Strategic Review of Tropical Fisheries Management

Project R7040

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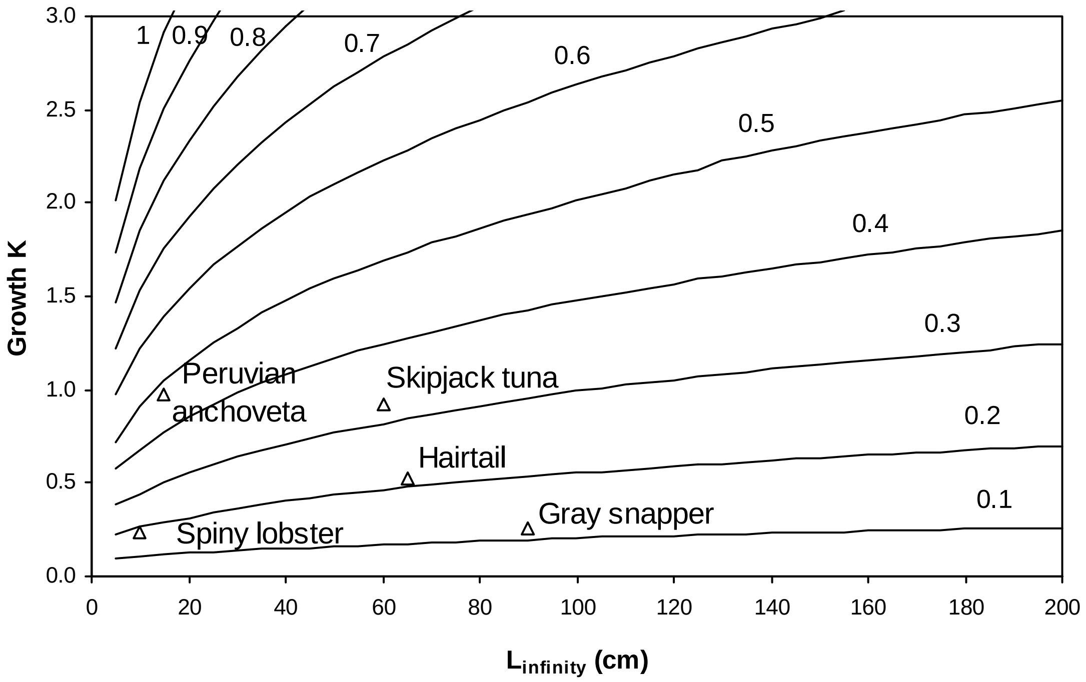
Fisheries Management Science Programme



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Contents

List of Tables

List of Figures

1. Introduction and Summary

Many of the world's poorest people are particularly dependent on fish for both food and employment. It is the common property nature of aquatic resources that makes them so attractive to the rural poor, many of whom are landless and lack alternative opportunities. Coastal artisanal fishing communities are frequently geographically dispersed and isolated. The fisheries tend to exploit a large number of species of low export value using a number of different gear types. Information available for management is often limited and conventional means of monitoring, surveillance and enforcement usually impractical and costly. As a result, artisanal and especially subsistence fisheries are frequently under or inadequately managed by government. Whilst limited data for management of commercially important fisheries may be available, flexible management plans are rare, and there is room for improvement. Conventional stock assessment methods are frequently prohibitively expensive and difficult to perform due to the complexity of species and variety of harvesting methods. Such methods have been developed principally for temperate water species and are not directly applicable to tropical fish. Furthermore, these methods often fail to account for the complex social and economic situations of artisanal fisheries. In formulating management policy for such fisheries, these complex characteristics must be considered. To date, universally workable solutions for the sustainable management of such fisheries have yet to be identified.

The particular characteristics of tropical coastal fisheries have meant that assessment methodologies have developed slowly compared to those in temperate waters. The application of scientific and technical solutions to the management of these fisheries, particularly small-scale subsistence and artisanal fisheries, has frequently been unsuccessful. This project has addressed these constraints to development with sustainable exploitation through a strategic assessment of tropical fisheries management with the following purposes:

1. To evaluate relevant research methods for the development of assessment models appropriate to the circumstances of tropical coastal fisheries.

