
Management Strategies for New or Lightly Exploited Fisheries

Final Technical Report



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Professor John Beddington
MRAG Ltd
47 Princes Gate,
London SW7 2QA

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Dr G. P. Kirkwood

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The research in this project was carried out for MRAG by Ms Catherine Barry, Dr Geoff Kirkwood (project leader), Dr Murdoch McAllister, Dr Chris Mees and Mrs Julie Rossouw. Dr Paul Medley acted as an external consultant to the project and he completed development of the model and developed the computer software used to evaluate management strategies for the Tongan fishery.

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Final Technical Report

1. Executive Summary

A new or lightly exploited fishery represents an invaluable opportunity for a developing country, but they are poorly placed to ensure sustainable development of such fisheries, due to limited resources and the limited availability of data for such fisheries. The purpose of this project was to develop precautionary management methods for such new or lightly exploited fisheries.

The project was conducted in two phases. In the first phase, new Bayesian statistical and decision analysis methods were developed to derive precautionary effort-based management strategies for such fisheries. These have been published in a series of papers in the primary literature.

The second phase consisted of two case studies. The first was of the newly discovered Namibian orange roughy fishery. The Bayesian methods developed in the first phase were applied to data from the fishery, and these were used annually by the advisory group appointed by the Namibian government to recommend annual TACs. A project scientist participated in this group. The new methods were disseminated to Namibian fishery scientists via tutorial workshops and the final assessment paper was written jointly with a Namibian scientist.

The second case study was of the Tongan seamount fishery for snappers and groupers. The project funded continued collection of detailed fishery statistics and these were analysed to show that the fishery remained lightly to moderately exploited. A software package was developed to model the fishery and evaluate alternative management strategies. A policy of effort-based management, allied with closure of individual seamounts where necessary, was shown to provide sustainable and equitable management. The results and management guidelines were disseminated at a series of regional workshops.

2. Background

While the majority of the world's fish stocks are at least fully exploited, there do remain a number of lightly exploited fisheries, many in the waters of developing countries, and new fisheries continue to be found. A new or lightly exploited fishery represents an invaluable opportunity for a developing country, either for enhancing food security or for securing long term employment opportunities or export income. They are, however, characterised by very limited data availability. This implies that any assessment of the status of the stocks is inevitably highly uncertain, and too rapid development can easily lead to overexploitation well before this can be detected in stock assessments. This

latter statement in fact applies to all new or lightly exploited fisheries, regardless of where they are found. For developing countries, the contrast between opportunities and pitfalls is particularly great, since they rarely have the funding or expertise available for rapid accumulation of the necessary data.

For long-established fisheries with extensive sets of historical data, there is a plethora of well-understood and tested stock assessment techniques that can be used to provide scientific advice for man agent. These techniques, however, perform rather poorly when applied to the types of data typically available for new or lightly exploited fisheries. In essence, the problem arises because these techniques fail to take sufficient account of uncertainties. Methods for Bayesian stock assessment and decision analysis have recently been suggested as a theoretically consistent and highly appropriate approach to accounting for such uncertainties (McAllister et al, 1994; McAllister and Ianelli, 1997; Punt and Hilborn, 1997).

Accordingly, this project was planned to have two phases, the first strategic and the second adaptive. The first phase was to consist of a review and theoretical study of the applicability of Bayesian stock assessment and decision analysis methods for new or lightly exploited fisheries. The second, adaptive, phase was to consist of two case studies, in which researchable constraints relating to new or exploratory fisheries in developing countries were identified and addressed.

The first case study fishery chosen was the Namibian orange roughy fishery, which was discovered and for which an exploratory fishery established on it in 1994. Orange roughy is a fish found at depths of 800 -1200 m and it is extremely slow growing and long lived (estimates of maximum age exceed 100 years). As a consequence, they are exceptionally vulnerable to overfishing. Orange roughy were first fished commercially in New Zealand, and an extremely profitable fishery soon developed. Very soon thereafter, signs of severe overfishing became apparent in the New Zealand fishery, and the stocks are only just appearing to recover, following very substantial reductions in catch limits. The potential value of fisheries for this species, found at depths and in areas rarely fished previously, was however well established. This led to widespread searches for fishable concentrations of orange roughy, and the discovery of orange roughy of Namibia was only the latest of such discoveries.

As other orange roughy stocks elsewhere (e.g. Australia) have shown the same extreme vulnerability to overfishing and tendency for rapid overcapitalization, the new Namibian orange roughy fishery presented an ideal opportunity for field-testing the methods developed in the first phase of the project. Accordingly, in late 1996 the Namibian Ministry for Fisheries and Marine Resources (NMFMR) agreed that project scientists should be involved in undertaking collaborative research on Namibian orange roughy and participating in a working group developing recommendations for management of the stocks.

The Tongan demersal fishery for snappers and groupers, a complex multi-species and multi-fleet fishery carried out on seamounts and banks around Tonga, was studied extensively in FMSP project R 5484. As a result, considerable information on the main species captured, their biology and on the fishery itself was already available at the

start of this project. This project also developed guidelines for setting management targets for such complex fisheries. These included:

- ! Management by species and depth band would be too complex for practical implementation;
- ! Management targets would best be set based on the most vulnerable or most valuable species, but determining such management targets requires detailed species specific information, and technically skilled stock assessment specialists to analyse it.
- ! Management should be based on effort controls and closed areas.

The data requirements required to meet these guidelines are still high, and considerable technical knowledge would be required to analyse the data and to apply the management targets. In practice, however, the resources available for data collection and analysis are limited. Thus, the question remains as to whether appropriate management methods and targets can be developed for such complex fisheries where data and resources for data collection are limited, and whether these can be shown to be likely to work in practice. The current project aimed to address these questions..

An important aspect of project R5484 was that it had funded continued collection of species-specific catch and effort data and length frequency samples by officials of the Tongan Ministry of Fisheries. Unlike the fishery data customarily collected by the Ministry, these data were spatially disaggregated, in that they could be assigned to individual seamount and bank fished. Length frequency data collected between 1987 and 1996 had been analysed extensively in project R5484 to obtain estimates of key biological parameters. Catch and effort data for the same period had also been extensively analysed, but these had generally failed to reveal any substantial declines in CPUE on which to base reliable estimates of stock sizes. These analyses indicated that the Tongan seamount fishery could be classified as lightly exploited.

Experience elsewhere has clearly indicated that at least some populations of species similar to those taken in the Tongan fishery can be highly vulnerable to overexploitation. This is particularly true for isolated seamounts, where the exploitable stock found on the seamounts is almost certainly a unit stock. The Tongan fishery exploits a considerable number of seamounts, and there are almost certainly other populations of fish on seamounts in the region that are not directly exploited by the fishery. On the surface, this may suggest that the Tongan stocks may not suffer the same risk of overexploitation, but this depends strongly on the extent, if any of migration between seamounts at different stages of the life history of the fish. If this is small, then the same high risk of overexploitation remains. At present, little if anything is known of the extent of migration.

Two fleets exploit this fishery: an older artisanal fleet, originally funded by UNDP, which can only fish seamounts relatively close to the main ports, and a newer commercial fleet which is able to fish more distant seamounts. Consequently, the seamounts nearer to port are at most risk of potential overexploitation, and that risk is likely to fall disproportionately on the artisanal fleet, which are in any case less profitable and many of the vessels are in urgent need of maintenance.

Before the current series of projects in Tonga, as indicated the Tongan Ministry only collected aggregate catch and effort data in port, so neither the species composition nor the seamounts on which the catch had been taken were known. Discussions with officials reveal that, in the absence of a good reason to do so, the Ministry would be reluctant to continue to spend the additional funds required to collect data disaggregated by species and seamount that had been funded by earlier projects. Should such data collection be halted, then there may be no means of detecting declines of CPUE at individual seamounts that would indicate likely overexploitation.

