A REVIEW OF THE 1994
STOCK ASSESSMENT FOR ORANGE ROUGHY

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AFMA

FRDC

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INTRODUCTION

AFMA arranged for Dr Richard Deriso and Dr Ray Hilborn to undertake a review of the 1994 Stock Assessment Report for Orange Roughy. They arrived in Australia from the United States on 18 September 1994. On Monday 19 September 1994 they were briefed by AFMA officials and separately by industry representatives on the aims of the review.

They then flew to Hobart where they held meetings with CSIRO scientists and other scientists involved with producing the stock assessment report. They investigated the South East Fishery Stock Assessment Group (SEFSAG) stock assessment process for orange roughy in 1994 and reviewed the data inputs to the assessment including:

- stock structure
- age and growth
- partial recruitment and maturity
- proportion spawning
- catches
- catch per unit
- abundance estimates - acoustic and egg production surveys

They also reviewed the quantitative assessment looking at the stochastic SRA model and approach, parameter estimates and data assumptions, AFMA's risk criteria, sensitivity analysis and an overview of, and suggested improvements to the assessment.

SUMMARY

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BACKGROUND

Stock assessments of orange roughy have been made on an annual basis since 1989. The assessments have been based largely on research carried out by CSIRO and the Tasmanian Division of Sea Fisheries. The assessments were reviewed by the Demersal and Pelagic Fish Research Group of the South East Fisheries Research Committee of the Standing Committee on Fisheries and Aquaculture. Assessments in 1993 & 1994 have been approved and accepted by the SEFSAG.

On the basis of these stock assessments the Commonwealth government has introduced quota management of the orange roughy, and other species in the South East Fishery. The catch of orange roughy peaked at over 40,000 tonnes in 1990 and under the quota restrictions has been declining towards the target of 3,000 - 5,000 tonnes.

BACKGROUND CONTINUED

Since orange roughy has been the major income earner for the South East Fishery for a number of years, this radical decline in Total Allowable Catch (TAC) is having a large impact on the fishery.

AFMA has recently established its stock assessment group for the South East Fishery and has supported further review of the stock assessments. The most recent orange roughy workshop (Feb 1994) highlighted a range of uncertainties in the assessment and SETMAC saw a strong need for an independent review of our present understanding of the status of orange roughy around eastern and southern Tasmania to provide for broad confidence in and acceptance of the analysis and its conclusions.

While industry has shown itself to be willing to support the reduction in quotas up to the present, there is an understandable desire on their part to ensure that the reductions in TACs being made in this fishery are warranted on the basis of the evidence available, and on AFMA's part to ensure that the long term security of the resource is assured whilst the industry is not being restricted unnecessarily.

NEED

The immediate need for the review of the orange roughy stock assessment arises from

1. the magnitude of quota reductions being applied and management decisions with major significance for industry and the future of the resource are being made which require greater (more widespread) confidence in and acceptance of the stock situations and the affect of future harvest strategies.

2. the fact the recent South East Fishery Stock Assessment Group (SEFSAG) stock assessments have not been subjected to comprehensive review by internationally recognised, independent scientists.

On the recommendation of the Demersal and Pelagic Fishery Resources Group (SPFRG) and SEFSAG, a Workshop was held to review the current status of orange roughy stock assessment (CSIRO, Hobart, February 1994). The objectives of the Workshop were to examine the major sources of uncertainty in the 1993 assessment and to develop a strategic research plan to reduce them. The Workshop was attended by Australian orange roughy scientists from several research agencies, industry scientists from Australia and New Zealand, representatives from industry, Australian Fisheries Management Authority and the Australian Bureau of Agricultural and Resource Economics, and invited overseas experts in orange roughy biology, acoustic biomass assessment, and stock assessment and modelling methods.

The Workshop addressed a number of sources of uncertainty in the current stock assessments for orange roughy in the eastern and southern management zones of the south west sector of the South East Fishery. These included:

NEED CONTINUED

- the error bounds associated with each point estimate of biomass
- continuing uncertainties about stock structure
- the proportion of orange roughy spawning at St Helens
- species composition of acoustic marks at St Helens and in the southern zone
- problems of under-reporting and mis-reporting of catches
- the possibility of recent low levels of recruitment
- how sensitive the current assessments are to all these sources of uncertainty

The Workshop also agreed that there was no scientific value in continuing the adaptive management experiment set up in 1993 to determine stock structure. More detail is provided in the Workshop summary (Bax and Lyle, 1994). A research plan was developed to address most of the uncertainties.

As a result of the February Workshop, a reassessment of the 1993 orange roughy assessment was undertaken and presented to the SEF Stock Assessment Group in May 1994. This 1994 orange roughy assessment is now incorporated in a draft stock assessment report of the SEFSAG following the Stock Assessment Plenary in July 1994. The 1994 assessment has addressed many of the uncertainties identified from the February Workshop, and has also incorporated some new information not available at that Workshop.

As management decisions taken on the basis of the present assessment will have major implications for the orange roughy fishery, it is important that all stakeholders have confidence in the result of the 1994 assessment, which in essence will seek to ensure that the best use has been made of the available data.

Therefore a review was proposed to independently assess the levels of uncertainty in the existing analyses and to suggest methods for increasing certainty in future assessments. SETMAC discussed the need for a review twice and each time placed a high priority on progressing the review as quickly as possible.

OBJECTIVES

The main objective of the project was to ensure that management action taken on the valuable orange roughy fishery is based on the best available scientific advice, noting that the present assessment is by no means a "routine" scientific task. This objective requires an international-standard, independent review and will be achieved through 4 sub-objectives:

OBJECTIVES CONTINUED

1. Reviewing estimates of abundance and basic biological parameters (mortality rates, growth, stock structure, recruitment and variability, proportion of spawners breeding each year) used in assessing orange roughy stock status in the South East Fishery:

2. Reviewing statistical methods used in the 1994 stock assessments:

3. Reviewing methods of estimating the risk associated with the 1994 assessment:

4. Reviewing means of improving future stock assessments in the light of objectives 1-3.

METHOD

The review was done by 2 independent scientists:

1. Professor Ray Hilborn, University of Washington, Seattle

2. Dr Rick Deriso, IATTC, La Jolla, California

The two scientists spent about one week working in the Hobart laboratory of CSIRO, meeting with industry and managers, reviewing the available data and discussing the methods used in the assessment with the relevant scientists. After this period the scientists produced a report based on their conclusions from the work done in Hobart.

INTELLECTUAL PROPERTY

The report of the reviewers is a public document after their receipt by AFMA and FRDC. No value is assigned to the intellectual property content for the purposes of this proposal. Any data or analyses provided by CSIRO, AFMA or other participating agencies for the purposes of the review are to be used for that purpose only. Other than the review report, publication of any analyses arising from the review may not be made without the written consent of the agency concerned.

