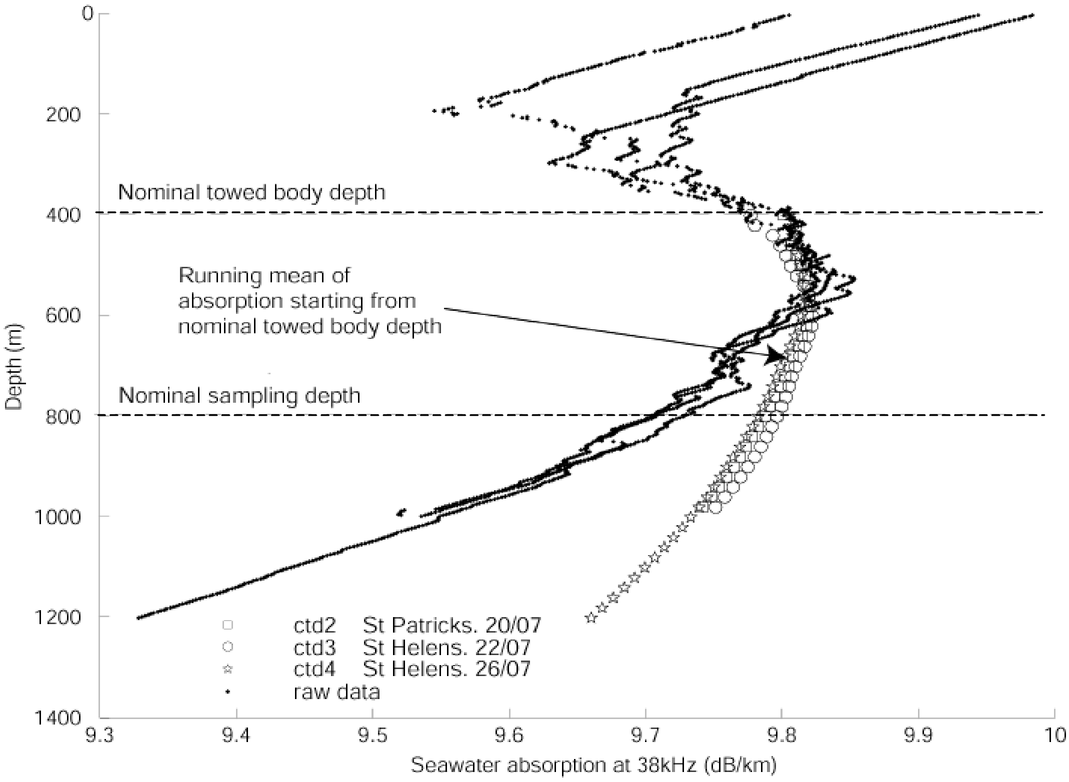
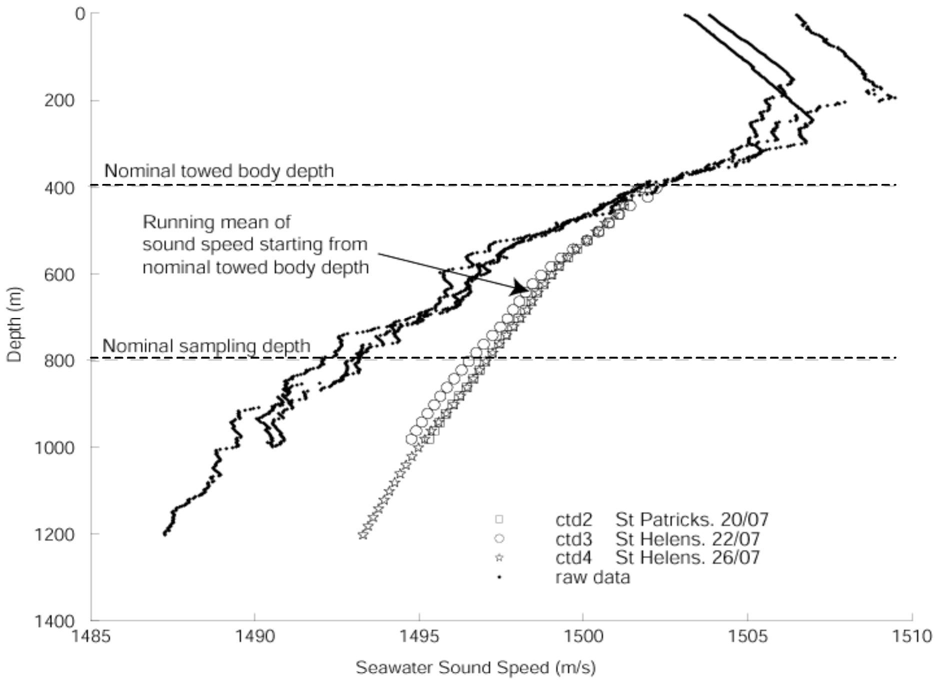



**Figure 2.3. Depth vs sound speed velocity in water for July 1999 cruise based on three CTD casts**




The acoustic system calibration parameters used for processing the acoustic survey data are outlined (Table 2.2). The $S_{vc}$ gain parameter for the MUFTI transducer is depth dependent and is discussed in section 2.3.1. Addition detailed information regarding the acoustic calibration is held in the internal document “SS9903 Calibration summary” (Ryan, 2000).

**Table 2.2 Summary of 38kHz Pole and MUFTI transducer calibration settings used to process the acoustic data with initial set parameters and subsequent calibrated (measured) values.**

| Parameter | Pole-mounted | MUFTI @ 400m | MUFTI @ 600m | Units |
|---|---|---|---|---|
| Pulse length | 3 | 1 | 0.3 | ms |
| Bandwidth | 0.38 | 3.8 | 3.8 | kHz |
| Equivalent beam angle | -20.7 | -21.1 | -21.1 | dB re 1 sr |
| $S_{vc}$ gain set (measured) | 26.7 (26.7) | 31.7 (see Deep Water Calibration Section) | 31.7 (see Deep Water Calibration Section) | Simrad gain |
| Absorption set (measured) reference depth 800 m | 9.0 (9.76) | 9.0 (9.78) | 9.0 (9.76) | dB km $^{-1}$ |
| Sound velocity set(measured) reference depth 800 m | 1498 (1500.7 ± 0.5) | 1498 (1495.6 ± 0.5) | 1498 (1495 ± 0.5) | ms$^{-1}$ |

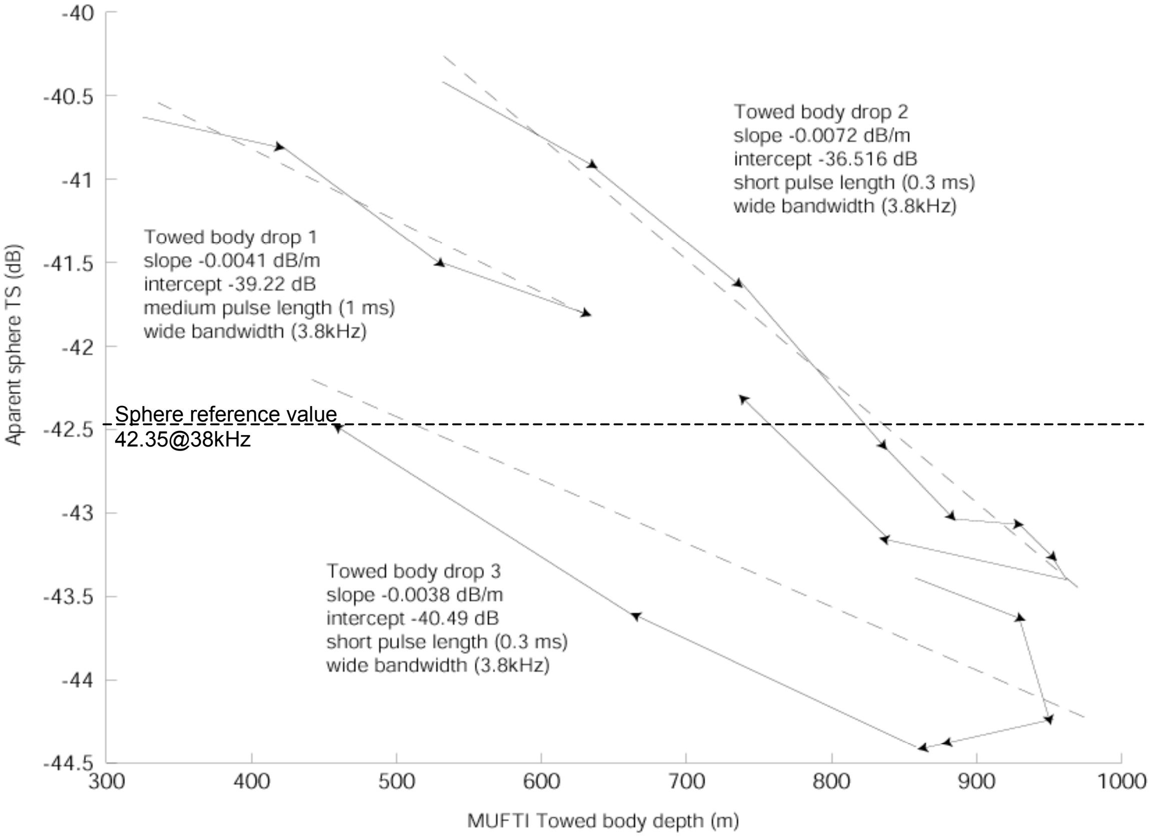
## 2.3.1 Deep water calibration.

The 38kHz EDO transducer in the MUFTI system decreases in sensitivity with depth, while having a significant hysteresis in this sensitivity (Kloser 1996). To calculate this depth dependant $S_{vc}$ gain parameter, the MUFTI system, with sphere of known target strength (-42.35 dB @ 38kHz) suspended beneath it, was lowered and raised through the expected working range in 50 m steps. It was held at each depth interval for a period that was long enough to collect sufficient (>100) target measurements. The compensated $TS_c$ at beam angle zero was measured and a subsequent plot of this value vs. depth allowed the relationship between transducer depth and change in sensitivity to be established (Table 2.3 and Figure 2.4). Corrections based on this relationship were entered into the ECHO software prior to echo-integration.

**Table 2.3. Slope and intercept of TS vs. towed body depth relationship**

| Drop Number | Depth range (m) | Pulse Length (ms) | Bandwidth (kHz) | Slope (dB/m) | Intercept (dB) | Required correction (Intercept - 42.35) (dB) | Comments |
|---|---|---|---|---|---|---|---|
| 1 | 325-630 | 1 | 3.8 | -0.0041 | -39.224 | -3.1 | Used for MUFTI surveys set at medium pulse length (1ms) and wide bandwith (3.8 kHz) |
| 2 | 530-740 | 0.3 | 3.8 | -0.0072 | -36.516 | -5.83 | Not used. Result very different from other towed body drops from this and previous survey years. |
| 3 | 460-950 | 0.3 | 3.8 | -0.0038 | -40.49 | -1.86 | Used for MUFTI surveys set at short pulse length (0.3ms) and wide bandwith (3.8 kHz) |

**Figure 2.4. The decrease in sensitivity with depth for the EDO 38kHz MUFTI transducer.**




In previous years, the MUFTI system was operated in a narrow (400-550 m) depth range with the system gain set such that the required correction was zero at the middle of this range. By operating in this narrow depth range the potential for gross error when correcting for tow depths away from this nominal operating value was minimised. However, in 1999 the survey designs required the MUFTI system to be operated at two different depth ranges; at 400-550 m for the 'Grid' surveys at St. Helens Hill and at 600-800 m for the 'Star and Loop' surveys at St. Helens Hill and for the MUFTI surveys at St. Patricks Head. This deeper survey mode is a long way from the depth at which zero compensation is required (475 meters with the EK500 $S_{vc}$ set to 31.7 in 1999) hence the accuracy of the depth vs. sensitivity relationship will have a larger effect for deeper surveys. Compounding this potential for error is the fact that the MUFTI system is being raised and lowered through a greater range of depths while the sensitivity and hysteresis characteristics of these greater depth ranges have proved difficult to quantify (Figure 2.4). There could be over 2 dB difference to the measured $s_A$ values depending on the operating depths and which of the three results of the towed body drops was used. In practice only the results from towed body drops 1 and 3 were used as these correlated with each other and with historical results. An estimate of the accuracy of this calibration is within ±1 dB. Given this potentially large calibration error a new transducer has been purchased that is oil based and reported to have reduced hysteresis.

## 2.4 *Saxon Progress* Acoustic System Calibration

The *Saxon Progress* acoustic system was uncalibrated for this cruise.

## 2.5 Acoustic Data Collection and Quality Assurance

The ECHO software was used to collect, quality assure and analyse the acoustic data on a SUN workstation (Waring *et. al.*, 1994). 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 enabled the user to specify background and spike noise thresholds, correct for calibration and absorption changes, remove bad data, and edit bottom and dead-zone levels.

Each transect was quality-checked and processed using ECHO. Quality plots were inspected and any outliers were checked against the raw echogram to confirm whether they were genuine high values caused by fish aggregation or due to inclusion of bottom signal.

Background $S_v$ noise was measured for each survey by obtaining the average $S_v$ value below the bottom signal, where there was no acoustic reverberation signal, and subtracting this value from all $S_v$ data, as described in Kloser (1996). Spike $S_v$ noise occurred at very high values (commonly > -25 dB) due mainly to unsynchronised sounders for the vessel-mounted data or occasional high vibration and electrical noise from the MUFTI system. Spike $S_v$ noise greater than the threshold was replaced by the $S_v$ value immediately above in the water column. Large areas of data that were adversely affected by vessel movement for the vessel-mounted transducer or electrical noise for the MUFTI transducer were marked as being bad and were not included in processed summary data.

The Simrad EK500 was preset at fixed values of absorption and sound velocities throughout the cruise. Corrections to the data were required where the mean absorption and sound velocity differed from the fixed values as determined by data from the CTD casts carried out during the voyage (section 2.3). These values were entered into the ECHO software prior to processing.

Bottom editing was required when automatic depth tracking in the Simrad EK500 failed to correctly predict the bottom signal. If the acoustic bottom line was not redrawn with a mouse on the ECHO program, these high bottom signal values could corrupt the acoustic data. The algorithm for determining the deadzone was as per Kloser (1996).

## 2.6 Conclusions

High quality acoustic data were successfully collected with both the vessel-mounted and deep-towed multi-frequency systems.

Successful calibration of equipment resulted in an estimated calibration accuracy of $\pm$0.5dB for the vessel-mounted system and $\pm$1 dB for the MUFTI system.

The move to MUFTI surveys that operate at a variety of depths has increased the potential for calibration error due to the change in sensitivity with depth and associated hysteresis of our existing 38kHz transducer. A new oil based 38kHz transducer with a reduced depth-sensitivity bias has been purchased for use in future surveys.

Temperature and salinity profiles from CTD casts enabled corrections to be made to the acoustic data for sound velocity and absorption. ECHO software was used to quality-check and process the data. Importantly, the relationship between depth and sensitivity was measured experimentally and corrected, to the degree possible using ECHO software.

# 3 ORANGE ROUGHY BIOLOGY – 1999 SURVEY DATA

Alan Williams, Tim Ryan, Rudy Kloser and Jeremy Prince

## 3.1 Introduction

Biological samples from the St. Helens Hill and St. Patricks Head were collected by trawling. The commercial trawler Saxon Progress carried out demersal trawling during four 5-day trips over a month-long period starting on July the 9$^{th}$ (Table 1.1). Two observers were aboard during trips 2 and 3, with only one aboard for trips 1 and 4. Although the vessel mainly targeted prominent fish marks surveyed by the *Southern Surveyor's* acoustic system ('aggregation' samples), trawls were also targeted at diffuse fish marks on areas of flat bottom adjacent to the seamount and canyon, and adjacent deep areas ('backscatter' samples). An additional program of pelagic trawling to collect samples from the water column was carried out by *Southern Surveyor*, but is reported only briefly here.

## 3.2 Sampling equipment and methods

A standard commercial McKenna roughy trawl fitted with a 40 mm cod-end liner was used by *Saxon Progress*. Pelagic trawling carried out by *Southern Surveyor* used an IYGPT pelagic trawl fitted with the MIDOC multiple opening/closing cod-end system. CSIRO Marine Research provided biological data collection protocols (see Appendix C).

An important development in sampling design for this survey was designating demersal trawls as either 'aggregation' or 'backscatter' samples. The criterion for identifying aggregation samples was: targeted at a region where a distinct and large fish mark was seen with the deep towed acoustic body and resulting catch was large enough (> 1 tonne) to confirm the mark was sampled.

Data recorded from demersal trawls included catch composition, fish length, and sex and maturity stage for orange roughy. Catch composition was used to assess the proportions (numbers) of fish in marks and recorded as the proportions (numbers and weight) of seven fish groups using a simple classification incorporating fish size and swimbladder type: orange roughy, oreos, sharks, whiptails, morid cods and miscellaneous species (high and low scatterers) (Kloser et.al. 1996). Species composition was examined by 100 m depth strata in each region using weighted means from amalgamated trawl catches; catches were unstandardised for tow time and sample depth was estimated as tow mid-point. About 90,000 individual fish were recorded in total.

Up to 200 individuals of each fish group were measured from each shot (length recorded in millimetres, with rounding-up to centimetres): standard length for roughy (together with sex and maturity stage), and the length to mid-point of the tail fin for other groups (due to the variety of species involved). Maturity stages were based on the scheme of Pankhurst (1988); however, the NIWA photographic key was used for the first time and this includes an additional 'partially spent' stage for males and females. Samples of orange roughy (1,128 fish) were retained for subsequent removal of otoliths at the Georgetown fish processing works. To the extent possible, it was intended that samples would be taken from spawning aggregations and from backscatter samples throughout the survey. The ovaries from selected batches of roughy were also kept for histological examination.

## 3.3 Results and discussion

### 3.3.1 Catch composition

**Spatial and temporal distribution of fishes**

During its month long survey of St. Helens Hill and St. Patricks Head the *Saxon Progress* attempted 50 trawl shots of which 45 proved suitable for samples. For analysis, the trawls were separated according to region (St. Patricks Head or St. Helens Hill) and mark type (aggregation or backscatter) (Table 3.1).

**Table 3.1 Summary of trawl stations for the two regions and mark type**

| Location | Mark type | Trip 1 | Trip 2 | Trip 3 | Trip 4 |
|---|---|---|---|---|---|
| St. Helens Hill | Aggregation | 7, 8, 13, 14, 15 | 27 | 33, 34 | |
| St. Helens Hill | Backscatter | 5, 6, 9, 10, 11, | 23, 24, 25, 26, 28, 29, 30 | 32, 35, 36, 37, 38, 39, 40 | 42, 43, 44 |
| St. Patricks Head | Aggregation | 16, 17 | 19 | 41 | |
| St. Patricks Head | Backscatter | 1 | 18, 20, 21, 22 | 31 | 45, 46, 47, 48, 49 |

The locations of trawls on the seabed were estimated from vessel positions during towing, bathymetric ranges and notes made by the observers at the time. Trawl mid-point locations, with an estimated error of ± 200 metres, are shown together with the proportion of roughy and bycatch on a trawl-by-trawl basis (Figure 3.1).

Ten large catches (> 1 tonne) of orange roughy were taken during the first three trips (Table 3.2); the largest roughy catch taken on trip 4 was only 650 kg.

**Table 3.2 Dates and weights of large orange roughy catches (>1 tonne) at St. Helens Hill and St. Patricks Head**

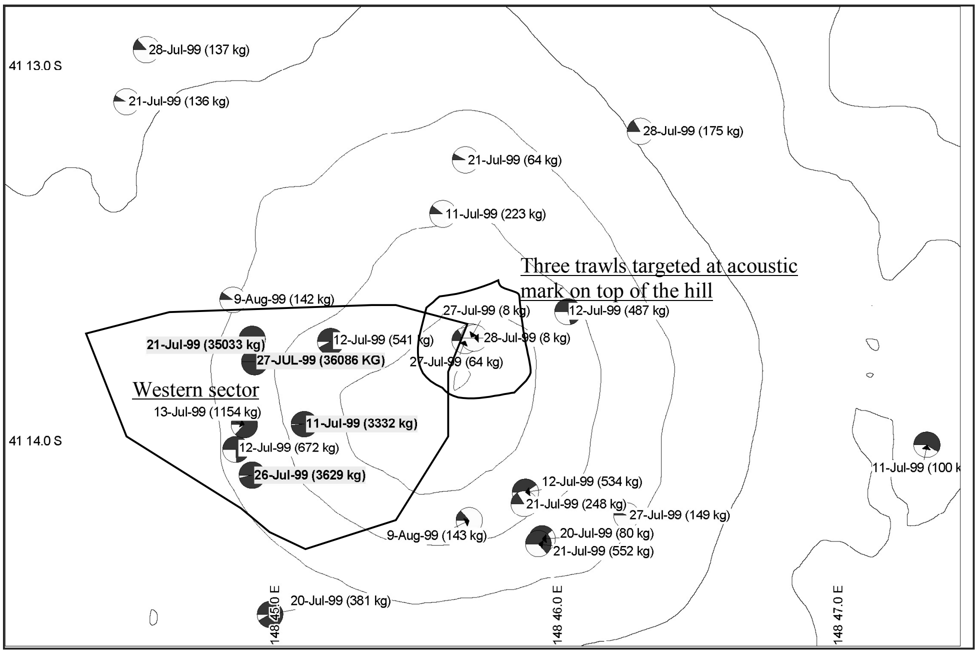
| St. Helens Hill | | St. Patricks Head | |
|---|---|---|---|
| Date | Roughy (kg) | Date | Roughy (kg) |
| 10-Jul-99 | 3267 | 12-Jul-99 | 2500 |
| 12-Jul-99 | 1000 | 12-Jul-99 | 30000 |
| 20-Jul-99 | 35000 | 17-Jul-99 | 2660 |
| 25-Jul-99 | 3500 | 18-Jul-99 | 1500 |
| 26-Jul-99 | 36000 | 27-Jul-99 | 45000 |

Collectively, the data clearly show that the only large catches of orange roughy taken at St. Helens Hill were from distinct aggregations in the western sector, a pattern that is consistent with their distribution in recent years. There were roughy aggregations on this part of the hill from 10th July, when the survey commenced, through to at least the 26th July- the end of the third trip. Catches were low (maximum < 350 kg roughy) on other parts of the hill, and there was also a high proportion of bycatch (on average 78% by weight).

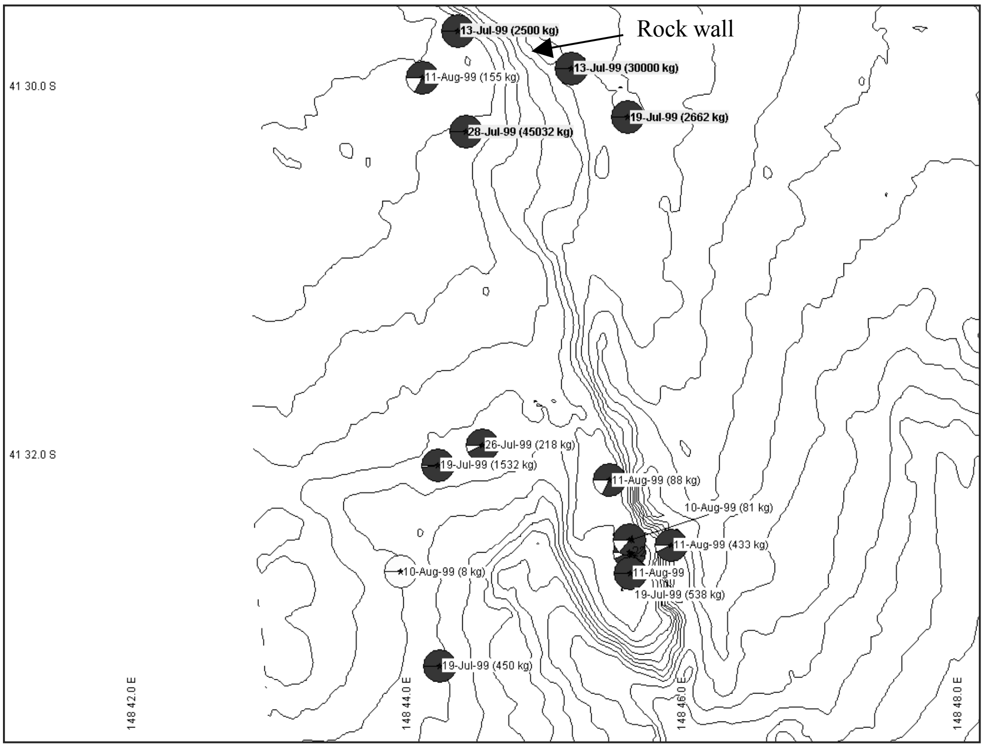
A strong mark consistently seen around the top of St. Helens Hill throughout the survey was targeted with three trawls. Small catches (8, 8 and 64 kg) containing telescope cardinalfish and blue grenadier (with few roughy), confirmed that the mark was primarily made up by these fast moving species which have large, gas-filled and therefore highly reflective swimbladders.

**Figure 3.1. Spatial distribution of trawl samples showing proportion by weight of orange roughy and bycatch with the date and total catch by weight (trips 1-4)**

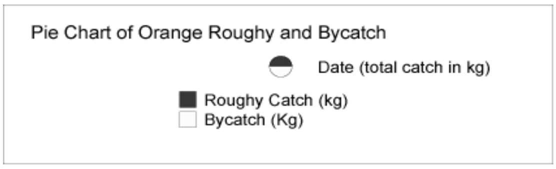
**(a) St Helens Hill**




**(b) St Patricks Head**




**Legend**



The spatial distribution of roughy on the hill is consistent with the MUFTI loop survey data that also showed orange roughy schools in the western sector. MUFTI data indicated the likely presence of schooling orange roughy in the northeast sector but this was not confirmed by any large roughy catches.

Several large catches of roughy taken at St. Patricks Head showed that roughy were also persistently aggregated there over approximately the same period as at St. Helens Hill. These catches were taken from large aggregations at a site commonly known as the Rock Wall. This is located at the northern end of the ridge that lies on the western side of the canyon feature (Figure 3.1b). The location of large roughy catches correlated well with acoustic information that consistently measured the most substantial mark at the northern end of the ridge on numerous occasions from the 10th July until the 1st of August.

A delay in starting trip 4 (due to the need for extra roughy quota for *Saxon Progress*) meant that no trawling was undertaken between the 28th July and the 7th August. The lack of large catches after the 8 th August indicated the spawning aggregations in both regions had dispersed sometime during the preceding 10 days.

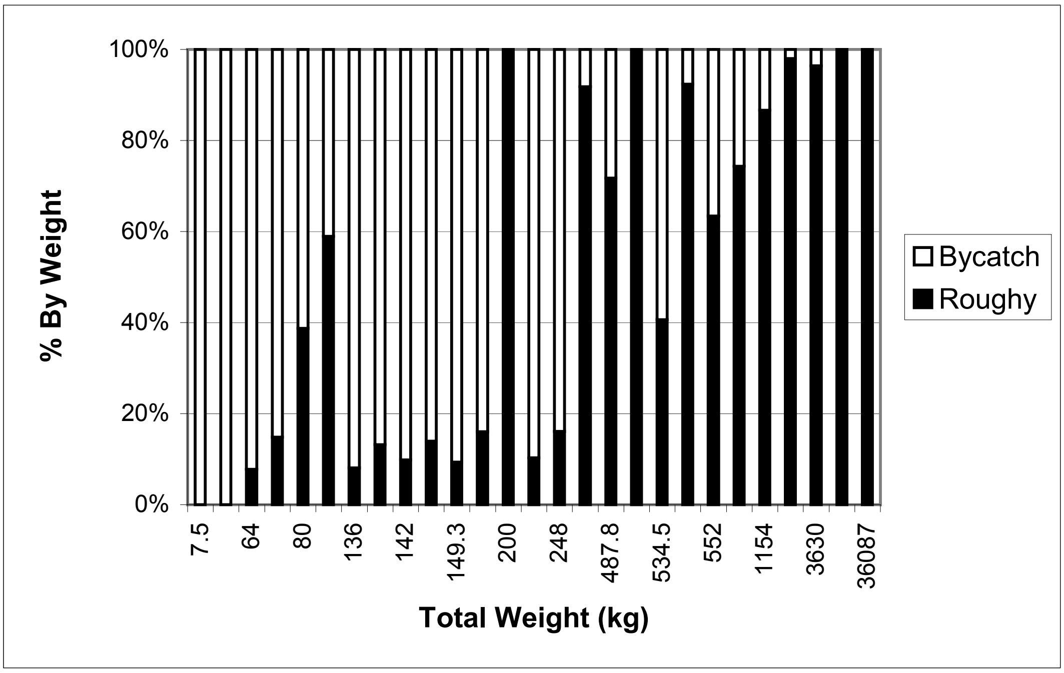
At St. Helens Hill, there was a higher overall proportion of bycatch in trawls (Figure 3.2). A simple mean proportion by weight for each region (not weighting the mean to take account of catch sizes) showed that bycatch was about 45% at St. Helens Hill compared to just 14% at St. Patricks Head. These differences were due to the greater proportions at St. Helens Hill of whiptails (predominantly *Caelorinchus subserrulatus*), morid cod (predominantly *Halagyreus johnsoni*) and miscellaneous high-scatterers.

**Depth distribution of fishes**

Trawl catch data, amalgamated into 100-metre depth intervals at each site, showed distinct depth-related patterns of species composition (Table 3.3).

**Figure 3.2 Proportion (by weight) of roughy and bycatch in individual trawl samples**

**(a) St Helens Hill**




**(b) St Patricks Head**

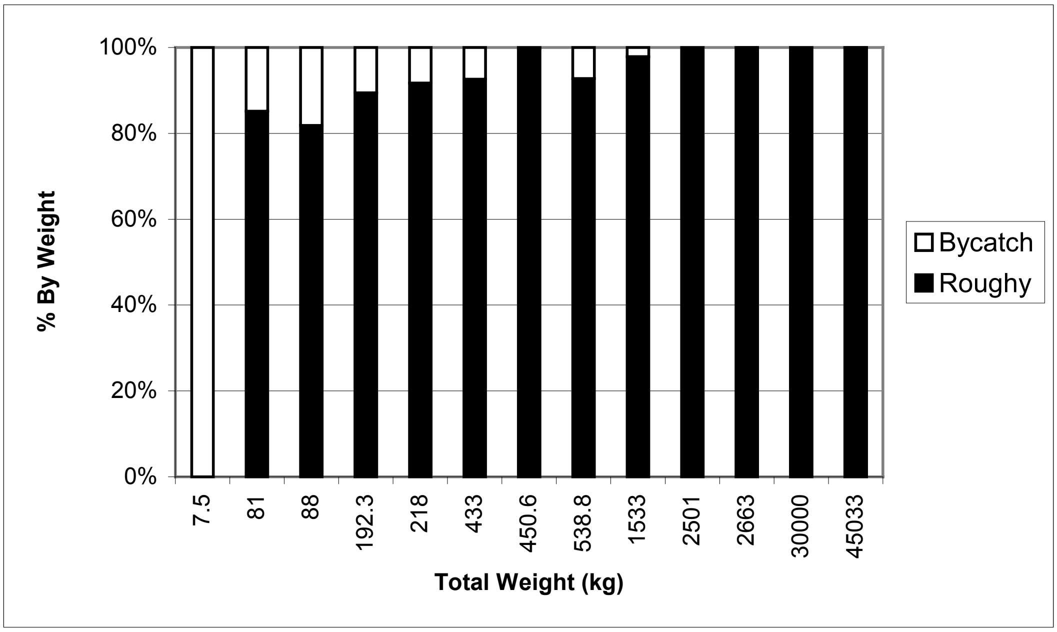


**Table 3.3 Proportion of numbers of 'acoustic fish groups' in each 100 m depth stratum at St. Patricks Head and St. Helens Hill (trips 2 & 3 only) based on weighted means**

| St. Patricks Head | No. trawls | Acoustic group | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Depth stratum (m) | | Roughy | Cod | Oreo | Shark | Whiptail | Misc_high | Misc_low |
| 800-900 | 3 | 0.998 | 0.000 | 0.000 | 0.000 | 0.002 | 0.000 | 0.000 |
| 900-1000 | 4 | 0.965 | 0.002 | 0.004 | 0.004 | 0.024 | 0.001 | 0.000 |
| Total individuals | | 41318 | 13 | 28 | 31 | 203 | 9 | 3 |
| St. Helens Hill | | | | | | | | |
| Depth stratum (m) | | Roughy | Cod | Oreo | Shark | Whiptail | Misc_high | Misc_low |
| 600-700 | 3 | 0.095 | 0.048 | 0.016 | 0.000 | 0.270 | 0.540 | 0.032 |
| 700-800 | 1 | 0.151 | 0.273 | 0.076 | 0.012 | 0.035 | 0.448 | 0.006 |
| 800-900 | 6 | 0.964 | 0.016 | 0.000 | 0.001 | 0.016 | 0.002 | 0.001 |
| 900-1000 | 5 | 0.209 | 0.166 | 0.010 | 0.027 | 0.550 | 0.019 | 0.019 |
| Total individuals | | 34123 | 871 | 45 | 62 | 1377 | 197 | 55 |

Data from trips 2 and 3, the period corresponding to the acoustic survey, showed that roughy were highly abundant in the 800-900 m stratum both at St. Patricks Head and St. Helens Hill where they accounted for 99.8% and 96.4% of fish numbers respectively. Roughy also made up 96.5% of numbers in the 900-1000 m stratum at St. Patricks Head, but substantially lower proportions at other depths on St. Helens Hill: 21% in the whiptail-dominated 900-1000 m stratum and < 15% around the summit (< 800 m) in small catches dominated by morid cod, whiptails and high acoustic scatterers (blue grenadier and telescope cardinalfish).

Although depth-related patterns are not shown separately for aggregation and backscatter samples (because of the relatively few trawls made overall) these summaries are consistent with depth distributions seen in the overall survey period and in the survey of 1996.

### 3.3.2 Size and age structure

#### Fish length

A total of 3786 roughy was measured at sea and used to calculate the mean length of fish in aggregation and backscatter marks in both regions; a subset of data matching the time of the acoustic survey (trips 2 and 3) is shown (Table 3.4). These data were also used to estimate the mean weight of roughy in each mark type/region for biomass estimation. Weights were generated using the standard formula to convert length to weight, where

$$weight = 17.54 * \left(\frac{length}{100}\right)^{2.4} \quad \text{(kg)} \qquad 3.1$$

where *length* is the length of orange roughy in cm.

An additional 1086 frozen then thawed individuals from those retained for otolith collection were measured and weighed in the processing factory. These data were used to evaluate the standard length-weight conversion formula (equation 3.1) (Elliot and Kloser 1993).

**Table 3.4 Mean length (SL) of orange roughy at St. Helens Hill and St. Patricks Head in aggregation and backscatter samples (trips 2 and 3)**

**St. Helens Hill, Aggregation (3 trawls)**

| Sex | No. fish | mean length (cm) | S.D. |
|---|---|---|---|
| Female (37%) | 173 | 37.1 | 2.5 |
| Male (63%) | 297 | 35.2 | 2.5 |
| **Weighted mean** | | **35.9** | |

**St. Patricks Head, Aggregation (2 trawls)**

| Sex | No. fish | mean length (cm) | S.D. |
|---|---|---|---|
| Female (16%) | 65 | 37.0 | 3.0 |
| Male (84%) | 336 | 34.4 | 2.3 |
| **Weighted mean** | | **34.9** | |

**St. Helens Hill, Backscatter (12 trawls)**

| Sex | No. fish | Mean length (cm) | S.D. |
|---|---|---|---|
| Female (67%) | 308 | 36.5 | 2.7 |
| Male (33%) | 153 | 33.7 | 3.3 |
| Weighted mean | | 35.6 | |

**St. Patricks Head, Backscatter (5 trawls)**

| Sex | No. fish | Mean length (cm) | S.D. |
|---|---|---|---|
| Female (63%) | 356 | 34.6 | 2.8 |
| Male (37%) | 210 | 32.3 | 2.8 |
| **Weighted mean** | | **33.8** | |

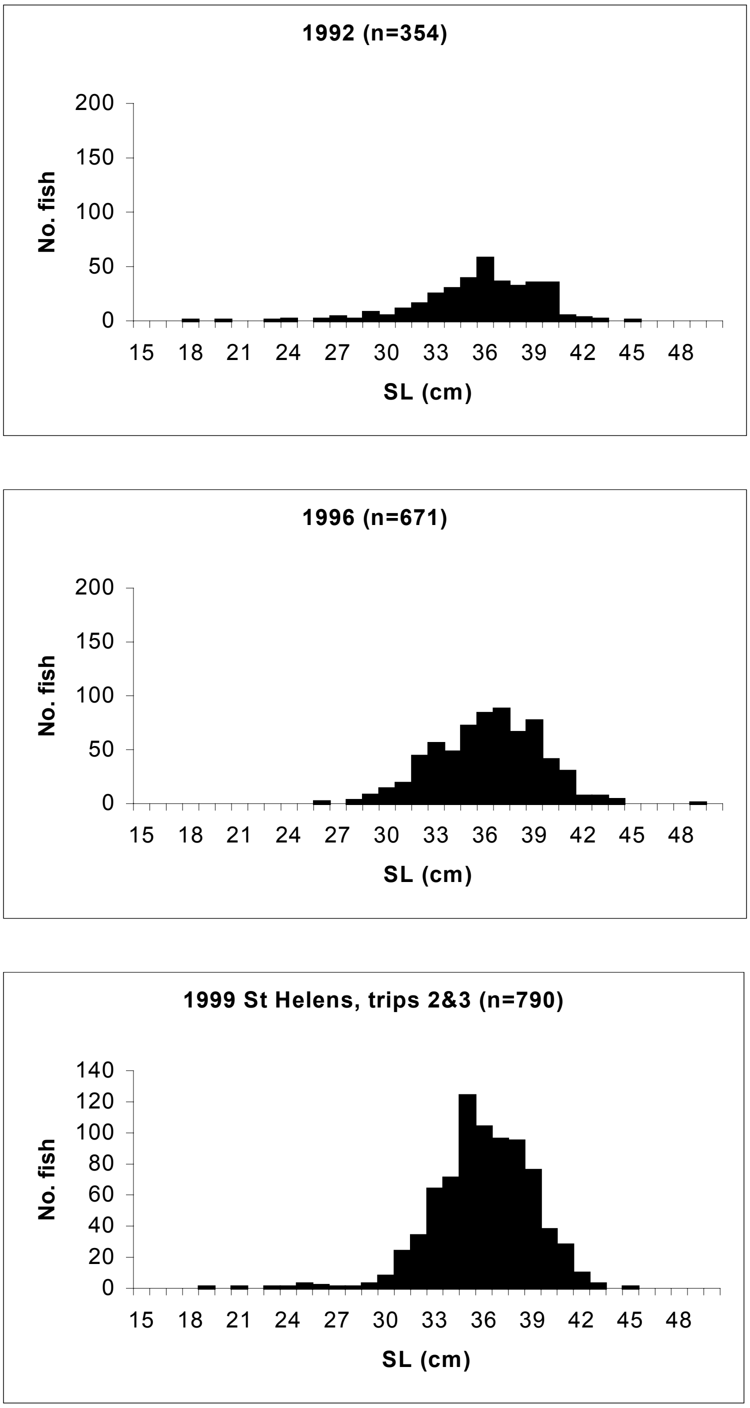
There were three noteworthy patterns in the length frequency data. First was that the overall length profile (frequency histogram, mean length and modal length) for roughy at St. Helens Hill in 1999 was not substantially different to that in previous surveys (Figure 3.3). Note though, these data provide an overview only because data are not split by sex or do not distinguish aggregations from backscatter.

The other patterns of interest were the slightly greater mean length of roughy at St. Helens Hill compared to St. Patricks Head (weighted to include both sexes), and the slightly greater mean length in aggregations than backscatter in both regions (Table 3.4). The between-region pattern is not robust for aggregations because of the predominance of (smaller) males at St. Patricks Head where only two trawls were taken (females were virtually the same length in both regions). However, there is a strong suggestion that there are proportionally more small fish in backscatter than aggregations, and that relatively small fish of both sexes predominate in the backscatter at St. Patricks Head.

**Fish weight**

Because mean weights are based on data converted from fish lengths, patterns of fish weight with respect to region and aggregation/backscatter mirror those seen in the length summaries in the previous section. Fish in aggregations have a greater mean weight than those in backscatter, and the means are greater at St. Helens Hill than St. Patricks Head (Table 3.5).

**Figure 3.3 Length frequency histograms for 1999 and previous surveys years at St. Helens Hill. Data is combined for both sexes and not separated into backscatter and aggregation trawl shots**




Orange roughy length frequencies from St Helens Hill (SL, data rounded up to nearest cm). Data for both sexes, schools and backscatter amalgamated. (For the longer 1999 survey, only data from acoustic survey time- trips 2 & 3- are shown)

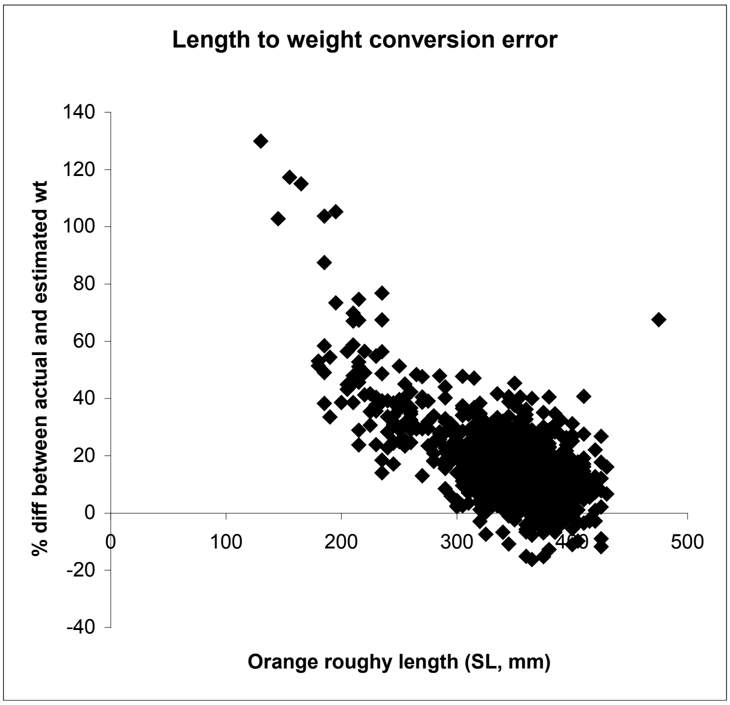
**Table 3.5 Mean weight of orange roughy in aggregations and backscatter at St. Helens Hill and St. Patricks Head based on length/weight conversion for individual fish**

| | | Trips 2-3 | | Trips 1-4 | |
|---|---|---|---|---|---|
| | | No. of fish | Mean wt (kg) | No. of fish | Mean wt (kg) |
| St. Patricks Head | Aggregation | 401 | 1.41 | 598 | 1.38 |
| | Backscatter | 566 | 1.31 | 931 | 1.36 |
| St. Helens Hill | Aggregation | 470 | 1.51 | 1070 | 1.55 |
| | Backscatter | 461 | 1.46 | 1167 | 1.38 |

The retention of a large number of orange roughy (1086 fish) for otoliths provided a second set of weight data. This was not used to calculate mean weights because (1) use of the conversion formula was consistent with the approach in previous years, (2) weight underestimation due to freezing and thawing was not measured, and (3) the weight data set was only about one third the size of the length data set. However, having the factory recorded weights enabled us to check the conversion formula.

Orange roughy standard length plotted against the difference between recorded and estimated weight (Figure 3.4) showed that the use of the conversion formula overestimated fish weight in the great majority of cases. The degree of overestimation was high (commonly between 20 and 40%) and greater in smaller fish. Loss of body fluid during freezing and thawing will undoubtably result in an underestimate of recorded weight (see Appendix E), and therefore an overestimate in the difference between recorded and converted values. The magnitude of the difference observed and its correlation with length warrants further investigation (see Appendix E).

**Figure 3.4 The difference between recorded and estimated weight of orange roughy for frozen then thawed fishes.**



**Fish age**

Otoliths collected from retained orange roughy were aged by the Central Ageing Facility (CAF) and age structure data incorporated into the 1999 stock assessment. These data displayed as age frequency plots (Figure 3.5 a-d) substantiate some of the regional and aggregation/backscatter patterns observed in length data, although there are some differences.

Consistent with patterns in length data are the greater proportion of older roughy at St. Helens Hill compared to St. Patricks Head, although in age data it is only apparent in aggregations (Figure 3.5 c,d), and the strong suggestion that there are proportionally more young fish in backscatter than aggregations at St. Helens Hill, but not at St. Patricks Head (Figure 3.5 a,,b). These patterns are sensitive to the effect of individual trawl samples because there is high between-trawl variability in the orange roughy population composition and few trawls were taken. For example, one small backscatter trawl from St. Helens Hill late in the survey (#44) containing many very small fish may have influenced the aggregation/backscatter comparison (Figure 3.5a,c). The three trawls taken from aggregations at St. Patricks Head (all trips) contained an unusual predominance of males that down-sized the mean length; whether it depressed the age profile relative to backscatter (Figure 3.5b) and St. Helens Hill (Figure 3.5d) remains to be evaluated. Irrespective of this sensitivity, however, the examination of age composition with respect to aggregation/backscatter is more insightful than without this distinction.

### 3.3.3 Sex ratios and maturity stage

**Sex ratios**

Overall, female orange roughy were more numerous than males, making up between 60% and 63% of aggregations and backscatter at St. Helens Hill and 66% of the backscatter at St. Patricks Head respectively (Table 3.6). Aggregations at St. Patricks Head contained a relatively very low proportion of females (26%), however, this ratio was based on only 3 trawls that contained, relative to most other samples, a disproportionately high number of males.

**Table 3.6 Sex ratios of orange roughy in aggregations and backscatter at St. Helens Hill and St. Patricks Head (trips 1-4)**

| | | No. trawls | No. of fish | | Percentage | |
|---|---|---|---|---|---|---|
| | | | Male | Female | Male | Female |
| St. Patricks Head | Aggregation | 3 | 440 | 158 | 74 | 26 |
| | Backscatter | 8 | 315 | 616 | 34 | 66 |
| St. Helens Hill | Aggregation | 6 | 393 | 677 | 37 | 63 |
| | Backscatter | 20 | 440 | 665 | 40 | 60 |

The sex ratio of orange roughy in individual trawl shots around an aggregation can vary greatly (Pankhurst 1988). Considerable sex segregation is often observed depending on where the catch is taken in relation to the spawning aggregation and sex ratios are commonly skewed. This phenomenon was clear in the first two small samples taken from the aggregations at St. Helens Hill in which the proportions of female roughy were 95% and 97% (based on 200 individuals per sample in catches of 350 and 500 kg). However, large catches tended to have a greater proportion of males (Figure 3.6). This observation, taken together with the relatively high proportion of females overall, perhaps indicates that males spend longer in aggregations (that produce large catches) than females.

**Figure 3.5 Age frequency distributions in aggregations and backscatter at St. Helens Hill and St. Patricks Head**

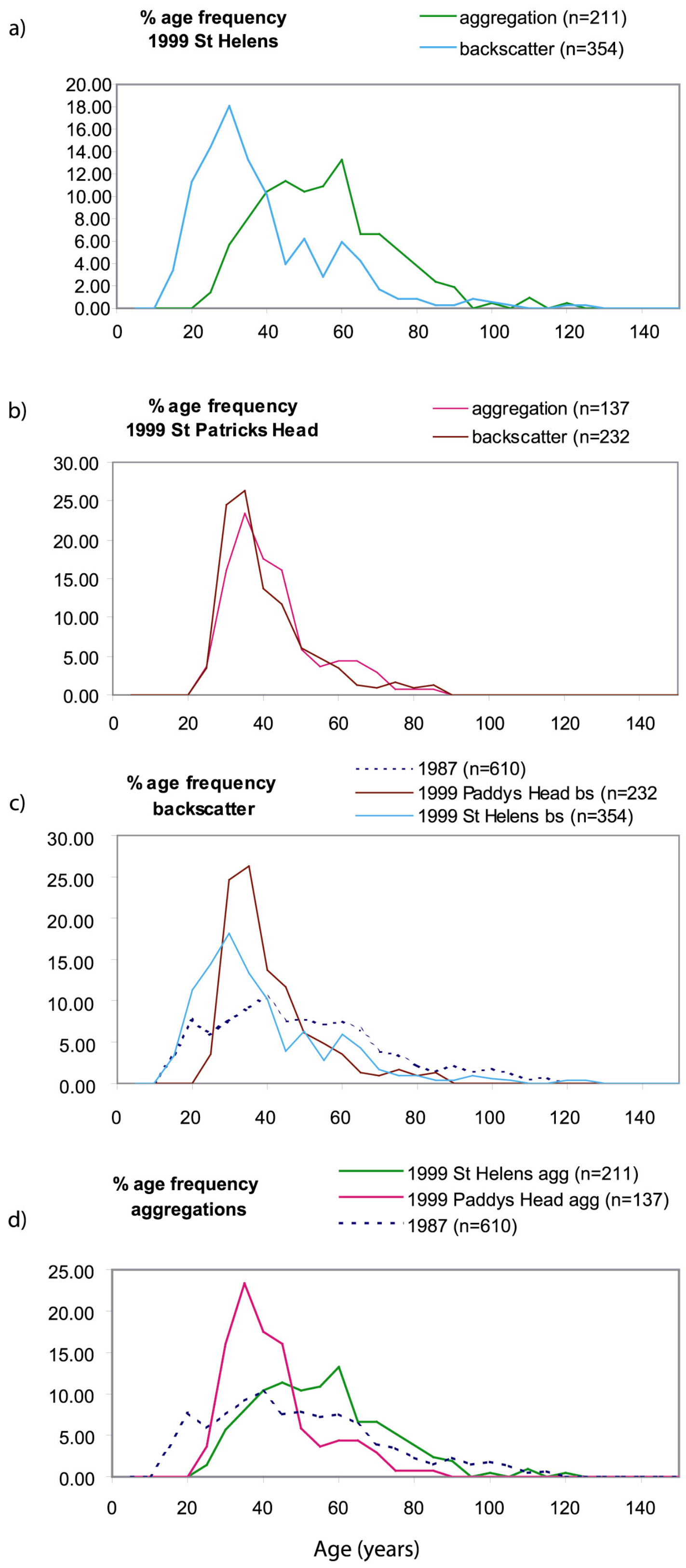
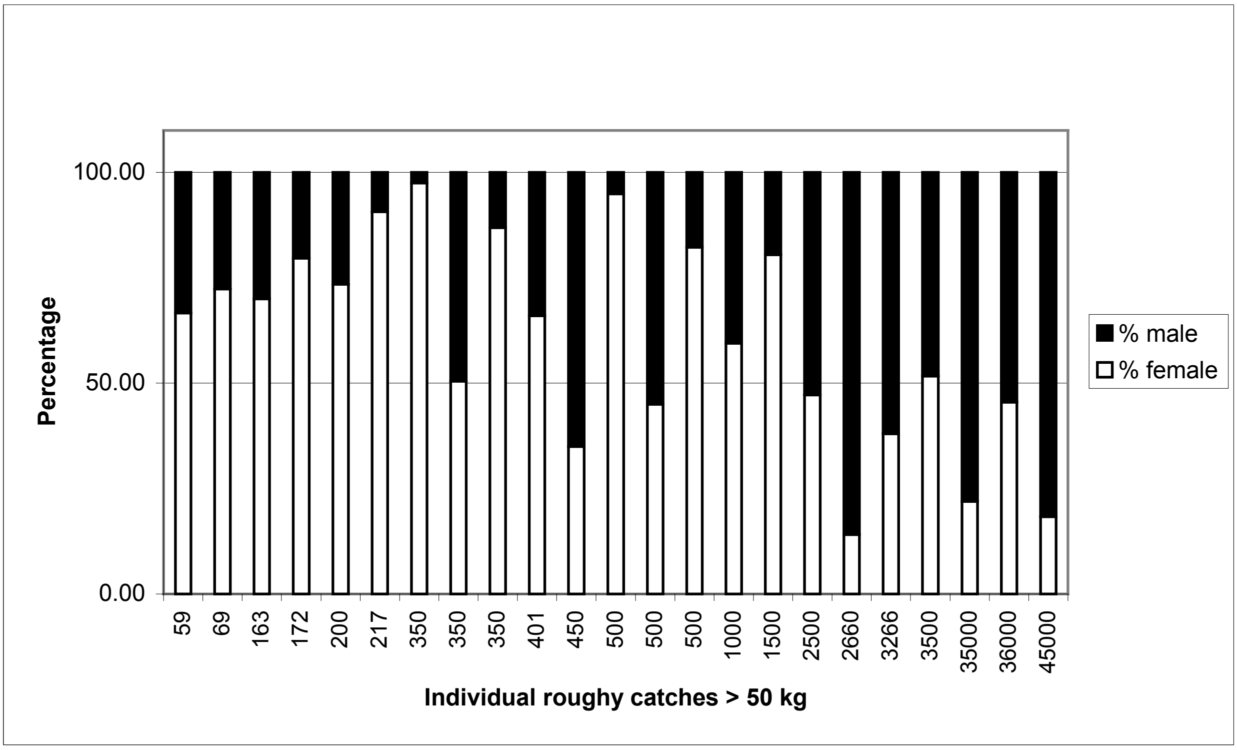


**Figure 3.6 Sex ratio of orange roughy in trawl samples containing > 50 kg of roughy (St. Helens Hill and St. Patricks Head combined)**




## Maturity stage

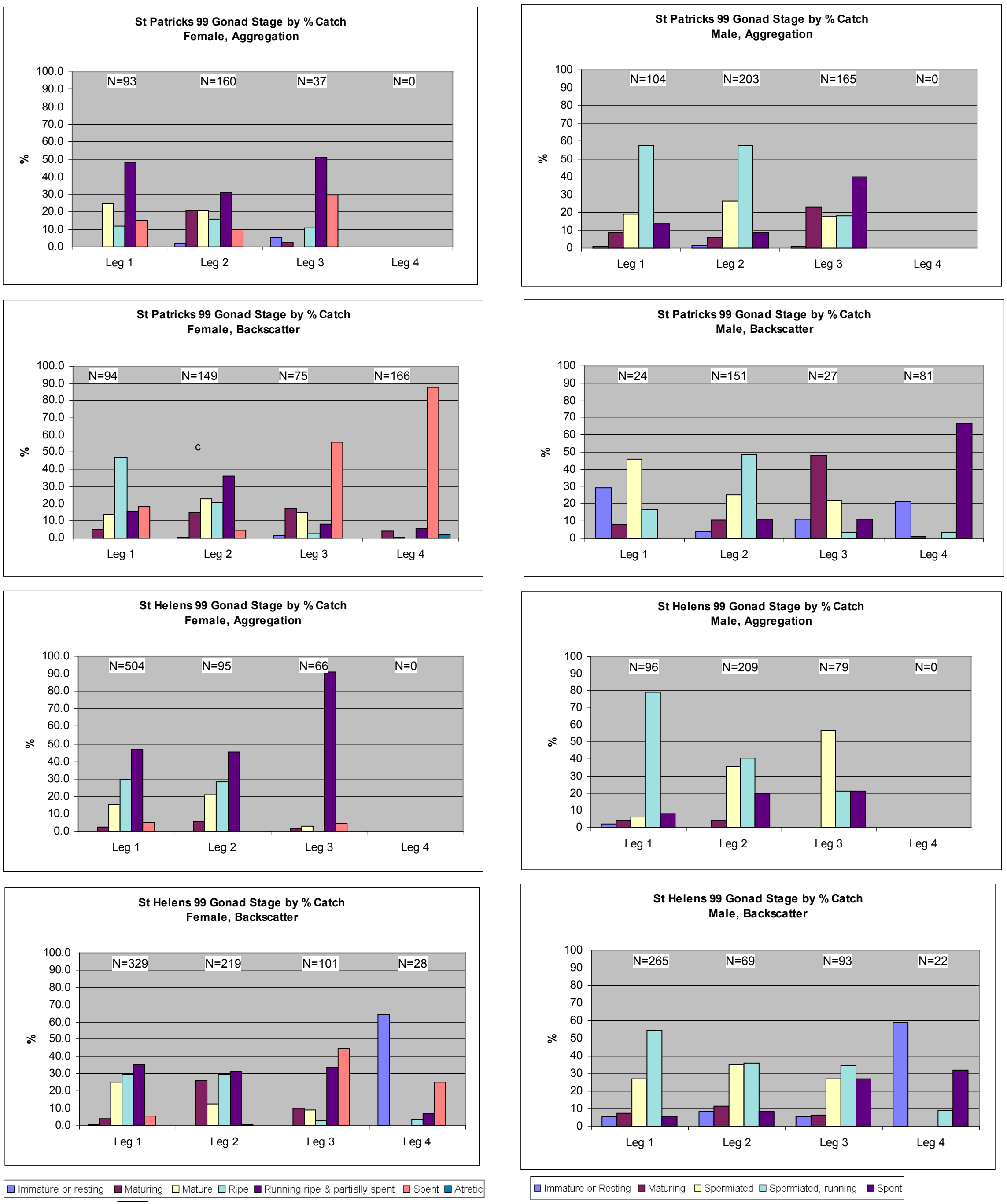
The main aim of examining gonad maturity stage was to document the timing of the acoustic survey in relation to the time of spawning. We aggregated the counts of the partially spent phase for females (NIWA Female Stage 8) into the running ripe phase (NIWA Female Stage 5) (Table 3.7) because the observer had problems applying the NIWA classification system. This did not affect our interpretation of spawning time.