The key researchable constraint identified therefore for this fishery is the possible level of the risk of overexploitation and the extent to which this can be detected by either spatially and species disaggregated CPUE data or by aggregate CPUE data. The means identified to address this constraint was to develop a detailed spatial model of the dynamics of stocks on different seamounts, allowing for different degrees of migration between seamounts at different life history stages. The model also should attempt to predict the dynamics of fleet sizes of the two fleets. With this model describing the dynamics of the fish and the fishery, management of the fishery was to be simulated, based on the two alternative data collection strategies. The performance achieved in terms of catches and maintenance of stocks at sustainable levels would then be compared and management guidelines identified.

3. Project Purpose

A clear constraint to development of sustainable fisheries for countries that have new or lightly exploited fisheries is the availability of suitable methods for assessing such fisheries and for providing appropriate management advice on precautionary development strategies. To address this constraint, this project had the objective to develop precautionary management methods for new or lightly exploited fisheries by which :

- (1) sensible targets for effort levels and yields can be set when little data are available;
- (2) the best way for the fishery to move towards those targets in the early stages of development can be determined;
- (3) various fishery monitoring procedures can be evaluated so that appropriate but practicable monitoring of the developing fishery can be implemented; and
- (4) various management decision rules can be evaluated so that rules can be implemented which would allow timely reaction to unexpected trends in stock levels.

4. Research Activities

This project was carried out in two phases. The first phase consisted of a theoretical study of assessment methods and management strategies suitable for new and developing fisheries. The second phase involved the conducting of two case studies of new and developing fisheries. The first of these was a case study of the newly discovered Namibian orange roughy fishery. The second involved a study of the Tongan seamount fishery for snappers and groupers, which had previously been studied in FMSP project R 5484.

4.1 *Theoretical study*

The theoretical phase involved the development of new Bayesian assessment methodologies and extensive computer simulation studies aimed at investigating their properties and the properties of management strategies using them. The results of these studies were written up and submitted for publication in major international fisheries journals. At the date of writing this report, two have been published and the other two are in press. A summary of the findings is given in section 5.1 below.

4.2 *Namibian orange roughy case study*

Following the discovery of fishable concentrations of orange roughy (*Hoplostethus atlanticus*) off Namibia and the establishment of an exploratory fishery for that species in 1994, in late 1996 the Namibian Ministry of Fisheries and Marine Resources (NMFMR) agreed to collaborate in this project, with orange roughy being a case study fishery. Under this agreement, project scientists conducted research on development and evaluation of management strategies for NOR and provided advice on the management of orange roughy (NOR).

In January 1997, a project scientist, Dr McAllister, attended a meeting of the Deepwater Fish Working Group on NOR, held in Swakopmund, Namibia. The goal of this meeting was to formulate recommendations for the NMFMR on a fishery management plan for NOR for the next 14 years and to set a total annual allowable catch (TAC) for NOR for the 1997-1998 fishing season. The meeting consisted of NMFMR scientists, government officials, industry members, and invited scientists. At the meeting, Dr McAllister about the choice of modeling input parameters in an assessment carried out by Industry consultants (D. Butterworth and T. Branch).

Immediately following the meeting, an outline of initial research planned on NOR was provided to NMFMR (McAllister and Kirkwood (1997a)). Two months later, a report of results of these studies was provided to NMFMR (McAllister and Kirkwood, 1997b). This report attempted to replicate the results tabled at the January 1997 meeting by Butterworth and Branch and reported the results of additional evaluations of potential management strategies.

Dr McAllister also attended the January 1998 meeting of the Deepwater Fish Working Group on NOR, held at Swakopmund, Namibia. At that meeting carried out the modelling using a modified version of the approach used by the Industry consultants

(D. Butterworth and T. Branch). The fishery management recommendations of the working group were based on these results.

Under separate funding, Dr McAllister attended the January 1999 meeting Deepwater Fish Working Group on NOR in Swakopmund, Namibia. This meeting formulated recommendations for NMFMR to set a total annual allowable catch (TAC) for NOR for the 1999-2000 fishing season. Dr McAllister performed the quantitative stock assessment using a fully Bayesian statistical approach. This approach more thoroughly accounted for the uncertainties in model parameters than the method applied in the previous two years. In doing this, he collaborated with a NMFMR scientist, Dr. C. Kirchner, to produce a working paper for the meeting (McAllister and Kirchner, 1999). As in 1998, the management recommendations of the working group were based on these modelling results.

Other related research activities funded separately from this project but stemming from it are described in section 6.

4.3 Tongan seamount fishery case study

Project funds were allocated to allow the collection by officials of the Tongan Ministry of Fisheries of spatially and species disaggregated catch, effort and length frequency data to be continued for the duration of the project. This meant that, by the end of the project, these data were available for the years 1987-91 and 1993-98. The extended CPUE data set was analysed with a view to determining whether there were signs of substantial depletion of stocks of the main species targeted on individual seamounts.

Project scientists (Dr C. Mees and Mrs J. Rousseau) undertook a visit to Tonga in October 1996 in order to collect data on costs and prices experienced by both the artisanal and commercial fleets and information on fishing patterns of the fleets (Rousseau and Mees, 1996). Following this, an initial specification of the biological and fishery model was completed (Rousseau, 1997) and a preliminary spreadsheet version of the model was programmed.

Following the resignation of Mrs Rousseau, an external contractor, Dr P. Medley, took over the development and programming of the computer model. A detailed specification of the operational model was completed in February 1998 (Medley, 1998). This specification identified the need to collect some further information about the fishery, especially on what criteria the fishermen used to decide which seamount to fish and how long to continue fishing there. A second field visit was therefore undertaken by project staff (Dr C. Mees and Ms C. Barry) in November-December 1998 to finalise estimates of biological, fishery and economic parameters.

Using this information, Dr Medley completed development of a software package that simulated the operations of the fishery and the dynamics of the fish, and which also allowed simulations of assessment and management of the fishery (Medley, 1999). Documentation for this model is reproduced as Annex I to this report. This model was then used to undertake management strategy simulations and to develop management guidelines.

Just before the end of the project, the results were disseminated during a visit to Tonga and Fiji by project staff Dr C. Mees and Ms C. Barry (Mees and Barry, 1999). This involved two workshop presentations in Tonga and an international workshop held at Suva, Fiji, at the offices of the University of the South Pacific (MRAG, 1999). During these workshop presentations, several sessions were devoted to allowing participants to use the software package developed by Dr Medley. These were facilitated by a comprehensive tutorial (Kirkwood, 1999) which is reproduced as Annex J to this report. A set of Microsoft Powerpoint slides used during the dissemination workshops is reproduced in Annex K.

5. Outputs

5.1 Theoretical study

As indicated in section 2 of this report, almost by definition there is very little information available directly for a new or developing fishery on which to base sound scientific advice on appropriate development strategies that would lead to establishment of a sustainable fishery. In order to produce reliable assessments, virtually all fishery assessment techniques used commonly in both the developing and developed world rely on the availability of time series of abundance indices (typically catch per unit effort, CPUE) that show suitable “contrast”. Such time series contain observations of CPUEs corresponding to levels of fishing effort sufficient to have caused substantial changes in stock size. Naturally, these are normally available only for established fisheries. Reliable stock assessments calculated using standard techniques also require suitably accurate estimates of key biological and fishery parameters. Again, these are rarely available for a new or lightly exploited fishery.

This is not to say, however, that there is no information that can be used to assess such fisheries. Prior to their starting or soon thereafter, it is not uncommon that some type of abundance survey will have been carried out. In such cases (e.g. the Namibian orange roughy fishery described in section 5.2 below), there will be some estimates of unexploited stock sizes, albeit uncertain. Even in the absence of dedicated abundance surveys, experience from other similar but established fisheries for the same or similar species elsewhere in the world may suggest, for example, typical stock densities per unit area of seabed in appropriate depth ranges that might be expected for this species. Tentative estimates of unexploited stock sizes might then be calculated using bathymetric charts of the potential fishing grounds. In the same vein, initial estimates of otherwise unknown biological and fishery parameters might be inferred from those estimated for similar fisheries and species elsewhere.

