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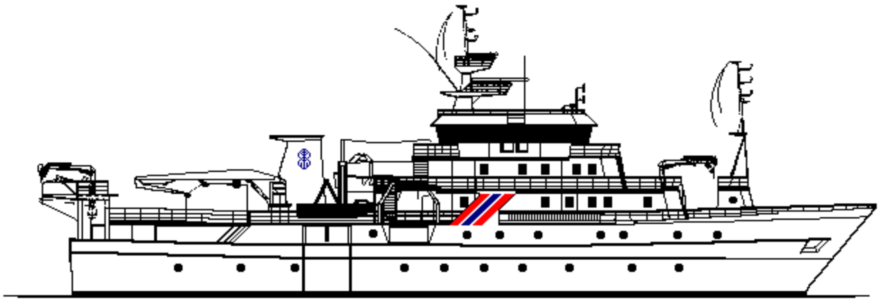

SURVEYS OF FISH RESOURCES OF NAMIBIA

Cruise Report No 5/99

Orange roughy survey
6 July – 31 July 1999

Ministry of Fisheries & Resources
Swakopmund, Namibia

Institute of Marine Research
Bergen, Norway

SURVEYS OF THE FISH RESOURCES OF NAMIBIA

Cruise Report No 5/99, Part 1

Orange roughy survey
6 July – 31 July 1999

by

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ABSTRACT

The third biomass assessment survey on orange roughy in Namibian waters took place from 6th to 29th July 1999. The survey was conducted with the *RV Dr Fridtjof Nansen*, *FV Emanguluko, FV Hurinis* and *FV Southern Aquarius*. The objectives of the survey were to determine the distribution, mean density and abundance of orange roughy on three of the known fishing grounds (Johnies, Frankies, and Rix) and in areas adjacent to the aggregations. Further development of a suitable methodology for abundance estimations using acoustics was to be determined, including to establish if hull mounted transducers are suitable for surveying deep water species in Namibia.

The *RV Dr Fridtjof Nansen* undertook the acoustic surveying while the trawling was conducted by commercial vessels. Johnies was acoustically surveyed 7 times, Frankies 10 times and Rix 7 times. A total of XX bottom trawl hauls were conducted by the two commercial vessels *FV Emanguluko* and the *FV Hurinis* for acoustic target identification. *FV Southern Aquarius* conducted a separate random trawl survey for swept area purpose, although these trawls were also used to assist in acoustic target identification.

Biological samples were collected and analysed from all of the trawl hauls. *Orange roughy dominated the catches of the central areas of the grounds. A few large catches of orange roughy were made in the spawning aggregations, such that in total orange roughy made up 95 %, 63%, and 93% respectively of the catches for Johnies, Frankies, and Rix. The proportion of orange roughy in the catches decreased when moving away from the central areas of the fishing grounds. In the surrounding areas of the aggregation most catches were less than 1 tonnes and were dominated by species like black oreo (Allocyttus niger), hake (Merluccius capensis), and various species of grenadiers and rat-tails.*

The sex ratio of orange roughy in the catches varied between coverages of the grounds, with Johnies having the proportion of 47 : 52 , Frankies 58 : 41, and Rix 43 : 56% males : females respectively, the remainder being juveniles. Length at 50 % maturity for females occurred at 21.3 cm at Johnies, 22.6 cm at Frankies, and at 26.7 cm at Rix. The 50% maturity for males showed a similar 21.7 cm, 22.5 cm, and 27.0 cm for the same grounds. The level of spawning activity varied with time between grounds and between sexes within a

ground. The highest proportion of running and spent males was found at Johnies, while highest proportion of spent females was found on the last day of the survey at Rix. There were differences in the development of the maturity stages between the first and second coverage of Frankies and Rix. At Johnies the proportion of running and spent females increased somewhat during the survey period but this was less pronounced for males.

Data on fish density (acoustic back-scatter and trawl catch rates) were analysed in a similar manner to previous surveys. A combination of acoustic to assess the density and biomass of roughy in spawning aggregations, and random swept-area trawling to estimate densities of roughy associated with, but outside of these aggregations may yield the most valid estimate of the total abundance. However, as each of these techniques has its own biases, combining the two may not be strictly appropriate.

The biomass for all three grounds, using largest survey area, was estimated by targeted acoustics to between 45 and 50 000 tonnes, (approximately 21 000 tonnes, 15 000 and 6 000 tonnes for Johnies, Frankies and Rix respectively). This estimate decreased to 16 000 tonnes when only the areas with confirmed catches were included in the calculations. This method produced the highest biomass estimate for the three grounds. Alternatively the biomass using the scrutinised method for the whole area of Johnies was estimated to be between 21 800 tonnes and 25 600 tonnes. This estimate decreased to between 1 812 tonnes and 7 700 tonnes when only the identified aggregations area were considered. The biomass estimate for the whole area of Frankies, using scrutinised acoustics method, was shown to be between 4 300 tonnes and 18 000 tonnes. This estimate decreased to 2 400 tonnes when calculations were done on the 3 aggregations only. The biomass estimate for Rix, using scrutinised method, was shown to be between 6 200 tonnes and 10 000 tonnes for the whole area and the verified aggregation area. The biomass for all three grounds using the scrutinised method was estimated to be between 12 300 tonnes and 35 700 tonnes. Combined Acoustic and swept area (outside strata 1) estimated biomass to 11 714 tonnes for Johnies and Frankies together. Trawl-based acoustics assessment method was tried for Johnies, and estimated orange roughy was 57 000 tonnes. The method is strongly dependant on the catch composition in all layers because of the low backscatter for orange roughy and that trawling is only in the bottom channel.

The biomass for the three grounds was calculated by using the swept area method, as 30 250 tonnes, of which 8 150 at Johnies, 2 400 tonnes at Frankies and 19 700 tonnes at Rix.

The limitations of the different methods are discussed, and emphasis is put on the value of the survey data as relative estimates indicating stock changes over time rather than giving an absolute estimation of biomass.

Several experiments were conducted to investigate some of the major biases known to occur when surveying roughy acoustically or by trawling. The proportion of roughy near the bottom was estimated to give an indication that the inclusion of a dead-zone correction may increase the total biomass estimate by a third. An assessment of the acoustic backscatter of various targets was collected during part of the survey using 18 and 38 kHz frequencies. A visual comparison of these data suggest that orange roughy aggregations appear similar at both frequencies and that use of different frequencies to discriminate between roughy and other species may be of limited value.

In general, weather conditions were considerably better than in 1998 and the relative biomass estimates are considered of comparable or better validity compared to the previous estimates. Despite repeated coverages of the grounds, close co-operation between fishing and research vessel, and efficient utilisation of the technical equipment and scientific knowledge available, the distribution, spawning activity and behaviour of orange roughy was substantially different to previous surveys, especially at Johnies and Rix. The survey method had to be adapted to allow for this, but even so, the estimates on these two grounds should be sued with some caution.

CHAPTER 1 INTRODUCTION

1.1 Objectives

Overall research objectives

Deep sea fish species are a major focus of the Namibian fishing industry at present. This is a group of fish stocks about which little is known, both in Namibia and elsewhere. Owing to their high value, even stocks of a moderate size will be of large financial importance to Namibia. These species are however expected to be very slow growing, and hence will be highly susceptible to over-fishing.

The major species targeted by the Namibian deep-water industry at present is orange roughy, therefore research is directed primarily at this species. The fishery expanded rapidly between 1995 and 1997, but commercial catch rates and previous survey results suggest that the abundance has declined considerably during the past two years.

Various stock assessment techniques have been attempted elsewhere, but with limited success. The combination of trawl sampling and acoustic sampling compliment each other to some extent, and seem to offer the most promising hope of providing an accurate estimate of abundance. These methods have therefore been adopted in Namibia and indices of previous surveys in Namibia now form the main input to stock assessment models used for management purposes.

Orange roughy occur in dense aggregations close to the sea bed in deep water as well as dispersed at varying and low densities in regions adjacent to the aggregations. This, combined with the low target strength of orange roughy compared to other species, results in the acoustic abundance estimation technique being stretched to its limit and special investigations will be required before the acoustics method can be used for providing absolute estimates. Current estimates are therefore intended for use as relative estimates. Similarly, swept-area estimates rely on several critical assumptions regarding in particular the catchability of orange roughy. Until this is known, these estimates must also be used as relative indices.

Surveys conducted in July 1997 and July 1998 on three of the aggregations known to occur within the Namibian EEZ showed that the acoustic and swept area methodologies could be adapted to assess orange roughy. Aggregations could be delineated, and assessed acoustically, while in general trawling enabled the identification of these shoals. Partially randomised trawling seemed to be successful at assessing the abundance of disaggregated roughy outside of the aggregations.

The current survey aimed to investigate some of the problems of assessing deep-water shoaling species while providing the third relative estimate of the abundance in the three most important areas of known orange roughy concentrations.

The *RV Dr Fridtjof Nansen* will not be available for surveys for many more years and a suitable methodology must be developed for local vessels. The *RV Welwitchia* therefore participated in the 1999 survey in order to test the performance of the acoustic system in deep waters.

The survey therefore had a number of objectives, of which the first was considered of primary importance:

1) To determine the distribution, mean density and abundance of three of the known spawning aggregations of orange roughy in order to obtain an index of abundance relative to the 1997and 1998 surveys .
2) To determine the proportion of fish outside of aggregations.
3) To continue investigations of a suitable methodology to determine orange roughy abundance using acoustics combined with trawling, concentrating on:
    - Reducing biases in the current abundance estimates, i.e. estimation of the dead-zone correction, use of dual frequency information to identify targets)
    - Determining the true survey variability by conducting multiple consecutive surveys of small aggregations.
4) To establish if the RV Welwitchia is suitable for surveying deep water species, using hull-mounted transducers.
5) To determine length-frequency, length-weight relationship and maturity parameters of each aggregation.

6) To collect stomach contents, otoliths and tissue samples for later analysis.
7) To make an estimate of the orange roughy conversion factor.
8) To monitor the oceanographic conditions at the aggregations, specifically of profiles of temperature, dissolved oxygen, salinity and currents.
9) Sample orange roughy larvae and eggs.
10) To train Namibians in the techniques used during the survey.

While every effort was made to follow this survey plan, this was changed as circumstances and opportunities arose.

1.2 Participation

The Scientific staff from the Institute of Marine Research (IMR) in Bergen, Norway were:

Bjørn Staalesen	IMR Cruise Leader, data	7–29/7
Magne Olsen	IMR Divisional engineer, data	7–29/7
Tore Mørk	IMR Chief Instrument Technician	7-29/7
Tor Johansson	IMR Instrument Technician	7–29/7

The scientific staff from the National Marine Information and Research Centre (NatMIRC), Swakopmund, Namibia were:

Dave Boyer	Namibian counterpart to cruise leader, acoustics	7-29/7
Arved Staby	Swept-area survey, data, acoustics	7-29/7
Paul Kainge	Biological sampling, acoustics	7-29/7
Johnny Gamatham	Biological sampling	7-29/7
Malakia Shimhanda	Biological sampling	7-29/7
Shaun Wells	Biological sampling	7-29/7

The following Fisheries Observers from the Directorate of Operations (MFMR), Walvis Bay, Namibia participated:

Dave Kaanandunge	Biological sampling	7-29/7
John Koita	Biological sampling	7-29/7
Mathias Iiyambo	Biological sampling	6-16/7
Johannes Sacheus	Biological sampling	6-16/7

Several consultants were contracted to assist with the survey. These were:

Ian Hampton	Acoustics, survey design	18-25/7
Manual Barange	Acoustics	1–16/7
Benoit Caillart	Biological sampling	1-16/7
Alan Rees	Commercial vessels	18-31/7
Gavin Pope	Commercial vessels	6-16/7

1.3 Cruise schedule

The *RV Dr Fridtjof Nansen* left Walvis Bay on 7th July at 09h00, one day later than planned, and steamed directly to Johnies. The *FV Emanguluko* had departed at Johnies on the 7th July to conduct some commercial trawls on Rix and joined the *RV Dr Fridtjof Nansen* at 09h00 8th July. Survey work was conducted at the three roughy grounds by both vessels, starting with Johnies, then moving on to Frankies on 10th July and finally Rix from 14th to 15th July.

The *RV Dr Fridtjof Nansen* returned to Walvis for a change of crew at 08h00 on 16th and departed again at 16h00 on 18th July. The *FV Hurinis* accompanied the *RV Dr Fridtjof Nansen* on this leg of the survey. Frankies was visited first and surveyed from 19th to 21st July, followed by Johnies from 22nd to 25th and then finally Rix between 26th and 28th July. The *RV Dr Fridtjof Nansen* returned to Walvis Bay at 06h00 on 29th July.

The FV *Southern Aquarius* conducted random swept-area trawl-hauls on the three grounds Johnies, Frankies and Rix from 6th to 10th, 11th to 13th and 14th to 16th July respectively.

Weather conditions during the first leg of the survey were generally good, the only work to suffer being the trawling of the *FV Emanguluko* during one night while on Johnies. During the second leg the a Force 8 gale interrupted the surveying by *RV Dr Fridtjof Nansen* and the *FV Hurinis* for about 12 hours at Johnies, but otherwise the survey was conducted without any further disruption from the weather.

1.4 Survey activities

Working on the basis that:

- equal importance should be given to obtaining accurate estimates from all three grounds,
- peak spawning will be towards the end of the month, and that spawning will peak first at Johnies, then later at Frankies and finally at Rix,

the *RV Dr Fridtjof Nansen* initially conducted preliminary assessments of the three grounds during the first leg of the survey, starting at Johnies, then moving to Frankies and finally

Rix. Ten days were available for this work, thus approximately 3 days was allocated to each ground.

At each ground a broad area was surveyed that encompassed all areas where orange roughy had been found during the previous surveys or during commercial activities of the previous 6 months.

This broad survey was then followed by more directed surveys, either to determine the distribution of roughy more precisely or to gather abundance data.

At Johnies the first survey did not detect any roughy aggregations and so was repeated using a similar grid, but with the transects offset by 0,5 nm. Even after this survey no aggregations had been found and therefore it was decided to move on to Frankies and hope that any roughy at Johnies would aggregate before the second leg.

