Participatory Fishery Stock Assessment

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1 Executive Summary

- This project has completed the development of an innovative multi-criterion decision-making methodology to provide management advice for data-poor, artisanal fisheries in developing countries.
- The method applies Bayesian decision analysis. All analyses have explicit risks with the optimum action maximizing the expected utility. The method focuses on rapid inexpensive assessment methods to initiate adaptive management.
- Probability modelling based on parameter frequencies. Complex models can be broken down into simpler components. This will make multispecies assessment more viable.
- Probabilities are modelled using multi-dimensional kernel smoothers. Smoothing is carried over all dimensions. Random draws from the posterior are very fast.
- Fisher interviews form an important component of the method. Interviews are used to:
    - calculate a preference score as a proxy for utility.
    - estimate a prior probability for logistic stock assessment model.
- The method supports fishing experiments as well as standard catch-effort data models. Fishing experiments allow catchability (fishing mortality) to be estimated rapidly.
- A multispecies stock assessment method has been developed which should improve catchability estimates for sets of species.
- The software is object-orientated, making it "future-proof" and easier to extend. The object-orientated structure is applied to the model structure as well as the software. This allows the user to combine model components in different combinations making the models more flexible.
- Field testing in Zanzibar, Tanzania was mainly used to develop and to check the practical methods. Interviews and fishing experiments were used to carry out rapid assessments and prepare the way for management.
- Field testing in the Turks and Caicos Islands was used to test whether interviews can be relied upon to provide sensible management advice. It was shown in the Turks and Caicos case that interviews provided advice which, if applied in 1974, would be expected to have obtained much greater benefits from the fishery than that which was obtained under no catch control.

2 Background

2.1 Developmental Need

Across the developing world coral-reef fishery resources are of central importance in the suite of livelihood assets employed by tens of thousands of fisher communities. However, the coping and adaptive strategies of the majority of communities appear largely unable to stem falling catches or the destruction of reef habitat.

There are a number of reasons for the dilemmas faced by stakeholders in coral reef fisheries management. At one level, the potential for success of those (often external) voices calling for restraint in the level of fishing is constrained by the significant poverty imperative faced by most dependent stakeholders in these fisheries. Human population growth implies that limited resources are being targeted by ever increasing numbers of fishers. This creates a negative feedback cycle of increasing poverty and increasing fishing pressure that further reduces natural productivity of coral reefs. At another level, despite the importance of such fisheries to the wider economic and nutritional health of coastal communities, investment in management by the State is usually minimal. This situation is exacerbated by the fact that the poverty faced by fisher communities perpetuates their social and political exclusion such that they are often without effective means to participate in or influence what limited management decision-making may currently be underway. Finally, the technical assessment of such complex eco-systems is challenging and costly. What technical advice there may be available is often of somewhat dubious quality.

Management research agencies (e.g. Universities; development agencies; FAO & UNDP), State management authorities and NGOs are constantly seeking approaches to address these resource, governance and technical constraints. Issues of resource limits are being addressed through the promotion of alternative livelihoods or the enhancement of resource productivity (or access to new resources) through FADs, artificial reefs, mariculture, improved post-harvest technology and increased resource value through market development etc.

This project focuses on addressing governance and technical issues through the provision of improved information for use by dependent stakeholders. There are two key areas of information that this research will focus on.

1. Access to clear, reliable and cost-effective resource assessments. Existing assessment methods often demand detailed time-series of catch and effort data, data beyond the scope of the majority of State (NGO) agencies in developing countries operating under severe financial constraints. While these data should be used where they are available, their absence should not prevent stock assessments and management advice.

2. Decision-making – Protocols that rigorously capture stakeholder knowledge, objectives and utility (all now recognised as being of central importance in establishing a governance mandate and therefore to the potential success of management) are generally unavailable in fisheries.

2.2 Researchable Constraints

For most small scale fisheries in developing countries there are no stock assessments. Management may still be introduced without scientific advice, but may help maintain poverty rather than reduce it.

Poverty in fisheries will only be reduced when a rational and clear policy is taken towards fisheries management. Clear scientific advice should reduce conflict as long as it takes due account of people's opinions and beliefs. In this sense, science should be seen more as a form of independent arbitration, not as a way of dictating management decisions. Without science, overfishing is an inevitable part of development

Science is necessary to:

- Minimise the number of poor management decisions
- Learn from management mistakes and build on knowledge of the resource over time.
- Arbitrate between conflicting views on how the resource should be managed.

Uncertainty exists in all management decisions and needs to be taken into account. Presenting scientific results as absolute certainties is misleading and undermines scientific evidence. As scientist cannot assess the stakes at risk themselves, they cannot and should not directly advise on which decision to take, only likely consequences.

Where science is conducted, it often does not clearly translate into management advice. There is a need to make such connections clearer. Some types of scientific research are expensive and inappropriate for the value of the fishery.

Science needs to be combined with fishers' beliefs to reach democratic decisions. Without good governance in fisheries conflicts increase and management may fail even if the science is well conducted.

There is an increasing need to allow access to advanced scientific methods to countries which most need it by providing robust software. Although many good assessment techniques exist, they require high statistical expertise to implement. Software encapsulating robust techniques is required to ensure methods are used.

2.3 Scientific Background

2.3.1 Decision Theory

The problem of how to include statistical information into decision-making in some formal way was solved by combining two areas of mathematical research, game theory and Bayesian statistics. The method requires a Bayesian approach to the analysis of data (Gelman *et al.* 1995) and utility. Utility is simply a measure of the relative preference stakeholders have for particular actions/outcomes, and need not necessarily be monetary. Decision analysis has been applied with success to many simple problems, and discussed a great deal in the fisheries literature (Punt and Hilborn, 1997), but mainly concentrating on the Bayesian approach to modelling rather than practical implementation of the methodology. For a potentially useful application of the technique three areas need to be researched:

- Capturing stakeholder knowledge. This includes subjective stock information from fishermen and other experts, including a measure of uncertainty.
- Adding information from fisheries data. Modelling diverse fish communities, common in developing country fisheries to allow inclusion of all relevant information as well as information that can be obtained rapidly through good scientific techniques.
- What the community wants. Obtaining measures of utility from the fishing community based on relative preferences for different potential management actions.

2.3.2 Capturing Stakeholder Knowledge

It has long been recognised that fishers possess information about the stocks they fish which would be useful for scientists (e.g. Ruddle *et al*., 1992; Pomeroy and Williams, 1994; MRAG, 1999; Townsley 1998). Such information could improve assessments and indicate how far fishers need to be persuaded if their beliefs contradict fisheries data. In either case, quantitative information on the state and behaviour of stocks is useful. Press (1989; pp. 103-124) describes a general approach, which used interviews to estimate a subjective prior distribution for an unobservable variable. While no direct observations are available on relevant fisheries variables, it is possible to use this method to summarise the fisher's knowledge of the stock status, based particularly on past experience and how they believe the stock would respond to changes in fishing activity.

There are two major problems with the blind application of the Press (1989) method. Firstly, Press restricted his work to well-educated experts, whereas fishers often have poor education. The questions need to be both clear and simple to reflect this, and probably a certain amount of leeway given in obtaining answers without rigorous control. Secondly, the values on which opinions are sought can not usually be obtained directly (e.g. f_{MSY}, MSY), but through the interpretation of a model. The model will not be known by the fishers so there are implications to their answers which they would not understand. For this reason, direct feedback to the fishers is necessary to confirm the results.

2.4 Multi-species Modelling

Broadly speaking there have been two alternatives to modelling multi-species fisheries (see review, Medley *et al.* 1993):

- Fit individual population models to each species with implicit fixed (through natural mortality) or explicit variable species interactions (such as multi-species VPA; Sparre 1991). A significant problem with this approach is the large number of parameters these models require when fitting to real data, as well as various assumptions about the degree and type of interactions between species. Although this is not a theoretical problem if sufficient data is available, in practice such approaches are limited to a few fisheries and commercially important species.

- Group species together as biomass, either in such forms as a biomass dynamics model or the Ecopath model. These approaches have become popular because the demands for data are more limited than the single-species approach. Although useful as general indicators of status, they require stronger assumptions regards the population dynamics and are rarely if ever tested.

An alternative is to use species abundance models, which have been the most widely used approach in ecological research. It has been demonstrated empirically that most, it not all, communities follow consistent patterns (Magurran 1988). Species abundance models form the basis for the study and interpretation of species diversity and are often used to measure human impacts on species communities. Previous methods to fit species abundance models have assumed the collection method of animals is not selective (e.g. Bulmer 1974). This is inadequate for many applications, including the analysis of species composition data in fisheries. In many cases, and particularly fisheries, it is the different species selectivities (i.e. catchabilities) that are most of interest.

Dynamic depletion models are an important class of models used in modelling fish populations. Depletion models require an estimate of the number of individuals removed from the population, and an index proportional to the population size, both recorded over time. These models can be used to estimate current and past population sizes as well as catchability for single stocks (Hilborn & Walters 1992). A multi-species extension of depletion models allows multiple catchabilities to be estimated which would at least partially explain species composition. However, a problem immediately arises in that, even if sufficient data is available, it is impossible to fit models where there is insufficient contrast (i.e. depletion) in the abundance index. This will be true for all species that are rarely caught, which may either be rare in the community or have a low catchability.

Estimates can be greatly improved if it is assumed a species' population size is conditional on the population sizes of other species. Conditioning allows us to make good estimates of catchability and initial population size for species having a good contrast, and to improve estimates in other species where depletion is not so clear. This is reasonable if there is some foundation for the observed abundance patterns. Most of these models are justified on the division of niche space (May 1975, Sugihara 1980), but agreement is not universal, particularly on the application of the log-normal (Ugland & Gray 1982). Nevertheless, whether the observed abundances are a direct result of ecological processes or a statistical artefact, the empirical patterns can still be used to develop conditional models.

A method is provided for multi-species modelling of short-term perturbations in fish communities based on this approach. Short-term perturbations can be obtained from fishing experiments (e.g. Gaudian *et al*. 1992), and therefore the method does not rely on (usually unavailable) long-term historical data sets. Although this method was developed using a maximum likelihood approach, it can equally well form part of the basis for a Bayesian approach. As well as improved estimates, a multi-species approach allows full recognition of the impact of fishing on the biodiversity of the ecosystem. Most fisheries analysis concentrates on the common species, and rare species are almost never considered. The impact of fishing on rare species is an important consideration for biodiversity management.

2.4.1 Utility and Multi-criterion Decision-making

Within the Bayesian decision-making framework we need some measure of preference between different potential outcomes, which is usually referred to as utility (Berger 1985). While utility can have a clear meaning as a theoretical quantity, measuring it for an individual or a community is in practice more difficult. Decision-making in real-life situations falls within the subject of multi-criterion decision-making. There are a number of multi-criterion decision-making methods which have been the subject of research, including *The Delphi method*, *Goal programming*, *Multi-attribute Utility Theory* and the *Analytical Hierarchical Process* (*AHP*). AHP is one of a general set of methods using hierarchical structures and additive weights to analyse and support complex decision-making. It is broadly based on two useful techniques (Saaty 1995):

- Pair-wise comparisons between outcomes to score and identify preferences. Pair-wise comparisons have the advantage that they are relatively easy for people to do and contain an internal consistency check to ensure answers given make sense.
- A hierarchical approach to structuring problems as a score function. This allows the preference to be simplified and quite different criteria to be combined in defining preferences. For example, a set of fishing grounds could be rated in terms of distance from port, catch rate and weather conditions in quite complex ways, yet a single score derived for each ground. This technique is particularly useful if preferences include issues not covered by the stock assessment, as will usually be the case.

Multi-criterion decision-making methods have successfully been applied in both the private and public sector to structure and apply analytical thinking to decisions. However, these methods usually target well-educated upper and middle management personnel and are not immediately applicable to fishing communities in developing countries. There will be a need therefore for some adaptation of the chosen methodology.

3 Project Purpose

This project has completed the development of an innovative multi-criterion decision-making methodology to provide management advice for data-poor, artisanal fisheries in developing countries.

The primary technical aim of the project is to develop a practical method of fishery assessment which combines scientific information with traditional knowledge (what the community believes) and what the community wants from its resource. The purpose of the method is to address poverty by allowing fishing communities to make better use of their natural resources.

- The method represents an improved strategy for the management of capture fisheries important to poor people. The focus of the project is to develop a method to improve management of small scale fisheries, which harbour the poorest fishers in developing countries.
- The new method will be disseminated to international and national organisations. The method is generally applicable and will be encapsulated in software and manual for distribution to interested organisations and individuals.
- The new strategy will be promoted for the benefit of poor people. The strategy (to involve the fishers and their community in the stock assessment and fisheries management process) will benefit the poorest, who otherwise are often not included in the management process.

The potential production from the resource base tends to be neglected in small scale fishery assessments. Often there is inadequate quantitative information or scientific information is difficult to understand and does not easily combine with other non-scientific information relevant to the decision. Poor information on the state of the resource will lead either to severe under-fishing (risk averse) or overfishing (risk prone), both contributing to poverty.

In a rapid assessment, there is no chance to obtain a time series of information. As fish stocks are dynamic, the lack of time series data makes assessment difficult. The only time series information is held by fishers who are able to remember past events. Although memories can be vague, they may provide useful information on potential yield as they refer to past periods, hopefully when exploitation was relatively light. Most importantly, they may be the only information on this period.

The perception of many fishers is that controls are imposed upon them, at best, based on evidence which may be counter to their own experience and collected in ways they do not understand. Governance of fisheries should improve if due account is taken of fisher's beliefs and their needs. The final decision should reflect their wishes. In addition, it follows the good governance principle that the fishing community is allowed to take responsibility for its own decisions.

An important use of the technique is the explicit use of fisher's opinions on the state and productivity of the resource. This gives a clear demonstrable respect for their opinions, which should make decisions more acceptable.

Conflicts often result from misunderstanding different points of view. Fisheries are no different in this. There is often a misunderstanding between fishers and scientists, for example, and fishers may not be fully aware of the diversity of opinion among their own community. By seeing how their beliefs may conflict with each other and with scientific knowledge, some resolution may become apparent. By bringing out into the open differences in opinion on foundation beliefs, it should become easier to see what the key issues are in resolving conflicts.

3.1 Why use this method?

The approach has four distinct advantages over other stock assessment approaches.

- You can involve the fishing community by using interview information. Even if these beliefs are unreliable, there is considerable political advantage in involving fishers in the assessment and they can see that their views are being taken into account. It is arguably necessary if co-management is being applied.
- You can combine data from many sources, and in particular, you are able to use rapidly collected data and so may be used as a start point for an adaptive management system.
- The method applies decision analysis making use of utility (a measure of the desirability of an outcome) and risk to help in deciding management actions. This means the method can be used even when only a little information is available.
- Combining sources also allows you to build up information for quite complex models. Breaking down complex models into simpler building blocks makes multispecies assessments easier.

4 Participatory Fish Stock Assessment Method

4.1 Method Summary

The method allows you to organise complex information sources into a hierarchy that provides information on a fishery model used to assess fishery controls. This allows information from many sources to be combined, and in particular involve fishers and the fisher community in the stock assessment process.

The fishery simulation model is reduced to a set of parameters for which information is needed. Parameters govern the growth, mortality and impact of fishing on the fish stock, and the benefit of fishing to the fishers in terms of catch.

Information on the fish stock is reduced to parameter frequencies. As long as information can be reduced to a parameter frequency it can be use in the model. This allows disparate data sources to be combined into a single assessment.

The frequencies must be independent. Non-independent parameter estimates must occur within the same frequency, so that their dependence can be represented by the way they occur together.

Frequencies are treated as though they have been drawn from an underlying probability distribution. The underlying distribution is re-estimated from the frequency using kernel smoothers.

Parameter frequencies may be generated any number of ways, including direct draws from a probability distribution (e.g. MCMC), interviews and empirical bootstrapping. The last two are supported in the software.

Using frequencies has several advantages and disadvantages:

1. A complex set of parameters can be broken down into simpler subsets which can be assessed separately.
2. Each source can be checked independently. Gross errors can be minimised as each set can be checked separately to ensure estimates are reasonable. For example, catch and effort models might be fitted in the normal way, and the observed – expected plots inspected to ensure the fit is reasonable. All other standard checks can be applied to ensure results are valid.
3. The method can be made robust. Non-parametric techniques can be used to obtain frequencies.
4. Given a set of parameter frequencies, computation of the posterior is straightforward, fast and exact.
5. The individual PDF derived from the frequencies may be inaccurate. Given each smoothed frequency represents the source PDF exactly, the corresponding posterior distribution is also known exactly. However, inaccuracies between the kernel model and the underlying PDF will be represented in the posterior. These inaccuracies will have two sources:
    - The frequency itself contains errors both in precision and bias. Precision errors occur due to small sample size. Monte Carlo

simulations can in principle be used to make very large numbers of draws from underlying distributions, but in practice there is a limit. However, the accuracy required is lower than might first appear because numerical integration over the probability, along as it is not too flat, will be accurate for estimations required. Biases are more of a problem, but no different to any other modelling. There is a limit to the value of minimising these statistical errors in parameter estimates where model structure error and utility estimate errors become limiting factors on accuracy.

- Smoothing errors. The smoothing parameters allow the kernel to cover regions between the frequencies. By definition, they will also naturally provide the relative weight between information sources. In general, independent estimation of smoothing factors is better than subjective estimates. However, it is possible that parameter weighting will be incorrect, and adjustment is provided in the software.

The method offers a practical decision analysis application for use in fisheries management. This deals explicitly with uncertainty through probabilities and the use of target and limit reference points

The aim of decision analysis is to make the best use of all information however uncertain. The methodology consists of separate components which are represented by parameter frequencies. Current components which are supported consist of:

- An interview to get subjective belief from fishers or other persons with relevant knowledge.
- The use of fishing experiments and non-destructive survey methods (such as visual census).
- The use of any usual stock assessment models and data.

Results can, and should, be updated as new information becomes available. The methodology allows learning from experience by adding new information as it becomes available.

Limitations of the approach are same as any of those usually applied to mathematical modelling and stock assessment. The approach has not developed any new components except for a new multispecies model, but has developed a new way to combine these components into a single assessment. The method does not replace the standard set of stock assessment methods. Instead it combines current methods so that instead of having several scientific assessments, a single integrated assessment is produced. Also, sources of information which cannot usually be incorporated formally into an assessment can be used by this method. Nevertheless, any problems with models or data will be reflected in poorer advice, as in any stock assessment.

The method indicating the optimum decision is not the same as a prediction for the outcome. The prediction is represented by the probability distribution, which may be very uncertain. The method chooses the “optimum” action based on this uncertainty, so if the decision-makers are risk-averse, actions are taken that will tend to avoid the worst outcomes rather than just assume the expected outcome. But the only way to improve on the action is through obtaining more and better information, by carrying out further stock assessment studies, for example. The usual tests on the model can still be carried out to improve it. This is why the focus on the reference points is the applied control rather than the state of the fishery.

4.2 Simulation Models

Simulation models are used to focus the assessment on management advice. The chosen model needs to adequately describe the dynamics of the system and be able give indications of what might happen under any particular management regime. These predictions can be used to provide management advice.

For management to be useful, it must be able to control the fishery in some way. The chosen control will limit fishing activity either through catches or effort. Other controls, such as selectivity, are not currently available. The results from simulations are summarised to produce recommended levels of control, such as fishing effort, which should be more easily observed or estimated in the fishery than fishing mortality, for example.

Simulations are used to identify target and limit reference points. The target reference point identifies a control with the highest expected preference among fishers. The limit reference point identifies the control with the highest acceptable risk of overfishing.

Two simulation models are available. The simplest, the logistic model does not discriminate between fish sex, size or even species, but lumps the fished biomass into a single variable. It relies on basic knowledge of population dynamics – exponential increase when mortality is low and some maximum environmental carry capacity for the population.

For multispecies assessment, a dynamic multispecies multi-gear yield-per-recruit is used. Multispecies multi-gear yield-per-recruit accounts for the direct effect of fishing on the stocks. This is probably the simplest type of multispecies assessment. More complex approaches might try to account for competition and predation, which, apart from increasing uncertainty in the assessment results, require considerably greater knowledge of the ecology of not only the fished species, but all species in the ecosystem.

A fishery will be made up of a number of parts, such as species, fishing grounds, gears and fishing communities. Each fishery should, ideally, have a model developed specifically for it. However, it is pointless trying to use more realistic models unless significant amounts of information are available. Simpler models which encapsulate basic biological behaviour will probably be more accurate in data poor situations.

4.2.1 Logistic Model

Although a number of models exist for stock assessment, the biomass dynamics models possess an advantage in their simple demands for data (catch and effort) and in their basic assumptions. In multi-species fisheries, such as coral reefs, the model may be used to provide advice on the general productivity of the system and avoid trying to model hundreds of species. Models of the population dynamics of individual species could wait until better information comes available.

The simplest and most commonly used biomass dynamics model, the Schaefer model, provides advice on a limit reference point, the maximum sustainable yield (MSY). This limit reference point can be used to restrict the risk of unsustainable fishing to an acceptable level.