Such estimates are characterised by the fact that they have considerable uncertainty attached to them, and it is essential that this uncertainty be properly accounted for in any assessments using them. Unfortunately, this is very difficult to do for most standard assessment techniques. The one exception is the so-called Bayesian stock assessment technique, which makes explicit statistical use of all prior information, updating and refining it as more information is obtained directly from the fishery. Results obtained using this assessment method are also ideally suited for use in formal

decision analyses, in which the risks associated with different potential fishery development strategies can be properly assessed.

Accordingly, the first phase of this project consisted of a review and theoretical study of the potential use of Bayesian stock assessment methods for new and exploratory fisheries. The results of this have been published in four scientific papers in major international journals. The first three of these report results obtained directly during the project; the fourth paper arose from discussions at an international conference on fishery management under uncertainty at which results of this and a number of other similar projects were presented. The key findings of each of these papers are described below.

The first paper, McAllister and Kirkwood (1998a), reviews the general conceptual basis for applying Bayesian statistical methods in fisheries stock assessment and the management of fisheries under uncertainty. It also provides a detailed example application to illustrate how the methods could be applied for providing quantitative advice to fishery managers under uncertainty. This example assessment makes use of the logistic model (known in the fisheries assessment literature as the Schaefer stock production or biomass dynamic model). This assessment method is the one that would most usually be suitable for application to developing fisheries. Throughout the paper and the example application, many practical tips are given on how properly to apply Bayesian methods that could be particularly useful in developing fisheries where relatively few data exist on the species and fishery of interest. This paper is reproduced as Annex A to this report.

A second paper (McAllister and Kirkwood, 1988b) directly addresses the problems of newly developing fisheries. It begins by reviewing the conceptual basis for applying Bayesian statistical methods and decision analysis for the management of newly developing fisheries and it provides a detailed illustration of the application of Bayesian methods for providing quantitative advice to fishery managers in a hypothetical newly developing fishery.

An important finding is that fishery management policies that attempt to control fishing effort rather than the total amount of fish caught each year could provide up to 40% higher yields for the same level of risk of stock depletion. The paper also evaluates and suggests a number of specific options for applying precautionary decision rules during the development phase of the fishery. Selected appropriately, such decision rules can help to reduce substantially the risk of heavily depleting fish stocks due to uncertainty in estimates of population dynamics parameters. It is, of course, impossible to guarantee that such outcomes will not come about, so the further evaluates and suggests options for applying precautionary decision rules that will help to increase the chance of stock recovery if the stock happens to become heavily depleted from over-fishing. Simulation studies reported in McAllister and Kirkwood (1988b) suggest that effort-based management using Bayesian assessment techniques and incorporating suitable precautionary decision rules can lead to sound sustainable management of a new or developing fishery.

One somewhat surprising result is that it may be more risky to be more precise than less precise in specifying one's prior knowledge about fish stock dynamics, providing

that precautionary decision rules are in place. This finding has important and wide-ranging ramifications, since it is very common in standard assessments to fix values of parameters that are actually not well known. The paper also examined the possible effects of other possible sources of bias in prior distributions assumed for parameters. These were found to be most severe for a negatively biased prior distribution for the catchability coefficient, because this led to positively biased estimates of stock size. This paper is reproduced as Annex B to this report.

In comparison with more standard fishery stock assessment techniques, Bayesian stock assessment methods are computationally rather more intensive. With the widespread availability of quite powerful personal computers, this property does not seriously impede the use of these techniques in developing countries. However, it does impede the carrying out of extensive evaluations of alternative management strategies, since these require the repeated simulated application of Bayesian assessments over a number of years. In such studies, some evaluations can overextend even the most powerful of work stations. This issue was addressed in the third paper (McAllister and Kirkwood, 1999 in press).

This paper discusses the issue of whether or not it is appropriate to simplify the stock assessment component of a fishery management system (FMS) within a simulation evaluation of the FMS. Such a decision involves a trade-off between increased computing time and a potential loss in accuracy of simulation results. The trade-off was evaluated for a Bayesian shortcut which implements a multivariate conjugate prior (MVCP) distribution to approximate the information in historical data. Conjugate priors that have been applied before in fisheries stock assessment allow only one parameter to be treated as uncertain. The MVCP prior that this paper examines allows several parameters to be treated as uncertain, as is typically the case in fisheries stock assessment.

Relative to computations in which there is no simplification of the stock assessment, it was found that the bias added by assuming a MVCP is less than 10% in most cases and that the ranking of policy options according to different criteria for policy evaluation does not change. This encouraging finding holds when some effort is put into identifying bias correction factors for the conjugate prior, because without these correction factors the bias in policy performance indices relative to the non-simplified stock assessment can be substantial (e.g., > 20%). The pay-off in using MVCPs is that computations can be up to 4 times faster when the MVCP is implemented and when evaluation horizons are up to 40 years long. This paper is reproduced as Annex C to this report.

The third paper was presented at the 1998 ICES Symposium on Fishery Management Under Uncertainty, held in Cape Town in November 1998. Also presented at that symposium were a number of other papers addressing this issue, in which a variety of approaches were adopted. A session of the symposium was specifically devoted to discussing the different approaches, and as a result Dr McAllister was asked to coordinate the writing of a review paper (McAllister et al, 1999 in press) discussing the advantages and disadvantages of the various approaches. Although this paper did not stem directly from the current project, many of the ideas therein relating to the Bayesian

approach were based on experience gained during the project, and the results of the review are, of course, highly relevant to the current project.

The paper notes that a wide variety of modelling approaches have been developed over the last few decades to provide quantitative advice to fishery managers about the potential consequences of proposed alternative management actions and to improve the design of fishery management systems. The paper surveys these approaches to identify the main differences among them in their application of decision theory, particularly in the methods used to account for uncertainty, and to identify model structures that need to be considered.

Six inter-linked model structures were identified that need to be considered in fishery management system evaluation: population dynamics, data collection, data analysis and stock assessment, setting harvest controls, the harvest decision process, and imperfect implementation. It was concluded that the most essential are the first four, though the last two require consideration in each individual situation.

The paper then identified some trade-offs that are often made when modelling methods are formulated that can strongly affect model results and the advice given. These include trade-offs between accounting for parameter and model uncertainty, the influence of the choice for weighting alternative operating models on the trade-off between yield and the extent of precaution adopted, and the trade-off between political acceptability of the management options evaluated and the extent of improvements in FMS performance that can be obtained. It was concluded that it is important that practitioners develop their modelling applications carefully to limit the extent of the reducible trade-offs (e.g., only the first two above) and to make their choices transparent to all. This paper is reproduced as Annex D to this report.

5.2 *Namibian orange roughy case study*

Following the discovery of fishable concentrations of orange roughy (*Hoplostethus atlanticus*) off Namibia (NOR) and the establishment of an exploratory fishery for that species in 1994, in late 1996 the Namibian Ministry of Fisheries and Marine Resources (NMFMR) agreed to collaborate in this project. Details of the research activities undertaken are given in section 4.2.

At the January 1997 meeting of the Deepwater Fish Working Group on NOR, Dr McAllister provided advice about the choice of modeling input parameters in an assessment carried out by Industry consultants (D. Butterworth and T. Branch). He also participated actively in discussions leading to recommendations for NMFMR on a fishery management plan for NOR for the next 14 years and to set a total annual allowable catch (TAC) for NOR for the 1997-1998 fishing season.

Subsequent to the meeting, two reports were submitted to NMFMR (McAllister and Kirkwood, 1997a and 1997b). The first report indicated the initial work that would be provided under the project, and outlined the main stock assessment problems and the proposed modelling approaches to deal with these problems. The second report, reproduced as Annex E to this report, indicated that the procedure of Butterworth and Branch that evaluated the risks of alternative catch quota policies for Namibian orange

roughly in the January 1997 meeting had been programmed and run. Their results were replicated with acceptable precision. However, two errors in their application were identified. Fortunately, it was found that in combination, these effects of these errors cancelled each other out.