The initial survey of Frankies determined the distribution fairly clearly and therefore two repeat surveys of 3 Sisters and Frankies Flats were conducted to assess the abundance in these areas. 21 Jump St was not surveyed a second time as no roughy were found in this area.

Some roughy aggregations were found at Rix during the first survey of this ground, but as these did not match closely with the commercial catches a second survey was conducted using a similar grid, but with the transects offset by 0.5 nm from the first survey. A third survey was then conducted on the core area of aggregations to obtain a first estimate of the abundance of roughy on this ground.

Spawning was most advanced at Frankies and therefore it was decided to survey this ground first during the second leg of the survey. In addition, the *RV Welwitchia* had been withdrawn from part of the survey to participate in a BENEFIT activity and therefore was only available for 4 days. As Frankies is only 120 nm from Walvis, compared to Johnies which is 220 nm, this enabled the *RV Welwitchia* to spend a greater proportion of her very limited time conducting acoustic tests with the *RV Dr Fridtjof Nansen*.

The first coverage at Frankies during the second leg was at Three Sisters. *RV Welwitchia* accompanied *RV Dr Fridtjof Nansen* and *FV Hurinis* undertook target identification trawl hauls. The comparison of the *RV Welwitchia* and the *RV DR Fridtjof Nansen* was conducted under moderate to calm seas and the *RV Welwitchia* left after approximately 36 hours of data had been collected. A total of 10 surveys were conducted at Frankies were surveyed, 5 of Three Sisters, 3 of Frankies Flat and 21 Jump Street once, plus the initial survey of the entire area.

The two remaining vessels continued to Johnies arriving on 22nd July. The *RV Dr Fridtjof Nansen* undertook three systematic coverages of the ground, twice with a with transects 1 nm apart (0,5 nm offset), and once with transects 0.5 nm apart. Aggregations were only detected during this final survey and 2 intensive surveys were conducted over the region of dense roughy concentrations. Each survey with systematic transects 1 nm apart.

The vessels arrived at Rix on 26th July and undertook two initial broad coverage with 1 nm transect spacing. The subsequent two surveys were undertaken with an average 0.5 nm spacing, without finding any marks that were verified as clean orange roughy marks. Surveying of this area ceased at 17h00 on 28th July.

FV Southern Aquarius left Walvis Bay on the 6th July at 15h00. She conducted a random trawl survey at Johnies from the 7th July at 13h00 until 10th July at 14h00.She then continued at Frankies from 11th July at 02h00 until 16h00 on 13th July with random trawling. Rix was survey from 02h00 on 14th July to 16th July at 09h00.

A map of the area is shown in Figure 1. A total of XX nm were steamed by the *RV Dr Fridtjof Nansen*, 3 tows and 47 CTD stations were conducted. The *FV Emanguluko* conducted 64 and the *FV Hurinis* 46 targeted tows, while the *FV Southern Aquarius* made 96 random tows. The three commercial vessels caught a total of XX, XX and XX tonnes of orange roughy respectively.

Detailed maps of the three investigated areas (Johnies, Frankies, and Rix) are given in Figure 2, while the acoustic surveys conducted are summarised in Table 1. A summary of the random tow at Johnies, Frankies and Rix are presented in Table 2.

Table 1. Summary of acoustic surveys by area

Ground	Date & Time (UTC)	Survey number	Transect interval	Log No.	Depth range (m)	Latitudinal range (S °min)	Comments
Johnies	7/7 10h00 - 9/7 13h00	1	1 nm	4366 - 4901	500 - 1200*	26°15’ - 26°40’	Systematic transects
Johnies	9/7 13h40 - 10/7 12h30	2	1 nm	4908 - 5058	600 - 1100*	26°36.5’ - 26°17.5’	Systematic - offset by 0.5nm
Johnies	22/7 07h50 - 22/7 23h15	3	1 nm	7158 - 7308	600 - 1100*	26°17’ - 26°36’	Systematic transects
Johnies	23/7 02h20 - 23/7 14h30	4	1 nm	7325 - 7431	600 - 1100*	26°29.5’ - 26°17.5’	Systematic -offset by 0.5 nm
Johnies	24/7 10h55 - 24/7 22h40	5	0.5 nm	7474 - 7632	600 - 1050*	26°30.25’ - 26°18.25’	Systematic - offset by 0.25 nm
Johnies	24/7 22h40 -	6	1 nm	7634 -	750 - 950	26°20’ - 26°34’	Systematic transects
Johnies	- 25/7 15h10	7	1 nm	- 7780	750 -950	26°33.5’ - 26°20.5’	Systematic - offset by 0.5 nm
Frankies (all)	10/7 22h30 - 12/7 10h20	1	1 nm	5153 - 5557	500 -1000*	24°15’ - 24°49’	Systematic transects
Frankies Flats	12/7 12h50 - 12/7 18h10	2	0.5 nm	5557 - 5618	500 - 750	24°31’ - 24°35’	Random transects
3 Sisters	12/7 18h30 - 13/7 01h30	3	0.5 nm	5618 - 5695	600 - 850	24°37’ - 24°42’	Random transects
3 Sisters	13/7 01h40 - 13/7 13h10	4	0,5 nm	5696 - 5790	600 - 850	24°37’ - 24°42’	Random transects
Frankies Flats	13/7 13h30 - 13/7 19h40	5	0.5 nm	5794 - 5852	500 - 750	24°31’ - 24°35’	Random transects
3 Sisters	19/7 09h30 - 19/7 21h00	6	0,5 nm	6559 - 6635	600 - 850	24°42’ - 24°37’	Systematic transects at 45°
Frankies Flats	19/7 21h30 - 20/7 07h10	7	0.5 nm	6650 - 6721	500 - 850	24°31’ - 24°35’	Random transects
3 Sisters	20/7 10h10 - 20/7 19h10	8	0.5 nm	6733 - 6816	600 - 850	24°37’ - 24°43’	Random transects
21 Jump St.	20/7 21h15 - 21/7 05h10	9	1 nm	6838 -6925	500 - 750	24°27 - 24°16	Systematic transects
3 Sisters	21/7 07h20 - 21/7 17h00	10	0.5 nm	6948-7043	600-850	24°37’ - 24°42’	Random transects
Rix	14/7 09h40 -14/7 20h50	1	1 nm	5992 - 6103	500 - 1000	22°38’ - 22°25’	Systematic transects
Rix	14/7 21h30 - 15/7 09h10	2	1 nm	6095 - 6214	500 - 1000	22°26.5’ - 22°39.5’	Systematic - offset 0.5nm
Rix	15/7 07h10 - 15/7 15h10	3	1 nm	6220 - 6268	600 - 900	22°35’ - 22°27’	Random transects
Rix	26/7 11h50 - 27/7 02h30	4	1 nm	8012 - 8145	550 - 950*	22°37 - 22°20	Systematic transects
Rix	27/7 02h30 - 27/7 11h30	5	1 nm	8146 - 8222	550 - 950*	22°20.5’ - 22°33.5’	Systematic - offset 0.5nm
Rix	27/7 12h10 - 27/7 21h00	6	0.5 nm	8227 - 8308	500 - 950*	22°34’ - 22°27’	Systematic transects
Rix	27/7 21h45 - 28/7 13h35	7	0.5 nm	8312 - 8420	500 - 950*	22°26.75’ - 22°35.25’	Systematic - offset 0,25 nm

* Depth range varied (maximum reported)

Table 2 Summary of swept-area surveys by area

Area	Dates	No. of tows	Total ORH catch (kg)	Total catch (kg) (all species)
Johnies	6/7 - 16/7	17	186 441	195 276
Frankies	4/7 - 7/7 20/7 - 22/7	35	6 213	9 778
Rix	2/7 - 3/7 23/7 - 24/7	27	50 979	54 969

Figure 1. General locality map of the areas surveyed during the July 1998 orange roughy survey.

CHAPTER 2 MATERIALS AND METHODS

2.1 Hydrography and meteorology

A ‘Sea Bird 911 plus’ with an additional oxygen sensor, was used for salinity, temperature and oxygen measurements. Real time plotting and logging was done by using the Seabird Seasave software installed on a PC. Seabird files (*.cnv), were converted into ICES format by using CNVICES software (Floen & Sand, 1995) and saved as *.dxf, and then visualised and edit by Autosketch software. Water samplers (Niskin bottles) mounted on a ‘Sea Bird Carousel’ were activated one near the sea surface and one just above bottom surface for collection of water samples. These were used for oxygen calibrations and salinity corrections and thus were prior to analysis treated with standard ‘Winkler’ method and Guildline Portasal salinometer, respectively.

During the first leg a total of 12, 9 and 7 CTDO stations were carried out on Johnies, Frankies and Rix respectively Two or three stations were done on an east-west axis, thereby covering different bottom depths, at the southern and northern ends of Johnies and Rix, while a transect of 3 stations were taken at the latitude of the main aggregation of these grounds. Three transects of three stations each were taken on the latitude of the three grounds at Frankies (3 Sisters, Frankies Flats and 21 Jump St.). On the second leg of the survey the number of CTDO stations was 7, 3, and 9.

2.2 Trawl sampling

2.2.1 Vessels and gear

Trawling operations were carried out by three commercial fishing vessels: the *FV Emanguluko* and the *FV Hurinis* identified acoustic marks for the *RV Dr Fridtjof Nansen*, while the *FV Southern Aquarius* conducted the swept-area survey.

The main characteristics of these vessels are:

- FV *Emanguluku*, a 35 m factory stern trawler, 433 GRT, 1400 kW power (1900 HP),????????? operated by Glomar Fishing Ltd.

- *FV Hurinis*, a 42.9 m factory stern trawler, 784 GRT, 1545 HP, operated by Atlantic Sea Products Ltd.
- FV *Southern Aquarius*, a 55 m factory stern trawler, 1154 GRT, 3600 HP, operated by Gendor Fishing Ltd.

Both FV *Emanguluku* and the *FV Hurinis* deployed the same deep water net and gear set-up throughout the survey. The net is based on the standard New Zealand 'Arrow' rough bottom trawl, with cut-away lower wings. Sweep and bridle lengths were 100 m and 50 m respectively. A 'rock-hopper' bobbin rig was used. The net had a 5-6 m headline height when towed at 3-3.5 knots. Wingspread is estimated at 15 m. A 20 mm cod-end liner was fitted.(BS DID EMANG borrow a trawl or is it their own Hampidjan ??!!XX)

The *FV Southern Aquarius* used a commercial 120 mm Arrow trawl without small meshed inner liner. The net opening had previously been measured at 6 m and the wing-spread at 20 m.

Trawling on aggregations were generally only carried out after acoustic surveys had been completed. This was done to allow the aggregations to distribute naturally on the ground, without disturbance from trawling activities. In addition, no commercial activities were allowed on grounds within the 24 hour period preceding a survey.

2.2.2 Trawl catch sampling

The catches from all trawl-hauls were sorted by species. Length, weight, and sex were collected for orange roughy, hake and oreos, and gonad stage data were collected for orange roughy. A random sample of about 200 individuals of each species was taken from each catch. When a large catch was made, several smaller samples were taken to ensure a representative sample structure was obtained. Some length frequency data were collected for other by-catch species during the second leg. The total number sampled, the sample weight and total weight of each species caught was recorded.

Small catches on the commercial vessels (less than approx. 500 kg) were fully sorted and weighed. When a large catch was taken, factory product figures from each tow were used to back-calculate the whole-round weight. Counts were taken of the number of trays of fish for each tow, multiplied by their average weight, and then again by the official conversion factor of 2.1. Although not used, some conversion factor trials were undertaken.

The catch-effort and biological information for each trawl was captured on standard NatMIRC data sheets. The information was transferred to the *Dr Fridtjof Nansen* where it was entered into various spreadsheets for analysis.

2.3 Biological analysis

The methodology followed during biological sampling is outlined in Appendix XX

2.3.1 Length frequency distribution

Length frequency data were weighted by the proportion of each trawl-haul sampled to represent the total catch per trawl-haul.

2.3.2 Reproductive stages

The reproductive stages follow the system commonly used in New Zealand and Australia after Pankhurst *et al* (1987):

Stage	**Female**	**Male**
1	Immature/resting	Immature/resting
2	Early maturation	Early maturation
3	Maturation	Maturation
4	Ripe	Ripe/running ripe
5	Running ripe	Spent
6	Spent	

The maturity data were adjusted for catch sizes. Ogives are expressed by the logistic growth curve.

(1)

$$\%maturity = \frac{100}{1 + e^{(a + b * L_c)}}$$

and

(2)

$$L_{50} = \frac{-a}{b}$$

where a and b are estimated, L_e is the proportion mature in length category, and L_{50} is the length at 50 % maturity.

2.4 Acoustic

2.4.1 Survey grids

Acoustic surveying was conducted continuously throughout the cruise. Separate coverages were run, generally, with east-west transects, for most coverages in a semi-randomised stratified design with average spacing. The areas to be surveyed were pre-selected, partly based on prior knowledge of fishing effort and hence expected fish density, and partly on the results of the previous surveys. Average transect spacing was 0.5 nm for coverages used for abundance estimation and 1.0 nm for determining distribution.

A summary of the various surveys that were conducted during this cruise is presented in Table 1.

Johnies

Johnies was surveyed 7 times in total. Two initial surveys were conducted to determine the distribution and behaviour of orange roughy. These had equally-spaced transects at 1 nm intervals, the second set being offset by 0.5 nm.

The first survey covered all areas that had previously been surveyed and updated with any commercial catches made during the past year. Survey 2 covered most of the area surveyed during survey 1, but with the outer limits somewhat reduced, especially the north-western and south-eastern corners. These two regions have never shown any signs of roughy.

As no roughy aggregations were found during the first leg of the survey, Johnies was re-surveyed again with a fairly wide area grid pattern during Leg 2 (Survey 3). Again no aggregations were detected, but commercial trawl results of the previous few days suggested that roughy were concentrated to the west and south-west of strata 1, therefore Surveys 4 and 5 were concentrated around this region.

Aggregations were found at about 850 m depth between 26°22 and 26°27 during Survey 5 and therefore two additional grids were conducted in this region.