In the difference equation form, the multi-gear logistic fisheries model is written as an equation describing how the population changes through discrete time (usually annual), as:

$$
\begin{aligned}
B_{t+1} &= B_t + rB_t\left(1-\frac{B_t}{B_\infty}\right) - C_t \\
C_{gt} &= \frac{F_g}{\sum_g F_g}\left(1-e^{-\sum_g F_g}\right)B_t \qquad (1) \\
F_g &= q_g f_{gt}
\end{aligned}
$$

where B_t is the stock biomass at time t, and C_t is all catches combined in the fishery, F_g = fishing mortality, q_g = catchability and f_g = effort for gear g. The model requires three population parameters: B_{now} = state at the start of the projection ($B_0 = B_{now} * B_\infty$), r = the rate of population growth, B_∞ = unexploited stock size, and as many catchability parameters as there are gear types. Apart from being slightly more accurate when fishing mortality is high, the catch equation avoids negative estimates for catches when fitting the model, so it is preferred to a linear catch model.

The state of the stock is defined as the biomass (B_t) divided by the unexploited biomass (B_∞). If the stock state falls below that required for the maximum sustainable yield (0.5), the stock is overfished.

4.2.2 Yield per recruit

Yield-per-recruit models focus on balancing the benefits from growth against losses from natural mortality. Growth is modelled as the weight form of the von Bertalanffy growth equation, which calculates mean weight as a function of age.

$$W_a = W_\infty\left(1-e^{-K(a+a_0)}\right)^b \qquad (2)$$

where W_a = the weight at a years after recruitment, W_∞ = the asymptotic weight (W_{inf}), b = exponent converting length to weight (W_{exp}, usually close to 3.0), K = instantaneous growth rate, and a_0 = age at recruitment to the fishery such that the average weight at recruitment is defined by the model. This means that a_0 implicitly includes the growth model parameter t_0.

The yield-per-recruit combines the weight function with the negative exponential population model. Assuming knife-edge selection (i.e. all animals recruit to the fishery at the same age for all gears (g) and thereafter catchability is constant), the per-recruit stock biomass at equilibrium can be calculated as:

$$B = \sum_{a=0}^{A} e^{-\left(\sum_g F + M\right)a} W_\infty\left(1-e^{-K(a+a_0)}\right)^b + \frac{W_\infty e^{-\left(\sum_g F+M\right)A}}{1-e^{-\left(\sum_g F+M\right)}} \qquad (3)$$

The biomass is summed over discrete ages for simplicity to an age A where further growth is negligible and all fish can be combined into single "plus" group undifferentiated by size. Similarity with continuous recruitment can be improved by making the time units smaller. Fishing mortality is assumed linearly related to effort as for the logistic model (equation (1)). The unexploited biomass is found by setting $F_g=0$ for all gears.

The yield is simply the catch equation summed over the age classes:

$$YPR_g = \frac{F_g}{F_g + M}\left(1 - e^{-\left(\sum_g F + M\right)}\right)B \qquad (4)$$

Fishing mortality is assumed constant over age and size (knife edge selection). At equilibrium the total YPR remains constant and can be summed to infinity using the discount rate (as a series sum) over time.

This equation can also be adapted to a non-equilibrium system, where the fishing mortality regime has changed and the population is moving to a new equilibrium under the new regime. In this case, the initial population structure depends on the old equilibrium state (numbers in equation (3)):

$$\begin{aligned} N_a &= e^{-\left(\sum_g F_{old} + M\right)a} \\ N_{a+t} &= N_a\, e^{-\left(\sum_g F_{new} + M\right)t} \end{aligned} \qquad (5)$$

These equations can be substituted into the biomass and YPR population equations to get the incremental change in biomass and catch until the new equilibrium state is obtained. This approach includes an assessment of short term losses versus longer term gains often resulting from a decrease in fishing effort.

Unlike the logistic model, there is no pre-defined overfished state for yield-per-recruit biomass.

In multispecies terms, YPR is carried out separately for each species. Clearly catchability, natural mortality and growth parameters are required for each species. Each species stock state is treated the same, so there is no discrimination between abundant and rare species. However, for the preference scoring, species can be weighted which takes account of their importance in the catches.

4.2.3 Controls

4.2.3.1 Effort

The effort control is applied through the catch equation used in both the simulation models. A new effort is set as the new control and the stock is projected forward from its current state under the new fishing mortality. More complex changes to effort are not supported.

4.2.3.2 Catch Quota

The catch quota control is applied as a future limit to catches. A new effort must also be supplied as the maximum effort. This is used to calculate catches. If catches exceed the quota, this maximum effort is scaled back to a level where the catches are met. This allows effort to change, but catches remain fixed if the effort is high enough to reach it and if the stock is not overfished. Setting the quota above the MSY means it will have no effect and the maximum effort control will apply.

4.2.3.3 Refuge

Management can provide a refuge from fishing by setting up closed areas or no take zones. In these areas, no fishing is allowed. Such zones may provide many benefits beyond that dealt with in this assessment model, and each of these benefits may be sufficient to justify a closed area. In particular, a no-take zone, if large enough, may maintain an unexploited habitat and ecosystem with which the fished area may be compared. This may not only preserve adult and juvenile fish. Where fishing causes habitat damage, or pollution and temperature effects may also be having impacts, such information is invaluable in helping management make decisions.

The refuge control (probably a closed area) indicates what proportion of the stock is protected from fishing. The control only applies to the logistic model. It is assumed that there is no adult migration between the protected and unprotected stock. Migration would reduce the effective refuge size. The two separate stocks are modelled independently. If there has been no previous refuge, both stocks will be at the same level. Once the control is applied the protected stock will rise to the unexploited level. The exploited stock will be subject to the new mortality based on a new effort level defined for this control.

The stock is initially split in proportion according to the control. The control splits the unexploited stock size and the recruitment between the refuge and exploited areas according to the control proportion.

$$
\begin{aligned}
R_{t+1} &= R_t + \alpha\, r\left(R_t + B_t\right)\left(1 - \frac{R_t}{\alpha B_\infty}\right) \\
B_{t+1} &= B_t + (1-\alpha) r\left(R_t + B_t\right)\left(1 - \frac{B_t}{(1-\alpha) B_\infty}\right) - C_t \\
C_{gt} &= \frac{F_g}{\sum_g F_g}\left(1 - e^{-\sum_g F_g}\right) B_t
\end{aligned}
\qquad (6)
$$

where R_t = refuge population, B_t = exploited population and α = proportion of the stock protected. Catch is only removed from the exploited population. This will result in an immediate decrease in catches after the control is introduced and effectively a decrease in catchability. There is a longer term gain in stock size as productivity is boosted by the refuge stock. As the model suggests, refuges are a good way to protect the stock and achieve the limit reference point. It is unlikely, however, that a target reference point above zero will be identified unless overfishing is already occurring. In general, an effort control will be better at achieving a target as it deals directly with fishing costs whereas other controls do not.

Alternative models describing the effect of a closed area could be proposed. However, unless they limit the catch they will have no effect, so this loss cannot be avoided. Closed areas may also reduce effort and therefore costs, but this represents an indirect effort control, which will not be optimised. Such a control may well not be universally popular or achieve fishers' objectives.

4.2.4 Target Reference Point

Indicators must be converted to measures of preference, so that risks can be properly assessed. For example, fishers may wish more to avoid low catches rather than make large catches, and hence be risk averse. This requires that indicators be converted to some measure of utility (an economic measure of satisfaction).

The simulation model calculates the overall catch and effort for the fishery projection. These can be converted to the relative change in CPUE and effort from the current CPUE and effort. These relative changes are assumed to apply equally to all fishers, so that if CPUE is 85% and effort 80% of the initial CPUE and effort, then the fishers CPUE is also 85% and 80% of his/her current CPUE and effort. The main assumption is that any effort or other control is applied proportionally to all fishers.

The optimum Bayesian decision is to choose the action that maximizes the expected preference. Using the preference data and model (see Section 4.5), the discounted preference score can be summed for each simulation leading to a relative measure of how much preferred that outcome would be. The expected preference score is the average of the simulations where the simulation parameters are drawn at random from their posterior probability distribution.

The maximum is found by interpolating between the control increments using a polynomial function. Finding the maximum by direct means would be very slow and produce an unnecessary degree of accuracy. If greater accuracy is required, the range of the control (minimum – maximum) can be reduced around the optimum point and/or the number of control increments can be increased.

4.2.5 Limit Reference Point

The limit reference point is designed to limit the chance of overfishing to some acceptable level. Overfishing is defined here as forcing the stock biomass below some limit state defined as the proportion of the unexploited biomass. The limit state may be set by the user, but is a generally excepted point for some models, most notably 50% for the logistic model. The probability is calculated as the chance that a scenario state taken at random from all scenario states combined over time, species and simulations, is below the limit state. This position is found through interpolation using a polynomial function. The method, as well as working for the current simulations, will work with stochastic simulation models or under more complex management simulations. It could also be interpreted as the expected proportion of time that stocks will spend in the overfished state under each management regime.

4.3 Probability Assessment

4.3.1 Introduction

The ideas for the approach presented here originate with Press (1989), in which the author presented a method he used to estimate the probability of nuclear war. Nuclear war is similar to overfishing in that we do not want to have several observations before being able to estimate if and how it might occur. Press (1989) suggested using interviews with experts and kernel smoothers to generate a prior probability. This method was applied here to obtain a prior probability, but it was noticed that the approach can be easily extended to dealing with very many other sources of information.

Kernel smoothers provide the building block for probability density functions. Silverman (1985) provides a detailed description of the use of kernel smoothers in estimating densities in one dimension. This method has been adapted here to multiple dimensions.

4.3.2 PDF Estimation Using Frequency Data

4.3.2.1 Normal Kernel Smoother

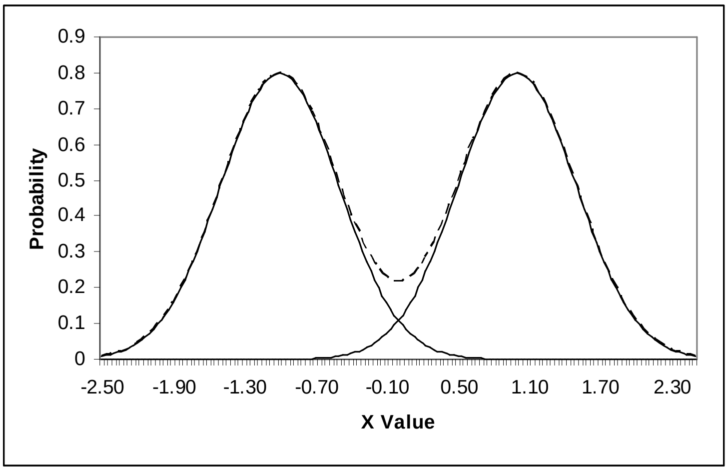
Given a set of frequency data, how can a probability density function be obtained? One option would be to fit a parametric distribution. This would require knowledge of the appropriate shape of the function. While in some cases we would be able to propose a function, such as the normal or log-normal, in many others it would not be possible. There is a risk of proposing an incorrect function and introducing structural error even if the distribution is parsimonious. Instead, a more general non-parametric technique using kernel smoothers is used.

Silverman (1986) provides details on kernel estimators for density functions. The basic aim is to estimate the probability density function from which the frequency has been drawn. There are two requirements. Firstly, a kernel function must be chosen. It has been shown that the particular choice of function is not particularly important in trying to estimate a density (Silverman 1986), so the function can be chosen more for convenience than mathematical requirements. The normal or Gaussian function was chosen for the current model for two reasons:

- The multivariate normal offers a simple way to calculate and maintain individual multidimensional kernel models through use of its covariance matrix. In particular, the posterior of a normal mixture can be calculated directly.
- Where very little data is available from interviews, for example, the normal distribution has a natural shape which it is assumed can represent an individual's subjective prior as well as building into a community density function once enough data are available.

Secondly, the method requires a smoothing parameter for each dimension which controls the degree of spread of the density around each point in the frequency. These parameters are important. Not only do they change the look of the density, but it is a measure of the uncertainty associated with each point in the frequency and hence the frequency as a whole.

Each probability density function is represented by a smoothed probability distribution around a set of points. The points are either derived from interview, and represent the prior belief of interviewees (expert stakeholders / fishers) or derived from bootstraps from a fisheries model. Frequencies can be obtained by other means, but these are not supported by the PFSA software. The discrete frequency data is smoothed by spreading the probability around each point using the normal kernel function (Figure 1).



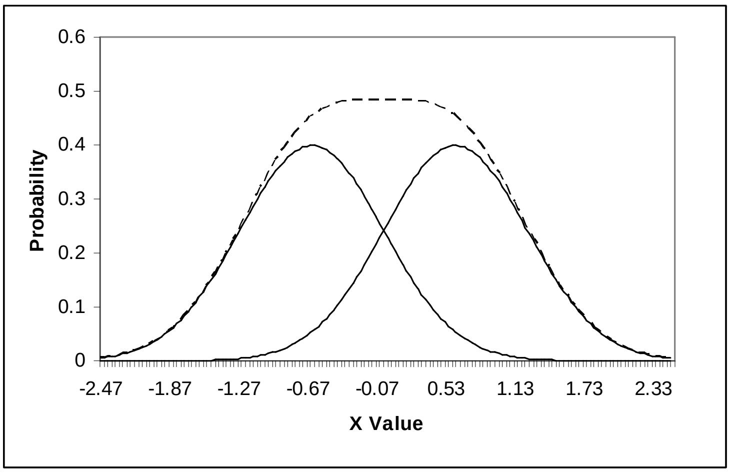


Figure 1 An example of two points forming a mixture distribution in one dimension. In the first, the smoothing parameter (Sigma parameter in the normal distribution) is relatively small and produces two modes. In the second, the smoothing is greater and a single flattened mode is produced.

4.3.2.2 Posterior Random Draws

The use of the multivariate normal kernel allows a relatively simple calculation of the posterior normal. Assuming equal weight to each point in each parameter frequency list, we choose a point at random in each list. These can then be combined to calculate a posterior kernel from which a random set of parameters can be drawn.

The multidimensional normal kernel function is given by:

$$\mathrm{K}(\theta|\mu,\Lambda) = \frac{1}{(2\pi)^{d/2}|\Lambda|^{1/2}} \exp\left(-\frac{1}{2}(\theta-\mu)^T \Lambda^{-1}(\theta-\mu)\right) \tag{7}$$

The probability of a particular vector of values now depends upon the N points in the parameter frequency, as:

$$\Pr(\theta | X, \Lambda) = \frac{1}{(2\pi)^{d/2} |\Lambda|^{1/2} N} \sum_{i=1}^{N} \exp\left(-\frac{1}{2} (\theta - \chi_i)^T \Lambda^{-1} (\theta - \chi_i) \right) \tag{8}$$

where the covariance matrix (Λ) of dimensions d is chosen to smooth the density. Combining the series to produce the posterior density is relatively simple. Given M densities, the posterior is given by:

$$\Pr(\theta | X_1, \Lambda_1, \cdots, X_M, \Lambda_M) \propto \prod_{j=1}^{M} \left[\sum_{i=1}^{N_j} \exp\left(-\frac{1}{2} (\theta - \chi_{ji})^T \Lambda_j^{-1} (\theta - \chi_{ji}) \right) \right] \tag{9}$$

The probability is made up of a set of multinomial terms, each consisting of a unique combination of values taken from each of the density functions. A random term can be drawn from the posterior by choosing a random point from each density. These points combined from a posterior kernel with a mean and covariance based on the mixture property:

$$\Pr(\theta | \mu, \Lambda) \propto \exp\left(-\frac{1}{2} (\theta - \mu)^T \Lambda^{-1} (\theta - \mu) \right)$$

where

$$\mu = \left(\sum_{j=1}^{M} \Lambda_j^{-1} \right)^{-1} \left(\sum_{j=1}^{M} \Lambda_j^{-1} X_{ji} \right) \tag{10}$$

$$\Lambda = \left(\sum_{j=1}^{M} \Lambda_j^{-1} \right)^{-1}$$

where X_{ij} is the i^{th} data point chosen at random from the parameter frequency j. The mean of the posterior is the weighted mean of set of individual vectors where the weights are the individual inverse covariance matrix for each frequency. A random posterior parameter vector can be obtained by choosing a set of independent random normal variables of the same length as the vector, and applying the linear transform:

$$\rho = \mathrm{P} Z + \mu$$

where (11)

$$\Lambda = \mathrm{P}^T \mathrm{P}$$

So, P is equivalent to the square root of the posterior covariance matrix.

The posterior and the individual kernel covariance matrices and their inverses need be calculated only once before beginning a set of random draws. This makes the random draws themselves very fast.

Subsets of parameters can be dealt with separately. It is important to note that individual kernels do not have to have frequency data covering all parameters. The inverse covariance matrix for a subset of parameters has implicit rows and columns filled with zeros for those unrepresented parameters. These zeros indicate no information (infinite variance) and have no influence on the posterior.

4.3.2.3 Constraints

Parameters will often be constrained to particular ranges. Many population parameters will be constrained to positive values, and in many cases an upper bound is useful even if not strictly required. Parameter constraints are defined by the population models.

Constraints are dealt with by reflecting parameter estimates back into the valid region. Essentially, all the probability mass is conserved and reflected from the boundary which seems a reasonable representation. When choosing a random value, if it outside the boundary, it can be reflected back into the valid region, making the reflection algorithm very fast.

For each draw from the posterior distribution, the expected utility is calculated for each management action. This may involve complex calculations not only to get the output variables such as catch, but also to change this to the appropriate utility.

4.3.2.4 Estimating the Parameter Frequency Covariance Matrix

It is clear from the above that the parameter frequency kernel covariance matrix is an important component of the posterior as it provides a weight for each parameter frequency. The covariance matrix is the fitted kernel smoothing matrix. The relatively more heavily smoothed a frequency is, the lower weight it will have in the posterior.

The method applied is to reduce a multi-dimension frequency to a series of independent one dimension frequencies. Each of these can be smoothed separately, and then converted back to the original matrix. This can be achieved through linear transforms of the data. The transform chosen is the linear transform to obtain the principle components, which are a set of uncorrelated variables constructed from the original data.

The method is as follows:

1. Firstly the covariance matrix of the data is obtained by calculating the variances and covariances in the usual way.
2. Singular value decomposition (see Press *et al*. 1989) can then be used to reduce the covariance matrix into orthogonal matrices:

$$\Lambda = \mathbf{V}\ \mathbf{W}\ \mathbf{V}^{\mathbf{T}} \tag{12}$$

3. $\mathbf{W}$ is the diagonal matrix containing the scaling terms for the independent PCA scores. The scores themselves can be calculated from the data and the linear terms in $\mathbf{V}$. This is also particularly convenient because the inverse of the covariance matrix is simply the reciprocal of the scaling terms back into the equation.

$$\Lambda^{-1} = \mathbf{V}\ \mathbf{W}^{-1}\ \mathbf{V}^{\mathbf{T}} \tag{13}$$

4. The scaling values in the diagonal matrix $\mathbf{W}$ now become the smoothing parameters to be estimated. That is, the PCA score vector is calculated, the smoothing parameters for these scores are found and substituted for the relevant scale parameter in $\mathbf{W}$. This is done for each PCA score vector (i.e. dimension). The smoothing matrix and its inverse can then be calculated from equations (12) and (13).

The square root of the covariance matrix is found using the square root method (Faddeeva, 1959) which works with positive symmetric matrices (i.e. covariance matrices).

The data are standardised using a mean and standard deviation calculated across all parameter frequencies to prevent numerical errors in the matrix routines. This has been found to work well. It eliminates scaling problems between parameters (e.g. q and B_{inf}) and differences among parameter frequencies should not be enough to create problems for a robust matrix decomposition routine unless there are significant incompatibility problems among data. As all data are scaled in the same way, the equations (7) to (11) defining the posterior distribution still apply and the linear scaling of the random variables can be easily reversed.

4.3.2.5 Estimating the Smoothing Parameters

The least-squares cross-validation method used for one dimension is described in detail in Silverman (1986). The idea is to find a smoothing parameter which minimizes the mean integrated square error between the estimated and true density. A score can be calculated using cross-validation, where each data point is removed in turn and the density from the reduced set becomes independent of the data point. Intuitively it can be seen that a good fit would be obtained by minimising the difference between the estimated densities and these independent values. In fact, the score is directly related to the error, so minimising the score minimises the squared error (see Silverman 1986). Where the number of frequency values is small, the least-squares score for the normal (Gaussian) kernel can be calculated directly as:

$$\begin{aligned} M_0(h) = {} & \frac{1}{2\sqrt{\pi}\, n^2 h}\left(2\sum_i \sum_j Exp\left(-\frac{1}{4}\left(\frac{X_i - X_j}{h} \right)^2 \right) + n \right) \\ & - \frac{4}{\sqrt{2\pi}\, n(n-1)h} \sum_i \sum_j Exp\left(-\frac{1}{2}\left(\frac{X_i - X_j}{h} \right)^2 \right) \end{aligned} \qquad (14)$$

where X_i = the i^{th} data point, h = smoothing parameter, n = number of data points. For larger numbers of data (say, over 100), the score becomes time consuming ($\frac{1}{2}\, n\,(n\text{-}1)$ calculations). Instead of the direct score, an approximation is used which is close to M_0 for large samples.