McAllister and Kirkwood (1977b) also reported additional evaluations carried out that tested the sensitivity of risk estimates to variations in model assumptions. In particular, the coefficient of variation (CV) in the 1996 biomass estimate was increased to more realistic values and uncertainties in recruitment deviates and the rate of natural mortality were incorporated. Results suggested that when such changes were made, the risks of implementing a 15000 t catch quota remained similar to those reported by Butterworth and Branch for a 14 year time horizon. When calculated over a 7 year time horizon, the risks were considerably lower than those for a 14 year time horizon. However, when a much longer time horizon was evaluated, reflecting the very slow dynamics believed to apply to orange roughy stocks, the results suggested that the 6000 t target TAC may result in large risks of over-depletion in the long term. These risks could be substantially reduced if a lower target TAC were to be adopted, however there are good reasons to believe that these results may be rather pessimistic, and much further work is needed before any change in target TAC is contemplated.

At the January 1998 Deepwater Fish Working Group Meeting on NOR, Dr McAllister actively participated in the this meeting and carried out all the computer modelling, using a modified version of the modelling approach provided by the Industry consultants (D. Butterworth and T. Branch). This approach more accurately accounted for the catches taken in previous years and incorporated either an acoustic or a commercial trawl estimate of NOR abundance. Analyses performed included a detailed examination of the risks associated with alternative TAC levels, depending on which abundance estimate was considered most reliable. As a result of these analyses, the working group subsequently recommended a TAC for the 1998/99 season of 12000 t. The report on the status of orange roughy in 1997/98 is reproduced as Annex F to this report.

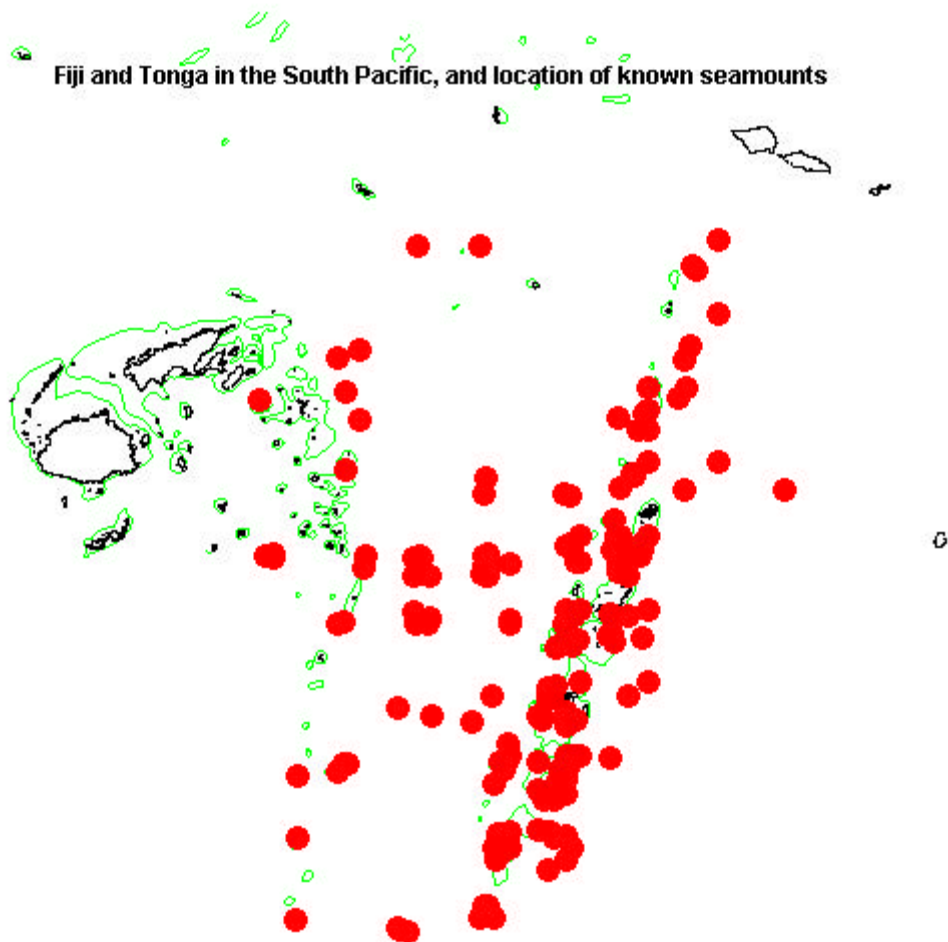
For the January 1999 Deepwater Fish Working Group Meeting on NOR, Dr McAllister collaborated with a NMFMR scientist, Dr. C. Kirchner, to produce a working paper for the meeting (McAllister and Kirchner, 1999). This paper described a fully Bayesian statistical approach to assessing NOR. This approach more thoroughly accounted for the uncertainties in model parameters than the method applied in the previous two years. This methodology was applied at the meeting. In particular, previous assessments had treated the stock as a single stock, but it has been managed assuming four separate aggregations. Evidence available at the meeting suggested that the assumption of a unit stock may not be correct, and separate risk analyses were carried out for each aggregation. Based on these results, the working group recommended that the TAC for the 1999/00 season should be lowered to 9000 t. The McAllister and Kirchner (1999) paper is reproduced as Annex G of this report, and the report on the status of the orange roughy stock for 1998/99 is reproduced as Annex H.

5.3 Tongan seamount fishery case study

5.3.1 Analysis of Tongan seamount CPUE data

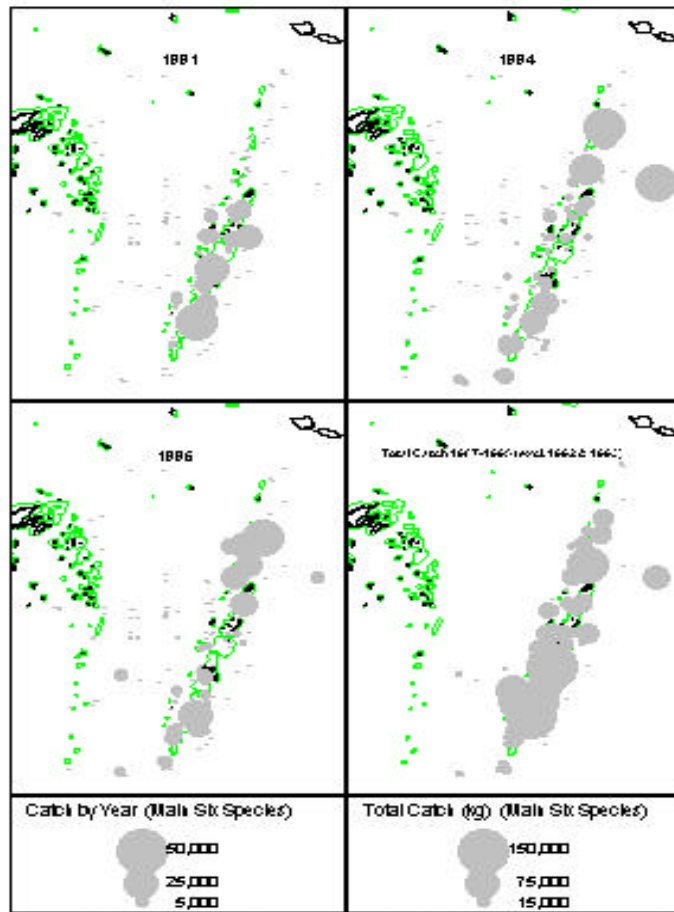
The Tongan seamount fishery is a complex fishery. Fishing occurs from both artisanal and commercial fishing vessels on both the banks surrounding the islands of Tonga, and on more distant seamounts. The location of known seamounts is shown in Fig 1.

Figure 1. Locations of known seamounts around Tonga.



The spatial distribution of catches as the fishery developed is shown in Fig 2.

Figure 2. Spatial distribution of catches of the main six species in 1991, 1994, 1995 and 1996.