**Table 3.7 Nomenclature used to describe gonad maturity**

| Female | | Male | |
|---|---|---|---|
| Phase 1 | Immature or Resting | Phase 1 | Immature or Resting |
| Phase 2 | Maturing | Phase 2 | Maturing |
| Phase 3 | Mature | Phase 3 | Spermiated |
| Phase 4 | Ripe | Phase 4 | Spermiated, running |
| Phase 5 | Running Ripe (& Partially Spent, phase 8) | Phase 5 | Spent |
| Phase 6 | Spent | Phase 6 | Partially Spent |
| Phase 7 | Atretic | | |

For discussion purposes, the data from individual shots have been aggregated on a daily basis for each of the two principle locations (St. Patricks Head or St. Helens Hill). This increases sample sizes and decreases the influence of intershot-variability, making overall trends in gonadal stage through the spawning season more evident. Additionally, the data have been aggregated by survey leg and trawl type to allow the entire data set of gonad stages to be viewed on one figure (Figure 3.7).

**Figure 3.7 Gonad stage data for St. Patricks Head and St. Helens Hill aggregated by survey leg and trawl type (aggregation or backscatter).**




A total of 3,607 fish was measured over 13 days of sampling. During this period the numbers measured on a daily basis ranged from 0 to 714. On all but 2 days of sampling sample sizes were >100 fish per day.

The results presented show that the two locations generally appear to have followed the same trends in gonad maturity. No clear differences were observed between the two locations.

The first samples of the eastern zone fish were attained on the 10 July from a small mark at the southern end of the St. Patricks Head aggregation site in 895-914m. The small 192kg catch (118 individuals) was 80% female of which almost 50% were ripe; the highest proportion of ripe females observed during this study. Approximately 15% of the females were running ripe and almost 20% were spent. The remainder of the females were mature or maturing. The few males were relatively small and >80% did not appear likely to participate in spawning during 1999. The remainder <20% were ripe. No running ripe or spent males were observed in this first shot.

The first samples taken from St. Helens Hill were caught on 11 July. The sample of 271 individuals was 45% female. These females were principally (approx. 40%) running ripe and partially spent. Mature fish not spawning in 1999, and ripe fish not yet spawning each comprised around 20% of the female catch, while spent fish comprised approximately 10% of the female catch. The male catch was almost 50% running ripe with approximately 30% ripe. About 20% of the males were maturing or immature and did not appear likely to participate in the 1999 spawning. Several spent males (<5%) were also observed.

These early catches containing principally ripe and running ripe fish together with a small proportion of spent females and males, show that orange roughy had already commenced spawning at both St. Helens Hill and St. Patricks Head when these samples were taken. The prevalence of ripe fish that were not yet running ripe and the relatively low proportion of spent fish suggest that while spawning had commenced it was not far advanced.

Female catches for both St. Helens Hill and St. Patricks Head through the period 11-21 July were dominated by fish that were mature, ripe and running. Throughout this period, catches of males were generally 80-90% fully spermiated and running ripe. Spent males were generally around 10% of male catches until 20 and 21 July when they increased to 20% of the male catch.

During the third sampling period, 26-28 July, a marked increase in the proportion of spent fish was noticed. The male catch in both locations was generally 20-40% spent and the female catch from both locations was generally 30-60% spent. Also evident during this sampling period was a decline in the proportion of ripe females from around 20-40% of the female catch to <5%. This decline was first observed on 26 July.

These data suggest that the period 12-25 July was a sustained period of active spawning, with new ripe fish continually entering the spawning aggregations and with spent fish progressively leaving the aggregations. The rapid decline of ripe females in the female catch after 25 July and the rapid rise in the proportion of spent males and females at this time show that the spawning season of 1999 was drawing to an end.

There was no evidence of any continuing spawning in the area by the time of the final sampling period 9-11 August. The small daily catches at that time were comprised almost entirely (>95%) of spent and immature fish.

### 3.3.4 Water column communities

In addition to the demersal trawling undertaken by *Saxon Progress*, pelagic trawling was targeted at midwater marks to provide information on the species present and their size compositions. Seven pelagic trawls were made by *Southern Surveyor* with the MIDOC system. Each trawl provided six samples: four were depth-stratified and two integrated through the water column during the descent and ascent of the net to sampling depths.

In overview, we attempted both to characterise the primary stratified layers of micronekton in the water column and to identify particular acoustic marks close to what were believed to be orange roughy schools. Water column characterisation was done by sampling four strata of ~250 m (surface to ~900 m) during the day and night at the St. Patricks Head ground. Acoustic marks were targeted around the St. Helens Hill in the ~700-850 m depth range in the northeastern and western sectors during the day and night. At the St. Patricks Head ground, several depth-stratified marks were targeted in the main canyon during day and night. Marks here were diffuse and near-bottom (in ~850 m) or clearly stratified and higher in the water column (~700-500 m and 450-350 m).

The 42 catches (7 trawls x 6 samples) were generally high, with an average of 74 individuals (exclusive of gelantinous zooplankton and euphausids). All catches were sorted to species or species-group and weighed and counted, and all individuals were measured (excluding gelantinous zooplankton and euphausids). Diversity was high with 74 taxa of mainly fishes, squids and crustaceans represented; several taxa contained more than one species. Deep marks (>700 m) near the seabed were primarily the lanternfish *Lampanyctus australis* and the whiptail *Coryphaenoides subserrulatus*, with low numbers but high biomass made up by the Johnson's cod (*Halagyreus johnsoni*). In stratified marks higher in the water column, the lanternfish *Diaphus danae* and the prawn *Sergia potens* were most numerous. Large numbers of the pelagic tunicate *Pyrosoma atlanticum* were caught in shallow depths (<300 m and at the surface). Day/night differences were due to the ascent, at night, of diel vertical migrators, particularly the lanternfishes.

Swimbladder characteristics (size and gross structure) were determined for a range of species to assess their acoustic reflectivity. Large individuals of several species were photographed, while individuals of large and small species were retained frozen for laboratory examination. The dominant water column scatterers (lanternfishes, whiptails and morid cod), as well as those making up prominent marks in the shallow reaches of St. Helens Hill, the telescope cardinalfish (*Epigonus telescopus*) and alfonsino (*Beryx splendens*), have gas-filled or spongy-matrix swimbladders. They are more reflective than the wax-ester filled bladder of orangy roughy and therefore contribute strongly to acoustic backscatter.

## 3.4 Conclusions

Aggregations of spawning orange roughy were restricted to the western sector of St. Helens Hill in the 800-900 m depth range. Large catches of ripe fish confirmed that a large spawning event also occurred at the northern end of the St. Patricks Head ridge in 800-1000 m depth.

Large numbers of whiptails and morid cod at St. Helens Hill, particularly in the eastern sector, resulted in higher proportions of bycatch at St. Helens Hill than at St. Patricks Head.

The overall size distribution of roughy at St. Helens Hill was not substantially different to that in previous surveys (based on data amalgamated for sex and without distinguishing aggregations from backscatter). Length and age data suggest there were proportionally more older and larger fish at St. Helens Hill than St. Patricks Head, and in aggregations compared to backscatter.

The standard length-weight conversion formula appears to upwardly bias fish weight when using frozen then thawed fish; a check on the length to weight formula for both fresh and frozen then thawed fish needs to be conducted in the next survey (see Appendix E).

Gonad maturity stage data and large catches confirmed that the acoustic survey spanned the main spawning event; spawning aggregations in both regions had dispersed within 10 days of the survey's completion.

The dominant components of marks in the deep water column around St. Helens Hill are lanternfishes, whiptails and morid cod, while prominent marks around the top of the hill are telescope cardinalfish and alfonsino. Because their gas-filled or spongy-matrix swimbladders are more reflective than the wax-ester filled bladder of orangy roughy, these fishes contribute strongly to acoustic backscatter.

# 4. ORANGE ROUGHY ACOUSTIC BIOMASS ASSESSMENT – 1999 SURVEY DATA

Rudy Kloser and Tim Ryan

## 4.1 Introduction

Assessing the biomass of orange roughy on the two fishing grounds of St. Patricks Head and St. Helens Hill over the spawning period was the primary objective of this project. The acoustic data obtained during the anticipated peak spawning period from the *Southern Surveyor's* deep towed MUFTI system and vessel mounted Pole system were used to calculate snapshot biomass estimates. The acoustic and biological data obtained from the industry vessel *Saxon Progress* provided the necessary temporal coverage to monitor the stock over the spawning season. This data assisted in ensuring that the snapshot biomass estimates obtained from *Southern Surveyor* data were made inside the peak of the spawning period (see chapter 3).

## 4.2 Methods

### 4.2.1 Acoustic Survey Designs

In July 1999, we surveyed two sites on the east coast of Tasmania where orange roughy are known to aggregate: St. Helens Hill and St. Patricks Head. St. Helens Hill is a conical seamount rising from 1000 m depth to 600 m (Figure 4.1a). St. Patricks Head is a 5 nautical mile long ridge that runs North to South and is shallowest (800 m depth) in the north (Figure 4.1b). Different survey designs were required to suit the topography of the two grounds.

**St. Helens Hill Surveys**

Three different types of surveys, 'Grid', 'Star' and 'Loop' were conducted at St. Helens Hill to explore sensitivity to steaming direction, species composition and to take advantage of sampling gear deployment (Table 4.1, Figure 4.2).

The first survey type was based on 5 North – South transects along 0.5 minute longitude lines used in similar surveys since 1989 (Kloser *et al* 1996). The second survey design was a star pattern centered on the hill's apex that divided the hill into 6 transects of equidistant angular locations. This survey design was trialed after feedback from the industry and optimised the turning of our deep water towed body. Deploying our deep towed body at depth required 1500 – 1800 m of cable to be streamed in the water. This long length of cable necessitated that gradual turns at the end of transects. The Star survey pattern assisted in creating gradual turns between transects. The third survey design of "loops" that followed the depth contours (700, 750, 800, 850, 900 and 1000 m) of the hill enabled the MUFTI towed system to be deployed at a fixed height 180 – 250 m above the seabed. At ranges of 180 – 250 m the three frequencies (12, 38 and 120 kHz) of the MUFTI system could be used for species composition as well as for echo integration. The operational mode of the transducers is given (Table 4.2).

**Figure 4.1a Relief map of St. Helens Hill bathymetry from AGSO dataset, 3 x vertical exaggeration.**

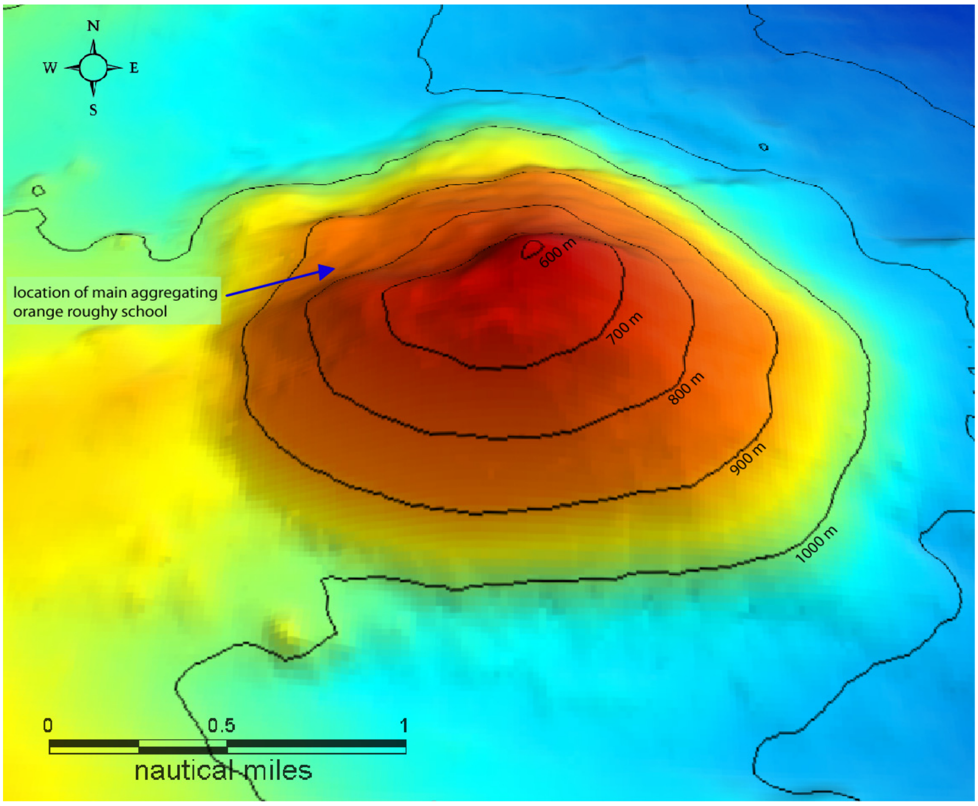



**Figure 4.1b Relief map of St. Patricks Head bathymetry from AGSO 1999 dataset, 7 x vertical exaggeration.**

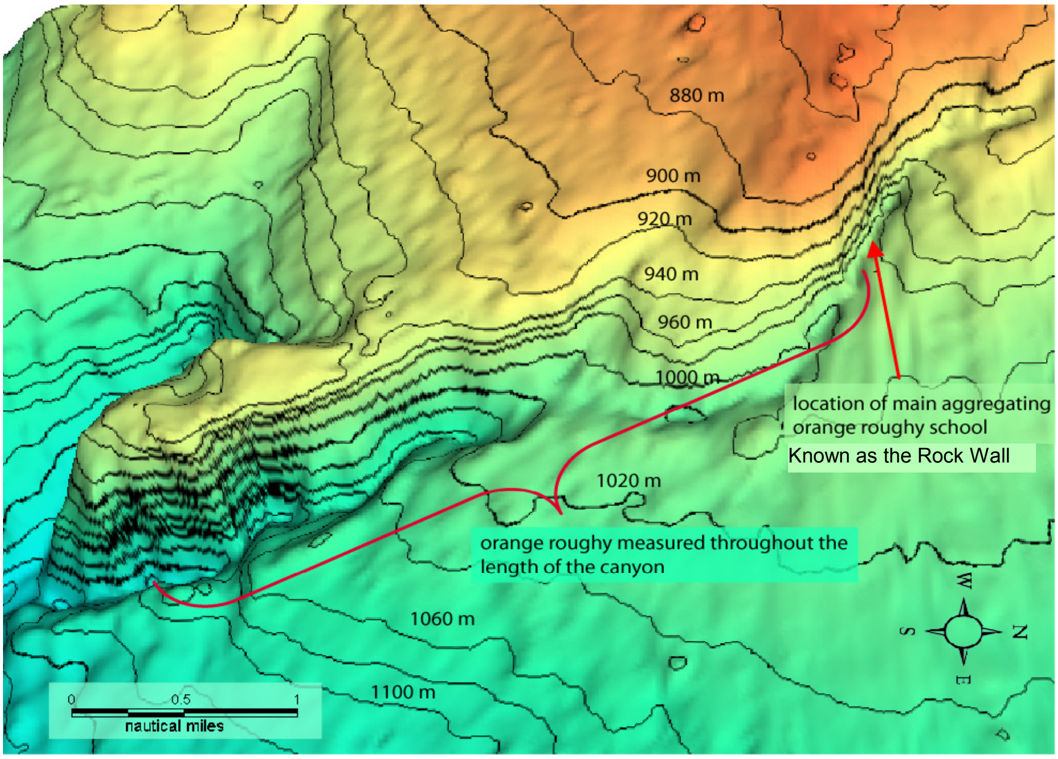


**Figure 4.2 St. Helens Hill survey designs: (a) Rectangular Grid, (b) Star Pattern and (c) Loops.**

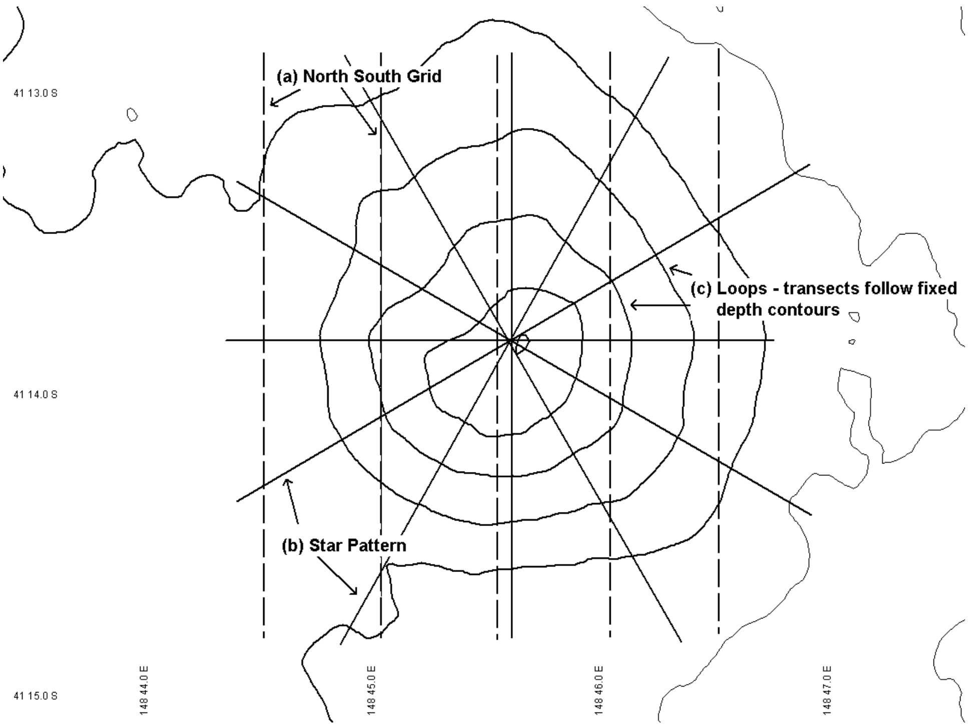



**Figure 4.3 St. Patricks Head survey designs: (a) East-West Grid, (b) Zig Zag, (c) North-South deep tow, (d) following the canyon ridge and (e) towed body drop above the fish schools.**

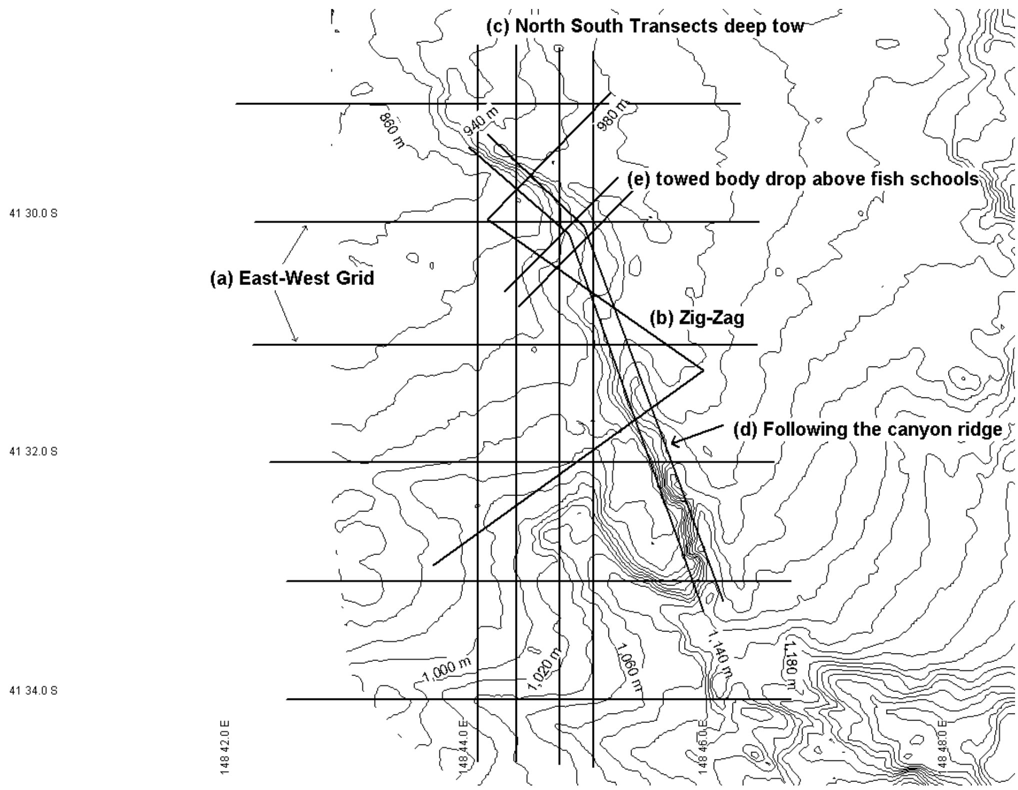


**Table 4.1 Summary of survey designs used at St. Helens Hill.**

| Type of Survey | Design comments | Summary of survey design |
|---|---|---|
| Grid | To allow the 1999 results to be included in the 1989-1996 time series. | Based on our traditional survey pattern that has been carried out since 1989. 5 North – South transects along 0.5 minute longitude lines (Figure 4.2). |
| Star | Feedback from industry highlighted the need for greater sampling intensity in the regions where the roughy are likely to be found. Secondarily this design optimises the turns for the MUFTI system. | Star pattern that divides the hill into 6 transects of pseudo random locations. (Figure 4.2). |
| Loop | Allows the MUFTI system to be flown at a height within the range 180-250m above the seabed. This is sufficiently close to allow discrimination of the acoustic species by mixing of the 12, 38 and 120kHz echograms whilst being a distance that does not cause orange roughy avoidance. | A series of transects that follow the depth contours of the hill via clockwise loops at 700, 750, 800, 850, 900 and 1000m nominal depths (Figure 4.2). |

**Table 4.2. Operational mode for surveys on St. Helens Hill**

| Type of Survey | Operational modes |
|---|---|
| Grid | 38kHz Pole, 38kHz MUFTI towed approximately at 500 meters |
| Star | 38kHz Pole, 38kHz MUFTI towed approximately at 500 meters |
| Loop | 12, 38 and 120kHz MUFTI towed 180-250 meters above the seabed |

### St. Patricks Head Survey Designs

The acoustic surveys at St. Patricks Head were carried out with several East - West transects spaced at random locations orthogonal to the underlying topography and fish distribution (Figure 4.3). The number and extent of the east west surveys was adaptively changed to maximise the number of transects on the orange roughy acoustic marks:

- Greater number of transects were included at the northern end of the ridge where the fish were mainly aggregated to allow both a suitable sampling intensity and sufficient coverage to map the school distributions.
- Greater North-South extent to ensure that the orange roughy distribution was bound. A lesser North-South extent once distribution was understood to allow more efficient use of ship time.
- Reduced MUFTI transects due to the time consuming nature of surveying with a towed system.

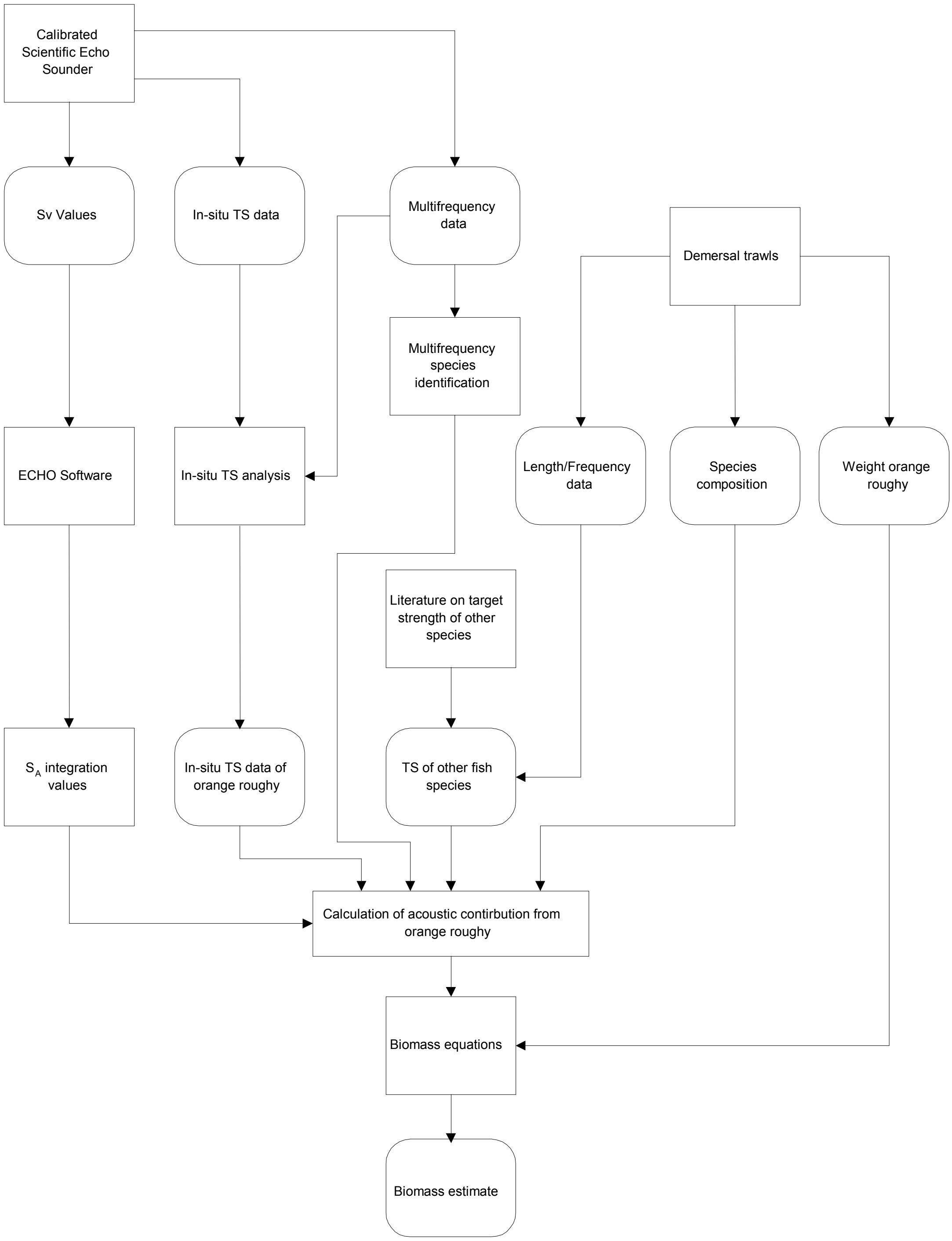
Species composition of the acoustic marks was investigated by deeply towing the MUFTI system along the ridge. MUFTI was deployed at 150 – 250 m above the sea floor at depths of 700-750 m along the depth contours in an approximate NNW direction (Figure 4.3).

## 4.2.2 Acoustic data analysis

### Overview

The procedure for estimating the acoustic snapshot biomass of orange roughy is described below and illustrated (Figure 4.4).

**Figure 4.4 A simplified flow diagram of the procedure to combine the calibrated acoustic data with *in-situ* and literature target strength values, demersal trawls and multi-frequency species identification.**



The calibrated echo sounder digitises the acoustic echo signal along a transect line and provides range-corrected volume backscatter ($S_v$ proportional to fish per unit volume) values in depth bins. The acoustic system was calibrated with a 42 mm tungsten carbide calibration sphere (Foote *et al*. 1987; Simrad software version 5.3, 1996). This volume reverberation calibration technique combines the electrical and acoustic constants of the system, $G_o^2$ (for a given transmitter power, Pt, pulse length, τ, and band width) and the equivalent beamwidth, ψ, (provided by the transducer manufacturer). Sound velocity, c, and absorption constant, α, are required to give range, r, independent values of the volume reverberation signal, Sv dB re 1 μPa at 1m, that is expressed in logarithmic form as:

$$Sv = 10\lg(P_r) + 10\lg(r^2 10^{2\alpha r}) - 10\lg(\frac{P_t G_0^2 r_0^2 \lambda^2 c \tau \psi}{32\pi^2}) \quad \text{dB re 1 μPa at 1 m} \quad (4.1)$$

These $S_v$ values are quality assured and integrated in our ECHO software by summing the depth bins vertically by water depth and averaging horizontally by *k* (0.1 n.mile ) interval distance to yield area backscatter ($s_A$ proportional to fish per unit area). The equation to calculate the mean $s_A$ (area backscatter) per integration interval, $\overline{s_{Ak}}$ , is given:

$$\overline{s_{Ak}} = \frac{\sum_{p=1}^{m} \delta \sum_{d=1}^{\frac{h}{\delta}} 10^{\frac{Svdp}{10}}}{m} 4\pi 1852^2 \quad \text{m}^2 \text{ n.mile}^{-2} \quad (4.2)$$

Where $S_v$ is the volume backscatter, *m* the number of pings in the integration interval, *h* the height of the defined school above the acoustic bottom and δ the height of the digitized signal quanta.

These $s_A$ values are a measure of the total acoustic backscatter from the water column and can include backscatter contributions from orange roughy as well as the mix of bycatch and mesopelagic species that exist with roughy at these depths.

Two general methods are used to partition the acoustic data to calculate fish biomass using the echo integration method. The first method defined as 'school based', relies on the identification of distinct schools of orange roughy using echogram structure, fish catch and multi-frequency acoustics. The defined schools are classified and bounded using the ECHO software (Waring et al 1994, Kloser et al 1998). The classified schools are echo integrated along each acoustic transect and a mean area backscatter obtained. Assuming 100% orange roughy in the defined schools, the mean area backscatter is converted to a mean density :

$$\overline{\rho_{ij}} = \frac{\overline{s_{Aij}} \frac{Wsor}{1000}}{4\pi 10^{\frac{TSor}{10}}} \quad \text{tonnes n.mile}^2 \quad (4.3)$$

Where $W_{sor}$ is the mean orange roughy weight in kilograms and $TS_{or}$ is the mean target strength of orange roughy.

For the second method to obtain an estimate of orange roughy biomass in mixed fish species regions, it is necessary to calculate what portion of the acoustic backscatter, $s_A$, is attributable to orange roughy. This is commonly achieved by combining the trawl species catch composition, length and weight data with target strength estimates of orange roughy and other acoustically dominant groups of fishes to yield an area density of orange roughy (Kloser *et al* 1996).

Taking into account the presence of other fish species, the mean density of orange roughy for each transect, $\overline{\rho_{ij}}$, is given by :

$$\overline{\rho_{ij}} = F_{s\_or} \cdot \frac{\overline{s_{Aij}}}{\sum_{s=1}^{p} F_s \cdot 4 \cdot \pi \cdot 10^{\frac{\overline{TS_s}}{10}}} \cdot W_{s\_or} \qquad \text{tonnes n.mile}^2 \qquad (4.4)$$

Where *Fs* is the proportion of each fish species, *Fs_or* the proportion of orange roughy, *p* the number of fish species, *Ws_or* is the mean individual fish weight in kilograms, and $TS_s$ is the mean target strength of each fish species.

This method of assigning the trawl catch to the acoustic return suffers from poor precision in estimating both the contributions of associated species with high acoustic target strengths and from species close to the seabed. The stock size of orange roughy at St. Helens Hill has declined to a level where this technique is no longer applicable (Kloser and Ryan 1999).

To improve the precision and accuracy of acoustic surveys of orange roughy, we apply the ‘schools method’ and only integrate echoes that originate from orange roughy. Identification of orange roughy schools is based on echo structure and dynamics, fish capture and most importantly multi-frequency acoustics, MUFTI (Chapter 7). The ability of the MUFTI data to discriminate regions of orange roughy greatly assisted the identification of school marks for the 1999 survey year, although the highly mixed nature of the fish community at St. Helens highlighted some limitations with the current MUFTI system. The method of school based analysis gives only an estimate of biomass contained in the aggregating homogeneous schools of orange roughy. It relies on the majority of orange roughy being in an aggregated mode rather than being dispersed and mixed. The amount of orange roughy contained in the non-aggregating regions is more difficult to estimate and is not covered in this analysis.

The three types of surveys, Loop, Grid and Star, that were carried out on the two grounds of St. Patricks Head and St. Helens Hill, required slightly different methods to calculate the biomass. These differences related to calculation of the area of the survey and the stratification of the along transect acoustic data.

**Loop survey analysis (St. Helens Hill)**
The Loop surveys involved towing the MUFTI system a constant (180-250 m) depth above the seafloor in series of clockwise loops around the hill. The series of loops was broken up into discrete transects of one complete clockwise circuit. Each loop transect was visualised as a 3-frequency mixed echogram using ECHO software to enable regions of aggregating orange roughy to be identified (Figure 4.6). These were marked on the MUFTI 38kHz single frequency echogram and echointegrated in 0.1 nautical mile intervals to give $\overline{s_{Ak}}$ (equation 4.2).

The biomass is then calculated via the following steps.

- Calculate survey area
- Calculate the mean $s_A$ for the survey area
- Use the mean $s_A$ for the survey and its area to calculate biomass.

**Calculation of survey area**
The Loop transect GPS positions were plotted in Mapinfo. This software package was then used to calculate the area of the inner (< 700 meter) and outer loops. The area of the survey annulus $A_l$ is then:

$$A_l = \textit{Outer bound area} - \textit{inner bound area} \qquad (4.5)$$

**Mean $s_A$ for the survey area**
The Loop transects are considered as a series of 0.1 nautical mile interval, randomly placed echointegration samples around the hill area. The logistics of towing the MUFTI system at a deep depth and in a loop provides a randomising effect. The mean $s_A$ for the survey area is then a simple mean of all the echointegration samples.

$$\overline{s_{Al}} = \frac{\sum_{k=1}^{n} \overline{s_{Ak}}}{n} \quad \text{m}^2\ \text{n.mile}^{-2} \qquad (4.6)$$

where $n$ is the number of integration intervals for the survey area.

**Biomass estimate for Loop survey**

The estimate of biomass $B_l$ is then calculated using $\overline{s_{A\,l}}$ and the area of the Loop survey $A_l$:

$$B_l = \frac{\overline{s_{A\,l}} \frac{Ws}{1000} * A_l}{4\pi 10^{\frac{TSor}{10}}} \quad \text{tonnes} \quad (4.7)$$

where $Ws$ is the weight of orange roughy in kgs and $TS_{or}$ the mean target strength of orange roughy in dB

**Grid survey design biomass estimate method (St. Helens Hill and St. Patricks Head Grid surveys).**

The biomass estimate is calculated via the following steps.

- Assume each transect is a sample.
- Calculate survey area
- Calculate the mean $s_A$ for each transect then average these mean $s_A$'s to get a mean $s_A$ for the whole survey area.
- Use mean $s_A$ for the survey and its area to calculate biomass.

**Calculation of survey area**

The area for the North-South Grid design at St. Helens, $A_g$, is calculated by finding the average transect length for the stratum region and multiplying this by the east-west extent of transects plus the mean transect width, that is one half of a transect width either side of the outermost transects

$$A_g = (Y_{lg} + \frac{Y_{lg}}{k})\overline{Lj} \quad \text{n.mile}^2 \quad (4.8)$$

Where $\overline{L_j}$ is the mean transect length for the stratum region and $Y_{lg}$ is the longitudinal extent of the stratum region and $k$ is the number of transects.

A similar calculation of $A_g$ is made for the east-west Grid design that was used at St. Patricks Head.

$$A_g = (Y_{lt} + \frac{Y_{lt}}{k})\overline{Lj} \quad \text{n.mile}^2 \quad (4.9)$$

where $\overline{L_j}$ is the mean transect length for the stratum region and $Y_{lt}$ is the latitudinal extent of the stratum region and *k* is the number of transects.

**Mean $s_A$ for the survey area**

For each transect *t* the mean $s_A$ per integration interval is averaged to give $\overline{s_{At}}$ , the mean $s_A$ per transect.

$$\overline{s_{At}} = \frac{\sum_{k=1}^{n} \overline{s_{Ak}}}{n} \qquad m^2 \text{ n.mile}^{-2} \qquad (4.10)$$

where *n* is the number of integration intervals for the transect.

A mean $s_A$ of all the transects is calculated to give $\overline{s_{Ag}}$ , the mean $s_A$ for the survey area.

$$\overline{s_{Ag}} = \frac{\sum_{t=1}^{m} \overline{s_{At}}}{k} \qquad m^2 \text{ n.mile}^{-2} \qquad (4.11)$$

Where *k* is the number of transects.

**Biomass estimate for Grid survey**

The biomass $B_g$ is then calculated using $\overline{s_{Ag}}$ and the area of the Grid survey $A_g$

$$B_g = \frac{\overline{s_{Ag}} \frac{Ws}{1000} * A_g}{4\pi 10^{\frac{TSor}{10}}} \qquad \text{tonnes} \qquad (4.12)$$

**Star survey design biomass estimation method. (St. Helens Hill)**

To reduce the potential biasing effect of the variable sampling intensity that is inherent in the Star design the survey has been broken up into 100-meter depth ranges.

The biomass estimate is then calculated via the following steps.

- Calculate area for each 100 meter depth range.
- Calculate the mean $s_A$ for each discrete 100 meter depth range.

- Use the mean $s_A$ and area of each 100 meter depth range to calculate a corresponding biomass.
- Sum up biomass for each depth range to get total biomass for entire survey area.

**Calculation of area for each 100 meter depth range.**
The bathymetry data was contoured using Vertical Mapper enabling Mapinfo to be used to calculate the area of the annulus of each 100-meter depth interval.

**Calculation of mean $s_A$ for each discrete 100 meter depth range**
A mean area backscatter, $\overline{s_{Ad}}$ , is calculated for each 100 metre depth range.

$$\overline{s_{Ad}} = \frac{\sum_{k=1}^{n} \overline{s_{Ak}}}{n} \qquad \text{m}^2 \text{ n.mile}^{-2} \qquad (4.13)$$

where $n$ is the number of integration intervals in the depth range.

**Biomass estimate for Star survey**
The biomass for each depth range, $B_d$, is calculated as follows:

$$B_d = \frac{\overline{s_{Ad}} \frac{Ws}{1000} * A_d}{4\pi 10^{\frac{\overline{TSor}}{10}}} \qquad \text{tonnes} \qquad (4.14)$$

The total biomass $B_s$ is found by summing up the calculated biomass from each depth range.

$$B_s = \sum_{1}^{p} B_d \qquad \text{tonnes} \qquad (4.15)$$ where $p$ is the number of depth ranges.

# 4.3 Acoustic biomass assessment results and discussion

## 4.3.1 Overview of Surveys

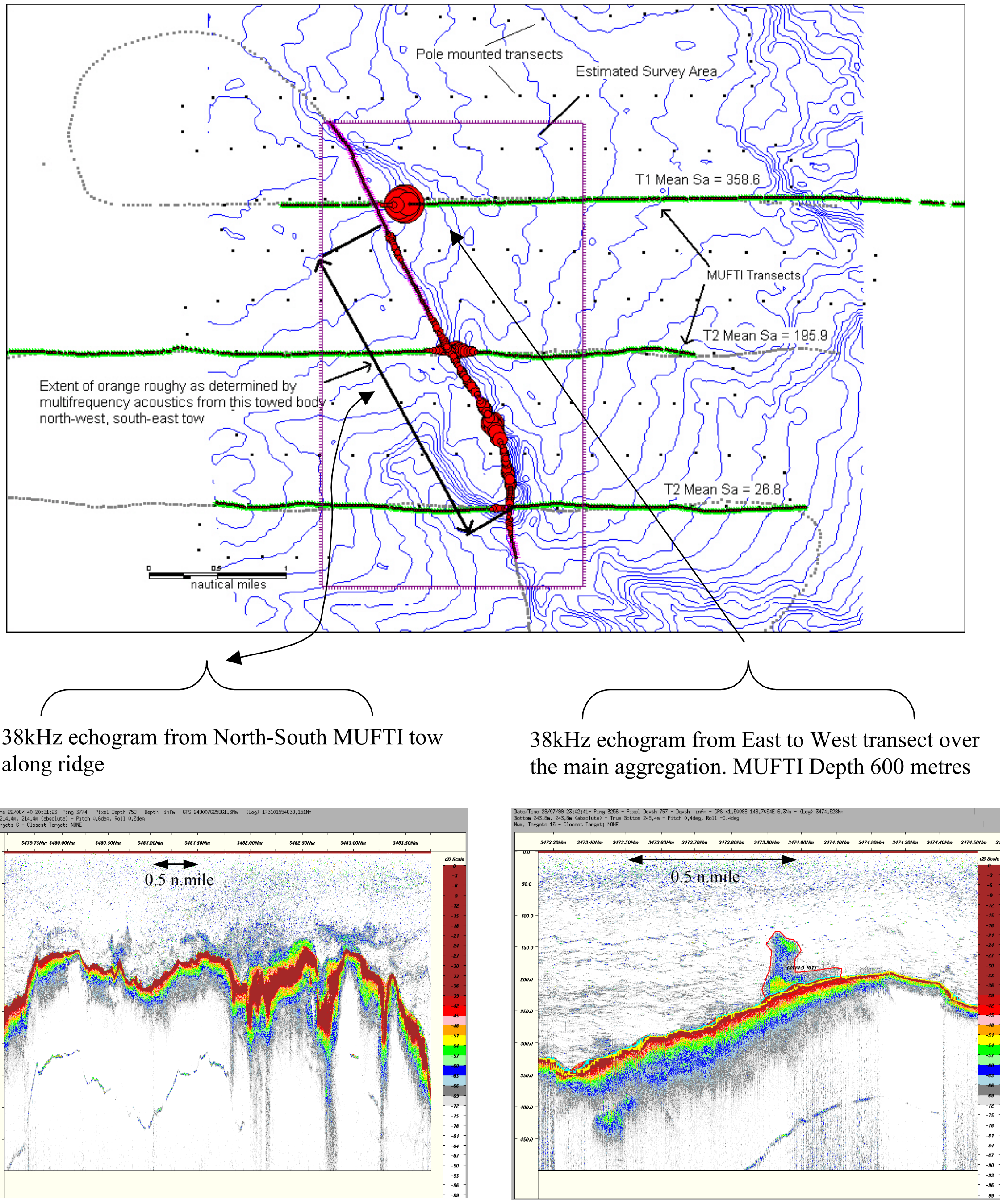
Visual inspection of the initial surveys by both the towed acoustics and the *Saxon Progress* system indicated that the overall biomass of orange roughy on the two grounds was relatively low this year, especially at St. Helens Hill. The most striking feature was that few identifiable acoustic marks at St. Helens Hill could be confidently attributed to orange roughy.

The Southern Surveyor's hull-mounted system detected many acoustic marks in the appropriate depth range (700-1000 m) but these could not be confidently attributed to orange roughy by trawling or multi-frequency acoustics. A persistent but mobile acoustic mark around the top of the hill (600 – 750 m depth range) was identified as alfonsino and or cardinal fish by both methods. As both these species have large gas-filled swim bladders they produced highly intense marks to the vessel mounted transducer when schooled tightly, but produced marks similar to orange roughy schools when dispersed.

Multi-frequency acoustics was the only method that reliably identified orange roughy in deep water marks, but showed that most marks were attributable to other fishes (myctophids, whiptails and morid cods). During the first survey of St. Helens Hill several small orange roughy schools were found in deep water to the north and west. In later surveys, distinct schools were found in the NW (800-900 m), NE (800 m) and SE (750 m). The size and intensity of these schools from visual inspection were greatly reduced from the previous survey in 1996.

A relatively large aggregation of orange roughy was identified at the St. Patricks ground. It persisted strongly over the ground for the two-week survey period, although it moved locally, changing its position (and potentially density) over periods of hours and days. The main body of fish was located on the north-eastern end of the prominent ridge, but moved on and off the ridge during the survey period. Large catches of orange roughy (2-30 tonnes) were obtained from tows in this region by the *Saxon Progress*.This main body of fish extended along the ridge south for 3-4 nautical miles but petered out at the southern extremities (Figure 4.5). The school did not show any large east-west extent. Details of the surveys undertaken at both grounds and the associated analysis are as follows.

**Figure 4.5. MUFTI survey of St. Patricks Head on the 31st of July showing area backscatter values ($s_A$) proportional to circle size for each 0.1 n.mi. interval.**



The acoustic biomass constants of target strength and weight at St. Helens Hill were held constant in this analysis to be consistent with previous years (Table 4.3). Biological data (Chapter 3) showed that the mean standard length of orange roughy at St. Helens Hill was 35.9 cm with a mean weight of 1.5 kg. The mean length of orange roughy at St. Patricks Head was measured as being smaller at 34.9 cm which yields a 1.4 kg mean weight and slightly smaller target strength (Table 4.3).

**Table 4.3. Mean weight and target strength constants used when calculating biomass at St. Helens Hill and St. Patricks Head**

| | St. Helens Hill | St. Patricks Head |
|---|---|---|
| Orange roughy weight (kgs) | 1.5 | 1.4 |
| Orange roughy target strength (dB) | -50.0 | -50.3 |

### 4.3.2 St. Helens Hill Biomass Estimates

The dates and types of surveys conducted at St. Helens Hill are outlined (Table 4.4). In summary, detailed acoustic surveys using *Southern Surveyor* were undertaken on the 19th, 24th, 26th and 31st of July. Surveys were selected for more detailed analysis based on the need to analyse at least one survey from each of the three designs, Grid, Star and Loop during the peak of the spawning period, high data quality and coincident vessel and towed body acoustics. The surveys that fitted these criteria were conducted on the 19th and 31st July. These surveys were analysed as outlined in the methods and a biomass assessment based on school identification carried out for the three survey types (Table 4.5).

**Table 4.4. Summary of acoustic surveys – St. Helens Hill.**

| Survey instruments | Survey ID | Start time (local) | Duration (hours) | Survey Design | No. of transects | Comments |
|---|---|---|---|---|---|---|
| Pole, hull | SH1, SH2 | 19-07 16:53 | 2:05 | Grid | 5 | |
| Pole, hull | SH3, SH4 | 19-07 19:03 | 3:38 | Star | 6 | |
| Pole, MUFTI | SH5, SH6 | 19-07 23:00 | 5:59 | Grid | 5 | |
| Pole, MUFTI | SH7, SH8 | 20-07 5:34 | 9:00 | Star | 6 | |
| MUFTI | SH9 | 20-07 15:23 | 8:15 | Loop | 8 | |
| Pole, hull | SH10, SH11 | 24-07 12:00 | 7:23 | Star | 6 | |
| Pole, hull | SHl2, SH13 | 24-07 19:29 | 5:17 | Grid | 8 | Grid survey plus three repeat transects along 148.45 |
| MUFTI | SH14 | 25-07 2:58 | 6:30 | Loop and diagonal pass | 2 | Multifrequency. Not a complete formal survey |
| MUFTI | SH15 | 26-07 13:36 | 6:07 | Loop | 5 | |
| Pole, MUFTI | SH16, SH17 | 26-07 20:00 | 5:24 | Grid | 5 | |
| Pole, MUFTI | SH18, SH19 | 27-07 1:56 | 6:36 | Star | 6 | |
| MUFTI | SH20 | 28-07 5:58 | 5:24 | MUFTI drift | 1 | West side of St. Helens Hill |
| Pole, MUFTI | SH21, SH22 | 31-07 14:15 | 5:13 | Grid | 5 | Very large marks on SW and NW sectors |
| MUFTI | SH23 | 31-07 19:43 | 10:14 | Loop | 8 | |

**Table 4.5. Biomass estimates of orange roughy at St. Helens Hill at 38 kHz based on survey type (Grid, Star and Loop) and surface (Pole) and deep towed MUFTI transducer deployments (reasons for null values and ranges of values given in the text)**

| Survey ID | Survey type | Survey instrument | Date (local) | % Biomass above the deadzone | Biomass estimate. (tonnes) |
|---|---|---|---|---|---|
| SH5 | Grid | Pole | 19-Jul-99 | - | Null |
| SH7 | Star | Pole | 20-Jul-99 | - | Null |
| SH21 | Grid | Pole | 31-Jul-99 | 66-64 | 1885-4662$^{+}$ mean of ranges (3300) |
| SH6 | Grid | MUFTI | 19-Jul-99 | - | Null |
| SH8 | Star | MUFTI | 20-Jul-99 | 65 | 5186 |
| SH22 | Grid | MUFTI | 31-Jul-99 | 77-80 | 3548-6958$^{+}$ mean of ranges (5200) |
| SH9 | Loop | MUFTI | 20-Jul-99 | 66 | 2562 |
| SH23 | Loop | MUFTI | 31-Jul-99 | 58 | 1093 |

$^{+}$ two different interpretation scenarios of school classification

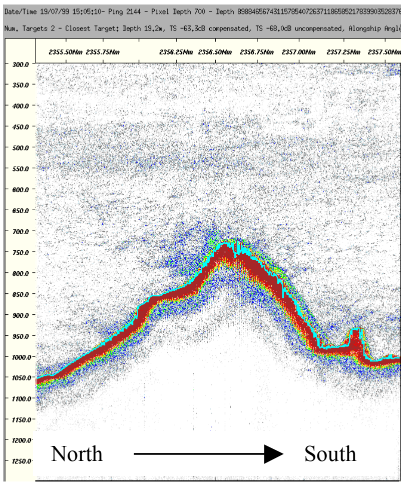
Results from the range of surveys undertaken at St Helens Hill are summarised (Table 4.5). There were zero values from both surface mounted (Pole) and deeply towed (MUFTI) surveys SH5, SH6, SH7 because these were schools-based estimates (relying on confident identification of orange roughy schools) and had no acoustic marks that were considered to be from orange roughy (Figure 4.6). The diffuse marks in these echograms highlight the uncertainty in identifying orange roughy schools with any confidence and are consistent with a low biomass of orange roughy.

In surveys where orange roughy were confidently identified but present as low numbers of fish in ill-defined marks (SH21 and SH22) the biomass estimate is given as the range representing the minimum and maximum extent of school area. The sensitivity of the estimates to species composition are shown for survey SH22 (Table 4.6). The maximum bound (scenario 4), where all school marks are assumed to be orange roughy (something that is not supported by any of the ancillary trawl and multi-frequency data) was 17 000 tonnes compared to the species identified estimate of 3500-6900 tonnes.

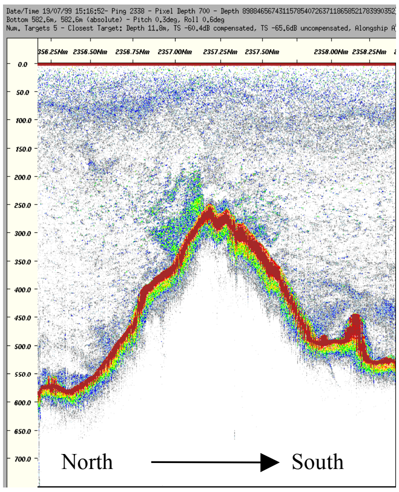
Inspection of the single frequency echo structure, the use of MUFTI, trawl data, fishers information and historical school locations gave a basis for the inclusion or otherwise of school marks in the echo-integration. Of these the MUFTI played the most significant role. The biomass estimates presented are the mean of the most plausible interpretation scenarios. There was insufficient data to determine whether a statistical difference in biomass existed between the Star and Grid survey designs, due mainly to the low levels of biomass observed on the ground and the uncertainty in defining schools.

**Figure 4.6. St. Helens Hill echograms for transects through the north west region where high catches of orange roughy occur. The echograms show transects from SH5, SH6, SH7, SH21 and SH22. The orange roughy schools included for analysis are marked.**

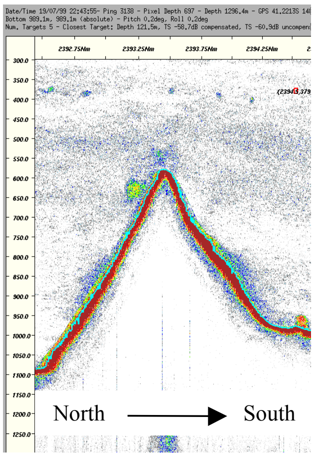
SH5, Transect 2 Grid Survey, Pole system 19th July



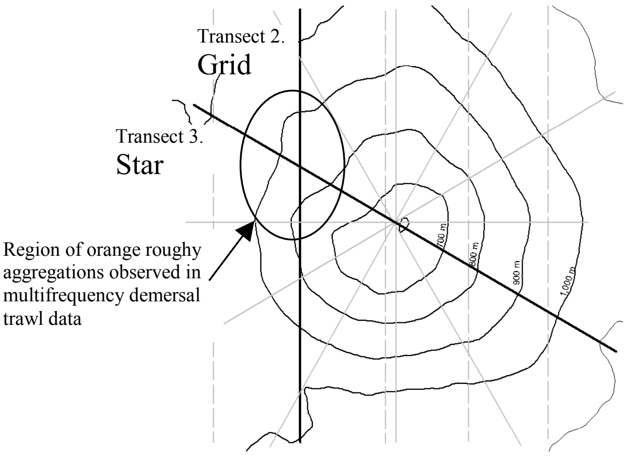

SH6, Transect 2 Grid Survey, MUFTI system 19th July



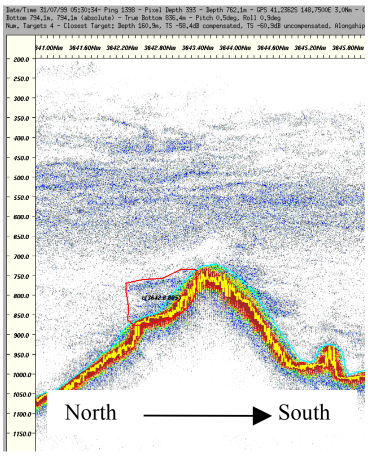

SH5, Transect 3 Star Survey, Pole system 19th July




Location of grid and star transects that went through the main area where orange roughy aggregations had been observed




SH21, Transect 2 Grid Survey, Pole system 31st July




SH22, Transect 2 Grid Survey, MUFTI system 31st July

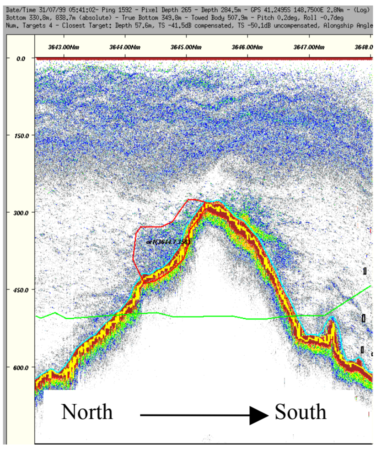


**Table 4.6. Sensitivity analysis of school structure to the biomass assessment for survey SH22.**

| Scenario | Biomass estimate (tonnes) | Comments |
|---|---|---|
| 1. Schools on the northwest sector only | 3500 | Supported by MUFTI, historically, by trawl information and school structure |
| 2. Schools on the northwest and northeast sector | 6900 | Supported by MUFTI. Would not have been included if not for MUFTI. |
| 3. Schools on the northwest and southwest sector | 13600 | Orange roughy school on the southwest corner is not supported by MUFTI but strong echostructure could lead to school being included if MUFTI were not available |
| 4. All school marks are due to orange roughy | 17000 | Not considered credible but included to highlight the upper bound of values. |

Results from the Loop surveys, in which the species composition of orange roughy marks was well defined by multi-frequency acoustics, showed that the biomass of orange roughy ranged from 1093 – 2562 tonnes. This is less than half the biomass calculated for the similar MUFTI Grid and Star surveys (for the case of the Grid survey we assume this to be 5200 tonnes, the mean of the range of plausible estimates, see Table 4.5).

There was no noticeable avoidance reaction by orange roughy when this was monitored for the Loop surveys SH9 (Figure 4.7). Avoidance is detected when the towed transducer is within 150 m of the orange roughy and the movement of the fish creates a void in the echogram that is reverberation-weak and quite distinct. Avoidance of the towed system by orange roughy was observed during survey SH23, and the lower estimate of orange roughy biomass may be influenced by this avoidance (Figure 4.8).

The above observations indicate that the low biomass values for the Loop surveys represent a credible result and that the biomass of schooling orange roughy on the grounds is very much less than previously estimated. They also show that the Loop survey method using multi-frequency acoustics is the method of choice to estimate the biomass of orange roughy in future years given the small size of the stock there.