Again, the method is described in detail by Silverman (1986) and is based on the same score except n is substituted for (n-1) in equation (14) to create a score $M_1(h)$. In this form, fast Fourier transforms can be used to carry out the convolution between the data and the kernel. This reduces the score to a simpler exponential sum:

$$\left\{ (b-a)^{-1} + M_1(h) \right\} = (b-a) \sum_{l=1}^{M/2} \left\{ Exp\left(-\tfrac{1}{2} h^2 s_l^2 \right) - 2\, Exp\left(-\tfrac{1}{2} h^2 s_l^2 \right) \right\} \left| Y_l \right|^2 + \frac{1}{\sqrt{2\pi}\, n h} \qquad (15)$$

$$s_l = 2\pi\, l\, (b-a)^{-1}$$

where a and b are the interval range of the values, M is the number discrete transform components (an integer power of 2), h is the smoothing parameter and Y_l is the discrete Fourier transform of the discretized data. The data is discretized by allocating it to a fixed interval vector. The intervals are $\delta = (b\text{-}a)/M$, so that the k^{th} point has a value $t_k = a + k\delta$. For each data point X lying between t_k and t_{k+1}, $n^{-1}\delta^{-2}(t_{k+1}\text{-}X)$ is added to k^{th} value and $n^{-1}\delta^{-2}(t_{k+1}\text{-}X)$ is added to the $k{+}1^{th}$ value. All points are added in this way. (Note: These weights are displayed in the software Plot | Plot Kernel graphs). The fast Fourier transform routine used is described in Press *et al.* (1989).

A parabolic interpolation method was used to find the minimum of the score (see Brent's procedure in Press *et al.* 1989). Once the minimum has been bracketed, the procedure finds it rapidly and does not require the differential of the function, making it more robust than many other methods. The start point for h is the normal distribution estimate: $1.06\, n^{-1/5}\sigma$ where σ^2 = PCA scale parameter. The start bracket is 0.25 and 1.5 times the start value, which is extended to ensure it includes the minimum. To prevent degenerate behaviour, h, is given a lower limit of 10^{-3} of the standardised data.

Use of fast Fourier transforms makes fitting the kernels to even very large data sets rapid. This technique is used in generating the stock state probability density functions, and only takes a small amount of time compared to the basic stock size and preference calculations.

4.3.2.6 Algorithm

Given enough data in each frequency, the following standard method is applied:

1. All frequency data are scaled using the same global mean and standard deviation calculated from all frequencies.
2. For each frequency in the list:
    a. The data covariance is calculated from the data.
    b. The covariance matrix is decomposed using singular value decomposition that produces a set of scale parameters and uncorrelated PCA scores.
    c. For each PCA score
        i. The least-squares cross-validation score is either calculated directly if the number of frequency values is small or on Fourier transformed data if the number of data is large. The data are discretized and a Fourier transform is applied carrying out the convolution between the data and the kernel.
        ii. The minimum least-squares cross-validation score is found by adjusting the PCA scale parameter using a standard minimisation routine.
3. The new rescaled covariance matrix and its inverse are recalculated from the decomposition with the new PCA scale values.
4. The overall inverse covariance matrix is found by summing the inverse matrix for each frequency. The covariance matrix is found by inverting it. The square root of the matrix is found through separate square root decomposition.
5. For each random parameter set required for the simulation:
    a. A sum vector is set to zero. For each frequency in the list, a point is taken from the frequency at random and multiplied by its inverse sigma matrix, then added to the sum vector. The resulting vector is the sum of the parameter values weighted by each inverse covariance matrix.

b. The sum vector is multiplied by the overall inverse matrix to get a random posterior mean point.
c. Independent random draws are made from the standard normal to fill a vector with the same length as the number parameters in the overall frequency. This is multiplied by the square root of the covariance matrix and added to the mean point to produce a random number draw from the posterior.

4.3.3 Building Prior Probability Density Functions for Population Parameters

An important component of Bayesian statistics which forms the foundation of the method described here are prior distributions. Priors are the belief including uncertainty that you start with and update with scientific observations. There has been an on-going debate over priors as they introduce subjectivity which science generally avoids. As a result, scientists have focused on finding uninformative priors which do not influence final results.

In this methodology, priors are seen as a benefit rather than a nuisance. They allow the stock assessment scientist to start the assessment process immediately and do not require a long wait before any advice can be given. However, this requires a reasoned approach to building informative priors, and care should be taken that they do not overwhelm the results when other data are available.

The most obvious source of priors are the fishers themselves. It is recommended that interview data is used for the logistic simulation model. With reasonable differences in opinion, interviews still allow significant uncertainty, but involve fishers in the results. If you can show they have influenced the results, so that their opinion is demonstrably taken into account, they should be more likely to accept the final recommendations.

Many parameters in the yield-per-recruit models are not suitable for interview. It may be possible to develop methods in future to generate views on natural mortality and maximum size and so on, but these parameters are so far removed from fishers everyday experience that such priors may not be useful. An obvious additional source of information would the experience of scientists in other countries with similar species.

Fishbase (www.fishbase.org) is a database of information on many fish species and in particular is a source of parameter estimates for growth and mortality parameters. These parameters can be easily downloaded and copied into a spreadsheet. Although the reliability of parameters may be questionable in many cases, they are probably a good way to build a prior probability which allow you to conduct YPR analyses.

There is no standard way to do this, but following techniques are suggested.

- If the species has many independent estimates for its parameters, you should load these directly into the frequency. The smoothed probability distribution would probably represent a reasonable prior as long as the estimates cover the range of environmental and ecological characteristics which apply to your fishery. You can exclude estimates which appear questionable.

- You can build estimates of natural mortality using Pauly's (1980) empirical equation for each set of growth parameters and your fisheries mean annual surface temperature (see Sparre and Venema 1992). As the regression is based on log-values, you should not find that resulting smoothing matrix is singular. The equation has the form:

  $$\ln M = -0.0152 - 0.279 * \ln L_\infty + 0.6543 * \ln K + 0.463 * \ln T$$

  where M and K are the mortality and growth rates (year^{-1}), L_∞ is asymptotic length (cm) and T is the mean annual water surface temperature (^oC).

- *Winf* can be found from L_∞ using weight-length conversion estimates. The weight-length conversion parameters are also available from fishbase, but you can sample to get your own relatively easily. If you only use, for example, the bootstrapped estimate of the weight exponent, the model will use an implicit uninformative prior (uniform on 2.5-3.5). Alternatively, if you are using Fishbase estimates that are independent of the growth parameter estimates, you can sample them randomly to do the conversion.
- The age at recruitment can be found from information on the smallest fish in the catches, converted to age using the inverse von Bertalanffy growth equation for each set of growth parameters. Given a reasonable sample of the catch, it would be advisable to use a lower percentile rather than the smallest individual as the mean size of recruitment.
- If the parameter sets are too heavily correlated (if the smoothing matrix is close to singular an error will occur), you could add small random numbers drawn from a normal distribution to the problem parameter. For example, using Pauly's empirical equation ignores the observation errors in the equation's parameter estimates. It would be quite legitimate to add this error back in.
- The number of parameter estimates for many species will be too small to estimate the smoothing matrix. For these species you might consider using all similar species as a group. For example, species belonging to the same genus might be expected to have similar parameter estimates. There are three approaches to using this information.
  1. Simply use all similar species estimates as the prior. Many species would then share the same prior.
  2. Use all species estimates combined to estimate the smoothing matrix, then copy this matrix to those species with few frequency values using "drag and drop" on the probability form, or use Frequency | Excel | Export Smoothing Matrix and Frequency | Excel | Add Smoothing Matrix. The probability distribution would use the actual values as the mean, but spread the probability around these values using the smoothing matrix. You can also scale this matrix up to indicate greater uncertainty for the species if the smoothing matrix does not cover the variation between the few parameter estimates.
  3. Build a dependent probability model based on the parameter estimates (see the PFSA Help file). This uses correlations between

parameter estimates to build a more realistic parameter set from the similar species parameters. It is useful where you have no parameter estimates for a species, for example, but wish to take account of its size (almost all species have an *Lmax* indicator). Larger fish have a large *Winf* and may tend to grow more slowly, and so on. The method works by choosing parameters estimates regressed towards the mean for that species size.

Catchability parameters might be estimated from interviews in the same way as for the logistic stock assessment or from fishing experiments. Unfortunately, catchability is dependent on more than just the gear type, so using other fishery's catchability would require care.

It is important to note that priors may favour parameter values far from the true value. They allow you to start the assessment process, but it is very dangerous simply to stop assessments at that point. Fishers' beliefs, like anyone else, may well be incorrect and biased. In particular, fishers may well be optimistic over the productivity of their resource. However, even in this case priors still provide a measure of how much scientific information may be required to overcome this belief.

4.3.4 Probability Function Errors

Currently, it is up to the user to try to ensure each parameter frequency is a good representation as possible by looking at a graph of the frequency data and the estimated probability density function (PDF). The graph should indicate whether an error has occurred in the process. Errors include problems in fitting the smoothing parameters and singular covariance matrices.

Smoothing failure can occur when the fitting process degrades the smoothing parameter to a very low value. The software should detect this and prevents the parameter from going too low, but is effectively still unable to estimate it. The PDF tends to become very spiky as the probability is gathered tightly around each observation (i.e. there is little or no smoothing). This can happen particularly where the number of parameter frequencies is small and the dimensions are high. In many cases smoothing failure does not matter much. For example, it is quite common under very high exploitation levels for the resource state smoothing to fail in the analysis as the majority of points gather at boundaries. For the necessary statistics, this is not particularly important and generally occurs at an implausibly high exploitation level. It does matter, however, if smoothing fails in one of the parameter frequencies used to generate the posterior. In this case, the only alternative is to supply subjective smoothing parameters based on the graph plots. This has not yet occurred in tests on real data.

There is no one solution to the related problem of a singular posterior matrix. In general this should not happen unless there is an underlying problem with the data. The most likely problem stems from the parameter scaling. If data sources have large differences, it is possible that numerical errors will occur as the covariance matrix comes close to singular. This is interpreted as incompatible data sources.

Assuming that the frequency data is drawn from a likelihood without bias, there will still be an error between the estimated and true PDF. Silverman (1986) notes that this error becomes much larger as the dimensions of the PDF increase. Whereas only 4 values are required to estimate a standard multivariate normal with one dimension for a relative mean square error at zero of less than 0.1, 842 000 draws are required for the same accuracy of a multivariate normal with 10 dimensions. Clearly, considerable gains in accuracy can be made by exploiting independence (or near independence) between parameter frequencies. Otherwise, the number of frequencies must be as high as possible.

As Monte Carlo numerical integration is used to collapse the posterior over all but one or two dimensions to calculate the indicator variables, the accuracy of the actual PDF is not as important as might at first appear. Integration, like calculating an average, will mean these errors are much reduced in the final result. Of greater importance are biases and errors in the parameter frequency sources, and can only be addressed through improving the underlying source models and fitting process.

All parameter scales are currently assumed to be linear. There is an argument for placing some parameters on a log-scale, for example the unexploited biomass in the logistic model. If a log scale was used, it would have to be applied consistently across all parameter frequencies. With large numbers of frequency values, the results should not be sensitive to this choice. However, a log-scale may increase accuracy in estimating the PDF for smaller numbers of values, and should be considered as an option for future designs.

4.4 Models Fitted to Data

4.4.1 Approach

Fitted models are structured as a linked hierarchy of sub-models. The structure allows greater flexibility, speeds up the fitting process and will allow easier development in future.

The basic structure is to have a multispecies model at the top level (if appropriate), the single species population models next and then generalized linear models which fit to data. There can be many species populations for each multispecies model and many generalized linear models for each single species model. The generalized linear models (GLM) link the population models to observations. The population models are more likely to be non-linear and more difficult to fit. By separating out the linear components, the overall model should become easier to fit. Furthermore, it should be easier to change a population model, for example, without changing the rest of the model structure, helping interaction with the software user, and making it easier to develop other models to fit in this hierarchy.

While the multispecies approach is new (see below), the separation of the single species model and GLM is a formal, more integrated approach of what is already commonly done (see Hilborn and Walters 1990; Hassen and Medley 2001). In many cases, a GLM is applied to observations to produce a population index. The population index is then used to fit the population model. While this pre-processing may be easier with some complex data sets, it introduces a redundant parameter and ignores possible correlations between the GLM and population model parameters.

The basic approach is to include the population size as a variable in the GLM. For any set of population parameters, the GLMs can be fitted to the population sizes. This is fast even if a GLM contains many parameters. A slower non-linear minimizer can then be used to minimize the fitted GLM log-likelihood with respect to the smaller number of population parameters.

4.4.2 Generalized Linear Models

McCullagh and Nelder (1989) provide a description of generalized linear models as implemented in the current software. GLMs consist of a linear predictor, link function and variance function. The link function describes the relationship between the mean and the linear predictor. The variance function depends on the error model chosen. With an identity link function and constant variance, the fit is standard least-squares. With other link functions and variance functions, the model must be re-weighted and fitted over a number of iterations. Under most circumstances, the number of iterations is small.

The least-squares estimates are found using singular value decomposition (SVD) to invert the information matrix (Press *et al*. 1989). SVD is slower than other methods, but robust. The iterative weights are calculated as described by McCullagh and Nelder (1989; page 40), who also give a justification.

Three links and errors are provided, although these can be easily expanded in future. The links represent the most commonly in fisheries.

Identity-normal: This is standard least squares regression.

Log - Poisson: This is the standard log-linear model. Linear terms are multiplicative. Independent variables can be linearized by taking their logarithms.

Complementary log-log - Poisson: This is the GLM form of the single gear catch equation:

$$\begin{aligned} \mu &= (1-\exp(\exp(\eta))) \\ \eta &= \ln(\ln(1-\mu)) \end{aligned} \qquad (16)$$

where μ = expected value (probability a fish is caught) and η = linear predictor. The linear predictor is multiplicative, so log-effort is used as an offset (i.e. no parameter is fitted to it). The population size occurs as the binomial parameter, N, in this model, which most naturally would therefore use a binomial error. However, the variance function used is the Poisson, which is greater than the binomial variance. This is probably more suitable for over-dispersed data, where N is being fitted rather than known, and when applying quasi-likelihood assumptions (see McCullagh and Nelder 1989 for a discussion of quasi-likelihood).

Currently linear predictors support a constant, covariates and an offset (a variable with no parameter). Discrete factors are not supported yet. Although complex GLMs could be supported in future, the emphasis in the software is on simple single parameter GLMs, which are most likely for the fisheries data being considered.

4.4.3 Single Population Model

4.4.3.1 Logistic Model

The logistic model fitted to the data is the same as that used in the simulation model (see equation (1)). However the fitted catch-effort model is a GLM of the form:

$$\hat{C}_t = B_t\left(1-\exp\left(\exp\left(\ln(q)+\ln(f_t)\right)\right)\right) \qquad (17)$$

This is fitted separately for each gear. The log-likelihood is the sum of the individual GLM log-likelihoods which are calculated for the Poisson and normal distributions as appropriate. Other GLMs can be added if population indices are available.

The three population parameters are fitted using the downhill simplex method of Nelder and Mead (1965; described in Press *et al.* 1989). While the method is slow, it was found to perform better on the logistic model than other methods (including Solver in MS Excel) even when the differential of the function was available. The logistic model can exhibit some difficult non-linear behaviour and a robust minimizer was preferred.

The parameters were given maximum and minimum limits to prevent unrealistic results. The initial population, B_0, is defined as the proportion of the unexploited size and therefore varies between 0 and 1.0. The intrinsic rate of increase produces erratic behaviour above 2.0. Estimates above 2.0 indicate a shorter time unit should be used. The unexploited biomass must be above the maximum observed total catch in any time period. Although the theoretical unexploited biomass could be infinite (or at least a small proportion of the mass of the earth), a limit was placed so that the maximum total catch would be no higher that 1% of the biomass. If catches do not discernibly decrease the resource size, the resource size estimate can become arbitrarily high. This is capped at a high level. If the estimate drifts to this level, the resource is hardly exploited at all, and this estimate is adequate for fisheries decision making. No boundaries are applied to the catchability parameters which are fitted through regression.

Table 1 Parameter limits for the fitted logistic model. Max refers to the maximum observed in the time series.

Parameter	Minimum	Maximum
B_0	0	1.0
R	0	2
B_∞	Max(Total Catch)	100* Max(Total Catch)

4.4.3.2 Linear Depletion Model

The simplest population model assumes a closed population with changes only coming about through catches (Leslie & Davis 1939):

$$N_t = N_0 - \sum_{j=0}^{t-1} C_j \qquad (18)$$

where N_0 = the initial population size, N_t = population size in numbers on day t and C_j = the catch on day j. Clearly, the initial population size must be greater than or equal to the sum of the catches.

An extension of this model allows use of the initial population size parameter from fishing experiments. An additional population state parameter can be drawn from the uniform distribution. This can be used with the estimate for the current population size to estimate the unexploited population size. This makes better use of the experiment depletion data.

4.4.3.3 Linear Depletion Model with Natural Mortality

The simple extension to the linear model allows for natural mortality as well as catches:

$$N_{t+1} = N_t e^{-M} - C_t e^{-M/2} \tag{19}$$

where M = the natural mortality rate. It is difficult to fit M in this model using pure maximum likelihood approach, so its practical usefulness is probably limited. No data was available to test it.

4.4.4 Multispecies Model

The obvious approach to modelling multispecies communities is to fit separate population models to each species with implicit fixed (natural mortality) or explicit variable species interactions. A significant problem with this approach is the large number of parameters which these models require when fitting to real data. Although this is not a theoretical a problem if sufficient data is available or the number of species being explicitly modelled is small, difficulties in data collection make such approaches impractical.

The most widely used approach to modelling communities has been to fit species abundance models. It has been demonstrated empirically that most, it not all, communities follow a consistent pattern (Magurran 1988). Species abundance models form the basis for the study and interpretation of species diversity and are often used to measure human impacts on species communities.

Previous methods to fit species abundance models have assumed the collection method of animals is not selective (e.g. Bulmer 1974). This is inadequate for many applications, including the analysis of species composition data in fisheries. In many cases, and particularly fisheries, it is the different species catchabilities that are most of interest.

Dynamic depletion models are an important class of models used in modelling fish populations and to estimate catchability. Depletion models require the number of individuals removed from population and an index proportional to the population size, both recorded over time. These models can be used to estimate current and past population sizes as well as catchability for single stocks (Hilborn & Walters 1992). A simple multi-species extension of depletion models allows multiple catchabilities to be estimated which would at least partially explain species composition. However a problem immediately arises in that, even if sufficient data is available, it is impossible to fit models where there is insufficient contrast (i.e. depletion) in the abundance index. This will be true for all species that are rarely caught, which may either be rare in the community or have a low catchability.

Estimates can be greatly improved if it is assumed a species population size is conditional on other species. Conditioning allows estimates for species having a good contrast to estimate catchability and initial population size to improve estimates of catchability in other species where depletion is not so clear. This is reasonable if there is some foundation for the observed abundance patterns in ecology or evolution. Most of these models are justified on the division of niche space (May 1975, Sugihara 1980), but agreement is not universal, particularly over the application of the log-normal (Ugland & Gray 1982).

For the current analysis the broken-stick and log-series abundance models were used, although other models such as the geometric or log-normal could equally be applied. These four models have been found to fit the widest variety of communities (Magurran 1988). The broken-stick model is appropriate where a single resource is being shared more or less evenly between species, and has most commonly been observed in narrowly defined communities of taxonomically related organisms (May 1975). The log-series (and in its deterministic version, the geometric series) is appropriate where fractions of the available resource have been pre-empted by species in sequence. The log-series has been most commonly observed where one factor dominates the ecology of the community, and can also be seen in small samples where only the commonest species of the log-normal are represented. These two models represent extreme cases in terms of evenness and the distribution of a resource among members of a community.

4.4.4.1 Multispecies Population Models

The simplest depletion model assumes a closed population with changes only coming about through catches (Leslie & Davis 1939). The multispecies form of this model is:

$$N_{it} = N_{i0} - \sum_{j=0}^{t-1} C_{ij} \tag{20}$$

where N_{i0} = the initial population size of species i, N_{it} = population size in numbers on day t and C_{ij} = the catch on day j. Using Equation (20) we can generate a set of population sizes (N_{it}) over T days with a set of i input parameters (N_{i0}) and the catch data (C_{ij}). We assume some community model for the initial population sizes.

For the broken-stick model, the number of individuals in the r^{th} most abundant of S species is defined as:

$$N_{r0} = \frac{N_T}{S} \sum_{n=r}^{S} \frac{1}{n} \tag{21}$$

where S = the number of species and N_T = total number of individuals of all species in the community.

For the geometric series, a species in rank r will have a population size N_{i0}, defined as:

$$N_{r0} = N_{00} \beta^{r} \tag{22}$$

where the β parameter is always less than or equal to 1.0.

Equations (21)-(22) can be used to provide the initial population size in Equation (20). Where the rank of a species is known, the joint likelihood can be calculated and all parameters fitted using normal methods. The problem is that ranks of species are not known and all species-rank permutations need to be considered.

4.4.4.2 Fitting the Model

Assuming the species abundances are independent, the parameter likelihood of a set of observed catches of S species can be estimated as the joint likelihood between the species abundance model and the population model. This assumes all S species have been drawn at random from the species abundance model, and does not prevent two species occupying the same rank. This is not a problem if all species are assumed to be equally catchable as the initial species abundances are forced to fit to the curve with the greatest likelihood across all ranks. This is the standard approach. If catchability is allowed to vary however, all species will tend to be mapped to the most probable rank. The way to address this is to allow only one species in each rank.