BENEFICIARIES

The direct beneficiaries are:

1. the operators of the South East Fishery, especially those with orange roughy quota;

BENEFICIARIES CONTINUED

2. the Australian "owners" of the orange roughy resources who are relying on AFMA to manage the resources for long term sustainability.

There may be other spin-offs if the independent scientists brought new methods and ideas into Australian stock assessments and risk analysis that can be transferred to assessments of other species.

STAFF

G Rohan	AFMA	Manager, Southern Fisheries	2 weeks
K Parkinson	AFMA	Manager, South East Fishery	2 weeks
G Hewitt	SETMAC	Executive Officer	1 week
R Deriso	independent scientist		2 weeks
R Hilborn	independent scientist		2 weeks
N Bax	CSIRO		1 week
A Smith	CSIRO		1 week
T Koslow	CSIRO		1 week
J Prince	industry funded scientist		2 weeks

Members of the South East Fishery Stock Assessment Group also reviewed the report arising from this project and provided their own assessment to AFMA.

FINAL COST

The final cost of the project was $53,626 made up of salaries and on costs of $32,000 plus travel of $21,616.

DISTRIBUTION

The review has been distributed to the members of SETMAC and the SEFSAG.

CONCLUDING REMARKS

The primary indicator for the success of the project was the degree of recognition among industry, scientists and managers that the stock assessment of orange roughy is the best available for providing a basis on which Total Allowable Catches (TACs) can be set.

The review of the orange roughy fishery and stock assessment by Drs Hilborn and Deriso produced a most satisfactory outcome. After examining both the data inputs and the procedure used in the assessment they concluded that the assessment was consistent with the best methods used elsewhere in the world and that in comparison with assessments of orange roughy in other places, the Australian assessment was much less ambiguous. They also supported the management approach adopted by AFMA for conservation of the stock.

The report of the consultants was accepted by industry, AFMA and the members of the Stock Assessment Group.

A Review of the 1994 Stock Assessment for Orange Roughy

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1.0 Summary

At the request of the Australian Fisheries Management Agency we conducted a review of the 1994 stock assessment of orange roughy which had been prepared for the South East Fishery Assessment Group. Our assessment is that the stock is nearing or has reached full exploitation and harvests should be reduced to the long term sustainable levels. We feel that this assessment is reasonably robust since three separate indices of abundance, acoustic surveys, total egg production, and analysis of catch-per-effort all show a substantial decline in stock abundance.

While any of these indices may have fallen for reasons other than a decline in stock abundance, the fact that all three measures indicate that the stock is approaching about 30% of virgin biomass is reassuring. The methods used to measure abundance and calculate stock trajectories are consistent with the best methods used elsewhere in the world. In comparison to assessments of orange roughy in other places, we found this assessment to be much less ambiguous, as all indices of abundance show the same trend and the analysis of single or separate stocks hypotheses also are consistent.

We reviewed all the data and assumptions used in the July 1994 assessment and recommended the following changes be made for the assessment

1. CPUE data for the eastern zone not be used in the assessment,
2. The reliability assigned to the acoustic surveys be reduced,
3. The reliability assigned to the egg survey be reduced,
4. The egg survey data be inflated to account for egg mortality and advection in all runs and for southern spawners in the combined spawning runs, and
5. The 1990 acoustic survey be adjusted to account for change in percent spawning

CSIRO scientists ran a revised assessment based on items 1-4 above. The results are presented in the report and while generally consistent with the July 1994 assessment, they do suggest that the stock is somewhat less depleted.

We believe that the weight of the evidence on stock structure provides somewhat more evidence that some of the spawners at St. Helens come from the southern zone, and therefore managers should give slightly more weight to the results from a combined analysis compared to the separate stock analysis. In the combined analysis it will be more cautious to assign more of the catch to the southern zone in order to reduce interference with the spawning stock.

The AFMA strategy of maintaining the stock at 0.3 of virgin biomass is consistent with what is known of ecologically sustainable development, and we recommend that AFMA

chose a policy that is expected to keep the stock above the 0.3 level 50% of the time in a 5-10 year time horizon.

We were concerned that the only ongoing data collection for this stock is collection of catch statistics, logbooks, and age reading and that collection of age samples, acoustic and egg surveys require special funding. We consider that the long term management of the fishery depends upon regular (although not annual) collection of age and fishery-independent indices of abundance and such programmed research should be regularly funded.

We found that there are considerable disagreements about methods of measuring stock abundance between Australian and New Zealand scientists, and suggest that the level of cooperation and exchange of ideas on methods be increased.

Recommendations

We recommend that :

1. an ongoing program of regular data collection be established based on fishery-independent indices
2. CPUE not be used when fishery-independent measures can be obtained
3. age, length and fecundity data be routinely collected
4. further research on stock structure be performed
5. decision makers generally use the median (or 50%) values of probability distributions when considering the target stock biomass
6. decision makers consider the expected stock size in 5-10 years when evaluating alternative management policies
7. simulation trials be performed to see how TAC's will change for different target stock sizes and management policies
8. alternative forms of management rules be considered that might include adjusting fishing mortality rates in relation to stock size or total egg deposition
9. an analysis of the new age distribution data with respect to selectivity ogive, natural mortality rate, evidence for episodic recruitment and the amount of interannual variation in recruitment be conducted
10. further age samples be collected and analyzed in 1995
11. a thorough statistical analysis of the proportion spawning data be performed using modern statistical methods

12. the 1990 acoustic index in St. Helens be increased by 30% to account for changes in % spawning

13. the CV on the 1992 egg survey be increased to 0.5

14. combined area runs have a more explicit analysis of spawning locations

15. future acoustic and egg production estimates be adjusted to reflect year to year changes in percent spawning

16. egg production estimates be adjusted for southern spawners

17. future log book data include zero shots

18. GLIM analysis of CPUE be used to see if intense fishing reduces catchability

19. that an experiment in the southern management zone be conducted to see if stock re aggregate on hills when fishing is reduced

20. the CV used in the acoustic estimate for St. Helens be assumed to 0.4 until a statistical analysis of the uncertainty is conducted

21. future acoustic surveys in St. Helens should include (1) multiple snapshots, (2) species composition at each depth

22. future southern zone acoustic surveys include species composition analysis

23. the 1992 and 1994 southern zone acoustic surveys be compared for correlation in mark locations

24. a thorough review of the possibility of egg mortality and advection be performed, and the differences between the high apparent mortality and advection in the New Zealand assessment be understood

25. an egg survey in St. Helens be repeated in 1995

26. a literature review be conducted to determine any useful information on the possible steepness of the stock recruitment relationship for similar species

27. until such a review is conducted, the steepness be adjusted so that the spawning biomass for MSY be 0.3 of virgin.

2.0 Introduction

We were contacted during 1994 by AFMA to conduct a review of the 1994 orange roughy stock assessment. Our terms of reference for the review are given by the following objectives:

1. Review estimates of abundance and basic biological parameters (mortality rates, growth, stock structure, recruitment variability, proportion of spawners breeding each year) used in assessing orange roughy stock status in the South East fishery;

2. Review statistical methods used in the 1994 stock assessments;

3. Review methods of estimating the risk associated with the 1994 assessment;

4. Review means of improving future stock assessments in the light of objectives 1-3.

The four objectives were meant to ensure that management action taken on the valuable orange roughy fishery is based on the best available scientific advice.