**Figure 4.7.** **Frequency mixing for identification of acoustic species at St. Helens Hill. The red is associated to 12 kHz and is dominated by large gas bladdered species; green is associated to 38kHz and is dominated by small gas bladdered lanternfishes (myctophids); blue is associated to 120 kHz and is relatively strong for orange roughy. The combined frequency echogram clearly shows the difference between the frequencies and the school of orange roughy blue/green and the distribution of large and small gas bladdered fishes.**

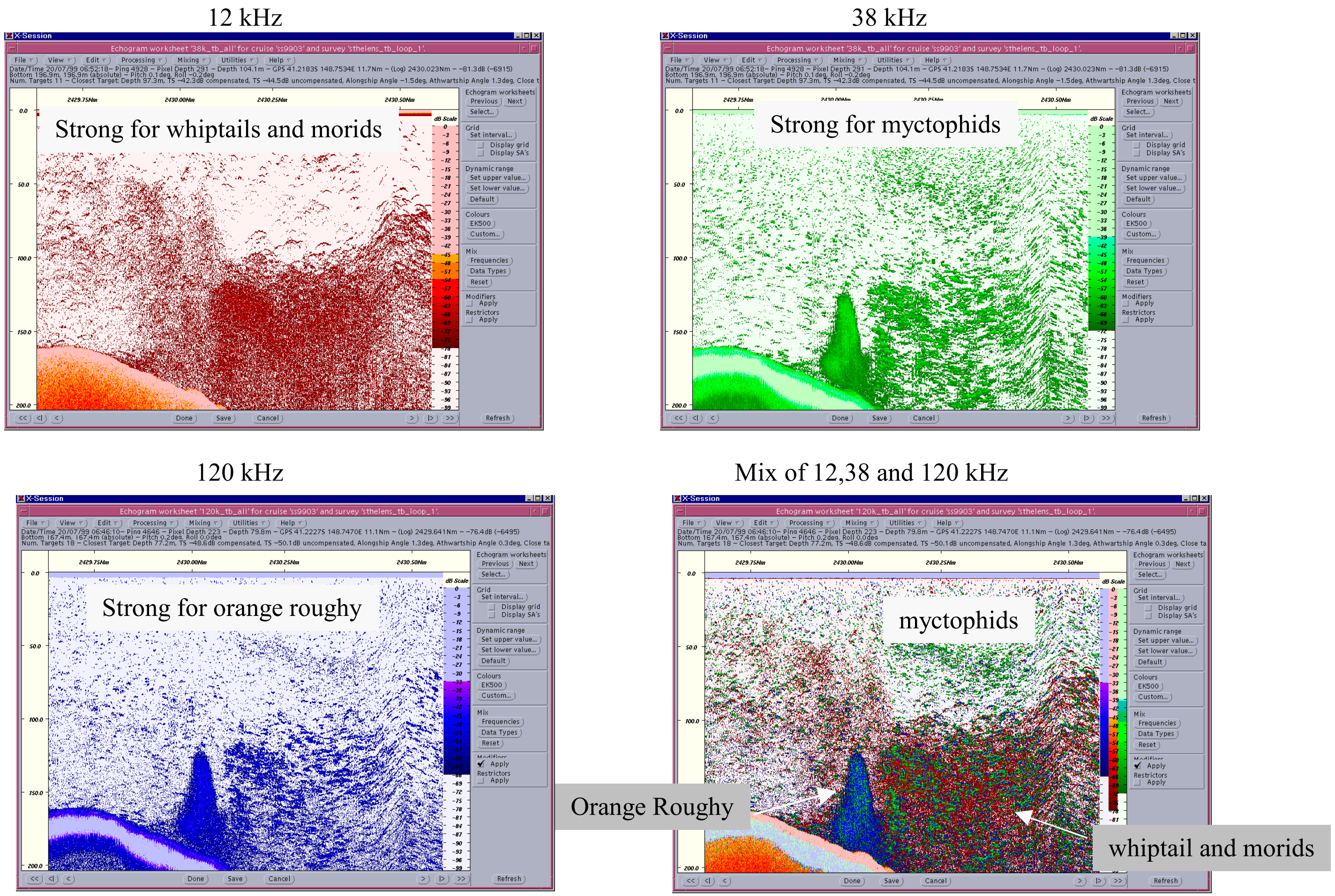
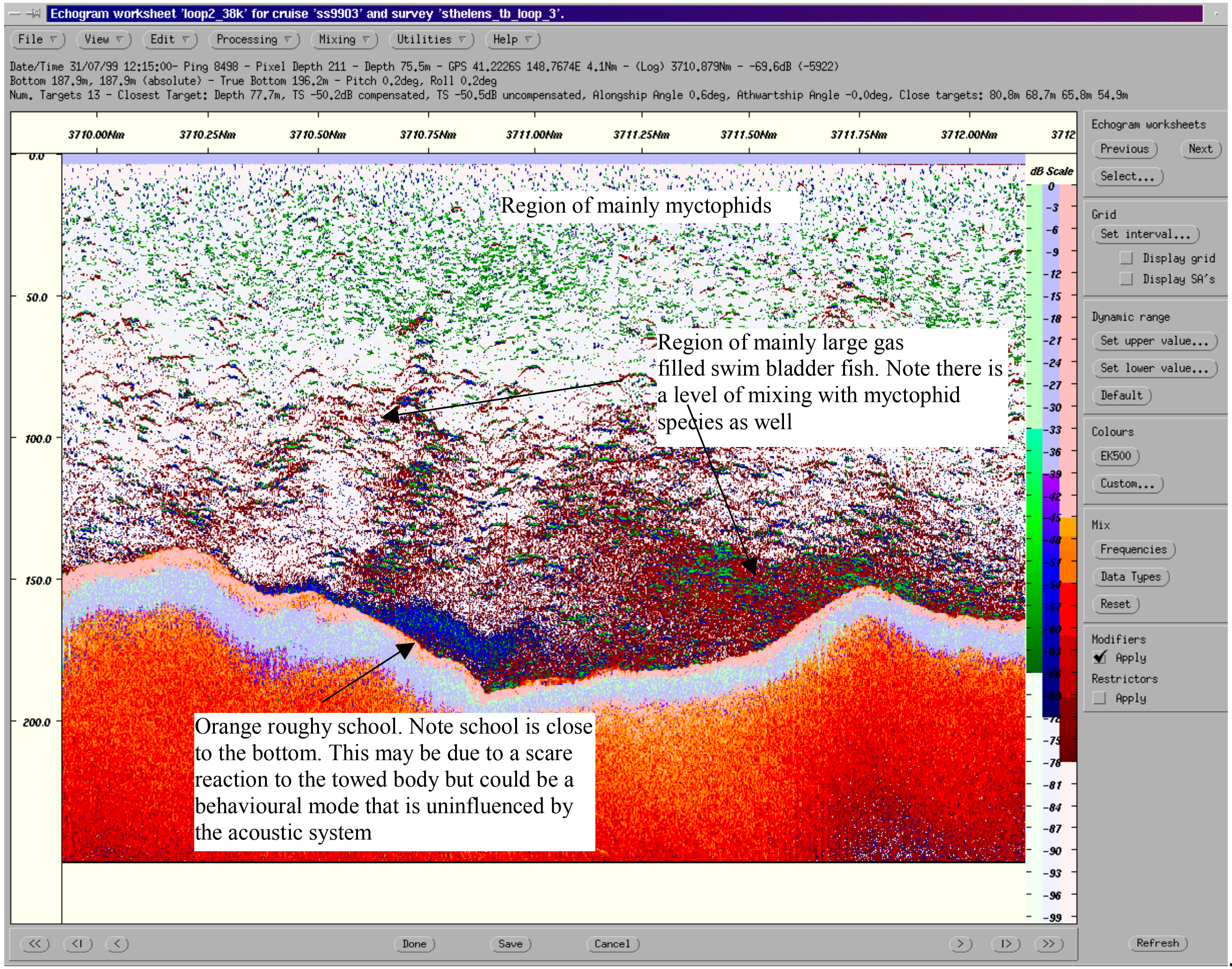


**Figure 4.8 Multifrequency visualisation of three frequency (12, 38 and 120kHz) echogram data from Loop survey SH23, transect 2 showing an orange roughy school close to the bottom in what may be a scare reaction to the acoustic system**



**Schools based time series for St. Helens Hill**

The Grid and Star survey results from the surface and deeply towed transducers can be compared to the time series of acoustic data 1990 – 1996 (Kloser and Ryan 1999). This shows that the biomass of orange roughy on St. Helens Hill has declined to 3300 and 5200 tonnes for the vessel and towed transducers respectively. This represents a reduction in biomass from 1996 of 50% and 45% respectively (Table 4.7), and has occurred at a time when the stock is expected to be in the rebuilding phase (Bax 1997).

**Table 4.7. Summary of school based echo integrations (1990-1999) using data from Kloser and Ryan (1999).**

| Survey | 38kHz Transducer | Total Biomass (tonnes) |
|---|---|---|
| 1990 | Vessel mounted | 38600 |
| 1991 | Vessel mounted | 29500 |
| 1992 | Vessel mounted | 20100 |
| 1993 | Vessel mounted | 8100 |
| 1996 mean of two surveys | Vessel mounted | 6600 |
| 1999 mean of two scenarios | Vessel mounted | 3300$^{+}$ |
| 1991 | MUFTI | 27800 |
| 1992 | MUFTI | 31000 |
| 1993 | MUFTI | 10500 |
| 1996 mean of two surveys | MUFTI | 9300 |
| 1999 mean of three scenarios | MUFTI | 5200$^{++}$ |

\+ Based on two scenarios for survey SH21. 1999 result is corrected for TVG error. 1990-1996 vessel mounted results presented here have not been corrected for TVG error. If corrected the 1990-1996 values would be approximately 20% higher.

++ Based on mean of three numbers: The Biomass estimate for Star survey SH8 and two different interpretation secnarios for Grid survey SH22. 1999 result is corrected for TVG error. 1990-1996 vessel mounted results presented here have not been corrected for TVG error. If corrected the 1990-1996 values would be approximately 10% higher.

### 4.3.3 St. Patricks Head Biomass Estimates

The dates and types of surveys conducted at St. Patricks Head are outlined (Table 4.8). In summary, detailed biomass surveys using *Southern Surveyor* were undertaken on the 18$^{th}$, 22nd, 23rd and 29$^{th}$ of July. Visual analysis of all the acoustic surveys were undertaken to provide an understanding of the data quality and dynamics of the fish schools and four surveys were selected for detailed analysis. These four surveys were characterised by high data quality, good spatial coverage and generally well-supported species identification. Estimates of biomass of orange roughy on the ground from these four surveys are detailed (Table 4.9). The biomass results need to be treated with some caution as the school identification process was difficult due to the dispersed distribution of orange roughy over the fishing ground at certain times. For this reason the vessel mounted data was analysed twice to give an upper and lower bound on the biomass estimate. On the first analysis of single frequency vessel mounted data, multifrequency information was used to assist in the process of defining schools and deciding species type. This procedure is likely to overestimate the vessel mounted biomass estimates; as discussed in Chapter 7, the vessel-mounted estimates using this procedure can be as much as 6.4 times higher than the multifrequency estimate. For the second analysis the multifrequency information was ignored so that only schools that were well aggregated and clearly definable were defined. This estimate from the second analysis represents a lower bound but also is more readily compared to the 2001 industry biomass estimates that had no multifrequency data to assist in interpretation.

For both the 1999 and 2001 seasons, the vessel mounted acoustics could only clearly distinguish from the backscatter the strong aggregations of roughy found at the northern end of St Patricks Head (i.e. “Rock Wall” and “Milk Run” regions) while only the MUFTI system was able to measure the weaker aggregations of roughy at other parts of the ground. For the 1999 season, MUFTI surveys SP6 and SP18 were post-stratified into transects that were either inside or outside the region where vessel mounted acoustics had readily distinguished roughy schools. The school backscatter signal outside the main aggregating region was 36% and 38% for surveys SP6 and SP18 respectively. This is an important result that should be considered for any future monitoring program that uses vessel mounted acoustics alone; that is a very significant proportion of biomass can exist in regions where vessel mounted systems cannot confidently distinguish schooling orange roughy. Further, if only vessel-mounted systems are used it may be possible for measured aggregations to remain stable while a decline or increase in the total stock remains undetected.

**Table 4.8. Summary of acoustic surveys at St. Patricks Head using both the vessel mounted pole transducer and the deep towed MUFTI system.**

| Survey instruments | Survey ID | Start time (local) | Duration (hours) | Survey Design | No. of transects | Comments |
|---|---|---|---|---|---|---|
| Hull | SP1 | 18-07 4:21 | 6:24 | Grid | 8 | |
| Hull, MUFTI | SP2, SP3 | 18-07 11:29 | 5:15 | North South | 3 | MUFTI tows along contour lines |
| MUFTI | SP4 | 18-07 17:20 | 3:36 | Mufti Tow | 2 | |
| MUFTI | SP5 | 18-07 21:20 | 2:10 | Zig zag | 3 | Mufti Mode |
| MUFTI | SP6 | 18-07 23:55 | 8:06 | Grid | 6 | Mufti Survey |
| MUFTI | SP7 | 19-07 8:28 | 2:45 | tb drop | 2 | TS/Calibration work |
| MUFTI | SP8 | 22-07 5:05 | 6:40 | Grid | 5 | Mufti survey. Logging failed on one transect. |
| MUFTI | SP9 | 23-07 13:17 | 10:13 | tb drop/tb survey | 5 | |
| MUFTI | SP10 | 24-07 6:26 | 3:53 | TB drop | | |
| Pole, Hull | SP11, SP12 | 25-07 21:36 | 4:20 | reconnaissance survey | 2 | |
| MUFTI | SP13 | 26-07 3:06 | 6:20 | tb mufti tows | 3 | |
| Pole, Hull | SP14 | 29-07 9:38 | 3:52 | Grid | 9 | |
| MUFTI | SP15 | 29-07 17:15 | 3:05 | tb mufti drift | 1 | |
| Pole, Hull | SP16/SP17 | 29-07 22:33 | 5:17 | Grid | 10 | |
| MUFTI | SP18 | 30-07 7:45 | 9:10 | Grid | 4 | 3 E-W transects plus run N-S along ridge line |
| MUFTI | SP19 | 30-07 19:18 | 4:57 | absorption experiment | 1 | |
| MUFTI | SP20 | 31-07 14:03 | 2:12 | TB drop | 1 | Towed body drop on roughy and transducer calibration. |

**Table 4.9. Biomass estimates from grid survey**

| Survey ID | Survey instrument | Date (local) | Biomass estimate. Lower Bound (tonnes) | Biomass estimate. Upper Bound (tonnes) |
|---|---|---|---|---|
| SP1 | 38kHz Hull | 18-Jul-99 | 1780 | 14815 |
| SP6 | 38kHz MUFTI | 18-Jul-99 | - | 14773 |
| SP16 | 38kHz Pole | 29-Jul-99 | 5830 – 15912 | 5830 – 15912 |

Orange roughy aggregations were particularly dispersed during surveys SP1, and SP6 making accurate school definition difficult. The very low, lowerbound value for survey SP1 may be due to the fish being so dispersed that they were beyond the limits of detection by the vessel mounted system. Catch data suggested that regions identified as orange roughy schools also contain a proportion of higher reflectance by-catch species, which bias biomass estimate upwards. Due to the limited detailed multi-frequency data available the magnitude of the bias is unknown, but we interpret the biomass estimates as an upper bound of for orange roughy on the St. Patricks ground.

This view is supported by the small (1.0 – 0.9 factor) difference between upper bound estimates from the vessel mounted system (14800 – 15900 tonnes) and the deeply towed MUFTI (14800). Typically we note a 1.6 factor difference between vessel mounted and deeply towed surveys (Kloser, 1996). The small difference between these surveys points to an over estimation of school size consistent with the inclusion of high reflectance bycatch species for the vessel mounted surveys. This bias is inherent with vessel mounted systems where defining of schools is difficult.

The influence of high reflectance by-catch species is removed to a large extent by using the deeply towed MUFTI system for species identification in visualised mixed 3-frequency echograms (Figure 4.7). Thus, the schools for the MUFTI data could be precisely defined with little influence from bycatch species.

The MUFTI survey SP6 ($18^{th}$ July) of 14800 tonnes represents our best estimate of orange roughy on the grounds at the time of the survey based on several considerations:

The MUFTI towed systems offers the advantages of increased signal to noise, lower dead-zone uncertainty, less affect from adverse weather, greater digitising resolution and lower potential for error in the seawater absorption calculation.

Three-frequency MUFTI data enabled precise discrimination of orange roughy schools.

There were a suitable number of transect lines.

The timing of the survey was well placed in relation to the build up and decline of the stock.

## 4.4 Conclusions

The relative biomass of orange roughy at St. Helens Hill was estimated to be 3300 tonnes and 5200 tonnes from the Southern Surveryor vessel mounted and towed transducers respectively. This represents a reduction of orange roughy biomass at this ground of 50% and 45% when compared to the 1996 survey for vessel and towed transducers respectively. This reduction in biomass is occurring at a time when the stock is expected to be rebuilding (Bax 1999).

The small size of the orange roughy stock at St. Helens Hill is making vessel mounted surveys very sensitive to school identification. We consider that vessel mounted acoustics are no longer a viable method to survey orange roughy at St. Helens Hill.

The multi-frequency Loop survey at St. Helens Hill produced a school biomass of 2200 tonnes, and due to improved species identification by multi-frequency acoustics, is most likely to represent the best absolute estimate of stock size.

The MUFTI surveys at St Patricks Head indicated that over 35% of the biomass existed in regions where the vessel mounted acoustics could not clearly distinguish orange roughy. Any future acoustic monitoring program should therefore be aware that a significant proportion of the total biomass cannot be measured using existing vessel-mounted acoustic technology. The immeasurable component of the biomass could be a large source of uncertainty when trying to monitor changes to the total biomass.

A relatively large aggregation was surveyed at St. Patricks Head; our provisional biomass estimate based on MUFTI grid survey SP6 is 14 800 tonnes. But while the school was persistent, it was also spatially dynamic (mobile). Further surveys are needed to clarify the size of the stock because of the uncertainty in estimates stemming from school mobility.

# 5. SENSITIVITY AND PRECISION OF COMMERCIAL AND SCIENTIFIC ECHOSOUNDER SYSTEMS FOR DEEP WATER STOCK ASSESMENTS

Tim Ryan and Rudy Kloser

## 5.1 Introduction

This chapter addresses objective 3 of this study, that is "to compare the sensitivity and precision of acoustic surveys using scientific vessel-mounted and towed-body acoustic and industry vessel-mounted acoustics". It describes the method and results of a comparison between our scientific acoustic systems and a commercial fisheries system installed on the *Southern Surveyor*. Our aim is to highlight the difficulties and necessary considerations when using scientific and industry acoustics to monitor orange roughy abundance.

### 5.1.1 Background

Historically, acoustic biomass surveys of orange roughy at St. Helens Hill have been performed using scientific research vessels and equipment. Over the last decade, CSIRO has developed scientific acoustic systems and techniques to overcome or minimise many of the problems encountered when working on deep-water species. Specifically, the use of a pole-mounted transducer has improved the data quality and the ability to operate in marginal weather conditions. The pole can be lowered 3.5 metres below the vessel's hull reducing acoustic attenuation from near-surface bubbles. The development of MUFTI (Multiple Frequency Towed Instrument), a deep-towed acoustic system, significantly improved survey precision (Kloser 1996). By deeply towing an acoustic system the effects of ship's motion and attenuation due to near-surface bubbles are greatly reduced or eliminated (Kloser 1996). Deep-towing the system reduces the range between transducer and target. Accordingly, this reduces range-dependant effects such as absorption of sound in seawater, the sampling volume and dead-zone height (Kloser 1996).

The MUFTI system can operate at three frequencies simultaneously and when deep-towed can bring orange roughy within the effective working range of all frequencies. A software package, ECHO, was developed for acoustic data collection and quality assurance. This software is used for visualisation and echointegration of the acoustic data. The package was further enhanced to enable visualisation of multifrequency data, which has proved to be a very effective tool for interpreting echograms to distinguish between regions of orange roughy and bycatch species (Kloser et. al. 1998 and see also chapter 7).

While there are significant technical advantages with cruises that use these systems, they are costly to run and complex to organise. This becomes a limiting factor on the duration and frequency of orange roughy acoustic surveys. Industry vessels have the potential to greatly reduce the cost of acoustic biomass surveys by using their installed commercial fisheries sounder. Additionally surveys from an industry vessel offer the following advantages:

- Industry vessels are likely to be on the fishing ground during the peak spawning period so that well-timed formal acoustic surveys can be carried out with minimum extra effort.
- Greater temporal coverage.
- Possibility of having a survey each year.
- Recording of echogram along trawl shot lines.

In spite of these considerable advantages, there are also a number of limitations with present commercial acoustic systems that may mean that they are not adequate for surveying a deepwater species such as orange roughy. This was evaluated by comparing the performance of the commercial and scientific echosounder systems installed on the *Southern Surveyor* to determine if commercial acoustic systems can be used for quantitative acoustic surveys of orange roughy. Specifically, we assessed:

- System signal-to-noise
- Deadzone height
- Dynamic range
- Signal degradation due to bad weather and pitch/roll signal loss
- Sidelobe interference
- Interpretation of echogram information
- Sampling volume
- School dimension measurements
- Calibration accuracy (on-axis and beam pattern)

The latter two points were not measured in this study but are discussed.

## 5.2 Acoustic Equipment

Three acoustic systems installed on the *Southern Surveyor* were compared in this study, these were:

- EK500 scientific echosounder with 38kHz split-beam pole-mounted transducer, “The Pole System”.

- EK500 scientific echosounder with 38kHz split-beam deep-towed transducer, "The MUFTI System" (Multiple Frequency Towed Instrument).

- Furuno fisheries echosounder with 28kHz single beam hull-mounted transducer. Data was recorded by Echolistener digitiser and logging system, "The Commercial System".

The Commercial system was similar to the one that was being used aboard the industry vessel *Saxon Progress*; this will allow the findings of this study to be transferred to industry vessels using similar commercial fisheries echosounder systems. For further details of acoustic sampling equipment refer to Chapter 2. Commercial fisheries echosounders with improved performance characteristics such as the Simrad ES60 have been used since this 1999 study was undertaken. Having a high signal to noise, large dynamic range and a narrow-beam, split-beam transducer these systems should have a performance that is comparable with the Pole system.

The main specifications of the three systems are shown (Table 5.1).

**Table 5.1. Comparison of key parameters of the three echosounder systems.**

| | Scientific systems | | |
|---|---|---|---|
| | MUFTI System | Pole System | Commercial System |
| Frequency | 38 kHz | 38 kHz | 28 kHz |
| Echosounder | EK500 (ver 5.3) | EK500 (ver 5.3) | Furuno |
| Digitising system | EK500 (ver 5.3) | EK500 (ver 5.3) | Echolistener |
| Dynamic range (dB re 1 W) | 160 | 160 | Instantaneous: 72 Total 112 |
| Split beam transducer | Yes | Yes | No |
| Deepwater Multifrequency capability | Yes | No | No |
| Transducer beamwidth (degrees) | 6.5 | 7.3 | 14 |

## 5.3 Methods of measuring system performance parameters

For selected acoustic surveys at St. Helens Hill the MUFTI, Pole and Commercial systems were operated concurrently thus allowing the performance of the systems to be directly compared. Specific performance parameters were measured for a subset of selected transects.

### 5.3.1 System signal-to-noise measurement

For the Scientific systems, the noise level was measured by integrating a clear region of echogram below the seafloor (Kloser 1996).

No absolute noise measurement could be made for the Commercial system, as this system was uncalibrated. As an alternative measure, echogram screen-gain was increased until the noise floor became apparent; the depth at which this occurred was then noted. This noise floor depth defines the effective working range of the system. The same method was applied to the Scientific systems to allow direct comparison.

### 5.3.2 Interpretation of echograms

Echo-integration of the acoustic return signal relies on interpreting information in echograms, especially distinguishing marks that are orange roughy and differentiating these from marks due to bycatch species. Interpretation is potentially the single largest source of error unless the schools are large and/or intense. To evaluate differences between systems, we examined an example transect that had a sizeable aggregated orange roughy school measured concurrently by the MUFTI and Commercial systems. The echograms were inspected and a qualitative discussion made regarding their interpretation.

### 5.3.3 Signal degradation due to bad weather

A visual inspection of echograms from selected transects was made and a qualitative assessment made of the effect of weather on the data quality. Transects were selected to demonstrate:

- Examples of the greatest difference in quality between the systems.
- Some subtle artefacts.
- Good data quality on all three systems.

### 5.3.4 Sidelobe interference from nearby features

The wider beam Commercial system is more likely to be susceptible to sidelobe interference from nearby bathymetric features. Echograms were inspected for instances where sidelobe interference was observed on the Commercial but not the Scientific systems.

### 5.3.5 Deadzone height measurements

The spherical nature of the acoustic wavefront means that there will be a time delay between the central and outer beams of the signal striking the seafloor. This time delay converts to a distance that is referred to as the deadzone height: a zone that starts at the true seafloor depth and goes some distance into the water column, where it is impossible to distinguish the return water column signal of fish from that of the seafloor. Deadzone height is greater on sloping ground because there is a larger range of seafloor depth in the beam.

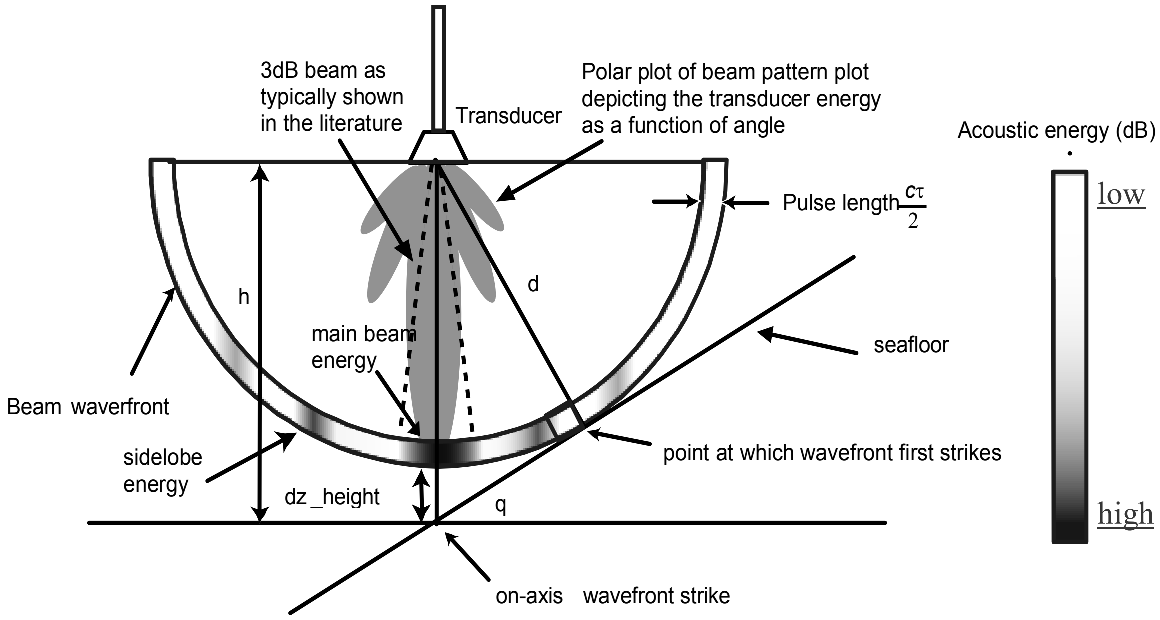
**Theoretical deadzone measurements.**

The mechanics of an acoustic wavefront striking a sloping seafloor are shown (Figure 5.1). It shows the energy-domain information of the beam pattern with a time-domain diagram of a spherical wavefront emanating from a transducer, and an acoustic pulse spreading uniformly in time in a spherical manner from the transducer. Also depicted is the transducer beam pattern which determines how much energy there will be in at any point in the spherical wavefront. The manner in which the beam pattern concentrates most of the energy into the central beam is what gives the impression of a cone rather than a sphere of spreading energy. Indeed, diagrams in the literature usually depict only the central beam while some models of deadzone height have also only considered the central beam (Ona and Mitson 1996). If mistakenly interpreted, polar plots of transducer beam pattern can also lead to misconceptions. These charts are in the energy domain and contain no information as to the temporal nature of the beam spreading.

If the seafloor slope and transducer beam pattern were known, the wavefront striking the slope could be modelled and thus a precise theoretical deadzone height determined. The beam pattern is complex and unique for each transducer; modelling the precise theoretical deadzone height would not be a trivial process and would have to be redone for each transducer. More work is required in this area but this is beyond the scope of this report.

The model presented here calculates a theoretical worst case of deadzone height based on a spherically spreading acoustic wavefront. It is acknowledged that because a transducer concentrates energy into a main central beam as a function of its beam pattern the amount of off-axis energy that would increase the deadzone can be dramatically reduced. Therefore, in practice, the deadzone should be something less than our theoretical worst case calculations. Scientific transducers with narrow beams and less energy in the side-lobes will be more effective in reducing the deadzone than commercial fisheries transducers that have wide beams and ill defined side-lobes. Note that this simple model is for sloping ground and does not account for the small deadzone height that occurs on flat ground due to the spherical nature of the beam's wavefront (Ona and Mitson 1996).

**Figure 5.1 Modelling of deadzone height based on a spherical wavefront hitting a sloping seafloor with the acoustic energy contained within (as determined by the transducer beam pattern) shown in greyscale.**




Based on Figure 5.1 the deadzone height is calculated as:

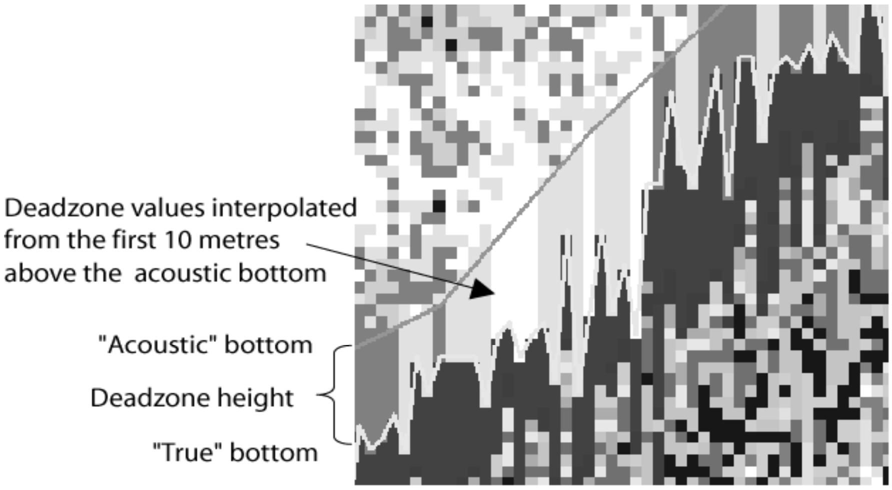
$$dz\_height = \left(\frac{d}{\sin(90-q)} - d\right) + \frac{c\tau}{2} \quad \text{(m)} \qquad 5.1$$

Where τ is the pulse length, *q* the slope of the seafloor, *d* is the shortest distance to seafloor, *h* the on-axis distance to seafloor and *c* the speed of sound in water.

**Experimental Deadzone Measurements**

Experimentally we measure the deadzone height as the distance between the "true" bottom (peak of return signal minus half the pulse length) and the "acoustic" bottom (the point at which the seafloor is first struck by the wavefront). Using ECHO software on a selected transect the "true" and "acoustic" bottoms were marked and the mean difference between the two measured for selected transects (Kloser 1996), (Figure 5.2).

**Figure 5.2 Section of echogram showing how the deadzone is estimated**




## 5.4 Results and discussion of system performance parameters

At St. Helens Hill the MUFTI, Pole and Commercial system data were logged concurrently during the 27th of July Star pattern survey. Transects 1, 2 and 4 were selected for analysis to assess the performance of each acoustic system. The echograms for these transects were inspected and qualitative comparisons made regarding the performance of the systems in various sea conditions. For a sample transect, the signal-to-noise for each system was assessed and measurements of the deadzone height made. To allow a qualitative discussion about the interpretation of echograms an example transect that contained a sizeable orange roughy school was chosen from the 29th of July survey at St. Patricks Head.

### 5.4.1 Signal to noise measurements and effective working range of the acoustic systems.

An acoustic survey at St. Helens Hill on the 27th of July was carried out with the MUFTI, Pole and Commercial systems running concurrently. The signal-to-noise of the Scientific acoustic systems was measured but this measurement could not be made for the Commercial system as it was uncalibrated. As an alternative the effective working range was measured. For the Scientific systems the noise floor depth (i.e. the effective working range) was below that of the maximum echogram range; the effective working range was therefore not a limitation with the scientific systems. The noise floor for the Commercial system first appeared at 1150 metres, which was well below the depths of interest, (Table 5.2).

**Table 5.2 Signal-to-noise measurements for 27th of July St. Helens Hill Star survey, transect 2**

| | Towed Body | Southern Surveyor Pole Mounted | Southern Surveyor Commercial Sounder |
|---|---|---|---|
| Signal to Noise (Sv dB re 1m) | -150.7 | -161.9 | Not calibrated |
| Echogram range setting (metres) | 700 | 1200 | 1200 |
| Effective range before noise becomes a factor (metres) | >700 | >1200 | >1150 |

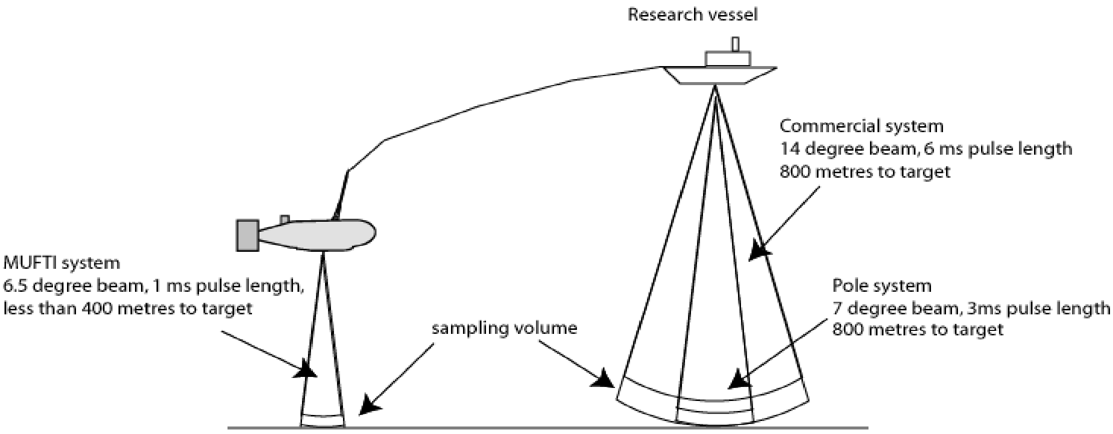
In summary the Commercial and both the Scientific systems were able to record digitised acoustic data with an acceptably low signal-to-noise.

### 5.4.2 Interpretation of echogram information

Interpretation of school composition from echogram information is potentially a large source of error because orange roughy have a comparatively low acoustic reflectance compared to many co-occuring bycatch species. Reflectance is determined by changes in impedance, and the principal internal structure of fishes governing impedance change is the swimbladder. Fishes with large gas-filled bladders present considerably higher acoustic targets than those with wax-ester filled bladders (including orange roughy) or that lack swimbladders, eg sharks. Four groups of fishes that commonly occur with orange roughy are relatively highly reflective due to the strucutre of their swimbladders: oreos, whiptails and morid cod on the bottom and in the near-bottom water column, and lanternfishes (mytophids) through the deep water column. For example, morid cod with a very large gas-filled swimbladder present a target that may be as much as 79 times that of an orange roughy (Kloser et. al. 1997). Because of these large differences, echo-integration results are highly sensitive to the decision rules applied to categorising regions of echogram as either orange roughy or bycatch. However, the use of multi-frequency data in conjunction with single-frequency echograms is increasingly raising our level of confidence in school identification.

Confident interpretation of single-frequency echograms relies on having sufficient fine-structure detail and this is related to the acoustic sampling volume. A wider beamwidth, longer pulse length and greater distance to target will all increase the sampling volume (Figure 5.3 and Table 5.3).

**Figure 5.3. Diagram of acoustic beams for the three systems showing how sampling volume of the 3dB beam is proportional to beamwidth, pulse length and distance to target.**




Visualising the multi-frequency data from the MUFTI system Multi-frequency echogram interpretation using the ECHO software is a very effective tool for interpreting regions of echogram. The multi-frequency data can clearly distinguish between regions of schooling orange roughy and bycatch species as well as regions where there is a mix of species (Figure 5.4c). It is difficult to make these distinctions confidently with single frequency systems.

**Table 5.3 Factors contributing to 3dB acoustic beam sampling volume assuming they relate to the transducer beamwidth.**

| System | 3dB Beamwidth (degrees) | Pulse length (m) | Distance to target (metres) | Cross-sectional distance of footprint (m) | Sampling volume ($m^3$) + | Echogram interpretation |
|---|---|---|---|---|---|---|
| Commercial | 14 | 9* | 800 | 200 | 270000 | Most difficult |
| Pole | 7 | 4.5 | 800 | 100 | 34000 | Second most difficult |
| MUFTI | 6.5 | 1.5 | <400 | 50 | 2800 | Easiest |

* Estimated pulse length from the echogram. Furuno system changes pulse length automatically when autoranging.

+ Appendix G has the calculations for the acoustic sampling volume

How does sampling volume (related to the size of the acoustic ‘footprint’) affect the data acquisition by the systems used in this survey? The 3dB point footprint size of the Commercial system is double that of the Pole system and four times that of the MUFTI. In terms of sampling volume, the Commercial system is roughly an order of magnitude greater than the Pole system and two orders of magnitude greater than the MUFTI system. To put these measurements into perspective, for the commercial system’s sampling volume imagine a cylinder whose cross-sectional area is larger than the MCG football ground (170 m x 150 m) with a height about 1 metre less than the main goal posts (10 m).

Clearly, the problem with large sampling volumes is that echo-integrating defined schools assumes that the area defined as a school contains only one species - orange roughy. Given the large sampling volume of the Commercial and even the Pole system it is probable that a proportion of bycatch species are also ensonified. Since many of these species are more reflective than orange roughy, the effect will be to upwardly bias the estimate of school biomass.

### Examples of interpreting single-frequency acoustic data

Figure 5.4a shows the single-frequency 38kHz MUFTI data. In this case, the high quality data had sufficient detail to easily discriminate the main body of schooling orange roughy from the bycatch species. There is a region of dispersed signal at the end of the transect that is harder to interpret; this highlights that high quality single frequency data has limitations. The multi-frequency data were able to identify this region as mixed-species.

Interpretation of the Commercial data for the same transect (Figure 5.4b) is not as straightforward. The boundaries between roughy and non-roughy regions are ill-defined. Orange roughy school definitions would almost certainly include significant contributions from by-catch species. In this example the sidelobe interference is a major problem. Firstly, this interference must be identified as such and not be attributed to fish. Secondly, it is difficult to determine where the sidelobe interference ceases, if at all, and schooling fish commence. This example of Commercial data would need MUFTI and/or trawl catch data to support interpretations but even then the potential uncertainty is high.

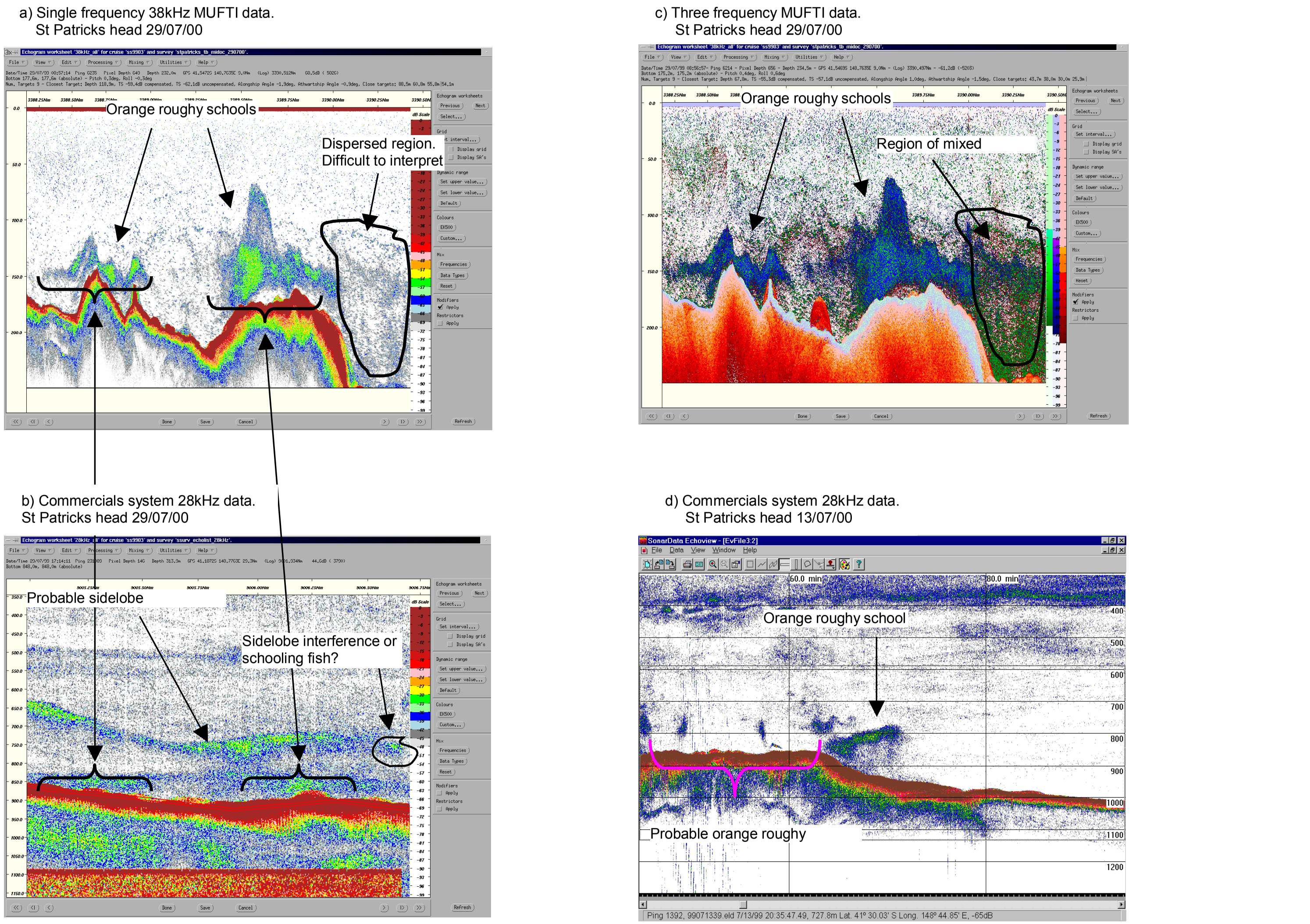
The Commercial data is not always as difficult to interpret. (Figure 5.4d) shows schooling roughy at St. Patricks Head on the 13$^{th}$ of July. The roughy are sufficiently aggregated to allow a clear distinction to be made between them and the surrounding bycatch species. The school is also sitting a distance above the acoustic bottom so that in this case it is unlikely that there is a significant amount of fish in the deadzone region. A demersal trawl targeted this school and caught 30 tonnes of orange roughy at this time.

### Improving interpretations using trawl catches and commercial fishers observations

Trawl catch data provide essential ground truth information that help confirm interpretations. To be used effectively it is critical that the location of the trawl touchdown and sweep be estimated as accurately as possible. Care needs to be taken with the method used to estimate trawl position to ensure that it is robust and used in a consistent manner between the various observers and surveys.

Our own interpretations of the acoustics could be significantly enhanced if the fishing vessel skipper's interpretation of echograms were formally recorded. To date this has not been done. This is a prime opportunity to utilise the experience of the skipper and to involve them in the process of quantifying the state of the fishery. It would be instructive to correlate the skipper's echogram interpretations with what comes up in the trawl. It is recommended that a method be devised to formally record the skipper's interpretations.

## Figure 5.4. Interpretation of echograms for the MUFTI and Commercial systems at St. Patricks Head, 29/07/1999 08:40



### 5.4.3 Signal degradation due to bad weather and pitch/roll signal loss

The effect of weather on data quality is shown by transect echograms from three acoustic systems when the vessel was ‘beam-on’ and ‘into the weather’ respectively (Figures 5.5 and 5.6). Echograms from transect 4 were recorded while the vessel was beam onto the swell with a 20 knot wind blowing (Figure 5.5). The Commercial system data was severely degraded by aeration under the vessels’ hull and would not be suitable for quantitative work (Figure 5.5a). The 38kHz Pole data shows a significant improvement over the Commercial system: there is a small number of noise spikes but the quality of the echogram is acceptable (Figure 5.5b). The 38kHz data from the MUFTI system is the best of the three systems and has no obvious indication of aeration or noise spikes (Figure 5.5c).

The data quality is at its highest when running with the weather but is may also be acceptable when running into the swell (Figure 5.6). An example is of this is seen in Transect 1 in which the Commercial system data show some subtle but significant artefacts (Figure 5.6a). At the far end of the transect there is a sudden dropout in the acoustic signal and the backscatter near the seafloor ceases to be seen. There is a series of moderately strong noise spikes about one-third the way along the transect that would need to be excluded from any echo-integration.

These comparisons show that the Commercial system data are more sensitive to poor weather but can be acceptable in certain circumstances, such as recording data while running with the swell. The survey design may need to be adjusted in bad weather so that all transects run with the swell or at least in a direction that is favourable to obtaining acceptable quality data.

#### Pitch/Roll Signal Loss

The signal loss due to aeration and platform movement was not modelled for the systems in this study, however, this has been done in a different study for a similar Pole and MUFTI arrangement (Kloser et al, 1999) (Table 5.4).

**Table 5.4 Signal loss due to platform motion and aeration (Kloser et al, 1999)**

| Transect description | Signal loss |
|---|---|
| MUFTI into the sea | 18% |
| Pole into the sea | 51% |
| MUFTI with the sea | 11% |
| Pole with the sea | 32% |

These data show that the amount of signal loss on a vessel-mounted system is also highly dependent on the sea conditions at the time of survey and on the direction of the vessel in relation to the sea direction. The design of the vessel and location of the transducer will fundamentally affect the signal loss in various sea states: in the above example, with the systems on a relatively stable factory trawler platform, the amount of signal loss was high (over 50% for the worst case). This needs to be accounted for in any relative or absolute acoustic biomass estimates.

The Commercial system transducer that has a wide beam will have a lower signal loss due to platform movement when compared to a narrow beam system. However, in practice this advantage may be negated by the fact that fishing vessels such as those in the SEF typically have a large pitch/roll movement compared to larger scientific research vessels.

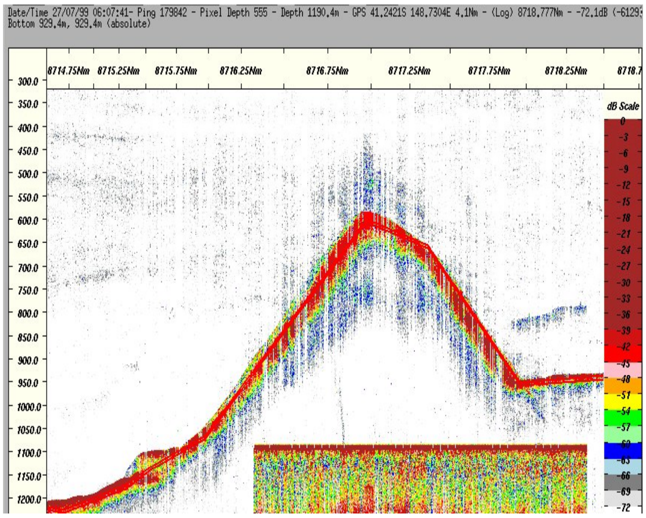
### 5.4.4 Sidelobe interference from nearby features

The contribution of sidelobe interference is demonstrated in an example from Transect 1 (Star survey at St. Helens Hill on July 26$^{th}$). At the start of the transect there is a portion of Commercial system echogram that could be mistaken for a fish school (Figure 5.6a). Closer inspection of this and the corresponding 38kHz Pole echogram (Figure 5.6b) and consideration of the topography of the region leads to the conclusion that what is being seen is sidelobe interference from the side of St. Helens Hill. This effect is seen only in the Commercial system data as this system has a transducer with a much wider (14-degree) beamwidth and larger sidelobes.

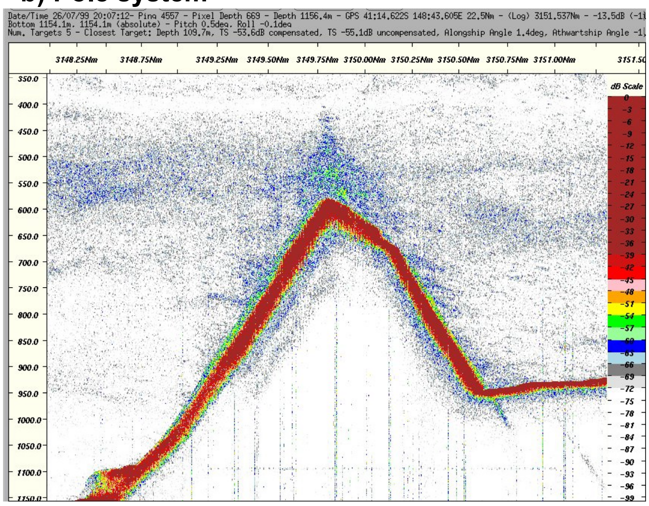
The possibility of sidelobe interference needs to be evaluated for all data from sloping ground, particularly data from the Commercial system that is the most susceptible of the three systems. This effect can be quite subtle and is easily mistaken for fish schools.

**Figure 5.5 Echograms from St. Helens Hill Star Transect 4 on the 26th of July at 20:00 UTC. Poorest data quality for this survey with the vessel was sailing beam on to the weather.**

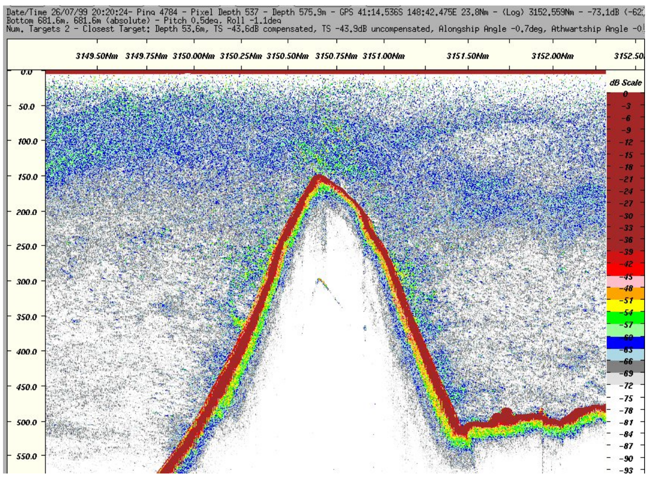
**a) Commercial system**




**b) Pole system**




**c) MUFTI system**




**d) Survey design**

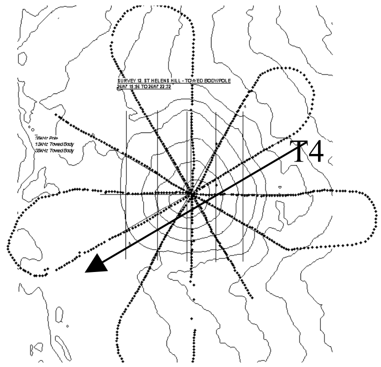
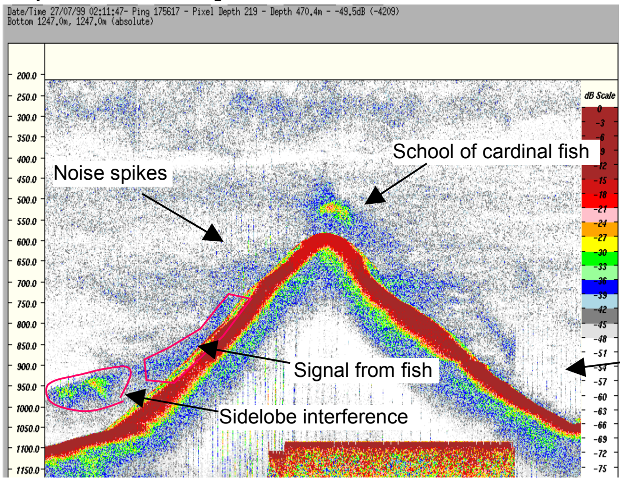


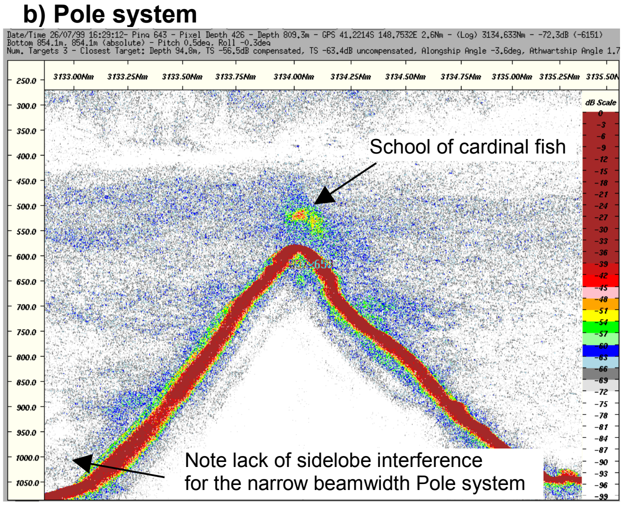
**Figure 5.6. Echograms from St. Helens Hill Star Transect 1 on the 26th of July at 16:00. Vessel was sailing into the weather.**

**a) Commercial system**

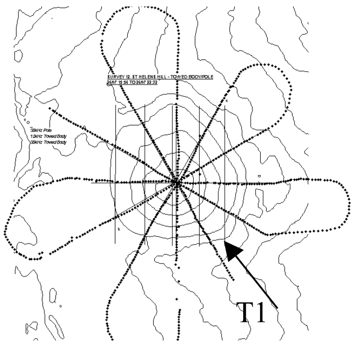



Note this region where there is a dropout of the acoustic signal and the backscatter that was being seen ceases. This did not happen with the Pole system.

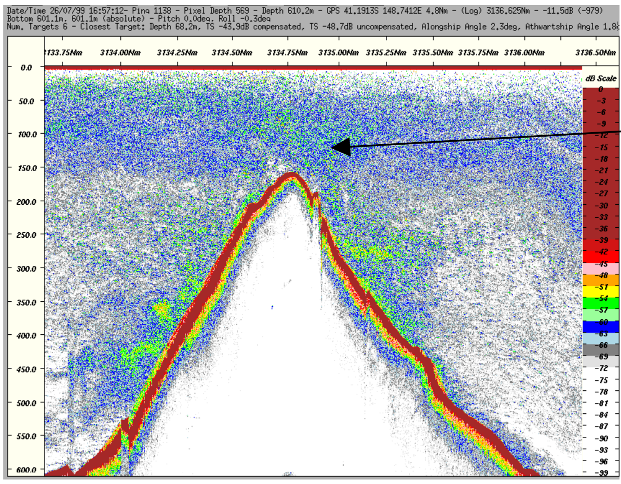
**b) Pole system**




**d) Survey design**




**c) MUFTI system**



Note the absence of the strong school mark above the hill. It appears that the fast moving and flighty cardinal fish moved away from the towed body. Alternatively, the greater sampling volume of the vessel systems meant that the school was within the vessel's sounder beam but was outside the closer towed body beam.

### 5.4.5 Deadzone height measurements

Deadzone heights for Transect 2 (Star survey at St. Helens Hill on July 27th) were measured for each of the systems using the ECHO software (Table 5.5). The theoretical worst case deadzone for a 16 degree slope was calculated using equation 5.1 (Table 5.5).

**Table 5.5. Experimental and theoretical deadzone height measurements for sloping ground (16 degrees), 27th of July Star survey, Transect 2 at St. Helens Hill.**

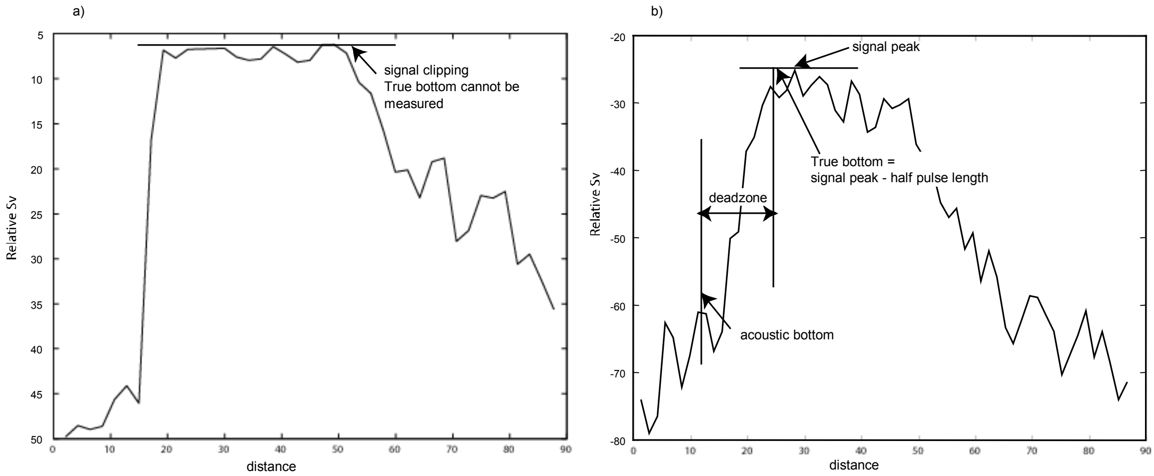
| Acoustic System | Pulse length | Mean Experimental Deadzone Height (metres) | Theoretical Worst Case Deadzone Height (metres) |
|---|---|---|---|
| 38kHz Pole | 3 ms | 25 | 34.5 |
| 38kHz Towed Body (at 400 meters) | 1 ms | 14 | 16.9 |
| 28kHz Furuno (Commercial) | 6 ms* | Not measurable. Assumed to be >25 and <36.8 | 36.8 |

* The Commercial system will change the pulse length automatically to suit the depth. This value is the estimated pulse length from the echogram.