To model the dependence between species, the species abundance model is separated from the likelihood model. The species abundance model defines the unexploited stock size for each species rank, which can be used in the likelihood model. If the rank of each species is known *a priori*, the model is easy to fit through normal methods. However in practice each species rank would not be known and all possible ranks for each species need to be considered.

Calculating the likelihood of all species-rank permutations is not possible when the number of species is of any reasonable size, the number of permutations being the factorial of the number of species ($S!$). However the problem can be reduced to a combinatorial problem. For any set of model parameters, a likelihood matrix can be calculated with rows representing the species and columns the ranks, so that the likelihood of species i being in rank r can be found in the matrix cell x_{ir}. The problem then is to fill each rank with one species. Once a rank is filled by a species, that column and row is eliminated and the next species-rank must be chosen from the remaining reduced matrix. Each time this is done, the likelihood in the matrix cell can build up the product for this combination. This reduces the problem to one of combinations rather than permutations. The sum of all these likelihood combinations is known as the permanent of the matrix, which unfortunately has no simple method of calculation (van Lint and Wilson 2001).

The combinatorial likelihood was calculated using dynamic programming using a tree structure to process the matrix. The process state is defined as the filled ranks in the species abundance model. Equivalent state likelihoods are added together, so that at any stage a state is all filled rank combinations of the tested species. There are two advantages of calculating the permanent in this way.

Firstly, impossible species-rank combinations can be eliminated early in the process greatly reducing the number of combinations which have to be calculated. For example, the obvious condition that the total catch cannot exceed the initial population size means that the largest ranks must probably be filled by the most abundant species in the catches. The wide variation in species catches usual for a multi-species catch should considerably speed up the likelihood function evaluation.

Secondly, the method allows fast fitting of species specific parameters, such as catchability. The dynamic programming method allows the process to stop before the last empty place is filled. At this point there is one species left and as many states as there are species. Each state has one empty rank which will be filled by the remaining species and an associated likelihood representing all species-rank combinations for the filled ranks. The parameters associated only with this species can be fitted using the likelihoods as weights. Using a generalized linear model regression framework, maximum likelihood parameter fitting can become very fast as this is only an extension of weighted least-squares. The information matrix can be calculated from the sum-of-squares weighted by each rank likelihood. Furthermore, by backing up and working down through the process to work through each species, lower states need not be recalculated every time, again reducing computation. In practice, the estimates converge quickly.

4.4.4.3 Likelihood Matrix

The population size (Equation (20)) needs to be connected to the observed catches through a likelihood model. To deal with rare species where the population can be small, zero catches have to be accounted for. The Poisson likelihood is used as it parsimonious as well as allowing for discrete catch numbers and zero catches. The log-likelihood for a set of observed catches, C_{it}, of species i over T days is:

$$L_{ir} = \sum_{t=1}^{T} \left(C_{it} \ln(\mu_{irt}) - \mu_{irt} - \ln\Gamma(C_{it}) \right) \tag{23}$$

The expected catches, μ_{it}, will depend upon the species abundance model for the initial population size:

$$\mu_{irt} = \left(N_{r0} - \sum_{j=0}^{t-1} C_{jt} \right) \left(1 - e^{-q_i f_t} \right) \tag{24}$$

Because the error models are the same for both species abundance models, the log-likelihood can be used as a comparative goodness-of-fit statistic. However, the geometric requires two parameters, the broken stick only one. The advantage of the geometric is there is no need to know the numbers of species in the model, otherwise a veil-line accounting for unseen species may be required (Magurran 1988).

Restating this in generalized linear model terms, the population size can represent the binomial trials and the remaining catch term the complementary log-log function. In the latter case, the log-catchability is fitted as the constant with the log-effort as an offset in the linear predictor. McCullagh and Nelder (1989) describe the weighted least-squares regression procedure for fitting these models. This is extended by using the additional likelihood weights when summing squares over ranks. Using generalized linear models also allows simple extensions to more parameters, other link functions, error models and quasi-likelihood assumptions.

4.4.4.4 Start Parameters

The starting parameters for a maximum likelihood fit present a special problem here as the shape of the condition likelihood could, at least in theory, contain many local maxima. In fact, there could be as many local maxima for the catchability parameters as there are species combinations. The maxima occur where species rank abundance and appropriate catchability estimates coincide. From any random start, the resulting maximum likelihood may not be the global maximum. Fortunately the potentially locations for all such maxima can be found very easily by fitting the catchability parameter to each rank separately. The likelihood matrix is filled with these best fit likelihoods initially to generate the weights. These are then replaced with the single current catchability value likelihoods as the fitting proceeds. As each species is processed to fit the catchability parameter on the first iteration, the start point is the catchability with the largest likelihood. This ensures the global maximum is found.

4.4.5 Empirical Bootstrapping

Empirical bootstraps were used to generate parameter frequencies. Press (1989) proposed bootstrapping as a robust technique to generate a non-parametric likelihood, although such approaches do not gain universal support from Bayesian statisticians (Gelman *et al*. 1995). For example, bootstrap estimates are not independent estimates, so they can only approximate the true likelihood and are invalid with small sample sizes. If the parametric likelihood is known, it will provide more accurate estimates than its non-parametric counterpart. Despite their problems, such non-parametric methods are still useful in an automated software system as they do not require the user to propose a parametric likelihood for their data and eliminate the potential error in making a poor choice. As the results are only dependent on the data, they reflect the data quality rather than the choice of error model. In this sense the results are more robust.

The method is simplified because data fits are limited to the generalized linear models, hence the technique only has to be applied to them. The basic method is to use randomized residuals (Manly 1997). The standardized residuals are calculated as:

$$R_i = \frac{Y_i - \mu_i}{\sqrt{V_i}} \tag{25}$$

using the i^{th} dependent variable observation (Y_i), the model best estimate (μ_i) and variance function (V_i) from the GLM. A new bootstrapped vector of dependent variable data (B_i) is created by adding a random residual (sampled with replacement) to the estimated value:

$$B_i = \mu_i + R_j \sqrt{V_i} \tag{26}$$

Fitting the model to these bootstrapped data (B_i) produces bootstrap estimates. As long as the number of residuals is large, a large number of smoothed bootstrap estimates should be a reasonable approximation to the likelihood. Otherwise, it is still a measure of uncertainty, but more formal claims cannot be made.

The dependent probability model uses linear models to regress observed parameter frequencies dependent on a common set of independent variables. This uses GLMs described in the way already described. The only difference is in the way the bootstraps are carried out. A set of GLMs will share the same independent covariates, but be fitted to separate parameters as dependent variables in the same record. The residuals between these models might be correlated as the dependent variables themselves may be correlated. Therefore the bootstrap residuals are random, but taken from the same records for all the models. That is, if a residual is selected from the 3rd data record for the first GLM, it selected from the 3rd record for all other GLMs. This means the bootstrapped estimated should, as far as possible, maintain correlations derived from the original data.

4.4.6 Stock Assessment Interview

An example interview including the stock assessment component, is presented in Section 4.6 (The PFSA Interview Technique) and in

Appendix 1. This includes notes on the meaning and interpretation of the different questions.

The time, catch and effort units need to be identified and used consistently for all interviews. This applies both to the stock assessment and preference components. If a fisher is more comfortable with different units, you will need to convert his answers. Units should identify those most easily understood by most of the interviewees. For example, a month may be better than a year in terms of assessing catch or effort.

- Identify the fisher's main gear, then last years CPUE (qB_{t-1}) and this year's CPUE (qB_t) for this gear.
- The current catch rates for all other gears used ($CPUE_i$).
- A catch rate range for the unexploited stock (U_l, U_h).
- The time for recovery (T).

The total effort in this fishery over the last year (f_{t-1}) have to be obtained from elsewhere.

The individual catch rates are regressed towards the mean of the sample. This is necessary as they are used as an estimate for the mean catch rate in the fishery although the question asks for the fisher's own catch rate. For the j^{th} fisher:

$$[\hat{q}B_t]_j = \left([qB_t]_j + \left(\sqrt{N}-1\right)\overline{qB_t}\right)\Big/\sqrt{N}$$
$$\text{where } \overline{qB_t} = \text{mean catch of the sample} \quad (27)$$

These values can be used to calculate the parameters for each fisher based on the logistic population model. The intrinsic rate of increase (r) can be calculated by solving the non-linear projection equation for the unknown r:

1. $$X_1 = X_0\left(1+r\left(1-X_0\right)\right) \cdots \; X_T = X_{T-1}\left(1+r\left(1-X_{T-1}\right)\right)$$
2. $$X_0 = \frac{\hat{q}B_t}{\hat{q}B_\infty}, \; X_T = \frac{U_l}{\hat{q}B_\infty}, \; \text{and } \hat{q}B_\infty = \frac{U_l+U_h}{2} \quad (28)$$
3. X_0 is the current stock state, defined as B_{now} in the logistic equation.

With r defined, catchability can be estimated from the current catch rate and effort adjusted for stock change due to production and catch:

4. $$\hat{q} = \left(\frac{\left(\hat{q}B_{t-1} - \hat{q}B_t\right)}{S} + r\,\hat{q}B_{t-1}\left(1-\frac{\hat{q}B_{t-1}}{\hat{q}B_\infty}\right)\right)\Big/ f_{t-1}\,\hat{q}B_{t-1} \quad (29)$$

This assumes a linear relationship between catch and effort, but should be a adequate approximation unless fishing mortality is high. The time S allows the time unit to be altered. For example, converting from a year to a month S is set to 12. This allows r to be rescaled between 0 and 2.0. Given the fisher's main gear catchability, $\hat{q}$, the unexploited stock size and other gear catchabilities can be found.

5.
$$B_\infty = \frac{\hat{q}B_\infty}{\hat{q}}$$
$$\hat{q}_i = \hat{q}\ \frac{CPUE_i}{\hat{q}B_t} \tag{30}$$

If equilibrium is assumed, last year and this year's catch rates are the same. This leads to a simpler equation (29), but doesn't affect the draws from the bootstrap which will still allow non-equilibrium estimates.

4.5 Utility

4.5.1 Overview

Economics in fisheries assessments have been dealt with by assessing costs and prices and constructing an economic model of the fishery profit. This is probably the best way to assess commercial fisheries, although it has problems.

- Cost of the assessment: such assessments are expensive and could not be extended to each small scale fishery.
- Problems with getting accurate data and dealing with confidentiality
- Unobserved variables, connecting observations to utility (for risk etc.)
- Non-commercial aspects of fishing not accounted for

An alternative to a formal approach is to ask directly what situation fishers would prefer, so that managers can try to target this. This approach does not necessarily supply a reason for preferring one scenario over another.

For small scale fisheries, a more direct approach is better. This could be obtained by asking directly which scenarios in the fishery are more preferred and which need to be avoided. This may not lead to greater understanding of the economics of the fishery, but should give the fishers the opportunity to select management targets more similar to their own needs.

Obtaining information on preferences for outcomes in the fishery has several significant advantages:

- It is simpler and faster to assess potential changes in the fishery
- It is probably robust to consider changes directly. This does not require an accurate model of the economics of the fishery, but does require fishers to be able to assess how changes in catch and effort might affect them.
- Asking fishers their preferences among outcomes gives them power over management objectives, but still allows independent scientific advice to make a contribution. This is consistent with all the advantages of community based management.
- The questions make fishers think more clearly about possible outcomes for the fishery. If community management is to be successful, it is important fishers understand possible management outcomes and can weigh up the impact of these on themselves and the community. This assessment approach not only obtains data for

assessment, but starts fishers thinking about what might happen and what they would prefer to happen.

- The method can be adapted to other questions and issues besides catch and effort.

Economic assessments may provide a better understanding of the commercial structure and forces employed in the fishery and explain fishery behaviour better. It is likely that economic models will explain behaviour over a wider set of circumstances. The advantage of interviews is that they could be repeated more quickly and easily as circumstances change.

A disadvantage is that it is left to the fisher to assess and balance complex issues. However, although imperfect, fishers are probably the best at assessing their own circumstances and the effect of changes in the fishery and will probably get better with practice.

The main source of error is the fishers' inability to assess accurately how they might react to changes in the fishery. This is exhibited in the narrow choice offered in scoring (see below) as fishers were unable to finely discriminate between outcomes. Problems with transferring information on their preferences into a score would probably also improve with repeating interviews, reducing this source of error.

A second source of error is in the way the utility model is used. The utility is averaged over respondents, so all are assumed to react in the same way, that is reduce or increase their fishing or catch by the same proportion. In practice, each individual will react separately to maximise their own utility and minimise loss. This makes the assessment pessimistic and the community utility curve will be flatter than that suggested in most assessments. It is unclear whether the maximum point would be much affected

A set of parameters can be randomly selected for some model which describes the utility resulting from a set of actions. By repeated random draws of parameters and calculating the utility each time, the average utility should estimate the expected utility for each action. This is a crude, slow Monte Carlo integration, but should produce robust results and be able to deal with complex calculations from parameters to utility. Another advantage is that, assuming the points themselves accurately represent the underlying probability distribution, the draws are exact and all modes are represented, so slower algorithms based on rejection or sample importance resample, are unnecessary.

4.5.2 Preference Interview

Although utility theory is well defined and methods for practical utility estimation are available (Keeney and Raiffa 1993), they need considerable adaptation and simplification to be used for assessing fishers' utility. Not only does the method need to be simple to understand, it has to be rapid to allow a broad cross section of the community to be represented and to avoid interview fatigue.

Simplification was achieved by:

- The variables examined were simple and consistent. The assessment focuses on catch (earnings) and effort (work done).

- Comparisons were made as relative changes from the present situation.
- Scenarios representing changes from the present situation were ranked then difference between them scored. The score for each scenario is the cumulative sum of these scores.
- The number of comparisons were minimised as dominance was automatically taken into account in the method.
- All comparisons were pairwise, so fishers only had to consider two options in any comparison.
- The utility scoring method allowed a hierarchical structure, so species were scored separately from total catch. This would also allow more complex models to be built than those applied here.

It is worth noting that standard utility and multi-attribute decision making techniques were tried. These techniques in general require fairly sophisticated interviewees who have a clear understanding of the issue and are prepared to spend considerable time building up the information necessary to support the method. These were not found to be suitable for fishers in the context of the interview, although they may not be ruled out under all circumstances. Such methods are useful in analysing decisions, and this is probably the primary way they are used in decision-making. This analytical capability could be re-examined as a tool to help a small group of fishers representing the fishing community come to some decision on the community's behalf.

Interviews are based on households as the fundamental economic unit.

The full interview, including both the stock assessment and preference is described in section 4.6 (The PFSA Interview Technique) and in

Appendix 1.

4.5.3 Preference and Utility

Utility analysis in this context is concerned with mapping outcomes to a position on the real line such that the distance between points indicates how much more one outcome is preferred over another. Although each outcome or state may be described by any number of variables, this complexity is reduced to a single utility variable. The difficult reduction step is carried out by the fisher.

The ranking alone does represent utility to a degree. A scenario clearly has a higher utility if it is preferred to another. Quantifying the distant between scenarios is more difficult and probably not accurate. However, the ranking itself provides considerable information on the relative value of changes in catch and effort in the fishery.

4.5.4 The Catch-Effort Scenarios

Scenarios represent possible changes in the catch and effort as they relate to the fisher. Changes are represented as +/-25% steps relative to the present and are constructed to maximise the information obtained for a regression information matrix. The scenarios, which were given a letter for easy identification, can be laid out in relation to the current catch and effort (**I**).

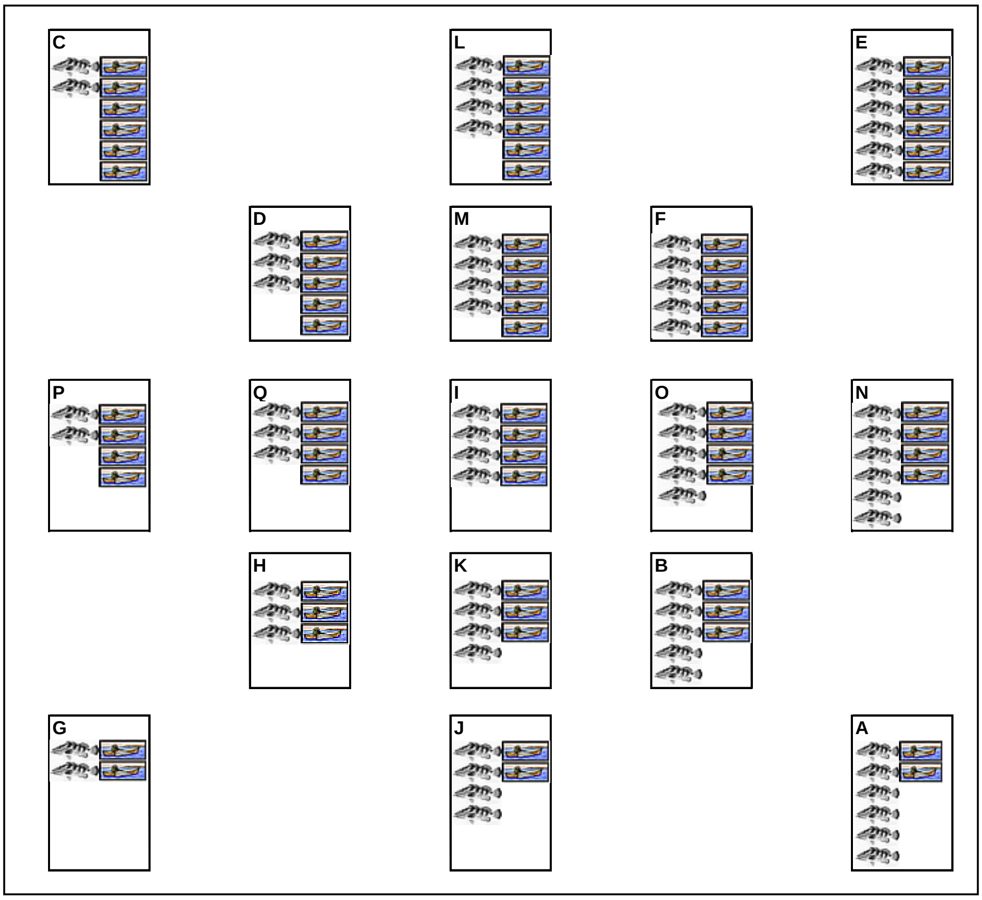


Figure 2 The different scenarios are used to assess fisher preference. The central scenario I represents the current situation with 4 fish and 4 boats representing the current catch and effort respectively. Effort and catch is decreased by 25% and 50% around this current value.

One scenario will dominate another where it is clearly better. If we assume higher catches are always better and higher effort always worse, any scenario where the catch is higher than or equal and effort is lower than or equal to another scenario will always be preferred. For example, **O** will always be preferred to **I**, as catch is higher and effort is the same. These dominance relationships can be used to rank all 17 scenarios more rapidly with the fewest number of comparisons. **A** represents the best, and **C** the worst scenarios, so it is only necessary to map all other scenarios between these two.

Scenarios can be ranked using a binary tree (see

Appendix 1). The tree starts with seven scenarios already ranked according to the dominance relationships. Furthermore, scenarios may not need to be added at the apex, but further down applying dominance rules. Also as the tree nodes are completed, the rules can be applied to aid placement.

4.5.5 Scoring

The score is calculated as the cumulative sum of the difference scores between the ranked scenarios. The scores between ranked scenarios are additive, as they are assumed to measure the relative distance along a utility line. So, by ranking and then asking for a score (0 – no difference, 4 large difference) between consecutive scenarios, all scenarios can be scored.

Using this method, scenario scores can be calculated by making only pair-wise comparisons.

There are a few assumptions which can be made about catch and effort utility curves. Firstly, the curves are monotonically increasing for catch and probably mostly monotonically decreasing for effort. The effort curve is less certain as some fishers complained of boredom if they were prevented from going out fishing. Given the interest in sports fishing, this does not seem unreasonable. Secondly, they are bounded at zero as fishers would never go fishing if they did not expect to catch something, so utility should never fall below the point where they stop fishing altogether. The CPUE or catch at which they abandon fishing should set the lower bound on the utility.

There are also upper limits to the utility curve. This is a logistical limit to the amount of catch that can be handled and the effort which can be applied. Excluding religious days, the number of days fishing a month is probably limited to 25. The amount of fish which a vessel can handle is likewise limited. Changing these limits, such as employing more crew or purchasing larger vessels would change the nature of the fishery and hence the assessment would have to be undertaken again.

4.5.6 Errors and Feedback

If the results from the preference assessment are used without feedback to the interviewee, results may not accurately represent true preferences. By their very nature, questions are abstractions and may draw out abstract or inconsistent answers. The way to avoid this is to present back to the interviewee the implications of their answers which they can adjust interactively.

The rank order provided a method to check consistency of replies. Basically, the interviewer can check the reasoning of the fisher in why some order was chosen. Originally this was intended to see whether a fisher understood the object of the exercise and perhaps exclude those that did not. In practice, consistency was used as a tool to help fisher understanding rather than test for it.

Firstly, dominance was assumed and used in ordering the scenarios. For example, it was assumed that a scenario with the same catch as another, but for less fishing effort would invariably be preferred. Fishers were, however, given the opportunity to change this order, and in some cases they did, giving good reasons. For example, some conch fishers in the Turks and Caicos

Islands said they would prefer 2 rather than 1 week's work a month even for the same catch simply to avoid boredom as they had nothing else to do.