The process followed in the review was to meet for one day (19 September 1994) with industry and managers then work for five days in the Hobart laboratory of CSIRO. We met there for three days with orange roughy assessment scientists. After those meetings, we returned to Melbourne for a meeting (26 September) with industry and managers who were briefed on our findings. The initial meeting with AFMA and BRS (19 September) was attended by Mr. Geoff Rohan, Mr. Kim Parkinson, Dr. Bruce Phillips, Dr. Russel Reichelt, Dr. Jeremy Prince, Dr. Steve Jackson and ourselves. The initial meeting with industry (Also 19 September) included, Dr. Jeremy Prince, Ms. Gail Hewitt, Mr. Stewart Richey, Mr. Darby Ross and ourselves. Participants during various sections of the meetings in Hobart were Drs. David Smith, Tony Smith, Ron Thresher, Tony Koslow, Jeremy Lyle, Jeremy Prince, Keith Sainsbury, Derek Staples, Nic Bax, Mr. Kim Parkinson, Ms. Cathy Bulmann and ourselves. On September 26th we met with SETMAC, which included Mr. Geoff Rohan, Mr. Kim Parkinson, Dr. Jeremy Prince, Ms. Gail Hewitt, Mr. Stewart Richey, Mr. Darby Ross, Dr. Derek Staples and ourselves.

We relied on the following documents for this review: July 1994 Stock Assessment Report 1994 plus Appendices, 21 August 1994 Fishery Assessment Report -- The South East Fishery 1994, 12 September 1994 Comments on the Stock Assessment of Orange Roughy in the South East Fishery by Dr. J. D. Prince, 12 May 1994 Orange Roughy Assessment Report 1993, Egg Production and Acoustic Survey Biomass Estimates for Orange Roughy on the St. Helens Spawning Ground and in the southern Zone in 1992 by Dr. J. Anthony Koslow et al., and The Very ad hoc Orange Roughy Working Group Meeting -- 15 to 17 June 1988 by Dr. Cathy Bulman et al. We used additional material in the form of computer output of sensitivity analyses and alternative stock assessment projections, age structure data, our own references, and materials from other fisheries.

The limited time for this project precluded us from an in-depth analysis of raw data and computer programs used for orange roughy assessment. Our intention was to conduct such an analysis of some sub-set of the data if we thought it was needed. However, there is consistency of the assessment results among three different indices of abundance. We concluded that no such in-depth analysis was necessary.

An agenda for our Hobart meetings was agreed on we arrived. It included all the major elements of the stock assessment and required little modification during our meetings. This report is structured along this agenda.

3.0 Data sources and assumptions

3.1 Stock Structure

We confine our comments here to the stock structure of roughy in the eastern management zone and southern management zone. There are three main hypotheses about stock structure:

1. The St. Helens site and the southern management zone have separate resident stocks, but St. Helens is the major spawning location for both resident stocks plus additional spawning possible from other non-residents.

2. St. Helens and the southern management zone contain separate stocks with separate spawning sites.

3. The St. Helens and southern management zone are part of the habitat for a single completely mixed stock.

Several techniques have been used to address the stock structure issue, including genetic techniques (electrophoresis and mt DNA), otolith analyses (whole otolith micro-chemistry, micro-probe, morphology of shape), heavy metal concentrations, proportion spawning, meristics, age composition of the fish, size composition of the fish, and information on locations of known spawning sites. The weight of evidence is sufficient to discount the third hypothesis (a completely mixed stock), but is not sufficient to eliminate either of the other two hypotheses. The first hypothesis (resident stocks with a major shared spawning location) is somewhat favored over the second hypothesis, according to our interpretation of evidence presented on stock structure. A summary of those interpretations is given below in Table 1.

Table 1: Agreement levels of particular stock structure information with each of the three stock structure hypotheses.

Technique: Hypothesis:	1	2	3
a. genetic	--------- no evidence ----------------------		
b. otolith microprobe	yes	less	no
c. otolith morphology	yes	yes	no
d. meristics	yes	less	no
e. heavy metals	--------- inadequate sample design -------		
f. proportion spawning	--------- consistent with all ---------------		
g. known spawning grounds	yes	less	yes
h. size of spawning fish	yes	yes	weak
I. age composition	yes	yes	no

Given the possibility that either hypothesis one or two could be true, we address the consequences of those hypotheses to management. In particular, we consider the consequence of management under one of the hypotheses when in fact the other one is true.

Consequences of management under the second hypothesis (two separate stocks with separate spawning) when in fact hypothesis one (resident stocks with shared spawning) is true include:

1. Over-estimation of stock size -- because some southern management zone fish are counted twice (once in the St. Helens spawning aggregation and again by CPUE, acoustic, and catches taken in the southern management zone).
2. Under-estimation of risk that the stock is below threshold and target levels -- a direct consequence of point (1.).

The higher risk with this form of management can be reduced somewhat by increased frequency of data collection of the southern management zone and St. Helens abundance.

Consequences of management under the shared spawning site hypothesis (#1) when in fact hypothesis (#2) is true are just the opposite of the points listed above: 1) under-estimation of stock size and 2) over-estimation of risk.

3.2 Age and growth

During our review, Dave Smith presented a new age structure sample, comprising over 1000 individuals. This sample showed a number of interesting features including (1) evidence that the natural mortality rate was about 0.06 if one assumes recruitment has been random about a constant mean over the last 100+ years (rather than the 0.046 in the published assessment), (2) some evidence for systematically higher age class strengths at ages over 100 and possible episodic variation in year class strength, and (3) an apparent selectivity ogive that was quite different from the selectivity ogive derived from examination of the "last major zone" (LMZ) of the otoliths.

There is considerable confounding between the estimate of M and the selectivity pattern. If one uses the LMZ data as the maturity and selectivity ogive, then either there has been a period of poor recruitment in the ages younger than age 60 or so, or the natural mortality rate changes considerably at about age 60, from a very low value to a value of about 0.06. A M=0.06 is not consistent with constant recruitment and the LMZ selectivity ogive. If poor recruitment of orange roughy younger than age 60 has occurred, then medium-term sustainable yields are likely much lower than those estimated in the stock assessment.

It is possible that the LMZ ogive is not the selectivity ogive for the fishery, and younger fish spawn less frequently than older fish after they have achieved sexual maturity. The alternative explanations of the age distribution data need considerably more examination as they were just tabled at the review meeting.

It is obviously quite desirable to have a further age sample from the 1995 fishery. This would provide a cross check on many of the features of the age sample just examined, and would provide an opportunity to check for changes in growth rate as the stock has been depleted.