The primary demersal species targeted are Lutjanidae (snappers), Lethrinidae (emperors) and Serranidae (groupers). These species are bottom dwelling carnivores, and are long-lived (20 years or more) and slow growing, and other members of these families studied elsewhere have been found to have limited reproductive capacity. Because of these life history characteristics, these species are likely to be vulnerable to overexploitation.

The species captured occupy different depth ranges, leading to differential targeting by the different fishing fleets. The deeper water seamount species are fished by both the artisanal and commercial fleets, but they are particularly targeted by the commercial fleet. The six species of most commercial importance for export are *Pristipomoides filamentosus*, *P. flavipinnis*, *Etelis coruscans*, *E. carbunculus*, *Epinephelus morrhua*, *E. septemfasciatus*. The artisanal fleet also fishes lethrinid species on the shallower banks, but these have not been considered in detail in this project, which has concentrated on the seamount fisheries fished by both fleets.

Available data on catches taken in the fishery on seamounts and banks are illustrated in Fig. 3. Also shown are the proportions of the catches made up of the top 6 species.

Figure 3. Total annual catches recorded in the detailed catch and effort database taken on seamounts and banks. Note that data are only available for two months in 1993 and for 10 months in 1998

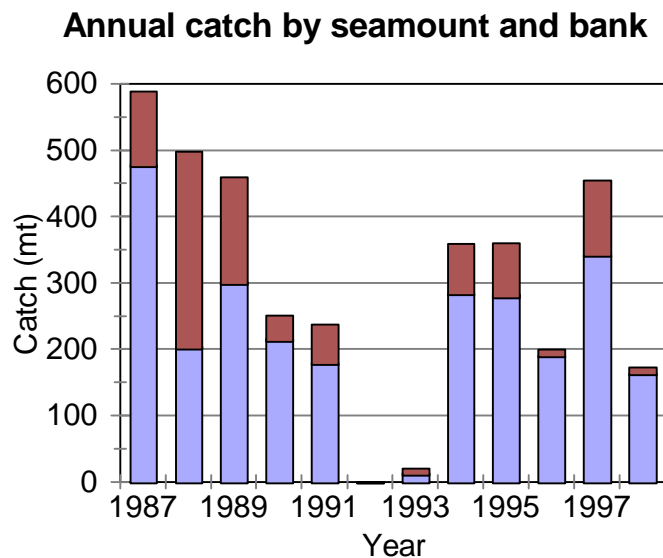
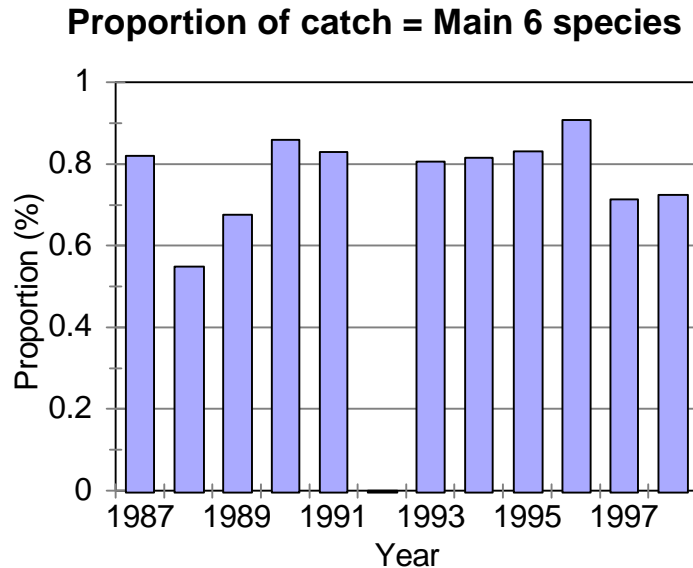


Figure 4. Proportions of the annual catches made up of the main six commercial species.



Over the period 1987-91 and 1993-98, data on catches by species, seamount and depth for individual fishing trips by individual vessels have been collected during the previous and current projects. For all vessels, data are available from 2826 trips to 260 seamounts. These comprise data for 2025 trips to 135 seamounts by artisanal vessels, and 811 trips to 217 seamounts by commercial vessels. Most seamounts were visited relatively infrequently, and thus for many there are few data available to assess their status.

From these data, several sets of CPUE data have been extracted and analysed. Firstly, at the most aggregated level, series of annual total catches (aggregated across seamounts and all species) per trip have been extracted for the artisanal fleet, the commercial fleet and both fleets combined. Secondly, equivalent CPUE series were extracted for trips where the six most commercially important species were taken (otherwise called the top 6 species). Finally, corresponding series separated by seamount were extracted, for those trips on which one or more of the top 6 species were taken. Of these third sets of series, ten sets corresponding to those seamounts to which had been visited the most times over the period were selected for more detailed analysis. In decreasing order of total numbers of trips, those seamounts had codes 1103, 1403, 509, 1401, 1320, 1304, 1309, 1003, 1005, and 1104.

Initially, possible trends over time in these various CPUE series were analysed by simple linear regression, seeking to identify those cases where there was a negative slope in the regression of CPUE against time that was significant at the 5% level.

For all seamounts combined, the catch of all species per trip has actually increased as fishers diversified. For the top 6 species, the aggregated catch per trip has declined since 1987 for both the artisanal and the commercial fleet, but not substantially.

On individual seamounts, there is evidence that some populations of the top 6 species may have declined, sometimes apparently substantially. Plots of these data and regression statistics are shown in Annex K. Where substantial declines have been apparent, they typically are greater for the artisanal CPUE than for the commercial CPUE. This may be due to declining catchability in the aging artisanal fleet, or improved targeting over time by the commercial fleet.

Another feature of the artisanal series on individual seamounts is that, in many cases where substantial and apparently significant declines were detected, these arose from CPUE data that were relatively similar to each other pre-1992 or post-1992, but where the post-1992 level was substantially below the pre-1992 level. This suggests that the apparent declines in CPUE might possibly be an artifact of some feature not adequately captured by the data collected. Reflecting the considerably smaller number of trips recorded for the commercial fleet and the much greater number of seamounts visited, the commercial CPUEs showed considerable interannual variation. Not surprisingly, therefore, few of the regressions against time were significant.

Status of seamount populations

Viewed as a whole, the fishery data analysed indicate that, while there has been an overall increase on CPUE aggregated across all species since 1987, there has been a decline in the biomass of the key species since 1987. However, this decline is generally consistent with light to moderate levels of exploitation. While this conclusion appears valid for the fishery as a whole, there are indications that some individual seamount populations may have been reduced to rather lower biomass levels. As expected, these are typically the seamounts nearer to ports.

The conclusion regarding the status of the fishery as a whole suggests that there is no need for urgent action to curb overall exploitation levels. Nevertheless, there is evidence that individual seamount populations can be and possibly are being affected rather more substantially. There is thus a need at least to continue monitoring the status of those individual seamounts that are closer to the ports and that receive the greatest number of fishing trips.