Secondly, their current activity was assumed to be optimum. So, the scenarios with the same catch rate but fishing more or less than now are presumed to be less preferred than the current level of catch and effort. If it is not, the fisher should be able to explain why not. This was used at first as a method to test understanding, but fishers clearly felt caught out when faced with an inconsistency with their answers, and in most cases would belligerently keep to their original answer to avoid losing face. On the one hand, this may have encouraged them to think more carefully as they searched for similar traps in the questions. On the other hand, it was counterproductive as it reduced the interview to an intellectual game rather than a real discussion about outcomes in the fishery. As a result of this experience, this comparison was used as a way of linking the scenarios to reality in explaining the scenarios to the fishers. The aim was to get the fishers to think as clearly as possible about what the scenarios would mean to them in reality.

The method works through contrasting catch and effort variables and forces the fisher ranking the scenarios to define an exchange rate between them. Whereas the ranking works well, it was less certain that the scoring was as accurate. Scoring nevertheless gave the fisher the opportunity to draw a distinction between small and large differences between scenarios.

4.5.7 Preference Model

The additive nature of the scoring technique suggests a quadratic model of each variable with a single interaction term should be adequate in modelling the score. The model interpolates the score and smoothes through errors. Pure interpolation is too sensitive to errors.

The simplest model to fit to the preference score is the quadratic equation:

$$1+U_1 = a_{10} + a_{11}x_1 + a_{12}x_1^2 \tag{31}$$

The units are arbitrary, and the model can be scaled to any value. With two variables, and assuming utility independence, the model expands to:

$$(1+U_1)(1+U_2) = (a_{10} + a_{11}x_1 + a_{12}x_1^2)(a_{20} + a_{21}x_2 + a_{22}x_2^2) \tag{32}$$

This potentially has 8 parameters:

$$\begin{aligned}(1+U_1)(1+U_2) = {} & \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_1^2 + \alpha_4 x_2^2 \\ & + \alpha_5 x_1 x_2 + \alpha_6 x_2 x_1^2 + \alpha_7 x_1 x_2^2 + \alpha_8 x_1^2 x_2^2\end{aligned} \tag{33}$$

As the scores are arbitrarily scaled, α_0 can be set to zero. In practice, it would be difficult to fit all the remaining parameters to real data. They will be intrinsically correlated as they are fitted to same variables, albeit transformed. Therefore it seems sensible to focus on the lower order parameters, but allow at least one interaction term. Hence the last 3 terms (α_6- α_8) were not fitted (assumed to be zero). Further research may indicate more parsimonious or better representation of this utility curve.

The fishers current catch and current effort in the preference model is set to 1.0. So the scenario **I** is (1.0,1.0), scenario **G** is (0.5,0.5) and so on. The relative catch and effort for the fishery compared to the present can be calculated from the simulation model. This relative change is assumed the same for fishers. Given the overall catch and effort is set as c_t and f_t as proportions of the current catch effort at time t respectively, the fisher's score becomes:

$$U_t = \alpha_1 c_t + \alpha_2 f_t + \alpha_3 c_t^{\ 2} + \alpha_4 f_t^{\ 2} + \alpha_5 c_t f_t \qquad (34)$$

where the parameters are estimated from a least-squares fit to the scenario scores. Graphs of the scores estimated from the scenario ranking method can be found in the software (Figure 3).

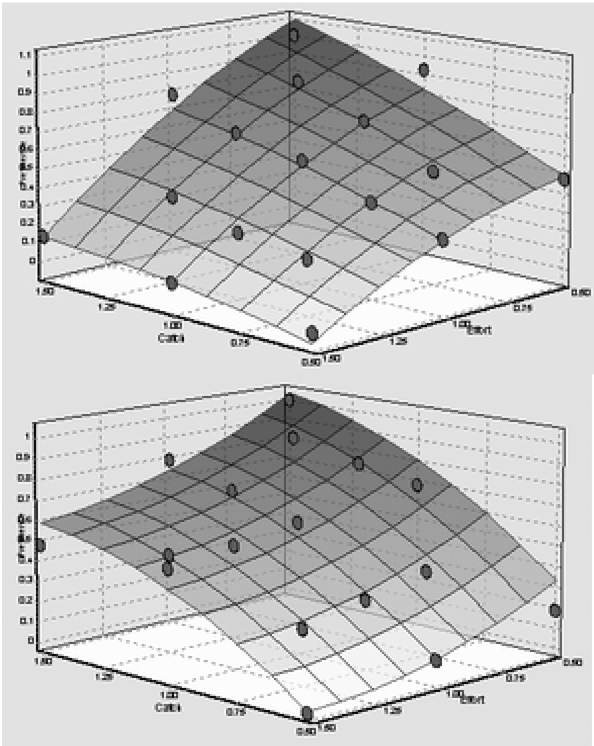


Figure 3 Example preference curves fitted to interview data. In cases of point outliers, the interviewer could check with the interviewee that the scenarios are in the right order. They may also be evidence that the model is too inflexible for good individual curves.

Where there are more than one species, the change in the overall catch (c_t) is calculated as the weighted average of the changes in individual species. The more important a species is to a fisher the higher the weight. These weights could be the current proportion that each species makes up of the total catch or the catch value, or based on a preference score obtained in a similar way to the scenarios.

4.5.8 Price Cost Ratio

As an alternative to the interview preference, a simple linear price-cost function is provided. The global price-cost ratio function requires a single Price : Cost Ratio parameter (PCR) which weights the proportion change in catch relative to the proportional change in effort from the current situation such that:

$$U_t = \alpha c_t - f_t \qquad (35)$$

If the score is proportional to profit, the weight might be calculated as the current value of the catch divided by the current catching cost: PCR = α = (Price*Catch)/(Effort*Cost). Clearly, the higher the PCR value, the more important changes in catch are relative to changes in effort. The default value is 1.0, so, for example a 10% increase in catch coupled with a 10% increase in effort will be viewed just as good as no change in either. The function is provided mainly as exploratory tool to allow some analysis before interviews are completed. Alternatively, even without other interviews being conducted, a user can conduct the full preference interview to obtain some reasonable preference curve.

4.5.9 Calculating the Discounted Preference Score

Given a time series of projected catch and effort changes (c_t, f_t), the time series of preferences can be obtained. The discounted mean preference score is calculated as:

$$U = \left(\sum_{i=1}^{n} \sum_{t=0}^{T-1} P_i U_{it} e^{-\delta t} + \frac{U_{iT} e^{-\delta T}}{1-e^{-\delta}} \right) \Big/ n \qquad (36)$$

where U_{it} is the preference score of fisher i at time t, P_i = the fishers importance (if used) and δ = discount rate. Importance weights a fisher's score, and could represent the importance of the fishery to his/her household income and the size of the household. The discount rate can be obtained for each fisher, or a global discount can be used. Note the sum only has to be continued until an equilibrium state is attained (i.e. c_t and f_t no longer change) at some time T, where after the infinite sum can be calculated. The mean score is the total divided by the number of fishers (n).

The target reference point is found by maximising this mean preference score.

4.5.10 Other MADM Approaches

As in other approaches, the scoring method allows hierarchical structuring consistent with many other multi-attribute decision making methods. In principle it would be possible, for example, as well as the overall effort (days working) score, but separately to score different types of effort (each gear for example) in the same way as the catches might be broken down by species. Although such structuring does make it seem possible to construct quite complex models suitable for interview, obtaining information on all these factors is time consuming. Even getting the basic information suggested in the interview (see section 4.6) was difficult and led to interview fatigue for many fishers. While more information might be desirable, it would probably have to be obtained using a staged approach and would no longer be so rapid. It could form part of an adaptive management programme however.

A variety of methods for obtaining utility measures were considered. The following were tested, but could not be understood by the fishers and were simply too time consuming:

- Gambling games: the point where a person expresses indifference between a fixed payment (or loss) and a gamble (e.g. tossing a coin for two other payments or losses) means the two options have the same expected utility.

- A scoring technique known as Analytical Hierarchical Process (AHP) was tried. The technique uses pairwise comparisons to obtain a ratio score indicating how much more one option is preferred relative to another. It is widely used in business for decision-making.

The AHP pairwise approach and similar hierarchical score weighting methods were used as the basis for the current approach.

Ranking rather than direct scoring was found to be the only scoring method that worked. Fishers were not able to give preference ratios, for example. That is, it was not possible for them to say one option was even twice a good as another, let alone discriminate at accuracies to 10%. Instead, they were in many cases, but not all, able to say whether the difference was relatively large or not and scale this difference on a value of 0-4. Because the ranking means such differences are cumulative, this scaling could only be linear. This was born out with checks by asking for preferences amongst scenarios which were not consecutive among the ranks. The scoring between these was nowhere near that required for ratio scores.

4.6 The PFSA Interview Technique

4.6.1 Introduction

Rapid Rural Appraisals have been widely used to collect valuable information for a wide variety of co-management projects, and serve as a background for the Participatory Fisheries Stock Assessment (PFSA) technique. Originally developed for terrestrial and agriculture studies in the developing world, RRA's are a multi-disciplinary, semi-structured and comprehensive research method, which has been widely adapted to fulfil a variety of information roles. There are several types of RRA commonly used including Participatory Rural Assessment (PRA), Topica and Monitoring RRA's (McCracken *et al*, 1988). The PFSA technique uses a PRA approach.

Participatory Rural Assessments are designed to foster community involvement in management in all stages of project development and assessment. PRA's are designed to be empowering to local people, awakening the development potential of a local community (Dovie, 2003). Such assessments facilitate management through meetings and discussion with key representatives of the scientific, local community and other stakeholders (i.e. environmental NGO's, local community groups, commercial/recreational interests, indigenous peoples etc.) to develop effective management strategies (Crosby *et al*, 2002). The stake holders are identified as part of the RRA and subsequently involved in all stages of the process. The techniques applied are generally quick and cheap in collecting valuable information, as opposed to longer-term projects which can be expensive. This can make them especially useful for managers working within tight budget and time constraints.

A properly conducted project will assess development needs, priorities, consider feasibility, actions and community based monitoring. Interview data is the key source, and other data sources can be included where they are available (published and unpublished research data, aerial photographs, maps etc). The interviews are semi-structured and informal, but bias should always be avoided and standardisation is an important consideration (Pido, 1995). They may also include analytical games such as ranking by conducting two-way comparisons and producing a ranked list of preferences. By including other data and opinion a workable solution can be identified. The aim of any successful RRA is to involve local people in decision making (McCracken *et al*, 1988; Dovie, 2003). Most successful PRA's involve a structured process of preparatory activities, identifying key informants to work directly with the PRA, a semi structured interview, and finally a dissemination workshop and open forum (Pido, 1995).

PRA's have been successfully adapted to a variety of fisheries management projects (Ali, 1995; Pido, 1995; Aiken, 1999, Mahon *et al,* 2003), collecting valuable socio-economic information and data on fishers, landing sites, gears, middlemen, as well as fisheries targets and size-frequency data. Most follow the principles of identifying stakeholders, fishers and key contacts to facilitate information collection, a semi-structured interview process and a strong focus on dissemination back to the stakeholders.

In theory, interviews should be based on a random sample of fishers. To do this, a list of all fishers is required before starting. In practice, it may be rather more important to attempt to collect a "representative" sample acceptable to the fishing community. The sample can always be expanded as fishers come to understand what is being attempted and wish to join the process. The sample can always be stratified between those who wish to be interviewed or are identified by government as appropriate interviewees, and a random sample of others who otherwise may form a voiceless majority.

4.6.2 The PFSA Semi-Structured Interview

The interview technique developed by the Participatory Fisheries Stock Assessment project obtains information directly relevant to stock assessment, forming an important part of the co-management process and actively involving fishermen in the decision making process.

The interview involves two distinct components which can be considered alongside existing scientific data where appropriate and can be split if necessary:

- Stock Assessment Interview
- Preference Interview

The stock assessment interview poses questions directly relevant to the stock size and status now, in the past, and in future. These are used to form a picture of how each fisherman perceives the fishery and its behaviour. The preference interview allows each fisherman to consider their current situation against a variety of other scenarios that may be brought about by changes in catch and effort. These scenarios are then ranked and scored so that they form a representation of the individual's preference.

To date the technique has been field tested in Zanzibar (East Africa), and The Turks and Caicos Islands (TCI). In Zanzibar two distinct reef fisheries were assessed in-conjunction with the Institute of Marine Science, and in the TCI the Queen Conch (*Strombus gigas*) fishery was assessed in-conjunction with the Department for the Environment and Coastal Resources (DECR). The advisories submitted can be found in the appropriate field reports.

The field testing of the PFSA methodology has shown that the technique is effective and adaptable, and provides valuable additional data that can increase the scope of fisheries management globally by providing a rapid method of stock assessment (which is currently limited), whilst facilitating co-management and encouraging better management practices. It is hoped that this technique will now be used widely in future stock assessment, and it is the aim of this document to aid field workers to overcome some of the problems and issues that may be encountered when using the two interview stages of this technique.

4.6.3 Interview Steps

4.6.3.1 Identify the fishery and the fishers

The first step when undertaking the PFSA interviews is to identify the fishery of interest (reef fishery, pelagic fishery, long line, trap, gillnet etc) and deal only with the single fishery during the course of the interviews. Discussion involving other fisheries would only confuse matters.

4.6.3.2 Introducing the PFSA and encouraging participation

The PFSA interviews could be conducted by arriving at a landing site and beginning with available fishers. However, experience has shown that introducing the technique to fishers before conducting the data collection may ensure better participation and fit more within the framework of co-management which PFSA should help to promote. This can be achieved through village meetings or by involving PFSA in pre-arranged events such as workshops which may already take place. Organising a village meeting will vary between locations, though there is usually a local protocol for establishing such events such as visiting the village She ha, fisheries officer, spokes person etc. This will allow a time and location for the introduction to be set and should ensure good participation.

4.6.3.3 Initial interviews

An important consideration when using the PFSA technique is to trial the method before collecting field data. The interview method can be learnt quickly, and conducting some preliminary trial interviews will aid the interviewer to establish their interview manner and identify potentially ‘leading’ or ‘biased’ presentation. Ideal subjects include persons with prior experience of the fishery in which you are interested (ex-fishers, fisheries officers, researchers etc).

During this period the researcher can also identify ways of increasing the rate of data collection by involving persons who have experience in the fishery. If the researcher does not have strong links with the fishing community, identifying key informants such as fisheries officers, beach recorders or a village spokes person/head-man to aid introductions to fishers. This can rapidly increase the number of fishers who will agree to participate, and will also reduce the time needed for locating individual fishers and thus the total time needed for the data collection phase of the project.

Other considerations at this point may include any logistics. In some locations fishers can be located on foot and are found in concentrations at landing sites or simply within the community. However, there may also be situations where fishers are more widely dispersed (particularly in artisanal fisheries) and less accessible. This may require that transportation be factored into the research programme as well as the additional costs that this may infer to the overall budget. Or there may be specific seasonal windows when data may most rapidly be collected. This may include periods of rough weather or lunar phase when fishing activity is reduced and more fishers will be readily available for interviewing.

Interviews can also be aided by developing a list of all fishers in the fishery as the basis for sampling. This provides valuable information on how many fishers there actually are, will provide some indication of how many you intend to interview, whilst aiding fisheries officers or fishers to suggest who the next person to interview at a particular time should be.

4.6.3.4 The Interviews

Once a meeting or at least introduction to the work you plan to undertake has occurred, and the interviewer is happy with presenting the questions and recording the data then the interview phase proper can begin. Opening interviews may still be part of the learning process until the technique is completely familiar. If specific time periods for the interviews have been agreed with fishers then these should be adhered to.

Data can now be collected intensively by spending time in the field over a set time period (as maybe the case if the data collection is undertaken by a visiting researcher), or extended over a longer time frame if the researcher is a resident fisheries officer or similar. Ideally time in the field will be maximised so as to complete the data collection rapidly as part of the rapid stock assessment technique. Typically a researcher will visit an area daily and complete as many interviews as can be undertaken during a day. The number completed can be expected to vary depending on fisher availability. The location of the interviews may also vary. Ideally a fixed location including a desk will best serve data collection, but only where fishers are readily available. More often the researcher will conduct the interview after locating the fisher, with the interview taking place in a house or at some communal gathering point.

4.6.4 Interview Questions

The aim of the questionnaire is to extract from the fisher his/her view on the state of the stock, its productivity and preferences with respect to catch and effort and catch composition. The interview represents the core questions for developing prior probabilities and preference scoring for stock assessment. Additional questions could be added for other purposes, however the current questionnaire is already a considerable undertaking and additional questions would probably best form part of a separate interview. Most information is obtained indirectly. Direct questions, such as ‘Do you think the stock is overfished’, suffer not only from potential political bias, but also have an unclear meaning. However, indirect questions could lead to over-interpretation from the fishers’ point-of-view. Care is needed in presenting the results of the analysis and in discussing their meaning.

Questions apply to one fishery only. Separate questionnaires should be conducted for each fishery, although some data, such as preference information, may need to be only collected once.

The following section introduces each question contained within the interview, the purpose of each question, and how the question may be presented by a researcher. Examples of question presentation and some additional alternatives are given where necessary, though some are considered straightforward. It may be useful for the researcher to have a copy of the actual interview to hand to aid this exercise. Key words are highlighted where necessary.

Units: Effort, Catch, Time

Purpose: These are not questions, but identify the units of catch and effort used for this fishery. Units should identify those most easily related by the interviewees. For example, a month may be better than a week in terms of assessing catch or effort. Units of effort may vary for each gear. However, some common currency is necessary to allow exchange between them. This is almost always a fishing (person or boat) day. Where there is only one gear, other units may be chosen and the wording changed in the questions accordingly.

Catch may be measured in baskets, bunches, kilos, lbs etc. Units themselves are not important, but must be those usually used by fishers and consistent throughout all interviews for each fishery. Where necessary, conversion factors may need to be estimated. Units of time can be chosen to allow easiest assessment. The units should allow fishers to understand the changes in effort and catch in the questionnaire and appreciate the impact of these on their working life and income. The time unit should be no less than a week, and no more than a year.

Presentation: Discussions with the fishers in preliminary meetings in the fishery will quickly allow the units to be set for effort, catch and time. These will then be used throughout the remainder of the interviews and are a standard common to each interview.

Section A: Stock Assessment Interview

Q1) For how many years have you been fishing?

Purpose: This can be used as a weighting factor, as older fishers have greater experience. Years are probably best estimated by getting the fisher to relate when s/he started fishing to major historical events.

Presentation: Straight forward, but it may help to involve land mark years with older fishers to aid memory.

Q2) Which is your main gear, the one you are most familiar with?

Purpose: This gear is referenced throughout the rest of the interview. Other gears the fisher may use are compared to it.

Presentation: Straight forward, simply interested with the gear that the fisher relies on the most when fishing in the fishery you are concerned with.

Q3) Normally, how many sets/hauls do you make in one *unit of effort*?

Purpose: This allows the relative CPUE between fishers to be measured. A day's fishing could, for example, consist of hauling 20 or 200 traps (or alternatively setting a series of nets). The catch from 200 traps would be expected to be significantly larger. This should only apply where a number of gears are used. For example, numbers of fishers per boat, if boat days are the recognised measure of effort. If there is little or no variation between boat days, this information is not necessary.

Presentation: Substitute the unit of effort as interpreted earlier in the interview (beginning of the interviews) into the question. For example:

"How many traps do you haul in one *day*?"

Q4) In each *unit time*, how many *units of effort* do you usually spend fishing in this fishery?

Purpose: This establishes the normal working activity in this fishery from this fisher. It is used as a bench mark in the assessment of preferences. Obviously, the number of effort units will be constrained by the unit of time. So, for example, you cannot have more than 28 fishing days in a lunar month.

Presentation: Substitute the *unit of time* and *units of effort* for the standards set for the fishery. For example:

"In a *year*, how many *days* do you usually spend fishing in this fishery?"

Q5) How many *units of effort* did you actually fish this last year?

Purpose: This is used in the stock assessment to estimate this last year's effort. This should be an estimate of the actual fishing time rather than some measure of normal activity.

Presentation: Substitute the *units of effort* with the standard set at the start of the interview. For example:

"How many *days* did you actually fish in the last year?"

Q6) Normally how many *unit catch* do you catch in one *unit effort*?

Purpose: This is the current fisher's CPUE. It is used both in the preference and stock assessment. The fisher may need help in defining the average, for example, by working through his higher and lower range CPUE. It is also important the catch is well-defined.

All catches should be included. If required, the catch can be distributed among the catch categories (A,B,C,D). Even if the assessment will not be multi-species, a breakdown of catches into large and small fish may provide useful information.

Presentation: Substitute in the units of *catch* established at the beginning of the survey. Example:

“Normally how many *kg’s* of finfish do you catch in one *day*?” or “How many *lbs* of cleaned conch do you land in one *day*?”

If dealing with categories then phrase the question to address each of them.

Q7) Over the last few years, has your catch rate been about the same, declining or increasing?

Purpose: This allows the fisher to indicate whether the stock is at approximate equilibrium, or has been changing. If change has occurred, the next question is required to assess how much the fisher believes the catch rate has changed in one year. It is important for the fisher to remove any effects other than population size. The interviewer will need to check that changes in catch rate cannot be attributed to changes in gear or fishing practices.

Presentation: Self explanatory question

Q8) If the catch rate has been changing: In the same season last year, normally how many *unit catch* did you get in one *unit effort*?