The theoretical deadzone heights, based on a simple model, are a worst case estimate. They can potentially be reduced substantially using a narrow beam transducer: the experimental deadzone height for the narrow beam Pole system is 10 metres less than the theoretical worst case estimate (Table 5.5).

The deadzone height of the Commercial system could not be measured experimentally due to clipping of the bottom return signal (Figure 5.7a). This is a result of the Echolistener having insufficient dynamic range to be able to measure both the very low pelagic return signal and the extremely high bottom return signal. Because it has a longer pulse length, wider beamwidth and larger sidelobes, the Commercial system would measure a deadzone height that is higher than that of the Pole system; however, this is still likely to be less than the theoretical worst case of the Commercial system. The deadzone height of the Commercial system at St. Helens Hill for transect 2 is somewhere between 25 and 36.8 metres.

**Figure 5.7 a) Commercial-system bottom return signal. Insufficient dynamic range causing clipping of the signal making it impossible to obtain a "True" bottom measurement. b) Pole-system bottom return signal with no clipping and "True" and "Acoustic" bottoms selected.**




The relevance of deadzone height to acoustic measurements are influenced by changes in the sizes of orange roughy schools. In the early days of the St. Helens Hill fishery the schools were much larger and extended well up into the water column so that the deadzone height relative to the overall school size was less significant. Now that smaller schools are observed at St. Helens Hill, the deadzone height is a major source of uncertainty. Orange roughy schools close to the bottom at the time of survey may have been undetected by any of our acoustic systems.

Four main factors that affect the deadzone height are distance to seafloor, transducer beam pattern, signal pulse length and the slope of the ground. While the latter cannot be controlled, the first three can be minimised by using a shorter pulse length with narrow beam transducers and/or towing the transducer at depth to reduce the distance to seafloor. Our results showed that these strategies are very effective in reducing the deadzone height with the deep towed, short pulse length MUFTI system having a deadzone height that was at least a factor of two less than the vessel mounted systems.

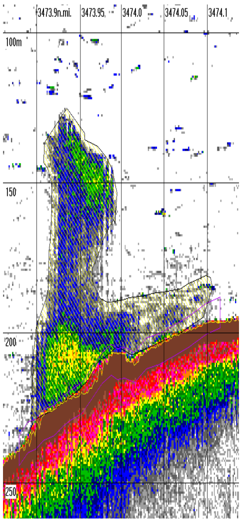
## 5.4.6 School dimension measurements

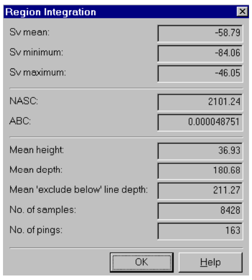
Orange roughy school dimensions may, in certain circumstances, be a useful index of orange roughy abundance (Kloser and Ryan 1999). This technique has the advantage that because school dimension measurements are independent of the return signal strength they do not have many of the uncertainties associated with echo-integration of the return signal. Hence, most of the sources of uncertainty discussed in this chapter (calibration, aeration signal loss etc) will have a lesser effect on the uncertainty in school dimension measurements which may make it a suitable technique to apply to the Commercial system data. Despite this, there are a number of considerations and corrections needed when measuring school dimensions (detailed in the ICES Research Report 238).

One consideration is that school dynamics have a marked effect on school dimension measurements; this was illustrated during the 1999 St. Patricks Head acoustic surveys when dramatic changes in school dimensions were observed. Over an 11 day period the school area decreased by a factor of 2.4 while echo-integration along the corresponding transect showed that the transect biomass differed by less than 10% (Figure 5.8). In this case, if school area alone was used as an index of biomass the results would have been grossly inaccurate.

**Figure 5.8 Example of changing school dynamics for the main schooling aggregation of orange roughy at St. Patricks Head**

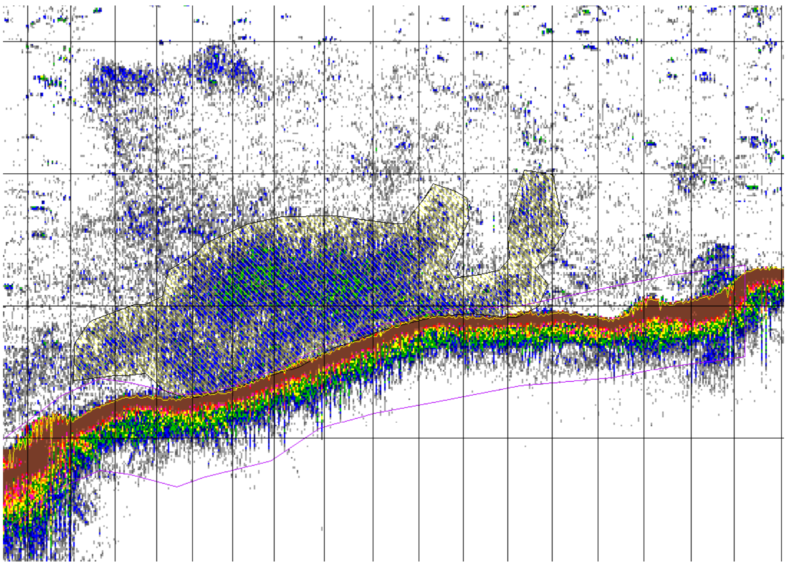
St Patricks Head. Towed body Survey 3.
Transect 1. 29/07/00 22:54. Along latitude -41:30



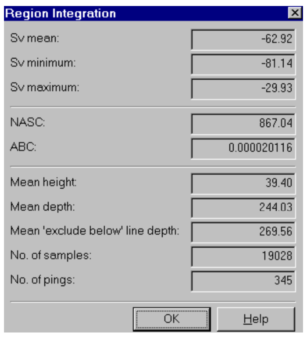




Towed body survey 1
Mean Height. 36.9 m
Distance. 0.21 nmiles
School area.14,351 $m^2$
Mean $S_A$ 2101 $m^2$ $nmile^{-2}$
Echointegraion index = School distance by Mean $S_A$ = 441

St Patricks Head. Towed body Survey 1.
Transect 3. 18/07/00 18:26. Along latitude -41.30



Towed body survey 3
Mean Height. 39.4 m
Distance. 0.56 nmiles
School area.40862 $m^2$
Mean $s_A$ 867 $m^2$ $nmile^{-2}$
Echointegration index = School distance x Mean $s_A$ = 485



Regions such as St. Patricks Head that are characterised by very mobile, dynamic orange roughy schools where inter-transect variability is likely to be high, may be poorly suited to using school dimensions as an index of abundance. While there may be a high variability in school dimension metrics if a statistically sufficient number of measures were made, the average of metrics may form a robust indicator of biomass. This approach to the use of school indices is further investigated in chapter 8.

The reduced size of the stock at St. Helens Hill meant that the Commercial system was not able to effectively delineate regions of orange roughy. Therefore, this type of Commercial system will not be able to produce a robust school dimension index unless sufficiently large aggregations of orange roughy stock form at St. Helens Hill.

### 5.4.7 Calibration: consistency issues

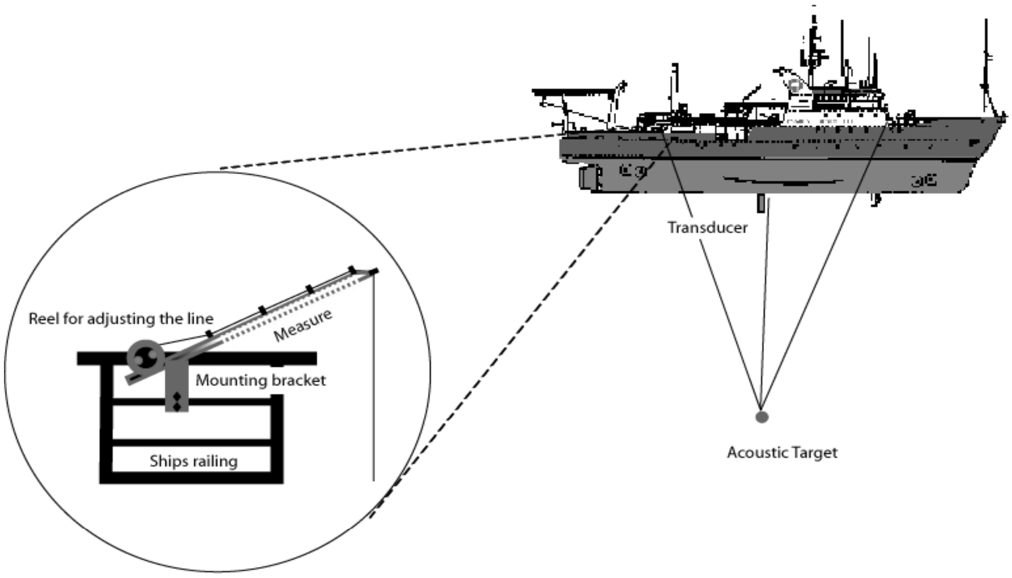
The on-axis calibration of the Pole and MUFTI systems were carried out using a standard calibration sphere according to the method described by Foote et al. (1987). The Pole and MUFTI systems have a split beam transducer that enables the target sphere under the transducer to be precisely located. With proper care this calibration can be measured to within ±0.2 dB (Foote et. al. 1987). However, as environmental conditions are not always ideal, we typically aim for a calibration accuracy of ±0.5 dB.

To convert the on-axis calibration into an absolute calibration requires an accurate measurement of the equivalent beam angle (EBA) of the transducer. Usually the beam pattern of the transducer is supplied by the manufacturer from which the user can calculate the EBA for a given sea temperature. For our scientific acoustic equipment we have also mapped the beam pattern of the transducer at the surface to check its accuracy.

The Commercial system was uncalibrated for this survey. Absolute and relative calibration of the Commercial system requires the accurate measurement of the target sphere location within the beam. A relative calibration can be made by moving the target sphere along and athwart ships and looking for the point at which there is a peak return signal. At this point the sphere is in the centre of the beam allowing the on-axis return signal of the sphere to be measured. It is envisaged that this method would be reasonably accurate and simple to do. Absolute calibration requires the transducer beam pattern to be quantified. Using a similar set-up as that described by Foote et. al. (1987) but with distance markers on the suspension lines (Reynisson 1985, 1990; MacLennan and Simmonds 1992) a geometric technique is used to calculate the position of the sphere based on its depth and the lengths of the three suspension wires (Figure 5.9). The return signal strength of the target sphere is measured for a series of calculated positions to enable the transducer beam pattern to be mapped. Although good results were reported using this method it is not a simple procedure and great care would be needed if accurate and reproducible results were to be obtained.

If echo-integration results are to be compared between surveys and vessels, it is fundamental that all vessels have an absolute calibration performed. Further work will need to be done to devise a straightforward and robust method if commercial systems are to be calibrated on a regular basis.

**Figure 5.9 Calibration setup for measuring return signal from a target sphere of known reflectivity. The split-beam scientific systems can locate the target sphere by direct measurement. Measurement of the amount of wire out and geometric calculations are needed to locate the target sphere when calibrating single beam systems.**




## 5.5 Conclusions

1. The potential to use industry vessel acoustics to monitor orange roughy abundance was evaluated by examining the sensitivity, precision and general difficulties associated with three acoustic systems on the *Southern Surveyor.* These were a scientific vessel-mounted system (Pole system), a scientific towed-body system (MUFTI), and system similar to that used on industry vessels (Commercial: a Furuno echosounder with Echolistener data logging system). High quality Simrad ES60 systems have recently become available and are used by some of the roughy fleet. Having a high signal to noise, large dynamic range and a narrow-beam, split-beam transducer these systems should have performance that is comparable with the Pole system.

2. All systems were able to produce echograms with an acceptable signal-to-noise ratio in the right operational conditions. However, factors such as sidelobe interference, signal degradation due to bad weather, and pitch/roll signal loss have the potential to significantly reduce data quality, especially for the Pole and Commercial systems. Sidelobe interference was only observed on the Commercial system in these surveys.

3. The limited ability of any acoustic system to sample the water column adjacent to the seabed (deadzone) affects the accuracy of this kind of biomass estimation survey. An estimate of the immeasurable deadzone signal needs to be made for all systems but this was not possible for our Commercial system because its limited dynamic range prevented direct measurement of deadzone height (and therefore an estimate of deadzone signal).

4. Absolute calibration of Commercial acoustic systems is fundamental to biomass estimation if echo-integration results are to be compared between surveys and vessels. The method described by Reynisson (1985, 1990) should be further investigated to see if it would provide a calibration method that is robust and logistically practical.

5. Visualisation of the three-frequency MUFTI data enables a vastly superior interpretation of echograms when compared to the other (vessel mounted) systems. Confident interpretation of echograms from vessel mounted systems was not possible unless the schools were of reasonable size and intensity. We were unable to confidently identify orange roughy schools at St. Helens Hill in the data from the vessel-mounted systems. Although there was a large aggregation at St. Patricks Head that could be detected by all systems, there was often insufficient detail in the data from vessel-mounted systems to allow precise definition of schools. Interpretation of data from the Commercial system is least reliable for a number of reasons: most importantly because they are more prone to sidelobe interference, and the system's acoustic sampling volume is an order of magnitude greater than that of the Pole and two orders higher than the MUFTI system. The multi-frequency data from the MUFTI system generally enable accurate delineation of schools due to the relatively small sampling volume and the ability to discriminate between orange roughy and bycatch species.

6. Estimating school dimensions is very sensitive to the interpretation and definition of school boundaries through time. Our results at St. Patricks Head showed that use of school dimensions may not be suitable due to the dynamic nature of the aggregations. However, if sufficient measures of schools are taken, a statistical approach may be applied to the metrics to obtain averages of school dimensions that are a robust indicator of biomass. This is investigated further in Chapter 8. School dimension measurements were shown to be a useful index of orange roughy abundance at St. Helens Hill in the early years of the fishery, but it has not been established that this result can be applied to other fisheries.

7. Trawl catch data from marks often extend the confidence with which acoustic data can be interpreted, but fishing skippers' interpretations of marks would add to process. Their interpretations are not formally recorded presently, and a method should be developed to do this.

# 6. ACOUSTIC MONITORING OF THE ORANGE ROUGHY STOCK OVER THE JULY SPAWNING PERIOD

Tim Ryan and Rudy Kloser

## 6.1 Introduction

The fishing vessel *Saxon Progress* carried out a month long program of acoustic and biological sampling at St. Helens Hill and St. Patricks Head from July 9$^{th}$ to August 10$^{th}$. This program was designed to provide additional temporal coverage needed to monitor the orange roughy stock over the entire spawning period because the scientific survey by the *Southern Surveyor* covered only the peak spawning event (within the period from July 18$^{th}$ to August 1$^{st}$). The objective was to use the industry acoustic data to provide a series of relative biomass estimates throughout the month-long sampling period. Having established the peak of spawning, the calibrated scientific acoustic data would then be used to provide a precise biomass assessment within that time period (see Chapter 4).

## 6.2 Acoustic survey designs and analysis methods

### 6.2.1 Acoustic survey equipment

An Echolistener echosounder digitising and logging system was connected across a Furuno 28kHz fisheries sounder on the *Saxon Progress*. The *Southern Surveyor* had vessel mounted and deep towed acoustic systems that are fully detailed in Chapter 2.

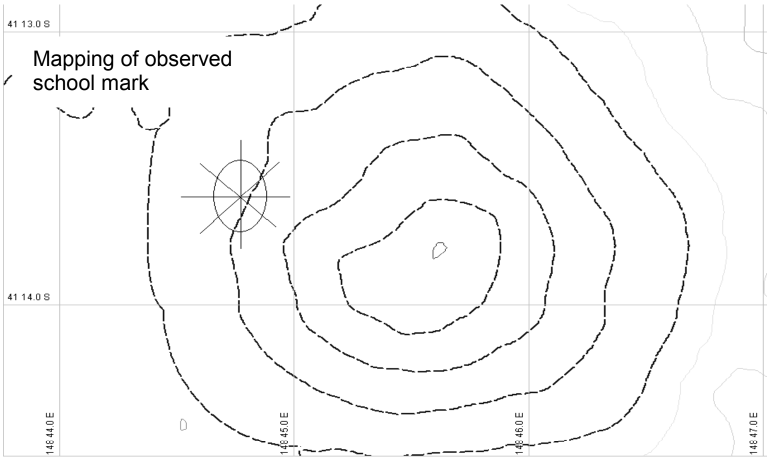
### 6.2.2 Acoustic survey designs

The industry acoustic surveys had two components: first, to conduct a series of structured acoustic monitoring surveys of the fishing grounds at St Helens Hill and St Patricks Head. The second, to map out the size of orange roughy aggregations with ‘adaptive’ surveys (intuitively placed transects that covered the main orange roughy schools most effectively).

The structured industry acoustic surveys were set up to follow the same design as the vessel mounted scientific surveys conducted by the *Southern Surveyor*, thus allowing results between the two vessels to be compared. The designs were a 5-transect North-South grid and 6 transect equi-angle Star pattern design at St. Helens Hill and a East-West grid at St. Patricks Head (see Figures 4.2, 4.3 from Chapter 4 and also Appendix D for an outline of the survey protocols).

The adaptive surveys were designed to investigate the area and density extent of the schools to provide a relative index of abundance. We hoped also to be able to use these data to examine school dynamics in relation to the underlying bathymetry, currents and time of day. To measure the horizontal area extent, the industry vessel was to opportunistically run star pattern transects over the centre of any significant schools (Figure 6.1).

**Figure 6.1. Mapping of observed school mark using a four-transect star pattern over the predicted centre of the school.**




### 6.2.3 Analysis methods

We intended to complete a quantitative analysis of these data, but because there were insufficient suitable surveys to do this we undertook only a qualitative analysis. A visual inspection of sequential echograms was made to establish if there had been a build-up and/or decline of the orange roughy stock over the month long survey period. Transect echograms with similar gain settings from industry and scientific data were collated onto a single page for each survey. Each page of transects were arranged according to survey type and date and laid side-by-side. In this way the complete sequence of surveys over time and all their transect echograms could be viewed at once (Figures 6.2, 6.4 and 6.5). The state of the stock was described across the series of echograms for the duration of the survey period. Interpretation of the echograms was assisted by reference to the size, time and location of trawl catch data, and when available the MUFTI multifrequency data.

## 6.3 Results and discussion

### 6.3.1 Review of survey data to allow selection of an appropriate analysis method

It was intended to apply the technique of schools-based echo-integration to produce a relative biomass estimate for each formal industry acoustic survey, ie. tracking the size of the orange roughy stock through the month-long survey. This technique has proven to be effective in past surveys at St. Helens Hill (Kloser and Ryan 1999) and in New Zealand (Kloser et al 1999).

To be successful, the technique requires that there are aggregated single-species schools that can be clearly distinguished from bycatch species and background noise. These conditions were not met in this survey. The limitations of the (commercial) acoustic system of the industry vessel data (Chapter 5) combined with the lack of consistent strongly aggregating schools meant that we were generally unable to confidently identify orange roughy marks on the industry acoustic echograms. Where schools were identified, they were often very dispersed so it was not always possible to precisely define the school area. The effects of bad weather also excluded some surveys from being echo-integrated. Although some data from St. Patricks Head were suitable for echo-integration there were insufficient data points to establish a relative time-series. Hence it was concluded that biomass estimates based on the industry data using the schools-based echo-integration would have had too large an uncertainty to be able to use them to track the state of the stock over the month-long survey.

The second technique to be evaluated (using the horizontal area extent of mapped schools as an index of abundance) was not possible because the industry vessel did not carry out opportunistic mapping surveys of schools as detailed in the survey plan. In the absence of a suitable quantitative method, a qualitative assessment of the data was made.

### 6.3.2 Results and discussion of acoustic monitoring surveys at St. Helens Hill

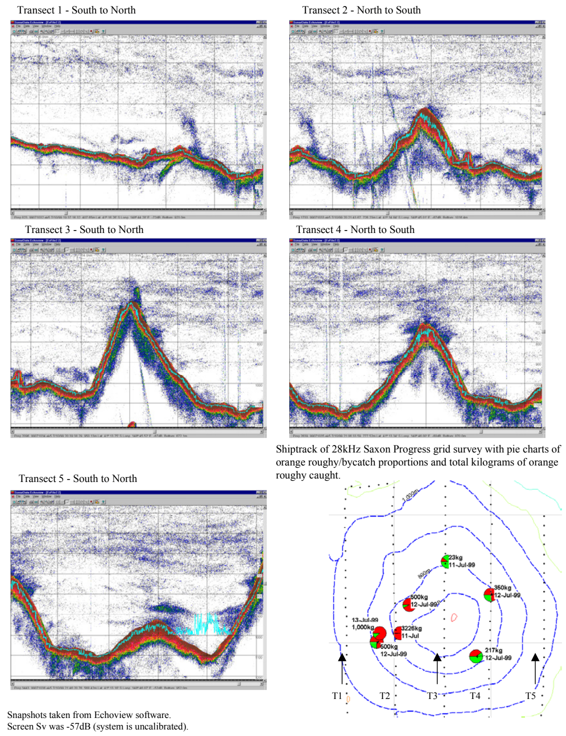
*Saxon Progress* carried out a series of four grid and four star acoustic surveys at St. Helens Hill between July 10th and August 9th(Table 6.1). The *Southern Surveyor* also carried out acoustic surveys from July 19th to 31st(Tables 4.4 and 4.8).

**Table 6.1. *Saxon Progress* acoustic surveys used to assess buildup and decline of orange roughy stocks at St. Helens Hill.**

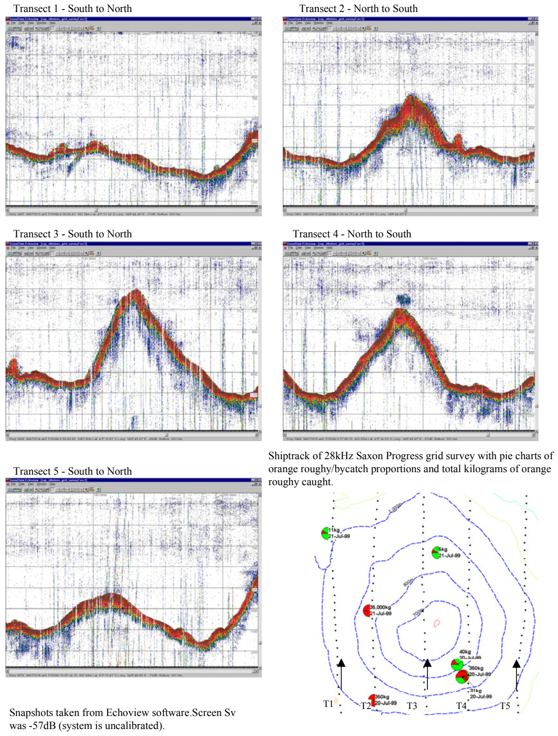
| Survey Name | Start Time (UTC) | Duration | Survey design | Number of transects |
|---|---|---|---|---|
| Grid survey 1 | 10-July-1999 19:42 | 1:59 | Grid | 5 |
| Grid survey 2 | 20-July-1999 07:52 | 2:12 | Grid | 5 |
| Grid survey 3 | 26-July-1999 17:33 | 1:56 | Grid | 5 |
| Grid survey 4 | 09-Aug-1999 16:58 | 1:52 | Grid | 5 |
| Star survey 1 | 10-July-1999 21:42 | 2:39 | Star | 6 |
| Star survey 2 | 20-July-1999 10:07 | 3:31 | Star | 6 |
| Star survey 3 | 26-July-1999 19:35 | 2:36 | Star | 7 |
| Star survey 4 | 09-Aug-1999 18:51 | 2:29 | Star | 7 |

## Figure 6.2 28kHz grid pattern acoustic surveys of St. Helens Hill by *Saxon Progress*.

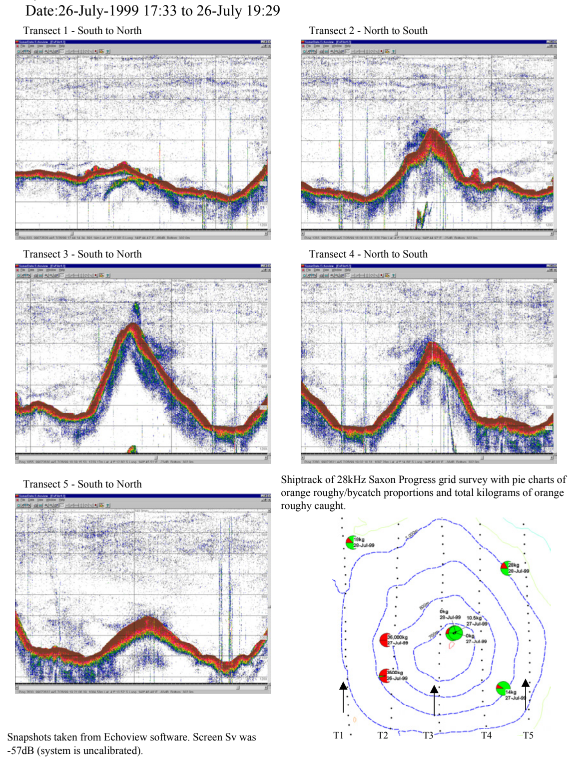
a) Saxon Progress Acoustic Survey of St Helens Hill. Rectangular Grid Survey 1
Date:10-July-1999 19:42 to 10-July 21:41



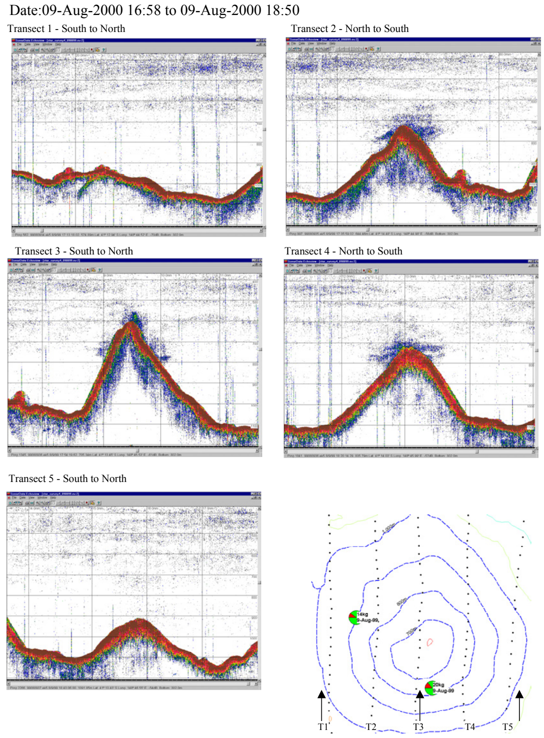

b) Saxon Progress Acoustic Survey of St Helens Hill. Rectangular Grid Survey 2
Date:20-July-1999 07:52 to 20-July 10:04




c) Saxon Progress Acoustic Survey of St Helens Hill. Rectangular Grid Survey 3
Date:26-July-1999 17:33 to 26-July 19:29




d) Saxon Progress Acoustic Survey of St Helens Hill. Rectangular Grid Survey 4
Date:09-Aug-2000 16:58 to 09-Aug-2000 18:50



**Synopsis of St. Helens Hill observations**

The most important result was the lack of identifiable acoustic marks at St. Helens Hill that could be confidently identified as orange roughy. Many acoustic marks were detected in the appropriate depth range (700-1000 m) in the series of echograms from the vessel mounted system (Figure 6.2), but these could not be confidently attributed to orange roughy.

A persistent acoustic mark that moved around the top of the hill (600 – 750 m depth) was identified from trawl catches and multi-frequency acoustics as a mix of highly reflective bycatch species including alfonsino and cardinal fish. As both these species have large gas-filled swim bladders, they produced highly intense marks when schooled tightly, but produced marks similar to orange roughy schools when dispersed.

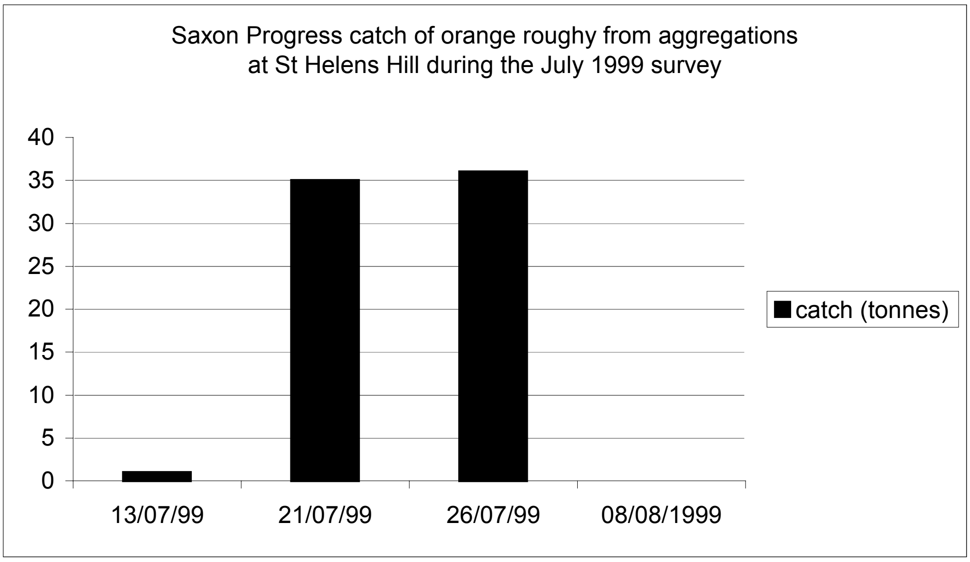
Our multi-frequency acoustic system proved to be the only method available to confidently identify the deep water marks as being from orange roughy (Figures 4.7 and 4.8). It showed that there were very few marks attributable to orange roughy aggregations; most were attributed to lanternfishes (myctophids) in the water column and whiptails and morid cod nearer the bottom. Several small orange roughy schools were found in deep water to the north and west of St. Helens Hill during the 19th of July survey by *Southern Surveyor*. Distinct schools were found in the NW (800-900 m), NE (800 m) and SE (750 m) in later *Southern Surveyor* surveys. From visual inspection, the size and intensity of these schools were greatly reduced from the previous survey in 1996.

**Inspection of echograms to identify changes in stock size at St. Helens Hill**

The industry acoustic data cannot be used to give a precise measure of orange roughy school size over the month-long survey period because of the lack of clear orange roughy marks and the uncertainty about the composition of the majority of the marks. Visual inspection of the echograms did not provide a means by which to observe changes in the school size density for the same reasons. However, the small quantities of orange roughy encountered also made it difficult to estimate school size using vessel mounted industry or scientific acoustics. Orange roughy aggregations of the size and intensity of those observed in past years would most likely have been successfully tracked through time by the industry vessel survey.

The trawl data show that large catches of orange roughy were taken between the 21st and 26th of July on the W-NW sector, with small catches at either end of the season (Figure 6.3) (but note that some large catches were linked to commercial imperatives and quota availability). Despite this, the trawl data show clearly that there was a build-up and decline over the month long survey that the industry acoustic system was unable to detect.

**Figure 6.3 Trawl catches from W-NW sector of St. Helens Hill where roughy were found in the greatest abundance in July 1999**




### 6.3.3 Results and discussion of acoustic monitoring surveys at St. Patricks Head.

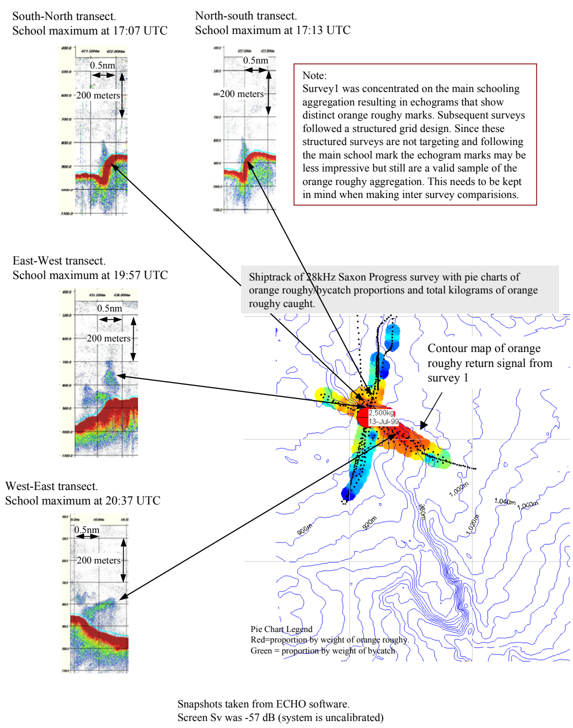
Between July 10th of and August 10th at St. Patricks Head there were a series of four 28kHz acoustic grid surveys carried out by the *Saxon Progress*(Table 6.2). This data set was supplemented with four 38kHz vessel mounted acoustic surveys carried out by the *Southern Surveyor* from the 17th – 29th of July. The *Saxon Progress* acoustic survey from the 10th of August was incomplete so that effective acoustic coverage was from the 13th of July to the 1st of August.

**Table 6.2 Industry and scientific acoustic surveys used to assess buildup and decline of orange roughy stocks at St. Patricks Head.**

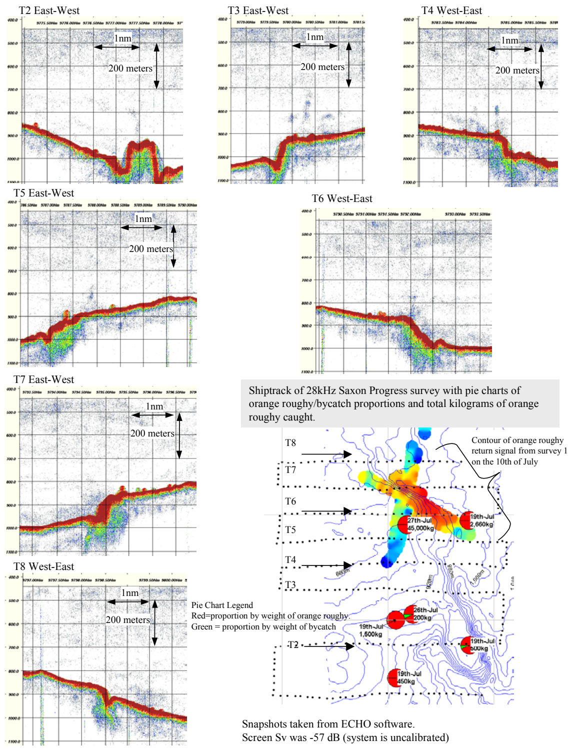
| Survey Name | Vessel | Start Time (UTC) | Duration | Survey design | No. of transects |
|---|---|---|---|---|---|
| SXP_Grid survey 1 | Saxon Progress | 13-July-1999 16:59 | 4:25 | Targeting schooling aggregation | 4 |
| SXP_Grid survey 2 | Saxon Progress | 26-July-1999 02:23 | 3:41 | Grid | 8 |
| SXP_Grid survey 3 | Saxon Progress | 26-July-1999 11:25 | 2:11 | Grid/ZigZag | 6 |
| SXP_Grid survey 4 | Saxon Progress | 10-Aug-1999 03:47 | 5:49 | Grid | 4 |
| SS_Grid survey 1 | Southern Surveyor | 17-July-1999 18:21 | 6:24 | Grid | 6 |
| SS_Grid survey 2 | Southern Surveyor | 25-July-1999 11:36 | 4:08 | Grid | 6 |
| SS_Grid survey 3 | Southern Surveyor | 28-July-1999 23:38 | 3:52 | Grid | 7 |
| SS_Grid survey 4 | Southern Surveyor | 29-July-1999 12:30 | 5:27 | Grid | 8 |

## Figure 6.4 28 kHz grid acoustic survey of St. Patricks Head by *Saxon Progress*.

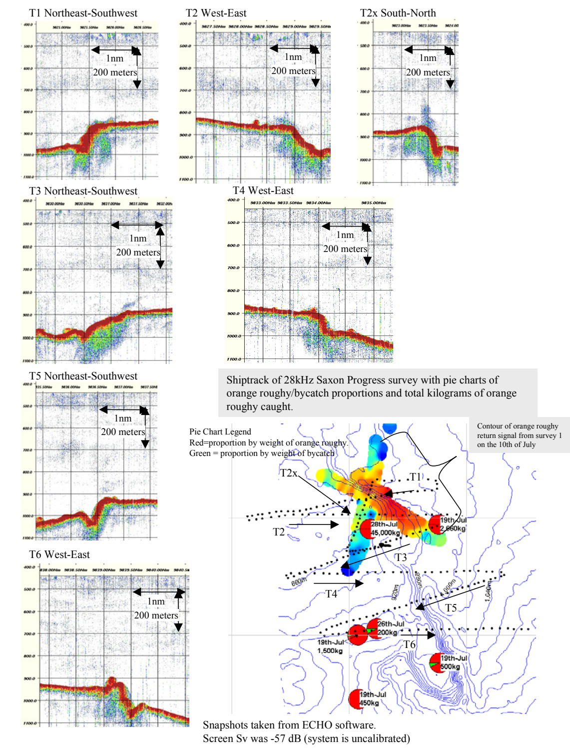
a) Saxon Progress Vessel mounted echosounder data. Survey 1
St Patricks Head, 13/07/99 16:59 to 13/07/99 21:24 UTC



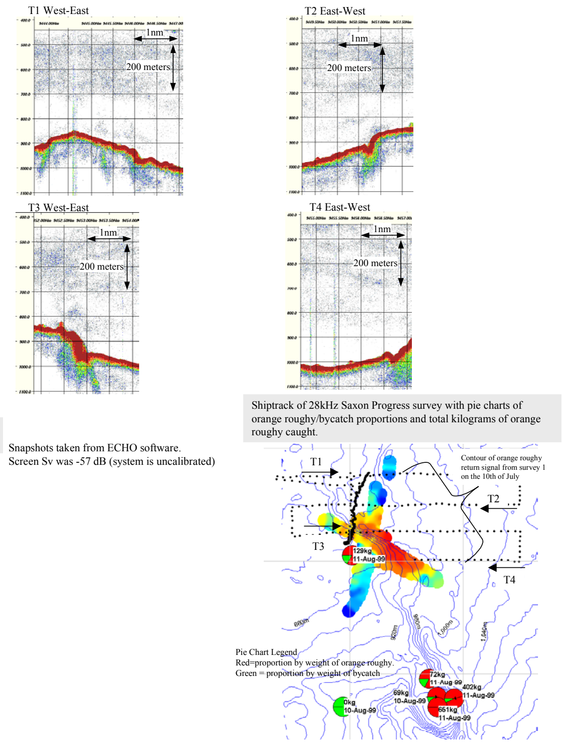

b) Saxon Progress Vessel mounted echosounder data. Survey 3
St Patricks Head, 26/07/99 02:23 to 26/07/99 06:04 UTC



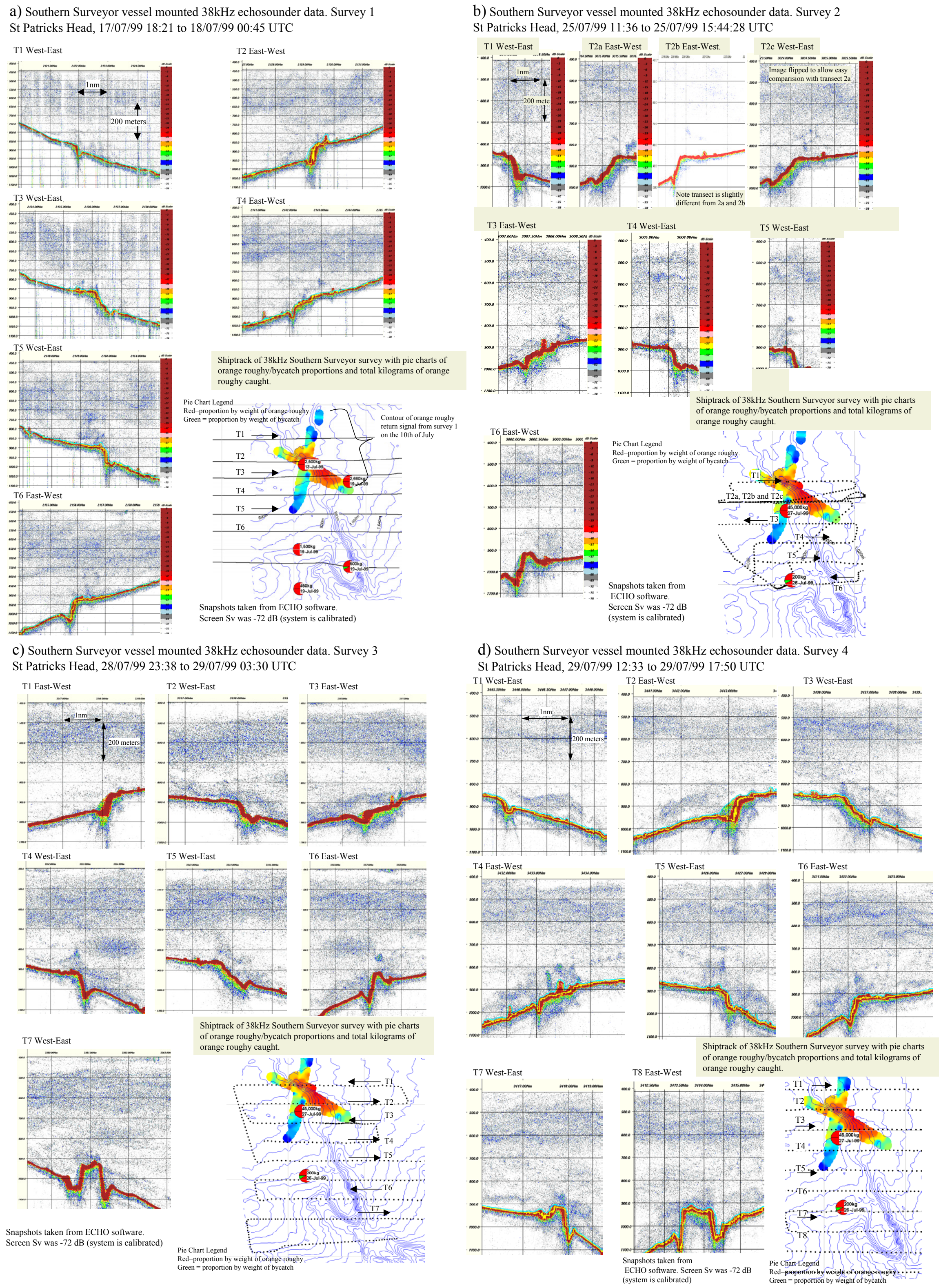

c) Saxon Progress Vessel mounted echosounder data. Survey 4
St Patricks Head, 26/07/99 11:25 to 26/07/99 13:36 UTC




d) Saxon Progress Vessel mounted echosounder data. Survey 5
St Patricks Head, 10/08/99 03:47 to 10/08/99 09:36 UTC



## Figure 6.5 38 kHz grid acoustic survey of St. Patricks Head by *Southern Surveyor*.



**Synopsis of St. Patricks Head observations**

A large aggregation of orange roughy was surveyed at St. Patricks Head (Figure 6.4a). It persisted over the ground during the period from July 13th to August 1st although it moved locally, changing its position over hourly and daily periods. The main body of fish was located on the northeast end on the region known as the Rock Wall, and moved on and off the ridge between surveys. It extended along the ridge south for 3-4 nautical miles and petered out on the southern extremities and did not show any large east-west extent. Large catches of orange roughy (30-45 tonnes) were obtained from trawl shots in this Northeast region by the *Saxon Progress* (Figure 6.6).

While the location of the main aggregation roughy was stable, the spatial dynamics were dramatic at times, varying from tightly aggregated, to dispersed and up in the water column (Figure 6.7). Transect 3 from the 22nd of July survey (Figure 6.7.b) is of particular interest as the aggregation is high in the water column, some 200 m above the seafloor. This aggregation is interpreted as orange roughy based on single frequency acoustics but further work will be done with the multifrequency data to confirm this. Measurements of school dimensions using the MUFTI data quantified the large changes that were observed (Table 6.3). These echograms and school measurements show that the school was large and dispersed on the 18th of July while on the 29th of July it was a factor of 2.8 times smaller in area but with a 2.6 time higher mean $S_A$ value (i.e. intensity). Echointegration of the two schools indicates that the 29th July school is just 14% larger than the school of the 18th of July (Table 6.3).

The dynamics of orange roughy schools observed at St. Patricks Head on hourly and daily scales may be related to environmental forces such as deepwater currents and tides. Observations of surface and deepwater bottom currents suggested a strong northerly set on the grounds at the time of measurement. The relationship between currents and school dynamics is seen as a priority for future work.

**Figure 6.6 Trawl catches from Northeast end of St. Patricks Head where roughy were found in the greatest abundance in July 1999.**

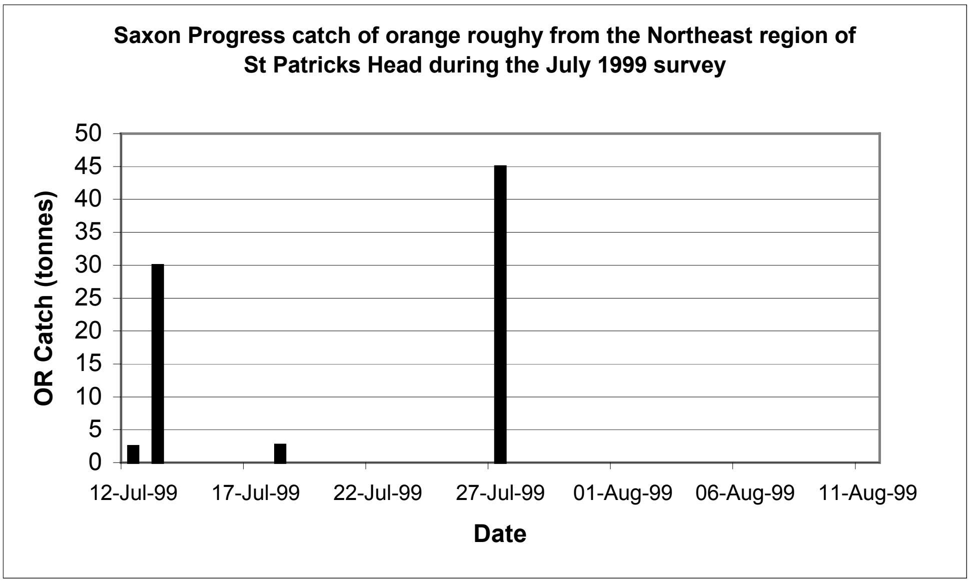
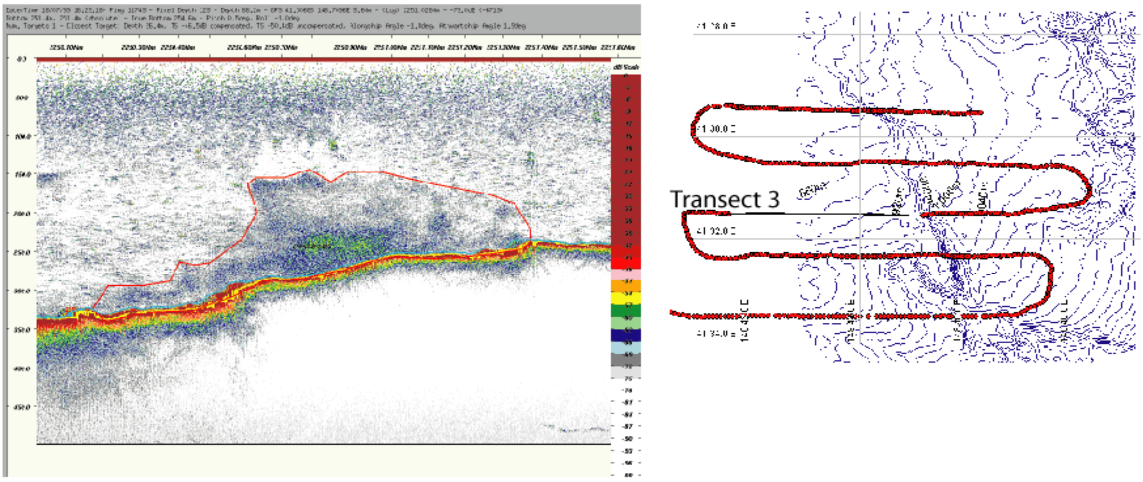
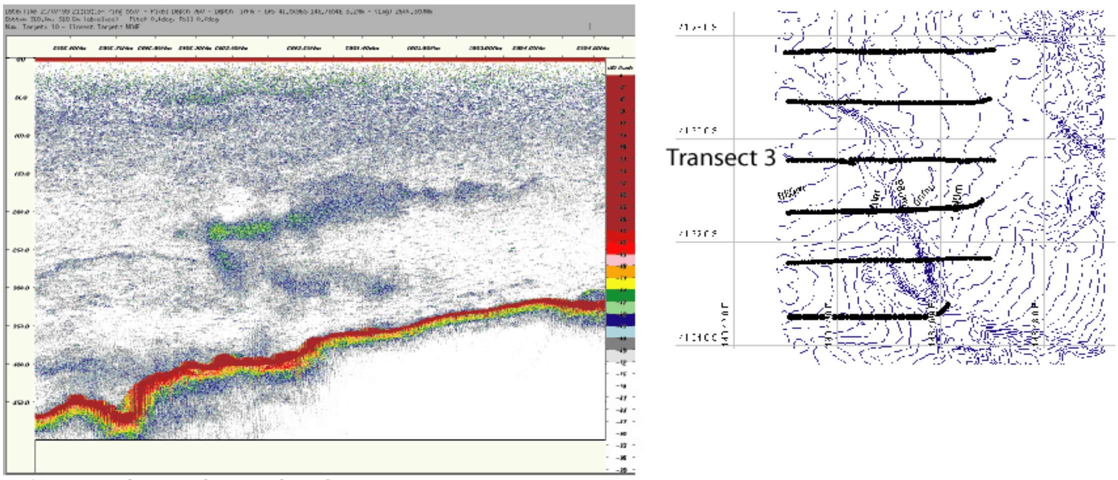


**Figure 6.7 MUFTI transects over the main aggregation of orange roughy at St. Patricks Head.**

a) St Patricks Head. Towed Body Survey.
18th July 1999. Transect 3




b) St Patricks Head. Towed Body Survey.
22 July 1999. Transect 3




c) St Patricks Head. Towed Body Survey
29th July 1999. Transect 1

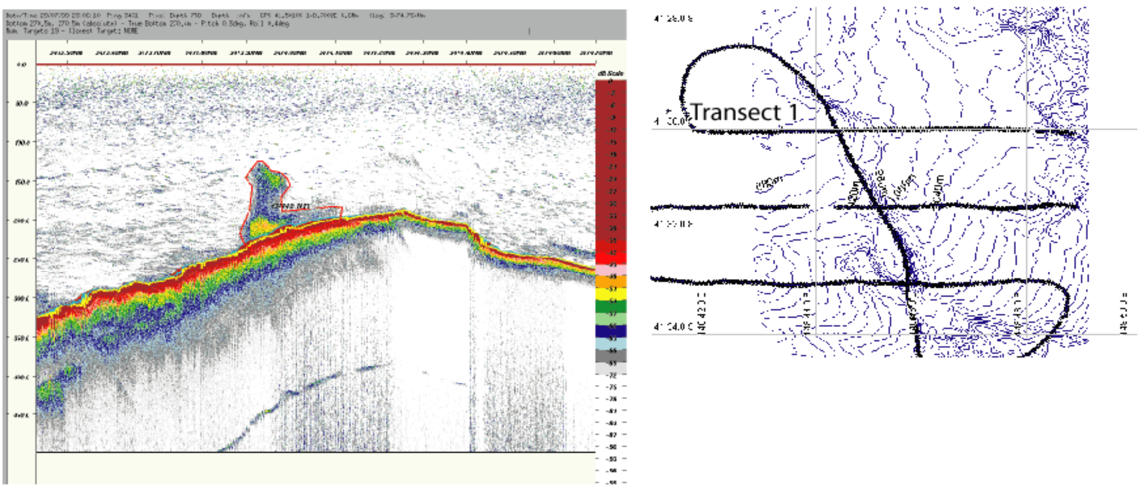


**Table 6.3 Measurement of school parameters for the main aggregation of orange roughy at St. Patricks Head.**

| Date | Mean school height (m) | School length (n.mi.$^2$) | School area ($m^2$) | Mean School $s_A$ ($m^2$/n.mi.$^2$) | School echointegration index |
|---|---|---|---|---|---|
| 18$^{th}$ July | 36.9 | 0.21 | 14351 | 2101 | 3.0e7 |
| 29$^{th}$ July | 39.6 | 0.56 | 40862 | 867 | 3.5e7 |

**Buildup and decline of orange roughy stocks at St. Patricks Head**
The industry acoustic survey at St. Patricks Head was able to detect sizeable schools of orange roughy, unlike the case at St. Helens Hill. However the dynamics of the aggregations and their often dispersed mode made precise definition of schools difficult, and echo-integration less accurate.

There was a large orange roughy school already on the ground at the start of the industry survey (13$^{th}$ July) (Figure 6.4a). At this time, a trawl of 30,000 kg of orange roughy was taken, supporting the identification of the acoustic mark. Comparing this school with a transect along the same line 13 days later (Figure 6.4c Transect 2x South-North) shows that the school marks are almost identical in spite of the two week interval. A second large trawl catch of 45,000 kg on the 27$^{th}$ of July showed again that there were orange roughy present in large numbers. Three days later on the 29$^{th}$, a large school mark can be observed along transect 4, survey 4 with the *Southern Surveyor*'s 38kHz vessel mounted system (Figure 6.5d). On the 1$^{st}$ of August the main aggregation of orange roughy was still large enough to be readily located and the MUFTI system was lowered onto it to successfully obtain *in-situ* target strength measurements.

The acoustic data are incomplete for the 10$^{th}$ of August survey making it difficult to draw a conclusion about the size of orange roughy schools at that time. The trawl data from that period all show small catches (<700 kgs) of orange roughy, which suggests that the stock had mostly left the area.

### 6.3.4 Synopsis of industry observations for St. Patricks Head and St. Helens Hill

Industry vessels were on the grounds for the entire spawning season and developed a working knowledge of the environment and how it relates to orange roughy aggregations. Jeremy Prince has synthesised a collective understanding of their views as follows:

*"Industry was very conscious that most of the spawning activity was occurring at St. Patricks Head rather than at St. Helens Hill. Industry members have long maintained that St. Patricks Head has in some previous years been similarly important to the spawning of orange roughy.*

*The most commonly supplied explanation by fishers for the distribution of spawning in 1999 was the nature of bottom currents through the area. Fishers commented that the behaviour of the trawl gear around St. Patricks Head indicated strong bottom currents from the south. Around St. Helens Hill there was reported to be little bottom current, although some fishers reported a weak bottom current out of the north. The fishers who* *supported this explanation believe the foremost condition is conducive for roughy spawning and the latter is not.*

*In support of this notion it was generally noted that around St. Helens Hill the aggregations of orange roughy were generally deeper than usual in 950-1,000m, which was interpreted as the roughy seeking colder, deeper water of southern origin below the warmer more northerly water.*

*The distribution of the aggregating roughy created problems for some fishers trying to fill their quota. The St. Patricks Head area is generally difficult to trawl because of the presence of many large rocky mounds. There is one generally known trawl shot at St. Patricks Head called the "Paddock" but in 1999 the aggregation was some distance from this shot, along the rough edge of a bluff which could not be trawled. Successful fishers at St. Patricks Head successfully targeted fish moving around the aggregation site improvising short shots between the rocky mounds.*

*Fishing conditions at St. Helens Hill were more difficult than usual because there were relatively few aggregations of orange roughy and these were generally deeper than usual around the base of the hill in 950-1,000m, amongst some pinnacles and ravines that are found on the southern and western side.*

*The operators of one vessel that is used principally for market fishing had leased a large holding of eastern zone quota. They found themselves unable to fish around St. Patricks Head and struggled through the entire length of the season trying to fill their quota allocation around St. Helens Hill."*

## 6.4 Conclusions

1) Acoustic data from the month-long industry vessel monitoring survey showed no clear pattern of build-up or decline of orange roughy, or indication of a mass influx, during the spawning period at either St. Patricks Head or St. Helens Hill. This was despite other clear evidence (eg. catch data and gonad maturation, Chapter 3) that showed a build-up and decline had occurred during the survey period with peak abundance during the middle two weeks when the *Southern Surveyor* was carrying out scientific acoustic surveys.

2) Industry vessel acoustic data were useful to confirm an absence of large aggregations of orange roughy at St. Helens Hill, but was of limited value to estimate stock size or the build up and decline of the spawning stock. Changes in school size that may have occurred during the survey month could not be measured with the industry acoustics at St. Helens Hill, primarily because of the difficulty in interpreting the composition and boundaries of the marks that were present. For industry acoustics to be successful at St. Helens Hill, orange roughy must be present in larger, homogeneous schools, or the acoustic system needs to be improved to give higher quality data that can enable confident interpretation of marks.