The key areas to explore in the existing, and in any future age distribution samples are (1) the selectivity ogive, (2) natural mortality rate, (3) evidence for episodic recruitment and (4) estimates of annual variation in year class strength.

3.3 Partial recruitment and maturity

These issues were generally discussed in section 3.2. One interesting trend is that the data indicate a general increase in fecundity per female over time. If this trend continues it has implications for the stock productivity and spawner recruit relationships.

3.4 Proportion Spawning

The proportion of fish which are estimated to be spawning each year is an important input into the estimates of total spawning biomass from either acoustic surveys or egg production surveys. It is less important for the acoustic surveys if those surveys are only used as relative indices of abundance provided the proportion spawning does not change over time. ANOVA results on the female roughy of eastern Tasmania indicate that the proportions have indeed changed over time. The 1990 proportion is 54% compared to 71-72% for the 1991-1992 samples from the ANOVA results for mid-March to mid-April. Data collected on proportion of spawners indicate some large deviations from the ANOVA results. An unbalanced design of data from different years is also a problem. Clearly there is much uncertainty about the actual proportion of spawners and about the extent of the changes in proportion spawners in eastern management zone from 1990 to 1992. Nevertheless, the best estimates are those given by ANOVA, and year-specific values are recommended for all assessments. In addition, we recommend that the CV's on acoustic indices be increased to reflect the uncertainty in the proportion spawners-- the uncertainty has already been incorporated into the egg production CV. Whether the changes in proportion spawners over 1990-1992 is a reflection of density-dependence or environmental changes or estimation error is not clear at this time.

We recommend that the analysis of proportion spawning be reviewed and revised as necessary after consultation with a qualified statistician . We note that contemporary analyses of these kinds of data typically follow from logit-transformed proportions with some type of sample size weighted ANOVA.

One inconsistency noted from the application of the proportion spawning results is that the 1992 proportion spawning estimate has been applied to the egg production estimate for 1992, but the relative acoustic indices do not reflect year-specific changes in proportion spawning. We recommend that future analyses with acoustic indices be adjusted to reflect the year-specific changes in proportion spawning.

Proportion spawning estimates for females in the southern management zone show a decline to about 20% during the July-August period with the exception of one data point. The fact that the decline is not to zero indicates that not all southern management zone fish who spawn are present at St. Helens during the July-August time period. An upward adjustment to the egg production estimates are recommended to account for the 20% proportion spawners in the southern management zone, but only in the "combined area" assessments.

3.5 Catches

Several adjustments have been applied to reported catches to account for total removals. The 1992 estimated adjustment was supplied to the assessment group by the compliance unit. The compliance unit in turn made adjustments based on exports, known processor catches, and other sources of information. The exact procedure of the adjustment was not shown to the assessment team in July 1994, but we recommend that this should be done -- at least to the extent that the analysts are comfortable that no flaws are present in the compliance units methods. The 1993 catch estimates for the eastern management zone and southern management zone were apparently biased by mis-reporting of area of catch. The methods of adjustment for mis-reporting appear reasonable to us. The application of transponders to vessels may reduce this problem in future years, but there is always a risk of mis-reporting which would bias separate area assessments for the eastern management zone and southern management zone, but would not have any effect on the combined area analyses. Adjustments for burst bags and other losses are difficult for us to evaluate.

3.6 Catch per unit effort

General linear models (GLIM) were applied to catch and effort data collected from logbooks of fishing in both the eastern management zone and southern management zone. The GLIM models developed for the CPUE analysis are quite reasonable; indeed the use of logarithm of effort as a covariate is a novel approach to the problem of adjustment of catch rates for non-linearity between fishing mortality rate and observed fishing effort. One limitation of the data set is that zero catch shots were not required entries in to the logbooks. but they should be made a requirement in the future. Catch per unit effort information can be a useful index of abundance if proper care is taken to standardize the index against changes in fishing practices and if the aggregation size of schools changes with changing fish density. Because of the difficulties involved in standardization, its' reliability is difficult to assess. Fisheries in other parts of the world have shown that changes in CPUE may be related to changes in catchability rather than changes in abundance. Even more seriously, CPUE has not declined whereas the abundance of the stock has declined. In certain other fisheries, CPUE has proven to be a reliable index of abundance. Despite the reservations given above, the confirmation of CPUE trends in the St. Helens area with trends indicated by assessments omitting that data is sufficient in our opinion to establish its usefulness in assessments where other fishery-independent surveys are not available. In particular, its application to the southern management zone assessment is a reasonable way to proceed recognizing that changes in CPUE may be due to fish or fishermen behavior rather than fish abundance..

We have serious concerns about the application of the CPUE indices in the eastern management zone. Application of CPUE to past data is not needed given that other fishery-independent surveys (both acoustic time series and a valid egg production survey) have been made. Another problem with application to historical data in the eastern management zone is that the CPUE index was only considered to be useful for the eastern management zone after it was found that it confirmed historical trends in abundance indicated by the other survey methods. Confirmation of the historical trends does, however, provide additional evidence that depletion has occurred in the St. Helens site. Two further problems with the GLIM estimates are that the 1991 estimate does not adequately account for the closure of the fishery during part of that year and, secondly, that the 1993 estimate does not account for the effect of mis-reporting of catch and effort.

If suitable corrections are made for the CPUE in the eastern management zone, the revised indices would be better. They could be used to estimate a catchability coefficient for the past data, which could be applied to future CPUE data in eastern management zone assessments. However, one would want to be careful about using the CPUE in the future because there are a priori reasons to expect it could be flawed. Clearly fishery-independent scientific methods, such as acoustic and egg production surveys, are the preferred methods for future data collection. Fishery-independent measures are a viable alternative for the eastern management zone. It is less clear that they are a long term alternative in the southern management zone.

One supposition by industry is that roughy become less catchable after repeated shots at a given locality. We recommend that this issue be addressed by a GLIM analysis which considers elapsed time between shots at a given locality (or some other measure of repetition of shots at a locality) as a potential explanatory variable. That analysis would indicate within-season effects, but it would not address the more general concern that the fish become less catchable from one year to the next. The research recommendation of adaptive management of specific sites within the southern management zone is an experimental approach to this issue.

3.7.1 Acoustic surveys, Eastern Zone

Hull-mounted acoustic surveys were conducted in 1990 through 1993, while towed-body surveys were conducted in all years except 1990. The hull-mounted data were used in the assessment and have had a major impact on assessment results since there was a substantial drop from 1990 to 1991, and no significant drop in the two years thereafter. Prior to this year, the 1990 data were not used in the assessment because the data were not standardized to the same target strength as those from later years (the data base for such adjustments was first made available to the assessment scientists this year.) The addition of the 1990 data is a significant contribution to the final results. Our understanding is that the towed-body data are considered of higher quality due to a smaller "dead zone" but that it was felt important to use the 1990 data, so hull-mounted data were used. This would appear to be a reasonable decision.