2. To evaluate the utility of existing strategies for the implementation of management advice.

The report consists of three substantive chapters. Chapter 2 contains a detailed socio-economic assessment of various instruments and implementation strategies applicable to tropical capture fisheries. This chapter, it is fair to say, poses problems rather than offers detailed solutions. It is planned to utilise the insights obtained from this chapter in the further development of the Fisheries Management Science Programme and, in particular, to address detailed issues of how socio-economic considerations need to be explicitly taken into account in drafting fisheries management guidelines.

The state of world fisheries is usually characterised as one of total overexploitation. In such a situation, the key management issues that need to be addressed involve a procedure which inevitably has to lead to a scaling back of the level of fishing effort which in tropical coastal fisheries can be extremely painful, especially when viewed from a socio-economic perspective. However, it is far from clear from the assessments that have been done that the status of all the tropical coastal fisheries are in this perilous overexploited state.

In Chapter 3, a detailed assessment of the fisheries for tropical large marine ecosystems has been conducted using a technique developed by FAO (Granger & Garcia 1996). The data used were the FAO statistics published regularly by FAO. This analysis has been conducted for each of the tropical large marine ecosystems and indicates that there is the potential for increased fishing in a number of these ecosystems. In such a situation, however, compared to overexploited fisheries, there is a rather different management issue that needs to be addressed. What is critical in such situations is that fisheries are only permitted to develop to a level at which the fishing effort is appropriate to the capacity of the fish resource. Manifestly as well as scientific and technical issues, the socio-economic implications of this are clearly very different from those of the overexploited fisheries.

The results of this chapter need to be treated cautiously as the simple models that have been used are not particularly robust to variations in input data and, in particular, aggregation across a large ecosystem must be treated with some caution. Nevertheless, they do indicate that there is some potential in certain of the tropical large marine ecosystems while at the same time indicating that a number are very significantly overexploited. As far as we are aware, this is the first time that the concept of tropical large marine ecosystems has been applied in this aggregated way to tropical coastal marine fisheries.

One of the clear requirements identified in Chapter 2 and implicit in Chapter 3, is that there is a significant need for simple and robust fisheries assessment methods which can estimate the potential of a particular resource, its capacity in terms of the level of fishing effort and its current status ie whether it is currently exploited sustainably or not.

In Chapter 4, these problems are addressed directly and, using two approaches, significant simplification of fishery methods is developed. In the first approach, simple empirical relationships between the life history parameters of a species are used to develop models of potential yield which can be determined by a simple assessment of fish growth. This particular process is limited by the underlying uncertainty in these empirical relationships. It is nevertheless potentially valuable.

In the second approach, optimal life history theory is applied to the key demographic parameters of exploited fish populations and using estimates of the Beverton & Holt invariants a significant simplifying of the basic stock assessment equations is developed. This enables potential yield and the level of fishing effort at maximum sustainable yield, to be estimated directly from the parameters of growth. Such parameters are well within the capacity of fishery institutions in developing countries to assess.

Although some of the key elements of the project goal have been achieved by the outputs, in particular the full synthesis of size and growth information for use in fisheries management, a significant element of the project which was aimed at assessing the question: “can effective bio-socio-economic models be developed” remains unanswered. With hindsight, a small project of this type was unlikely to both identify the problem and develop working models. These implications for the development of the programme are currently being explored.

2. The Socio-Economic Context

2.1 Introduction

2.1.1 Management, models and tropical coastal fisheries (TCFs)

> *The type of management solutions we formulate for TCFs depend, most fundamentally, on the way we conceptualise the TCF and the management problem it presents. Models can only provide information and advice on factors within the parameters of the conceptualisation.*

Management is defined as *'controlling a system towards specified goals'* (Reading, 1976). In considering the management of TCFs, we might usefully ask a number of questions based on this definition:

- what constitutes the 'system' ?
- what type of goals, what specific goals should management pursue ?
- who's goals, how are goals decided upon ?
- who is controlling the TCF ?
- how is the TCF controlled ?

Asking such questions suggests that the management problem of a TCF is in fact a complex of problems of different orders. An indication of these is given in Table 2.1 below. The table has two sections, one relating to models of the TCF itself, and one relating to models of its management.