Purpose: This assesses the fisher’s perceived CPUE last year and is used to adjust the model to allow for changes in stock size. Long term perceptions of trends should be obtained first, then related to changes over the last year. It should be verified that changes in CPUE are not due to changes in gear, fishing practices and so on. CPUE here is being used only as an index of stock size. If practices have changed, the fisher could be asked if he had applied his current practices last year, whether he would have expected a change in CPUE. Finally, it could be assumed no change occurred (i.e. the fishery is at equilibrium).

Presentation: Only need an answer here if the catch has changed. If the catch has changed then substitute in the units of *catch* and *effort* as in previous examples. For example:

“In the same season last year, how many *kg’s of fish* did you catch in one *day*?”

Q9) If you were to fish in a fresh ground (never fished before or like the old days), normally how much fish do you think you would catch in one day? (Get an estimated range)

Purpose: This is used to estimate the unexploited stock size. The value is compared to the current catch rate (question 0). The current catch rate divided by the unexploited catch rate indicates the current state of the stock assuming the CPUE is proportional to stock size. More generally, the answer indicates the fisher’s perception of the state of the fishery. The answer may need checking.

Presentation: It should always be greater than the current CPUE. If the fisher’s interpretation of the question is that the ground hasn’t been fished because its poor, his answer will be incorrect. Emphasize that the ground is like the one the fisher uses now, but as if nobody had ever fished before. A range is required to indicate a level the population might reach when it is effectively indistinguishable from the unexploited level.

Example:

“If you were fish an area of reef where nobody had ever fished before how many fish could you catch in one day?” and “What would be the most you think you could catch in one day? And what would be the least you would expect?”

Q10) If fishing were to stop tomorrow, how many months or years do you think it would take for the fish stocks to recover fully? ….or as close as possible to what it was before fishing started

Purpose: This indicates the rate at which the fisher expects the resource to increase. The higher the rate, the higher the productivity and the higher the sustainable catch. The fisher may not appreciate this interpretation. Fishers may well have direct experience of fishing ground recovery as they often leave and return to particular grounds. However, such recovery rates may be more closely related to immigration rates rather than population, so that this interpretation will be implicit in the model.

Presentation: The question aims to get an estimate of time to relate to the complete recovery of the fishery.

Example: “If fishing were to stop tomorrow, how long would it take for the number of fish to return to the number present before fishing began?”

Q11) Do you think the amount of fishing for the size of the resource: could be greater, is just right, is too much?

Purpose: This will indicate the general concern over the fishery. If the stock assessment indicates overfishing, but fishers generally say there could be more fishing, you can expect some resistance to the stock assessment results.

Presentation: **Self explanatory question**

A.ii Constraints

The following questions define minimum and maximum constraints on the preference scores. This prevents the model identifying optima in locations outside the possible range. Minimum constraints are related to the opportunity costs of alternative livelihoods and maximum constraints to logistic limits. However, these constraints do not define, for example, the minimum income required from the fishery to feed a family. These sorts of limits should be picked up by the preference scores.

In general, accurate estimates of the minima and maxima are not required if they are far from the current situation (i.e. greater than or less than 50% of the current CPUE or catch), as they will probably never be met.

Q12) What is the minimum average *unit catch* in one *unit effort* you would fish before switching to an alternative livelihood?

Purpose: This defines the minimum utility from fishing and is essentially the opportunity cost of fishing. If there are effectively no immediate alternatives this can be set as zero by default.

Presentation: Substitute in the units established earlier in the interviews. For example:

"What are the minimum average *lbs* of conch you would fish in one *day* before switching to an alternative livelihood?"

Q13) What are the minimum average *units of catch* in a *unit of time* you would accept before switching to an alternative livelihood?

Purpose: This defines the opportunity cost of the total utility from this fishery. This should be considered separately from question 0 above. For example, a very high catch rate, but only allowing one day's fishing may not match the income from some alternative employment. If there are effectively no immediate alternatives this can be set as zero by default. Similarly if a fisher can easily switch to other activities when he is not fishing, there is effectively no minimum.

Presentation: Substitute in units of catch and time previously established.

Example:

"What are the minimum average *number of fish* you would accept in a *lunar month* before switching to an alternative livelihood?" or alternatively, "What is a low number of fish you would catch each day during a lunar month that would make you consider switching to an alternative livelihood?"

Q14) What is the maximum *unit catch* in one *unit effort* you could cope with, with your current gear?

Purpose: This allows the fisher to define a constraint on the maximum catch he can cope with. For example, limited boat storage capacity may mean early departure from the fishing grounds rather than higher catches on a good day.

Presentation: Substitute in the units previously established. For example:

"What is the maximum number of *lbs of conch* you could collect in one *day* with your current *boat*?" or "What is the maximum *number of fish* you could cope with in one *day* with your current boat?"

Q15) What are the maximum number of this gear you could haul / set in a *unit effort*?

Purpose: This places a realistic limit on the gear which can be set. For example, number of traps which can be hauled, or number of fishers which a boat can hold. Relevant to traps, nets and set long-lines, less so to handline/collection fisheries. Only applicable to fisheries where the gear is set and left.

Presentation: Substitute in gear and effort units. For example:

“How many *traps* could you haul in one *day*?” or “How many nets could you *set* in one *day*?”

Q16) What are the maximum *units of effort* you could apply with your current gear(s) in a *unit time*?

Purpose: This defines any constraints the fisher perceives on increasing effort. In particular, effort may be limited by weather and season and by the length of the *unit of time*. For example, if the fishery operates the 2 weeks around new moon, the maximum effort would be 14 days. Management controls allowing effort to exceed 14 days will have no effect. **Presentation:** Substitute in the units of effort and time previously established. For example:

“What are the maximum *number of days* you could fish with your current gear in one *year*?”

A.iii Other Gears

Q17) Other gears

Purpose: This summarises the CPUE and activity of other gears used by the fisher in this fishery. In particular, a reference point (current fishing practice) and possible constraints are required. (Only gears used in this fishery should be included, not gears used for other fisheries.)

Presentation: These are the same questions (q’s 3-6, 16) as for the main gear.

Section B: Preference Interview

B.i Background

Q18) Including you, how many people are in your household?

Purpose: This should indicate all dependents on the fisher. This can be used in weighting the preference.

Presentation: Self explanatory

Q19) What proportion of your household income depends on your catch from this fishery?

Purpose: This should indicate the fisher’s contribution from this fishery as a proportion of the household income. Income to the household from other people or from other fisheries must not be included in this proportion, only in the whole. This can be used in weighting the preference.

Presentation: Straightforward, though it can be beneficial to determine what other sources of income to the household exist through additional conversation.

B.ii Discounting

Q20) If you use an interest paying deposit account in the bank for your savings, what annual interest is paid?

Purpose: The discount rate is related to bank interest rates, loan rates and so on. However these are bound up with issues such as money supply, risk and other non-local effects. Although the bank rate can be used as an indicator of discount, it may be quite different to the true discount rate of the fishing community. Many fishers don't use bank accounts, or may not know the rate of interest.

Presentation: self explanatory

Q21) What is the time delay indifference point between current 1 month earnings now and 1 month earnings + 20%:

Purpose: This question aims to estimate the fisher's discount rate. The discount rate indicates the rate at which the future is devalued. Nobody realistically takes account in their day to day living of what will happen in thousands of years, and few of us take much account of what will happen beyond the next twenty years. Discounting is a simple way to adjust future values to represent more realistic estimates of true values. The discount rate is related to bank interest rates, loan rates and so on. However these are bound up with issues such as money supply, risk and other non-local effects. Although the bank rate can be used as an indicator of discount, it may be quite different to the true discount rate of the fishing community. It is therefore better, if a reliable method can be found, to obtain the discount rate from the fishers themselves.

Presentation: To obtain an estimate of a person's discount rate, it is necessary to separate it from other issues. In particular, in testing for indifference between to outcomes, only the time delay should vary, rather than the two scenarios being compared. This prevents the comparison being confounded with utility.

For example, a simple question would be: Which would you prefer more, $100 now or $120 in 1 year's time. If the interviewee prefers $120 in 1 year, the delay should be increased and the preference obtained until the approximate indifference point is identified. This can most easily and quickly be found by bracketing the point and repeated bisection (see box).

It was found in tests that the simple question posed above without further information did not work. Fishers found it difficult to think abstractly, so answers could be quite wild as they were interpreting the comparison in different ways. It is much better to find some activity which they actually do, such as saving schemes, and define two schemes which have a fixed quantified difference in payout which does not vary over time. By looking for the indifference point between schemes by varying the delay of the payout, the discount rate can be defined (see box).

Example: Using a savings scheme *Opato*.

There are two identical savings schemes which you are invited to join. In both you save the same amount each month and the payout is 50000 each month to one of the members. Payouts follow a sequence order of members: from the first to last, then back to the first again. Each has the same number of members and the same rotation time between pay outs. In the first, you get paid immediately. In the second, you are 24th in line and so must wait 2 years for your payment, but the local hotel has added a bonus to support it, so the payout is a little more, 60000. Which would you prefer?

The indifference point can be most rapidly found through bisection of a bracket. The "bracket" is the pair of values within which the indifference point must lie. If the interviewee rejects 24th in line, then the bracket is 0 and 24. If necessary, double the number in line until the interviewee prefers the first scheme. Now the bracket encloses the indifference point. Bisect the difference and check in which half the indifference point lies. These become the new bracket. Repeat this process until the interviewee finds it too difficult to choose or the bracket is very small.

For example, the following table shows a series of preference selections for different places in line of the *Opato* scheme.

Second Scheme	Interviewee's	New Bracket	
Delay	Answer	Low	High
24	Reject	0	24
12	Reject	0	12
6	Reject	0	6
3	Accept	3	6
4	Accept	4	6
5	Reject	4	5

Answer: 4.5 months

B.iii Catch and Effort Preference

The catch and effort set consists of various scenarios representing the effort applied and catch obtained within the defined unit time.

The time unit is important as preference will vary with the time chosen. For example a fisher may prefer a high catch rate, but probably not if this was achieved by limiting his effort to one day a month. The time unit should be no less than a week, and no more than a year. In general, a month is probably the best measure as it allows more variability in effort and catch, but a unit should be chosen with which the fisher feels comfortable.

As in the discounting question, some level of abstraction is necessary to avoid fishers getting bogged down in the minutiae of fishing. Comparisons are always made with current practice and catch, including degree of variability. However, fishers will need to ignore the constraints, as these are taken into account elsewhere. For example, if a fisher cannot undertake more effort because of weather, we are still interested in his preference for doing so if this constraint was removed. This is because the preference for impractical scenarios still has an influence on the shape of the preference curve within the feasible region.

There are 17 scenarios with different levels of catch and effort measured as a difference from the current catch and effort levels for each fisher. The various catch scenarios are firstly ranked for preference. Then the relative scores between scenarios are recorded depending on how much one is liked over another. Scenario **I** represents the fishers current catch and effort.

Ranking the 17 scenarios is most quickly done using the binary tree. After comparing two scenarios, if the non-tree scenario is preferred it goes down the left branch and is compared with the next scenario in line, or if is less preferred it goes down the right branch. Comparisons continue until a free place in the tree is found.

The start points for each scenario in the tree are illustrated in the diagram. Only scenarios **E**, **G**, **F** and **H** could be compared to the current situation (scenario **I**). Scenario **B** starts with **N**; **J** and **K** with **O**; **M** and **L** with **Q**; and **D** with **P**.

In fact, scenarios **E**, **F**, **G** and **H** should all be worse options than the current situation unless there are constraints. For example, if the fisher prefers **G** to **I**, there is nothing stopping him reducing his effort and making scenario **G** his current option. He might not be able to do the same with scenarios **E** and **F** as his effort may be constrained by weather, availability and so on. So, although his preference should be for scenario **I** on all these initial comparisons, it is worth checking this first to ensure the fisher understands what is required of him.

It is important to note that some scenarios are dominated by others and comparisons need not be sought from fishers unless to check his/her understanding of what is required. For example, a fisher should clearly prefer any scenario where he catches more fish for the same amount of effort. The ranking can be speeded up by recognising dominance when it occurs.

The binary tree only serves to aid ranking and has no other purpose.

Once all scenarios have been entered in the tree, the scenarios can be scored. During scoring it is worth confirming the rank order as with more thought a fisher may well change his mind. These are difficult questions that require consideration of many issues.

Scoring allows the fisher to indicate the degree of difference in preference between scenarios. It is quite possible that fishers are indifferent among some scenarios and have a strong preference among others within the ranking sequence. When ranking it should be made clear that they will have this opportunity. Therefore, they need not spend time ordering scenarios that they are essentially indifferent between.

4.6.5 An Example of a Preference interview

Here we consider a typical preference interview from start to finish taking into account each step of the process of determining the positions of different scenarios in the binary tree, and how the questions for each comparison were composed. This example is based on a real interview conducted in Zanzibar for a coral reef hook and line fishery. To aid understanding it is recommended that researchers try to follow each step of this case study as if they were undertaking the interview themselves.

Card **I** represents the fishers current catch and effort and serves as the start point for comparisons in the binary tree. The first step is to deduce the fishers normal catch and effort. This has already been determined in the Stock Assessment (Q7). So the fisher catches 17 fish/day, and spends (Q5) 20 days/lunar month fishing. (See Figure 2 for the different cards).

Therefore his normal catch is 17x20=340 fish/lunar month.

The pictures are then used to represent catch/lunar month for a variety of potential fishery scenarios. Card **I** represents 340 fish, and 20 days effort. Thus one fish image represents 340/4=85 fish, and one boat image represents 20/4=5 days. So the base units are 85 fish per 5 days of effort. These values can be used in all calculations and to represent the catch and effort comparisons to the fisher during the interview.

The questions can be presented in a variety of ways. The example here uses the number of fish and the amount of time the fisher will be fishing for, though in some instances fishers may have trouble with pure numbers and more explanation may be required.

It is often important to get the fisher to focus on the choice being made, initially the qualitative exchange. For example, when comparing Cards for scenarios **K** and **O**, the focus is on an increased catch with the same amount of fishing, or a decrease effort with the same amount of catch. Which would the fisher prefer, more income from this fishery or more time off to do other things. It is important that the fisher then considers the quantities involved.

Undertake the comparisons:

Start: Cards E and I

Q) What would you prefer: 510 (85x6) fish for 30 days fishing in a lunar month OR stay with the existing 340 fish for 20 days fishing?

A) Preference for I over E

Explanation: The fisher should prefer Card I which represents his current effort, otherwise he would be trying to fish more often, or there are some constraints that exist which prevent him from doing so. This comparison can be used to inform the fisher on what he should consider when undergoing the interview.

Cards E and Q

Q) What would you prefer: 510 fish in 30 days OR 255 (85x3) fish in 20 days?

A) Preference for Q over E

Explanation: The fisher is unwilling to fish everyday even though the catch rate (CPUE) is higher. He may have other responsibilities, know that he physically couldn't fish everyday etc.

Cards E and P

Q) What would you prefer: 510 fish in 30 days OR 170 (85x2) fish in 20 days?

A) Preference for P over E;

Explanation: Even though the CPUE is even lower in scenario P, the fisher would still be willing to accept this rather than spend all of his available time fishing. He values the time he needs for other work/activities

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Cards E and C

Q) What would you prefer: 510 fish in 30 days OR 170 fish in 30 days?

A) Preference for E over C;

Explanation: There is no need to undertake this comparison as C represents the worst case scenario offered by the questionnaire.

Now repeat the exercise with card F

Cards F and I

Q) What would you prefer: 425 (85x5) fish for 25 days (5x5) effort in a lunar month OR 340 fish for 20 days effort?

A) Preference for F over I

Explanation: The fisher was willing to work that much harder for the extra catch, although in reality he found that weather constraints prevented him from doing so.

Cards F and Q

Q) What would you prefer: 425 fish (85x5) for 25 days fishing OR 425 fish for 20 (5x4) days fishing?

A) Preference for Q over F

Explanation: Even though the fisher would have caught more fish in the lunar month if he preferred F, the catch rate in situation Q is higher. Therefore the fisher would prefer higher catch rates and lower effort in this comparison. F is written into the tree.

Cards I and H

Q) What would you prefer: 340 fish in 20 days or 255 (85x3) fish in 15 (5x3) days?

A) Preference for I over H

Explanation: The fisher was not willing to accept a lower total catch with a proportional reduction in effort. This is due to the need to maintain income at its current level and the fisher is not willing to decrease this.

Cards Q and H

Preference for H over Q

Explanation: H can be automatically placed in the tree ahead of O as the catch rate is higher, even though the catch is the same the effort is not.

Cards I and G

Q) What would you prefer: 340 fish in 20 days OR 170 fish in 10 days?

A) Preference for I over G

Explanation: The fisher is unwilling to accept a 50% decrease in total catch even if the effort was halved and the catch rate remained the same.

Cards Q and G

Q) What would you prefer: 255 fish in 20 days OR 170 fish for 10 days fishing?

A) Preference for Q over G

Explanation: Even though the overall catch rate is lower in scenario Q, the fisher would prefer to catch more fish and accept a lower catch rate suggesting that a decrease in catch may have a negative impact on his current situation.

Cards P and G

Q) What would you prefer: 170 fish 20 days OR 170 fish in 10 days?

A) Preference for G over P. G is placed to the left of P in the binary tree.

Explanation: The fisher would have to work twice as hard for the same catch (a 50% reduction in catch rate).

Now continue the comparisons by moving towards the right of the binary tree:

Cards Q and L

Q) What would you prefer: 255 fish for 20 days fishing OR 340 fish for 30 days fishing?

A) Preference for Q over L

Explanation: The fisher would not be willing to work continuously for a slightly higher catch but lower catch rate.

Cards P and L

Q) What would you prefer: 170 fish for 20 days fishing OR 340 fish for 30 days fishing?

A) Preference for P over L

Explanation: Although the catch rate is higher in scenario L, the fisher is still unwilling to fish everyday.

Cards C and L, and E and L

Comparisons could be undertaken using the format described for most comparisons. However, L can also be automatically placed in the tree as L always represents a better scenario to C, and a worse scenario than E. This is due to differences in catch rate as the effort remains the same.

Cards Q and M

Q) What would you prefer: 255 fish for 20 days fishing OR 340 fish for 25 days fishing?

A) Preference for M over Q

Explanation: The fisher would be willing to work a few more days to ensure that his catch remained at its current level.

Cards H and M

Q) What would you prefer: 255 fish for 15 days fishing OR 340 fish for 25 days fishing?

A) Preference for M over H

Explanation: Although the catch rate is lower, the fisher would be willing to fish more days to maintain his current catch.

Cards P and D

Q) What would you prefer: 170 fish for 20 days fishing OR 255 fish for 25 days fishing?

A) Preference for D over P

Explanation: Neither of the scenarios were appealing to the fisher, but having to chose the fisher would take the higher catch even if it meant more time fishing.

Cards G and D

Q What would you prefer: 170 fish for 10 days fishing OR 255 fish for 25 days fishing?

A) Preference for D over G

Explanation: Neither scenario appealed, though the fisher would try for the higher total catch even if it meant exerting considerably more effort.

Now consider the scenarios to the right of the norm (scenario I):

Cards O and J

Q) What would you prefer: 425 fish for 20 days fishing OR 340 fish for 15 days fishing?

A) Preference for O over J

Explanation: The fisher would be continue to fish with the same effort as he does now and have a higher total catch, even though the catch rate in scenario J is much greater. The fisher does not need the additional time away from fishing to fulfil other needs.

Cards F and J

Q) What would you prefer: 425 fish for 25 days fishing OR 340 fish for 10 days fishing?

A) Preference for F over J

Explanation: The fisher would exert more effort to increase his total catch even though the catch rate (CPUE) is lower. However, he is unable to do this as weather constraints typically reduce the total time he can fish for.

Cards O and K

Q) What would prefer: 425 fish for 20 days fishing or 340 fish for 15 days fishing?

A) Preference for O over K

Explanation: The fisher would maintain his existing effort and gain a higher total catch at the end of each lunar month.

Cards F and K

Q) What would you prefer: 425 fish for 25 days fishing OR 340 fish for 15 days fishing?

A) Preference for F over K

Explanation: The fisher would be willing to work harder for more catch, even though the catch rate in scenario K would be considerably higher, but the total catch is lower.

Cards J and K

These scenarios can be ordered without asking the question as the same catch is obtained for less effort in scenario J.

End: Cards N and B

Q) What would you prefer: 510 fish for 20 days fishing OR 425 fish for 15 days fishing?

A) Preference for N over B

Explanation: The fisher would maintain his current effort for a higher catch. The extra time made available in scenario B is not as important as the total catch and thus the income generated.

The binary tree can now be collapsed and the order of the scenarios transcribed to Biii on the interview sheet (the catch and effort preference scoring). The pair-wise scoring relies on a 0-4 scale to determine how strongly the scenarios differ, however, most fishers may be unfamiliar with such a scoring method. To aid understanding, descriptive terms have been assigned to each of the 0-4 scores. The descriptions are shown on the data sheet.

Conducting the scoring:

The scoring is conducted in a similar manner to the preference placing in the binary tree. Once the tree has been collapsed and the preference ordered transcribed pair-wise comparisons are conducted:

Example:

Scenarios A & N

Q) Between these two situations you preferred A to N. If these were real situations would you:

0) Do not mind;
1) Prefer it somewhat;
2) Prefer it;
3) Strongly prefer it;
4) Very strongly prefer it?