Frankies

Frankies was initially surveyed with 1 nm systematic transects to determine the distribution of roughy. Frankies Flats and Three Sisters had a number of aggregations so these two areas were surveyed more intensively twice more during the first leg. The majority of these aggregations occurred at Three Sisters and therefore this area was surveyed another 3 times during the second leg, while Frankies Flats was surveyed once. A transect spacing of 0.5 nm was used on all grids. Little fish was found on 21 Jump St. in first leg, so this area was re-surveyed during the second leg using 1 nm systematic transects to ascertain if any roughy aggregations had formed in the intervening 8 days.

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Rix

An initial survey was conducted on Rix using 1 nm transect spacing covering a wide area. Small and indsticnt targets were found on the northern edge of the "box" and south on the upper edge of Willy's Valley. Two more coverages of this area were made in an attempt to further define the distribution of roughy, but no clear aggreagtions were found.

The broad survey was repeated during the second leg. This was continued further north than previous coverages, to 22°20'S, as faint plumes were detected at about 850 m from 22°26 and southwards. These aggregations were then identified by several trawls as sharks and other mixed demersal fish, and so the next survey started at 22°27'S. Later a further trawl caught 85 kg of roughy at 22°24, but too late to include this ragiuon in subsequent coverages.

In total 7 suurveys were made iof Rix.

2.4.2 Species identification

Two commercial vessels, *FV Emanguluko* and *FV Hurinis*, were used solely to identifying acoustic targets. Attempts were made to identify all targets that were likely to have a large proportion of roughy, but samples come not be obtained from some due to the ground being unsuitable for trawling or lack of time. These targets were identified based on previous experience or by using the known identity of similar targets in same general vicinity. Trawls were only considered valid if the total catch was more than 100 kg.

The trawling results of the swept-area survey were also used extensively to identify target despite the different catch selectivity of the *FV Southern Aquarius*, which had a much larger meshed trawl belly (9" compared to 6" in *FV Emanguluko* and *FV Hurinis*) and lacked a cod-end liner. The catches of *FV Southern Aquarius* may therefore have under-estimated the proportions of small roughy and smaller by-catch species. No compensation or correction factor has been made for this potential bias.

The results of the commercial vessels both prior and after the survey were used to support the identification of targets, thus giving greater confidence, especially when uncertainty arose.

2.4.3 Hardware

RV Dr. Fridtjof Nansen was equipped with two Simrad EK 500 echo sounders. During this survey they were recording at 18 and 38 kHz respectively. The 18 kHz transducer was hull mounted and had an opening angle of 10.9 ^{o}, while the 38 kHz transducer had an opening angle of 6.8 ^{o} and was mounted on a protruding keel which was positioned 2.5 m below the hull throughout the survey. Echosounder settings are listed in Appendix 30. The previous echosounder calibration prior to the survey was conducted on the 3rd August 1998. Acoustic data were logged over a phased range of 500 m such that bottom signal was always recorded. The fixed phase range was changed manually. The depth intervals covered were from 500 to 1200 m at Johnies, between 500 and 1100 m at Frankies, and from 500 to 1000 m at Rix.

2.4.3 Data processing

Echoview (SonarData Version 1.50) was used to record and interpret the acoustic data gathered. Shoals of orange roughy were identified based on prior knowledge and targeted trawls, and isolated in a layer drawn tightly around the shoals. The s_V threshold used to store data and calculate mean s_A per region was -76 dB. Relevant data was then extracted, and exported to Excel for post processing.

The Bergen Echo Integrator (BEI) was also used to integrate the acoustic area back-scattering coefficient (s_A). The threshold used during scrutinisation and echogram interpretation was also -76 dB. Shoals of orange roughy were identified according to the Echoview scrutinisation, and isolated in a layer drawn only to contain the shoals. The s_A allocated to roughy was based on the calculated s_A according to the trawl species composition and the assumed target strengths of the by-catch species groups: hake, oreos, sharks, rat-tails and "other species" (see below). The remaining s_A was allocated to the by-catch species groups in proportion to the species composition in the trawl catches used to identify each particular mark; no allowance was made for the different target strengths of these species.

All scrutinised data was stored in the BEI database with a resolution of 1 nm horizontally and 10 m vertically.

The following relations were applied to convert s_A-values (mean integrator value per unit area) to numbers of orange roughy:

$$(3) \qquad TS = 10 \log (\sigma/4\pi) = 20 \log L - 82 \ [dB]$$

$$(4) \qquad \sigma = 1/(10^7 * L^{-2})$$

$$(5) \qquad n = S_A * A * (1/\sigma) = S_A * A * 10^7 * L^{-2}$$

where TS is the average acoustic target strength of one individual fish, L is the length of the fish, expressed in centimetres, σ is the back-scattering cross section of a single fish and A is the area of the strata in question. The TS used originates from investigations carried out in Tasmania (Kloser et al., 1997), but updated according to unpublished TS measurements made by Kloser and Soule in New Zealand in 1998.

In previous orange roughy surveys the back scattering data were allocated to orange roughy using several different methods. The first two methods; targeted acoustics and scrutinised acoustics, yielded mean s_A values per transect, from which mean s_A value per coverage was calculated, and hence numbers of fish and biomass. The allocation of s_A was based on the results of trawling conducted in the vicinity of the fish targets, but with a subjective allowance for the targeted nature of the trawling. In the third method, trawl based acoustics, the acoustic data were used to calculate mass of fish per interval, and then mass per strata and ground were calculated. In this method s_A was allocated objectively according to the mean species composition (by weight) of all trawls conducted in any particular strata.

The third method; trawl-based acoustics, was disregarded after the 1998 survey as the trawl results were found not to be representative of large areas of fish targets in a strata, but rather of fish within the immediate vicinity of the trawl. The trawling also sampled the bottom zone, but probably did not account for fish in the pelagic. This resulted in a large over-estimate of the roughy component, especially as the target strength of roughy is so much lower than most other species. This method was therefore not used for the current survey.

The trawl samples taken during the current survey indicated that the species composition of the roughy aggregations was considerably more mixed than in previous years; hence the targeted method may no longer be appropriate. However, as the species composition of trawl catches is in itself not a particularly good reflection of the true species composition, this method was retained as a sensitivity indicator: by assuming that the species composition of aggregations was pure roughy a maximum possibly biomass could be calculated.

The average absorption coefficient (α) at 38 kHz between the surface and near bottom in the region of highest roughy density was calculated for each ground and Leg, using CTD data in Francois and Garrison's (1982) expression for α as a function of frequency, depth, temperature, salinity and pH (assumed to be 8.0 throughout in this case). (The equations are given on p. 43 of MacLennan and Simmonds. Note that the frequency, f in their Eqn. A2.1, is in kHz). The speed of sound, c , was assumed to be constant at 1500m/s throughout the water column, as the expression is relatively insensitive to c. The following values were obtained.

Survey	CTD Station	Depth (m)	α (dB/km)	Correction (dB)	Correction Factor
John. Leg 1	611	736	10.38	0.38	1.092
John. Leg 2	639	754	10.39	0.39	1.095
Frank. Leg 1	618	725	10.43	0.43	1.105
Frank. Leg 2	634	697	10.40	0.40	1.096
Rix Leg 1	631	693	10.34	0.34	1.082
Rix Leg 2	647	719	10.41	0.41	1.100

This procedure is essentially the same as that used in 1998, except that in that survey a single correction (0.2 dB, F = 1.05) for all of the grounds and surveys was used. The small variation between the estimates in the above Table indicates that this was a reasonable approach, given the far greater uncertainties in other factors. NOTE THAT THE INFORMATION ON CORRECTION FOR ABSORPTION IN THE 1998 CRUISE REPORT, AND THE VALUE QUOTED, (EFFECTIVELY 0.89) ARE INCORRECT.

2.5 Assessment Methodology

2.5.1 Targeted acoustics

Aggregations of roughy were identified from the acoustic data based on their acoustic appearance, usually supported by targeted trawl-hauls. As a general rule, only targets that could be identified with some reasonable level of confidence as pure orange roughy were included in the estimation of density with this method. Targets with a mixed species composition, even if orange roughy did form the major proportion, were not included as the mean back-scattering cross-section from the topical orange roughy distributions was considerably lower (see Appendices xxxxx) compared to the other species with their occurring size distributions.

The s_A values of each aggregation were recorded from Echoview. The mean s_A values was calculated for each transect:

(6)

$$\overline{S_A} transect = \sum S_A[ORH] \Big/ n$$

Where s_A[ORH] = the s_A value allocated to orange roughy for each interval

and n = transect length

The mean s_A for the entire survey is calculated weighting each s_A value/transect by transect length, as follows:

(7)

$$\overline{S_A} survey = \overline{S_A} transect * {}^{n}/_{\sum n}$$

The mean s_A for each survey was then calculated and hence the total biomass estimate derived.

A description of the formulas used for the method is given in appendix 29.

2.5.2 Scrutinised acoustics

The echo abundance (s_A values) derived from the echosounder bottom and near-bottom community were allocated to various groups of organisms based on both their absolute and relative (inter-group) comparison) s_A values, and their topical appearance on the echograms. They were as follows:

Orange roughy
Hake
Sharks
Rat-tails
Oreos
Other species

Mesopelagic species, other pelagics, orange roughy aggregations and dispersed hake tended to have characteristic acoustic appearances, which after a few trawls to confirm the species composition, could be allocated to their categories by visual examination of the acoustic echograms.

More dispersed targets, especially between the depths of about 600 m and 1000 m could not be identified to species or species group from the echograms. These allocations were largely based on the species composition identification in the vicinity, particularly of trawls taken at a similar depth.

As orange roughy has a much lower target strength than the other species, the s_A values attributed to roughy could not be allocated pro rata to the trawl catch composition. The roughy component of the total s_A values were very crudely estimated from the tables in Appendix 25, based on the target strength of roughy and other species used in the 1997 survey report (Huse, I. et.al, 1997).

2.5.3 Swept area

Random trawl survey design

A two-phase stratified random survey design (Francis 1984) was used on Johnies, but lack of time prevented this on the other two grounds, where a single phase survey was carried out. The number and distribution of trawls between strata was determined by the time available, results of last year's survey, and the need to cover a wider area than that of solely the known aggregations to reduce risks of missing fish distribution. The positions of the random tows were generated by a randomisation programme (NIWA random station programme) applied to each stratum. Tows were separated by 2 nm. The random position was designated as the vessel position at the start of the tow when the trawl started fishing on the bottom. The direction of the tow was generally along the depth contour where practical, in a north-south orientation specified by the scientists, but the skipper's discretion, weather, and the nature of the bottom also determined the direction of each tow. The duration of each trawl was approximately 30 minutes or 1.5 nm on the bottom.

2.5.5 Trawl survey stratification

Stratification of each fishing ground was based on the survey design in 1997 in which each ground was divided into six strata. There was a core region (stratum 1) where high catch rates by commercial vessels had been recorded during 1994-97, or during the 1997 survey. This stratum was designed to cover the area of main aggregations, and so its position could differ slightly between surveys. Tows in this stratum, which is by definition small and tight around the known area of high density, were not selected by random position, but involved an element of trawling on known tow lines (e.g. Three Sisters), or where fish aggregations were expected. A surrounding buffer zone (stratum 2) was defined where small aggregations might be expected, with variable catch rates. Additional strata were wrapped around these, both north and south at the known optimal depth range (strata 3 and 4), as well as shallower (stratum 5) and deeper (stratum 6) to ensure that the total likely area of orange roughy distribution was covered, and to minimise the risk of later finding aggregations outside the survey area. Stratification was modified for the second half of the survey, using information about fish distribution obtained from the first half of the survey, as well as from commercial fishing data from 1997-98, and improved knowledge of bathymetry. At Johnies, additional strata (9 and 10) were added in deeper water, and to the south. Stratification at Frankies was unchanged, but at Rix strata 2 and 6 were further subdivided (Figure 4).

Johnies:

1 High density area, defined approximately by latitude and longitude, between depths of 640-680 m

2 Buffer zone, 600 - 700 m

3 North area, 600-700 m

4 South area, 600-700 m

5 Inside stratum, 500-600 m

6 Outside, central stratum, 700-900 m

7 Outside, northern stratum, 700-900 m

8 Outside, southern stratum, 700-900 m

9 Out-outside, central-southern stratum, 900-1100 m

10 Southern region, 600-900 m

Frankies

1 High density areas:

1a) Three Sisters (650-800m)

1b) Frankies Flat (550-700m)

1c) 21 Jump St (550-650m)

2 Buffer zone, 550-700m

3 North area, 550-700m

4 South area, 550-700m

5 Inside stratum, 500-550m
6 Outside stratum, 700-900m

Due to time constraints, only strata 1 (a, b, c), 2, 3, and 6 were surveyed.

Rix

1 Northwest Box 700-850 m
2n Buffer zone, northern area, 550-900 m
2s Buffer zone, southern area, 550-900 m
3 Northern region, 550-900m
4 Southern region, 550-900 m
5 Inside stratum, 500-550 m
6n Outside area, central-northern, 900-1000 m
6s Outside area, central southern, 900-1000 m
7 Outside area, northern section, 900-1000 m
8 Outside area, southern section, 900-1000 m

Due to time constraints, only strata 1, 2n, 2s, and 6 were trawled.

2.5.6 Abundance estimation

Biomass indices were calculated for the survey area from random trawl data using standard area-swept methodology (after Francis 1981). Biomass, and its standard error, were calculated from the following formulae:

$$(13) \quad B = \Sigma (X_i a_i) / cb$$

$$(14) \quad S_B = \sqrt{(\Sigma s_i^2 a_i^2)} / c^2 b^2$$

where B is biomass (t), X_i is the mean catch rate (kg.km^{-1}) in stratum i, a_i is the area of stratum i (km^2), b is the width swept by the trawl gear, c is the catchability coefficient (an estimate of the proportion of fish available to be caught by the net), S_B is the standard error of the biomass, s_i is the standard error of X_i.