The eastern zone acoustic data are used as a relative index of abundance, which we also feel is appropriate since it eliminates a number of assumptions about target strength and population turnover rate. The internal sampling variability suggested a CV of 0.1, while a CV of 0.25 was used in the published assessment to allow for other forms of variation. The model fit suggested a cv of 0.27.

The acoustic survey as a relative index depends on four major elements, (1) the amount of sonic energy reflected from different depths, (2) the species composition at each depth (3) the target strength of each species and (4) the proportion of the entire spawning population present on the hill on the day of the survey.

There is considerable uncertainty in all four elements. We have examined the correlation between sonic energy from the hull-mounted and towed-body transducers and find that there is more variation than would be expected based on the internal sampling variance. The species composition data were not obtained in 1990 and 1993, and it is assumed that orange roughy constitute the same proportion of the population over time. This is likely not true both because the abundance of other species may have changed and as the stock has been depleted, we would expect that in general the proportion of orange roughy would decline. However, in most years most of the fish were found at the 600-800 meter depths where orange roughy are 95% of the fish, so the species composition should not be critical. In 1993 the distribution of orange roughy may have been deeper because of additional back-scatter detected at lower depths, and it is possible that the contribution of roughy from the lower depth strata was underestimated if the additional back-scatter at lower depths was not due to species other than orange roughy. Because no species composition data was collected for 1993 (the survey was opportunistically made during a different project) it is not possible to determine what caused the higher back-scatter at the lower depths. The target strength of orange roughy is very low and difficult to measure. This is particularly important in deep strata where other species are found that have much higher target strengths. This general uncertainty in target strength adds more uncertainty to the overall acoustic estimates.

All the acoustic estimates used in the assessment were obtained over less than one day on the St. Helens hill. There is an implicit assumption that the same proportion of the spawning population was present on the hill in each year, despite the fact that the time of the acoustic survey differed by over a week from year to year and the spawning season is relatively short. We had no way of judging the error introduced by the assumption of a constant proportion on the spawning ground, but we felt it might be considerable. Observations by scientists that abundance at St. Helens appears to be relatively constant during the spawning period limits errors introduced from a short survey. It is certainly more common for acoustic surveys to be spread out over several days or weeks. The acoustic estimate also depends on data on the percent of the population that is spawning, an additional element that can contribute variability to the final acoustic index. We discuss the available data on percent spawning in section 3.4.

Taking all of these factors into account, we felt it was more appropriate to use a CV of 0.4 rather than 0.25. Obviously it would be valuable to try to reconstruct the CV from a functional analysis of the components of the estimator but this was not possible in the time span of our review. Given that the model fit of the CV was 0.27, and in our experience such estimates from model fits are biased low (especially with few data points and several free parameters), we chose 0.4 as our best guess of a CV to use.

A higher CV on the acoustic survey helps explain the apparent anomaly that the acoustic survey did not decline appreciably from 1991 to 1993 despite the major removals from the stock. If the CV on the acoustic survey was low, we would have expected to see a decline in the survey. However, with a CV of 0.4 it is not at all unexpected that the acoustic index would not decline due to random variation.

In general we felt that the acoustic survey was a very valuable component of the stock assessment and a major contributor to the understanding of the status of the orange roughy fishery. We would recommend that acoustic surveys be conducted again in the future as soon as funds are available but we also recommend a number of changes in the procedure. These changes include (1) multiple snapshots over several weeks (2) species composition sampling at different depths and (3) a thorough analysis of the components of variance of the acoustic estimator. It should be possible for future acoustic surveys to be conducted from chartered vessels using the towed-body transducer. An adjustment to incorporate the 1990 hull-mounted index into the towed-body time series should be made.

3.7.2 Acoustic surveys, Southern Zone.

An acoustic survey of the southern zone was conducted in 1992 and used as an absolute estimate in the assessment. The southern zone poses considerably more challenges to an acoustic survey including (1) many locations to survey, (2) larger dead zones on steeper hills, (3) more species composition uncertainty with a generally lower percentage of orange roughy, (4) uncertain target strength for many of the other species, (5) uncertainty as to the percentage of fish in the southern areas that were in the survey area and (6) additional assumptions required to use acoustic survey as an absolute estimate.

Given these limitations, there is obviously considerable uncertainty in the southern acoustic estimate, but it does provide one of the few indices of the status of the southern stock. We recommended a CV of 0.5 for this index.

We should note that the southern index is likely a minimum estimate since all the fish may not be on hills (see problem 5 above), although it not believed that there are appreciable quantities of fish on the flats (based on bottom trawl surveys in other areas).

A new acoustic survey on the southern hills was conducted in 1994, but at the time of our review the results had not been analyzed. If future southern surveys are conducted it would be highly desirable to use depth stratification of species composition specific to the major hills, similar to that done in the St. Helens surveys. An analysis could be done to see if mark locations are correlated between the 1992 and 1994 surveys which may provide information on the stability of distributions of roughy over time.

There appear to be regions of non-trawlable ground where marks of roughy are consistently found. These areas would appear to provide a refuge and thus would help prevent severe overexploitation if the fish in these areas do not often frequent the trawlable grounds. It would be useful to follow the number and size of marks at these locations -- it would obviously be of some concern if the only marks were found in non-trawlable areas.

3.7.3 Egg Production Survey, Eastern Zone

The survey provides a reasonably robust method of spawning abundance estimation at St. Helens, particularly in 1992 when a fully developed sampling program was undertaken. The survey method is state-of-the-art and is used for assessments in fisheries in other parts of the world. The estimated coefficient of variation of 43% in 1992 reflects most of the uncertainties about the spawning biomass estimate. A minor upward adjustment to the CV is recommended, which is described below.

There are two features of the production estimate which warrant further investigation. Firstly, the assumption that there is no mortality of one-day-old eggs must surely be a minimum estimate. Secondly, the assumption that there is no advection of first-day eggs out of the sampling area must surely be a minimum estimate of egg loss due to advection. Estimates made for the abundance of first stage and second stage eggs support the above assumptions because there was no decline in the mean estimates for the two stages. Variances were not shown so that we were not able to assess the precision of that zero slope estimate. The paucity of eggs found near the periphery of the sample grid supports the assumption of low loss due to advection. However, the grid samples are few and far between at that distance, which means there is low statistical power to the low-loss finding. In the New Zealand Ritchie Hill survey, estimates of total advection plus mortality in first-day eggs are on the order of $Z=1.0$; however, advection of their sample area is apparently much larger based on findings of plumes of eggs at considerable distance from the spawning site. Biological information about a wide range of stocks throughout the world does not support such a high Z-1 for mortality alone. An adjustment on the order of 5% may be adequate for potential advection and mortality.

The geographical similarity between St. Helens and Ritchie Hill suggest that a meeting between New Zealand and Australian orange roughy scientists. There are considerable differences in methods employed by the two countries, both in their choice of assessment methods and in the form of egg survey employed. At the meeting, scientists could discuss both the egg surveys and the acoustic surveys.