This question is then repeated for each of the pairs: A-N, N-B, B-O,O-F, F-J, J-K, K-I, I-M, H-Q, Q-D, D-G, G-P, P-E, E-L, L-C.

4.7 Practical Application

4.7.1 Overview

The assessment consists broadly of three types of input which are combined to assess a set of decisions. The assessment consists of:

- Interview data which obtains the view of fishers and other stakeholders on the state and potential yield from the resource, and preferences among possible outcomes.
- Active data collection which allows rapid resource assessment in terms of current biomass and fishing mortality levels. This would most likely initially be done through a fishing experiment and resource survey.
- Other data compilation which brings to bear any other information on the issue which may be available, such as catch and effort data.

These separate sources of data are linked through mathematical models to describe common parameters. For example, population models may be used to convert answers given in the survey or catch and effort data to obtain biomass and catchability estimates. These sources of data and models are then used to build probability density functions which encapsulate all that is known about the parameters. These probabilities can be used to estimate the probability of the expected projected state of the stock under different fishing levels, and hence be used as the basis for a limit reference point.

These parameters, again through a model, define the outputs from the fishery, as catch in response to a control variable, effort. These variables are then converted to a preference score for the community. This allows the uncertainty in the parameters and therefore the risks to be taken explicitly into account. The management control can then be scored on the basis of its expected preference and a target control identified.

4.7.2 Policy and Management Objectives

Policy and objectives are presumed to have already been identified. These have been assumed in setting the target and limit reference definitions. Objectives are:

- To maintain fishing so that the probability that the biomass falls into an overfished state is at a particular level. The definition of "overfished" is defined by the limit state, and may be set to 50% of the unexploited biomass in most cases unless better information is available. The probability (1-50%) is a measure of management's risk averseness policy.
- To move fishing activity to a target level of fishing which has the highest expected preference for the fisher community based on the current uncertainty. Management may change issues such as how they measure fisher importance and whether it is used. They may also set a policy discount rate. A lower rate would favour lower risk policies.

Management should also plan what they will do if the stock becomes overfished, or fishing effort is between the target and limit, above the limit or below the target and so on. Management plans should address these issues in advance.

4.7.3 Control Variable

One or more variables under management control must have been identified which have an impact on the objective. This is limited to closed area, catch and effort controls in this case. For example, in many fisheries the numbers of fishers or fishing days could be limited, whereas catch could not. Fishers or fishing days would be the appropriate control variable. Other control variables, such as gear controls, would require other models besides the logistic model discussed here.

4.7.4 Survey Frames

An important prerequisite is information on the total system to be assessed. This information will be important in setting the sampling system and estimating totals. It could include:

- the number of households in the fishing community
- the resource area (i.e. a map of the fishing grounds and environs)
- numbers of fishers and boats by gear type
- annual catch by species or species group

4.7.5 Initial Assessment

The aim of the methodology is to be flexible, both in coping with a variety of types of fisheries, and dealing with the varied issues that may arise. This means the methodology could support any number of models, although only a limited choice is available through the current software. In defining the model linking information to the decision, an initial assessment is required focusing on community representatives.

The first job in the initial assessment will be to define precisely the issue to be resolved. In the simple example developed here, the issue is to define the optimal fishing effort which can be allocated among households. In theory it could be other more complex decisions, such as allocations of zones (seasonal closed areas), aid for the purchase of new fishing gear or boats, and so on.

Next the set of possible management actions needs to be defined. For example, while some management actions may be theoretically desirable, such as declaration of a distant closed area or a moratorium on fishing, they may be impossible to implement in practice. The set of possible management actions may be limited by a constraint (e.g. a minimum effort level which will be politically acceptable) or by type (e.g. mesh size or closed areas cannot be enforced).

As part of the assessment, the general fishery structure (map fishing grounds, list species/species groups, commercial, subsistence) will be required. This will form the basis for the questionnaire, to ensure questions are relevant and can be answered. The information would not only be from interview, but also some brief sampling from catches to obtain species groups, and assembling any other information, such as previous scientific work or maps.

Finally, the state of the stock must be linked to the set of possible management actions. This will be the result of an analysis of what information can be realistically collected as well as the issue and management options. Some issues may be intractable within a reasonable budget. For example, a decision which ultimately depends on ageing fish may be impossible to deal with unless a full ageing programme is conducted.

5 Outputs

5.1 Software, Source Code and Object Orientated Design

The software encapsulates the methodology and together with the help file, is the main output from the project. In the more complex fisheries assessments, the methodology and the software are synonymous (e.g. AD Modeller, Synthesis). So, although it is planned that the various parts of the method will be published, the methods will not get used unless this supporting software is provided. The software not only carries out the methods described, but the source code itself defines the specific methods more precisely than can be obtained from any report. The source code forms the most important part of the software documentation.

The software is written in Borland Delphi 7.0, an object orientated language. The object orientated design is not limited to the software (Table 2), but also conceptually is used throughout the method. Parameter frequencies, population models and generalized linear models are all self-contained units. It is not only possible to mix them in a variety of valid combinations, but they are more easily extended and updated. For example, additional population models can be added without affecting the fitting routines or other components. Similarly fitting routines based on MCMC rather non-bootstraps could be developed as an extension of the current source model structure.

It is hoped that an object orientated approach also helps users define and work with complex models. A significant problem in developing countries is the multispecies nature of their fisheries. Any currently available method (and those likely to be developed in future) will require large number of parameters to represent species change. As well as trying to reduce parameters, it is also of benefit to try to find a way to deal with this complexity. Reducing the problem into self-contained simpler components (parameter frequencies) that then interact at a higher level is a way to approach this. Each component can be checked and verified and, hopefully, understood by the researcher. If each component is proved correct, it should follow that the final results from the combined components are correct as well.

Table 2 The main software components used in the software. Components can be further extended and / or reused in other software.

Software Object Hierarchy	Purpose
Mathematical Functions (TMathFunction)	Handles general minimization, integration, and boundaries
Model (TModel)	Parameter handling Bootstrapping Likelihood, Names, hierarchies
Linear Model (TLinearModel)	Information matrix Linear regression
GLM (TGLM)	General iterative least squares Link and weight functions
Single Parameter GLM (TP1GLM)	Faster fitting for one parameter
Multivariate normal (TMultiNormal)	Handles covariance matrix manipulation and probability calculations
Kernel (TKernelPDF)	Handles frequency data and smoothing parameter estimation
Kernel List (TKernelPDFList)	Handles lists of kernels and posterior random draws
Combinations (TCombinations)	Handles likelihood matrix and supports matrix permanent calculation
Multispecies Model (TCommunity)	Handles species abundance model and individual species population models
Gear (TGear)	Simple knife edge selectivity, extensible to other selectivity models
Stock Assessment Interview (TStockAssessmentInterview)	Supports the stock assessment interview approach for the logistic model
Fisher Utility (TFisher)	Supports preference score calculation
Square Matrices (TSqMatrix)	Handles matrix data and supports matrix manipulations and calculations
Vectors (TVector)	Handles vector data and supports vector functions
Data Vectors (TDataVector)	Link vectors, shared data and transforms

5.2 Stock Assessment Method

The stock assessment methodology builds on current methods, but has some significant innovations. The population model hierarchical structure is a consolidation of current methods. The multispecies stock assessment method is new and PFSA is the only software which will fit it.

With the exception of the multispecies stock assessment model, all the population and generalized linear models are the same as those used in most stock assessments. Similarly, the simulation models are standard assessment approaches, albeit particularly interpretation has been placed on the simulations. The maximum likelihood fitting and non-parametric bootstraps are also standard methods chosen for their robustness and wide applicability.

Kernel smoothers have been used in fisheries assessments, particularly with transect density estimation and are widely used in statistics to smooth frequencies to represent probability density functions. Their use in calculating a posterior PDF has not been done as most interest is on other Monte Carlo approaches with parametric likelihoods. We are not aware of the multidimensional smoothing method being used elsewhere. As well as providing a common currency between information sources, modelling frequencies is potentially a very flexible non-parametric approach (e.g. adaptive smoothing).

The interview method and utility assessment are new, at least to fisheries. There has been little attempt to develop quantitative methods in interviews to derive these sort of data.

The reference point calculations follow standard principles. Although these particular ways of calculating reference points may not be in wide use, they are similar to those based on spawning stock biomass and other biomass indicators. They have been chosen due their requirement for as little data as possible.

5.3 Field Testing

5.3.1 Practical Test

The field test reports are in separate documents. These describe the detailed activities and results. For each of the three sites, data generated are stored in MS Excel spreadsheets.

The field testing was mainly used to develop and test the methods used to collect data. In particular, the interview method was developed in Tanzania, but also found to work for a very different fishery in the Turks and Caicos.

The other main rapid method was to use fishing experiments to estimate catchability. In summary the following was identified:

- Experiments potentially allow estimates of catchability and recovery. Recovery was not monitored properly on this field testing but should form part of future assessments.
- The experiments are best carried out on patch reefs. Indicators are now that fringing reefs allow significant immigration which is difficult and expensive to monitor. This was addressed using a tagging experiment. The scale of the experiment to estimate migration rates would have to be much larger and could only be done in a few cases.
- Scaling up an experiment to the whole stock needs checking. It is currently recommended that the assessment is limited to the experiment area and scaled up based on effort or area to the whole fishery. As long as these sorts of assumptions are ultimately tested, they are probably reasonable to start an adaptive management system.
- Experiments need not be repeated at all sites. Information from experiments can be shared through use of parameter frequencies.
- Experiments were useful not only to provide scientific information, but also to involve fishers in the assessment and provide common evidence for discussion. Observing their own catch rate decline was a significant reason for fishers to agree management action.

Results were generally accepted by fishers at presentations, although fishers invariable raised issues and constraints on the assessment. These were often astute observations and there were clear opportunities to involve fishers in designing experiments and monitoring results. There was universal appreciation for involvement them and the rapid feedback. Most fishers had not had feedback from scientific research even where it had been conducted.

The general co-operation and support suggests that the next step, implementation of management actions based on scientific advice, will be possible.

5.3.2 Turks and Caicos Islands Retrospective Analysis

When the project was reviewed in March 2002, concern was expressed as to the value of the stock assessment interview data. It was agreed to test the method on a fishery with good catch and effort data, so that the accuracy of the interview information could be compared with the standard stock assessment. In particular, it was of interest to see how well management would do if actions were based only on the interview data. The Turks and Caicos Islands conch fishery was identified as a suitable location because of its long catch and effort time series.

The fishery is managed through a quota, so this is the appropriate control. A standard stock assessment using the logistic model fitted to the catch-effort time series indicated the current quota of 1.675 million pounds as too high; and recommended lowering it to 1.6 million pounds landed weight. Using the preference information, the stock assessment based upon both the interview and catch-effort model combined and the catch-effort model alone suggest a lower quota around 1.53 and 1.38 million pounds respectively. Interviews by themselves are much less accurate (as indicated by the much lower limit control), but nevertheless recommends a target of 1.68 million pounds, reasonably close but above the other targets.

Table 3 Target and limit controls for the Turks and Caicos Islands Conch fishery based on catch-effort and interview data.

Scenario	Target Control	Limit Control
Interviews and Catch-Effort Model Combined	1531254.07	1580855.29
Interviews Data Only	1678103.40	791651.55
Catch-Effort Model Only	1384882.67	1432696.19

If it is assumed that fishers knew as much in 1974 as they do now, we can use the interview data as representative of what would have been obtained had the interviews been conducted at the beginning of the time series. Hence, the interview-only target quota can be applied at that point to see what might have happened to the fishery had this stock assessment method been applied, assuming that the logistic and maximum likelihood parameter estimates are correct.

The actual total catch over the period 1975-2002 was 45.47 million pounds. Had the 1.68 million pound quota been applied, the results suggest a total catch of 47.00 million pounds. This quota would realise higher catches in the longer term by foregoing higher catches in the late 1970s. A discount rate of around 5% yields approximately the same net present value between the two options.

The real gain, however, would have been the rise in catch rate (Figure 4). The catch-effort model suggests the stock was in an overfished state in 1974 and an enforced quota would have led to stock recovery. In other words, the catch would be met with much less work and costs than is now applied (from 3300 boat days down to 2500 boat days to realise the same catch). It indicates considerable benefits to using just interviews in this case, but would need more testing to make the case as a general statement. In particular, in cases where it turns out the logistic is not the best model, it needs to be shown that interviews may still have value in setting initial targets.

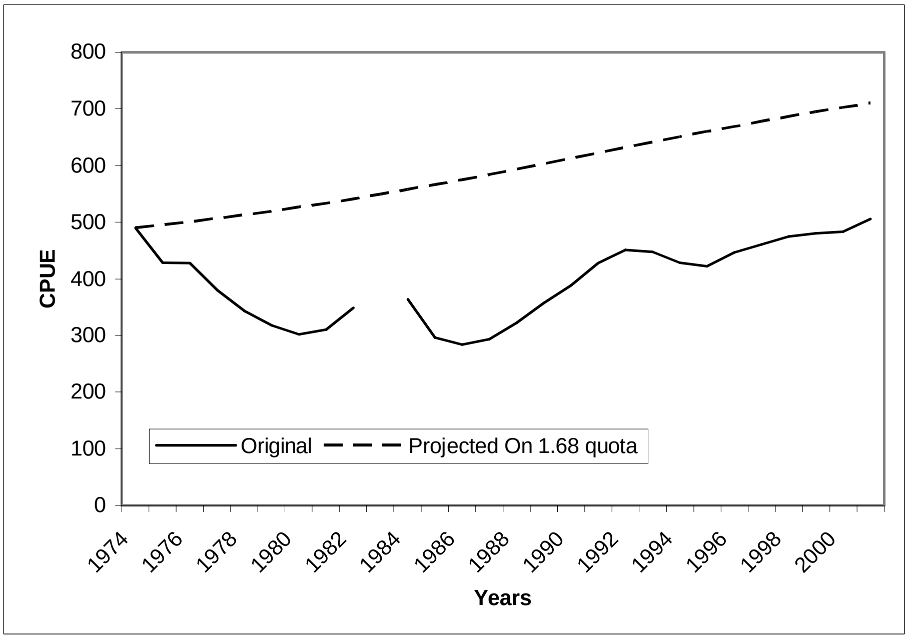

Figure 4 Expected catch per boat day (CPUE) from the fitted logistic model and the projected CPUE with 1.68 million pound quota.

The cost of applying the quota is that, without the depletion in the mid-1980s, less information would now be available on the behaviour of the stock, so that the current stock assessment would be less reliable. This would have to have been addressed through increased research activities.

5.3.3 Stock Assessments

Stock assessments were conducted at the three field test sites and management advisories were produced based on the target and limit reference points. The models (in the PFSA format) are also available with the software. The assessments used the techniques described.

6 Contribution of Outputs

6.1 Distribution

The software will be distributed on compact disks. The files, particularly the help file, are large and not suitable for distribution by email. The Institute of Marine Sciences will distribute the software to potential users in Tanzania.

Software will be further distributed through personal contact and workshops. The method will be introduced at Food and Agriculture Organization (FAO) and Caribbean Fisheries Unit (CFU) workshops where possible. CFU Workshops are planned from November 2003.

Interview sheet design and scenario cards suitable for printing will be distributed with the software.

It is planned to publish the multispecies stock assessment and kernel smoother methods as soon as possible. The papers will draw on the material in this technical report. The interview method will be published in co-operation with staff from the Institute for Marine Sciences, Zanzibar.

6.2 Necessary Further Testing and Development

There is a need to build up a track record to show the interviews are reliable enough to guide management in the right direction for the fishery. This can be done through further trials of the sort carried out for the Turks and Caicos Islands. Interviews will be needed for fisheries which already have a good stock assessment. Unfortunately, there are few fisheries in developing countries like this.

Otherwise, there is little point in continuing dedicated field testing. Although adjustment may prove necessary to the method to improve its reliability, it is clearly better in its current form than no assessments at all. Therefore it is recommended that the method begin application. The applications should be monitored so that adjustments can be made and the method improved while it is being used.

Continued testing will be undertaken using simulations and as part of normal stock assessment activities at workshops and elsewhere.

The next constraint to delivering the project goal is to implement a sustainable adaptive management system for each fishery. Fishers in Zanzibar agreed with the assessment and expressed interest in taking action. However, details on the appropriate management action were not agreed as the project did not have the resources to follow up the assessments.

6.3 Development of Local Expertise

The most cost-effective way to carry out rapid stock assessments is to use local staff. Unfortunately stock assessment requires expertise often not easily available. It is recommended therefore that small units of personnel are trained for carrying out assessments in each region. Assessments need only be conducted infrequently, so small numbers of dedicated personnel are probably adequate and more easily maintained.

The Institute of Marine Sciences (IMS) represents a potential source of expert personnel to form a stock assessment unit to serve the East African region.

Staff at IMS showed interest and aptitude for stock assessment. They were instrumental in development of the interview technique and were capable of conducting fishing experiments. Currently studies at IMS tend to be academic, and a re-balance towards more practical application of science would be of greater benefit to IMS and Tanzania.

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Appendix 1

Interview Sheet and Notes

The aim of the questionnaire is to extract from the fisher his/her view on the state of the stock, its productivity and preferences with respect to catch and effort and catch composition.

The interview represents the core questions for developing prior probabilities and preference scoring for stock assessment. Additional questions could be added for other purposes, however the current questionnaire is already a considerable undertaking and additional questions would probably best form part of a separate interview.

Most information is obtained indirectly. Direct questions, such as ‘Do you think the stock is overfished’, suffer not only from potential bias, but also have an unclear meaning. However, indirect questions could lead to over-interpretation from the fishers’ point-of-view. Care is needed in presenting the results of the analysis and in discussing their meaning.

Questions apply to one fishery only. Separate questionnaires should be conducted developed for each fishery, although some data, such as preference information, may need to be only collected once.

Units

These are not questions, but identify the units of catch and effort used for this fishery. Units should identify those most easily related by the interviewees. For example, a month may be better than a week in terms of assessing catch or effort.

Units of effort may vary for each gear. However, some common currency is necessary to allow exchange between them. This is almost always a fishing (person or boat) day. Where there is only one gear, other units may be chosen and the wording changed in the questions accordingly.

Catches may be measured in baskets, bunches, kilos, lbs etc. Units themselves are not important, but must be those usually used by fishers and **consistent** throughout all interviews for each fishery. Where necessary, conversion factors may need to be estimated.

Units of time can be chosen to allow easiest assessment. The units should allow fishers to understand the changes in effort and catch in the questionnaire and appreciate the impact of these on their working life and income. The time unit should be no less than a week, and no more than a year.

Stock Assessment Interview

For how many years have you been fishing?

This can be used as a weighting factor, as older fishers have greater experience. Years are probably best estimated by getting the fisher to relate when s/he started fishing to major historical events.

Which is your main gear, the one you are most familiar with?

This gear is referenced throughout the rest of the interview. Other gears the fisher may use are compared to it.

Normally, how many sets/hauls do you make in one *unit of effort*?

This allows the relative CPUE between fishers to be measured. A day's fishing could, for example, consist of hauling 20 or 200 traps. The catch from 200 traps would be expected to be significantly larger. This should only apply where a number of gears are used. For example, numbers of fishers per boat, if boat days are the recognised measure of effort. If there is little or no variation between boat days, this information is not necessary.

In each *unit time*, how many *units of effort* do you usually spend fishing in this fishery?

This establishes the normal working activity in this fishery from this fisher. It is used as a bench mark in the assessment of preferences. Obviously, the number of effort units will be constrained by the unit of time. So, for example, you cannot have more than 28 fishing days in a lunar month.

How many *units of effort* did you actually fish this last year?

This is used in the stock assessment to estimate this last year's effort. This should be an estimate of the actual fishing time rather than some measure of normal activity.

Normally how many *unit catch* do you catch in one *unit effort*?

This is the current fisher's CPUE. It is used both in the preference and stock assessment. The fisher may need help in defining the average, for example, by working through his higher and lower range CPUE. It is also important the catch is well-defined.

All catches should be included. If required, the catch can be distributed among the catch categories. Even if the assessment will not be multispecies, a breakdown of catches into large and small fish may provide useful information.

Over the last few years, has your catch rate been about the same, declining or increasing?

This allows the fisher to indicate whether the stock is at approximate equilibrium, or has been changing. If change has occurred, the next question is required to assess how much the fisher believes the catch rate has changed in one year. It is important for the fisher to remove any effects other than population size. The interviewer will need to check that changes in catch rate cannot be attributed to changes in gear or fishing practices.

If the catch rate has been changing: In the same season last year, normally how many *unit catch* did you get in one *unit effort*?

This assesses the fisher's perceived CPUE last year and is used to adjust the model to allow for changes in stock size. Long term perceptions of trends should be obtained first, then related to changes over the last year. It should be verified that changes in CPUE are not due to changes in gear, fishing practices and so on. CPUE here is being used only as an index of stock size. If practices have changed, the fisher could be asked if he had applied his current practices last year, whether he would have expected a change in CPUE. Finally, it could be assumed no change occurred (i.e. the fishery is at equilibrium).

If you were to fish in a fresh ground (never fished before or like the old days), normally how much fish do you think you would catch in one day? (Get an estimated range)

This is used to estimate the unexploited stock size. The value is compared to the current catch rate (question 0). The current catch rate divided by the unexploited catch rate indicates the current state of the stock assuming the CPUE is proportional to stock size. More generally, the answer indicates the fisher's perception of the state of the fishery. The answer may need checking. It should always be greater than the current CPUE. If the fisher's interpretation of the question is that the ground hasn't been fished because its poor, his answer will be incorrect. Emphasize that the ground is like the one the fisher uses now, but as if nobody had ever fished before. A range is required to indicate a level the population might reach when it is effectively indistinguishable from the unexploited level.