The coefficient of variation (*CV*) is a measure of the precision of the biomass estimate, and is calculated by:

$$(15) \quad CV = S_B / B * 100$$

Strata areas were defined once detailed bathymetry was confirmed, and random trawl stations were generated. The mean catch rate from trawls (note target trawls were not included) was applied to the area of these strata. A minimum of two trawls per stratum was required. No correction is made for possible herding by the trawl gear, or escapement of fish from the path of the trawl. It is assumed that all fish in the water column of height equal to that of the head rope above the trawl path are caught by the gear (i.e. $c = 1$) The effective area of bottom swept by the trawl (*b*) has been taken as the distance between the wing-ends.

Biomass index values presented in this report have been derived from the NIWA 'PC-biomass' programme, written in 'C'. Note that it uses km as its distance and area inputs, and so the results given in later sections have been converted back to nautical mile units. The rounding involved in this gives very minor variations in the results.

2.6 Experiments

2.6.1 Intercalibration with the *RV Welwitchia*

An intercalibration exercise was conducted for 30 hours with the *RV Welwitchia* during Surveys 6 and 7 of Frankies. For most of this period the *RV Welwitchia* followed the *FV Dr Fridtjof Nansen* at a distance of between 0.2 nm and 1 nm, although for a short period the distance increased to 4 nm after somebody dropped a clanger and blocked up the sewage system!! For a short period the *RV Welwitchia* led, but this caused navigational problems and was therefore not continued.

The EK 500s of both vessels were set up using the same parameters, both being zeroed to sea surface. The vessel logs were synchronised. Both vessels logged data to Echoview, although the *RV Welwitchia* did not have the full programme package and therefore was unable to view these data.

The total back scatter and visual appearance of aggregations that were identified as containing a high proportion of orange roughy were compared on both systems.

2.6.2 Comparison of 38 kHz and 18 kHz signals

The EK500 18 kHz echosounder was run throughout the survey and data from this system logged to Echoview during the second leg survey of Frankies. These data will be analysed at a later stage.

2.6.3 Dead zone density calculations

The theoretical height of the dead zone beneath all aggregations was calculated based on the nominal -3 dB beam angle, depth and bottom slope. By using the back-step function of Echoview, the s_A of two bottom layers; 1-2 metres and 2-3 metres from the bottom, was calculated. By assuming that the aggregations of roughy extended into the dead-zone at the same density as these layers, the proportion of roughy in the dead-zone was calculated.

CHAPTER 3 RESULTS

3.1 Relevant conditions

3.1.1 Hydrography

Temperature, salinity and oxygen profiles were established for aggregation areas in particular (**App. 1 – 6** for Johnies, **App. 7 – 10** for Frankies and **App. 11-14** for Rix). Bottom temperature varied between 3 to 6 ^{0}C in the areas. Salinity at deeper levels were stable around 34.5 ‰. Oxygen levels in the bottom layers were between 1 and 4 ml/l. On all three grounds there were decreases in oxygen levels down to approximately 400, and the level increased again at approximately 600 m and deeper. Comparison between water bottle sample and oxygen meter on the CTDO showed a 9.3 % average difference between the two. The bottle samples had the higher value, possibly due to air bubbles in the glass bottle the sample was stored in. The relative difference between CTDO and bottles were quite stable.

3.1.2 Meteorology

During the cruise the wind (Appendix 15) and the swells affected the acoustic sampling and the trawling to the extent that all together 3 days were conducted at reduced speed and 2 days were lost for surveying.

3.1.3 Sound absorption

Table xxx Absorption coefficients for each ground

	Correction factor
Rix	
Frankies	
Johnies	

3.1.4 Catch composition

A total of 148 trawls was made by the three vessels during the survey. These were a combination of targeted trawls directed onto acoustic marks as observed and recorded by scientists on *Dr Fridtjof Nansen*, and random trawls for the stratified random trawl survey.

The distribution of trawls on the three grounds is shown in Figure 3. The numbers of trawls on the three grounds by the vessels is detailed below **Table 3** (R=random, T=target, PT=pelagic trawl, BT=bottom trawl):

Table 3 **Trawls per area per vessel (R=random, T=targeted)**

Area	**Trawl type**	***Emanguluku***	***Southern Aquarius***	***Dr Fridtjof Nansen***	
				PT	BT
Johnies	R	10	33		
	T	10	18	2	5
Frankies	R	13	22		
	T	0	0	3	2
Rix	R	11	10		
	T	0	6	3	0
Total		**44**	**89**	**8**	**7**

Trawl station and catch details for each tow are attached as Appendix 17. A full list of all species caught is given in Appendix 31. The *Dr Fridtjof Nansen* used different trawl gear, and fished in a different manner to the commercial vessels, and so below we describe species catch from the commercial trawls only.

The total catch of all species was about 278 100 kg. Orange roughy was the main species caught on all grounds, and comprised 94% of the total. Hake was also frequently caught, with catches amounting to 5 700 kg. Sharks (a number of species of deep-water dogfish) were also common in some areas. The catch of orange roughy and the other main species or groups is summarised in Table 4:

Table 4 Total catch of the main groups of fish (in kg, percentage of total catch in parentheses) on the three survey grounds.

Species	Johnies	Frankies	Rix
Orange roughy	204 307 (95.9%)	6 214 (63.5%)	51 061 (92.7%)
Deep-water hake[1]	3 357 (1.6%)	1 828 (18.7%	580 (1.0%)
Oreos[2]	878 (0.4%)	343 (3.5%)	1 432 (2.6%)
Sharks[3]	1 868 (0.9%)	831 (8.5%)	5 340 (9.7%)
Rat-tails[4]	1 279 (0.6%)	139 (1.4%)	76 (0.1%)
Total catch	213 063 kg	9 779 kg	55 053 kg

[1] All *Merluccius paradoxus* [2] Primarily *Allocyttus verrucosus*
[3] Primarily *Deania calcea, Centroscyllium fabricii, Centroscymnus crepidater*
[4] Primarily *Coelorhinchus acanthiger, Nezumia micronychodon*

Figure 2 Strata boundaries, numbers, and depth contours for survey areas at Johnies (top), Frankies (middle), and Rix (bottom) in 1998. Strata in parenthesis were not fished this year.

Figure 3 Position of trawl-hauls carried out on the 3 grounds by *FV Emanguluko* (red diamond), *FV Southern Aquarius* (black circle), and *RV Dr Fridtjof Nansen* (blue square).

3.1.5 Distribution of orange roughy

Results of trawling by *Emanguluku, Hurinîs* and *Southern Aquarius* have been combined to evaluate the general distribution of orange roughy and other species. In the following sections data from target and random trawls have been used.

Johnies XX

Large catches of orange roughy were recorded in the central region (Figure 4), with stratum 1 yielding consistently good catches. Catches of around 1 tonnes/trawl also occurred in a south-westerly direction from this central region, especially in the first half of the survey. Catches were small to the north and south, as well as at depths of less than 600 m or greater than 900 m. There were no indications of other aggregations within the survey area. The new strata, added because of the extended distribution of commercial catches in the early months of 1998, gave generally low catch rates. Orange roughy made up 95% of the total catches (by weight).

In addition to catches of orange roughy being small away from the central area, the proportion of orange roughy in the outer trawls was generally low (Figure 4). Orange roughy dominated the catch in stratum 1, and in trawls to the south-west, but other species formed the bulk of catches elsewhere. Hake (blue) dominated in shallower water (stratum 5). Areas to the north and south gave mixed catches, with oreos, dogfish, and rattails contributing to the catch.

Frankies

Trawl-hauls were carried out over the central and northern area of Frankies from depths of 500 m to 900 m (Figure 5). No large catches were made at any time during the survey. The largest catch was about 3 800 kg, taken on the "Three Sisters" hills. Trawl-hauls made on the northern slopes of the "Three Sisters", on "Frankies Flat", and in the region of "21 Jump St" gave small catches.

The catch composition at Frankies was relatively mixed. Orange roughy accounted for only 63% of the total catch. Hake dominated trawl catches in a broad depth band from 500 m to 700 m (Figure 5), below where sharks and oreos were more prominent. Orange roughy had a very localised distribution, and only formed the majority of catch in the three ‘high density’ areas of stratum 1, and in one tow to the north in an area known as “Smiftons”.

Rix

Trawl-hauls were carried out in the central area of Rix between 550 m and 1 050 m (Figure 6). Most recorded small catches of orange roughy, but several in an area to the south of that commonly fished commercially gave good catches, with the largest being 30 000 kg. Catches were also generally small in stratum 1 which was the centre of commercial fishing in the last year (known as 'North Bank'). Orange roughy made up 93 % of the total catches (by weight).

Orange roughy were mainly at depths of 750 m to 900 m, where they dominated species composition (Figure 6). Hake were fairly scattered, but dogfish (*Centroscymnus* spp.) were widespread, and more abundant in catches than on the other grounds.

Figure 4 Catch of ORH, Johnies

Figure 5 Catch of ORH, Frankies

Figure 6 Catch of ORH, Rix

Figure 7 Catch by depth

3.2

Biology

3.2.1 Length frequencies

Length distributions of orange roughy for Johnies, Frankies and Rix varied somewhat between with coverages, with a particularly high proportion of smaller fish in the first coverage of Frankies. This may partly be due to the use of small meshed inner lining, but also to the few fish sampled. The mean length increased from the southern (Johnies) to the northern (Rix) ground. Mean length at Johnies was 25.3cm (1.leg) and 26.0 cm (2.leg) (Figure 8a and 9 a), while catches at Frankies were few and had a mean length of 17.8 cm and 27.3 cm (Figure 8b and 9b). Conversely catches from first coverage of Rix gave a higher mean, 28.5 cm to 27.8 cm, than second coverage (Figure 8c and 9c), although the inner lining was just used in the first coverage.

The orange roughy sex ratio in the catches varied between coverages of the grounds, with Johnies having the proportion of 58% and 41%, Frankies 47 % and 52%, and Rix 43% and 56% males and females respectively (and the remaining were undetermined juveniles).

Figure 8a Joh Emanguluko

Figure 8b Fra Emanguluko

Figure 8c Rix Emanguluko

Figure 9a Joh Southern Aquarius

Figure 9b Frankies Southern Aquarius

Figure 9c Rix Southern Aquarius

Length distributions for hake (*Merluccius paradoxus*) rattails (fam. Macrouridae), and oreo dories (Oreosomatidae.) were also obtained (Appendix 19). Only deep water hake (*Merluccius paradoxus*) was caught, which had a uniform distribution +/- 10 cm from the 51.7 cm mean length. The standard length of hake from the catches ranged from 29 cm to 82 cm. Rattails varied from 19 cm to 56 cm with the mean at 36 cm. (This is a combined graph for several species as distribution is only used in acoustic measurements. Oreo dories catches were dominated by warty oreo dories (*Allocyttus verrucosus*).1

3.2.2 Length weight relationship

Length weight relationships for orange roughy for each of the three surveyed grounds show very similar pattern, even though the number of fish included differ between 1.leg (Table 5) and 2.leg (Figure 10 a,b,c, Figure11 a, b,c, and Table 5). Frankies differ the most, probably from the lack of small orange roughy in the *FV Southern Aquarius* catches.

Table 5 Length weight relationship for Orange roughy in the surveyed areas.

Vessel	**Ground**	**Number of fish sampled**	**Growth Ln y=ax^b**	**Regression fit R^2**
Emanguluko	Johnies	2 095	Ln $y=0.1454x^{2.540}$	0.975
Emanguluko	Frankies	146	Ln $y=0.178x^{2.547}$	0.955
Emanguluko	Rix	497	Ln $y=0.120x^{2..596}$	0.946
Southern Aquarius	Johnies	3 998	Ln $y=0.145x^{2.540}$	0.966
Southern Aquarius	Frankies	1 421	Ln $y=0.178x^{2.490}$	0.849
Southern Aquarius	Rix	1 123	Ln $y=0.120x^{2.600}$	0.918

Figure 10 a,b,c

Figure 11 a,b,c

Hake *(Merluccius paradoxus*) was the main commercially utilised by-catch in most of the trawl-hauls (by weight). Length weight relationship is based on few fish in the largest length-classes, and fit to the trend-line is therefore poor (Appendix 32).

3.2.3 Reproduction

The highest proportion of running and spent males was found at Johnies (2.leg), while highest proportion of spent females was at Rix on the last day of the survey. There was a significant change in the proportion of the running and spent orange roughy between the first and second coverage of Frankies and Rix. At Johnies the proportion of running and spent females increased somewhat between the two coverage's, but not as pronounced as for males (Figure 12).

The length at 50 % maturity was estimated per ground and per sex by combining length with the proportion of orange roughy in a stage 3 (Maturing) and above state in the catches (Figure 13). For females the length at 50 % maturity was significantly higher (26.7 cm) for Rix than Frankies (22.7 cm) and Johnies (21.3 cm). Similar the 50% maturity for males occurred at 21.7 cm, 22.5 cm, and 27.0 cm for the same grounds. For Frankies the point of 50 % maturity is not so readily defined, as lengths from 18 to 23 cm are around 50 % level (see trend-line, Figure 14).

Figure 12 Development of maturity stages through the survey.

Figure 13 Day to day development of the maturity stages in catches through the survey (no of individuals/day).

Figure 14 Maturity ogives for males (left) and female (right) orange roughy from Johnies, Frankies and Rix.

3.4. Biomass assessment

3.4.1 Acoustic estimates - Johnies

The targets identified as orange roughy schools are given in appendix 20 and the survey estimates in Table 6.

Table 6 Biomass estimates for Johnies – targeted acoustics

Survey	Total length (nm)	No. transects	No of Schools	Spacing (nm)	Area (nm^2)	Mean sA (m^2/nm^2)	Number Millions	Biomass (tonnes)	CV
1	323.1	31	34*	1	323.1	4.41	24.71	15140	0.24
2									
5	127.1	25	9	0.5	63.6	13.53	15.91	9746	0.38
6	49.9	15	10	1	49.9	18.73	18.68	10322	0.25
7	46.6	14	6	1	46.6	19.17	17.86	9870	0.50

* No aggregations seen, estimate derived from scrutinised disaggregated distributions

The first survey on Johnies included all grounds where previous surveys or commercial catches had noted significant densities of roughy. As no aggregations were found during this survey the second survey concentrated around the "box", Strawberry Patch and the "corridor" between these two areas.