5.3.2 The Tongan seamount fishery software package

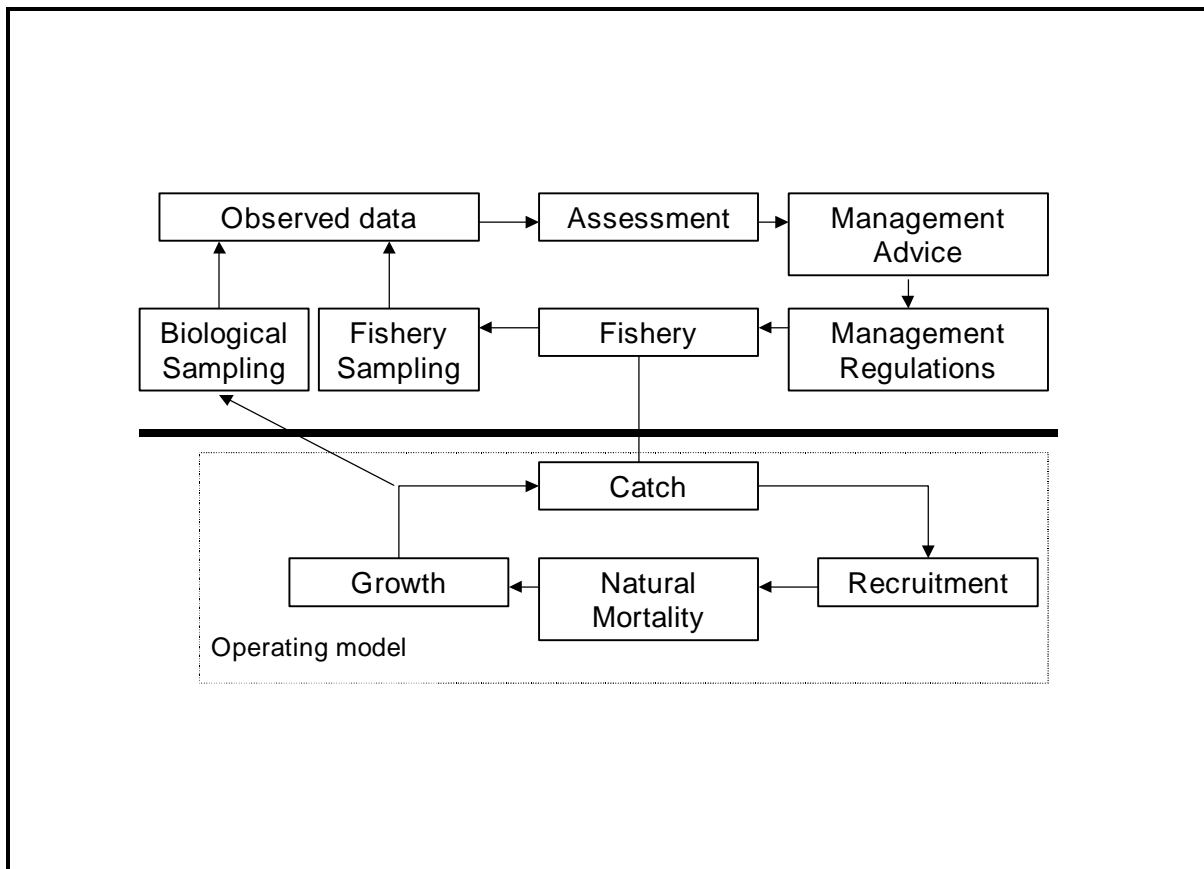
The ultimate purpose of the Tongan seamount fishery software package was to enable the carrying out of simulated management of the Tongan seamount fishery according to different alternative management strategies and to compare the performance of these alternatives. The software was developed under contract by Dr P. Medley. A description of the package and its underlying model structure is given in Annex I. Use of the package is explained in the introductory tutorial given in Annex J. Other output of the package can be seen in Annex K.

The procedure used to investigate the performance of alternative management strategies is known generically as management strategy simulation.

This procedure requires:

- ! A model of the biological dynamics of the fish population(s);
- ! A model of the fishery assessment and management process, which includes components for
 - < Simulated collection of catch, effort and/or biological sample data
 - < Simulated stock assessment using these data
 - < Simulated imposition of management controls, based on assessment results, according to the management strategy to be simulated.
 - < Feedback via the biological model.
- ! Collection of performance statistics for the management strategy simulated

The overall structure is illustrated graphically below.



In essence, management strategy evaluation involves repeated simulation of management of the fishery over a fixed number of years. Each year after the onset of management, catches and catch rate data are simulated, and data from the start of the simulated management to the current year are then used in a simulated stock assessment. The results of this stock assessment are then used to determine the levels of fishing to be applied in the following year, according to the management strategy being simulated. This process continues each year for the designated fixed number of years.

At the heart of the process is an underlying biological population model, which assumes that the dynamics of each seamount fish population follows a standard age-structured model, with a constant natural mortality rate, von Bertalanffy growth and a Beverton and Holt stock-recruitment relationship. However, the overall model used in the Tongan seamount fishery model differs significantly in two respects from more standard multi-population models, in that spatial dynamics (including mixing between populations) and fleet dynamics, both in terms of investment and the spatial distribution of fishing effort are modelled explicitly.

The spatial dynamics of the biological model are controlled by setting the rates of movement of larvae and adults between each seamount population. Fish (both larvae and adults) are assumed to move between seamounts at a constant average rate over time, where for each pair of seamounts, this rate is modified by the distance between the seamounts. High movement rates make all seamount populations behave like a single unit, whereas low movement rates make each behave as an independent population. Intermediate movement rates make nearby seamount populations behave roughly as a single unit, but distant seamount populations as independent units.

At the start of each week, each vessel may choose to remain in port (this occurs 1/3 of the time), search for new unfished seamounts, or fish at one of the known seamounts. The probability that a particular fishing activity is chosen depends on a score assigned to each activity, based on the expected profit from undertaking it. This means that, everything else being equal, vessels will on average tend to fish the seamounts nearer to port, since the steaming costs to reach them will be lower, and the available fishing time there will be greater. An additional “friction” factor can be set to reflect a stronger preference for fishing close to port, which may apply to the older artisanal fleet.

The sizes of the fleets are set according to a linear dynamic fleet investment and disinvestment model. At any time, the current fleet capital consists of the existing vessels and an additional cash account. Money is added to the account as a proportion of the net profit (revenue - operation costs). Fixed costs are removed in proportion to the fleet size, paid in equal installments over the life of a vessel. If the capital account falls to zero, a vessel is sold and its value credited to the account. If the capital account exceeds the value of a new vessel, one is purchased and the account debited by this amount.

The simulated weekly catches by each fleet on each seamount are assumed to be log-normally distributed, with means depending on the catchability coefficient of each fleet and the effort expended on that seamount by each fleet. These and the available historical simulated catch and CPUE data are then available for use in annual stock

assessments for each seamount, or for all seamounts combined using aggregated data. The assessments are carried out by fitting a Schaefer production, the primary output of which is the current estimate of the maximum sustainable yield and the effort level that would take the MSY.

Three types of management controls can be applied to the fishery:

- ! A vessel limit, based upon the effort required to achieve the MSY. This can be modified by a 'precautionary principle' parameter that reduces the vessel limit to some proportion below the MSY effort level.
- ! A catch limit, based on the standard MSY calculation. This can be again modified by a 'precautionary principle' parameter that reduces the catch limit to some proportion below the MSY level.
- ! Seamount closure, which is imposed when the estimated stock size falls below some designated low critical level, and then lifted when the estimated stock size has recovered to above critical levels.

These management controls can be applied singly, or either of catch limit or vessel limit controls can be applied together with seamount closure. Catch limit and seamount closure controls are applied immediately, however reductions in fleet sizes are assumed to occur slowly over time, as it is believed too difficult to remove vessels immediately. The vessel limit is applied by preventing the purchase of new vessels when the total fleet is equal to or exceeds this limit.

The performance of each management strategy is monitored by recording the following statistics throughout the simulation:

- ! The net present value of profits over the period of simulation
- ! The total catches over period of simulation
- ! The distribution of current biomass divided by unexploited biomass, for each seamount and each week of each simulation

Management strategies are then compared using these three performance measures.

The software package has a user interface that allows a user to:

- ! Follow a fleet's progress over time, in terms of fleet numbers, catches, catch rates and net profits
- ! Follow biomass trends over time
- ! Undertake a stock assessment
- ! Simulate multiple annual stock assessments
- ! Compare performance of different types of management

5.3.3 Results of management simulations

The seamount fishery software package was first used to investigate the behaviour of the model and its sensitivity to key parameters. Once this had been determined, the performance of alternative management strategies was investigated, initially in simple cases where there were only a few seamounts. Finally, management strategy simulations were carried out in situations with realistic levels of variability in the simulated CPUE data and in annual recruitment, and where there were approximately 30 seamounts available to be fished, not all of which were known to the fishers at the start of the simulation.