We recommend that uncertainty about the estimation of daily loss rate of eggs be incorporated into the estimated CVs for the spawning biomass estimate. At present, the assumption of zero loss rate is taken as a known for the spawning biomass calculation. The use of prior information on stocks throughout the world and current understanding of the biology of roughy are valid inputs into such an uncertainty estimate. The variances of the first and second stage egg data are additional inputs to reflect a range of possible loss rates. Incorporation of that uncertainty might boost the current CV estimate of 43% to roughly 50%.

Some adjustments are needed to apply the egg production estimates to stock assessments of the combined stock. Estimates of proportion spawning in the southern management zone are discussed under Section 3.4. They indicate that the St. Helens egg production estimate does not incorporate all spawners from the southern management zone. An upward adjustment of about 10% should be applied to the St. Helens spawning biomass estimate in order to represent the combined area spawning if the following three assumptions are made: 1. that the number of mature females in the eastern management zone and southern management zone is equal prior to the spawning time period, 2. that 20% of the spawners in the southern management zone do not spawn at St. Helens, 3. that the proportion spawning in the eastern management zone and southern management zone is equal. The 10% adjustment is highly uncertain and depends on the three assumptions given above.

We recommend that the egg survey be repeated in 1995 or as soon as feasible in lieu of any additional laboratory analysis of the 1991 data. The 1992 sample design should be used in future surveys because of its sound basis. How often egg surveys should be repeated in the future depends on a number of factors including availability of money and man-power, use of the alternative survey method of acoustic sampling, and desired precision of the stock assessment. The principal advantage of the egg survey, in comparison to acoustic surveys, is that the former gives an absolute estimate of the stock abundance. The acoustic survey has the advantage that four years of a time series are already available, which offers a consistent method of tracking the stock. In other fisheries, biannual or triennial surveys are taken (such as for the groundfish surveys of the NW Pacific).

4.0 Review of the quantitative assessment

4.1 The stochastic SRA model and approach

We have no major concerns about the model and risk analysis. The methods used are comparable with the best work being done around the world and this aspect of the stock assessment was particularly thorough and well done. Our preference would be to present median results rather than means or modes, but this is a minor point of interpretation. The one difference with similar assessments being performed in New Zealand is the failure to incorporate the length data, but the sensitivity analysis suggests this would probably have little impact on the assessment.

One change that might be considered in the model or analysis used in the future would be the incorporation of the age data directly into the analysis. This would add considerable computation burden to the model, and some assessment of the potential improvements in the assessment due to age data should be performed to see if the additional work is worthwhile.

A second change that might be considered is the construction of a model more closely aligned with the stock structure hypothesis #1 (two resident stocks with a major shared spawning ground). The current combined model is an approximation to such a model.

4.2 Parameter estimates and data assumptions

Having reviewed all the data sources and model assumptions, we chose a set of parameter values which we felt were the best set of assumptions to use in making management decisions. This involved choosing which data to use, which parameters to assume, and which models of stock structure to consider. The results are presented in section 4.5.

Natural mortality

The 1994 assessment used M=.046. The new data from Dave Smith suggested that M may be more in the range of 0.060 which would imply a long term sustainable yield about 30% higher than previously estimated. On the other hand, if recruitment has exhibited long term cycles then the M=.06 would be too high. The value of M has little impact on the short and medium term forecasts, and given the uncertainty in the selectivity ogive discussed in section 3.2 and 3.3, we chose the value of 0.046 for our revised run. Given the long life history of orange roughy, it is likely there will be several new age composition samples before the impact of M on the management policies would be significant.

Growth in length and weight

We recommended using the same values as the published assessment.

Recruitment and maturity ogives

We recommended using the same values as the published assessment, keeping in mind that the new age data suggest these values should perhaps be altered. This should have little impact on short or medium term management.

Recruitment steepness

The stock recruitment steepness reflects how much recruitment is expected to decline as spawning stock declines. The value of 0.75 was apparently chosen because it is used in New Zealand assessments and specifies that at 0.2 B0, the recruitment would be 75% of virgin recruitment. The use of this value in New Zealand is somewhat arbitrary, although .75 is probably at the lower range of many fish species. However, we recommend that a literature survey be conducted to see if there are any data regarding likely stock recruitment steepness for long lived, low fecundity species.

The steepness does not affect the short or medium term forecasts since the year classes that will enter the fishery for the next 10-20 years were formed before the fishery started. We did recommend that in the future the default assumption for steepness should be a value that yielded a biomass at MSY of 0.3 B0. If the literature search reveals useful information on the potential steepness, we would recommend the literature values be used.

Recruitment variability

We suggested no change in the assumed value, but recommend that the new age data, combined with aging error rates be used to try to provide a new estimate of recruitment variability. The new age data suggest that the assumed value of 1.0 may be too high. This does not affect the current assessment in any measurable way.

Catch data

While there are potentially some problems with the catch data we felt the values used were as good as any that could be obtained.

Abundance data for eastern zone

We recommended the following changes, the details of which are discussed in the earlier sections.

- Do not use CPUE data (see section 3.6)
- Set Acoustic CV=0.4 (see section 3.7.1)
- Set Egg survey CV=.5 (see section 3.73)
- Add 5% to the egg survey to account for possible egg mortality and advection (see section 3.7.3)

- Adjust the acoustic estimate for 1990 upwards by 30% (see section 4.2 introduction).

Abundance indices for Southern zone

We recommended no changes to the values used in the base assessment.

Abundance indices for combined run (Model I)

We recommended using the same adjusted indices for the eastern zone to index the entire stock, except that we added 15% (instead of 5%) to reflect the eggs produced by fish resident in the south and not spawning at St. Helens.

4.3 AFMA's risk criteria

AFMA has published preliminary management strategies whose principal elements are (1) maintaining the spawning biomass of at least 0.3 the virgin biomass, (2) if stock sizes falls below 0.3 B0 catch will be reduced low enough to allow rebuilding to 0.3 B0, and (3) if the stock size falls below 0.2 B0, catch will be zero. This is a sensible strategy and is consistent with strategies adopted by a number of management agencies. It should provide for long term sustainable harvesting consistent with the principles of ecologically sustainable development. We know of some strategies that are less cautions, for instance using 0.2 B0 as the level where management action takes place, while others have advocated more conservative policies.

Nevertheless, the two key levels 0.3 and 0.2 B0 remain somewhat arbitrary and would seem to be cautious given that the biomass to achieve MSY is about 0.2 B0 in the published assessment. We did recommend revising the stock recruitment steepness so that the estimated biomass for MSY is consistent with target B0. Given the biology of orange roughy and the lack of long experience managing it, caution is warranted. The key concerns are its long life, the low fecundity, and the aggregating behavior. However there are compensating factors of its biology that would argue against the need for extreme caution, which include the wide geographic range of the species and the fact that new areas and stocks are still being discovered and the apparent compensation of increasing fecundity as stocks have been fished down.