This survey also failed to find any aggregations that could be allocated to orange roughy with any confidence. Widely distributed scattering layers occurred throughout the region, generally being densest inshore of 650 m and deeper than 750 m. The inshore layer was largely by hake, while offshore sharks, rattails oreos and other demersal species dominated. Orange roughy occurred in most catches, and frequently in fairly high proportions. However the density was always low. there is an almost continuous scattering of fish on and near the bottom, up to 20 m or sometimes more from the bottom, and many trawls yielded anything up to 90% roughy (generally around 10%). This scatter had little structure to indicate which areas contained more or less roughy than others.

In an attempt to provide an indication of the roughy biomass, these scattered layers were scrutinised according to traditional methods, with the proportion of roughy allocated according to trawl catches. Due to the unknown catchability coefficients of the various species, the lack of samples, especially from the pelagic zone and, critically, the high degree of sensitivity of estimates due to the relatively low TS of roughy compared to other species, these estimates were considered highly dubious and the method was not repeated for other coverages.

Commercial trawls between the two legs (between Surveys 2 and 3) yielded fairly high catches in the Strata 1 and to the west, between 650 and 680 m, plus along a single trawl line to the south-west between 26°40' and 26°28'S at about 760 m; in the corridor between the "box" and Strawberry Patch. Therefore during the second leg, following an initial fairly broad survey, several more intense surveys were focused on this region. However Surveys 3 and 4 did not detect any roughy aggregations.

On the night of 24th July a gale force storm forced all vessels to heave to. Following this break some clear plumes extending over several transects were surveyed to the west of Strata 1 between 24°22' and 24°24'S and 820 and 850 m during Survey 5. Several large catches of roughy confirmed the identity of these aggregations. The following day roughy-like marks were noted slightly farther offshore, between 850 and 880 m, and several nm farther south between 26°27' and 26°34'S. A number of trawls targeted on these aggregations yielded small mixed catches with low proportions of roughy. Therefore while the appearance of these marks resembled roughy acoustically, their true identity could not be confirmed and the large extent over which they occurred suggests that they were not caused by roughy.

The day after the final survey of Johnies the commercial vessels, which had been permitted to commence fishing activities, reported high catches south-west of the "box" in the 900 to 1000 m depth zone south of 26°30's.

3.4.4 Swept area estimates – Johnies xx

Two sets of swept-area results are presented here:

- Strata 1 to 10, which includes the new areas surveyed in 1998
- Strata 1 to 8, which is directly comparable to the 1997 survey

Only trawl data from *Southern Aquarius* is included, and all target trawls have been discarded. All random trawls performed well, and none were excluded because of gear damage or poor bottom contact. The distribution of random trawls is given in Figure 4. Trawls were spread throughout the area, with at least two trawls per stratum, and the heaviest concentration in strata 1, 2 and 6.

Catch rates were at times very high in stratum 1 (Figure 4), with values approaching 50 000 kg.n.mile^{-1}. The depth band of stratum 1 covered 640 to 680m, with most large catches occurring at 660 to 680 m. Catch rates in other strata were low.

The total swept area estimate of orange roughy, based on all the randomly placed trawls taken in each strata is presented in Table 9.

Table 9 Swept area biomass estimates for Johnies, total 1998 survey area.

Strata	# trawls	Area Nm^2	Mean CPUE kg/nm	Std.Dev. CPUE	Biomass Tonnes
1	4	1.8	24 904	17 287	5 557
2	6	11.4	186	440	264
3	2	14.7	2	2	5
4	2	10.2	1	1	1
5	3	38.6	1	1	3
6	5	28.6	243	315	861
7	2	30.9	4	1	14
8	2	16.6	134	189	274
9	5	44.3	189	388	1032
10	3	53.9	21	32	136
	Total	251.0		Total	8 147

Highest fish densities, and hence catch rates, were recorded in stratum 1. This stratum dominated the biomass, even though it is a very small area. Stratum 9 was the next largest biomass. It had moderate catch rates, but is a relatively large area. Strata 2 and 6, which were important in 1997, were relatively minor in 1998 survey. The overall coefficient of variation of the biomass estimate is 27.5%.

The comparable biomass estimate to that of the 1997 survey is derived from summing the values for strata 1 through 8. The parameter values from Table b remain unchanged. The total biomass was 6 978.9 t, with a CV of 29.0%.

Figure 15 Location of trawls…Johnies

3.4.6 Acoustic estimates – Frankies

Table 10 Biomass estimates for Frankies – targeted acoustics

Survey	Total length of survey coverage (nm)	No. Transects	No of schools	Spacing (nm)	Area (nm^2)	Mean s_A (m^2/nm^2)	Number Millions	**Biomass (tonnes)**	**CV**
1	323.1	31	6	1	323				
2 F.Flats	51.4	8	3					**146**	
3 3 Sisters	66.5	10	11					**6588**	
4 3 Sisters	67.6	10	8					**2182**	
5 F.Flats	50.5	8	5					**507**	

6 3 Sisters	66.3	15	7	0.5	33.2	1.92	1.00	**756**	**0.81**
7 F.Flats	71.5	8	2	0.5	35.8	0.35	0.20	**150**	**0.69**
8 3 Sisters	72.1	10	7	0.5	36.1	1.65	0.93	**709**	**0.60**
9 21 Jump St.	69.9	12	2/3	0.5	35.0	0.24	0.13	**101**	**0.80**
10 3 Sisters	70.6	10	4	0.5	35.3	0.16	0.09	**68**	**0.82**

An initial broad survey of the entire Frankies area recorded a number of aggregations on 3 Sisters around 620 and 700 m and small aggregation on Frankies Flats. No sign of roughy was detected from the northern grounds, although trawl catches yielded a few kgs.

Frankies Flats and 3 Sisters were each surveyed twice over the next two days. 3 Sisters continued to yield the higher estimates with little being recorded on Frankies Flats despite the largest catch made by *FV Emanguluko* in the area being made on Frankies Flats. In addition one roughy aggregation was recorded at 760 m on Frankies Flats, just outside of the survey grid. Further grids were extended to include this depth zone, but roughy were not detected here again.

As the maturity stages of roughy on Frankies were more advanced than the other two grounds, this area was surveyed first during the second leg. The first survey of 3 Sisters was surveyed at 45°-225° due to the large southerly swell causing excessive roll of the *FV Dr Fridtjof Nansen* when surveying in an east-west direction. All other surveys were conducted along east-west transects.

3 Sisters had distinct aggregations occurring in three areas: between 24°40.5' and 24°41.5'S and the 790 and 825 m isobaths, 24°40' and 24°41'S and the 725 and 760 isobaths and smaller aggregations between 24°38' to 24°39'S and 600 to 700 m.

Frankies Flats continued to yield few aggregations, which is reflected in the biomass estimates. Similarly little roughy was again found on 21 Jump St. although *FV Hurinis* found a small aggregation to the north of Frankies Flats at 24°30'S which was not recorded acoustically.

3.4.9 Swept area estimates – Frankies xx

Stratification for Frankies was unchanged from 1998XX, but only strata 1 (a,b,c), 2, 3, and 6 were covered this year. The location of random trawls is shown in Figure 5. A total of 22 tows were completed, with one rejected through poor performance.

Catch rates were much lower than at Johnies, or at Rix. The maximum was about 10 000 kg.n.mile^{-1}, taken on the hills of the "Three Sisters" stratum (1a). This stratum also had several other tows with catch rates above 1 000 kg per nm. The only other area to have any notable catch was "Frankies Flat". Catch rates in all other strata were very low.

The swept-area estimate for Frankies and data for each stratum are given below in Table . Because catch rates last year were quite variable between the three sub-areas of stratum 1, they are treated separately this year.

Table 12 Swept area biomass estimates for Frankies

Strata	# trawls	Area nm^2	Mean CPUE Kg/nm	Std.Dev. CPUE	Biomass Tonnes
1a	4	4.9	3 021.1	4 663.2	1 848.5
1b	2	7.3	366.7	306.1	330.0
1c	2	4.1	88.0	42.0	44.3
2	6	98.1	0.3	0.6	4.2
3	4	30.1	30.9	61.6	115.3
6	3	150.0	3.4	4.2	63.9
	Total	294.5		Total	2 406.2

The total biomass index was about 2 400 t, with a CV of 60%. Biomass was concentrated in stratum 1, on the "Three Sisters", with some on "Frankies Flat". Other strata contributed little to the overall index.

The comparable biomass estimate from 1997, with the three sub-areas of stratum 1, and exclusion of strata 4 and 5, was 30 974.6 t.

Figure 16 Location of trawls …Fra

3.4.11 Targeted acoustics – Rix

Table 13 Biomass estimates for Rix – targeted acoustics

Survey	Total length (nm)	No. transects	Mean length (nm)	No of Schools	Spacing (nm)	Area (nm^2)	Mean s_A (m^2/nm^2)	Number Millions	**Biomass (tonnes)**	**CV**
1	107.1	11	9.74	3	2.00	214	2.96	7.65	**5 827**	**77.9**
2	109.2	12	9.10	6	1.00	109	9.2	20.85	**8 925**	**45.1**
3	42.5	10	4.25	6	1.00	43	15.0	13.16	**5 934**	**38.6**
4	14.5	5	2.90	4	Random	28	33.9	19.59	**9 866**	**34.7**
5	15.4	5	3.08	2	Random	28	31.4	18.14	**8 604**	**83.5**
6	18.8	5	3.76	3	Random	28	23.9	13.85	**6 697**	**55.3**
7	14	5	2.80	4	Random	28	37.5	21.69	**9 660**	**42.3**
8	14.8	5	2.96	3	Random	28	30.4	17.59	**7 831**	**46.4**
									7 918	

The first coverage detected one clear aggregation and two aggregations of uncertain identity. These were, however all included in the final estimate, which must therefore be used with some circumspection.

Surveys 2 to 8, including multiple random surveys were all conducted on aggregations that were in general, not closely associated with bottom. However targets were usually associated with areas of rough bottom, particularly at the top edge of a drop-off. It is possible that dead-zone and side lobe reflections may have affected the results.

Surveys 2 and 3 both detected 6 clear targets, while the repeated random surveys detected 4, 2, 3, 4, and 3 targets respectively.

All coverages are considered equally valid. One should however note the difference in the coverages of the grounds per survey.

3.4.14 Swept area estimate – Rix

It was hoped that there would be sufficient time this year to undertake enough trawling at Rix to provide a base swept-area estimate. However, in the two days the *Southern Aquarius* worked the area, 10 random tows were completed, of which one was rejected through gear damage.

Stratification for Rix was refined from 1997, with subdivision of strata 2 and 6 to reflect distribution of catch from the 1997 survey, as well as initial acoustic survey results. The location of random trawls is shown in Figure 6.

Catches were small with low catch rates in all but one tow in stratum 2s (Figure 6). The location of this was consistent with larger catches taken in target identification trawls in this southern part of the survey area. Catch rates in stratum 1 were low.

The swept-area estimate for Rix and data for each stratum is given below in Table 15. However, with a total of just 9 tows, these data should be regarded with little confidence.

Table 15 Swept area biomass estimates for Rix, *Southern Aquarius* trawls.

Strata	# trawls	Area nm^2	Mean CPUE kg/nm	Std.Dev. CPUE	Biomass tonnes
1	2	4.9	29.2	30.0	17.9
2s	3	23.3	6 836.1	11 833.0	19 683.1
2n	2	17.8	0.2	0.3	0.5
6	2	9.3	4.6	2.6	5.3
	Total	55.3		Total	19 706.8

Biomass was concentrated in stratum 2s, on the general slope at depths around 800 m. Other strata contributed little to the overall index. The CV was 99.8%.

The general nature of the bottom in the Rix area is undulating and hard. Trawls are often short, and carried out in a range of directions to work small patches of trawlable ground. This means that differences in the standard fishing ‘power’ of the *Emanguluku* and *Southern Aquarius* could be less than on a smooth bottom. Therefore, in an attempt to improve the estimate at Rix, an analysis combining the random tows done by both vessels was attempted. This added 5 trawls in the above strata from *Emanguluku* (Table 16).

Table 16 Swept area biomass estimates for Rix, *Southern Aquarius* plus *Emanguluku* trawls.

Strata	# trawls	Area nm^2	Mean CPUE kg/nm	Std.Dev. CPUE	Biomass tonnes
1	3	4.9	1 019.6	1 715.6	623.9
2s	5	23.3	4 104.3	9 165.3	11 817.6
2n	2	17.8	0.2	0.3	0.5

6	4	9.3	37.0	66.7	42.6
	Total	55.3		Total	12 484.5

The CV of this estimate was 94.6%. Stratum 2s required more intensive trawling, and even with the extra trawls it is uncertain how representative the overall catch rate and biomass results from this stratum are. All swept-area results for Rix should be regarded with caution.

Figure 17 Location of trawls…Rix

3.5 *Experiments*

3.6.1 Intercalibration with the *RV Welwitchia*

A total of 12 targets were detected by the *RV Welwitchia* during this experiment (Table xxx). Of these 8 were seen clearly by the EK500 of the *RV Welwitchia*, one was not detected and three suffered from acoustics disturbance. It is likely that this disturbance was caused by excessive vessel wake suggesting that the *RV Welwitchia* was too close to the *FV Dr Fridtjof Nansen* at times.

Of the targets that were comparable, 7 gave higher values on the *FV Dr Fridtjof Nansen*'s EK500 with a mean difference of 21%.