It should be noted that even in this case, the scenarios simulated were far simpler than the real seamount fishery, not the least because the numbers of seamounts considered were far fewer than there really are. However, it is believed that the scenarios considered were sufficiently realistic that the conclusions reached would carry over to the real fishery. In practice, it would not have been computationally possible to attempt to simulate management of a fishery with that many seamounts.

The investigations undertaken with the seamount fishery model showed clearly that, in addition to being a valuable tool for studying the research constraints identified, the software package represented an excellent teaching medium. Therefore, a detailed tutorial was developed for introducing the software to new users and demonstrating issues that arise in managing a spatially disaggregated fishery. This tutorial is reproduced in Annex J, and it was used successfully in the dissemination workshops held at the end of the project in Tonga and Fiji.

It is inappropriate in this final technical report to describe the results of all the investigations in detail. A selection of these was also used in the dissemination workshops, and this set of Microsoft Powerpoint slides is reproduced as Annex K. The main results and conclusions are described briefly below.

Sensitivity to balance amongst financial parameters

Even when only a single fleet is simulated, the model is quite sensitive to the balance between the financial parameters (price, variable costs including costs of travelling and fishing, fixed costs and the reinvestment rate). At one extreme, costs can so dominate prices received that the fishery will effectively never start, or will die out very quickly. If the fishery is profitable when it first begins, but only just, the fishery can be essentially self-managing, since fleet investment ceases well before the stock(s) have been reduced to low levels. At considerably higher levels of initial net profitability, however, fleet sizes can grow dramatically due to high levels of reinvestment. This inevitably leads to severely overexploitation of the stock(s) without drastic management intervention.

In view of this sensitivity, studies of the behaviour of the model have concentrated on those sets of financial parameter combinations where, in the absence of management action, there is the possibility that at least some but not all seamount populations will be fully to over exploited. The best estimates of financial parameters obtained from the actual fleets satisfy these conditions.

In reality there are two main fleets, the older artisanal fleet and the newer commercial fleet. The former is less profitable than the other. Model simulations indicate that, if all vessels of both fleets have potential access to all seamounts, then without management action the more efficient will eventually dominate the less efficient. This effect is seen strongly in simulations where the less efficient artisanal fleet is effectively restricted to the nearer seamounts that get exploited the most heavily. Especially when its reinvestment rate is lower, it finds itself harder and harder to afford to replace ageing vessels, and frequently dies out in the absence of management.

Other than subsidising the artisanal fleet, an obvious solution to this problem is for there to be some restriction of access by the commercial fleet to those seamounts on which the artisanal fleet depends most heavily. Whether or not this is sufficient to retain both fleets in profitability depends on whether the stocks on the restricted seamounts can support the artisanal fleet on their own.

For both fleets, the lower steaming times and costs associated with fishing the seamounts nearer to port meant that, all other things being equal, more profit could be made fishing them than the more distant seamounts. This implies directly that it is the nearer seamounts that will tend to be fished the hardest. In this context, the artisanal fleet is at an added disadvantage, since its steaming speed is lower than that of the commercial fleet. Thus, there are some seamounts that are physically out of its reach that can still be fished by the commercial fleet. This also means that the commercial fleet has alternative fishing sites available when the nearer seamounts are fished down that are not available to the artisanal fleet. This increases the relative disadvantage the artisanal fleet suffers over that mentioned above.

A further implication of the sensitivity of the model to the financial balance between the two fleets is that if there is a change (e.g. a new market opens up with higher prices, or a new investor or donor enters the scene), the status of the fishery can also change, both dramatically and quite quickly. In these circumstances, a fishery that previously managed itself can suddenly change to one that definitely needs management. If the status of the stocks has not been well monitored previously, perhaps because it did not seem necessary, this newly needed management action may be very hard to justify and take and in time.

Effect of biological assumptions

By far the most critical biological assumptions were those regarding the degree of mixing amongst seamount populations. Of those, simulations indicated that it was adult mixing that was much more important than mixing of recruits.

With extensive mixing, and with a number of more distant seamounts being fished lightly at best, the fishery was very robust to quite heavy levels of exploitation, because the populations on the lightly fished seamounts acted as a buffer (essentially a type of marine reserve). However, with no mixing or limited mixing, each seamount population acted like an independent population. This made them much more vulnerable to overexploitation, especially the ones nearer to port.

There currently is little or no evidence available to choose between the two extremes of extensive mixing or very limited mixing, though the balance of what evidence there

is probably favours the latter more than the former. In these circumstances, the precautionary approach gives a very clear message: in the absence of evidence to the contrary, one should assume that there is limited mixing. That is what has therefore been assumed on in the subsequent simulations.

Effectiveness of alternative management controls

The management controls considered in the simulations included setting of total catch limits; total effort limits (on total number of vessels, enforced by banning reinvestment in new or replacement vessels until the effort limit is reached, see Annex I), and either of these in combination with closure of individual seamounts. Setting catch limits on individual seamounts was not considered, as this was felt by all consulted to be impossible to enforce; indeed in practice even individual seamount closure would have to have the support of the fishers and be essentially self-policing.

Consistently in the simulations, even the simple effort controls considered outperformed the catch limit controls. This mirrored the conclusions of the theoretical study. An important factor causing this was the fleet dynamics. Catch controls do not directly or immediately affect the effort levels. Thus, when it is necessary to impose catch limits, that can still leave the fleet capacity out of balance with that needed to most efficiently take the catches allowed. Effort management achieves this balance by striking at the real problem, excessive fishing capacity, rather than excessive catches.

As neither the effort or catch controls tested exerted any control on the distribution of fishing amongst seamounts, unless they were applied in an very draconian manner(essentially leaving the nearest or most profitable seamount at optimum levels but the remainder underexploited), both still allowed overfishing at the nearer seamounts if that were still profitable. This implies that neither management control on its own is sufficient to ensure full sustainability.

This undesirable feature was obviated by the seamount closure option. When applied by itself, however, it suffered somewhat from the same problem associated with catch controls, in that it does not directly affect the effort levels. Also, by initially leaving excess capacity in the fishery, individual seamount closure alone often led frequent opening and closing of near seamounts. This obviously would pose a significant administrative and enforcement burden, and would be likely to be very unpopular. Seamount closure did, however, did have the additional bonus of distributing effort more evenly amongst seamounts.

Given the above, it was clear from the management simulations that the best performing management option was a combination of effort control with seamount closure. The seamount closure element acted to give immediate protection when needed, while the effort control returned the effort to levels compatible with a sustainable fishery.

Interestingly and importantly, in a number of cases this combination of management controls had the added benefit of at least slowing the tendency of the commercial fleet to dominate the artisanal fleet. This occurred despite the fact that the closures applying to both fleets. If it were possible to close nearer seamounts to just the commercial fleet, either by regulation or a voluntary cooperative agreement, this desirable feature would be enhanced.

Naturally, the status of individual seamounts can be assessed, and therefore if individual seamount closure imposed, only if catch and catch rate data are available.

Naturally, the status of individual seamounts can be assessed, and therefore if individual seamount closure imposed, only if catch and catch rate data are available for individual seamounts. It follows, therefore that a key query raised from the outset – whether or not it is necessary to continue to collect data for individual seamounts – has in principle been answered in the affirmative.

Technical Issues

As described earlier and as detailed in Annex I, management controls in the simulations are applied depending on the results of a stock assessment using the historical time series of catches and catch rates available for the whole fishery or an individual seamount. As expected, the reliability of these assessments is highest when there is a long time series of data which exhibit little variability. There are two main sources of variability in catch rates: those stemming from variations in catch rates by different vessels on different days, and those stemming from interannual variability in recruitment to the population. Naturally, the intrinsic variability in catch rates aggregated over all seamounts is less than that for individual seamounts.

The strength of the conclusions regarding management controls is naturally greatest, and they are most evident, when the data have relatively little random variability. As more and more variability is added, the assessments become less reliable and management performance is lower, though the rank order of management controls in terms of their performance (catch limits worst, effort control plus seamount closure best) is almost always retained.