We feel it would be best to use the median value of the probability distribution when assessing the consequences of any policy moving the stock above or below 0.3B0. This would simply mean that it would be equally likely for the stock to be above or below the target level. We also recommend that managers look at the 5 and 10 year time horizons rather than the current distribution of stock sizes. We find it harder to make a recommendation about how high a probability that the stock would drop below 0.2B0 would be acceptable. High values (>0.5) should certainly be avoided, but we cannot find any basis for making a recommendation regarding a specific acceptable probability. It is more important to avoid policies that have a significant probability of dropping as low as 0.1B0.

Given that the current assessment has the stock in the range of 0.3 B0, we would recommend that simulation trials be performed to determine how the catch and stock size trajectories would behave under different critical values for the decision rules. AFMA's preliminary strategies may prove to suggest large swings in quota as new data are obtained. We further recommend that alternative forms of decision rules be explored that include adjusting the fishing mortality rate in relation to stock size. This type of strategy may provide the desired stability.

If the fishery should be assessed to be below the target level, there is a tradeoff between rate of rebuilding and economic cost to industry. If possible, managers should choose a rate of rebuilding that is not devastating to the fishing industry, and we feel that managers should look to strategies that will return the stock to the target level in 5 to 10 years.

The management strategy at present is based upon model fits of current stock size in relation to B0. An alternative would be decision rules based on empirical estimates, such as acoustic or egg production. Some averaging over years would be required, and this might be achieved by down weighting old data in model fits. The advantage of such an approach is that it does not depend on B0, which has proved to fluctuate considerably in other orange roughy assessments.

4.4 Management (TAC) scenarios

The July 1994 assessment considered scenarios, which were shown on page 61 of the assessment. We considered the same scenarios. The TAC's for each region in each year are reproduced here in Table 2..

Table 2. TAC's for each management zone used in four scenarios.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Eastern Zone				
1995	0	1,000	1,500	2,000
1996	0	1,000	1,500	2,000

2004	0	1,000	1,500	2,000
Southern Zone				
1995	0	1,500	2,000	4,000
1996	0	1,500	2,000	3,000
1997	0	1,500	2,000	2,000
1998	0	1,500	2,000	1,500

2004	0	1,500	2,000	1,500
Combined Zones				
1995	0	3,000	4,000	5,500
1996	0	3,000	4,000	4,500
1997	0	3,000	4,000	3,500
1998	0	3,000	4,000	3,000

2004	0	3,000	4,000	3,000

4.5 Base case results

Using the revised parameter values and selected data sets as described in section 4.2, Tony Smith ran a revised case for us that represents the parameters we believe are most appropriate for the assessment (noting the failure to adjust the 1990 acoustic for percentage spawning). The results for the current stock size are shown in the Table 3 with the values from the July 1994 assessment shown in parenthesis. As discussed in section 3.1 our best assessment is that slightly more weight be given to the combined analysis and slightly less weight to the separate stock analysis.

Table 3. Stock reduction analysis estimates of prefishery biomass, proportion of current biomass over prefishery biomass, and the probability that the current biomass is below 0.2 or 0.3 B0. Results in parenthesis from July 1994 assessment

Zone	Prefishery biomass Mean	Prefishery biomass mode	B1994/B0 Mean	B1994/B0 mode	Probability B1994< 0.2 B0	Probability B1994< 0.3 B0
Eastern	118,000 (102,000)	102,000 (100,000)	0.34 (0.28)	0.32 (0.31)	0.08 (0.12)	0.44 (0.66)
Southern	127,000 (127,000)	107,000 (107,000)	0.35 (0.35)	0.31 (0.31)	0.12 (0.12)	0.45 (0.45)
Combined	202,000 (189,000)	188,000 (189,000)	0.24 (0.21)	0.23 (0.24)	0.43 (0.53)	0.75 (0.92)

Table 4 shows the projections for future stock size under different harvest scenarios. Again the July 1994 assessment values are in parenthesis.

Table 4. Probability that the biomass will be less than 0.2 B0 or 0.3 B0 in 1999, 2004 and 2014. Numbers in parentheses from July 1994 assessment.

Threshold	Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Eastern Zone					
0.2	1999	0.00 (0.00)	0.01 (0.01)	0.03 (0.04)	0.05 (0.07)
0.2	2004	0.00 (0.00)	0.00 (0.00)	0.02 (0.02)	0.06 (0.09)
0.2	2014	0.00 (0.00)	0.00 (0.00)	0.01 (0.02)	0.10 (0.15)
0.3	1999	0.07 (0.10)	0.20 (0.32)	0.29 (0.45)	0.38 (0.58)
0.3	2004	0.00 (0.00)	0.08 (0.11)	0.19 (0.28)	0.33 (0.49)
0.3	2014	0.00 (0.00)	0.02 (0.04)	0.13 (0.18)	0.28 (0.40)
Southern Zone					
0.2	1999	0.01 (0.01)	0.09 (0.09)	0.12 (0.12)	0.19 (0.19)
0.2	2004	0.00 (0.00)	0.04 (0.04)	0.11 (0.11)	0.09 (0.09)
0.2	2014	0.00 (0.00)	0.02 (0.02)	0.09 (0.09)	0.04 (0.04)
0.3	1999	0.16 (0.16)	0.36 (0.36)	0.43 (0.27)	0.51 (0.51)
0.3	2004	0.01 (0.01)	0.23 (0.23)	0.35 (0.27)	0.34 (0.34)
0.3	2014	0.00 (0.00)	0.13 (0.13)	0.27 (0.27)	0.17 (0.17)
Combined zones					
0.2	1999	0.04 (0.02)	0.27 (0.29)	0.37 (0.44)	0.37 (0.43)
0.2	2004	0.00 (0.00)	0.14 (0.13)	0.29 (0.33)	0.20 (0.21)
0.2	2014	0.00 (0.00)	0.08 (0.08)	0.24 (0.28)	0.10 (0.11)
0.3	1999	0.37 (0.43)	0.64 (0.79)	0.71 (0.86)	0.70 (0.86)
0.3	2004	0.04 (0.03)	0.48 (0.58)	0.62 (0.75)	0.54 (0.65)
0.3	2014	0.00 (0.00)	0.26 (0.30)	0.47 (0.54)	0.30 (0.35)

The results of our alternative data set are generally similar to the July 1994 assessment. We conclude that the stock has reached or is nearing the fishing down phase and that yields in all zones must be reduced to the estimated sustainable level. These results are slightly more optimistic than the July 1994 base case.

4.6 Sensitivity analysis

The sensitivity analysis performed in the July 1994 assessment were quite thorough. We see a need for sensitivity analysis in future assessments particularly with respect to the maturity and vulnerability ogives, and the assumptions of stock mixing in the combined stock analysis. The proportion of all eggs found at St. Helens is quite sensitive to assumptions about the relationship between the southern stock and the eastern stock and we suspect that the 10% increase we used may represent a lower bound on total egg production.