Table xxx Comparison of total s_A of roughy-like targets between *FV Dr Fridtjof Nansen* and *RV Welwitchia*

Mark	Trawls	Welwitchia Mean sA	Nansen Mean sA	Difference sA	Difference %
1	"SA97"	144	148	-3	-2
2	"SA97"	72	173	-101	-58
3	"SA97"	72	80	-8	-10
4	"SA97--vessel wake"	890	58	Discounted	
5	"H6 - vessel wake"	1732	152	Discounted	
6	"SA100 - vessel wake"	4421	330	Discounted	
7	"No targets"	614	64	Discounted	
8	"H6"	71	87	-16	-19
9	"H6"	102	180	-78	-43
10	"SA97"	284	351	-67	-19
11	"SA99"	491	590	-99	-17
12	"SA99"	176	170	5	3
		1412	1779	-367	-21

3.6.2 Comparison of 38 kHz and 18 kHz signals

The 38 kHz and and 18 kHz transducer were run simultaneously

3.6.3 Dead zone density calculations

Table xxxx Dead zone corrections for Frankies

	Biomass w/out DZC	Approx. DZC (%)	Biomass with DZC
Frankies 1	990	16.7	1155
Frankies 2	68	0.0	68
Frankies 3	4458	37.8	6141
Frankies 4	1413	49.7	2115
Frankies 5	238	50.7	359
Frankies 6	724	49.9	1085
Frankies 7	139	43.5	199
Frankies 8	560	26.2	707
Frankies 9	100	17.2	117
Frankies 10	50	19.0	60
Mean		33.23	

The calculated dead zone corrections for Frankies suggested a mean correction factor of 0.33, but this ranged from 0% to over 50% largely dependant on the density of roughy close to the bottom.

Chapter 4 Discussion

The nature of the orange roughy survey in July 1998 is a complex one. The depth ranges that are covered are moving towards the limits of performance for the modern equipment onboard RV Dr Fridtjof Nansen and the commercial vessels. The appearance of the orange roughy and its strongly aggregating behaviour makes it a challenging fish specie to try to assess by traditional acoustical and swept area methods. Data were collected on many of the biases that are believed to affect acoustic and/or swept-area survey estimates. Where possible these data have been analysed and reported here. In some instances considerable amounts of data have been collected and these require dedicated time to fully interpret. Some of the data collected will be made full use of in the species identification guide, the observer training and in conversion factor studies. Several of the other objectives could not be attempted (e.g. target strength estimations) due to extended periods of adverse weather conditions or equipment failure. The seasonality in aggregating behaviour also brings several aspects of uncertainty into the assessment and the timing of the survey.

Survey timing

Timing of the survey is a critical issue. Orange roughy typically form dense aggregations for spawning, and are fairly synchronous in the timing of spawning activity. The extent of possible turnover on Namibian grounds is unknown, but is not thought to be an issue in several New Zealand fisheries except when intensive trawling pressure disrupts and breaks up schools. Given a stable spawning distribution, the problem can arise with timing if the survey is too soon before spawning (and fish are still moving into the survey area), or too late (once fish have stated to emigrate).

Trawl data give two clues on whether timing was appropriate or not. The first is in the distribution of catches. The *Emanguluku* trawled on each ground between 2 and 9 July, with the *Southern Aquarius* covering the period from 14 to 24 July. The location of trawls differed between the two vessels, but generally they towed on a combination of scattered random positions, and targeted acoustic marks. The catches of each are shown in Figure (timecomp.doc). On Johnies, large catches were taken by the two vessels in stratum 1. Some smaller catches occurred to the south-west, but these were not substantial compared to the core area. It is possible that these represent scattered pockets of fish moving in or out of the main spawning ground, but overall the data indicate the distribution of fish was relatively stable during the period of the survey. This years survey showed very little fish outside the main aggregations and rise the question to what degree there is still a buffer zone of incoming fish to spawning ground or if the aggregation represent the bulk part of the stock.

The second source of data is information on gonad stage of fish. It is generally accepted with orange roughy that distribution is most stable at the time of spawning, characterised by high levels (greater than 50%) of ripe and running fish. Proportions of maturing, or spent, stages should be lower. The maturity stages combined with the catch composition and distribution indicate that the survey covered the main part of the spawning orange roughy on all three grounds, therefore, the timing of the survey was appropriate with respect to the timing of spawning.

Figure 18 Distribution of catch ….

4.1

Hydrography and meteorology XX

During the survey all together 47 CTD stations were carried out on the three grounds to capture data in the most important strata. The bottom temperature for the survey area varied between 8^0 C at 400 m to less than 4^0 C deeper than 950 meters for Johnies and Rix.

4.2 Trawl sampling XX

For the 1. Leg of the survey the *FV Emanguluko* used small meshed inner lining to capture if there was small orange roughy present on the ground together with commercial sized orange roughy. This was not very successful, little small fish was caught, and the inner lining was just used for the initial targeted trawls at Johnies on the 2. Leg with *FV Southern Aquarius* to avoid differences in gear performance compared to 1997 trawl survey. The difference in size, horsepower, reaction to bad weather conditions also made it uncertain to what extent the two vessels catch performance could be compared. The trawl sampling was as described in the procedure of the 1997 survey. Some conversion factor experiments were undertaken but is not included in this report. The weather conditions made it difficult to sample properly, and the sampling teams did a good job making the best possible out of the sampling. Also the facilitation of the sampling was generally good from the crews on all three vessels side.

4.3 Biology XX

Length frequencies varied with ground and coverages, partly because of two different mesh-sizes in the codend during first and second leg. The Emanguluko was likely to catch more small fish in the trawl as it had a small meshed inner lining for the whole leg, while Southern Aquarius only used the inner lining for the targeted trawls at Johnies. Mean length per ground was increased northwards, with Johnies being approximately 2 cm shorter than Rix and Frankies being more than 0.5 cm shorter than Rix.

More than 6 200 orange roughy sampled from all together 60 trawl hauls at Johnies, so the distribution should be representative for the area. Compared to last years 26.5 cm (n= 4 770) mean length for Johnies it is a decrease of between 0.5 cm (from *Southern Aquarius*) and 1.3

cm (from *Emanguluko*). The length weight relationship for the Southern Aquarius differed with less than 1 % from the 1997 survey so no condition factor changes could be observed between the two surveys.

From Frankies more than 1 700 orange roughy were sampled. 250 of these were from *Emanguluko* small meshed inner-lining trawls. These catches showed that immature orange roughy down to 8 cm were readily caught, and confirmed their presence in the same areas as the adult fish. This should be investigated further as research on the separation of the grounds and migration between grounds becomes prioritised. Compared to last years mean length the average at Frankies of 27.25 cm was 0,65 cm less (2.4 %) and the length weight relationship showed a decrease in weight of 6,3 % (n_{97}=694 and n_{98}=1 421) at 30 cm.

For Rix 21 trawl-hauls contained orange roughy. From this the average length from Emanguluko catches was 28.5 cm (n=506) and from Southern Aquarius catches 27.8 cm (n=1196). Survey 1997 showed an average length of 27,9 cm , in between the two 1998 values. The Rix distribution had a higher percentage of the catches around the mean values than the other two grounds. Although orange roughy down to 13 cm was registered. No length weight relationship was determined for Rix in the 1997 survey. The two length weight relationships for Emanguluko and Southern Aquarius were almost identical for 1998.

Reproduction

The highest proportion of running and spent males was found at Johnies (2.leg), while highest proportion of spent females was at Rix on the last day of the survey. Based on the male stages Johnies were already in spawning state, but with a lower proportion of females spawning at that time. The differences in the development of the maturity stages between the first and second coverage of Frankies and Rix confirm the build up for spawning. At Johnies the proportion of running and spent females increased somewhat between the two coverage's, but not as pronounced as for males. The relatively high proportion of non-spawning (stage 1 and stage 2) males and females during the spawning season, calls for further monitoring of the development on the grounds. Especially to see if several peaks of spawning can be observed throughout the year and if a large proportion of fish do not spawn each year.

The proportion of males was highest at Johnies (58%) and lowest at Rix (43 %). From the length at 50 % maturity it is evident that the fish was larger at spawning on Rix (26.7 cm) than Johnies (21.3 cm) and Frankies (22.7 cm). Compared to the 1997 the females have similar length at 50 % maturity per ground. This difference in length at 50 % maturity indicate that the grounds are either strongly separated and that they have developed different spawning strategies or that the larger fish seek northwards when maturing. Given the short period of fishing (since 1995) and the slow growth of orange roughy it is unlikely that the fish at Johnies already have adapted to the fishing pressure by lowering the length at maturity with 25 % compared to Rix. Further the orange roughy at Frankies have not changed the length at 50 % maturity even though very little orange roughy were found at peak spawning (and also so far this Quota year from commercial catches).

4.4 Survey methodology

4.4.1 Survey Design

The designs used on this survey, which were simple forms of adaptive sampling, were effective in concentrating survey effort into regions where it was most needed, although they were unlikely to have been optimum, in that transect spacing was not set or adjusted according to estimates of mean density or variance. (A practical difficulty in adapting the design in this way is that estimates of density and variance estimates were not immediately available during the survey due to the time needed to scrutinise the acoustic data and incorporate the trawl information on target identity).

The adaptive approach used, in which areas where no roughy were detected on the initial wide survey(s) were not subsequently re-surveyed, will be negatively biased if a significant portion of the biomass is missed on the initial survey(s) and is therefore excluded from further analysis. Although it appears unlikely from geostatistical estimates of aggregation size made from the 1997 survey data that any major aggregations would have been missed on transects spaced 1 mile apart, the possibility cannot be excluded, especially if the aggregations were smaller this year than last year.

The experiment in randomising transects, carried out at Rix in Leg 2, was successful in that it proved practicable, and has enabled valid estimates of sampling variance to be obtained for each of the 5 surveys. The fact that the 5 estimates were similar, both to one another and to the two other estimates made at Rix in Leg 2 is reasonably convincing evidence (given the large CVs) that during the course of these surveys there was no bias variable enough to override the sampling variance. In contrast, the large difference between the two replicate estimates at Johnies (Surveys 4 and 5) made within the same day could indicate a significant change in the bias, especially since it did appear as if the aggregations had moved off the bottom by the time of the second survey (which gave the higher estimate).

4.4.2 Technical considerations for the acoustic survey

Target identification

Partly because of their scarcity, and the reliance on a commercial vessel to identify specific targets, it took some time before roughy aggregations could be identified with any confidence from distinctive echo characteristics. In fact, apart from the very occasional characteristic "plume" or "cloud" clear of the bottom, classification was done as much by locality (particularly the depth zone) and the presence of similar marks on adjacent transects at the same depths, as by the echo characteristics *per se*. It was never possible to recognise the presence of roughy in the diffuse near-bottom layers which were commonly found both inshore and offshore of the aggregations, although trawls on these layers usually did capture some roughy. As this is an intractable problem with current acoustic technology, effort in improving target identification should be concentrated on identifying the aggregations, both through collecting more data on aggregation morphology, and by gaining a better understanding of their dynamics. The possibility of identification through multi-frequency signatures could also be investigated.

Estimation of roughy density in mixed layers

As previously discussed, the estimation of roughy density when roughy is a minor component in a mixture of species having far greater target strengths per unit weight is a major problem because of great uncertainty regarding the target strengths of the species in the mixture, and trawl selectivity. (Note that in the 1997 survey, a comparison between *Southern Aquarius* and *RV Fridtjof Nansen* catches indicated a substantial selectivity against smaller fish in *Aquarius*' catches). The likely difference between species in avoidance behaviour to the trawl gear, raise the question to what extent the catches are the true representation of species present on the aggregation surveyed acoustically and by trawl. Even if the species composition is right, the difference in Target Strength between species is uncertain. Since orange roughy has a low target strength each percent of difference in the species representation will have a huge impact on the biomass estimate. Given these problems it would seem wisest at this stage not to use acoustics to estimate roughy density in mixed layers, other than to obtain a semi-quantitative estimate of this component for methodological and behavioural investigations.

Dead zone problems

As discussed previously, a significant portion of the roughy biomass on this survey may have been missed (at least in some of the areas) by being too close to the bottom to be detected, especially when on uneven ground. The general conclusion is that the dead zone problem, which was thought to have been relatively minor on the 1997 survey, may have to be re-visited. Some preliminary analysis of the vertical density profile of roughy aggregations was conducted during the survey, but this proved to require time-consuming data manipulation and hence little was achieved.

The general conclusion is that the dead zone problem, which was thought to have been relatively minor on the 1997 survey, may have to be re-visited, especially as a subjective assessment of the data suggested that this problem was greater than in 1997.

Experimental work

4.4.4 Targeted acoustics

Targeted trawling by the commercial vessels to identify acoustic targets was reasonably successful at Johnies (at least during Leg 2) where most of the trawls were done, and where the vessels were generally close to *RV Fridtjof Nansen*. In the other two areas there was often a long time gap (sometimes many days) between detection of a target by *RV Fridtjof Nansen* and identification by trawl, raising doubts whether the targets captured were those detected by *RV Fridtjof Nansen,* or were even representative of them. At this stage, when much has still to be learned regarding recognition of roughy marks, it may be worth sacrificing some survey time to carry out more of the targeted trawling from the survey vessel, as direct verification of target identity shortly after detection would enable confidence in classifying targets to be built up more rapidly. This would have to be done with discretion however, because of the length of time required to shoot and retrieve the trawl, and the possibility of large, wasteful catches of roughy should the net pass through an aggregation. Methods of allowing the bulk of the catch to escape under these conditions should be considered.

Biomass estimation

The biomass estimates made by the Targeted Acoustics method rely heavily on the ability to recognise roughy aggregations, the assumption that these aggregations consist entirely of roughy, and the conclusion that most of the biomass is concentrated in them. These conditions did seem to apply for most of the surveys in Leg 2, although the fact that no aggregations were detected on a number of the surveys indicates that the method will not always be applicable. It furthermore indicates that the proportion in aggregations may vary considerably, even over relatively short time periods, introducing a potentially large and variable bias. The inclusion of the dispersed component through the Scrutinised Acoustic method does correct for this to some extent, but the larger the correction, the more susceptible the estimate becomes to errors in extracting the roughy component of the mixed layers. If, as it appears at present, orange roughy can only be estimated acoustically when the biomass is concentrated in recognisable aggregations, future work should be concentrated on understanding the dynamics of aggregation formation and dispersal to give the targeted acoustic method the best chance of success.