3) Orange roughy schools at St. Patricks Head were, on occasions, sufficiently large and aggregated to be clearly distinguished by the industry vessel acoustics. However, schools were dynamic, moving and dispersing over periods of hours and days. When dispersed, schools were difficult to detect and separate from other

backscattering bycatch species. Because of this it was not possible to monitor the size of the stock over the month long survey period, or to measure stock size at its peak. There was, however, sufficient survey coverage to conclude that there were consistently large aggregations of roughy on this ground during the middle two weeks (July 13th to August 1st) of the month-long survey.

4) The dynamics of schools at St. Patricks Head needs to be related to environmental factors such as deep water currents in future analyses.

# 7 ACOUSTIC SPECIES IDENTIFICATION IN DEEP WATER USING MULTIPLE FREQUENCIES

R.J. Kloser, T. Ryan, P. Sakov and J.A. Koslow

## 7.1 Abstract

Multi-frequency 12, 38 and 120 kHz acoustics were used to identify the dominant acoustic fish groups around a deepwater > 600 m seamount (a known spawning site of orange roughy, *Hoplostethus atlanticus*) by amplitude mixing of the frequencies. The frequency mixing method developed showed three distinct acoustic groupings based on fish size and swimbladder type: myctophids of total length less than 10 cm, morids and macrourids with lengths > 30 cm and orange roughy with a mean standard length of 36 cm. These three groups were the dominant groups caught in the demersal and pelagic trawls in the study area. A simple model of swimbladder resonance at depth of large and small gas-filled bladder fish groups is in agreement with our experimental observations. At 38 kHz the small gas-filled swimbladder fishes (myctophids) have a target strength similar to the wax ester filled swim bladdered orange roughy. During spawning orange roughy form large aggregations that extend up to 150 m into the water column and hence both near seabed and mid-water acoustic marks need to be identified. Traditionally, demersal and pelagic trawling is used to identify fish species in acoustic records. However orange roughy are rarely caught in mid water due to net avoidance. Using three frequencies these groups could be distinguished directly over their entire vertical extent from the acoustic records, reducing a major source of uncertainty (up to factor of 6.4) in the biomass estimates. Our results show that despite assessment models predicting an increased population (given current catch levels) the size of the orange roughy stock at the St Helens seamount has declined during 1996 to 1999.

## 7.2 Introduction

Species identification remains a critical requirement in interpreting acoustic recordings for fisheries management (Horne 2000). This is especially so in the deepwater orange roughy, *Hoplostethus atlanticus*, fisheries of Australia, New Zealand, Namibia, Chile and the High Seas ( Kloser et al. 1996, Huse et al. 1997, Clark 1999). Orange roughy are a long lived fish that have low recruitment and form large schools when spawning, making them vulnerable to over fishing. In Australian waters the major spawning aggregation was reduced by a quarter based on acoustic snapshot surveys between 1990 to 1993 (Kloser et al. 1996). This decline in biomass combined with catch and age data led to a fishery management strategy of reduced catches to rebuild the population in future years (Bax 1999). To establish whether the orange roughy stocks are rebuilding the acoustic echo integration method has been proposed to monitor the spawning aggregation. Orange roughy have a wax ester swim bladder and a very low target strength compared to the other dominant gas-bladdered species, hence the ability to accurately monitor the spawning population becomes very sensitive to the proportion of gas-bladdered species  (Kloser et al. 1997).

Traditionally trawl sampling is used to allocate species compositions to the acoustic records in mixed species situations. Net sampling has potential biases such as variable catchability between species and spatial and temporal extrapolation of patchy demersal and pelagic trawls. Orange roughy are typically captured with demersal trawls using headline heights of 5 to10 m and are not generally caught in mid-water with pelagic trawls, presumably due to their marked avoidance reaction (Koslow et al. 1995). However, acoustic measurements indicate that orange roughy schools range from the seabed to as high as 150 m into the water column. Pelagic trawls on these acoustic marks only capture a variety of midwater fishes many of which have gas-filled swimbladders (Kloser et al. 1997). This avoidance behaviour of orange roughy to trawl sampling could bias the assessment of species composition allocated to the acoustic records. A method is required that utilises the acoustic data to distinguish the major species groups throughout the water column.

Species identification at a single acoustic frequency is used in shallow water < 200 m using echo statistics and environmental factors (Rose and Leggett 1988, Scalabrin et al. 1994, as examples). These classification methods require a reference set of acoustic and biological data on schools that have been accurately captured and metrics obtained. In deep water > 750 m the resolution of the vessel mounted surface acoustics is poor and the time required to accurately capture fishes leads to small reference data sets. The avoidance response of orange roughy to midwater sampling gears compounds the problem, as not all fishes can be sampled equally. Fishers' observations of orange roughy schools show they aggregate and disperse over very short time frames when in a spawning aggregation, or that the observation tool is too coarse to accurately determine their true dynamics or school shapes. This makes using vessel mounted single frequency acoustic methods for species identification difficult in deep water.

Multiple frequency acoustic methods have been used to distinguish species or groups of zooplankton and discriminate between fish and zooplankton (Holliday 1977, Greenlaw and Johnson 1983, Cochrane et al. 1991, as examples). Fish species have been discriminated or sized using broadband or a number of discrete frequencies (Holliday 1972, Trevorrow 1996, as examples). In past acoustic surveys we observed that particular deep scattering layers at > 600 m depth were sometimes more prominent on either the 12 or 38 kHz hull-mounted echosounders on our research vessel. This observation is consistent with the change in resonance of small midwater fishes with depth (Andreeva 1964). However, we found that these echosounders and a further 12 kHz hull-mounted echosounder available on the vessel were unable to distinguish between orange roughy and other scatterers, either due to the large sampling volume or insufficient range in frequencies. We therefore placed three frequencies (12, 38 and 120 kHz) on a deep towed body, MUFTI, and trialed the system in 1996 during our routine acoustic survey of orange roughy. The multi-frequency methodology was further refined with a specific orange roughy survey in 1999. The aim of our study was to improve methods for understanding the distribution and abundance of deepwater species and in particular the abundance of spawning orange roughy.

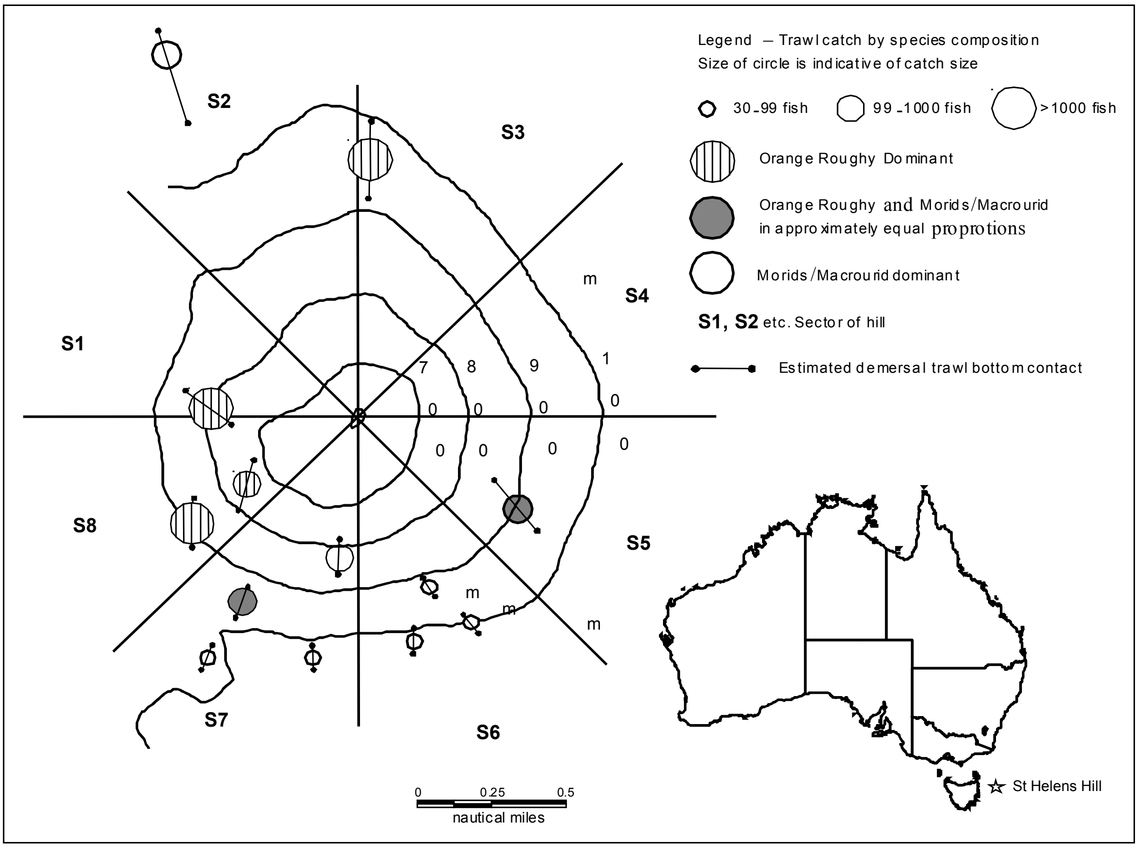
## 7.3 Material and Methods

### 7.3.1 Acoustic equipment

The acoustic equipment consisted of a purpose-built multi-frequency towed instrument (MUFTI) that housed the single-beam 12 kHz and split-beam 38 and 120 kHz transducers (Table 7.1). The towed body was a dead weight type (450 kg in air) that was 2.4 m long and 0.5 m in diameter with a flat base to avoid the use of acoustic windows. The MUFTI towed body housed the transducers, transmitters, pre-amplifiers, Falmouth

Scientific CTD and a "monitoring" pressure case. The "monitoring" pressure case contained equipment to measure physical parameters such as towed body pitch, roll, depth and operating voltage, all displayed and logged continuously aboard the research vessel. The towed body was connected to the vessel by 2500 m of electromechanical cable and is further described by Kloser (1996). The acoustic signals were received with a SIMRAD EK500 which had its transmitter disconnected and its receivers placed in passive mode. The acoustic ping and summary data were logged on a Sun workstation (now Linux) running ECHO, a customised software package for acquiring and processing fisheries acoustic data (Waring et al. 1994).

**Figure 7.1. Demersal trawl catch positions and the relative proportions of dominant species combined by swimbladder type of orange roughy and large gas bladder (macrourid and morids) associated to the sector of the St Helens seamount in July 1996. The MUFTI loop transect showing the vessels track at 850 m contour associated to Figure 7.3 is highlighted.**




## 7.3.2 Acoustic calibration

The acoustic system was calibrated at the surface and at depth with a 42 mm tungsten carbide sphere for all the transducers to obtain the on-axis echo integration constant (Foote et al. 1987, Simrad ver 5.3 1993). The target strength of the sphere at a given frequency was calculated following MacLennan (1981). This target sphere calibration technique combines the electrical and acoustic constants of the system, such as transmitter power, the transmitting and receiving efficiency of the transducer, and receiver gain. The equivalent beam angle is not calibrated using this method and was measured by the manufacturer of the transducer with tests on these values confirmed with a special calibration rig that rotated the transducers at the surface. The split-beam deep-tow transducers were also calibrated from 100 - 700 m to correct for changes with depth in transducer sensitivity and to test for changes in beam pattern by suspending a calibration sphere suspended fore and aft 10 m under the towed body and lowering the system through the water column (Kloser 1996). The seawater propagation parameters of absorption and sound velocity were calculated from the formulae of Francois and Garrison (1982) and MacKenzie (1981), respectively, based upon temperature and salinity profiles obtained during the surveys with a Neil Brown and Falmouth Scientific conductivity-temperature-depth recorder (CTD). Calibration results for the relevant depths are presented in Table 7.1.

**Table 7.1. Specification of the transducers for the MUFTI deep towed body and relevant calibration and instrument settings.**

| Transducer | 12 kHz | 38 kHz | 120 kHz | units |
|---|---|---|---|---|
| Manufacturer | MASA (single beam) | EDO Western (split beam) | Simrad (split beam) | |
| Equivalent Beamwidth | -10 | -21.1 | -20.6 | dB re 1 steradian |
| Beamwidth +/- 3dB | 40 | 6.5 | 7 | degrees |
| Bandwidth | 1 | 3.3 | 3.3 | kHz |
| Pulse length | 1.0 | 1.0 | 1.0 | mS |
| Target sphere TC 42 mm | -42 | -42.4 | -39.5 | dB re $1m^2$ |
| Calibration offset at 700 m | 18 +/-2dB | 1.4 +/- 0.5dB | 7 +/-1dB | dB |
| Integrated Absorption @850m towed body at 700m | 1.3 | 9.4 | 31.9 | dB $km^{-1}$ |

### 7.3.3 Acoustic sampling

Field samples were obtained from a spawning aggregation of orange roughy on St Helens Hill (eastern Tasmania $41^0$ 14.0’ S, $148^0$ 45.4 E) in July 1996 and 1999 as part of an ongoing acoustic survey for the management of the stock in the region ( Kloser et al. 1996, Bax 1999). St Helens Hill rises from 1100 m to 600 m and is conical in shape. The repeat surveys have used a system of straight line N-S transects at preset locations with the MUFTI towed body at a fixed depth of between 450-550 m (Kloser et al. 1996). To efficiently sample the fish species occurring around the hill the MUFTI system was towed in a circle 'Loop' with
1800-2100 m of wire in the water at 2-5 knots keeping the towed system a fixed 100–200 m above the seabed (Figure 7.3). For example, the ship would follow the 900 m depth contour but due to the long cable and vessel turning the MUFTI towed body would be sampling in the 800-850 m depth contour. The vessel circled the hill in this

fashion covering the 750–1100 m depth contours. This deployment method enabled optimal sampling of the fish species around the hill and minimised fish avoidance and down time due to turning of the vessel with long lengths of wire in the water when using traditional straight line transects.

### 7.3.4 Acoustic visualisation

To manage, edit and visualise the acoustic data, a specialised software program was written in C and C++ on a Sun workstation (now Linux) using X-Windows and an Oracle database (Waring et al. 1994). This software program was upgraded to include methods for visualising multi-frequency echograms (Kloser et al. 1998). The philosophy of the program operation involved scrutinising the individual acoustic frequencies and correcting the data by applying data modifiers and spatial restrictors. In this application, data modifiers included algorithms for noise thresholding or subtraction and applying compensation for known calibration offsets. The spatial restrictors (referenced from the surface, transducer or seabed) were applied to limit further computations on the particular data. Specifically, spatial restrictors were required on these data when effected by excessive platform movement and or electrical noise, and in redefining the start of the seabed echo. The resultant spatial offsets and data modifiers were displayed in a WYSIWYG (what you see is what you get) environment to ensure quality assurance and good user feedback for changes made. In mixing the frequencies, each frequency was allocated a separate colour pallet with independent intensity start and dynamic ranges. The user could then dynamically adjust the frequencies to highlight specific differences in the echograms. Once a given presentation system was finalised it was stored and all subsequent multi-frequency echograms viewed in the same way. The mixing algorithm used in this analysis involved displaying a particular frequency colour if it was higher in amplitude than the associated frequencies. The ability of the user to adjust the individual gains and dynamic ranges for each frequency in a dynamic fashion created an environment that greatly assisted in highlighting visual features in the frequency amplitude differences.

In total, 13 loops were carried out around St Helens Hill in 1996 with the MUFTI deep towed system and these were processed using the ECHO software. Each frequency was assigned a separate colour pallet (12 kHz red, 38 kHz green and 120 kHz blue) and adjusted for background noise, absorption and calibration. The frequencies were then combined with separate colour palettes and mixed using amplitude dominance (Figure 7.2). Figure 7.2 shows each individual frequency and the frequency mixing to highlight differences over an orange roughy aggregation. The figure shows how the user adjusted the individual frequency gains to ensure that the orange roughy was an even mix of all the frequencies amplitudes seen as an even mixture of red, green and blue pixels on the computer screen. The remaining multi-frequency echogram separated into two regions of colour dominance of red (high 12 kHz signal) and green (high 38 kHz signal), (Figure 7.2).

### 7.3.5 Biological Sampling

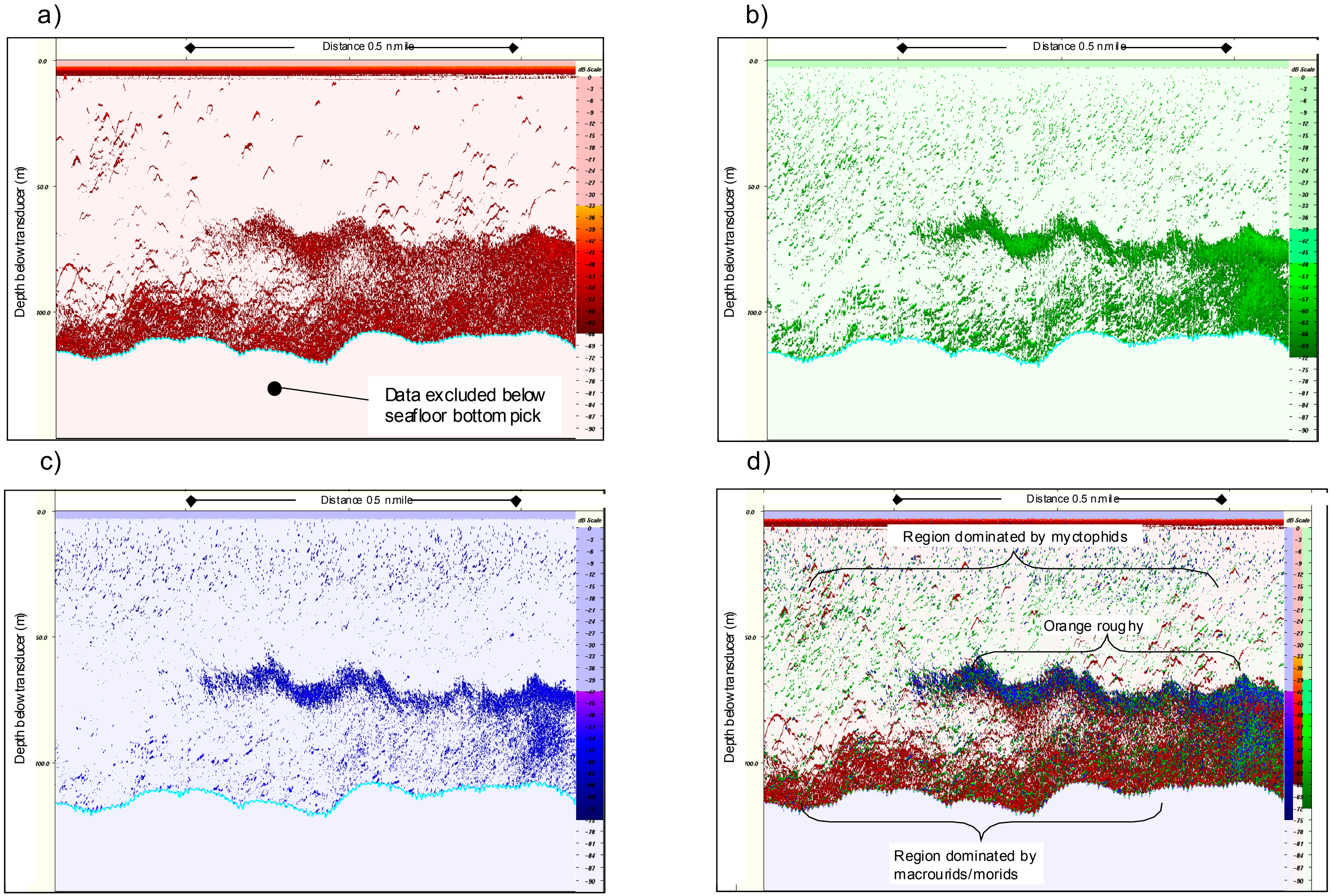
Biological samples were obtained from pelagic and demersal trawls that targeted fish concentrations that had been located acoustically. A large demersal trawl net was used to catch seabed fishes, while a pelagic trawl system, which sampled at specified depths, was used to collect mid-water samples. The demersal trawl net was a commercial orange roughy trawl with a 40 mm codend liner, headline length of ~35 m and height ~4 m. Demersal trawl time (actual fishing time) varied between 30 mins. on flat ground around the hills, to 5-15 mins. for target shots on marks. Vessel speed was around 3 knots but net speed was more variable. During target shots, the gear can be almost in free-fall (moving downwards at a steep angle). A large pelagic trawl was fitted with an opening/closing, five-net cod-end system based on the Multiple Plankton Sampler of Pearcy et al. (1977). The cross-sectional area of the net mouth when fishing, as measured by hydroacoustic sensors, was about 105 $m^2$. Mesh sizes in the trawl were 100 mm in the wings, 100 mm reducing to 20 mm in the body and 10 mm in the extension; cod-ends were 7 mm. Pelagic tow duration was 60 mins in predetermined strata beyond 650 m and 10-15 mins in target shots. Trawling was at a speed of 2.5 to 3 knots. The system could take four samples from known depths per deployment. Accurate target trawling of fish concentrations was possible with Scanmar acoustic sensors to monitor the geometry and position of the fishing gear in the water column.

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 in the depth range where orange roughy are found. 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 acoustic species based on a method established by Kloser et al. (1997). The demersal trawl catch was identified where possible to species, and numbers and weights obtained. Seven dominant acoustic groups were defined based on species abundance, morphology and swim bladder type: eels (2 spp), morid cod (3 spp) oreos (5 spp), orange roughy, sharks (10 spp), macrourids (14 spp) and 18 species of fish and crustacea that occurred in low abundance. Further analysis was only carried out for species groups that represented > 1 percent of the total catch.

The pelagic trawl catch was also identified where possible to species group and the species numbered and weighed. The species were grouped on abundance, morphology and swim bladder type as outlined in Kloser et al. (1997). The high abundance and similar size, morphology and gas-filled swim bladders of the myctophid species dominated the pelagic trawls. These represent the highest contribution to acoustic scattering. Small numbers of morids and macrourids were also captured in these trawls.

**Figure 7.2.** **Example of mixing three frequencies showing the individual frequencies that are first quality assured removing known artefacts a) red (12 kHz),b) green (38 kHz) and c) blue (120 kHz). A composite image (d) is produced where the frequencies have been optimised dynamically to highlight the amplitude differences in the echogram when there is an even mix on the region interpreted to be originating from orange roughy. The dominant red (12 kHz) is interpreted to be originating from regions of large gas bladdered species (morids and macrourids), green (38 kHz) highlights the small gas bladdered species and blue (120 kHz) highlights the orange roughy.**



### 7.3.6 Target strength

*In situ* target strengths as derived from the Simrad EK500 ver 5.3 were extracted from low-density regions associated to an acoustic group between frequencies at constant depth. The relevant target strength selection criteria used were target threshold, –65 dB, normalised echo length, 0.7 to 1.5, maximum gain compensation, 6 dB, and phase deviation 0.5. Regions were selected where the depth was 20 to 30 m from the transducer face, acoustic intensity was low, targeted by pelagic trawling and showed distinct differences in the frequency amplitudes, (Figure. 7.3). Selection of regions based on these criteria was expected to reduce the known biases in *in situ* target strength data due to depth and target density (Sawada et al. 1993, Soule et al. 1995 and Koslow et al. 1997). For each region the mean linear target strength was calculated for the 38 and 120 kHz split beam transducers and compared to previous target strength measurements summarised in Table 7.2, following Kloser et al. (1997).

**Table 7.2. Dominant species at St. Helens Hill with swim bladder description and estimated target strength at 38 kHz from in-situ measurements, Kloser et al. 1997.**

| Species | Swim bladder type | Mean total length cm | Approximate Target Strength 38 kHz | Multi-frequency category |
|---|---|---|---|---|
| Orange roughy | Wax ester filled | 36* | -48 to -52 | orange roughy |
| Small midwater fishes (9 species) | Gas filled | 7-10 | -48 to -55 | small gas bladder |
| Macrourids (8 spp) | Spongy tissue gas matrix | 34 | -42 | large gas bladder |
| Morids (2 spp) | Gas filled | 50 | -32 | large gas bladder |

* measured as standard length

### 7.3.7 Simple gas-bladder resonance model

To investigate the normal incident target strength (TS) of gas-filled swim bladders with depth and frequency, the simple model developed for spherical spheres by Andreeva (1964), adapted for prolate spheroids by Weston (1967) and applied by Holliday (1971) was used in the following equations with minor changes in notation:

$$TS = 10\log 10(\sigma_{bs}) \qquad (7.1)$$

$$\sigma_{bs} = a_{es}{}^{2}\left(\left(\left(\frac{f_p}{f}\right)^2 - 1\right)^2 + \frac{1}{\delta^2}\right)^{-1} \qquad (7.2)$$

$$f_p = f_o 2^{\frac{1}{2}} \varepsilon^{-\frac{1}{3}} (1-\varepsilon^2)^{\frac{1}{4}} \left\{ \ln\left[\frac{1+(1-\varepsilon^2)^{\frac{1}{2}}}{1-(1-\varepsilon^2)^{\frac{1}{2}}}\right]\right\}^{-\frac{1}{2}} \qquad (7.3)$$

$$f_o = \frac{1}{2\pi a_{es}} * \left(\frac{3\gamma P + 4\mu_1}{\rho}\right)^{\frac{1}{2}} \qquad (7.4)$$

$$P = (1 + 0.103D) * 10^5 \quad (7.5)$$

Here, TS is the target strength and $\sigma_{bs}$ is the acoustic backscattering cross section at the incident acoustic frequency, $f$, of the equivalent spherical swimbladder volume of radius $a_{es}$ with a prolate resonant frequency, $f_p$, and resonance quality factor of $\delta$. The prolate resonant frequency is a function of the spheroid eccentricity, $\varepsilon$, and the spherical resonant frequency, $f_o$, at a hydrostatic pressure, P, for fish depth, D and fish tissue density, $\rho$, with a ratio of specific heats for the swim bladder gas, $\gamma$, and the real part of the complex shear modulus of the fish tissue defined by, $\mu_1$. The eccentricity, $\varepsilon$, is defined by the ratio of the major semi-axis to the minor semi-axis for the equivalent prolate spheroid and is assumed to be five.

To explore the indicative form of the model for the species encountered in this study, literature values were used from previous studies on shallower water species, (Holliday, 1971). Specifically the following values were assumed, $\mu_1 = 10^5$ Pa, $\gamma = 1.4$ and $\rho = 1.075$ kg m$^3$ and $\delta = 5$. No measurements at depth were available for the equivalent spherical radius, $a_{es}$, of the gas-bladders but to best fit the experimental data these were set to 1.4 mm for the small gas-bladdered myctophids and 5.1 mm for the larger gas-bladdered macrourids/morids. These values represent the lower end of the range of values calculated by Brooks (1975) for mid-water species.

### 7.3.8 School size and biomass comparison

The size of orange roughy schools and associated biomass was calculated separately for both the single frequency straight line and multi-frequency loop surveys. Using the ECHO software the single 38 kHz frequency N-S transect data (MUFTI towed transducer at depth 450 m) were evaluated for echo structures that originate from orange roughy based on the accumulated knowledge of trawl catches and temporal school behaviour in the region. These echo features were circled with a mouse and the acoustic returns echo integrated by linearly summing the volume reverberation values vertically, automatically compensating for near seabed shadow-zone, and averaging horizontally according to Kloser et al. (1996).

The MUFTI multi-frequency loop transects circled the hill at 100 m depth contour intervals (750-1150 m depth) with the transducer 150 to 200 m above the seabed. The multi-frequency data were used to highlight the orange roughy based on the mixing of the three frequencies and regions on the echograms were circled with a mouse. The highlighted regions, on the 38kHz frequency, were echo integrated per transect to produce an area backscatter, $Sa_l$, value for each loop representing a contour interval area, $A_l$. The biomass, B, of orange roughy was calculated assuming a mean weight, W, of 1.5 kg and mean target strength, TS, of –50 dB re 1 m$^2$ where:

$$B = \frac{\left( \sum_{l=1}^{n} \overline{Sa_l} A_l \right) W}{4\pi 10^{\frac{TS}{10}}} \text{ kg.} \quad (7.6)$$

Further details of the biomass calculations are outlined in Chapter 4.2.

## 7.4 Results

### 7.4.1 Biological sampling

The species aggregated by dominant acoustic group are shown in Table 7.3 for both the demersal and pelagic trawl. Twenty-two demersal tows were carried out on St. Helens Hill (Figure 7.1), of which 15 contained > 20 fish with a total catch of 35.1 tonnes. The 45 species obtained were grouped into 7 categories and these were further refined to 3 categories based on catch compositions being greater than one percent of the total catch. Table 7.3 summarises the percentage catch by numbers for the three acoustically dominant species caught with the demersal trawl those being orange roughy (96%), macrourids (2%) and morids (1%). Figure 7.1 shows the trawl positions and the relative proportions of the dominant species where the morid and macrourid composition have been combined.

**Table 7.3. The numbers and proportions of each species group for 22 demersal trawls around St Helens Hill location of trawls as per Figure 7.1.**

| Acoustic group | Tot # | Tot wt | % composition | |
|---|---|---|---|---|
| | | kg | Tot # | Tot wt |
| Orange Roughy | 21685 | 34127 | 96 | 99 |
| Oreos (5 spp) | 22 | 20 | 0 | 0 |
| Sharks (8 spp) | 39 | 121 | 0 | 0 |
| Eels (2 spp) | 11 | 11 | 0 | 0 |
| Macrourids (8 spp) | 408 | 62 | 2 | 0 |
| Morid cods (2 spp) | 272 | 229 | 1 | 1 |
| Miscellaneous (18 spp) | 82 | 48 | 0 | 0 |
| Total | 22519 | 34619 | | |

Three pelagic depth stratified tows were targeted around the hill, 50 – 100 m above the seabed. The species compositions are summarised in Table 7.4. In total, the pelagic trawl caught 35 species of pelagic fish, squid and crustacea. In relation to acoustics the gas-bladdered myctophid was most abundant and accounted for 95.5 % of the catch. The dominant myctophids by numbers and swimbladder type (as determined by visual inspection at the surface) are shown in Table 7.4. The total length of the dominant myctophids formed strong length modes at 7 and 10 cm, Kloser et al. (1997).

**Table 7.4. Mid-water fishes with gas-filled swimbladders comprising >1% of the total catch by numbers in three pelagic trawls. Macrourid and morid species were caught in the mid-water trawls but are not included here as they comprised <0.3 % of the catch by numbers.**

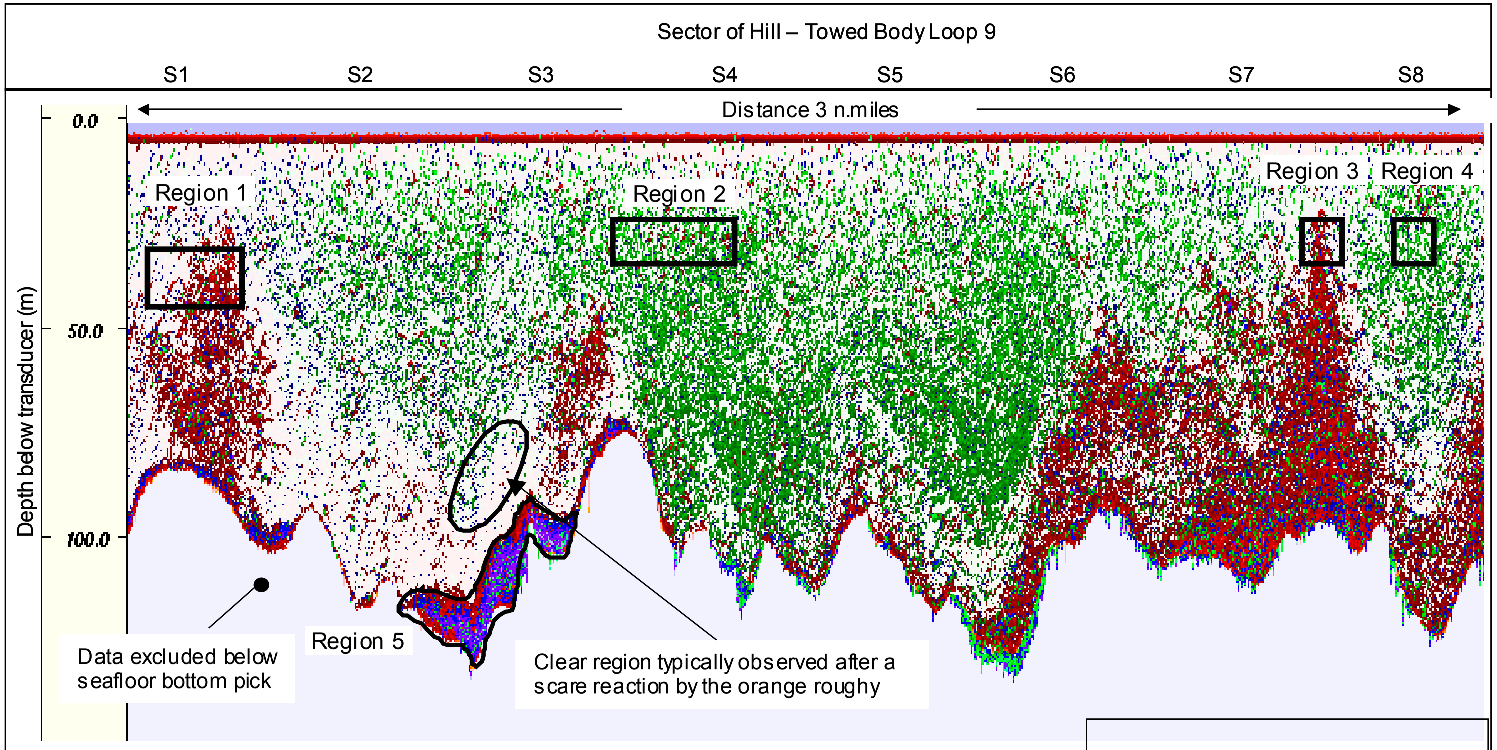
| Species | Total numbers | % of catch numbers | Swimbladder form |
|---|---|---|---|
| Diaphus danae | 87 | 30.2% | gas bladder |
| Lampanyctus australis | 72 | 25.0% | large oval gas bladder |
| Lampichthys proceros | 31 | 10.8% | large oval gas bladder |
| Photichthys argenteus | 25 | 8.7% | large thick-walled gas bladder |
| Argyropelecus gigas | 20 | 6.9% | large circular gas bladder |
| Hygophum hanseni | 19 | 6.6% | gas bladder |
| Lampanyctus sp. | 11 | 3.8% | elongate gas bladder |
| Diretmus argenteus | 7 | 2.4% | gas bladder |
| Metelectrona ventralis | 3 | 1.0% | large oval gas bladder |
| Total % catch of top 9 species | | 95.5% | |

### 7.4.2 Acoustics

The multi frequency acoustic loop survey data were analysed as outlined in the methods, (Figure 7.2). Figure 7.3 shows a loop of the hill and a compressed echogram highlighting the frequency differences by sector of the hill. The towed system was deployed at a mean depth of 700 m. From the compressed echogram it is possible to associate the dominant species grouping for each sector of the hill and relate it to the demersal catch (see Figure 7.1). Both the acoustics and demersal trawl distributions indicate that orange roughy were located in sectors 1, 2 and 3 and morids and macrourids were concentrated in sectors 6 and 7 as well as sectors 1 and 3 along with orange roughy. It should be noted that the demersal trawling was undertaken over several days whereas the acoustic loop transect was carried out in 1.5 hours. Complete congruence between the two data sets is therefore not expected.

To directly compare volume reverberation and *in situ* target strengths between frequencies, five regions were extracted based on depth, frequency dominance and sector on the hill associated with a particular species group (Figure 7.3). A summary of the echogram region volume reverberation (Sv) and *in situ* target strength metrics compared to biological groups is shown in (Table 7.5) and the difference in mean Sv at 12 and 120 kHz relative to 38 kHz is summarised in (Figure 7.4). Regions 1 and 3 are associated with large gas-bladdered species dominated by the 12kHz frequency, 4 to 8 dB higher than the backscatter at 38 and 120 kHz. The mean *in situ* target strengths in these regions range from –44.1 to –39.7 dB at 38 kHz and 1.5 to 2.1 dB higher at 120 kHz. In regions 2 and 4, which were associated with small gas-bladdered species, the 38 kHz frequency was dominant with the volume backscatter 5.3 to 11.6 dB higher than the 120 and 12 kHz frequencies respectively. The mean *in situ* target strength in this region ranges from –48.9 to –49.3 dB at 38 kHz and 7 to 8.7 dB lower at 120 kHz. Region 5, which we ascribe to orange roughy due to the characteristic avoidance response and trawl catch is characterised by high backscatter at 120 kHz, 2.9 to 4.6 dB higher than at 12 or 38 kHz respectively. The lowest backscatter for the orange roughy region was from the 38 kHz frequency. No *in situ* target strength data were obtained from region 5 due to the range from the transducer and density of fishes.

**Figure 7.3. Multi-frequency acoustic data from a loop transect around St. Helens Hill showing the dominant acoustic species distribution as a function of sector around the hill according to the frequency mixing of Figure 7.2. The towed body (MUFTI) is at a depth of ~700 m and is being towed clockwise with the vessel following the 850 m depth contour. The five regions extracted for volume reverberation and target strength measurements are shown by enclosed polygons.**




| Region | Dominant species group | Dominant frequency | Colour palette |
|---|---|---|---|
| 1 and 3 | Macrourids/Morids | 12kHz | Red |
| 2 and 4 | Myctophids | 38kHz | Green |
| 5 | Orange Roughy | 120kHz | Blue |

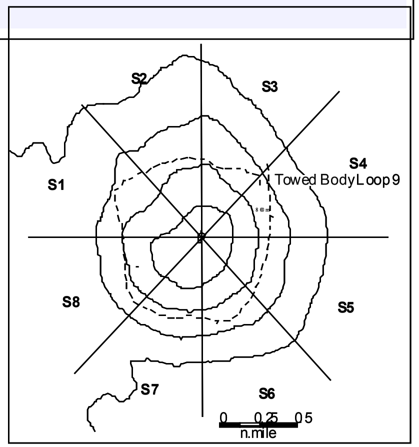
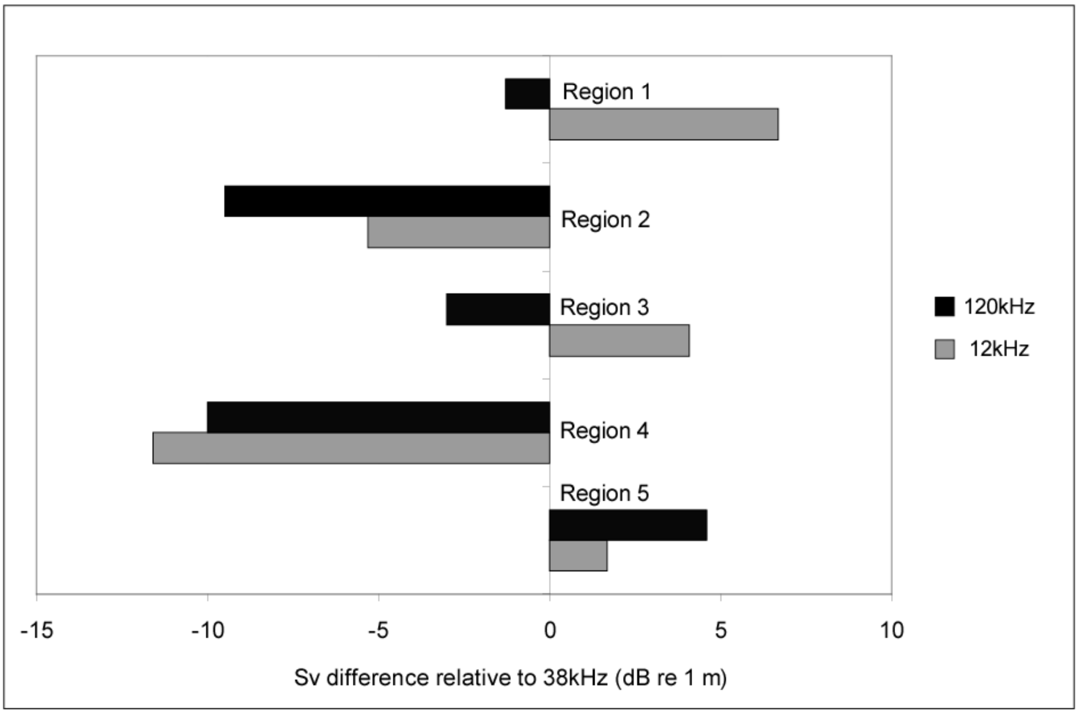


**Figure 7.4. Mean volume reverberation difference at 12 and 120 kHz frequencies relative to 38 kHz for each of the five selected regions based on Table 7.2. Region 5 associated with orange roughy has the lowest volume reverberation at 38 kHz..**




The resonance model of small ($a_{es}$ = 1.4 mm) and large ( $a_{es}$ = 5.1 mm) gas-bladders shows the potential change in target strength as a function of depth assuming constant swimbladder volume, (Figure 7.5). At the mean MUFTI operating depth of 750 m the experimental target strength measurements are compared to the simple model, (Figure 7.6). The target strength values for the 12 kHz frequency have been extrapolated using the 38 kHz *in situ* TS values and the difference in volume backscattering strength for regions 4, associated to myctophids, and region 1, associated to macrourids/morids. The simple normal incident resonance gas-bladder model supports the general trend in the target strength measurements with frequency and hence our interpretation that the 38 kHz frequency has a higher backscatter (relative to 12 and 120 kHz) for smaller gas-filled swim bladders and the 12 kHz frequency has a higher backscatter (relative to 38 and 120 kHz) for larger gas-filled swim bladders in this example, (Figure 7.4).

The estimated biomass of orange roughy on the St Helens Hill seamount during surveys in 1999 ranged from null to 7000 tonnes for the N-S grid surveys and 1100 to 2600 tonnes for the MUFTI loop surveys, Table 7.6. The null value obtained from the grid survey indicates that no schooling features were observed that could be attributed to orange roughy. The error on the biomass calculation due to improperly assigning species composition using the N-S grid surveys could be a positive bias as high as a factor of 6.4. This error in the biomass calculation can be observed in the school areas of the echograms where they pass over similar school features, (Figure 7.7). The estimated size of the orange roughy school defined from the grid survey has a mean school height of 82 m whilst the loop survey crossing the same school shows the mean school height to be 13 m. No avoidance of orange roughy due to the MUFTI transducer at >150 m above the school is evident in the echograms.

**Figure 7.5. Simple resonance target strength model of a spherical gas-bladder for small (radius, 1.4 mm ) and large (radius, 5.1 mm) fishes at 12 (solid), 38 (dashed) and 120 (dot-dashed) kHz as a function of depth, assuming constant swim bladder volume.**

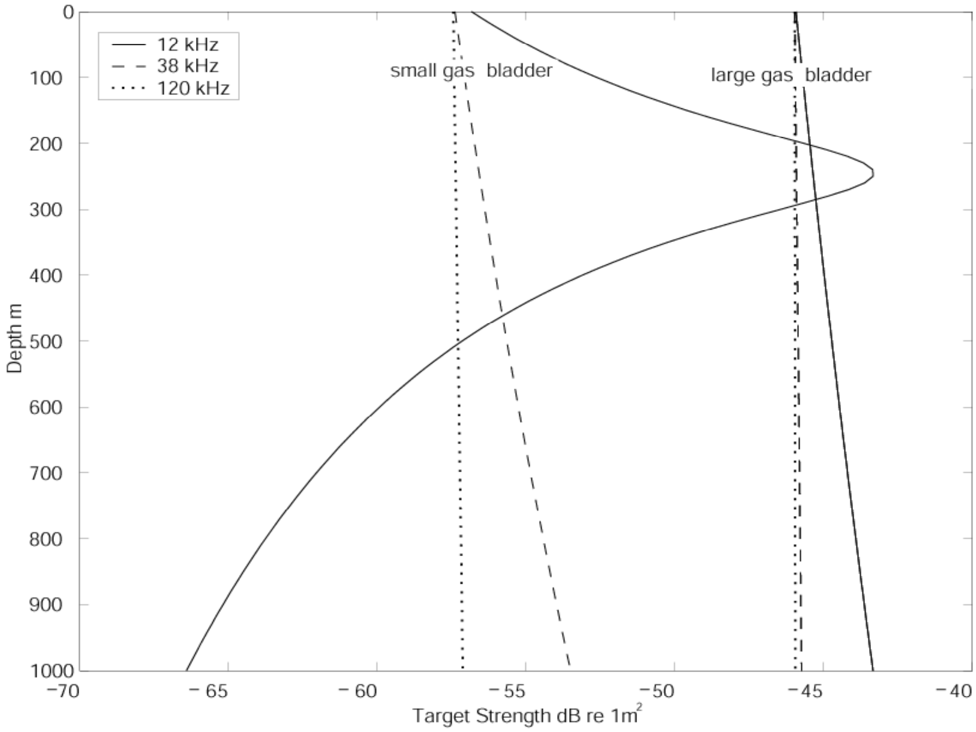


**Table 7.5. Summary of the frequency differences in volume reverberation and target strength for the selected regions identified in figure 7.3 with classification of dominant species.**

| Region | Frequency (Hz) | Mean volume reverberation Sv (dB re 1m) | Sv relative to dominant frequency in each region (dB re 1m) | Mean TS (dB re $m^2$) | Number of targets | Relative TS to 38kHz per region (dB) | Classification of dominant species based on pelagic and demersal trawling |
|---|---|---|---|---|---|---|---|
| 1 | 12 | -63.3 | 0 | na | na | na | large gas bladder |
| 1 | 38 | -70.0 | -6.7 | -44.1 | 190 | 0 | large gas bladder |
| 1 | 120 | -71.3 | -8 | -42.6 | 48 | 1.5 | large gas bladder |
| 2 | 12 | -69.9 | -5.3 | na | na | na | small gas bladder |
| 2 | 38 | -64.6 | 0 | -49.3 | 240 | 0 | small gas bladder |
| 2 | 120 | -74.1 | -9.5 | -56.3 | 81 | -7.0 | small gas bladder |
| 3 | 12 | -59.3 | 0 | na | na | na | large gas bladder |
| 3 | 38 | -63.4 | -4.1 | -39.7 | 206 | 0 | large gas bladder |
| 3 | 120 | -66.4 | -7.1 | -37.6 | 48 | 2.1 | large gas bladder |
| 4 | 12 | -77.1 | -11.6 | na | na | na | small gas bladder |
| 4 | 38 | -65.5 | 0 | -48.9 | 147 | 0 | small gas bladder |
| 4 | 120 | -75.5 | -10 | -57.6 | 24 | -8.7 | small gas bladder |
| 5 | 12 | -50.6 | -2.9 | na | na | na | orange roughy |
| 5 | 38 | -52.3 | -4.6 | na | na | na | orange roughy |
| 5 | 120 | -47.7 | 0 | na | na | na | orange roughy |

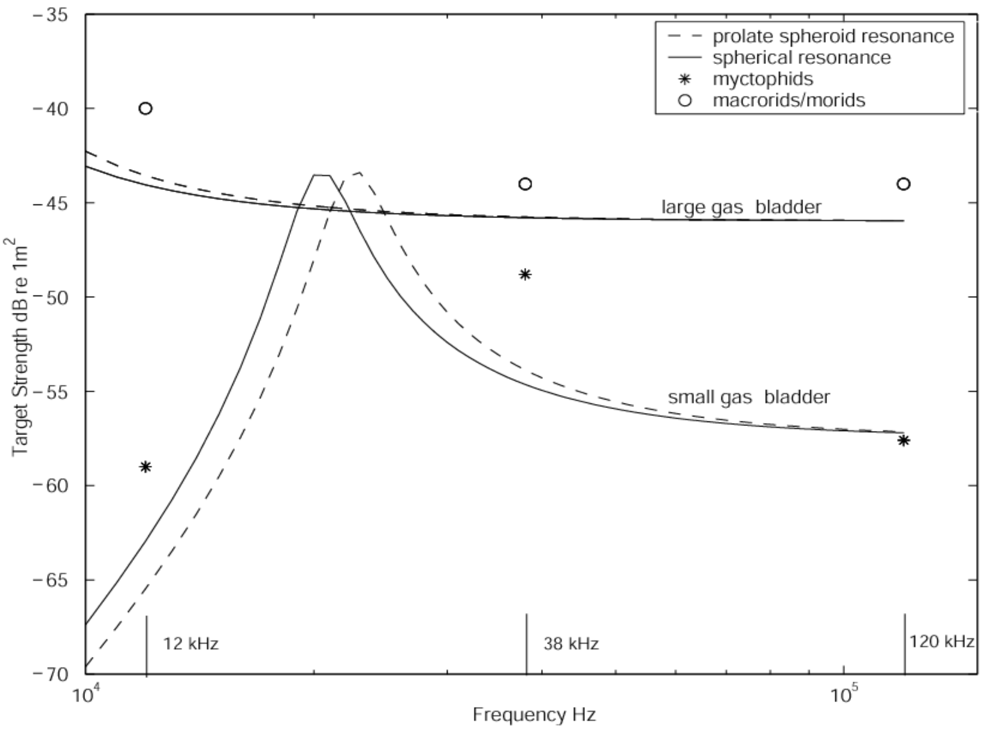
**Table 7.6. Biomass estimates of orange roughy at St Helens Hill at 38 kHz based on N-S grid surveys with MUFTI at 450 m depth and trawl species identification, MUFTI loop surveys at 150 - 200 m above seabed using frequency mixing to highlight orange roughy schools.**

| Date | Survey type | Biomass estimate (tonnes) | Dominant species identification method |
|---|---|---|---|
| Jul-96 | N-S Grid | 9300** | trawl |
| 19-Jul-99 | N-S Grid | Null | trawl |
| 31-Jul-99 | N-S Grid | 3500-7000+ mean 5200 | trawl |
| 20-Jul-99 | Loop | 2600 | multi-frequency |
| 31-Jul-99 | Loop | 1100 | multi-frequency |

+ lower value indicates stricter classification of orange roughy schools using multi-frequency classifications

** mean of two surveys

**Figure 7.6. Simple resonance target strength model at 750 m depth for a normal incident prolate (eccentricity of 5, dashed line) and spheroid (solid line) swimbladder for small and large fishes (equivalent spherical radius of 1.4 and 5.1 mm respectively) with experimental data for region 1 (macrourids/morids, o, symbol) and region 4 (myctophids, * symbol) at the three frequencies 12, 38 and 120 kHz. The 12 kHz target strength values have been extrapolated from the ratio of Sv differences between the 38 kHz frequency in table 7.5.**

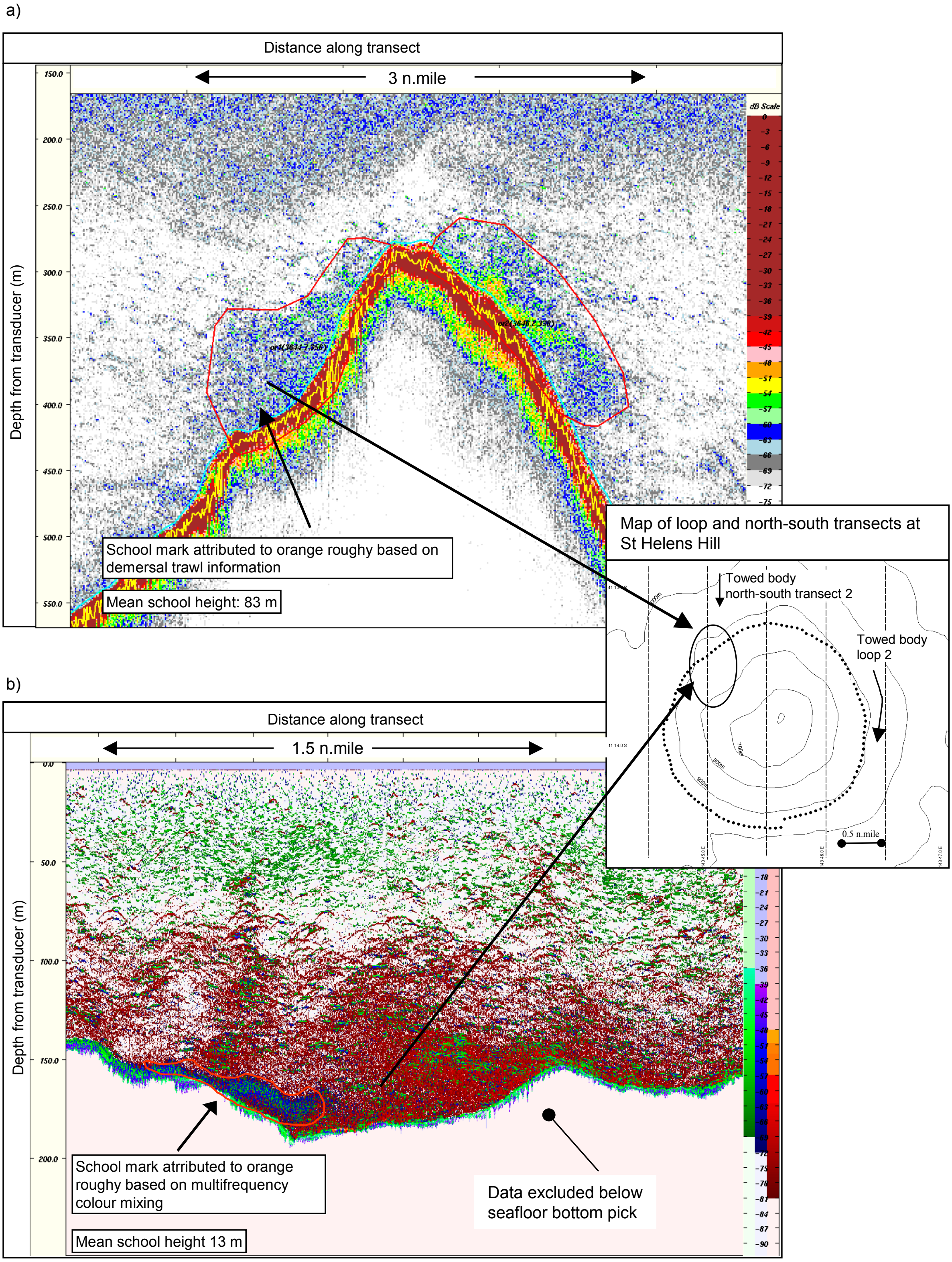


## 7.5 Discussion

Our acoustic system has identified three acoustic groups based on the amplitude differences in the frequencies. The ECHO software enabled these differences to be highlighted in a dynamic fashion that extracts the features of interest (Kloser et al. 1998). In this case we have attributed the frequency differences to three acoustic groups as determined by the type of swimbladder and fish size. The three groups are: myctophids of total length less than 10 cm, morids and macrourids with lengths > 30 cm and orange roughy with a mean standard length of 36 cm. The ability to identify orange roughy in schools from other species is a major advance in interpreting the single frequency echograms and has been used in several biomass surveys of orange roughy both in Australia and New Zealand with consistent observations (Kloser et al. 2000, see also Chapter 4).

Our knowledge of orange roughy avoidance behaviour and the location of orange roughy schools on St Helens hill enabled us to tune the ECHO software (Koslow et al. 1995, Kloser et al. 1997). The characteristic avoidance reaction of orange roughy is evident in the echogram Figure 7.3. A characteristic sign of avoidance on an echogram is the low reverberation region remaining when the orange roughy school moves. This can be observed in the region above the school observed in Figure 7.3. The implication of this avoidance is that any remote sensing species identification system needs to be far enough away from the fish (ranges from 100-150 m are typical) so as not to influence their behaviour. Our use of the 120 kHz frequency is not ideal due to its high absorption in sea water, 31.1 dB $km^{-1}$ re 1 μPa at 1 m, reducing the effective usable range to 200 m. To improve this method other frequencies and or pulse transmission methods should be explored.

**Figure 7.7. Example of the difference in school size and acoustic species recognition using acoustic data in July 1999 from the 38 kHz MUFTI N-S transects at 450 m depth and an associated loop transects at 750 m depth and height above bottom of 150 – 200 m.**



Simple frequency models of the resonance from small gas-bladders show a marked sensitivity to gas bladder size, eccentricity and depth (Johnson 1977, Babailov and Kanevskii 1988). For regions dominated by fishes with small gas-bladders, our experimental results show that the backscatter measured at 38 kHz is 5 and 12 dB higher than for the 12 and 120 kHz frequencies respectively. In this region the mean *in situ* target strength at 38 kHz is –49 dB and at 120 kHz is –57 dB. Based on a simple model (Weston 1967) we propose that swimbladder resonance is responsible for the high 38 kHz backscatter in this region. Conversely the absence of a gas filled swim bladder in orange roughy results in a relatively lower reflectance at 38 kHz which demonstrates that this frequency is not optimal for detection of orange roughy. For regions dominated by fish with large gas-bladders the results show a high backscatter at 12 kHz, 4-7 dB higher than 38 kHz and 7-8 dB higher than 120 kHz. For the region of aggregated orange roughy the backscatter at 120 kHz is 2.9 and 4.6 dB higher than for the 12 and 38 kHz respectively. Thus the 120 kHz frequency has the best discrimination for orange roughy due to its lower relative response to small and medium sized gas bladdered fishes. The 12 kHz wide beamwidth is best for the large gas bladdered fishes and the 38 kHz is best for the small gas bladdered species experienced in this study.