In the simulations, if assessments fail completely, no management action is taken. With very variable data, or with only a few years of data, the assessments can lead to rather silly conclusions regarding management controls (e.g. optimum fleet sizes of zero). In common with many other large scale management strategy simulations, these assessments are taken at face value when setting management controls, but obviously this would not be done in real life.

Indeed, these are the very circumstances for which the Bayesian assessment methodology was developed in the first phase of the project. These methods are, however, very computationally intensive. Even the management strategy simulations carried out for single a stock of orange roughy in four concentrations took many hours each to run on a fast computer. It was completely computationally infeasible to attempt to implement these methods within the complex seamount fishery model with large numbers of seamounts. Despite this, the highly desirable properties of these Bayesian assessment methods, confirmed in the Namibian orange roughy case study, indicate that effort control with seamount closure should perform considerably better when natural variability is high than the simple assessment methods used here. On these grounds, it is confidently believed that the recommended management controls will perform as expected if applied to the real fishery.

Finally, an unexpected additional bonus was afforded by seamount closure. This is that, if it leads to stock recovery, then the ability to estimate the parameters of the

Schaefer model is considerably enhanced, due to greater contrast in the data.

5.3.4 Management guidelines

The analysis of catch rate data from the Tongan seamount fishery described in section 5.3.1 above concluded that the fishery could be considered as lightly to moderately exploited at present. Thus there is apparently no immediate need to apply explicit management action. However, the simulations suggested that relatively minor changes in the financial characteristics of the two fleets can lead this situation to change considerably. In light of this, the following management guidelines were derived and presented to the Tongan Ministry officials and participants of the International Workshop in Fiji.

- ! Continue monitoring catches, catch rates and fleet sizes both for the overall fishery, and at the closer individual seamounts most frequently fished.
- ! Encourage cooperation between the artisanal and commercial fleets so that, where possible, at least some of the closer seamounts can be fished solely or mainly by the artisanal fleet.
- ! In the future, if there is evidence of increased investment in the fishery, leading to increased fleet sizes or fishing power, be prepared if necessary to implement curbs on effort levels.
- ! Unless effort can be practically diverted from the more vulnerable closer seamounts, be prepared to close them to fishing for a period or severely restrict fishing on them if necessary.

6. Contribution of Outputs

6.1 *Theoretical study*

Through their publication in major international fisheries scientific journals, the papers describing Bayesian assessment and decision analysis methodologies developed during the theoretical phase of this project (McAllister and Kirkwood, 1998a, 1988b, 1999; McAllister et al, 1999) have been widely disseminated. Particular care has been taken in writing up the papers to outline in detail the various steps involved in undertaking such assessments, and practical tips were given on their application. The value of using such methods for identifying precautionary management strategies for new and lightly exploited fisheries was particularly emphasised in McAllister and Kirkwood (1998b). Use of these methods should increase the likelihood that sustainable and precautionary management will be applied to such fisheries in developing countries.

6.2 *Namibian orange roughy case study*

The work undertaken in the Namibian orange roughy case study represents a direct application of the methods developed in the theoretical phase of the project to an actual newly discovered fishery in a developing country. Through the case study, NMFMR has been able to follow a precautionary development strategy that is based on the most thorough risk assessments methods available. The writing of a paper summarizing the science and management techniques applied in the developing NOR fishery in collaboration with scientists from NMFMR was initiated in June 1999 (McAllister et al, 1999 in prep).

Throughout this case study, the work has been organised in such a way that the results have been disseminated virtually immediately, via participation by a project scientist, Dr McAllister, in the NMFMR working group that provides management recommendations to the Ministry. It was also clear, however, that for the full benefit to be achieved, additional training of Namibian scientists involved in the assessments should be provided.

Fortunately, separate funding was provided through the Fisheries Information Advisory Services Project, Namibia (DFID Contract No: 5/1998) to enable two workshops on the application of Bayesian stock assessment techniques to be given to Namibian scientists. These were conducted in November 1998 and January 1999 in Swakopmund, Namibia, under the leadership of Dr McAllister. The first workshop was intended as an introductory course in Bayesian estimation and decision analysis methods of fisheries stock assessment for Government fisheries scientists. It was attended by 22 fisheries scientists. The second workshop was attended by fewer scientists, since most fisheries scientists who attended the first were out at sea on research cruises, and the primary intent was changed to provide focused instruction for an individual scientist that the NMFMR had appointed to specialize in these methods, Dr C. Kirchner. Following this, Dr Kirchner was able to participate fully in developing a paper for the 1999 Deepwater Fish Working Group Meeting on NOR.

In June 1999, the Namibian Government has agreed to fund a 1 year research contract to continue the research and educational work carried out by Dr McAllister with regards to NOR and other important marine species.

6.3 *Tongan seamount fishery case study*

The fishery for snappers and groupers on the seamounts and banks around Tonga, and its sustainable management, is of considerable importance to Tonga. Following the original investment via the UNDP funding of vessels used by artisanal fishermen, a small but expanding commercial fishing operation has also built up. This operation is more efficient and profitable than the artisanal fleet, which has been characterised in recent years by poor profitability and a lack of investment in maintenance.

As already noted, seamount fisheries can be quite vulnerable to overfishing. Sustainable and equitable management of this fishery requires implementation of a management strategy that protects the seamount populations from overexploitation and ensures a continued flow of revenue to the country, but which also attempts to ensure the continued viability of both the commercial and artisanal fleet. This has to be

achieved by a Ministry of Fisheries that has limited staff and resources to devote to the collection of the types detailed data typically collected routinely by fishery agencies in larger developed countries.

Analyses of the data and the seamount fishery model have indicated that, while the seamount fishery is currently lightly to moderately exploited, relatively small changes in the investment climate could lead to expansion of the commercial fleet, putting further pressure on the resource and the artisanal fleet. Management strategy simulations carried out during the project suggest that a strategy of effort limitation combined with individual seamount closure when necessary would allow both management goals to be met. This does require the collection of more detailed fishery statistics for at least the nearer seamounts than would normally be collected, but the benefits clearly outweigh the costs.

The primary target institution is the Tongan Ministry of Fisheries, which has the responsibility for management of the fishery. The research has been promoted to the Ministry during several field visits to Tonga, and at a series of dissemination workshops held in the region at the end of the project, attended by officials of the Ministry, the fishing industry and local NGOs. These workshops disseminated the results not only of the Tongan seamount fishery case study, but also those of the theoretical study conducted in the first phase of the project. The last dissemination workshop was an international workshop, held at the University of the South Pacific, and it was attended by fishery managers and scientists from Fiji, Papua New Guinea, Samoa, Solomon Islands, Tonga and Vanuatu, as well as observers from the Foundation for the Peoples of the South Pacific, FAO, and the University of the South Pacific. The software package and its accompanying comprehensive introductory tutorial were distributed to participants at each workshop.

In the future, it is intended that the seamount fishery model and the results of management strategy simulations using it will be written up for publication in international fishery research journals.

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Annex A: Bayesian stock assessment: a review and example application using the logistic model

Annex B: Using Bayesian decision analysis to help achieve a precautionary approach for managing developing fisheries

Annex C: Applying multivariate conjugate priors in fishery-management system evaluation: how much quicker is it and does it bias the ranking of management options

Annex D: Formulating quantitative methods to evaluate fishery management systems: what fishery processes should be modelled and what trade-offs should be made

Annex E: Bayesian Risk Assessment of Alternative Catch Quota Policies for Orange Roughy in Namibia: Some Preliminary Results

**Annex F: Report on the State of Orange Roughy (*Hoplostethus atlanticus*)
1997/98**

Annex G: Bayesian stock assessment of Namibian Orange Roughy (*Hoplostethus atlanticus*) for the 1999 fishing season using the sampling importance/resampling procedure.

**Annex H: Report on the State of Orange Roughy (*Hoplostethus atlanticus*)
1998/99**

Annex I: Tonga seamount model. External and Internal Documentation

Annex J: Tonga seamount model. Introductory tutorial

Annex K: Workshop slide presentations