4.4.2 Scrutinised acoustics

Estimates of dispersed orange roughy (not in aggregations) based on the acoustical appearance of echoes and trawl catches are considered to be inaccurate. Firstly, it proved to be extremely difficult to estimate the proportion of orange roughy in scattered layers of fish; pairs of trawls on apparently similar marks in the same general area often having proportional differences by an order of magnitude. Secondly, due to low target strength of orange roughy compared to other species, even small proportions of fish with swim-bladders masked any echo produced by orange roughy. An example, target containing 50 % orange roughy and 50 % hake would have an acoustic back scatter where 2.5 % were from orange roughy and the rest from the hake.

4.4.6 Swept area estimates

The trawl data were intended to fulfil three functions:

- Identification of acoustic targets
- Relative swept-area estimates
- Relative species composition

With attempts to cover three grounds, the number of tows was appreciably less than would have been done if the survey was designed solely for biomass estimation. Emphasis was placed on Johnies for swept-area work, as this was the ground with the largest biomass from 1997, historically the largest fishery, and also where the trawl work in 1997 didn't sample the distribution very well. Less effort was put into Frankies and Rix, given time constraints towards the end of the survey. This is reflected in the relatively high CVs on Frankies and Rix, which could have been lower if more tows were carried out. At Frankies, the trawl results are representative of abundance of fish at the time, and although not precise, the general level of the biomass index is appropriate. At Rix, however, little confidence is put into the swept-area result.

The involvement of two vessels further constrained the use of trawl data for valid swept-area estimation. Although the same trawl gear was used, the size and power of the two vessels was very different. This may, or may not, affect effective fishing power of the trawl on the bottom, but in trawl survey work world-wide use of the same vessel in a time series is a critical criterion in accepting results. If future survey work is undertaken, one vessel should be used to facilitate comparison WITHIN the survey, and the same vessel should be used each year to facilitate comparison BETWEEN surveys.

Gear parameters are also critical when evaluating trawl results. The area swept is a direct scaling factor on the biomass result, and if herding, or escapement occur relative to the wing-tip distance applied here, then the estimate applied as **absolute** may be incorrect. Vertical distribution is also important, as trawl gear may herd down orange roughy, which will inflate the catch rate. No marks were seen above the trawl headline during any trawls, so if this was a factor it had already occurred before the net reached the fish. The important point to take from the above is that trawl surveys are generally used as **relative** estimates, so that these sorts of factors do not matter if they remain consistent between years. If used as absolute, it must be recognised that there are numerous sources of bias, some potentially very large.

The main limitations of the trawling method are very dense aggregations causing short tows (with poorly defined catch per distance), distribution of fish above the bottom, and distribution over rough ground. Gear saturation was a minor aspect of the trawl survey. During the random trawl survey, only two trawls (both in Johnies stratum 1) were hauled because of marks on the net monitor indicating a large catch was being taken. The second aspect is unknown, as midwater trawl work during the survey was not extensive, and did not prove or disprove vertical extent. There were areas of foul ground, but most of the region is trawlable given appropriate trawl gear and experienced skippers.

The trawl swept-area estimates are based on all fish, not just those of recruited size. However, the proportion of the scaled length frequencies consisting of small, immature, fish that would be classed as non-recruited, is small, and would make little difference. Unless the proportion of pre- and recruited fish is changing markedly between surveys, the use of total biomass will not bias relative results.

4.4.7 Combined acoustics/swept area

In 1997 the targeted acoustic biomass estimates of roughy in aggregations and swept-area estimates of dispersed roughy were combined in an attempt to provide a “total” biomass estimate of the entire roughy component of the stock associated with the aggregations. This methodology is repeated here.

Results from acoustics and swept-area trawl should probably be regarded separately. They were combined here partly through a feeling that acoustics does not pick up dispersed fish well, and from interest in seeing how the numbers compared. However, we have no way of reliably assessing whether the estimates from the two methods are comparable. Intuitively it seems unlikely that they are. Trawl survey estimates need to be corrected by a factor (q, the catchability coefficient) to relate relative to absolute biomass. This is generally derived from a time series of data, where stock reduction analysis estimates virgin biomass, and the correction factor to scale relative indices to this. This parameter can vary between grounds, in New Zealand from 0.5 to 1.5. Similarly, there are a number of substantial uncertainties in the acoustic method which make the estimates also best viewed as relative.

4.5 Biomass estimates

Area-swept estimates are considered reasonable for Johnies and Frankies, but not for Rix. Even though the initial strata from 1997 were further subdivided, and a sub-set of strata fished rather than all, there were insufficient tows in stratum 2s to achieve either an accurate, or precise, result. It was not expected that most of the biomass would be in this stratum, with very little in the main commercial area of stratum 1. Rix also proved a difficult area to fish, with the nature of the bottom meaning it took longer to find patches of trawlable ground, and there was a higher chance of gear damage. Although only 2 trawls from Rix were rejected because of this, most tows suffered some torn meshes in either the lower wings or bellies.

The stratification now established for the trawling appears appropriate. However, the distribution of fish on Johnies and Rix is somewhat variable (at least between 1997 and 1998), and some preliminary trawling is required to determine the location of the high-density strata. Stratum 1 at Johnies last year was based on the depth range of commercial catches, translated into a rectangle and with latitude and longitude boundaries. The aggregations in 1998 were deeper than in 1997, and so although still in stratum 1 (640-680m), some trawls fell outside the longitude boundaries. There is no problem with this stratum moving slightly to encompass the area of the aggregation - in fact it is important that stratification is flexible to fulfil its function. However, this meant that the purpose of stratum 2 wrapping around the central aggregations in all directions became limited on the western (deeper) side, as there was just a 20 m window between 680 m and 700 m.

The vertical extension of orange roughy plumes potentially results in large amounts of fish passing over the headline, giving an under-estimate of the true density. Vertical herding of fish down into the trawl opening has, however, been observed in other roughy fisheries, and is likely to occur in Namibia. This will result in an over-estimate of the true abundance in the path of the net. It is not known how these factors may balance out.

A further problem with the trawl data, particularly for combining acoustic back-scattering values to the trawl species composition, comes from mesh selection of smaller fish species. This probably results in an under-representation of many of the smaller species which could account for much of the backscatter. This can result in a much larger proportion of the total S_A value being accredited to orange roughy, and an over-estimate of biomass.

4.6 Experiments

4.6.1 Intercalibration exercise

The *RV Welwitchia* was fully capable of detecting orange roughy targets and at least visually seemed to produce identical recordings. The s_A from the EK500 was consistently lower than that from the *FV Dr Fridtjof Nansen*'s system which is some cause for concern. This suggest a calibration difference which needs to be checked. Alternatively vessel wake may have caused some signal attentuation which while not visible on the echogram may have resulted in a reduced echo.

Due to the short time that the *RV Welwitchia* was available it was not possible to conduct this test under differing weather conditions. However the *RV Welwitchia* arrived just after a Force 8 gale and the sea swell was still fairly large. Despite this few pings were lost, once again suggesting that the *RV Welwitchia* is fully capable of surveying orange roughy under most weather conditions.

4.6.2 Comparison of 38 kHz and 18 kHz signals

4.6.3 Dead zone density calculations

4.7 Comparison with 1998 results XX

Orange roughy distribution

The overall distribution of orange roughy was similar between 1997 and 1998 surveys. This is expected from experience with New Zealand and Australian orange roughy fisheries, where both the location, and timing, of the spawning event is very consistent over time.

The aggregations on Johnies were slightly deeper (20 m) than in 1997, but still centred on the same latitude band. The signs on Frankies, although large aggregations were not encountered, also suggested the centres of abundance remain the “Three Sisters” and to a lesser extent “Frankies Flat”. The fishery at Rix is the youngest, and it was a surprise to both scientists and the officers on the commercial vessels, that good catches were taken to the south of the ‘North Bank’, and west of “Willie’s Valley”. This was south of where most catches were taken during the 1997 survey (Figure 6), and also in an area not covered by the main commercial fishery. It is not clear whether this area represents a shift in distribution (even though only a few miles), or whether the fish were missed in 1997. The acoustic survey last year covered the grounds, but there was limited support trawling to verify mark composition.

Trawl catch rates and biomass

Trawl catch rates in Johnies decreased strongly between 1997 and 1998 in the strata surrounding the main area of aggregation (stratum 1). Catch rates in strata 2 and 6 went from 11 802 and 9 701 kg.n.mile^{-1} respectively in 1997 to 440 and 315 kg.n.mile^{-1} in 1998 (Table E). However, the catch rates in stratum 1 were generally similar between the two years, with means of 29 638 and 24 904 kg.n.mile^{-1} in 1997 and 1998 respectively.

Table E Swept-area comparison of mean catch rate and biomass on Johnies in 1997 and 1998.

Stratum	Catch rate (kg/nm)		Biomass (t)		%of total	
	1997	1998	1997	1998	1997	1998
1	29 638	24 904	6 615	5 557	11.5	79.6
2	11 802	440	16 695	264	29.0	3.8
3	1	2	2	4	-	-
4	3	1	4	1	-	-
5	<1	1	1	3	-	-

6	9 701	315	34 293	861	59.5	12.3
7	8	1	31	14	-	-
8	4	189	8	274	-	3.9
Total			57 650	6 979		

The biomass index decreased from 57 650 t to 6 979 t. This was largely due to the low catch rates in strata 2 and 6, which because of their relatively large area accounted for almost 90% of the biomass in 1997.Their contribution in 1998 was 16%. Although the catch rates and biomass in stratum 1 were similar between the two years, the relative importance increased in 1998 to make up almost 80% of the total biomass. The fish in 1998 appeared to be more localised in stratum 1. Aggregations did not extend out to the west and to the south as in 1997, where high catch rates were taken in strata 2 and 6. It is possible that the distribution was more localised with higher fish densities in stratum 1, but this was not reflected in catch rates which were similar in 1997 and 1998 (and not higher in 1998).

These changes have been associated with a shift in the frequency of catch rates. In the table below the proportion of catch rates of a certain magnitude are summarised for the two years: In 1997 25% of random trawls had a catch rate over 20 t.n.mile^{-1}, but this dropped to 6% in 1998. The frequency of low catch rates increased from 64% to 79%.

Table F Comparison of catch rate frequencies between 1997 and 1998 surveys at Johnies (catch rate in kg.n.mile^{-1}).

Catch rate	1997	1998
0-499	0.64	0.79
500-999	0	0.06
1000-4999	0.04	0.03
5000-9999	0.04	0.03
10000-19999	0.04	0.03
≥20000	0.25	0.06

Similar changes occurred at Frankies (Table G). Catch rates and biomass decreased in the main strata of 1a ("Three Sisters") and 1b ("Frankies Flat"). Stratum 1a was the only area where reasonable catches occurred during the survey. Its relative importance increased from 55 to 77% of the total biomass.

Table G Swept-area comparison of mean catch rate and biomass on Frankies in 1997 and 1998.

Stratum	Catch rate (kg/nm)	Biomass (t)	%of total

	1997	1998	1997	1998	1997	1998
1a	34 107	3 021	17 186	1 848	55.4	76.8
1b	10 972	367	9 873	330	31.8	13.7
1c	201	88	n/a	44	-	1.8
2	185	-	2 245	4	7.2	-
3	429	31	1 598	115	5.1	4.8
6	5	3	93	64	-	2.7
Total			30 995	2 406		

The magnitude of changes seen on both Johnies and Frankies over a one year period is of concern. With only two surveys it is uncertain whether these changes are a true representation of a marked decrease in stock size, or whether availability or catchability have in some way changed. However, there was typically good correspondence between what was seen with acoustics, and what was caught in trawls. No substantial catches were taken where no marks were seen.

Another explanation for reduced abundance is that fish have for some reason decided not to move to the grounds from elsewhere for spawning this year, or have shifted location of spawning. However, this is not known to occur in New Zealand or Australian orange roughy fisheries, where spawning aggregations are consistent in their location and timing. It is known that not all fish spawn each year, but this would not account for the almost complete absence of fish at Frankies. Movement between spawning grounds is unlikely, given that length frequency distributions differ between Johnies, Frankies, and Rix, and these have remained similar between 1997 and 1998.

Figure 19 Distribution of orange …..Rix

CHAPTER 5 CONCLUSION

The survey was conducted in two legs with two different commercial vessels assisting the *RV Dr Fridtjof Nansen* in undertaking the random and targeted trawling for swept area purposes and for species identification. Altogether 133 trawls were undertaken by the commercial vessels, and 15 by *RV Dr Fridtjof Nansen.* Comparing the two commercial vessels catch performance was difficult due to difference in size, horsepower, and reaction to bad weather conditions.

Bad weather conditions caused the loss of two whole days of surveying and an additional three days with reduced survey activity.

Acoustic survey was undertaken by *RV Dr Fridtjof Nansen* with a 38 kHz transducer mounted on the retractable keel and a hull-mounted 18 kHz transducer. The 18 kHz was not used throughout the whole survey, as the weather conditions caused bubble saturation close to the hull.

Both acoustic and trawl surveying showed little orange roughy outside the main known grounds, except from Rix, where trawl sampling found the main aggregation south of the stratum 1 “box”.

Targeted acoustic, Scrutinised acoustic, Trawl sample based acoustic and Swept-area estimates were obtained.

For Johnies the acoustic estimate from targeted acoustic were 2 675 to 4 791 tonnes for the aggregations found. The high estimates of survey one and two (20 666 tonnes and 18 098 tonnes) must be used with caution as the schools were not verified. The scrutinised estimate was between 3 956 tonnes and 7 758 tonnes and the survey one and two (25 578 and 21 810) used with same precaution as for targeted acoustic. Compared to 1997 targeted acoustics decreased from 20 718 tonnes to between 2 675 to 4 791 tonnes and scrutinised acoustic decreased from approximately 38 000 tonnes to 3 956 tonnes and 7 758 tonnes.
Swept area estimates for Johnies were 8 147 tonnes (included stratum nine), with 5 557 tonnes in the stratum one and 1 032 in the new area stratum nine. Compared to last year the

estimate at Johnies decreased from 57 650 tonnes to 6 979 (excluded stratum nine), mostly due to the absence of fish in the large stratum six of 1997 survey. Fish was more localised in stratum one in 1998.