4.7 Suggested improvement to the assessment

See section 4.1

5.0 Future Research Priorities

Measuring stock status

The biggest gap in future research and data collection is the total lack of any institutional commitment to ongoing stock evaluation except via logbooks. We strongly recommend that an ongoing program of fishery-independent assessment be planned, including either egg survey or acoustic assessment, and aging. There should be an acoustic or egg survey on the St. Helens hill in 1995, and either bi- or tri-annually after that. It is more difficult to make recommendations regarding the southern stock, the repeatability of the acoustic survey between 1992 and 1994 should be assessed.

A fishery-independent estimate is greatly preferred to use of logbook data for determining abundance trends. Changes in CPUE can be expected due to changes in fishing behavior, changes in fish distribution and behavior and possibly fishermen's reporting of areas and number of tows. It would be a serious mistake to try to infer stock trends from logbook data when fishery-independent surveys can be performed at St. Helens. While tuning and adjusting the historical CPUE data may be possible to retrospectively construct an index that is consistent with the best model fits, we do not believe that logbook data could be used in the future to provide a "real time" measure of stock trends.

The other significant data collection that would be required for ongoing fishery management is age, length and fecundity sampling. This is particularly important to resolve some of the uncertainties about episodic recruitment and whether growth and fecundity will increase as a response to fishing down.

Methodological development

The primary area for future development of techniques is stock structure. The data available at present make it difficult to distinguish the extent to which fish found in the south area spawn at St. Helens. It appears that microprobe otolith studies may provide the best hope of determining such discrimination. There is also the potential for a well designed analysis of heavy metal differences that could prove informative.

Further research is also needed on the question of episodic recruitment as this could have significant impacts on medium term yields. Additional age sampling as recommended above would be a major source of data for this type of research.

The 1994 assessment recommended further analysis of the methods for survey of the southern zone. We agree that this is an important area for research, since the assessment methods for the southern zone are as yet largely unproved. Periodic closing of selected hills to examine fish aggregation dynamics would indeed be a useful experiment.

We consider further acoustic and/or egg surveys at St. Helens an essential ingredient in a management program which should be regularly funded.

Appendix I: Alternative hypotheses

The 1994 assessment and our review of it are all predicated on a paradigm of fish population dynamics and specific data items that includes the following assumptions

- The fish are long lived and the annual recruitment is a very small fraction of the population
- The fish we see on St. Helens and the southern hill constitute almost the entire population
- The proportion of fish that spawn is reflected in the trawl samples
- The mortality, recruitment and growth relationships are stationary in time.

The two key questions the stock assessment must address are how depleted is the stock and what level of long term yield is sustainable. Given the estimated natural mortality rate and age at maturity, one concludes automatically that the long term sustainable yield is very low in relation to the virgin population size. Further, the assumption that the eggs seen in 1992 at St. Helens constitute the entire egg production for the eastern stock (or nearly the entire stock in the combined analysis) automatically forces the assessment of the stock to say that it is depleted. This is supported by the large decline in the acoustic survey from 1990 to 1991, but not supported by the constant acoustic measures in 1991, 1992 and 1993. The CPUE data support the theory that there are fewer fish at St. Helens now than at the beginning of the fishery.

There are alternative models of fish population dynamics that have been observed in other fisheries which make qualitatively different predictions about long term sustainable yield and current levels of depletion. In the section below we briefly discuss the essence of the theory, the predictions the theory makes about the population, and the evidence for or against this theory.

Release from competition

This theory suggests that the orange roughy population is strongly limited by food, and that as the population has been fished down, the amount of food available per animal will increase, and there will be a growth and or fecundity response. It is possible that the age at maturity and total fecundity would rise, so that the sustainable yield would be higher than predicted under the standard hypothesis.

Evidence for this hypothesis is primarily that the fecundity has been observed to increase. There is no direct evidence against it. If this hypothesis is true, we would expect to see substantial changes in fecundity, growth rate and possible age at maturity in future samples from the population. If these changes occur, a revision of some of the underlying assumptions of the stock assessment would be warranted. One way to manage a stock under this hypothesis is to replace the stock biomass targets with egg production targets.

Episodic Recruitment

All the model runs assume that recruitment follows a stochastic stock recruitment relationship that is stable in time. Many stocks show episodic recruitment, where for a series of years (possibly decades) recruitments are higher or lower than average.

The major consequence of episodic recruitment is that the stock may change considerably despite our fisheries regulations. For instance, if a series of poor recruitment years is now entering the fishery, the stock would decline even if no catch is taken. Similarly, if a series of good years were to occur, the stock might increase beyond the expectations of the current models.

Episodic recruitment causes harvest strategies based on target stock levels to provide very unstable yields, periods of high yield followed by periods of low yield. A further danger is that after periods of unusually high recruitments the model estimates of the targets will be unrealistically high. It is similarly possible that if targets are set based on poor recruitments, the targets are low enough to cause recruitment overfishing.

The work that has been done on fisheries with episodic recruitment suggests that constant harvest rate strategies are considerably more robust than strategies based on critical levels of stock size. The large age sample presented during the review provides some evidence for episodic recruitment. There is no pressing need to modify the assessment in light of the possibility of episodic recruitment, but it should be considered in the process of formulating future assessments.

Cryptic biomass theory

The three stock structure models we considered in section 3.1 assume that the St. Helens or southern area acoustic and egg survey data reflect the entire population adjusted by the percent spawning from trawl samples. The most straightforward hypothesis is that most of the spawning biomass on St. Helens spends the non-spawning season in the southern hills, with only a small fraction of the population remaining in the St. Helens area. The possibility exists that some portion of the population is found somewhere else during the non-spawning season, and that some fraction of this "cryptic" population does not spawn at St. Helens or in known southern spawning sites. If the proportion of the "cryptic" population which spawns at St. Helens is smaller than the proportion of southern or St. Helens fish that spawn at St. Helens, then the three hypotheses considered above will underestimate the total stock biomass. In the extreme, the cryptic hypothesis could allow for a very large population either spawning elsewhere, or with a large proportion that does not spawn.

Possible evidence in support of the cryptic biomass hypothesis includes (1) there must be fish in the east that do not go south, otherwise meristic data would not be mixed, thus there is a cryptic population; the question is how big is it? (2) early on in the fishery large marks were reported that have not been seen again, particularly in the west, and (3) the 1994 Chatham Rise survey in New Zealand showed a substantial increase in the survey area after 2 years of no fishing, a rate of increase that is not compatible with the assumptions that previous surveys reflected the stock that was present.

The evidence against the cryptic biomass hypothesis is primarily that large numbers of roughy have not been found anywhere else, and that other spawning areas have not been found.

We feel that there is little evidence that large numbers of other roughy are associated with the fish stocks at St. Helens and the southern hills, and that the possibility of such "cryptic" fish should not be a factor in the setting of quotas unless some substantial new evidence of the existence of such fish is obtained. This does not mean that exploratory fishing for new hills, stocks, and spawning areas should not be encouraged.