We have used a simple resonance model to explain general trends in experimental observations. Our choice of gas-bladder size and, to a lesser degree, elongation greatly alters the form of the model output. We have not measured directly the expected swim-bladder size at depth or parameters such as the ratio of specific heats of the swim bladder gas and the fish tissue density and complex shear modulus over the frequency range. Measurements of swimbladder size would ideally be based on the required fish buoyancy at depth based on the fishes' lipid content. The effect of swimbladder orientation has also not been included (Babailov and Kanevskii 1988). We conclude from our spherical resonance target that the general trend that we observe with the experimental data will also hold for Gaussian changes in tilt orientations. Feuillade and Nero (1998) and Ze (1997) have developed more complex gas-bladder resonance scattering models. These models may be useful to explore more quantitative assessments of the multi-frequency method. In this work we have used the simple model as a conceptual tool to explore the relationships in the experimental observations of the swimbladder fishes, excluding orange roughy.

Orange roughy represent complex scatterers with an oscified head, dense backbone and high lipid content including a wax ester filled swimbladder making accurate modeling challenging. Existing models based on overall shape and composition parameters are necessarily simplistic and there is a large disagreement between model results between researchers (Barr 2001 and McClatchie and Ze 2000). *In situ* data appear to supports the model results of Barr (2001) where a 33.6 cm orange roughy has a model TS of ~ -51 dB and in-situ measurements of –51 to –52.1 dB (Kloser et al. 2000). No sensitivity analysis of the model to variations in radius of curvature and/or sound speed and density measurements of fish flesh and wax ester were performed, so the comparison may be fortuitous. The frequency response model of orange roughy proposed by Barr (2001) has many peaks for an individual fish but we propose that these peaks would smooth out for a range of fish sizes with more complicated composition and tilt angles that are encountered in the wild. The model of Barr (2001) does not explain the higher backscatter at 12 and 120 kHz experienced in this study.

A limitation of the equipment used in this trial was the wide 40 degree beam of the 12 kHz system. Unfortunately, to have a narrow beam at this low frequency similar to the 7 degree beamwidth of the 38 kHz and 120 kHz systems would require a transducer 1.2 m in diameter. The sampling width and volume at the half power points of the 12 kHz, 1 mS pulse length system at 100 m depth is 73 m and 3121 $m^3$ compared with 12 m and 112 $m^3$ for the 7 deg. 38 and 120 kHz frequencies; the 12 kHz frequency effectively samples 28 times the water volume compared to the 38 and 120 kHz frequencies at 100 m depth. As the 12 kHz shows higher reflectance for the fishes with large gas-bladders, they appear even more dominant on a multi-frequency echogram due to the greater sampling volume. Multi-frequency echograms derived from differing beamwidths complicates and limits quantitative assessment. To reduce the impact of differing sample volumes, the species mixtures need to be homogeneous over dimensions larger than the largest sampling volume, in this case 3121 $m^3$ at 100 m depth. Small, apparent orange roughy schools were sometimes completely absent from the 12 kHz records making unsupervised classification based on multi-frequencies problematic.

An obvious advantage of the multi-frequency technique we have developed is the speed at which the overall species composition can be obtained during a survey. The single loop survey of the hill was undertaken in 1.5 hours whereas the trawl sampling was undertaken over several days (with possible movement of fishes) and many parts of the Hill were untrawlable. The method of frequency mixing is also relatively insensitive to calibration errors. The user can isolate a characteristic in the echo space by adjusting the colour amplitude mixing to be equal at all frequencies. Frequency amplitude differences can then be observed in other parts of the image. We have supplemented our interpretation here by both physical sampling and using a simple resonance model to explain the gross differences observed. Using this species identification technique, the snapshot biomass of orange roughy at St Helens Hill is a factor of 2 to 6.4 lower than the traditional N-S grid surveys. The 1996 and 1999 N-S grid surveys shows that the estimated biomass on the grounds has continued to decline and our new method reinforces the observed decline. This decline in biomass is occurring at a time when the assessment model is expecting an increase and has major implications for the management of the fishery (Bax 1999).

This application of multi-frequency species identification has highlighted the problem of the 38 kHz frequency which is commonly used to survey orange roughy stocks. It appears that this frequency produces higher reflectance for myctophid fishes with small gas bladders at our operating depth than the 12 and 120 kHz frequencies. The 120 kHz frequency is the best of the three frequencies used for orange roughy discrimination but has a very limited range due to its high absorption. The method of frequency mixing developed here can be used more generally to explore echo features in a wide range of multi-frequency acoustic data sets.

# 8 SUMMARY AND ANALYSIS OF THE JULY 2001 EAST COAST ORANGE ROUGHY SURVEYS FROM INDUSTRY FISHING VESSELS

## 8.1 Introduction

In July 1999, we successfully collected acoustic data from industry vessels after having existing EchoListener equipment modified for deep water operation, Chapter 6. The utility of the information was in some doubt due to the single year of sampling and no identifiable schools at St Helens Hill and minimal sampling at St Patricks Head. Subsequently the orange roughy assessment group decided that an opportunistic survey be carried out on both spawning sites during July 2000. The original FRDC project 99/111 was extended to allow an extra survey program in July 2000. Unfortunately due to variable fishing vessel schedules, no acoustic or biological data could be collected from the existing vessels carrying EchoListener equipment used on the Cascade Plateau surveys. To minimise problems due to vessel availability we organised a dedicated St Helens Hill vessel *Celtic Rose* to survey during 2001 as well as developing recording capability for the high resolution ES60 acoustic data onboard the *Petuna Explorer*.

The objectives of the 2001 survey were to collect acoustic and biological data from industry vessels in a low-cost survey, and to assess the suitability of using such data to make qualitative and quantitative assessments on the biomass of orange roughy at the Eastern Zone spawning grounds. Survey sampling included taking 1000 otoliths from orange roughy for age estimates. The acoustics data were collected in two operational modes: 1) data collected during the course of normal fishing operations and 2) data collected from dedicated survey transects. Analysis is made of both types of data to investigate what information can be obtained from each. The advantages of data collected from these two operational modes are discussed with consideration to the cost and complexity of each method.

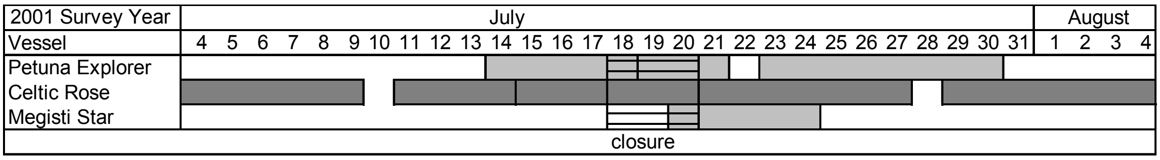
A number of factors influenced the selection of vessels for the survey: the vessels needed to perform the task voluntarily, have good acoustic characteristics and be fishing the east coast grounds during the spawning season. The *Celtic Rose*, limited by its size, has fished regularly at St Patricks Head and St Helens Hill which made it an obvious candidate, although its acoustic performance was unknown. The *Petuna Explorer*, with its state of the art Simrad ES60 system, was a desirable vessel and would most likely be fishing the east coast grounds in 2001. From March to June 2001, we invested effort into collecting acoustic data from the Petuna's ES60 system to assess the data acquisition, data quality and data management issues with that system (Ryan 2001). The *Megisti Star* became available opportunistically and had wiring in place to connect the Echolistener across the 28kHz transducer. This vessel provided extra coverage over the key peak spawning period and gave some redundancy.

To give the schools an opportunity to form up and for the vessels to have a clear area to survey, a voluntary closure was requested and organised by SETFIA. The closure ran from the $18^{th}$ to the $20^{th}$ of July.

## 8.2 Voyage Descriptions

Acoustic and biological data were collected over the 2001 spawning season from three fishing vessels, *Celtic Rose*, *Petuna Explorer* and *Megisti Star*. The *Celtic Rose* collected acoustic and catch data over the month long season and provided us with fish samples from 27 of their 76 trawls to support acoustic interpretation, estimate spawning condition and collect otoliths. *Petuna Explorer* collected acoustic data with its ES60 echo sounder and enabled our observer Mark Lewis to collect samples from 46 trawls at the peak of the spawning period. To collect background environmental information, 3 CTD casts were made from the *Petuna Explorer*. To enable the acoustic data to be corrected for losses due to vessel movement, a prototype motion reference unit was designed and built at CSIRO and installed on the *Petuna Explorer*. The *Megisti Star* collected acoustic data opportunistically over a three-day period with associated biological data from 22 trawls collected by an ISMP observer. Figure 8.1 shows the times the vessels were on the grounds collecting biological and acoustic information and also indicates the voluntary closure period which operated from 18th July 01:00 to 20th July 23:00.

**Figure 8.1 Summary of cruises – all survey vessels - July 2001.**




## 8.3 Acoustic Surveys from Industry Vessels

Tim Ryan, Rudy Kloser and Alan Williams

### 8.3.1 Acoustics - Equipment

Acoustic data were collected from the installed vessel mounted echosounder systems on each of the three vessels (Table 8.1). Sonardata Echolisteners were used on the *Celtic Rose* and *Megisti Star* to digitise and electronically record acoustic data from their 28 kHz wide-beam fisheries sounders. The Simrad ES60 software on the *Petuna Explorer* was updated to enable recording of the digitised acoustic signal, thus ES60 38kHz, narrow-beam data were recorded at full sample rate.

**Table 8.1. Echosounder Systems used on the Orange Roughy fishing vessels**

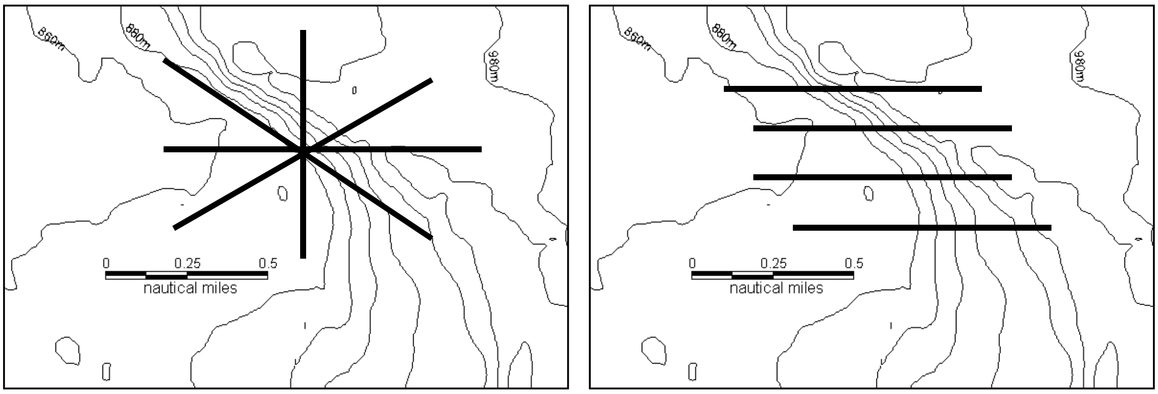
| Vessel | Echosounder | Frequency | Transducer | Logging system | Digital sampling resolution |
|---|---|---|---|---|---|
| *Celtic Rose* | Furuno FCV140 | 28kHz | 14° Single Beam | Echolistener (Serial No. EL113, Listen v2.2 ) | 0.5 m |
| *Megisti Star* | JRC JBF200 | 28kHz | 14° Single Beam | Echolistener (Serial No. EL2001, Listen v2.2 ) | 0.5m |
| *Petuna Explorer* | Simrad ES60 | 38kHz | ES38B 7° Split Beam | ES60 | 0.1 m |

## 8.3.2 Acoustics - Survey Methods

### Survey design

Low cost acoustic and biological surveys in 2001 were performed voluntarily by vessel operators. The vessels performed surveying tasks in between normal fishing operations and we optimised our survey strategy to maximise data quality. Within this constraint, the acoustic surveys needed to satisfy two objectives. Firstly, we needed acoustic data during the entire orange roughy spawning season on both grounds to monitor the school behaviour and monitor the build up and decline on the grounds. We envisaged that this coverage would occur during the vessel's normal fishing operations. Secondly, acoustic data were needed that would enable schools to be spatially quantified at a point in time. To this end, when significant schools were located, their extent was to be mapped out by a series of short transects crossing over the estimated centre of school or by using a short rectangular grid survey (Figure 8.2).

**Figure 8.2 Star and grid pattern survey designs used to map orange roughy school extent and obtain biomass.**




## 8.3.3 Acoustics - Analysis Methods

### Acoustic observation of the fishing grounds over the survey period

Acoustic echograms from the three vessels were inspected at St Patricks Head and St Helens Hill for data quality and orange roughy school distribution and dynamics. The computer screen or paper printout gains were set to give a consistent appearance when viewing data from each of the echosounder systems. Instances of poor quality data were noted and usually caused by poor weather and electrical and acoustic interference. This qualitative assessment proved a pre-screening for later analysis of the data.

### Calculation of School Metrics

#### Sampling of school marks during the course of normal fishing operations

During the course of normal fishing operations, the vessel passed over orange roughy schools for identification and subsequent capture. Each of these passes (transects) sampled the school's vertical cross section where the schools area extent, shape or the location of the maximum was not known. In order to determine the true size or even use the vertical cross section as a relative measure over time, metrics of the school shape on the echogram were obtained.

The echograms were inspected to identify 'roughy-like' schools and were determined based on:

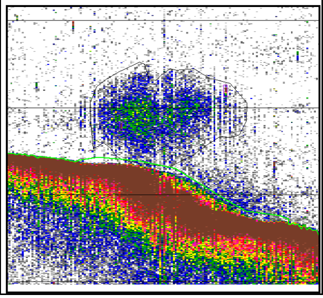
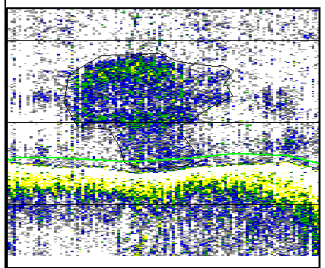
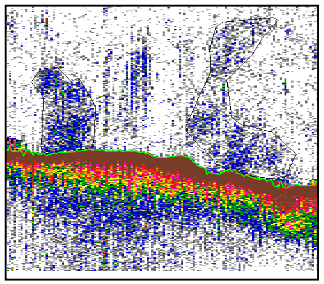
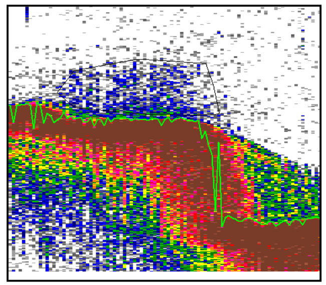
- school location, vertical cross sectional area, intensity, and dynamics,

- timing and duration of the spawning event,
- comparison with previous years data,
- comparison with St Patricks Head and St Helens Hill school shapes,
- comments by the various orange roughy skippers recorded at the time and over seasons
- location and size of the demersal trawl catches.

These factors were used in deriving a schools' likelihood of being made up of primarily orange roughy classified as *high*, *medium*, *low* or *indeterminate* (Table 8.2). The highest classification originated from echograms where the trawl catch was >3 tonne. These echograms were inspected first and effectively trained the user in interpreting other school features in the echograms and associating them with lower classification rating.

Schools on the digital echograms were defined by drawing polygons around the school feature using EchoView software. School polygon length, height and start/stop position were exported for further analysis and plotted in a GIS to give an overview of their spatial distribution (Figure 8.4).

**Table 8.2 Criteria and confidence levels used to classify fish schools as orange roughy**

| | Confidence that a school is correctly identified as orange roughy. | | | | |
|---|---|---|---|---|---|
| | High | Medium (a)* | Medium (b)* | Low | Indeterminate |
| Criteria | | | | | |
| Has general appearance of a roughy school | Yes | No | Yes | Possibly | No |
| Contrast between school signal and surrounding backscatter | High | Possibly low | High | Possibly Low | Possibly Low |
| Size of trawl catch verifying school composition is mostly roughy | >3 tonnes | >3 tonnes | None or < 3 tonnes | None or < 3 tonnes | None or < 3 tonnes |
| Spatial Location | Not a primary criteria if trawl catch is high and mostly roughy | Not a primary criteria if trawl catch is high and mostly roughy | Region known for roughy aggregations | Region known for roughy aggregations | Region not known for roughy aggregations |
| Examples | Trawl catch 40 tonne  | | Trawl catch 1 tonne  | Trawl catch 1.3 tonne  | No associated trawl catch  |

* Medium confidence assigned either where (a) acoustic evidence is inconclusive but trawl verification is strong, or (b) acoustic evidence is strong but there is no trawl verification.

#### Corrections to school indices

### Length correction

Due to the spreading of the beam with depth, the true length of a school section will be overestimated when calculated from vertical acoustics. This is because a school entering into (and leaving) the outer beam of the school will be some distance off centre while at that time the position is measured relative to the centre of the beam. The method of applying corrections to length based on an effective beam angel is noted (e.g. Diner 1998) but the applicability of applying these corrections to a deepwater species such as orange roughy needs to be investigated further. For this study we apply simple corrections for length and height based on the geometry of a spreading beam (Reid and Simmonds 1993).

Length is corrected using:

$$X_{true} = X_{meas} - 2 \cdot \mathrm{tand}(\theta) \cdot \frac{(D_{\max} + D_{\min})}{2} \qquad 8.1$$

where *Xtrue* = actual width of the school (m), *Xmeas* = measured width of the school (m), $\theta$ = half angle of the beam (deg), *Dmean*= mean school depth (m).

### Height correction

The acoustic pulse length will increase the measured height of the school but can be corrected with the equation:

$$Y_{true} = Y_{meas} - \frac{\tau}{2} \qquad 8.2$$

where *Ytrue* = actual height of the school (m), *Ymeas* = measured height of the school (m), and $\tau$ = pulse length (m)

School area was derived from the primary indices of corrected length and height:

$$A = X_{true} \cdot Y_{true} \qquad 8.3$$

where $A$ is the school vertical cross sectional area ($m^2$).

Area and mean school energy was combined as a way of producing an area index that is weighted by school density. In this way a small intense school could have the same index value as a large but dispersed school.

$$W_{area} = A \cdot S_A \qquad 8.4$$

where $S_A$ is the mean school backscatter and $W_{area}$ the school area weighted by backscatter.

#### Mapping of horizontal school extent based on dedicated vessel transects

Cruise track data were inspected to identify instances where the school marks had been mapped out with a series of transects. The horizontal school area was estimated by plotting the geographic extent of the defined schools in a GIS and then bounding the area with a manually drawn polygon (Figure 8.4). Metrics of school height, length and relative intensity were measured from these transects and, using the method described in Chapter 4.22, a biomass estimate of the amount of roughy within the bounds of the mapped schools calculated.

### 8.3.4 Acoustics - Survey Results

#### Data collection and data quality

Acoustic data from three vessels were collected successfully throughout the spawning period covering both grounds (Table 8.3). The surveys gave the largest spatial and temporal coverage of the fishing grounds by vessel mounted acoustics in any survey year to date and was carried out at a very low cost of data collection relative to a structured survey.

**Table 8.3 Details of acoustic data collection**

| Vessel | Acoustic System | Number of Days | Dates | Data (GBytes) |
|---|---|---|---|---|
| Petuna Explorer | 38kHz ES60 | 17 | 14th July 30th July | 15.5 |
| Celtic Rose | 28kHz Furuno | 32 | 4th July 4th August | 2.2 |
| Megisti Star | 28kHz JRC | 5 | 20th July 24th July | 0.6 |

The data quality varied between the vessels with the *Petuna Explorer's* acoustics being of highest quality (high signal to noise) due to its state-of-the-art ES60 echosounder combined with a well-located 7° beamwidth split beam 38kHz transducer. This echosounder has a large dynamic range and is able to log data at full sample resolution for both water column and seabed echoes. The split-beam transducer is easy to calibrate as per Foote (1982) and gives the potential for an accurate relative calibration to assist in interpreting the data (not calibrated this survey). Acoustic data were logged on the vessel's own computer with no new electronic equipment needed to be fitted to the vessel. The *Megisti Star* and *Celtic Rose* have more conventional 28 kHz fisheries sounders with wide-beam 14$^{o}$ single-beam transducers. Sonardata EchoListeners (limited dynamic range) were used to digitize and electronically record the acoustic data. Generally the quality of the *Megisti Star* data was good in terms of signal to noise and degradation due to weather conditions, with schooling aggregations clearly observed in the acoustic echograms. The *Celtic Rose* acoustic signal was very susceptible to degradation in poor weather conditions and has not been used in the quantitative analysis to date. However *Celtic Rose* acoustics have proven valuable in assessing the season long distribution of orange roughy on both grounds in a qualitative way. The *Celtic Rose* and *Megisti Star* systems were not calibrated for this survey and with their single beam transducers, calibration would have been more difficult and potentially less accurate than for split-beam transducers.

#### Spatial Coverage of the acoustics

Apart from the few occasions where the vessels took time out to map schools the acoustic coverage was determined by the commercial trawling activities of the vessels. The vessels fished regions where there was the highest likelihood of obtaining good catches with a minimum of risk to their gear. This resulted in intensive acoustic coverage at St Helens Hill south west and north east slopes and the northern end of St Patricks Head 'Milk Run' and 'the Rock Wall' sites. There was sparse or sometimes no coverage of other regions where orange roughy may be found but where trawling is difficult (e.g., the north west corner of St Helens Hill, the southern end of the St Patricks Head Ridge, Figure 8.3a and b).

**Figure 8.3a – Example vessel track at St Helens Hill, 2001 season**

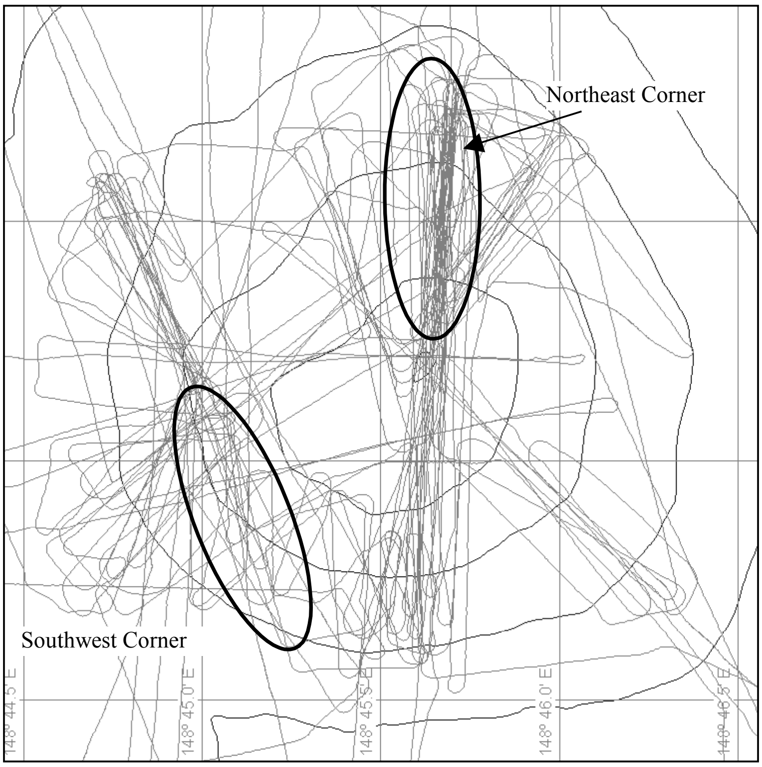
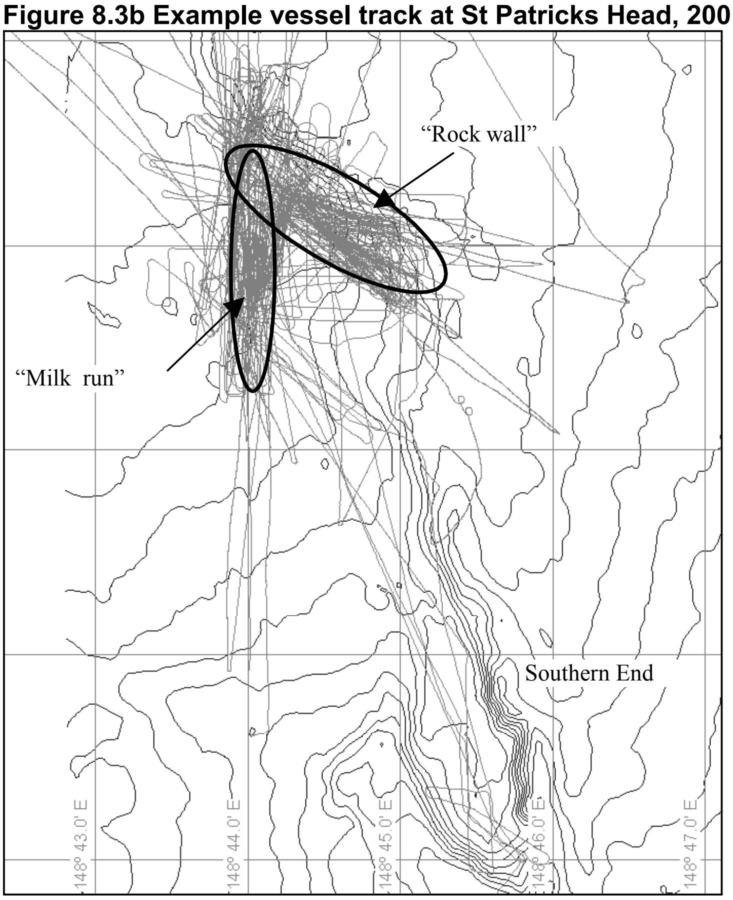



**Figure 8.3b Example vessel track at St Patricks Head, 2001 season**



## Acoustic observation of the fishing grounds over the survey period

### St Helens

Sizeable acoustic marks were observed on the vessel acoustics at St Helens Hill but, as in 1999, it was difficult to confidently attribute these marks to orange roughy based on visual inspection of the echograms. This concurs with comments from the skippers who reported that they would often shoot on significant marks but return empty trawls. For this reason the skippers refer to these marks as ‘ghost marks’. Conversely, some trawl shots did return reasonable catches of orange roughy even though there was not always a correspondingly significant acoustic mark. It appears that the overall situation is similar to 1999 where the main part of the school signal was due to other fish species, most likely a combination of morids, macrourids and myctophids (see Chapter 7). Hence, the presence or absence of orange roughy could not be confidently determined by the vessel acoustics, and by extension, there was no indication of a build up and subsequent decline.

### St Patricks Head

The first fish marks at the northern end of St Patricks Head were observed on the 6$^{th}$ of July using the *Celtic Rose* acoustics. These fish marks were quite dispersed and in some parts well above the seafloor. Three trawl shots targeted on the marks yielded few orange roughy leaving the composition of the marks in doubt. This demonstrates the limitation of single frequency vessel acoustics for orange roughy identification. By the 11$^{th}$ of July reasonable marks were observed at the ‘Rock Wall’ and targeted trawls a day later yielded 22 and 38 tonne catches of orange roughy. Marks were observed at irregular intervals for the remainder of the month, with large schools observed on the 18$^{th}$ and the 27$^{th}$. These marks were targeted and large catches (total 110 tonnes) of fish caught in a 10 hour period by a single vessel. The last survey day, 2$^{nd}$ of August using *Celtic Rose* acoustics, showed a small school mark of weak signal strength suggesting that the spawning aggregation had dispersed.

An overview of our own analysis and reports from skippers on the vessels shows that the orange roughy aggregation at St Patricks Head was dynamic, changing its location and density over hourly and daily periods with the main aggregation running north-south along the 700-900 metre contour giving it an oblong shape (Figure 8.6).

## Defining orange roughy schools and their associated metrics from acoustic data collected during the course of normal fishing operations at St Patricks Head

School marks were analysed using high resolution narrow beam *Petuna Explorer* ES60 acoustics. School boundaries could not be defined using a simple criteria such as a predefined threshold level as the schools showed a broad range of characteristics; ranging from a strong signal with unambiguous boundaries to a diffuse signal of indistinct contrast with surrounding acoustic backscatter. School boundaries were defined based on visual inspection of the structure and intensity of the school with a screen gain of –72dB. The defined schools were classified for likelihood of being primarily roughy following criteria in Table 8.2. Metrics of corrected school length, height, cross sectional area and relative school intensity weighted by cross sectional area calculated following procedures outlined in section 8.33, summarised in Table 8.4. In total there were 54 instances when schools marks were significant enough to be classified.

Maps of the start/stop positions of the defined schools with the lines colour coded according to the classification of the school (i.e. high, medium, low and indeterminate likelihood of the school being orange roughy) are shown in Figures 8.4a and b.

**Table 8.4 Summary statistics for 54 experimental school measurements**

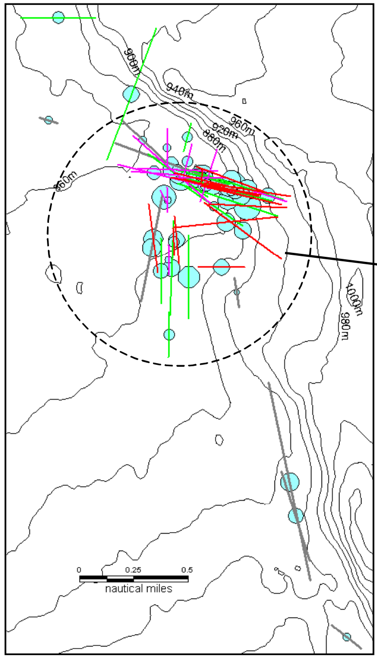
| Measure | Schools included in calculations | Mean | Standard Deviation (as % of mean) |
|---|---|---|---|
| Corrected Length (m) | All schools | 523 | 59 |
| Corrected Height (m) | All schools | 45 | 42 |
| Area ($m^2$) | All schools | 23073 | 66 |
| Area * School intensity | All schools | 1.22e7 | 102 |
| Corrected Length (m) | High and medium likelihood only | 485 | 54 |
| Corrected Height (m) | High and medium likelihood only | 52 | 38 |
| Area ($m^2$) | High and medium likelihood only | 25208 | 64 |
| Area * School intensity | High and medium likelihood only | 1.50e7 | 88 |
| Total area of region within which orange roughy were observed over the two week period (high or medium likelihood only) | | | 0.35 n.mile$^2$ |

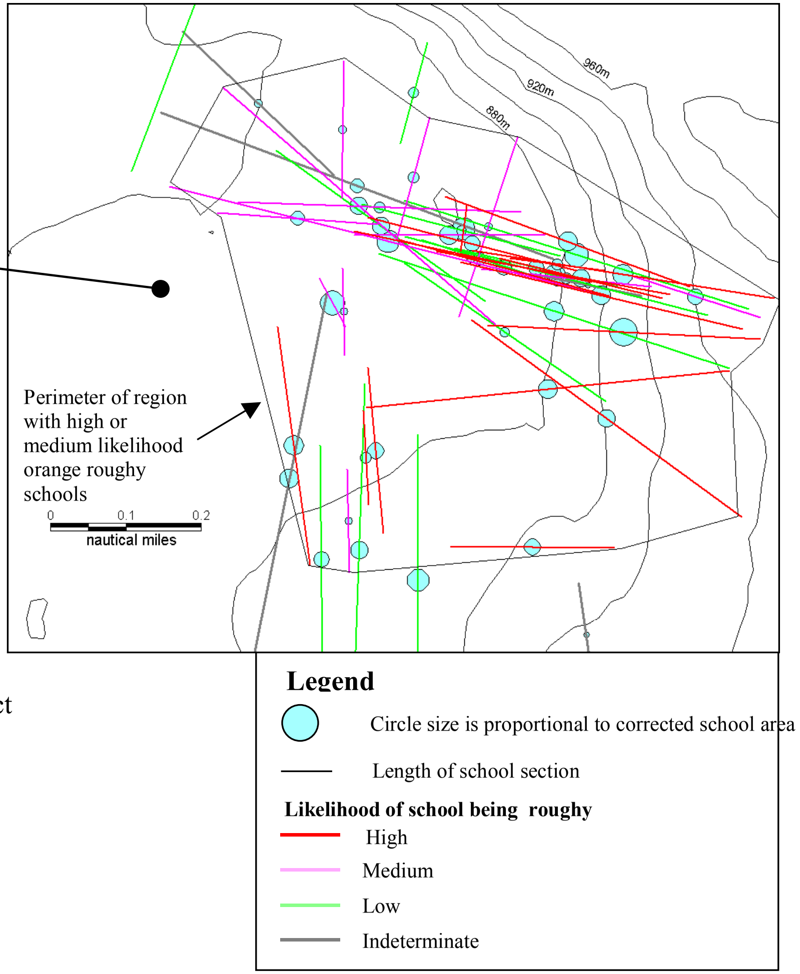
The majority of commercial fishing and therefore acoustic surveys took place at the northern end of St Patricks Head targeted on schools that could be readily captured. Of the 54 schools observed from 127 hours of normal fishing at the northern end of St Patricks Head, 17 were assigned a high likelihood of being orange roughy, 13 medium and 24 classified as low or intermediate. The average school length for high or medium likelihood orange roughy schools was 485 metres with a mean height of 52 metres giving an average school area of 2522 m$^2$. Other 'high likelihood' orange roughy schools may have existed outside the northern region but only brief surveys of other locations were carried out and no high or medium likelihood schools observed. This contrasts to the high resolution MUFTI survey in 1999 that showed orange roughy lying along the entire ridge region of St Patricks Head, Figure 4.5. As in 1999, it is probable that the industry vessel mounted acoustics (Simrad ES60 or Echolistener systems) could not detect low concentrations of orange roughy outside the intense schools. A major assumption with industry acoustic surveys therefore is the assumption that surrounding orange roughy biomass will be proportional to the changing school area.

Metrics of vertical school area derived from the corrected length and average height were plotted for each observed school and marked according to classification type (Figures 8.5a and b). On the same graph, the *Petuna Explorer*'s trawl catch data from the region were plotted (Figure 8.5a). Similarly the school area was weighted by average backscatter intensity and plotted (Figure 8.5b). Both indices of *school area* and *school area weighted by intensity* are highly variable (standard deviation of 66% and 102% respectively of the mean index value). This variability will be due to a combination of sampling variability and the dynamics of the schools. Repeat passes over the same point within a short space of time showed a large change in school metrics thus a large portion of the variability may be due to the school dynamics. To determine if a stable metric can be obtained over time will require data to be collected over many seasons.

There will be a distribution of school metrics due to the location of the sampling transect in relation to the school shape and location so that for a given school, the length and height measurements may range from a minimum at the school's outer edge to a maximum at its centre. This sampling distribution may account for some of the observed variability. The fishing methods had a large an influence on vessel movements, so that our transect directions can't be considered as being random; of the 54 transects analysed there were two predominate directions, 62% were E-SE with the remainder running approximately N-S (Figure 8.4c). Unless the school is circular, or transects are truly random in direction, the school orientation in relation to the transect will be a source of bias in our school metrics. Further work on modelling the distribution of metrics due to sampling needs to be carried out for various school shapes in order to better understand the causes of variability of our experimental observations.

**Figure 8.4 a) Defined schools – Entire St Patricks Region b) Defined schools – Northern End of St Patricks Head**




c) Compass plot showing corrected school length as a function of transect

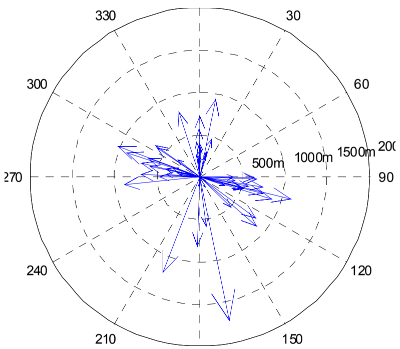


**Figure 8.5a School area indices and trawl catch from *Petuna Explorer* data, July 2001**

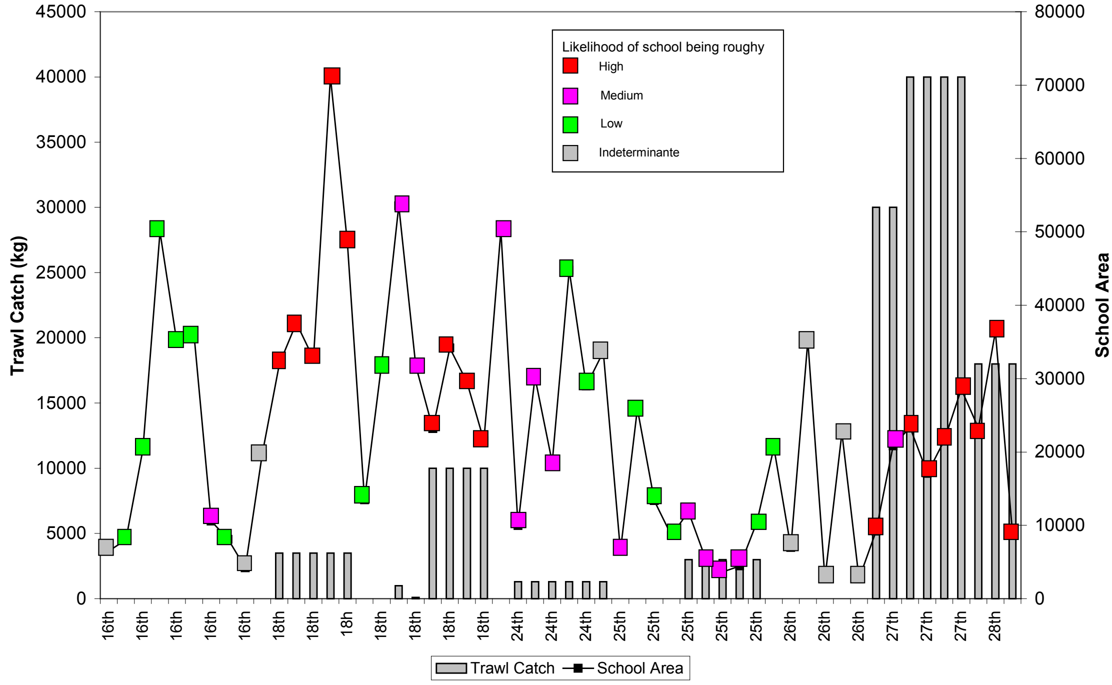
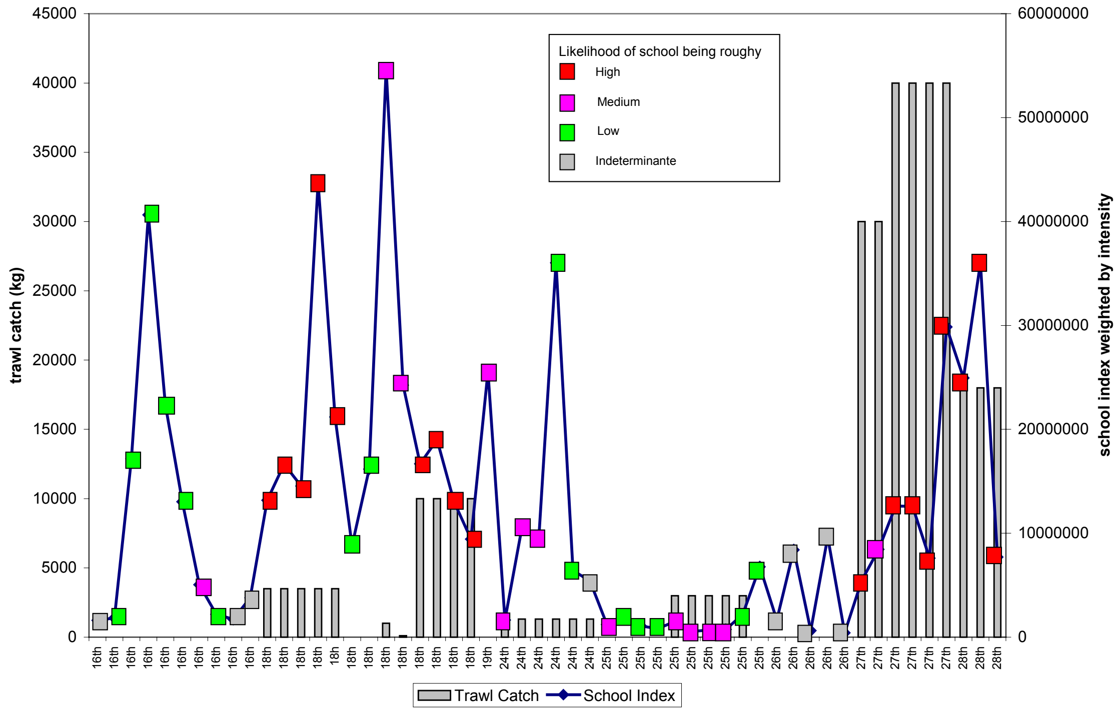



**Figure 8.5b School area indices weighted by intensity and trawl catch from *Petuna Explorer* data, July 2001.**



### Mapping the spatial distribution of the school(s) using acoustic data collected from dedicated survey transects

On an opportunistic basis, *Petuna Explorer* was asked to run a series of transects over observed schools to bound their spatial extent. Transects were intended to be quick and have a minimal impact upon fishing operations. However on the occasions when large schools were observed the vessel had the overriding goal of catching fish, so in practice there were few opportunities when the *Petuna Explorer* could break off and carry out planned acoustic transects. Despite this, the *Petuna Explorer* carried out a comprehensive survey of a school at St Patricks Head during a four hour period on the 18th of July. The vessel carried out both a star pattern over the estimated centre of the school and a series of east-west transects running from the northernmost to southernmost extent of the school. The star pattern survey did not successfully return over the school centre and in hindsight it seems likely that this design would have problems in effectively mapping out schools. The east-west grid transects bounded the school in all directions resulting in an oblong shape running north-south along the 700-900 metre contour, Figure 8.6.

The school areas were defined as outlined in the methods section (8.33) with the along track school reflectance plotted in a GIS to indicate spatial extent, Figure 8.6. A horizontal school area extent of 0.3 n.mile$^2$ was estimated by drawing a polygon in the GIS around the region occupied by the schools. Note how this value from a four hour time period is only slightly smaller than the horizontal area extent of 0.35 n.mile$^2$ occupied by all high or medium likelihood schools observed over the two week survey period, Figure 8.4. This suggests that whilst orange roughy schools were observed to be quite dynamic the main body of fish were constrained within a well-defined region.

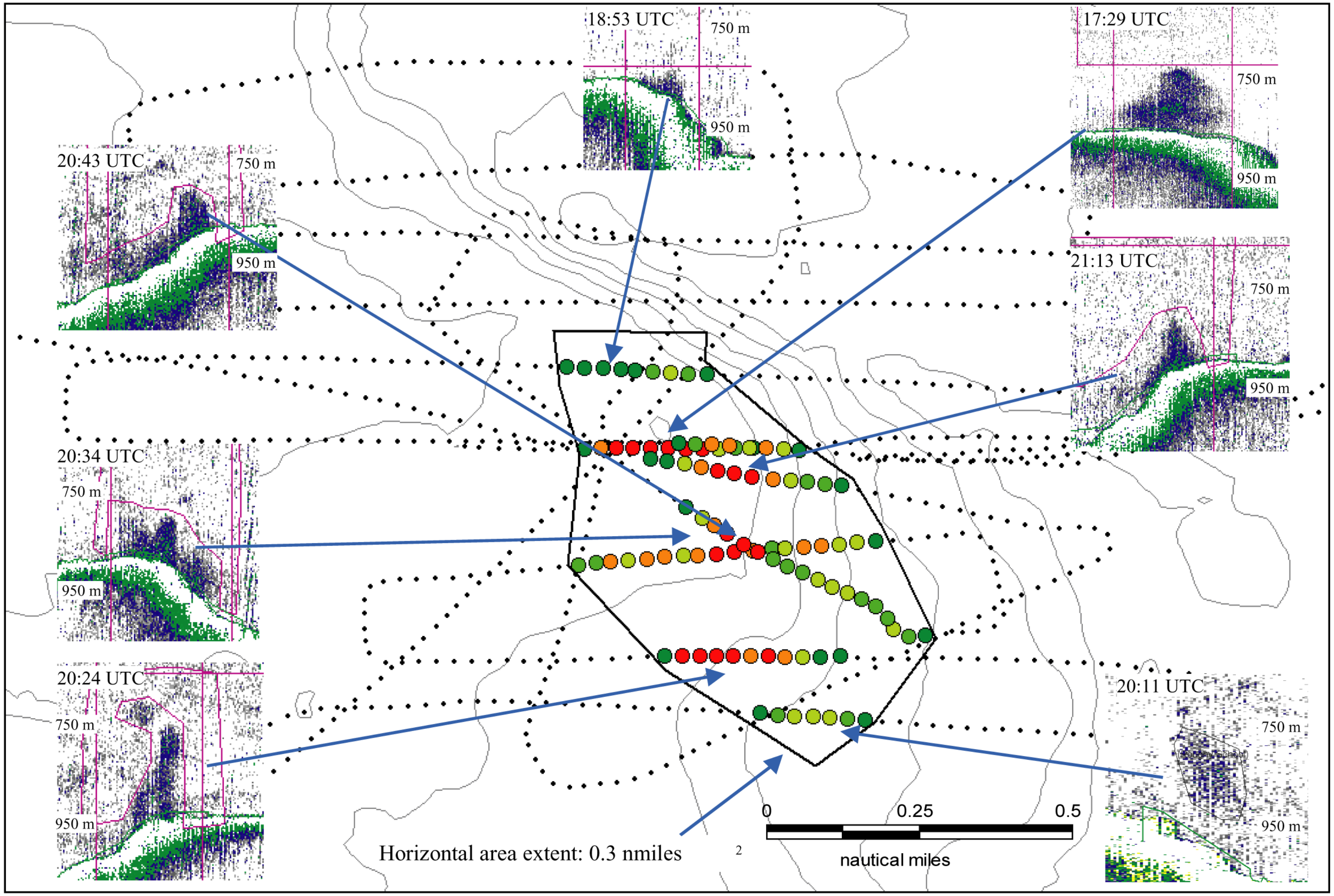
### Biomass estimate based on mapped school area

Inspection of transects that mapped the school and the associated echograms showed that a relative biomass estimate could be made from the data. The Petuna ES60 is uncalibrated so that the biomass estimate is a relative measure. A biomass estimate of 2180 tonnes was calculated based on the values in Table 8.5. This data point could potentially become the first in a series of relative biomass estimates from an industry vessel at St Patricks Head. The lack of coverage away from the northern end of St Patricks Head means that this estimate does not consider the potential for significant biomass to be located outside of the high intensity school region.

**Table 8.5. Values used in biomass estimation in 2001.**

| Parameter | Value |
|---|---|
| Mean Weight Orange Roughy (kg) | 1.24 |
| Estimated area extent (nmiles$^2$) | 0.3 |
| Mean $S_A$ ($m^2$/nmile$^2$) | 394 |
| Mean TS Orange Roughy (dB) | -51.5 |
| Relative Biomass Orange Roughy (tonnes) | 1650 |
| Biomass plus estimated deadzone correction of 10%(tonnes) | 1815 |
| **Biomass plus correction for vessel pitch/roll (20% of total) tonnes** | **2180** |

**Figure 8.6 Spatial extent of mapped school on 18th July 2001 at St Patricks Head**



### 8.3.5 Acoustics - Survey Discussion

The survey program was able to collect acoustic data from industry vessels at very low cost and with minimal impact on fishing operations. There were two types of acoustic data collected: 1) data collected during the course of normal fishing operations and 2) data collected from dedicated survey transects. The advantages and disadvantages of each of these data types are compared in Table 8.6.

**Table 8.6 Comparison of information provided by two survey methods from industry vessels**

| | Survey method | |
|---|---|---|
| Information provided | Normal fishing operations | Dedicated survey transects |
| Presence/absence of schools | Yes | Yes |
| Distribution of fishing effort | Yes | No |
| Qualitative description of fishery (overall impression of the schooling behaviour in space and time) | Yes | Possibly |
| Database of school metrics (size and shape metrics, density if system is calibrated) | Limited statistical analysis possible | Rigorous statistical analysis possible |
| Mapping of spatial extent of school | Possibly | Yes |
| Relative biomass estimate from calibrated systems | Unlikely | Possible |
| Advantages | Lowest cost method<br>No hindrance to vessel activities<br>No reliance on vessel following survey plans | Survey data not constrained by normal fishing patterns<br>Reduces bias resulting from normal fishers activities |
| Disadvantages | Only covers grounds that are suitable for fishing<br>Data limited to grounds that are suitable for fishing; relative changes in dispersed regions remain unknown dispersed regions<br>Results may be biased from normal fishers activities<br>Species identification a major uncertainty | Interruptions to fishing patterns (with possible cost of lost opportunity to vessel and/or charter cost to survey project).<br>May not be able to set up repeatable surveys every year<br>Species identification a major uncertainty |

**Utilisation of normal fishing operation data**

By using the acoustic data from normal fishing operations a time-series biomass index based on the survey average of school metrics could possibly be developed. The assumptions would be that over time:

- Schooling behaviour remains the same (i.e. schools can be dynamic but the nature of the dynamic is largely consistent over time).
- Fishing vessels operate in a similar manner in across survey years.

- Species composition remains largely the same.
- School metrics from difference acoustic systems can be corrected to allow comparison.
- A biomass index based on detectable schools would chart the state of the total stock

We note, however, it is not yet possible to validate some of these assumptions making the accuracy of such a schools based index difficult to estimate.

**Utilisation of dedicated survey transect data**

The dedicated survey transects at St Patricks Head on the 18th of July managed to bound the extent of the main schooling aggregation and confirmed our impression that the school was distributed in an oblong shape running north-south along the 700-900 metre contour. The spatial area extent was 0.3 n.mile$^2$. The survey was carried out in four hours giving a snapshot of the situation at that point in time. At the time of the survey, the schools were strongly aggregated and readily measurable by the vessel acoustics. The relative biomass estimate contained within this area was calculated to be 2180 tonnes. This number is from an uncalibrated system and hence is not at this point directly comparable with the biomass estimates from the 1999 survey.

The dedicated survey transects provide types of acoustic data that cannot be obtained from normal operation acoustic data. In particular, data can be recorded in controlled and repeatable transects that are not influenced by fish location or the fisher's trawling methods. Also, data can be obtained outside of the regions that are trawled. If the transects bound the school regions, then an echo-integration relative biomass estimate can be made. By using the school energy (i.e. echo-integration) the variability due to school dynamics should be removed. Dedicated survey transects generally require extra planning, cost, effort and cooperation of the vessel to be successful.

**Vessel selection criteria**

The data quality varied between vessels, and vessels need to be selected so that data quality is appropriate for the intended survey method. The survey program has improved our understanding of the performance of the various acoustic systems. A narrow beam 38 kHz ES60 system with a well located transducer is the preferred system. Compared to the Echolistener/Wide-Beam 28 kHz sounder systems the ES60 has several key advantages:

- High signal to noise
- Lower sampling volume due to the narrow beam transducer
- Simplest data acquisition
- Full sample rate resolution
- Large dynamic range

However to provide extra coverage or in the absence of an ES60 being available the Echolistener/Widebeam 28kHz fisheries sounder systems have the potential to provide useful information if it is accepted that data from these systems can increase sampling errors. The ES60 system used in this survey operates at 38 kHz while the other sounders operate at 28kHz. Care would need to be taken when comparing results from these systems with their different frequency and sampling volume characteristics.

**Uncertainties in vessel mounted data**

Species identification remains a major uncertainty for vessel mounted acoustics (as in the 1999 survey). The criteria developed for classifying the likelihood of schools being roughy is necessarily simplistic. The demersal trawl information is crucial to the process as it forms the starting point for classifying the schools. For example, at St Helens there were many occasions where sizeable school marks were observed but demersal trawling was not able to verify these as orange roughy, hence school metrics were not derived for that region. At St Patricks Head, there were sizeable aggregations that were trawled with large catches of roughy and only a very small bycatch. These confirmed roughy schools formed the basis for classifying all observed schools at St Patricks Head. The schools at St Patricks Head ranged from a high likelihood of being roughy to those that were indeterminate. The level of bycatch within our defined school regions cannot be determined from the vessel-mounted acoustics alone. It is therefore conceivable that the roughy/bycatch ratio could alter over time (as has been observed at St Helens) so that schools would still be observed, but the vessel mounted systems would be unable to detect the change in species composition. Hence there is a risk that time series data from vessel-mounted systems could give results that suggest a stable fishery when in fact there had been a decline in roughy abundance.

While useful information was obtained from the 2001 industry surveys, there are limitations with single frequency data collected from vessel mounted acoustics and the methods used in the 2001 surveys are amongst a number of possible techniques for monitoring orange roughy stocks (see chapter 9 of this report).

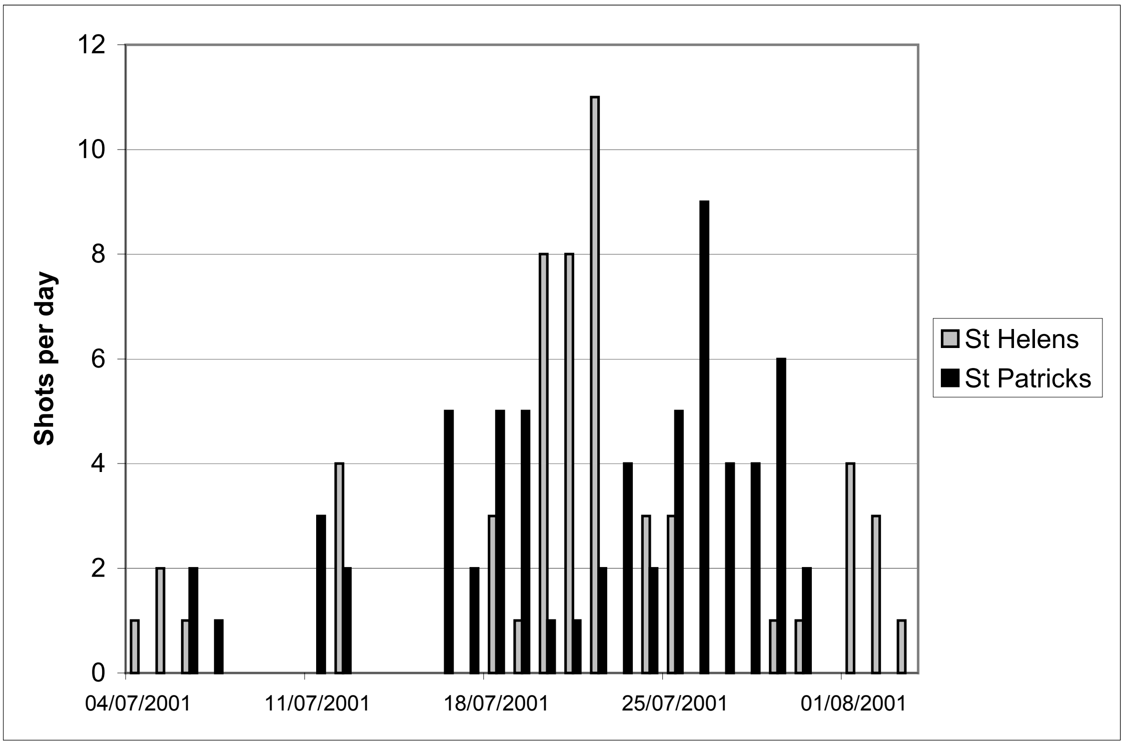
## 8.4 Orange roughy biology

Mark Lewis, Alan Williams, Rudy Kloser.

### 8.4.1 Introduction

Biological samples from the St. Helens Hill and St. Patricks Head were collected by demersal trawling. Demersal trawling was carried out using three commercial trawlers *Celtic Rose, Megisti Star and Petuna Explorer.* Sampling occurred throughout July (Figure 8.7) with the *Celtic Rose* covering from the beginning of July to the start of August. The *Petuna Explorer* covered most of the middle to late July including the peak spawning period and the *Megisti Star* gave extra coverage of the peak spawning period in mid July. The *Celtic Rose* collected acoustic data and shot data including the ratio of each acoustic group in each catch, without an observer on board. The shot data sheets and acoustic data were collected and backed up when the ship docked. The *Megisti Star* had an ISMP observer on board (Paul McCoy) and collected the same biological and acoustic information. The *Petuna Explorer* had Mark Lewis from CSIRO Marine Research on board to collect detailed biological information and acoustic data.

**Figure 8.7. Number of shots per day over the season for both areas, St Helens Hill and St Patricks Head combined for all vessels**




## 8.4.2 Sampling equipment and methods

The three vessels were different sizes and used trawl nets matched to their towing capabilities. No cod-end liners were used during the normal fishing operations characterising this survey.

The date and time of each trawl was recorded on a station log (Appendix C), and the locations of trawls on the seabed were estimated from vessel positions recorded during net deployment, landing and hauling, bathymetric ranges of the trawl and notes made by the observers at the time.

The catch was split into the seven acoustic groups used previously (Kloser et al. 1996 and section 3.2 of this report). The acoustic groups used were orange roughy, oreos, sharks, whiptails, morid cods, miscellaneous high reflectors and miscellaneous low reflectors. The fish species have previously been aggregated to these groups by comparing size and swimbladder type. On the *Megisti Star* and the *Celtic Rose*, the proportion of each acoustic group was entered on the data sheet. On the *Petuna Explorer* the proportions of each acoustic group were recorded as well as length data for up to 100 fish from each acoustic group per shot. Orange roughy length, sex and gonad maturity stage was also recorded for 100 individuals per shot. Orange roughy for processing were randomly selected from smaller catches and a few from each cod end split in larger catches. All the by-catch was retained for processing and only sub sampled if the amount was excessive. If sub-sampling was necessary, the proportion processed was carefully recorded on the data sheet.