For Frankies the acoustic estimate from targeted acoustic were 2 911 to 7 421 tonnes for the aggregations found. The high estimates of survey one (14 738 tonnes) must be used with caution as the schools were not verified. The scrutinised estimate was between 2 455 tonnes and 7 881 tonnes and the survey one (18 561 tonnes) must be used with same precaution as for targeted acoustic. Compared to 1997 targeted acoustics decreased from about 13 100 tonnes to between 2 911 to 7 421 tonnes and scrutinised acoustic decreased from approximately 13 300 tonnes to between 2 455 and 7 881 tonnes.

Swept area estimates for Frankies were 2 406 tonnes, with 1 848 tonnes in the stratum one. Compared to last year the estimate at Frankies decreased from 30 995 tonnes to 2 406, mostly due to the absence of fish in stratum **one a** (Three Sisters) and stratum **one b** (Frankies Flat) and also in stratum two, three and six of the 1997 survey. Very few aggregations were seen at Frankies during the survey.

For Rix the acoustic estimate from targeted acoustic were from 5 827 (whole area surveyed) to 9 866 tonnes for the aggregations found. The repeated surveys of the aggregation area gave a good impression on survey variability. The scrutinised estimate was between 6 234 tonnes and 10 020 tonnes, with the largest estimate for the repeated random survey of the aggregation. Compared to 1997 targeted acoustics decreased from about 15 940 tonnes to between 5 827 (whole area surveyed) to 9 866 tonnes and scrutinised acoustic were not for 1997 due to few trawls in the area.

Swept area estimates for Rix were 19 706 tonnes, with 19 683 tonnes in the stratum **two** and only 18 tonnes in stratum one of 1997 survey. Only nine trawls are included in the estimate. There were no swept area estimate for Rix in 1997 to compare with 1998 estimates.

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Appendix

Estimation of biomass and variance from acoustic data

This appendix describes the algorithms used for the following calculations:

(1) Estimation of the mean s_A and variance for a stratum or survey, based on the mean S_A values for the survey/stratum transects, and the transect length.

(2) Calculation of the scaling factor used to make a rough correction for differences in the target strength of Orange Roughy and other species when estimating Orange Roughy density in dispersed, mixed-species layers, for the scrutinised acoustic method.

(3) Estimation of Orange Roughy from S_A values and the length distribution of fish in identification trawls for a) clean Orange Roughy catches and b) mixtures of Orange Roughy and other species in the catch

(1) Estimation of mean S_A and variance

The algorithms are based on Eqs. in Jolly and Hampton (1992). For any stratum or survey:

$$\overline{S} = \frac{\sum_{j=1}^{M} L_j \left(\overline{S}\right)_j}{\sum_{j=1}^{M} L_j}$$

and

$$Var(\overline{S}_A) = \frac{\frac{M}{M-1} \sum L_j^2 \left[\left(\overline{S}\right)_j - \left(\overline{S}_A\right)\right]^2}{\sum_{j=1}^{M} L_j}$$

where $\left(\overline{S}_A\right)_j$ = mean S_A for transect j
L_j = length of transect j
M = No of transects in stratum/survey

(2) Estimation of scaling factor F for estimating Orange Roughy density in mixed layers

In any aggregation the number of fish/m^3 (N) can be estimated from:

No of fish/m^3 $\quad N = \frac{S_A}{\overline{\sigma}}$

$\overline{\sigma}$ = mean back-scattering cross section of all fish

$$\overline{\sigma} = \sum_{i=1}^{n} \mathrm{p_i} \cdot \overline{\sigma}_i \qquad (1)$$

where

$\overline{\sigma}_i$ = mean back-scattering cross-section of species *i*
p_i = proportion by number of species *i*
n = no of species

Number density of species *i* $\mathrm{N_i} = \frac{\mathrm{S_A}}{\overline{\sigma}} \cdot \mathrm{p_i}$

Weight density of species *i* $$\rho_i = \frac{\mathrm{S_A}}{\overline{\sigma}} \cdot \mathrm{p_i} \overline{\mathrm{w}}_\mathrm{i} \qquad (2)$$

where $\overline{\mathrm{w}}_\mathrm{i}$ denotes mean weight of species *i*

From (1) $$\rho_i = \frac{\mathrm{S_A} \cdot \mathrm{p_i} \cdot \overline{\mathrm{w}}_\mathrm{i}}{\sum_{i=1}^{n} \mathrm{p_i} \cdot \overline{\sigma}_i} \qquad (3)$$

If it is assumed that all targets have the same $\overline{\sigma}$ as roughy, we get a positively biased estimate ρ'_{ORH}:

$$\rho'_{\mathrm{ORH}} = \frac{\mathrm{S_A} \cdot \mathrm{p_{ORH}} \cdot \overline{\mathrm{w}}_{\mathrm{ORH}}}{\overline{\sigma}_{\mathrm{ORH}}} \qquad (4)$$

$\overline{\mathrm{w}}_{\mathrm{ORH}}$ = mean weight of roughy

p_{ORH} = roughy proportion

$\overline{\sigma}_{\mathrm{ORH}}$ = mean back scattering cross-section of roughy

If the other species present have an average back-scattering cross-section $\overline{\sigma}_{\mathrm{oth}} = \alpha \overline{\sigma}_{\mathrm{ORH}}$, equation 3 becomes for roughy

$$\rho_{\mathrm{ORH}} = \frac{\mathrm{S_A} \cdot \mathrm{p_{ORH}} \cdot \overline{\mathrm{w}}_{\mathrm{ORH}}}{\mathrm{p_{ORH}} \cdot \overline{\sigma}_{\mathrm{ORH}} + \alpha(1 - \mathrm{p_{ORH}}) \cdot \overline{\sigma}_{\mathrm{ORH}}}$$

$$= \frac{\mathrm{S_A} \cdot \mathrm{p_{ORH}} \cdot \overline{\mathrm{w}}_{\mathrm{ORH}}}{(\alpha + (1 - \alpha) \cdot \mathrm{p_{ORH}}) / \overline{\sigma}_{\mathrm{ORH}}}$$

i.e. $\rho_{\mathrm{ORH}} = \mathrm{F} \cdot \rho'_{\mathrm{ORH}}$ (from eq. 4) where

$$F = \frac{1}{(\alpha + (1-\alpha)\cdot p_{ORH})}$$

therefore F is a scaling factor by which the S_A value should be multiplied to give a more correct estimate of Orange Roughy density.

From TS values in Tables 7 and 15 in the 1997 Cruise Report, it seems as if the non-roughy mixtures commonly encountered had $\overline{\sigma}_{oth}$ values about 50 times greater than roughy (i.e. $\alpha \approx 50$), particularly if dominated by swim-bladdered species such as hake, dories and rat-tails.

Illustrative values:

p_{ORH}	$\alpha = 50$	$\alpha = 25$	$\alpha = 10$
	1/F	1/F	1/F
1	1	1	1
0.99	1.49	1.24	1.09
0.95	3.45	2.2	1.45
0.90	5.9	3.4	1.9
0.80	10.8	5.8	2.8
0.70	15.7	8.2	3.7
0.60	20.6	10.6	4.6
0.50	25.5	13.0	5.5
0.40	30.4	15.4	6.4
0.30	35.3	17.8	7.3
0.20	40.2	20.2	8.2
0.10	45.1	22.6	9.1
0.05	47.5	23.8	9.5

Therefore it can be seen that even a small proportion of other (swim bladdered) species will introduce a large positive bias into the roughy density estimate unless differences in TS are taken into account (i.e. the S_A values should not be proportioned solely according to the species composition in the catches.)

(1) Estimation of roughy biomass using length frequency information

a. If no other species present

Roughy Biomass = B_{ORH} = $A * \overline{\rho}_{ORH}$

Where $\overline{\rho}_{ORH}$ = mean weight of roughy/nmile^2

A = survey area in nmile^2

$\overline{\rho}_{ORH}$ is given by:

$$\overline{\rho}_{ORH} = \frac{\overline{S}_A}{(\overline{\sigma}_{kg})_{ORH}} \quad \text{....................................(1)}$$

where $(\overline{\sigma}_{kg})_{ORH}$ is the mean roughy scattering cross-section per kg, estimated from the length frequency distribution through the expression:

$$(\overline{\sigma}_{kg})_{ORH} = \frac{\sum_{i=1}^{N} n_i * \left[(\sigma_{kg})_{ORH}\right]_i}{\sum_{i=1}^{N} n_i} \quad \text{.............................(2)}$$

where $\left[(\sigma_{kg})_{ORH}\right]_i$ = scattering cross-section per kg for roughy in length class *i*

n_i = No of roughy in length class *i*

N = No of length classes

$$(\sigma_{kg})_{ORH} = \frac{\sigma_{ORH}}{W} \quad \text{..(3)}$$

where σ_{ORH} is the scattering cross-section of a Orange Roughy of weight w (kg), which is obtained from the target strength (TS_{ORH}) through the expressions TS_{ORH} = 20LogL + C_{ORH} and $TS_{ORH} = 10\text{Log}\frac{\sigma_{ORH}}{4\pi}$, giving:

$$\sigma_{ORH} = 4 * \pi * 10^{C_{ORH}/10} * L^2 \quad \text{.................................(4)}$$

From (3) and (4):

$$(\sigma_{kg})_{ORH} = \frac{4\pi * 10^{C_{ORH}/10} * L^2}{a_{ORH} * L^{b_{ORH}}}$$

$$= \frac{4\pi * 10^{C_{ORH}/10} * L^{(2-b_{ORH})}}{a_{ORH}} \quad \text{................................(5)}$$

where a_{ORH} and b_{ORH} are the coefficient and exponent respectively in the roughy weight/length relationship, $w = a_{ORH} * L^{b_{ORH}}$ (w in kg, L in cm).

Eq. (2) then becomes:

$$\left(\overline{\sigma}_{kg}\right)_{ORH} = \frac{4 * \pi * 10^{C_{ORH}/10}}{a_{ORH}} * \frac{\sum_{i=1}^{N} n_i * L_i^{2-b_{ORH}}}{\sum_{i=1}^{N} n_i} \quad \text{...........(6)}$$

where L_i is the midpoint length of length class i.

Substitution in (1) gives the mean weight density (in kg/nmile^2) for the surveyed area, and hence the biomass (in kg) for the area.

Constants needed:

C_{ORH} = -81.0 –1.0 (correction applied in Jan 1998)

= -82.0dB

a_{ORH} =

b_{ORH} =

b. Conversion: $\overline{S}_A$ → Biomass for mixed species

From Eq. (1)

$$\overline{\rho}_{Mix} = \frac{\overline{S}_A}{\left(\overline{\sigma}_{kg}\right)_{Mix}} \quad \text{................................(7)}$$

$\overline{\rho}_{Mix}$ =mean weight of all fish/nmile^2 in survey

$$\left(\overline{\sigma}_{kg}\right)_{Mix} = \frac{\sum_{j=1}^{M} n_j * \left(\overline{\sigma}_{kg}\right)_j}{\sum_{j=1}^{M} m_j} \quad \text{....................................(8)}$$

where $\left(\overline{\sigma}_{kg}\right)_j$ =mean scattering cross-section per kg for species j.

m_j = no of fish of species j in pooled sample

M = no. of species present in sample

Strictly, $\left(\overline{\sigma}_{kg}\right)_j$ for each species should be calculated from the length distribution of species j in the sample, but since these distributions are not available for species other than roughy, and approximation to Eq. (6), viz:

$$\left(\overline{\sigma}_{kg}\right)_j \approx \frac{4\pi * 10^{c_j/10} * \overline{L}_j^2}{\overline{w}_j} \quad \text{......................(9)}$$

has to be used, where c_j is the TS constant for species j, and $\overline{L}_j$ and $\overline{w}_j$ are the mean length and weight of species j.

The weight density for roughy in a mixture is given by:

$$\overline{\rho}_{ORH} = \frac{(W_{tot})_{ORH} * \overline{\rho}_{Mix}}{W_{tot}} = f_{ORH} * \overline{\rho}_{Mix}$$

where $(W_{tot})_{ORH}$ = total weight of roughy in the sample

W_{tot} = total weight of sample

(i.e. $f_{ORH} = \frac{(W_{tot})_{ORH}}{W_{tot}} =$ proportion by weight of roughy in sample)

from Eqs (7), (8) and (9):

$$\overline{\rho}_{ORH} \approx \frac{f_{ORH} * \overline{S}_A * \sum_{j=1}^{M} m_j}{4\pi * \sum_{j=1}^{M} \frac{m_j * 10^{c_j/10} * \overline{L}_j^2}{\overline{w}_j}}$$

For roughy, $\overline{L}_j$ and $\overline{w}_j$ can be obtained directly from the length frequency sample, but for all other species, they may have to be taken from the 1997 data – (Table 8 in 1997 Cruise report).

The c_j values for species other than roughy are given in Table 8 ("TS constant") of the '97 Cruise report. i.e.

Hake: -68.0dB

Oreo dories: -68.0dB

Rat-tails:-72.7dB

Sharks: -79.0dB

Note that for roughy, C_{ORH} = -81 – 1.0

= -82 dB

	C-values	σ	K
Roughy	-82.0	$10^{-8} L^2$	10^{-8}
Hake	-68.0	$10^{-5.7} L^2$	$10^{-5.7}$
Dories	-68.0	$10^{-5.7} L^2$	$10^{-6.2}$
Rat-tails	-72.7	$10^{-6.2} L^2$	$10^{-6.8}$
Sharks	-79.0	$10^{-6.8} L^2$	$10^{-6.8}$
Other	-68.0		

Estimation of mean S_A and CV from transects

From survey area:

$$\bar{S}_A = \frac{\sum_{i=1}^{N} L_i * (\bar{S}_A)_i}{\sum_{i=1}^{N} L_i}$$

$(\bar{S}_A)_i$ =Mean S_A for transect *i*

L_i = Length of transect *i*

N = No of transects in survey area

$$Var(\bar{S}_A) = \frac{\frac{N}{N-1} * \sum_{i=1}^{N} (L_i)^2 * ((\bar{S}_A)_i - (\bar{S}_A))^2}{(\sum L_i)^2}$$

$$CV = \frac{\sqrt{Var(\bar{S}_A)}}{\bar{S}_A}$$

References

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