The lower bound must be greater than the current catch rate.

If fishing were to stop tomorrow, how many months or years do you think it would take for the fish stocks to recover fully? ….or as close as possible to what it was before fishing started

This indicates the rate at which the fisher expects the resource to increase. The higher the rate, the higher the productivity and the higher the sustainable catch. The fisher may not appreciate this interpretation. Fishers may well have direct experience of fishing ground recovery as they often leave and return to particular grounds. However, such recovery rates may be more closely related to immigration rates rather than population, so that this interpretation will be implicit in the model.

Do you think the amount of fishing for the size of the resource, is: could be greater, just right, too much

This will indicate the general concern over the fishery. If the stock assessment indicates overfishing, but fishers generally say there could be more fishing, you can expect some resistance to the stock assessment results.

Constraints

The following questions define minimum and maximum constraints on the preference scores. This prevents the model identifying optima in locations outside the possible range. Minimum constraints are related to the opportunity costs of alternative livelihoods and maximum constraints to logistic limits. However, these constraints do not define, for example, the minimum income required from the fishery to feed a family. These sorts of limits should be picked up by the preference scores.

In general, accurate estimates of the minima and maxima are not required if they are far from the current situation (i.e. greater than or less than 50% of the current CPUE or catch), as they will probably never be met.

What is the minimum average *unit catch* in one *unit effort* you would fish before switching to an alternative livelihood?

This defines the minimum utility from fishing and is essentially the opportunity cost of fishing. If there are effectively no immediate alternatives this can be set as zero by default.

What are the minimum average *units of catch* in a *unit of time* you would accept before switching to an alternative livelihood?

This defines the opportunity cost of the total utility from this fishery. This should be considered separately from question 0 above. For example, a very high catch rate, but only allowing one day's fishing may not match the income from some alternative employment. If there are effectively no immediate alternatives this can be set as zero by default. Similarly if a fisher can easily switch to other activities when he is not fishing, there is effectively no minimum.

What is the maximum *unit catch* in one *unit effort* you could cope with your current gear?

This allows the fisher to define a constraint on the maximum catch he can cope with. For example, limited boat storage capacity may mean early departure from the fishing grounds rather than higher catches on a good day.

What are the maximum number of this gear you could haul / set in a *unit effort*?

This places a realistic limit on the gear which can be set. For example, number of traps which can be hauled, or number of fishers which a boat can hold.

What are the maximum *units of effort* you could apply with your current gear(s) in a *unit time*?

This defines any constraints the fisher perceives on increasing effort. In particular, effort may be limited by weather and season and by the length of the *unit of time*. For example, if the fishery operates the 2 weeks around new moon, the maximum effort would be 14 days. Management controls allowing effort to exceed 14 days will have no effect.

Other Gears

This summarises the CPUE and activity of other gears used by the fisher in this fishery. In particular, a reference point (current fishing practice) and possible constraints are required. These are the same questions as for the main gear.

Only gears used in this fishery should be included, not gears used for other fisheries.

Preference Interview

Background

Including you, how many people are in your household?

This should indicate all dependents on the fisher. This can be used in weighting the preference.

What proportion of your household income depends on your catch from this fishery?

This should indicate the fisher's contribution from this fishery as a proportion of the household income. Income to the household from other people or from other fisheries must not be included in this proportion, only in the whole. This can be used in weighting the preference.

Discounting

What is the time delay indifference point between current 1 month earnings now and 1 month earnings + 20%:

This question aims to estimate the fisher's discount rate. The discount rate indicates the rate at which the future is devalued. Nobody realistically takes account in their day to day living of what will happen in thousands of years, and few of us take much account of what will happen beyond the next twenty years. Discounting is a simple way to adjust future values to represent more realistic estimates of true values. The discount rate is related to bank interest rates, loan rates and so on. However these are bound up with issues such as money supply, risk and other non-local effects. Although the bank rate can be used as an indicator of discount, it may be quite different to the true discount rate of the fishing community. It is therefore better, if a reliable method can be found, to obtain the discount rate from fishers themselves.

To obtain an estimate of a person's discount rate, it is necessary to separate it from other issues. In particular, in testing for indifference between to outcomes, only the time delay should vary, rather than the two scenarios being compared. This prevents the comparison being confounded with utility.

For example, a simple question would be: Which would you prefer more, $100 now or $120 in 1 year's time. If the interviewee prefers $120 in 1 year, the delay should be increased and the preference obtained until the approximate indifference point is identified. This can most easily and quickly be found by bracketing the point and repeated bisection (see box).

Example: Using a savings scheme *Opato*.

There are two identical savings schemes which you are invited to join. In both you save the same amount each month and the payout is 50000 each month to one of the members. Payouts follow a sequence order of members: from the first to last, then back to the first again. Each has the same number of members and the same rotation time between pay outs. In the first, you get paid immediately. In the second, you are 24th in line and so must wait 2 years for your payment, but the local hotel has added a bonus to support it, so the payout is a little more, 60000. Which would you prefer?

The indifference point can be most rapidly found through bisection of a bracket. The "bracket" is the pair of values within which the indifference point must lie. If the interviewee rejects 24th in line, then the bracket is 0 and 24. If necessary, double the number in line until the interviewee prefers the first scheme. Now the bracket encloses the indifference point. Bisect the difference and check in which half the indifference point lies. These become the new bracket. Repeat this process until the interviewee finds it too difficult to choose or the bracket is very small.

For example, the following table shows a series of preference selections for different places in line of the *Opato* scheme.

Second Scheme	Interviewee's	New Bracket	
Delay	Answer	Low	High
24	Reject	0	24
12	Reject	0	12
6	Reject	0	6
3	Accept	3	6
4	Accept	4	6
5	Reject	4	5

Answer: 4.5 months

It was found in tests that the simple question posed above without further information did not work. Fishers found it difficult to think abstractly, so answers could be quite wild as they were interpreting the comparison in different ways. It is much better to find some activity which they actually do, such as saving schemes, and define two schemes which have a fixed quantified difference in payout which does not vary over time. By looking for the indifference point between schemes by varying the delay of the payout, the discount rate can be defined (see box).

Catch and Effort Preference

The catch and effort set consists of various scenarios representing the effort applied and catch obtained within the defined unit time.

The time unit is important as preference will vary with the time chosen. For example a fisher may prefer a high catch rate, but probably not if this was achieved by limiting his effort to one day a month. The time unit should be no less than a week, and no more than a year. In general, a month is probably the best measure as it allows more variability in effort and catch, but a unit should be chosen with which the fisher feels comfortable.

As in the discounting question, some level of abstraction is necessary to avoid fishers getting bogged down in the minutiae of fishing. Comparisons are always made with current practice and catch, including degree of variability. However, fishers will need to ignore the constraints, as these are taken into account elsewhere. For example, if a fisher cannot undertake more effort because of weather, we are still interested in his preference for doing so if this constraint was removed. This is because the preference for impractical scenarios still has an influence on the shape of the preference curve within the feasible region.

There are 17 scenarios with different levels of catch and effort measured as a difference from the current catch and effort levels for each fisher. The various catch scenarios are firstly ranked for preference. Then the relative scores between scenarios are recorded depending on how much one is liked over another. Scenario I represents the fishers current catch and effort.

Ranking the 17 scenarios is most quickly done using the binary tree. After comparing two scenarios, if the non-tree scenario is preferred it goes down the left branch and is compared with the next scenario in line, or if is less preferred it goes down the right branch. Comparisons continue until a free place in the tree is found.

The start points for each scenario in the tree is illustrated in the diagram. Only scenarios **E**, **G**, **F** and **H** could be compared to the current situation (scenario I). Scenario **B** starts with **N**; **J** and **K** with **O**; **M** and **L** with **Q**; and **D** with **P**.

In fact, scenarios **E**, **F**, **G** and **H** should all be worse options than the current situation unless there are constraints. For example, if the fisher prefers **G** to **I**, there is nothing stopping him reducing his effort and making scenario **G** his current option. He might not be able to do the same with scenarios **E** and **F** as his effort may be constrained by weather, availability and so on. So, although his preference should be for scenario I on all these initial comparisons, it is worth checking this first to ensure the fisher understands what is required of him.

It is important to note that some scenarios are dominated by others and comparisons need not be sought from fishers unless to check his/her understanding of what is required. For example, a fisher should clearly prefer any scenario where he catches more fish for the same amount of effort. The ranking can be speeded up by recognising dominance when it occurs.

The binary tree only serves to aid ranking and has no other purpose.

Once all scenarios have been entered in the tree, the scenarios can be scored. During scoring it is worth confirming the rank order as with more thought a fisher may well change his mind. These are difficult questions that require consideration of many issues.

Scoring allows the fisher to indicate the degree of difference in preference between scenarios. It is quite possible that fishers are indifferent among some scenarios and have a strong preference among others within the ranking sequence. When ranking it should be made clear that they will have this opportunity. Therefore, they need not spend time ordering scenarios that they are essentially indifferent between.

Fisher Name		Date	
Fishery		Interviewer	

Units

Units of effort (e.g. days fishing)		
Units of catch (e.g. kg, numbers, baskets etc.)		
Units of Time (e.g. Calendar month, Lunar month, year)		

Stock Assessment Interview

Effort and Catch Rates

6. For how many years have you been fishing?						
7. Which is your main gear, the one you are most familiar with?						
8. Normally, how many sets/hauls do you make in one *unit of effort*?						
9. In each *unit time*, how many *units of effort* do you usually spend fishing in this fishery?						
10. How many *units of effort* did you actually fish this last year?						
11. Normally how many *unit catch* do you catch in one *unit effort*?		**Catch Category**				
		A	**B**	**C**	**D**	**E**
12. Over the last few years, has your catch rate been about the same, declining or increasing?						
13. If the catch rate has been changing: In the same season last year, normally how many *unit catch* did you get in one *unit effort*?						
14. If you were to fish in a fresh ground (never fished before or like the old days), normally how much fish do you think you would catch in one day? (Get an estimated range)	Min					
	Max					

Fisher Name		**Date**	
Fishery		**Interviewer**	

15. If fishing were to stop tomorrow, how many months or years do you think it would take for the fish stocks to recover fully? ….or as close as possible to what it was before fishing started		
16. Do you think the amount of fishing for the size of the resource, is:	could be greater just right too much	
Constraints		
17. What is the minimum *unit catch* in one *unit effort* you would fish before switching to an alternative livelihood?		
18. What are the minimum average *units of catch* in a unit of time you would accept before switching to an alternative livelihood?		
19. What is the maximum *unit catch* in one *unit effort* you could cope with your current gear?		
20. What are the maximum number of gear you could haul / set in a unit effort?		
21. What are the maximum *units of effort* you could apply with your current gear in a *unit time*?		
Other Gears		

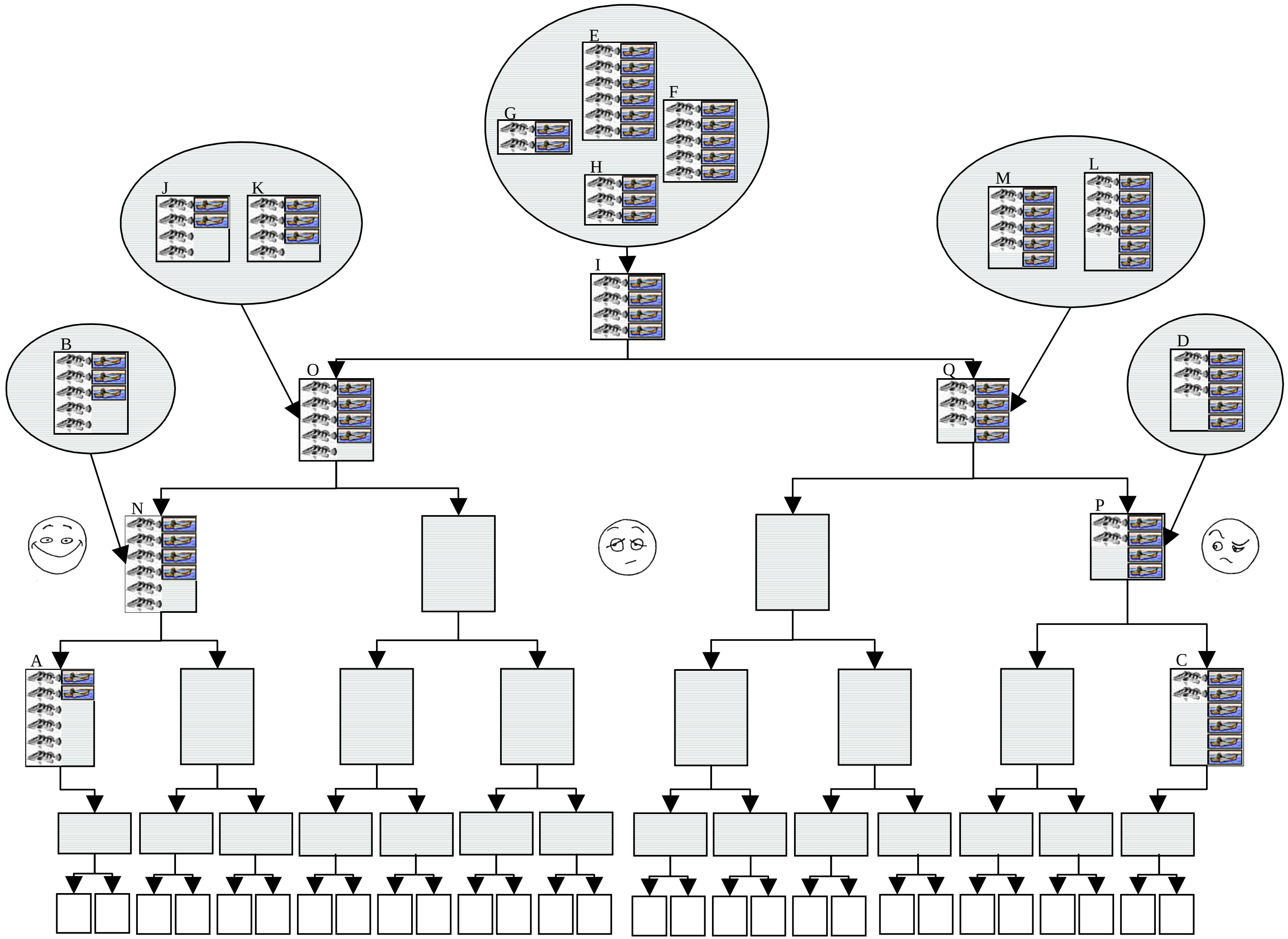
22. Other gears	1.					2.				
Sets / day (as for 8)										
Usual effort (as for 9)										
Days last year (as for 10)										
Current Catch Rate (as for 11)										
Catch Category	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**

Fisher Name		**Date**	
Fishery		**Interviewer**	

Maximum number of gear? (as for 21)		

Preference Interview			
Background			
23. Including you, how many people are in your household?			
24. What proportion of your household income depends on your catch from this fishery?			
Discounting			
25. If you use an interest paying deposit account in the bank for your savings, what annual interest is paid?			
26. What is the time delay indifference point between current 1 month earnings now and 1 month earnings + 20%:			
Time	**0**		**Time Units:** Days Months Years
Amount			

Fisher Name		Date	
Fishery		Interviewer	



Fisher Name		Date	
Fishery		Interviewer	

Catch and Effort Preference

Rank	Scenario	Pairwise Score
1 Best	A	
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17 Worst	C	

Scenarios

A. **50**% **increase** in catch and **50**% **decrease** in fishing (6,2)
B. **25**% **increase** in catch and **25**% **decrease** in fishing (5,3)
C. **50**% **decrease** in catch and **50**% **increase** in fishing (2,6)
D. **25**% **decrease** in catch and **25**% **increase** in fishing (3,5)
E. **50**% **increase** in catch and **50**% **increase** in fishing (6,6)
F. **25**% **increase** in catch and **25**% **increase** in fishing (5,5)
G. **50**% **decrease** in catch and **50**% **decrease** in fishing (2,2)
H. **25**% **decrease** in catch and **25**% **decrease** in fishing (3,3)
I. **no change** in catch or effort (4,4)
J. **no change** in catch and **50**% **decrease** in fishing (4,2)
K. **no change** in catch and **25**% **decrease** in fishing (4,3)
L. **no change** in catch and **50**% **increase** in fishing (4,6)
M. **no change** in catch and **25**% **increase** in fishing (4,5)
N. **50**% **increase** in catch and **no change** in fishing (6,4)
O. **25**% **increase** in catch and **no change** in fishing (5,4)
P. **50**% **decrease** in catch and **no change** in fishing (2,4)
Q. **25**% **decrease** in catch and **no change** in fishing (3,4)

Pairwise Scoring

Choose the phrase which best matches the preference:

0. I do not mind.
1. I prefer it somewhat.
2. I prefer it.
3. I strongly prefer it.
4. I very strongly prefer it.

Fisher Name		Date	
Fishery		Interviewer	

Catch Category Preference

Rank	Category / Species	Pairwise Score
1		
2		
3		
4		
5		

Pairwise Scoring

Choose the phrase which best matches the preference:

0. I do not mind.
1. I prefer it somewhat.
2. I prefer it.
3. I strongly prefer it.
4. I very strongly prefer it.

Appendix 2

Summary of Main Concerns Expressed During the Review March 2001

Concerns	Solution
Incorrect treatment of the decision as a prediction of outcome	Full, but intuitive, explanation of method to fishers using visual aids to obtain their agreement taking account of risks Explicit updating of results through data collection, so that the method is seen as a process rather than a traditional stock assessment. Make the method part of an adaptive management regime. Instead of advising on some optimum based on expected fisher utility, the optimum could balance the needs of information against immediate returns. The principle on how this balance might be achieved would have to be developed.
Fishers give biased information	A minimum level of uncertainty will be applied to avoid simply all fishers agreeing an unrealistic assessment. **Either** a current stock assessment is available to ensure fishers replies are reasonable **or** frequent updates will be available to correct the fisher information. Construction of priors from alternative sources, such as FishBase Test methodology at sites with good stock assessment information to allow simulation of the method to assess its performance. Implement the method as part of an adaptive management regime.
Fishing community objectives may not be in line with DfID programme objectives	Limit application to fisheries with professed interest in sustainable management. Provide checks within the software highlighting risk prone communities. Include explicit consideration of wider public interest/policy in the resources, such as an environmental cost constraint.
Association of the method with poor outcomes	Test method first on fisheries where information is readily available so that the different components can be assessed and successful outcomes are assured. Also test method in a variety of countries and fisheries to look for possible pitfalls, such as the violation of key assumptions.
More clearly defined indicator of community uptake of assessment results	Comparison between sequential interview surveys. Learning should bring subjective assessment approximately into line with posterior.

Appendix 3

Further Work

The following notes potential further work to extend and enhance the methodology. Most extensions are to increase the flexibility of the method. For example, bootstrapping to obtain parameter frequencies will only work well where considerable amounts of data are available (e.g. 20+ years of catch and effort data). Alternative methods will allow other types and amounts of data to be used.

Software Development

- Extension of GLMs to allow discrete factors, more link models and interactions
- Allow other user-defined functional links between estimated and kernel parameters.
- Improved standard techniques for multispecies assessments which are able to make use of able size frequencies. For example, dependent probability models might be further extended to allow combining data sources.
- Estimate gear size selectivity, perhaps using kernel smoothers and generalised additive models
- A multi-gear GLM link model should be developed based on conditional likelihood estimation.
- Allow preferences by animal size as well as species
- Using assessments to guide in data collection
- Estimate and/or use process error in population models (i.e. stochastic population models).
- MCMC estimation for likelihoods as well as bootstrap
- Fit kernels to known probability distributions
- Develop a method to allow logarithmic scale change between kernels
- Test alternative kernels (e.g. Student's t-distribution, gamma distribution)
- Adaptive kernel estimation - particularly clustering and smoothing clusters and identify inappropriate regions.
- Review current output and extend diagnostic tools for the models.
- Allow saving full scenarios fitting as part of model
- Allow more complex control projections, such as combinations of controls or varying controls over time.
- Consider the use of Generalised Additive Models for building conditional probabilities
- The smoothing parameter estimation routine does not take proper account of the boundary reflections. A method is needed to improve the fitting procedure to allow for boundaries without losing the current fitting speed advantage.

Further Research

Fishing experiments are a valuable but under-used tool in stock assessment. They allow scientists to estimate fishing mortality and monitor stock recovery. They were successfully used in Zanzibar on the coral fishery to estimate catchability and significantly enhanced the stock assessment.

They are particularly important as they are the only way to apply scientific principles of adaptive management without causing overfishing throughout the fishery. Without testing hypotheses in fisheries through experiments, it is not possible to apply true scientific assessments. The methods used have been successful, but they did not take full advantage of the methodology. Data was inadequate to address the effects of fish movement, for example. Considerably more research on experiments would be required to develop experiments as a standard stock assessment tool.

Fishing experiments are expensive and should not necessarily be applied in all fisheries. Instead, it is suggested that information from experiments is shared by using estimated parameter PDFs rather than point estimates. This would require some research on the way parameter values, such as catchability, might be used as priors in other locations.