Fish lengths were recorded to the nearest millimetre using the electronic CSIRO fish measuring board and down-loaded directly to a computer. Standard length was used for orange roughy, total length for the sharks, whiptails, eels and morid cod, and the length to the midpoint of the tail fin for the other species.

Both weight and length was recorded from individual roughy from several trawls in each area (373 fish) to calculate a weight-length relationship. Weights were recorded on a high precision motion compensated balance (POLS model S_120_3) accurate to 0.7% of total weight and precise to +/-0.1gram. The data were plotted and a 'line of best fit' calculated using Microsoft Excel (Equation 8.5). The weight of fish can vary depending on the method of handling and storage (Appendix E). Comparisons were made to the length weight equations used previously to see if they accurately predicted the weights measured in 2001 (Appendix H).

Summary statistics for mean length and weight at combined sites were not weighted by catch size as it was assumed that all catches were from the same population.

The gonad maturity stage of orange roughy was recorded using the standard classification (Table 8.7) that follows the scheme of Pankhurst (1988). The NIWA photographic key (Appendix F) was used, but the additional 'partially spent' stages for males and females were not recorded. Gonad maturity was used to document the timing of the acoustic survey in relation to the time of spawning. Data were combined for both grounds in the same way as was done in 1999.

Due to survey type this year (using only industry vessels during normal fishing operations) there were some differences to the methods used in the 1999 survey: no distinction was made between schools and backscatter for analysis of biological data for orange roughy (e.g. otolith collections); catch data were not analysed by depth strata; and no cod-end liner was used in trawl nets.

**Table 8.7 Nomenclature used to describe gonad maturity**

| Female | Condition | Male | Condition |
|---|---|---|---|
| Phase 1 | Immature or Resting | Phase 1 | Immature or Resting |
| Phase 2 | Maturing | Phase 2 | Maturing |
| Phase 3 | Mature | Phase 3 | Spermiated |
| Phase 4 | Ripe | Phase 4 | Spermiated, running ripe |
| Phase 5 | Running Ripe | Phase 5 | Spent |
| Phase 6 | Spent | | |
| Phase 7 | Atretic | | |

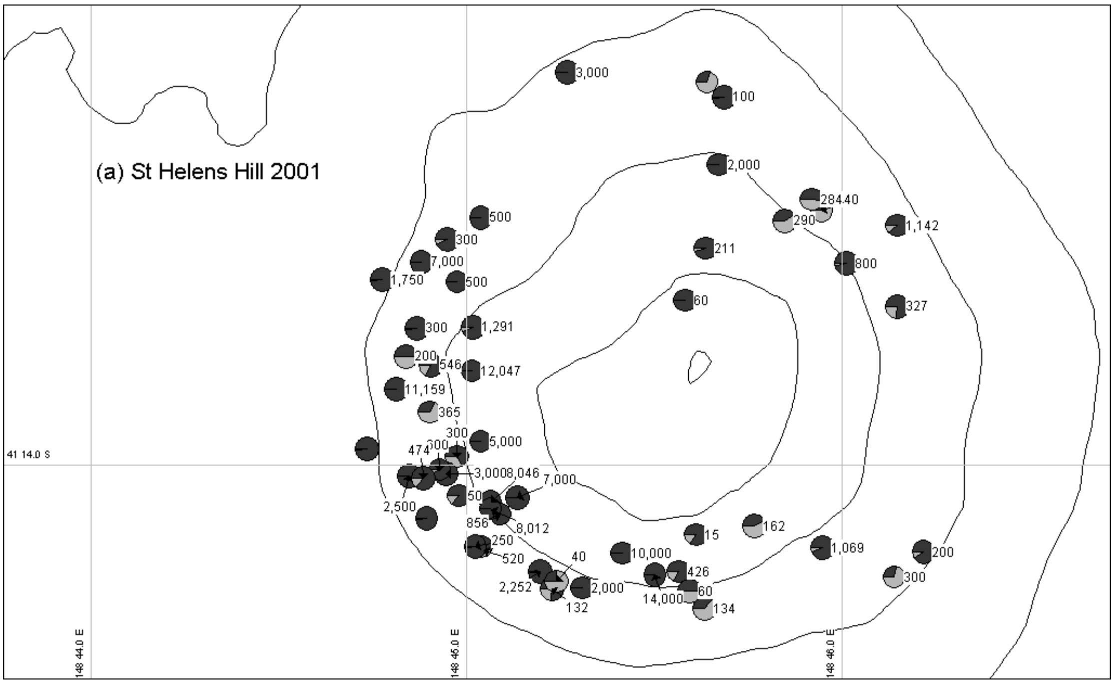
The *Celtic Rose* retained a bag where possible of 25 orange roughy from every shot for later removal of otoliths. This otolith collection was added to by the observer on the *Petuna Explorer*. Some otoliths were removed at sea when the conditions were suitable and the rest in port after trips. When otoliths were retained for later analysis the shot number was recorded by internally and externally tagging the bag so the fish could be linked back to the station details. After processing the otoliths were labelled with the vessel name, trip number, station number and fish number to allow the otolith to be referenced back to the length data for each fish.

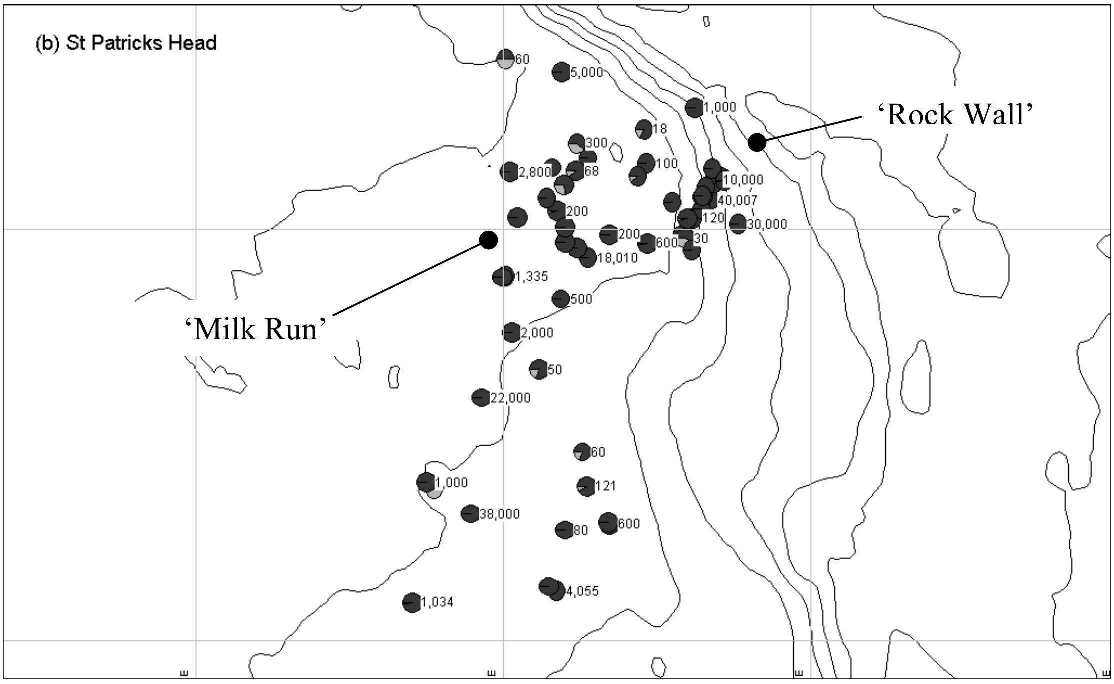
### 8.4.3 Results and discussion

**Overview of biological data**

During the month long survey of St. Helens Hill and St. Patricks Head, there were 141 shots: 55 on St Helens Hill and 65 on St Patricks Head retaining fish. 21 shots recorded no catch. Trawl mid-point locations were calculated from the estimated trawl position data and are shown together with the proportion of roughy and by-catch on a trawl-by-trawl basis (Figure 8.8).

**Figure 8.8 Trawl mid point locations and proportion of roughy in the catch by weight for St Helens Hill (a) and St Patricks Head (b). All vessels combined. Black is the proportion of orange roughy and the grey is the proportion of by catch, label is the catch size (kg).**



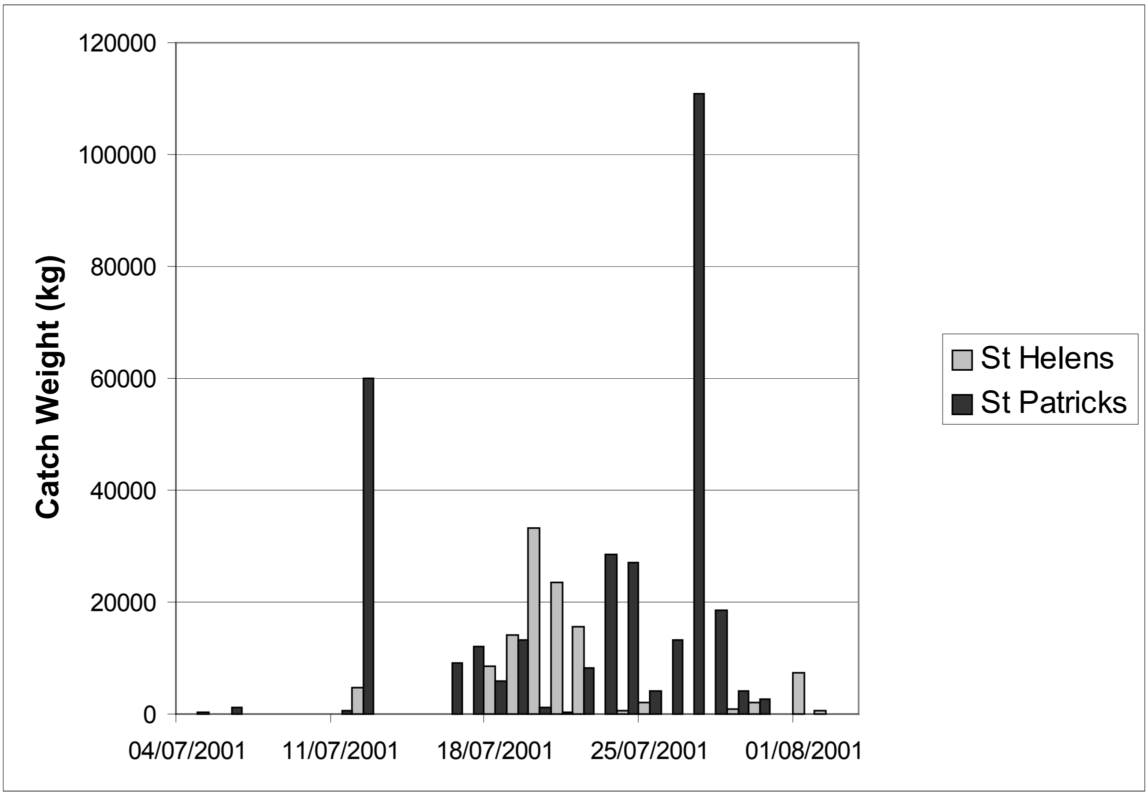




Lengths from approximately 6,950 individual fish were recorded. Total catch from all three vessels combined was nearly 441 tonnes of which over 434 tonnes was orange roughy from 141 shots (including the 21 shots that had no catch). The larger catches on St Helens Hill were in the south western sector and the largest catches on St

Patricks Head were off the 'Rock Wall' near the 'Milk run' in the northern section (Figure 8.8b). The single trawl in the southern section of St Patricks Head returned a catch of 4 tonnes of roughy with very little by-catch.

Orange roughy catch per day is shown in Figure 8.9. The largest catches were taken on the 12$^{th}$ and 27$^{th}$ of July. The largest individual catches taken during the survey was by the *Petuna Explorer* from the 'Rock Wall' on the 27$^{th}$ of July with one 40 tonne catch, and a total of 110 tonnes taken in a 10 hour period. The *Saxon Progress* caught 30 tonnes a short while before the *Petuna Explorer* at this same mark. This mark was the largest seen and in the usual position in the northern section of St Patricks Head near the 'Rock Wall' and were flighty and mobile.

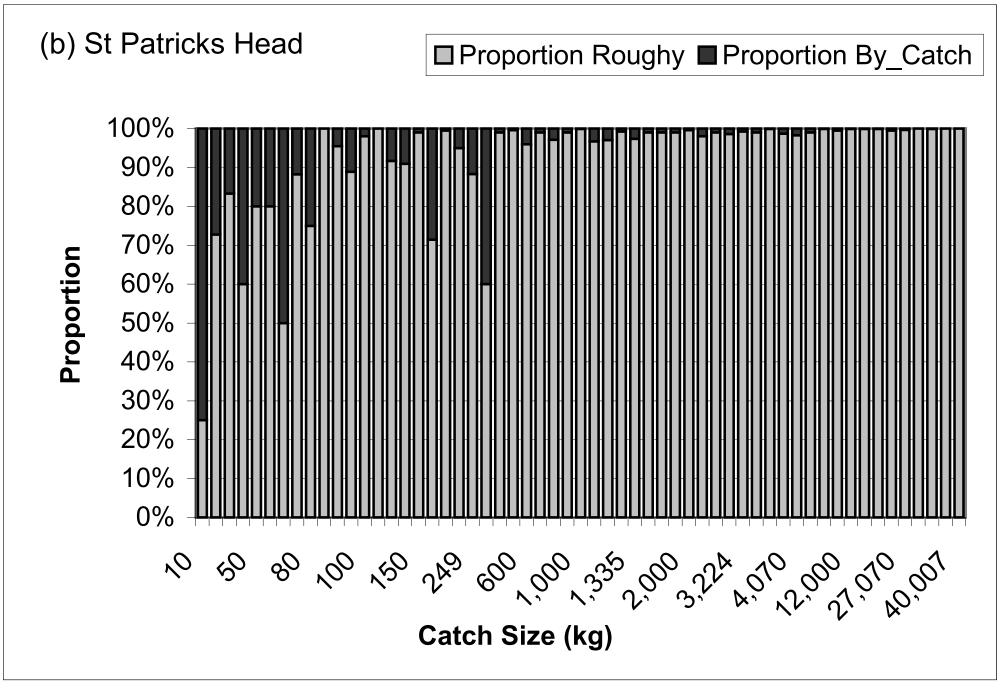
**Figure 8.9 Roughy catch per day for St Helens Hill and St Patricks Head. All vessels combined.**




The aggregations were quite mobile at both St Helens Hill and St Patricks Head. The aggregations were larger at St Patricks Head. The consistent mark on top of St Helens Hill consisted of cardinal fish with some blue eye trevalla and very little orange roughy. On the sides of the Hill the by-catch was dominated by sharks and whiptails, and a morid cod (*Halargyreus johnsoni*) which was spawning at the time.

The proportion of by-catch in the trawls decreased as the catches increase in size (Figure 8.10 a and b), as was noted in 1999, and was negligible in catches over ~1 tonne (2.02% for St Helens and 0.87% for Paddys Head). By-catch in catches < 1 tonne was higher at St Helens Hill (26.19%) compared to St Patricks Head (15.43%). Morids cods, mostly *Halargyreus johnsoni,* were the most common bycatch by weight (Table 8.8). Whiptails, dominated by the relatively small species *Coryphaenoides* *subserrulatus,* have constituted a larger proportion of the by-catch in previous years; their low abundance this year may be due to the lack of a cod-end liner in the trawl.

**Figure 8.10 Shows the proportion of by catch in each trawl. (a) St Helens Hill and (b) St Patricks Head. All vessels combined.**



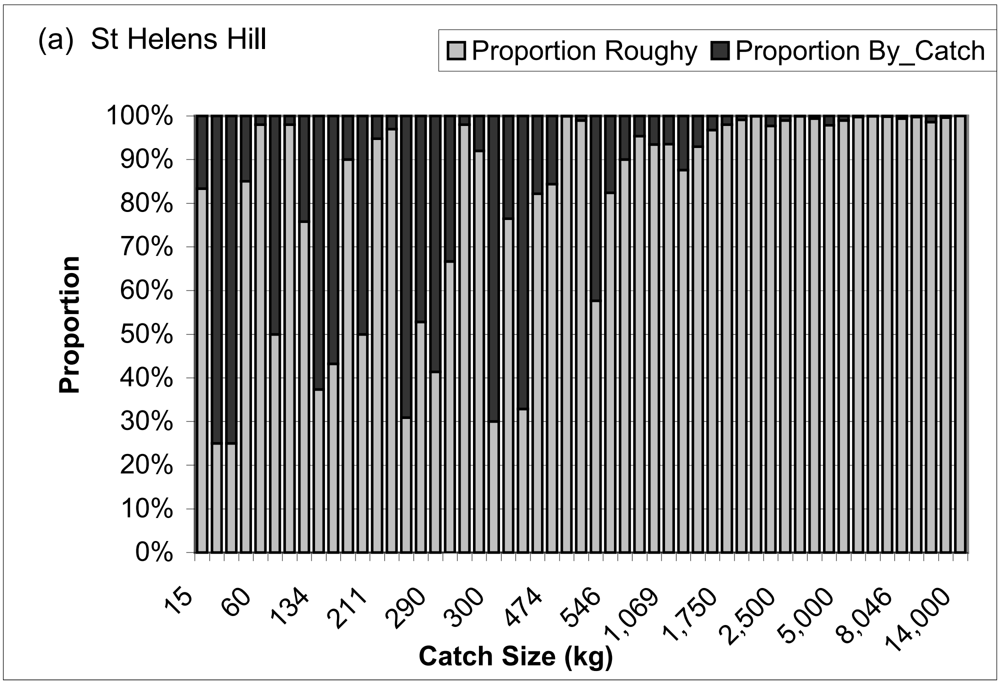




**Table 8.8 Average catch weight (kg) of each acoustic group for both areas in 2001.**

| | Roughy | Cod | Oreo | Shark | Whiptail | Misc High | Misc Low |
|---|---|---|---|---|---|---|---|
| St Helens Hill | 2138.54 | 38.22 | 2.96 | 7.46 | 7.04 | 1.43 | 2.60 |
| St Patricks Head | 5632.48 | 5.47 | 6.89 | 5.86 | 2.73 | 0.65 | 1.20 |

## Observations on school movements

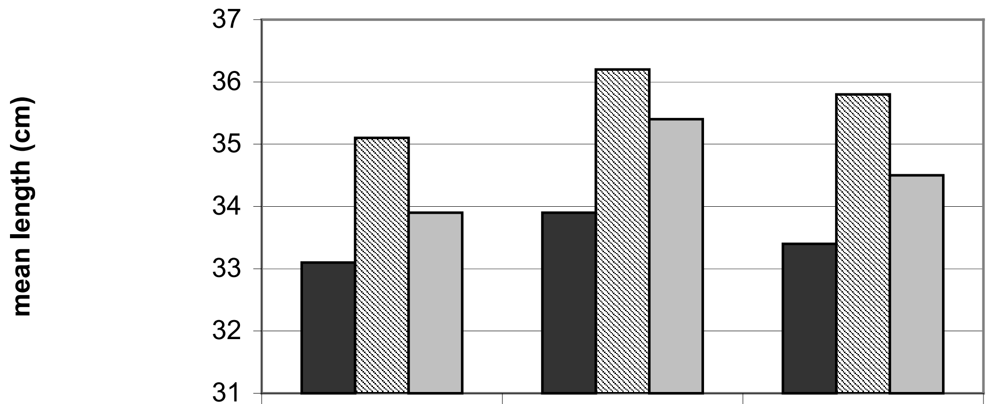
The large mark at St. Patricks Head was initially slightly off the Rock Wall at 12:00 hours on the 27th of July but in less than an hour it had thickened up and moved back on top of St Patricks Head near the Milk Run. This mark thickened up and partially dispersed during fishing operations. During the last shot on the mark, the fish were initially hard down but had lifted before the vessel reached them with the net in the water. The mark then seemed to move to the Milk Run on top of St Patricks Head at 11:00 hours on the 28th of July and disperse. At this time it appeared that the water currents changed from pushing the vessel to the north east when the school was forming up and intense, to pushing the gear to the south west when the school was dispersing and moving. There were no unusual tidal variations during this period but a front did come through from the south.

## Size and age structure

### Fish length

A total of 5731 orange roughy were measured and used to calculate a mean length for each area by sex (Figures 8.11 and 8.12a) and combined for both area and sex (Figure 8.12b). The general patterns are that male fish are smaller than the female fish in both areas (33.4 cm vs 35.8 cm) (Figure 8.11 and Figure 8.12b) and that, overall, orange roughy are larger at St Helens Hill than at St Patricks Head (35.4 vs 33.9 cm SL) (Figure 8.11). Of particular interest, and consistent with the findings in 1999, is that females are noticeably larger at St Helens Hill than St Patricks Head (Figure 8.12a). Greater proportions of small fish (< 35 cm) occurred at St. Patricks Head while conspicuously greater proportions of large fish (> 35 cm) occurred at St. Helens; there was a corresponding difference in modal length. The difference was less obvious for males and modal length was similar for both areas; however, relatively more large fish (> 35 cm) were observed at St. Patricks (Figure 8.12a). The average sizes of fish were not significantly different to those observed in 1999 (Chapter 3 of this report).

**Figure 8.11 The mean length (cm) and standard deviation (SD) of orange roughy from each location split by sex.**




| | St Patricks | St Helens | Combined Location |
|---|---|---|---|
| Male | 33.1 (2.4) | 33.9 (2.6) | 33.4 (2.5) |
| Female | 35.1 (2.5 | 36.2 (2.7) | 35.8 (2.7) |
| Combined Sex | 33.9 (2.6) | 35.4 (2.9) | 34.5 (2.8) |

**Figure 8.12a Length frequency plots for orange roughy over the 2001 season for St Patricks Head and St Helens Hill, separated by sex, all vessels combined. (n = number of fish).**

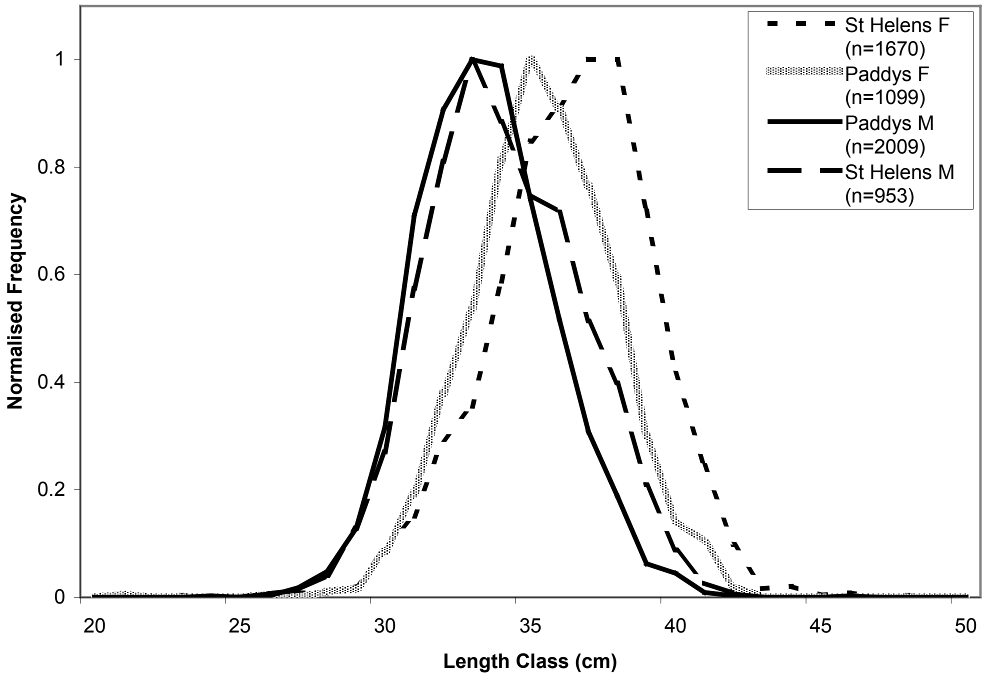
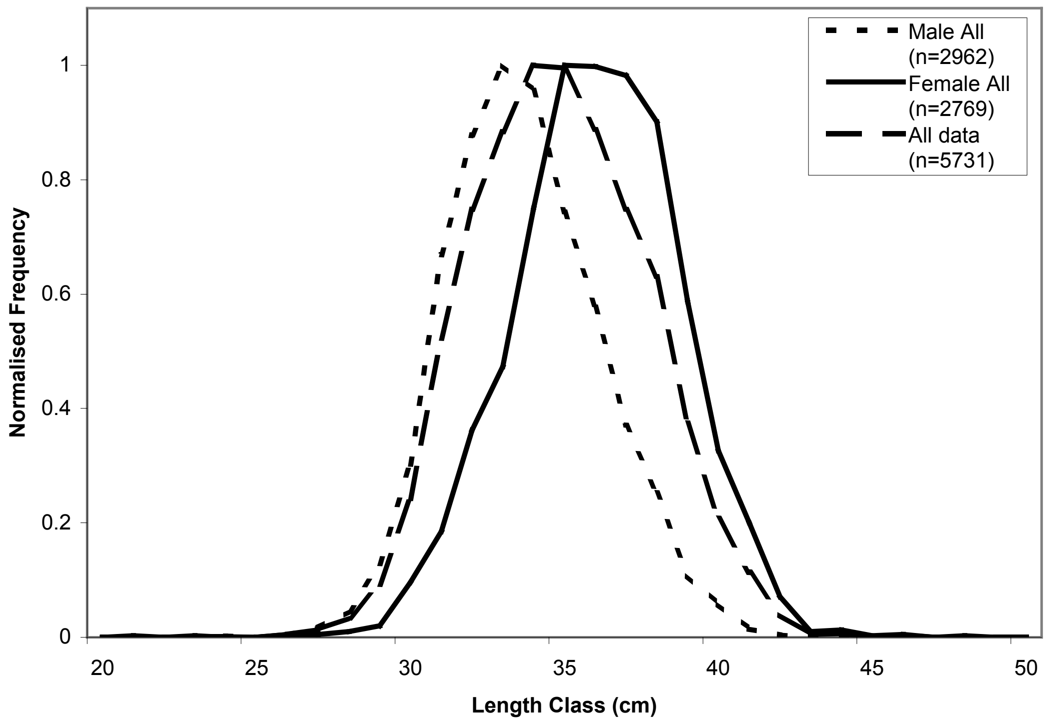



**Figure 8.12b Length frequency histogram for orange roughy over the 2001 season, sexes and locations combined. (n = number of fish).**



**Fish Age**

Otoliths collected from 1,277 retained orange roughy were aged by the Central Ageing Facility (CAF) as part of the systematic coverage of SEF species paid for by industry. Data are displayed here as age frequency plots (Figure 8.13a-c).

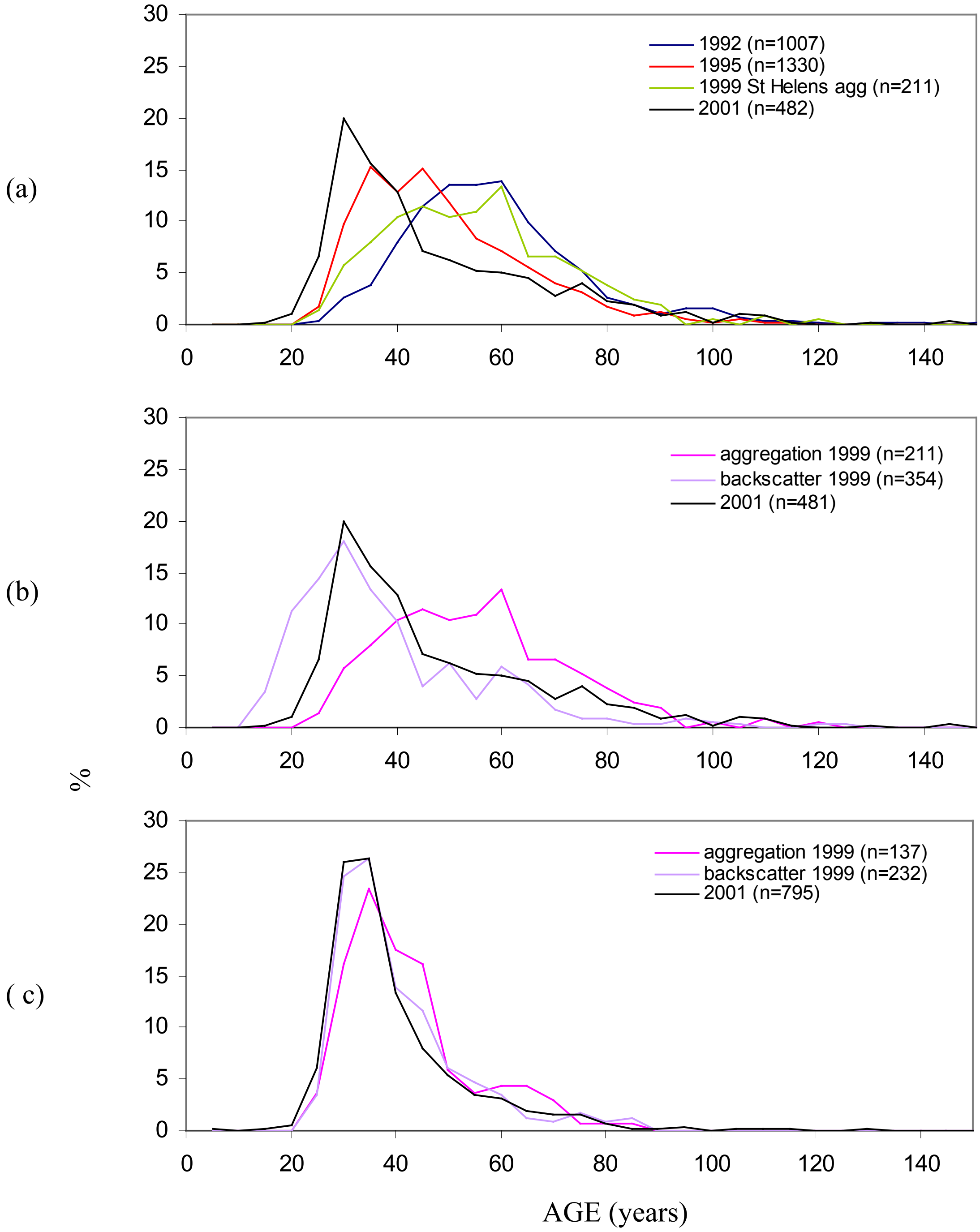
The majority of fish at both sites in 2001 were aged 30-40 years old: 48% at St Helens; 66% at St Patricks. There was double the proportion of fish ≥ 45 yo at St Helens than at St Patricks (37 cf 19%). Few fish at either site were less than 20 yo (~1%).

Samples from St Helens show the continuation of a trend seen in previous years with an overall reduction in the age profile of fish caught (Figure 8.13a). In the 2001 catches at St Helens, young fish (20-30 yo) represent a relatively large fraction of the overall sample, and old fish (≥ 40 yo) a relatively smaller fraction, compared to all previous years (1992, 1995 and 1999) (Figure 8.13a). The shift in age-profile during the last decade (1992 –2001) at St Helens is from 3% to 28% (young fish) and 93% to 57% (old fish). Note that in 1999, high proportions of very young fish (10-20 yo) were found in targeted (non-commercial) catches from backscatter around St Helens (Figure 8.13b) and that these samples are excluded from Figure 8.13a.

At St Patricks Head, the age profile of catches is very similar to 1999 (when there was little distinction between catches from aggregations and backscatter) (Figure 8.13c).

The age composition sample taken this year will prove very valuable to the Eastern zone stock assessment. Last years assessment (Wayte and Bax 2001) was unable to jointly fit the different trends in age composition indicated by samples from 1995 and 1999 - one of which (1995) indicated a large decline in the contribution of older fish to the fishery, while the other (1999) indicated little change from 1992. This led to advice to managers that uncertainty remained in the assessment. Under the most optimistic scenario, AFMA's management performance criteria could be met with little change in the current TACs. Under the more pessimistic scenarios, the fishery was over-fished and a rapid reduction in catches would be required to meet the performance criteria. The new age composition data appear (following limited analysis at the time of writing) to resolve the uncertainty in the assessment due to age structure and will enable far clearer advice on the status of the stock to be provided to fishery managers this year.

**Figure 8.13 Age frequency plots for orange roughy (sexes combined) comparing 2001 data with previous years. (a) St Helens, multiple years; (b) St Helens, 2001 and 1999; (c) St Patricks, 2001 and 1999. Note: 1999 data split by samples from main fish aggregations and backscatter.**




**Fish weight**

The average weight for orange roughy from each area shows that male orange roughy are lighter than females and that the fish from St Helens Hill are larger than the fish from St Patricks Head (Table 8.10).

**Table 8.10 The average weight of orange roughy (kg) split by sex and area.**

| | Location | |
|---|---|---|
| Sex | St Patricks | St Helens |
| Male | 1.1 | 1.13 |
| Female | 1.41 | 1.54 |
| Combined | 1.24 | 1.37 |

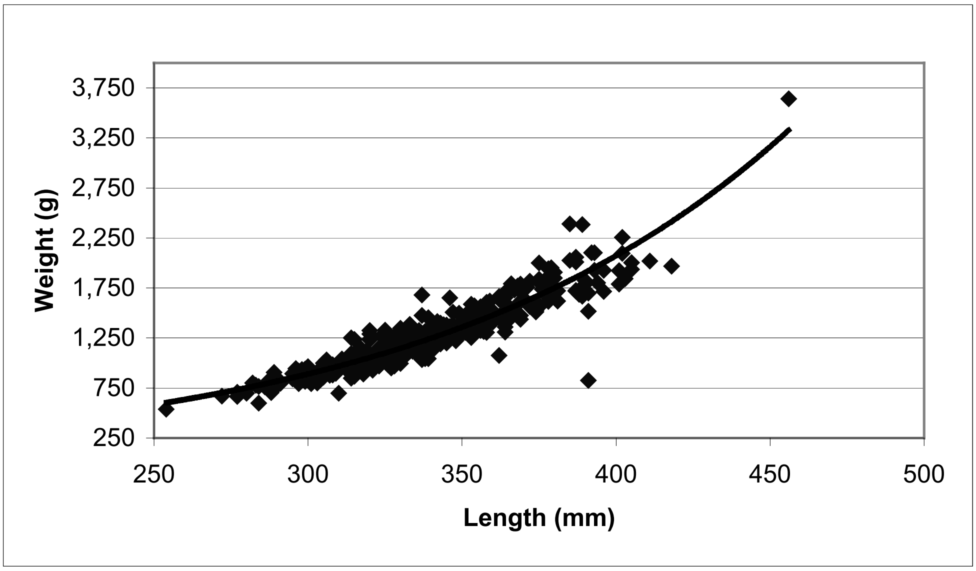
The weight data from this survey were used to calculate a length-weight relationship (Figure 8.14) and Equation 8.5.

$$weight = 70.637e^{0.0084/length} \qquad 8.5$$

Where *length* is standard length in millimetres and the *weight* in grams ($R^2$ = 0.86).

The length weight data gathered in the 2001 season are shown (Figure 8.14). The variation from the estimated weight increases for the larger fish. This increase in variation is expected as the larger fish (mostly females) are in the process of spawning and their weight would vary considerably depending on their developmental stage. That is, a female at stage 4 (just pre spawning) would be considerable heavier than the same fish at stage 6 after she had spawned. The GSI index (gonad weight as a percentage of body weight) from some early data (Bulman *et al,* 1994) is, on average, 5.07% for female orange roughy and would be higher for the later stages (up to 10%). This may account for most of the variation seen in the heavier fish.

**Figure 8.14 The length to weigh data gathered during 2001, all sexes and vessels data combined. The line is equation 8.5**




**Fish age**

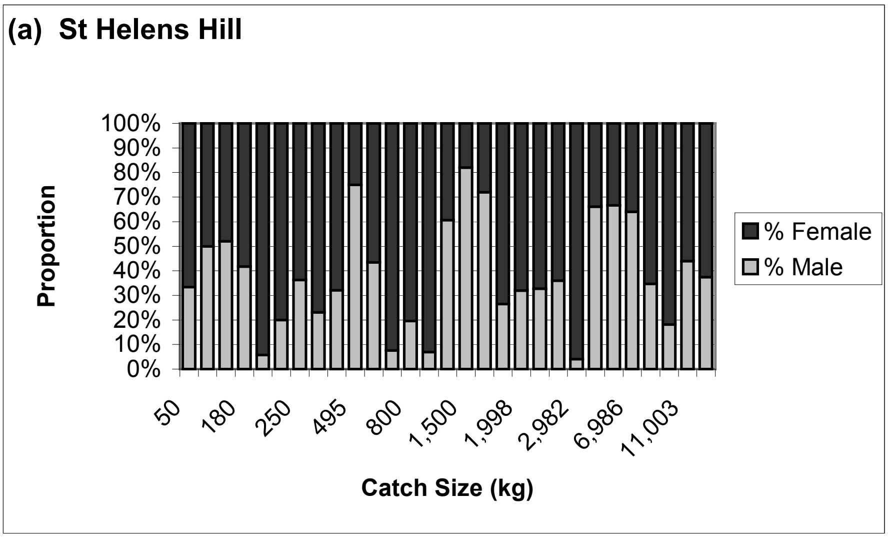
Otoliths were successfully collected from orange roughy both at sea on the *Petuna Explorer*, from fish retained on the *Petuna Explorer* when the weather was unsuitable for removal at sea, and from fish retained on the *Celtic Rose*: 576 sets from St Helens hill and 968 from St Patricks Head were collected in total and sent to the CAF for age determination.

## Sex ratios and maturity stage

### Sex ratios

A total of 3517 orange roughy were processed to determine their sex, gonad maturity stage and length. In total, 5731 orange roughy were processed without staging information: 2623 from St Helens and 3108 from St Patricks Head. As was the case in 1999, there were more males than females captured at St Patricks Head (64.6% to 35.4% respectively) and more females than males captured at St Helens Hill (63.7% to 36.3% respectively). Sex ratio data from this survey shows no clear trend with catch size for either St Helens Hill or, St Patricks Head (Figure 8.15, a and b), or through time over the survey period (Figure 8.16).

**Figure 8.15 The ratio of males to female for different catch sizes (> than 50 kg), (a) St Helens Hill, (b) St Patricks Head.**



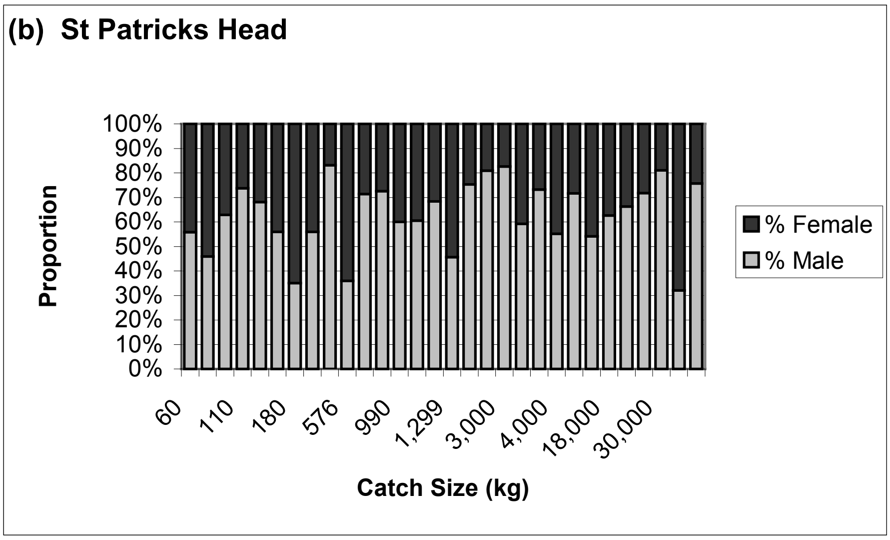
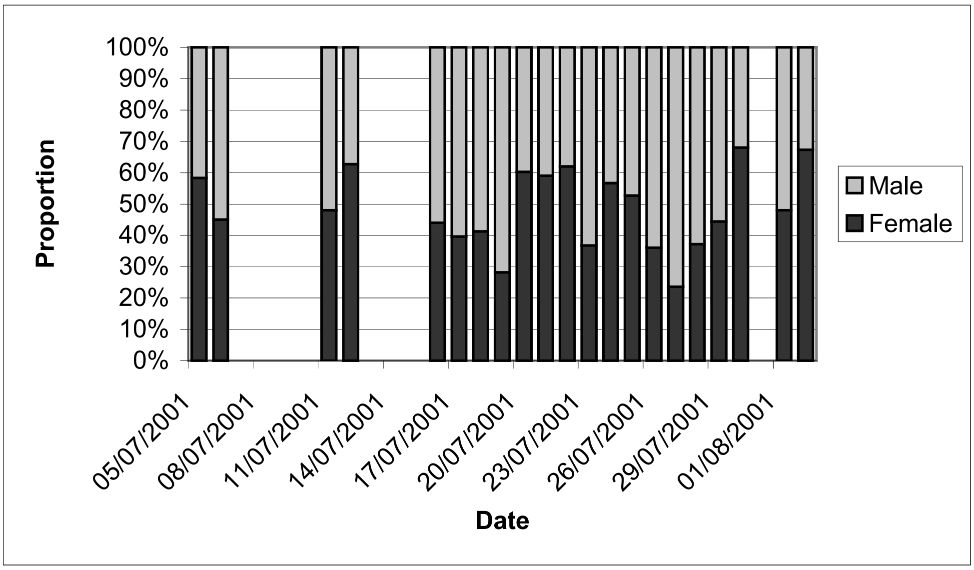



**Figure 8.16 Sex ratio of orange roughy in trawl samples (St. Helens Hill and St. Patricks Head combined)**

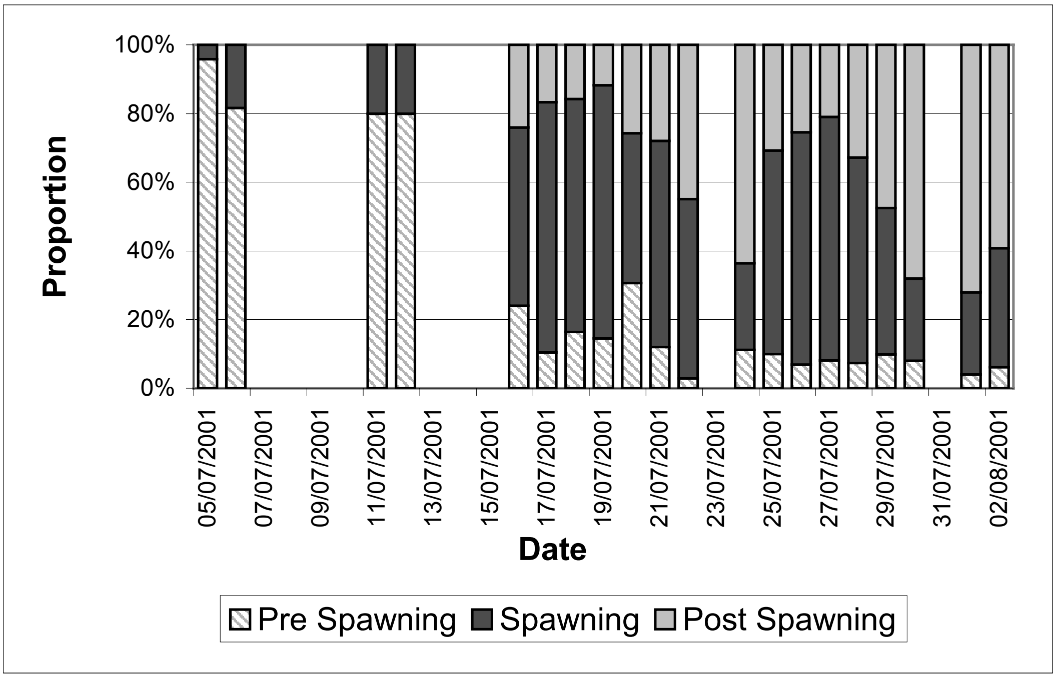



**Maturity stage**

Gonad maturity stage data from both St Patricks Head and St Helens Hill show spawning had started by 7th July (~20% of fish in spawning condition), was very active by the 16th of July (when > 20% fish were spent) and continued until at least the 2nd of August when the survey finished (Figure 8.17). In general terms, this pattern is similar to 1999 when spawning was evident at first sampling on the 10th July and declined after July 26th. The relatively low proportion of spawning fish on July 24th was in a small sample and not representative. Overall the information is consisten with one spawning event.

The data show that the survey covered the main spawning event in 2001, as shown by the rise and subsequent decline in the proportions of spawning fish and the increase in the proportion of post-spawning fish (Figure 8.17). It was apparent that collection of additional length, sex and stage data from at least two vessels is required to give simultaneous coverage of both St Helens Hill and St Patricks Head through time during an industry-based survey.

**Figure 8.17 Spawning activity of orange roughy during the survey. Pre-spawning is stages 1-4 females and 1-3 males. Spawning is stage 5 for females and stage 4 for males. Post-spawning is stage 6-7 in females and 5 for males. (St. Helens Hill and St. Patricks Head combined)**




**Notes on observer coverage**

The observer on the *Megisti Star* very kindly recorded all the information requested as well as his own, including the sex of the orange roughy, and provided the data to CSIRO. The only improvement would have been the addition of gonad maturity stage information. This presents a problem as there is usually only one observer per vessel and they are usually only able to collect length and maybe sex for each fish because the manual boards used for gathering length information are only capable of recording length and sex and the observer must gain the assistance of a member of the crew to gather the staging information. CSIRO has developed an electronic length board that will enable a single observer to record reproductive stage as well as species length and sex in future surveys.

## 8.5 Environmental data collection

### 8.5.1 CTD data

To obtain data on the ocean environmental conditions and to enable calculation of seawater absorption, CTD casts were made using a Seabird profiler (Table 8.11, Figures 8.18 and 8.19).

### Table 8.11 Summary of CTD casts – July 2001

| Cast Date | Location | Maximum depth (m) | Mean seawater absortion @ 800m (dB/km) |
|---|---|---|---|
| 19th July 09:58 | St Helens Hill | 1000 | 9.17 |
| 29th July 06:48 | St Helens Hill | 859 | 9.17 |
| 19th July 06:08 | St Patricks Head | 950 | 9.22 |

### Figure 8.18 Profile of seawater absorption at 38kHz for the three CTD casts

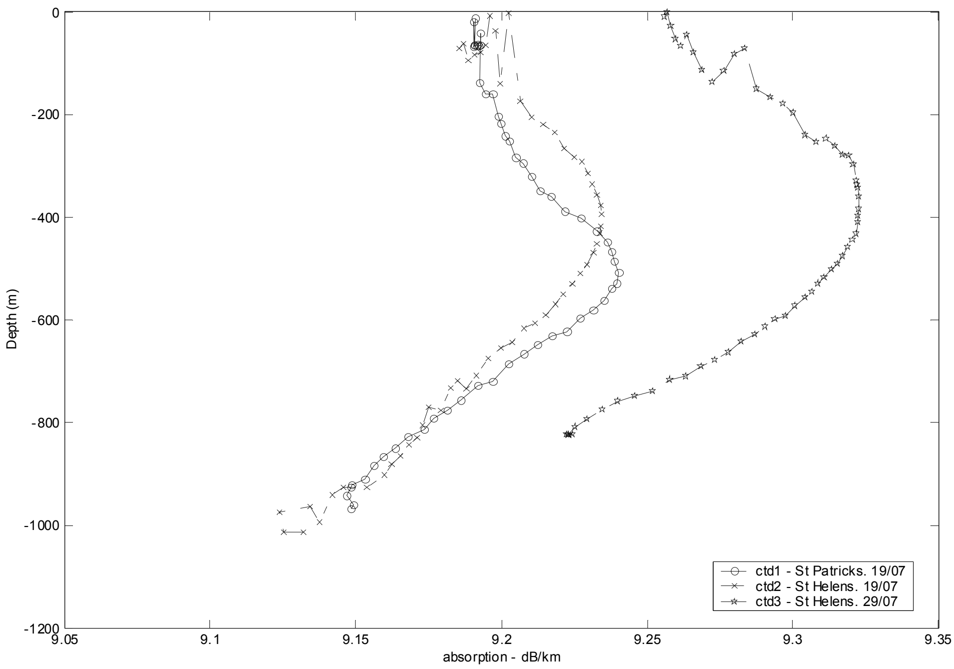
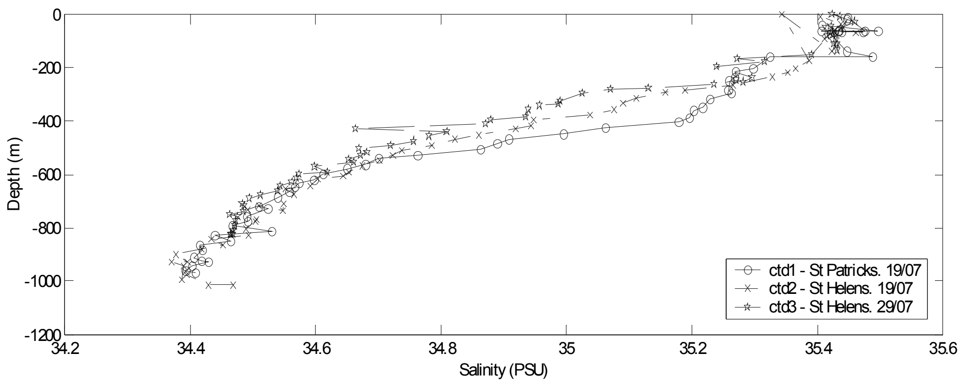
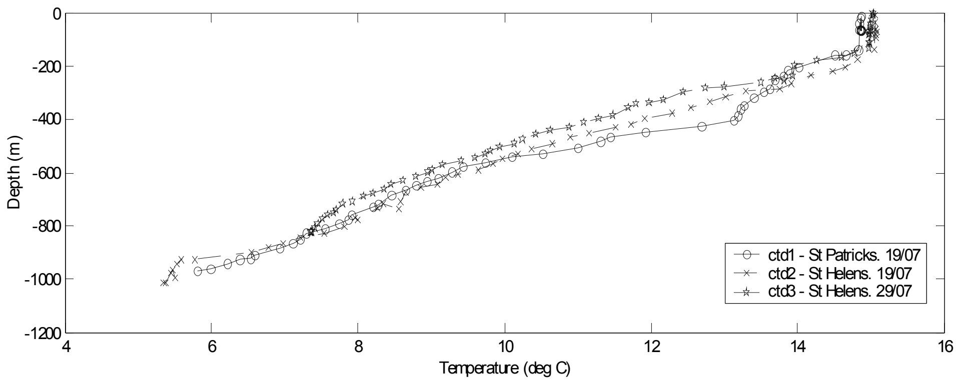


**Figure 8.19 Profile of Pressure vs Salinity and Temperature for the three CTD casts**




## 8.6 Vessel motion reference data collection

The vessel dynamics logger records parameters as listed in Table 8.12.

**Table 8.12 Vessel Dynamics Sensors**

| Parameter | Sensor details |
|---|---|
| Pitch/Roll | 2 x Lucas Schaevitz Accustar Clinometer Model 0211 1002-000 +/- 45 degree sensors |
| X,Y,Z axes acceleration | 3 x Columbia Research Model SA-107-BHP +/- 2 G |
| X,Y,Z axes roll rate | 3 x Watson Angular Rate Model ARS-C121-1A +/- 3 deg/sec/volt |
| 8 sensor channels in total. | |
| 10 Hz sample rate on all channels logged to file continuously | |

The aim of this logger was to investigate the performance of sensors for use in recording the motion of a fishing vessel. The key issue is what accuracy is required to allow satisfactory correction of quantitative acoustic data collected by the ship's echosounder.

The logger contained several different sensors. The pitch and roll sensors used in the system are relatively low cost electronic clinometer sensors. If these sensors deliver sufficient accuracy they would be ideal for use in a low cost, low maintenance logger for use on numerous vessels. However, because these sensors utilise pendulum based sensing, their accuracy is adversely affected by acceleration. To characterise this error due to acceleration a suite of six additional sensors (3 accelerometers and 3 roll rate) were included in this system. This suite of six sensors should provide sufficient information to completely characterise the true motion of the vessel allowing the real pitch and roll to be determined. The aim therefore is to compare the true pitch/roll values with those recorded from the clinometer sensors and evaluate the errors for a variety of sea states. If the clinometer style sensors prove adequate then lower cost system can be produced. The analysis of the data has not yet been carried out (Nov 2001) but will be carried out as part of future work in this area.

## 8.7 Conclusions from the 2001 survey

### 8.7.1 Acoustics conclusions

1) High quality acoustic data were collected at low cost (i.e. without charter costs) for the first time in the orange roughy fishery using a Simrad ES60 and have formed the basis for all subsequent data analysis. This development will enable other fisheries to benefit from the methods established.

2) The survey program was able to collect two types of acoustic data from industry vessels with minimal impact on fishing operations: these were 'during normal fishing operations' and ‘fishing plus opportunistic transect surveys of schools'. The advantages and disadvantages of each of the resultant data sets are compared; we note that any dedicated survey transects require extra planning, cost, and cooperation of the vessel to be successful.

3) The data collected enabled a limited analysis of orange roughy school vertical cross sectional area. School metrics (area and weighted area) were highly variable due to a combination of sampling variability (transect position relative to school area) and to school dynamics (changes in shape and position) over short temporal scales (less than an hour to hours).

4) Data showed it may be possible to develop a time-series biomass index based on school metrics but this will need key assumptions to be validated. One biomass estimate derived from this survey from a reliable echo integration analysis (school completely bounded) and another from metrics on 54 schools could form the basis for ongoing relative biomass indices at St Patricks Head.

5) The varying performance of acoustic systems on different vessels translates directly to the quality and utility of the data obtained. This survey program improved our understanding of the factors that determine the suitability of particular vessels for future science-industry cooperative surveys of spawning orange roughy. Limitations of existing systems and future methods are discussed.

### 8.7.2 Biological conclusions

1) The use of commercial vessels to gather biological data was generally successful, and contributed to successful development of an overall industry-based survey methodology. Improvements have been identified, in particular the need for observers on two vessels to enable collection of length, sex and maturity stage information from a greater number of catches simultaneously at both major grounds

2) Gonad maturity stage data and large catches confirmed that the survey spanned the main spawning event (between about the 16th and 29th of July). Large catches of ripe fish confirmed that a spawning event occurred at the northern end of St. Patricks Head in 800-900 m depth. Small aggregations of spawning orange roughy were only recorded from the south-western sector of St. Helens Hill.

3) In several important respects the 2001 survey repeated the biological patterns observed in 1999:

   - markedly different sex ratios between the two grounds (more males at St Patricks Head and more females at St Helens Hill) despite a near-even overall ratio
   - similar timing of the main spawning event
   - higher proportion of by-catch at St. Helens Hill (due in-part to the relatively small catches of orange roughy taken there)
   - no appreciable differences in mean length of the roughy population (by sex or ground)

4) Further investigation of the length-weight conversion formula shows it appears to overestimate the size of male fish by 8.28% and underestimate the size of females by 2.6% (work is continuing on this, see conclusion 5)

5) Measurement showed weight loss by orange roughy while frozen and during thawing may be substantial and have important implications for biological parameters and therefore biomass estimates.

6) Collection of data separately for aggregations and backscatter, which provided interesting results in the 1999 survey, was not possible from this method of survey.

7) Otoliths collected during the 2001 survey were aged and should provide a clearer picture of the status of the stock when incorporated into the population model.

# 9 ACOUSTIC SURVEY METHODS: SUMMARY, BENEFITS, FUTURE NEEDS AND DEVELOPMENT

## 9.1 Background

Alternative methods for fishery biomass surveys have many trade-offs in the areas of accuracy, cost, and application to the management objectives and population model of the fishery. This is particularly the case for acoustic surveys of orange roughy that are applied to the spawning population to estimate either an absolute or, more often, a relative index of abundance. During the early development of the orange roughy fishery in the Australian Eastern Zone it was important, and economically justifiable, to derive an absolute biomass estimate to set a total allowable catch. Since then, a relative index has been incorporated into the population model with associated biological and catch data to estimate the sustainability of the fishery (Bax 1999). However, relative acoustic surveys measure only the aggregated spawning population – not the turn-over of fish on the spawning grounds, or the proportion of fish that do not come to the spawning grounds each year. It has been assumed that these biological variables have remained constant after an initial change at the start of the fishery (e.g., Wayte and Bax 2001).

Changes in fishing patterns, fishery ecology and technology have also strongly influenced the choice of alternative methods for surveying orange roughy. One constraining factor is that there are now fewer opportunities for predictable science-industry collaborations during surveys because exploitation of several localised but widely separated spawning aggregations, reduced TACs and quota-trading has led to dispersal of the fleet during the spawning season. There have also been profound changes in fishery ecology. For example, an acoustic survey with a hull-mounted transducer is no longer viable at St Helens Hill because the abundance of roughy has declined to the extent that they are now ‘swamped’ by more acoustically-reflective gas-bladdered fishes that make up the backscatter. On the other hand, rapid adoption of technology (particularly for echo-sounding and navigation) by the commercial fleet and researchers has opened new opportunities to meet the challenges of surveying a species that aggregates over complex topography at 600-1200 m depth.

## 9.2 Summary of methods and findings of this project

Through this project we have investigated various applications of acoustic methods for surveying the aggregated portion of the orange roughy population in Australia’s Eastern Zone (Chapter 5). In broad terms, different methods are separated into either vessel hull-mounted or deep-towed systems that use either single or multiple frequencies. Vessel mounted survey methods can be performed with calibrated or uncalibrated acoustic systems (whereas deep-towed systems are research tools and therefore always calibrated). The choice of survey method is determined by the size and dynamics of the aggregated schools of orange roughy, steepness of the terrain, mix of backscatter species, cost of the survey and the management objectives. A range of options showing overall advantages and disadvantages referenced to cost and management objectives is outlined in Table 9.1. Of greatest current interest (as the value of the fishery declines) is the use of low-cost, industry-vessel based methods of data collection. In its simplest form, this involves logging uncalibrated qualitative acoustic data as part of normal fishing operations (Monitoring System 4, Table 9.1 and Chapter 8.3). A more quantitative industry-based method requires the calibration of the echo sounder and monitoring of the vessel motion in combination with directed surveys (Monitoring System 2, Table 9.1).

In 1999, we applied a hybrid of acoustic survey methods: we collected low resolution acoustic data from industry vessels over the entire spawning season with minimal associated biological data (spawning condition, length and catch composition), together with a dedicated survey at the height of the spawning season using the deep-towed multi-frequency instrument ('MUFTI'). This combination optimised the benefits of both survey strategies: low-cost industry acoustics and biological data provided high-quality intelligence about orange roughy location, spawning state and dynamics to the more quantitative and higher-cost systematic MUFTI survey. Further, by involving the fishers directly with the survey, a greater level of trust and cooperation was developed throughout the entire assessment and management process. Outputs from our project include relative biomass estimates of orange roughy on both the St Patricks and St Helens fishing grounds (Chapter 4). These results were incorporated into the orange roughy Eastern Zone population model and the outcomes accepted by industry, managers and scientists (Wayte and Bax, 2000).

In 2001, we used industry acoustics and biological data alone to assess the orange roughy population at St Helens and St Patricks Head (Chapter 8). We developed methods to capture high-resolution acoustic data (from a Simrad ES60 echosounder) that required no extra equipment on the fishing vessels and was completed for low cost. The cost-effectiveness of the methodology developed through this project makes regular recording of acoustic data an ongoing possibility. *A strong recommendation from our research is that collection of industry acoustic and associated biological data on the orange roughy fisheries be ongoing, and that the potential for other fisheries, such as blue grenadier and redfish, is explored*. There were important benefits of being able to directly observe the movements and dynamics of the fishers and orange roughy schools throughout two spawning seasons. For example, the lack of clearly identifiable orange roughy marks at St Helens Hill in 2001 industry acoustic data repeated industry's observations of low biomass made in 1999. Another observation repeated in both years was that schools of smaller (potentially younger) orange roughy were concentrated at the northern end of St Patricks Head and were spawning at the same time as the roughy at St Helens. Despite the importance of the qualitative information provided by this low-cost acoustic data, it has not been directly incorporated into the orange roughy population model. A time series of at least 3 years would be required, to enable variances in particular parameters to be estimated, before a reliable trend could be established. Industry systems need to be calibrated in order for results to be consistent and comparable and therefore of maximum value to fishery assessments; *we recommend that this becomes part of any future development of industry-based surveys* (and see below).

A key challenge for industry-based acoustic surveys is to quantify the relative precision of estimates of school size and school biomass. In this project we have developed some simple indices, with depth corrections, to produce the first data for these metrics of roughy schools. Acoustic surveys will need to be further developed, perhaps over many years, to establish the utility of the data for quantitative assessments. Further work needs to be carried out to understand the minimum detection limits of the various techniques/platforms. When stock sizes are small knowing the minimum detection limit of an acoustic sampling devise is particularly important when deciding which monitoring technique to adopt. The results presented here will assist in this endeavour, but will need additional research in the area of detection limits and school dynamics modelling to assist in the interpretation of the data.

The survey precision necessary to manage the fishery depends greatly on the harvest strategy that is adopted in future years for orange roughy. Additional research is required in the areas of incorporating a low-precision acoustic index into the population model, and the best harvest strategy to manage the unknown bias and precision of the data. The Eastern Zone orange roughy is at a critical stage where, after the initial fish-down of the virgin stock, we expect the population should be rebuilding given current catch levels. At St Helens Hill we observed a continuing stock decline from 1996 to 1999 (see Chapter 7). To accurately monitor the fishery under the current harvest strategy would require a monitoring program that could detect an approximate 2- 4,000 tonne change in fish abundance from a current spawning stock of 10 – 15,000 tonnes. This is not possible with current industry acoustic methods, or possibly with any future vessel mounted survey due to unknown species composition and poor sensitivity; the MUFTI towed system is the only method available that could attempt to reach this type of relative precision.

Our research also has implications for other fisheries such as the Cascade Plateau, where a biomass estimate has yet to be established after three years of industry acoustic surveys of the spawning stock (Prince and Diver 1999, 2001). As with St Patricks Head, the industry sounders would only sample the high-intensity, schooling portion of the biomass at the Cascade Plateau and not the biomass outside the large schools. For example, in the 1999 acoustic survey at St Patricks Head the MUFTI towed system detected approximately 37% of the orange roughy acoustic backscatter outside of the main aggregation region. The vessel mounted systems were unable to detect or distinguish orange roughy in these regions away from the main schooling aggregation. By only monitoring the schools it is possible to miss changes that are occurring in the less dense, but possibly large, components of the population that surrounds schools. This approach has the potential to create an index that is insensitive to large changes in surrounding biomass until the St Patricks Head or Cascade resource is depleted. Our project demonstrates that a calibrated echosounder, that can detect and sample the entire distribution of the population over the spawning grounds, is required for a quantitative biomass assessment. In addition, a deep-towed multi-frequency system is essential to identify and differentiate the other fish species at the spawning grounds, measure the lightly scattered orange roughy distribution, and to obtain target strengths of orange roughy and the associated species. Whilst over time a relative index using industry acoustics may prove useful, a calibrated multi-frequency, deep-towed instrument is the only method that can provide a quantitative biomass of high precision (Monitoring system 1, Table 9.1.) Selecting a management strategy for sustainable development of the orange roughy fishery needs an appropriate monitoring strategy. Low precision low cost monitoring methods (eg uncalibrated acoustic logging) will necessarily require greater safety factors in the management strategy to ensure that a precautionary principle of fishery management is employed.

**Table 9.1 Orange Roughy acoustic survey systems and methods ranked in order of decreasing cost and decreasing precision.**

| Monitoring System | Survey and Analysis Method | Estimated Relative Accuracy | Main Advantages | Main Disadvantages | Management objective |
|---|---|---|---|---|---|
| 1. Multi-frequency deep towed instrument MUFTI (calibrated and motion compensated) | Echo integration systematic survey | 20 – 40 %* | • species identification and species groups<br>• high precision of acoustic measurements and interpretation of results<br>• reduced uncertainty for seabed sampling<br>• target strength for absolute biomass<br>• samples highly and lightly aggregated parts of the spawning population | • high costs<br>• requires dedicated survey with vessel availability issues<br>• lack of flexibility in timing<br>• difficulty in surveying small highly aggregated and dynamic schools. | • can provide quantitative absolute and relative biomass estimates of high precision.<br>• only method suited for areas such as St Helens Hill where species composition is uncertain and roughy abundance low.<br>• Is the method of choice and would only not be used if cost was the overriding issue. |
| 2. Vessel mounted or shallow tow (calibrated and motion compensated) | Echo integration (directed surveys) | (40-60%)* | • low/medium cost from industry vessels<br>• medium quality data<br>• need narrow beam for better precision | • weather dependant (better with shallow tow)<br>• dedicated survey with vessel availability issues<br>• species identification poor<br>• near-seabed sampling not possible<br>• lightly aggregated proportion of spawning population missed | • provides a lower cost quantitative assessment for early management needs of a fishery assuming species identification and near seabed sampling are not major issue.<br>• could detect changes of management significance eg. St Patricks Head and Cascade Plateau. |
| 3. Vessel mounted | School indices (directed surveys during fishing) | unknown but considerably better with | • low cost<br>• may be quantifiable but requires development to prove utility | • unknown precision<br>• problems with estimating school | • initial impression of fishery, gives repetition of annual cycles, movements and |

| | | | | | |
|---|---|---|---|---|---|
| | | calibration | • can calibrate sounders | density (better with calibration)<br>• species identification not possible without trawling | dynamics.<br>• calibration of equipment provides opportunity to use data as relative index |
| 4. vessel mounted | school indices (undirected surveys) | unknown | • lowest cost,<br>• helps interpret fishers observations<br>• useful tool for dynamics/ presence absence. | • descriptive<br>• unknown precision<br>• sensitive to fish density<br>• sensitive to changes in fishers practices<br>• species identification not possible without trawling | • initial impression of fishery, gives repetition of annual cycles, movements and dynamics. Enables fishers to be part of the assessment process and self documents their observations.<br>• very cost-effective |

* the relative accuracy is indicative only and will vary greatly depending on the fish distribution near the sea bed and the species composition within and surrounding the schools.

## 9.3 Benefits flowing from this project

The research undertaken in this project has resulted in several planned benefits to the orange roughy fishery, as well as some indirect benefits to other fisheries such as blue grenadier, and associated development of environment indicators for deep water fisheries and seabed habitat mapping methods.

A major planned benefit of the research program was an acoustic assessment of spawning orange roughy in 1999 that has been incorporated into the orange roughy population model and accepted by industry, managers and scientists to ensure the sustainable development of orange roughy in the Eastern zone. The survey of orange roughy biomass in 1999 was carried out using both industry vessel acoustics and the deep towed MUFTI multi frequency towed body to optimise the advantages of both survey methods.

The multi-frequency acoustic method for distinguishing orange roughy from other species has been further developed in this project and represents a major step forward in the science of remote species identification. We have shown that in multi-species regions, existing deep-towed, single frequency acoustic methods can overestimate orange roughy biomass by a factor of 6. This ongoing development will ensure that the status of the resource is accurately known to ensure its sustainable development.

At the start of the project we successfully collected low-noise, deep-water industry acoustic data using wide beam 28 kHz echo sounders removing a major uncertainty cited in the project proposal. This benefit flowed directly to acoustic logging projects undertaken at the Cascade Plateau and South Tasman Rise funded by AFMA.

In 2001, we successfully collected high quality acoustic data at low cost (data collection and infrastructure) using new, narrow-beam 38kHz Simrad ES60 echo sounders. This development will enable high volume and low-cost data to be collected routinely from industry fishing vessels in future years. This development is easily transferred to other fisheries such as blue grenadier, and could also be used for environmental studies and seabed habitat mapping projects at relatively very low data collection cost (when compared to scientific survey methods).

Methods have been developed to analyse industry acoustic data and a first relative index of school size and school abundance. This low cost index could be continued in future years to compliment other indices in managing the Eastern Zone and Cascade Plateau fisheries.

## 9.4 Future development and recommendations

This project has significantly contributed to the development and application of acoustic methods for the sustainable management of the orange roughy resource, and has applications to other fisheries based on schooling species, as well as to collection of environmental data and mapping seabed habitats. However, several areas require ongoing development of both the acoustic method and its application, specifically these are:

Multi-frequency species identification is in its infancy; we have applied three frequencies to describe the major species-groups that occur with orange roughy (see

Chapter 7). Further development of this methodology to improve the remote identification of nekton and micronekton species or species-groups will include detailed fish scattering models to predict optimal frequencies and using additional frequencies of similar sampling volumes, as well as wide-band methods. *We recommend that this work be continued as part of any future acoustic-based fishery assessment of orange roughy or other species, such as blue grenadier, that form spawning aggregations*.

Development of a low cost method for generating an index of school abundance using calibrated echo sounders over at least a three-year time frame would enable the index to be incorporated into the population model and its long-term usefulness to be assessed. This low-cost data collection should be supplemented with higher resolution, deep-towed multi-frequency surveys at multi-year intervals, primarily to ensure species composition and biomass in the lightly scattered portion of the spawning aggregation are not overly biasing the results. After establishing a first data point with an inital deep-towed multi-frequency survey the frequency of these surveys should be determined by the population model uncertainty or based on changes in the fishery observed from the industry acoustic data. *We recommend that industry logging occur for at least the next three years*, *preferably with calibrated echosounders, in the Eastern Zone and Cascade fisheries. Further, to provide a best-estimate reference point for a time series of industry acoustic biomass estimates, a complementary deep-towed multifrequency survey should be carried out within this three year time period in the Eastern Zone and Cascade fisheries.*

Modelling of the acoustic data on schools and estimation of detection thresholds and error would assist in the interpretation of the school data and its long-term utility in fishery assessments School dynamics and industry sampling methods introduce large sampling variances and biases in the school index data. Understanding the links between school size variability and factors such as school density, location and sampling design would greatly improve the precision of the index for long term monitoring. *We recommend that advances in this methodology are a focus for outcomes from ongoing industry data logging*.

The low-cost and high quality acoustic data collected in this study has opened the possibility of using such data for understanding deep water environmental variations, including influences on the distribution and biomass of forage fishes and crustaceans in the micronekton. The ability to collect acoustic data throughout the water column at low-cost from multiple platforms represents a valuable opportunity. Coupling any derived index, for example of micronekton abundance, with indices on current circulation, surface temperature and ocean colour from satellite data would enable surface data to be more reliably extrapolated to depth. The environmental variability being observed at depth in several areas such as the South Tasman Rise, Cascade Plateau, Southern Hills and the blue grenadier grounds could be explored, and better population models and harvest strategies for sustainable management of the fisheries realised. *We recommend that research be conducted into developing low-cost acoustic logging from fishing vessels and coupling this with other environmental data such as ocean circulation modelling to develop environmental indices suitable for inclusion into population models.*

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# APPENDIX A - INTELLECTUAL PROPERTY

The FRDC's share of project income, based on the relative value of contributions in Part C of the Project agreement or unless otherwise justified, will be 20.98%. CSIRO considers there are two potential categories of intellectual property associated with this FRDC proposal. The first category is the copyright in the report on the survey of orange roughy in the easern zone. CSIRO expects that the IP generated in this form will be jointly owned by FRDC and CSIRO as per standard FRDC agreements.

The other category of IP which may be generated is the further development of the acoustic method by improving the multi-frequency technique for species identification. CSIRO considers any development in this area will be regarded as an accretion to CSIRO know-how and therefore will not form part of intellectual property generated from this proposal.

Please do not hesitate to contact Tim Managan at CSIRO should you wish to discuss this issue further.

# APPENDIX B - STAFF

| Staff Member | Position | Time (%) |
|---|---|---|
| Mr Rudy Kloser | Fisheries Acoustician | 30 |
| Dr Alan Williams | Fisheries Biologist | 20 |
| Mr Tim Ryan | Acoustics Data Analyst | 80 |
| Mr Gordon Keith | Programmer/Modeller | 30 |
| Dr Pavel Sakov | Programmer/Modeller | 30 |
| Mr Mark Lewis | Biological Technician | 30 |
| Dr Jeremy Prince | Fisheries Biologist | 10 |
| Mr Jeff Cordell | Acoustic Technician | 50 |

# APPENDIX C - BIOLOGICAL SAMPLING PROTOCOLS FOR INDUSTRY VESSEL OBSERVERS

## C.1 Data collection protocols 1999

### C.1.1 Biological sampling strategy for industry vessel

The overall aim is estimate the species-mix of fish marks and bottom scatter surveyed by echosounder. The top priority is St. Helens Hill, with St. Patricks Head and the two northern hills sampled according to the size and persistence of fish marks.

Species-mix will be recorded for seven broad categories of fishes based on their reflectivity and size. Targeted biological sampling will provide supplementary information on size and age classes, sex ratios and sexual maturity. Part of this work will be done on board, some will be done on fish passed to *Southern Surveyor* at sea, and the remainder will be done in the lab.

The overall aim is to target the significant marks seen during each of the four 5-day industry surveys, but balance the number of target tows with the need to sample bottom scatter. We anticipate about 3+ days trawling and up to 2 days acoustic survey during each 5-day survey.

Sampling of bottom scatter is critical to the analysis of biomass, even though it produces small catches with low commercial value and is relatively uninteresting for the vessel and crew.

Sampling at all four sites will be depth-stratified due to the general marked change in community structure with depth. Trawl sampling at St. Helens Hill will also be stratified by sector (east and west) around the hill.

Over the duration of the survey, our first priority is to complete at least two bottom-scatter tows in each of four 100 m depth strata (700-1100 m) in the two sectors around St. Helens Hill (16 tows) in addition to tows on marks (see Table A.1). A deep stratum off the hill will be towed if time permits. Allocation of time for additional tows will depend on the number of significant marks on St. Helens Hill and the need to sample the lower priority seamounts.

**Station data**

Station data are collected on the standard CSIRO data sheets. Most items are self-explanatory, but a couple of notes are relevant:

1. ‘depth’: the depth range over which the trawl has ground contact

2. ‘fishing time’: the duration of ground contact time

3. ‘start and end positions’: the positions of the vessel when trawl is fishing, AND if possible the positions of the trawl during ground contact (based on bathymetry)

4. 'Notes': it is often helpful to note the depth and appearance of marks that are targeted, and to provide a sketch

**Catch compositions**
The species compositions of catches are used to estimate the make-up of marks measured with acoustics. Composition will be estimated for all demersal tows.

1. Sort components of catch into the seven 'species acoustic groups': orange roughy, oreos, morid cods, whiptails, sharks, 'miscellaneous low-reflectors', 'miscellaneous high-reflectors' (see Table 8.8)

2. Weigh and count the combined individuals of each group

3. Subsample as necessary (see note below*) and scale-up weights and counts to total catch

*** Subsampling large catches**

1. Use crew estimate of total catch size (preferably use the same person's estimate each time, eg the skipper)

2. If catch > ~1 tonne, process a representative subsample and carefully estimate its proportion of the total estimated catch

3. For very large catches (> 1 split) take one subsample per bag-split and amalgamate results (species are not always evenly mixed through the cod-end, eg roughy mixed with oreos)

**Length frequencies (LFs)**
1. Lengths are collected to evaluate size classes within acoustic groups.

2. Roughy: take sexed, maturity-staged, LFs of up to 200 per tow (SL)

3. Measure to nearest mm; to be rounded-up to cm.

4. Other species: take all, or at least 200, LFs per 'acoustic group' per tow (unsexed, TL)

**Otoliths**
We aim to collect 1000 roughy for analysis of age structure in and out of aggregations, in the different areas of interest (St. Helens Hill, St. Patricks Head, and the two northern hills), and through the duration of the survey (see Table A.2). Whole fish will be collected at sea and the dissections done in the lab.

1. Place whole fish in polyweave bags (~20-25 per bag), label with shot details and store bags separately from main catch. This will enable them to be easily recovered during unloading.

2. Keep a running tally 'by ground' and 'by trip' on the Table A.2.

3. [Note: lab processing will include weight and length data to provide this relationship for biomass allocation to size classes.]

**Ovaries**
Ovaries will be collected for later macroscopic examination of maturity stage. These should be taken from St. Helens Hill to provide a contrast between 'on hill' and 'off hill' for the duration of the survey. Because ovaries need to be carefully removed and placed in 10% neutral-buffered formaldehyde solution, the batches of target fish will need to be passed to *Southern Surveyor* in a floated net bag. Collection will be during Trips 2 and 3.

1. Females should be identified via small incisions, carefully bagged up and transferred in batches of 10-20.

2. [Keep a running tally by 'on-hill' or 'off-hill' by trip on the Table A.2.]

## C.1.2 Collections from pelagic trawls taken by *Southern Surveyor*

**Catch compositions**
The species compositions of catches are used to estimate the make-up of deep-scattering marks measured with acoustics. Composition must be estimated for all cod-end catches from about 10 pelagic trawl tows targeted at mid-water marks.

1. Sort components of catch to species (or species-group for known difficult groups)

2. Weigh and count combined individuals of each species or species-group

**Length frequencies (LFs)**

1. Measure up to 100 of all species represented by > 3 individuals (unsexed, TL) from each cod-end

**Ovaries**
Ovaries will be collected for later macroscopic examination of maturity stage. These should be taken from St. Helens Hill to provide a contrast between 'on hill' and 'off hill' for the duration of the survey. Because ovaries need to be carefully removed and placed in preservative, the batches of target fish will need to be passed to *Southern Surveyor* in a floated net bag.

1. Record full biological details of target fish (fish number, length, weight, sex, gonad weight, maturity stage)

2. Place carefully removed entire, intact pair of ovaries in labelled polycarb container and fill with 10% neutral-buffered, technical-grade formaldehyde solution. Discard ruptured ovaries.

3. Keep a running tally by 'on-hill' or 'off-hill' and 'by trip' on the Table A.3.

**Swimbladders**

Swimbladder type and approximate size is evaluated to categorise fish in target-strength groups for analysis of the backscatter data. We have this information for most mid-slope fishes, but lack detailed swimbladder-size data for some species and have few good photographs of swimbladders.

**Table C.1 [St. Helens Hill = 4 depth strata (700-800, 800-900, 900-1000, 1000-1100) in 2 sectors (east and west)]**

| | First priority | tows | Second priority | tows |
|---|---|---|---|---|
| Trip 1 | St. Helens: 2 tows on aggregations per sector = 4<br><br>Other sites: 2 tows on aggregations = 2+ | 6+ | St. Helens: 2 bottom scatter tows in deep water (~1100-1200m) off hill = 2 | 2 |
| Trips 2 & 3 | St. Helens: 2 bottom scatter tows per depth stratum per sector = 8<br><br>St. Helens: 6 tows on aggregations per sector = 12 | 20 | Repeat tows for highly variable depth/ sector strata or small catches (ie <100 kg)<br><br>Additional tows in aggregations | + |
| Trip 4 | St. Helens: 2 tows on aggregations per sector = 4<br><br>Other sites: 2 tows on aggregations = 2+ | 6+ | St. Helens: 2 bottom scatter tows in deep water (~1100-1200m) off hill = 2 | 2 |

**Table C.2 Otolith table (keep a running tally)**

| Roughy for otoliths | St. Helens: main marks<br><br>(~125 per trip)<br>(25-50 per shot) | St. Helens: off hill<br><br>(25-50 per shot) | Other areas<br><br>(25-50 per shot) |
|---|---|---|---|
| Trip 1 | | | |
| Trip 2 | | | |
| Trip 3 | | | |
| Trip 4 | | | |
| Approx Target | 500 | 200 | 300 |

**Table C.3 Ovary table (keep a running tally- but mainly for Southern Surveyor)**

| Roughy for ovaries | St. Helens: main marks | St. Helens: off hill |
|---|---|---|
| Trip 1 | 0 | 0 |
| Trip 2 | 40 | 40 |
| Trip 3 | 40 | 40 |
| Trip 4 | 0 | 0 |
| Approx Target | 80 | 80 |

# C.2 Biological Data collection protocols – 2001 Survey

## C.2.1 Biological sampling strategy for industry vessel

### Overview

We anticipate taking samples from landed fish (factories in St Helens or Hobart) for an extended time during the spawning period, and at sea during peak spawning activity when a CSIRO observer will be on board.

1. Fish for otolith extraction need to be bagged separately and labelled with the shot number internally and externally.

2. Sampling at sea (biological and acoustics) must fit around the fishing activities.

No cod-end liner will be fitted at any part of the survey

### Station data

Station data will be collected on modified data sheets: these have only essential positioning information and a map to mark shot positions. Data will be transferred to the standard CSIRO form afterwards. Key items include:

1. ‘depth’: the depth range over which the trawl has ground contact

2. ‘fishing time’: the duration of ground contact time

3. ‘start and end positions’: the positions of the vessel when trawl is fishing, AND if possible the positions of the trawl during ground contact (based on bathymetry)

4. ‘Notes’: it is often helpful to note the depth and appearance of marks that are targeted, and to provide a sketch

**Catch compositions**
The species compositions of catches are used to estimate the make-up of marks measured with acoustics. In this survey only brief details will be recorded:

*With no observer:*

1. Skipper’s estimate of total catch and brief notes on bycatch (species and proportion)

*With observer on board:*

2. Catch sorted into the seven ‘species acoustic groups’: orange roughy, oreos, morid cods, whiptails, sharks, ‘miscellaneous low-reflectors’, ‘miscellaneous high-reflectors’

3. Weigh and count the combined individuals of each group

4. Subsample as necessary (see note below *) and scale-up weights and counts to total catch

**Subsampling large catches**
1. Use crew estimate of total catch size (preferably use the same person’s estimate each time, eg the skipper)

2. If catch > ~1 tonne, process a representative subsample and carefully estimate its proportion of the total estimated catch

3. For very large catches (> 1 split) take one subsample per bag-split and amalgamate results (species are not always evenly mixed through the cod-end, eg roughy mixed with oreos)

**Length frequencies (LF’s)**
*With no observer:*

1. Roughy LFs based on fish processed at factory for otoliths (shot details needed)

*With Mark on board:*

2. Roughy: take sexed, maturity-staged, LFs of up to 100 per tow (SL); measure to nearest mm.

3. Other species: take representative samples of key species only, up to 100 each per tow (unsexed, TL)

**Otoliths**

We aim to collect 1000 roughy for analysis of age structure and otolith shape in aggregations at St Helens and St Pats. These will be collected progressively in batches through the duration of the survey, but our aim to get most of them by the end of peak activity (see '*Otolith Table*'). Whole fish will be collected at sea and the dissections done in the factory.

1. Place whole fish in polyweave bags (~20-25 per bag), label with shot details and store bags separately from main catch. This will enable them to be easily recovered during unloading.

2. Keep a running tally 'by ground' and 'by trip' on the *Otolith Table*.

3. Note: factory processing will include weight, length, sex, maturity stage data. When possible fresh fish will be processed separately to provide a length/ weight relationship.

**Otolith table (keep a running tally)**

| Roughy for otoliths | St Helens: aggregations (25-50 per shot) | St Patricks: aggregations (25-50 per shot) |
|---|---|---|
| Week 1 (~300 total) | | |
| Week 2 (~300 total) | | |
| Week 3 (~300 total) | | |
| Week 4 (~100 total) | | |
| Approx Target | 500 | 500 |

**Figure C.1 Data sheet for trawl shots on St Helens Hill**

**St Helens Hill Locality trawl log sheet 2001.**

**Shot No** ________

*Sequential from Start of Survey.*

**Vessel** Celtic Rose **Cruise Name** CR-01 **Date** ____July 01

**Recorder**

**Please label all catch retained with the date and shot number off this form.**

Please enter the vessel position when shooting the net, when the net lands (if possible) and at the start of hauling in Degrees, Minutes and decimal minutes..

| | Latitude | Longitude | Depth under Vessel | Local Time |
|---|---|---|---|---|
| **Shooting the net** | S | E | m | |
| **Net on bottom** | S | E | m | |
| **Start of Hauling** | S | E | m | |

**Wire Out** m **Tow direction** **Actual Bottom Time** min

**Depth range fished** m **to** m **Layback Distance**

**Total Catch Weight** t

**Proportion of each acoustic group in total catch (as per sheets.)**

| | | | |
|---|---|---|---|
| | | **Whiptails** | % |
| **Orange Roughy** | % | **Morid Cods** | % |
| **Oreos** | % | **Miscelaneous High** | % |
| **Sharks** | % | **Miscelaneous Low** | % |

**Please label all catch retained with the date and shot number off this form.**

**PLEASE PLOT THE TRAWL ON THE REVERSE OF THE FORM.**

**Comments. (about the weather or tide, gear pushed to one side or other.....)**

**Figure C.2 Data sheet for trawls shots on St Patricks Head.**

**StPatricks Head Locality trawl log sheet 2001.**

**Shot No** ________
*Sequential from Start of Survey.*

**Vessel** Celtic Rose **Cruise Name** CR-01 **Date** ____July 01

**Recorder**

**Please label all catch retained with the date and shot number off this form.**

Please enter the vessel position when shooting the net, when the net lands (if possible) and at the start of hauling in Degrees, Minutes and decimal minutes..

| | Latitude | Longitude | Depth under Vessel | Local Time |
|---|---|---|---|---|
| **Shooting the net** | S | E | m | |
| **Net on bottom** | S | E | m | |
| **Start of Hauling** | S | E | m | |

**Wire Out** m **Tow direction** **Actual Bottom Time** min

**Depth range fished** m **to** m **Layback Distance**

**Total Catch Weight** t

**Proportion of each acoustic group in total catch (as per sheets.)**

| | | | |
|---|---|---|---|
| | | **Whiptails** | % |
| **Orange Roughy** | % | **Morid Cods** | % |
| **Oreos** | % | **Miscelaneous High** | % |
| **Sharks** | % | **Miscelaneous Low** | % |

**Please label all catch retained with the date and shot number off this form.**

**PLEASE PLOT THE TRAWL ON THE REVERSE OF THE FORM.**

**Comments. (about the weather or tide, gear pushed to one side or other.....)**

# APPENDIX D - ACOUSTIC SAMPLING FROM THE INDUSTRY VESSEL

## D.1 1999 Surveys

### D.1.1 Background

The purpose of the acoustic sampling over the 4 week period from the industry vessel is to monitor the build up and decline of orange roughy on the hill and dynamics of the spawning aggregation and associated deep water species. It is important to understand what is happening away from the hill and in the water column so that we can better understand the changes that occur and attempt to infer where the fish are coming from. The main region is St Helens Hill and effort should be allocated on this region in preference to St Patricks and Northern Hills. We plan 20 days of sea time in total for the trip and this will be divided into 4 trips. Both acoustic and trawl sampling is required by the industry vessel. The trawling is required to **identify acoustic marks as a priority** as well as obtain background tows. A biological sampling protocol is attached that outlines the requirements of the biological sampling

It is vital to have good acoustics for the surveys and as such great care needs to be exercised when collecting the data to ensure there is minimal interference from the vessels ancillary equipment and the sea state.

The vessel noise will change with vessel speed and a survey speed needs to be chosen that reduces the background noise whilst still ensuring a reasonable coverage per unit time. I would suggest an experiment from 6-9 knots to determine an optimal survey speed.

Ancillary equipment that interferes with the main echo sounder must be turned off during the survey. Characteristic tick marks and wave structures are signs of electrical and or acoustic interference. Isolate these noise sources by turning equipment off then on after a few minutes and observe change on the echogram.

Sea state will affect the acoustic data and is vessel dependant. In general the best steaming direction is traveling with the sea and it is best to leave the acoustic surveys for when the sea is predicted to be the calmest.

Always check that the GPS data is being recorded with the acoustic data during the survey at the start and end of each transect and every hour during normal operations.

### D.1.2 Acoustic Surveys

The industry vessel will be required to perform a structured acoustic survey each trip as directed by the observer. As well as performing associated biological sampling on marks observed.

Collection of acoustic data on the Industry vessel during the 4 surveys:

A log (as per attached example) needs to be kept of the start and end of each transect as well as a comment of the fish observed and the skippers impression of the composition of the mark. Also indicate in the log and on the maps provided where the trawls were performed and the dominant catch.

It is important to finish off a survey prior to any fishing this is primarily to avoid fish movement from effecting the results.

It is desirable on St Helens to perform the survey prior to fishing the marks so that they do not disperse or adversely change their behavior.

If other boats are in the region let them know when you plan to perform a survey and organise to complete the NW side of the hill before they fish.

### D.1.3 St Helens Hill survey

Rectangular grid with 5 transects as per map 1 at 8 knots or a speed that reduces the noise. If surveying in high seas run all transects with the sea. It is preferable to run N-S-N transects. 8hrs

Star grid (6 transects) over the center of the hill as per map 2. Concentrating on the NW sector. Repeat this sampling if time permits. Estimated time: 8 hrs

NOTE extend survey lines if still encountering fish marks.

### D.1.4 St Helens Hill Schools

Star pattern over the schools as per map 3.

Observe changes in school structure with time.

### D.1.5 St Patricks Head ground

Zigzag transects from 700 – 1100m over major fishing ground

Star pattern over the schools found.

Estimated time: 5 hrs (depending on marks found)

### D.1.6 Northern Hills

Perform two orthoganal transects on the centre of the hills to beyond the base or until end of acoustic mark and check for acoustic marks and identify accordingly with trawling. Estimated time: 1-2 hrs

### D.1.7 Acoustic Settings

The Echo Listener needs to be set to narrow bandwidth high gain operation with a sampling range of 300 - 1300m, 700 values. Absorption set to 6 dB/km.

EY500 needs to be set on 300-1300 m with 700 samples on long, narrow pulse length and absorption 6 dB/km.

## D.2 2001 Surveys

### D.2.1 Acoustic surveys

Industry vessel to perform two types of surveys:

1. Collection of acoustic data during the course of normal fishing operations.

2. Mapping surveys of significant fish marks.

Star pattern (4 equiangle transects) should be made over significant school marks. The star pattern should radiate out from the center of the mark with the transects ceasing once the mark end (see attached survey plans, maps 3 and 5). Where possible a series of 6 or so east-west or north-south transects should be made in such a way as to bound the extent of the school in all directions.

The survey should be completed in the one time period to avoid fish movement affecting the results. Where possible the survey should be completed prior to fishing the marks so that they do not disperse or adversely change their behavior.

### D.2.2 General comments on acoustic surveying

The vessel noise will change with the vessel speed and a survey speed needs to be chosen that reduces the background noise whilst still ensuring a reasonable coverage per unit time. If acoustic data quality is degraded consider adjusting the vessel speed to see if this makes a significant difference.

Ancillary equipment that interferes with the main echo sounder must be turned off during the survey. Characteristic tick marks and wave structures are signs of electrical and or acoustic interference. Isolate these noise sources by turning equipment off then on after a few minutes and observe change on the echogram

Sea state will greatly affect the acoustic data and is vessel dependent. In general the best steaming direction is travelling with the sea and it is best to leave the acoustic surveys for when the sea is predicted to be the calmest.

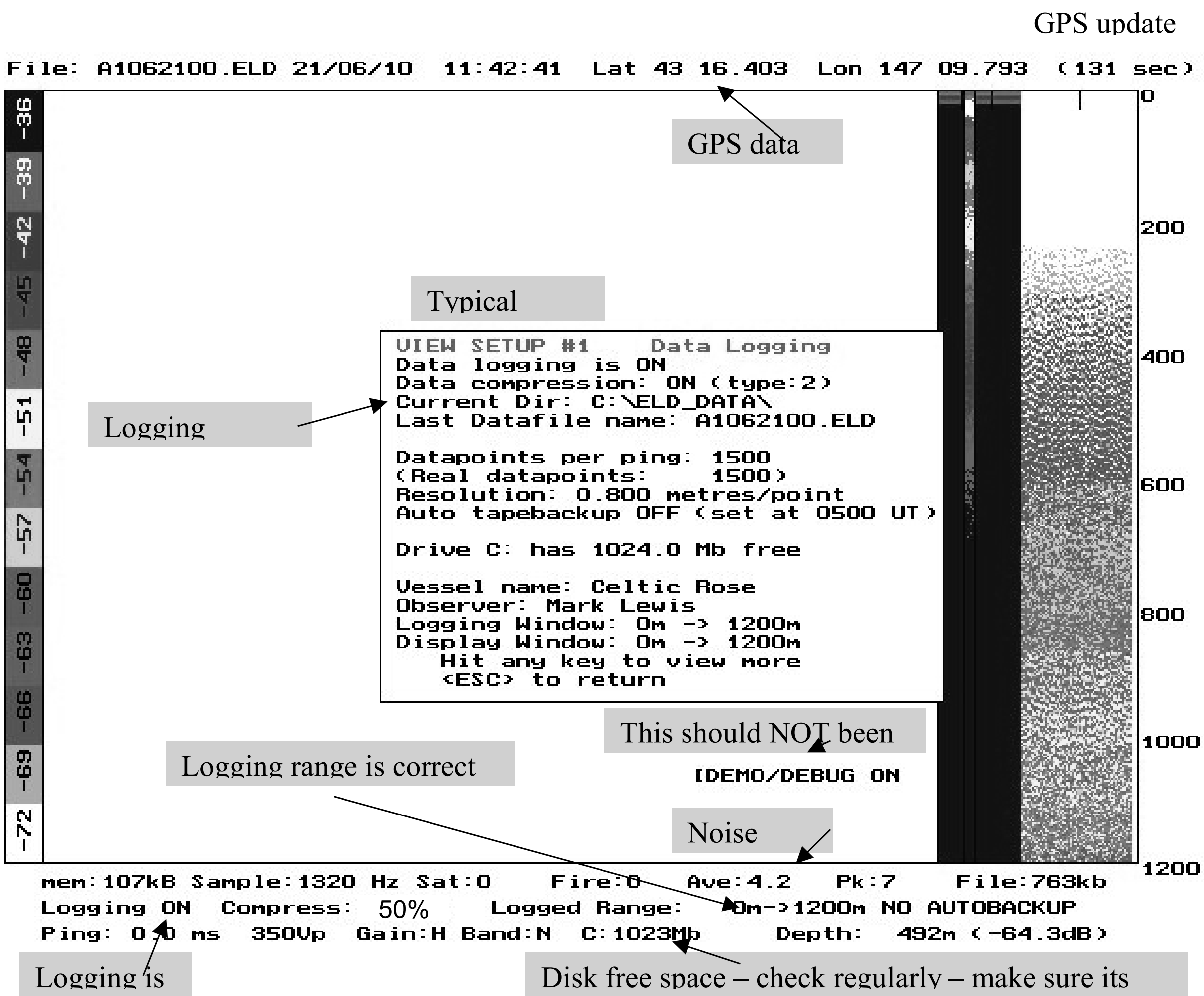
### D.2.3 Logging acoustic data with the Echolistener system

Figure D.1 shows typical echolistener settings with notes on key parameters to check. In particular always check that the GPS data is being recorded and that the hard drive is not full.

### D.2.4 Logging acoustic data with the ES 60 system

To give adequate signal to noise the ES60 needs to be run on long (3 ms) pulse length. Ensure that the system is actually logging when on the fishing grounds. Other sounders may interfere with the ES60 data. These should be either turned off when logging ES60 data or run in sync with the ES60

**Figure D.1 Typical Echolistener settings**



# APPENDIX E - WEIGHT LOSS DURING STORAGE OF ORANGE ROUGHY

## E.1 Introduction

It has long been recognised that fish lose weight after freezing due to evaporation of moisture; this increases substantially after thawing due to moisture loss from tissues disrupted by the formation of ice crystals. Despite this knowledge, and the decade-long history of orange roughy research in Australia, weight loss during orange roughy storage had not been quantified. Because this relationship is relevant to the calculation of biomass from surveys we calculated weight losses from a sample of fish during the most recent survey (2001) undertaken during this project.

## E.2 Methods

During recent work at sea a sample of 10 roughy was frozen for later analysis on board the fishing vessel *Saxon Onwards*. The fish varied in size from 36 to 46 cm SL and fresh weight of 1709.4 to 2967.7 g. Fish were weighed on board using a high-precision motion-compensating balance (POLS model S 120_3) accurate to 0.7% of total weight and precise to +/- 0.1 grams.

On land the fish were kept frozen whole in an industrial freezer at CSIRO Marine Research in Hobart and maintained at -20°C for the duration of the experiment. In the freezer the fish were stacked in a fish bin and interleaved with layers of plastic to simulate normal storage procedures and help reduce freezer burn by reducing the air movement around the fish. The fish were weighed at random intervals and the time of each weighing recorded. All efforts were made to reduce the time out of the freezer and any potential weight variations due to condensation. The fish were weighed on a calibrated balance (ISHIDA QB_6200E) with 0.1grams accuracy.

After 981 hours in the freezer five fish were selected and defrosted to evaluate weight loss during thawing and refreezing. The fish were left in a large sink until completely defrosted. During the first defrost the fish were not weighed until completely thawed to evaluate overall weight loss. During the next two defrosts (at 1173 and 1340 hours) the fish were weighed at regular intervals. After each defrost cycle the fish were re-frozen before the final weight was taken as the fish usually lost about 1% of its weight during the re-freezing process.

The rate of weight loss over time was calculated on the data up to the 981 hours as after that half of the fish were used in the defrosting experiment.

## E.3 Results

Whilst frozen the fish were found to loose only 0.0402 grams per hour or 2.146% of the initial weight over 981 h. The rate of weight loss decreased over time as shown in the diagram below (Figure E.1) and could be defined by the relationship:

$$Y = 2416.6 - 6.5115\log(X)$$

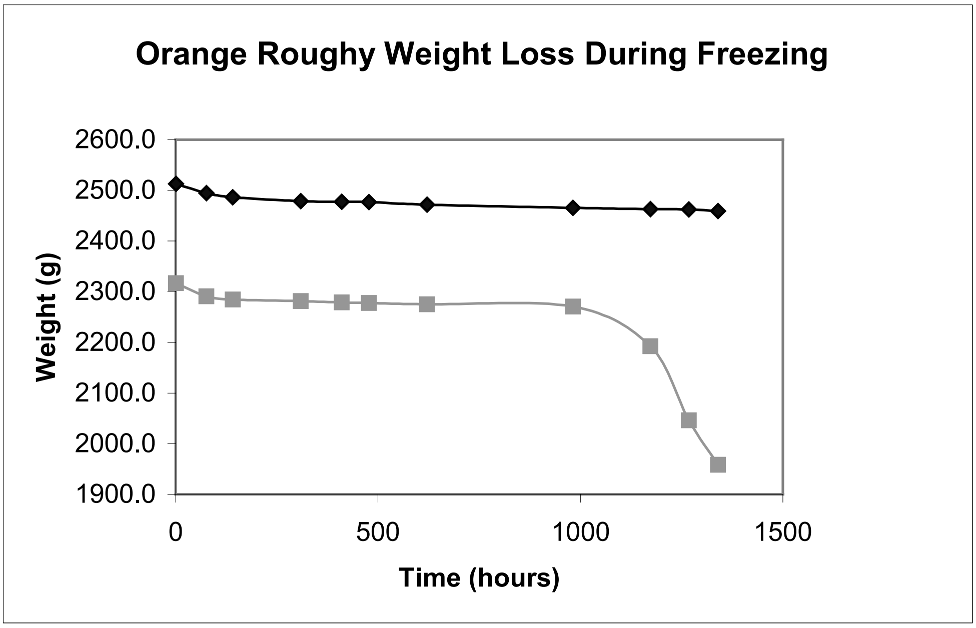
where $Y$ is the weight in grams and $X$ is time in hours.

The five fish defrosted at 981 hours lost an average of 78.34 grams during the first defrosting and re-freezing process (5.38% of initial weight) (Figure E.1). This one defrost cycle more than doubled the rate of weight loss over time changing from 0.0425 to 0.1061 grams/hr. During defrosting, condensation formed on the bags covering the fish, a sponge was used to collect some of the condensation and over 8 grams per fish was recovered at one point.

At 1173 hours the same five fish were again defrosted and found to have lost 251g on average over the defrosting period (11% of their original weight). If the fish had remained frozen, the expected weight loss would be 2.027% or 56.61grams. During the defrost the weight of the fish fluctuated due to ice forming from condensation with one fish gaining weight (16 grams) in the first 8 hours. As the fish warmed the weights dropped evenly as any ice present melted and drip loss continued. These five fish were weighed after re-freezing and found to have lost further weight during the refreezing process (11.8% of original weight compared to 2.060% without defrosting) (Figure E.2.a).

After a third defrost cycle starting at 1340 hours the fish had lost a total of 15.58% of the original weight (Figure E.2.b) while the fish that remained frozen lost only 2.19%.

**Figure E.1. Orange roughy weight loss over time during freezing and thawing: continually frozen (upper black line); fish frozen for 981 hours with the last three points showing weight after defrosting and re-freezing (lower grey line).**



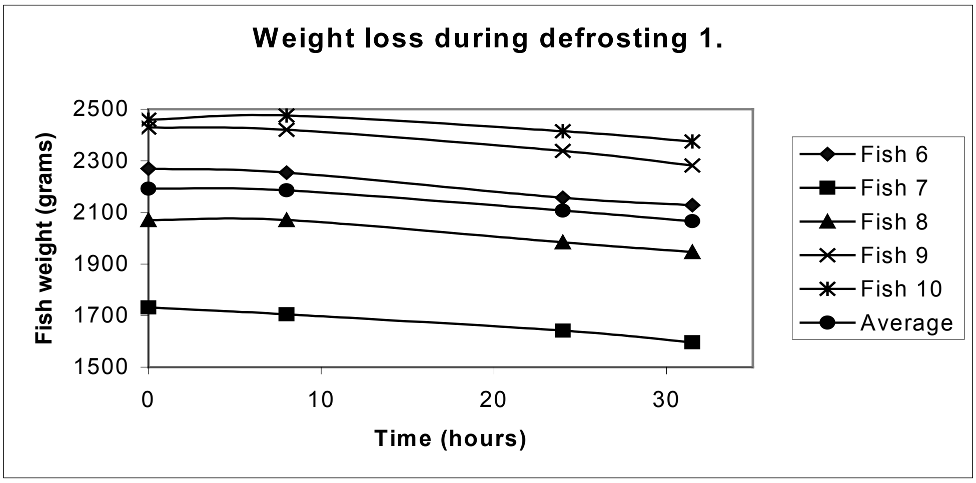

## E.4 Discussion and Conclusion

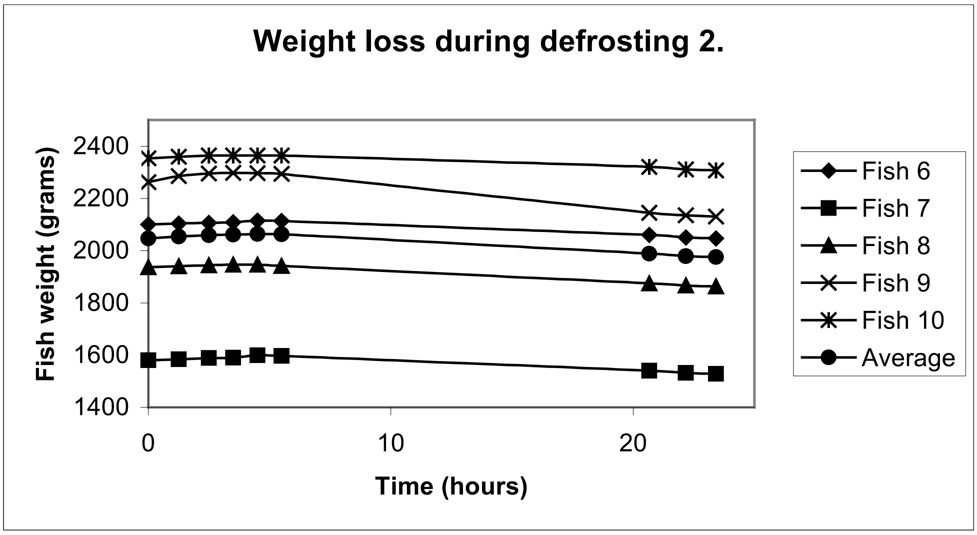
This work shows that orange roughy loose weight at the rate of 0.0425g/hr when frozen, even when loosely covered with plastic sheeting, and that weight loss increases noticeably when fish are defrosted and re-frozen (averaging approximately 5% weight loss per complete defrost cycle). The initial weight loss is relatively rapid as surface moisture is dried off, then the rate slows to be more constant as all future loss is through the skin.

This work has major implications for the storage of specimens for research purposes. Freezing for long periods, and defrosting in particular, will cause a substantial drop in weight that will influence parameters such as length/ weight relationships in biological research. These will flow through other calculations such as average weight for stock biomass estimation and comparisons of body weight to gonad weight (GSI).

There was also noticeable weight gain during the first few hours of defrosting caused by condensation of water vapour. This also has the potential to cause problems if not recognised. To avoid this during the present study the fish were always weighed and returned to the freezer as soon as possible.

**Figure E.2. Shows the rate of weight loss during defrosting: (A) second defrost cycle, (B) third defrost cycle.**


Weight loss during defrosting 1.
Fish weight (grams)
2500
2300
2100
1900
1700
1500
0
10
20
30
Time (hours)
Fish 6
Fish 7
Fish 8
Fish 9
Fish 10
Average


Weight loss during defrosting 2.
Fish weight (grams)
2400
2200
2000
1800
1600
1400
0
10
20
Time (hours)
Fish 6
Fish 7
Fish 8
Fish 9
Fish 10
Average

# APPENDIX F - GONAD STAGING SHEETS USED BY NIWA.

### Gonad stages for orange roughy

#### Females

1 **Immature or resting**
Ovary clear or pink, small. No eggs visible.

2 **Maturing**
Ovary pink, small eggs visible (as orange dots). Ovary small.

3 **Mature**
Orange, yolk filled eggs obvious (diameter 0.5-1.5 mm), filling the ovary. Ovary quite large, bright orange.

4 **Ripe**
Ovary large. Clear eggs are present (more than just one or two).Ovary has mottled orange appearance, with mixed orange and clear eggs.

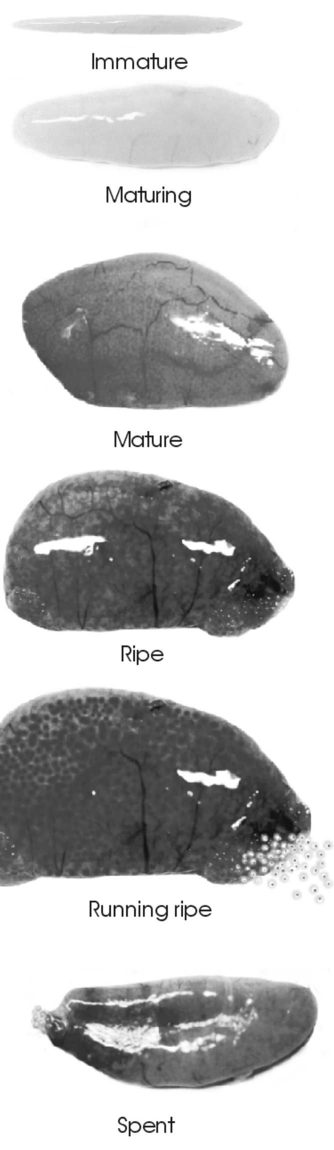
5 **Running ripe**
Ovary large and thin walled, fragile. Most eggs clear (hydrated). Eggs flow freely when light pressure applied to the abdomen.

6 **Spent**
Ovary flaccid and bloody. Some residual eggs often present.

7 **Atretic**
Eggs yellow or blackish. Degenerating.

8 **Partially spent**
Ovary somewhat flaccid, slightly bloody. Contains substantial numbers of clear freely flowing eggs, may have orange eggs also. Some eggs lost.

9 **Immature showing atresia**




At CSIRO Marine Research we combine the stage 8 into stage 5 in the females as we do not believe that the orange roughy is a batch spawner. The same for the males, stage 8 into stage 4, as we believe these fish are either in the process of spawning or just finished. Distinguishing between stage 5 & 6 (female) and 4 & 5 (male) determined at the time using criteria above and the number of eggs, or amount of sperm and the condition of the ovary or testis.

**Males**

1 **Immature or resting**
Testes small and threadlike when immature.
Hard and brown with no milt when resting.



Immature

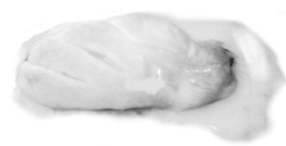
2 **Maturing**
Testes increased in size, but still small,
no milt expressible when cut.

Maturing

3 **Spermiated**
Viscous milt present when cut.
Testes can be relatively large.

Spermiated

4 **Spermiated, running**
Free-flowing milt. Testes shape and outline often not sharp like (3) because of milt. Flows freely with light pressure on the abdomen.

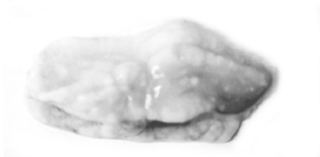


Running

5 **Spent**
Testes rather flaccid, and bloody.
Almost no milt is expressible.
Often has a 'glazed' brownish appearance.

Spent

8 **Partially spent**
Testes still quite large with some free flowing milt.
Brownish tinge, posterior end withered and bloody.

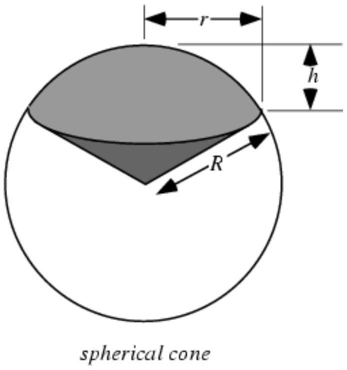


Partially spent

# APPENDIX G - VOLUME OF A SPHERICAL CONE CALCULATION

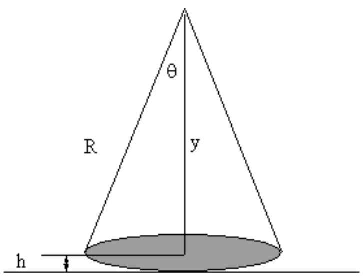
The sampling volume of a 3dB cone of acoustic beam is calculated as follows.

**volume of a spherical cone**




$$V := \frac{2}{3}\pi \cdot R^2 \cdot h$$

where h is the vertical distance between where the upper and lower radii intersect the sphere and R is the sphere's radius.




**Calculation of h**

y:=cos(θ).R;   h:=R – y;   h:=R - cos(θ).R

subsituting for h we have the volume of a spherical cone as:

$$V := \frac{2}{3}.\pi.R^2.(R - \cos(\theta).R)$$

the sampling volume of a conical acoustic pulse will be:

Vt=V2-V1 where

V2 is the volume of the cone at distance R2 (i.e. R+pulse length) and V1 the volume of the cone at distance R.

Substituting, the volume of a spherical cone can be written as

$$V_t := \left[\frac{2}{3}\cdot\pi\cdot\left(R_2\right)^2\cdot\left(R_2 - \cos(\theta)\cdot R_2\right)\right] - \left[\frac{2}{3}\cdot\pi\cdot(R)^2\cdot(R - \cos(\theta)\cdot R)\right]$$

# APPENDIX H - HISTORICAL LENGTH WEIGHT EQUATIONS

## H.1 Introduction

Historically three equations have been used, H1-H3. The data these equations were calculated from was collected in the late 1980's and early 1990's. The protocols at the time were that the department of Sea Fisheries (now Tasmanian Aquaculture and Fisheries Institute) measured to the half centimetre and rounded down. The BRS (Bureau Rural Resources) and CSIRO measured to the millimetre and rounded up. The data collected during this survey was measured to the mm and used in that form for the calculations (as has been standard practice since 1996). This difference in measurement method and the information on weight change in storage (Appendix E) indicates that these equations need to be further evaluated.

## H.2 Methods

The data from the 2001 and 1999 field seasons were entered into the historical equations and the difference between the predicted weight and the observed weight is discussed.

The 1999 data was collected at the factory and the fish had been frozen for up to 1 month before measurement. The 2001 data was collected on the Petuna Explorer using a motion compensated balance(POLS model S_120_3 accurate to 0.7% of total weight and precise to +/-0.1gram) prior to storage.

### H.2.1 Historical Equations

The formulae used in 1999 (Chapter 3):

$Weight = 17.54*(length/1000)^{2.4}$ H.1

Where *length* is standard length in mm and *weight* in kilograms.

The equations H.2 and H.3 are used in the stock estimates provided to the South East Fishery Stock Assesment Group (Lyle *et al*, 1989).

**Female** $Weight = 0.0351* length^{2.970}$ H.2

**Male** $Weight = 0.0383* length^{2.942}$ H.3

Where *weight* is in grams and *length* is in centimetres.

## H.3 Results and Discussion

**Table H.1 Mean Weights from field data and estimates using the stock assessment equations. Weight is in kilograms. The percentage difference is the difference between the observed and the expected weight.**

| Equation Number | Mean Wt 2001 | Equation Estimates 2001 | Mean Wt 1999 | Equation Estimates 1999 |
|---|---|---|---|---|
| 8.6 | 1.282 | 1.322 | 1.207 | 1.373 |
| 8.7 Female | 1.471 | 1.434 | 1.1 | 1.205 |
| 8.8 Male | 1.114 | 1.215 | 1.338 | 1.457 |
| Average % Difference | | 4.90 | | 10.73 |

When you compare the data collected in the field with the predictions from the equations there is some variation (Table H.1). This is a cause for concern as the weights used to calculate the equations were not measured fresh but some time after capture and storage in either ice or brine. Due to some recent work (Appendix E) fact that fish loose weight during storage can now be quantified. Further work needs to be done to more fully investigate the effect of different methods of storage but at 5% of original weight per defrost cycle this could amount to a significant amount.

Some of the difference may be accounted for with the different method of measurement used by other organisations. This data shows a clear need for further work on the length weight equations and a definite need to standardise the method of collecting length weight data.

## H.4 Conclusion

To make comparisons between years and from different organisations it would be helpful if all length data would be collected and stored accurate to the mm as is done by CSIRO Marine Research. It would also help if all fish were measured before storage or if measured after storage then the length of time in storage and the method of storage should be recorded.