Table 2.1 Different orders of problems involved in the management complex of TCFs

Problem order	**Questions addressed**
Assessment models	
Conceptual problems	*What constitutes the TCF system ?* *What type of system is it ?* *What are its boundaries ?* *How do we think of the fishery ?*
Theoretical problems	*Are assessment models adequately specified ?* *Are assessment models applicable to TCFs ?*
Operational problems	*Does sufficient data or the capacity to generate it exist in order to make assessment models operational ?* *Does sufficient capacity exist for on-going use of assessment models as tools of management ?* *Do assessment models provide useful advice for management ?*
Management models	
Conceptual problems	*How do we think of the management problem ?*
Policy problems	*How do we choose management goals ?* *How do we choose management strategies ?*
Technical problems	*What management instruments can be used in pursuit of management goals ?*
Implementation problems	*How do we implement management policy ?* *How do we gain compliance ?* *How do we adapt to a changing management environment ?*

The type of management solutions we formulate for TCFs depend, most fundamentally, on the way we conceptualise the TCF and the management problem it presents. Models can only provide information and advice on factors within the parameters of the conceptualisation.

It follows that if the conceptualisation of the fishery and the management problem is insufficient, the models we develop based on it will be insufficient, the management advice those models can provide (analytical insights, quantitative/qualitative information) will be insufficient, and the management strategies based on that advice will be insufficient. As a result, the fishery will not be well managed.

Section 2.2 deals with the problems associated with assessment models in the prevailing fisheries science paradigm. Section 2.3 deals with problems associated with the management of TCFs. A brief Section 2.4 derives a number of principles for TCF management from Sections 2.2 and 2.3.

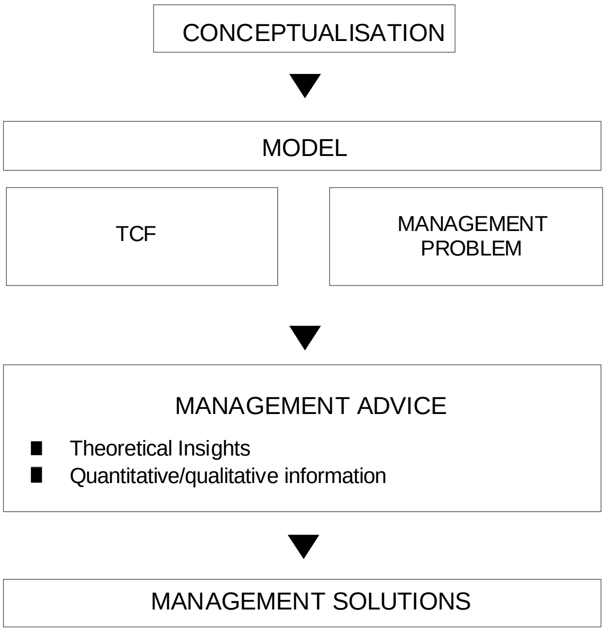

Figure 2.1 Conceptualisation of TCFs and their management

2.2 Assessment models and TCFs

2.2.1 Assessment models in the fisheries science paradigm

While claims for what models can do is the point of much of the literature, their limitations in relation to providing management advice for TCFs are less explicitly documented. A number of conceptual, technical and application problems are highlighted.

The prevailing fisheries science paradigm, at its most basic, conceptualises a biomass called a ‘fish stock’ comprising a population of a single species of fish, which is affected by fishing activity (effort) through increased fish mortality. Under a certain set of conditions, the effort in the fishery becomes too great, the biomass is depleted and the fishery ceases to provide any benefits. The management problem is then conceived as regulating (limiting) fishing effort (and so fish mortality) in order to attain the desired choice of theoretical equilibria specified by the models (Wilen, 1979). The biological models (e.g. for the general case see: Schaefer, 1954; Beverton & Holt, 1957; Ricker, 1958. For the application to TCFs see: Appeldoorn, 1996;), and their extensions, the bio-economic models (e.g. Clark, 1990; Hanneson, 1992; ref. application to TCF) and bio-socio-economic models (e.g. Charles, 1989; Panayotou, 1982; Yew & Heaps, 1996) that are available to assess TCFs are all models within this paradigm, and as such, share many common assumptions and features. The basic conceptualisation they offer is summarised in Figure 2.2, below.

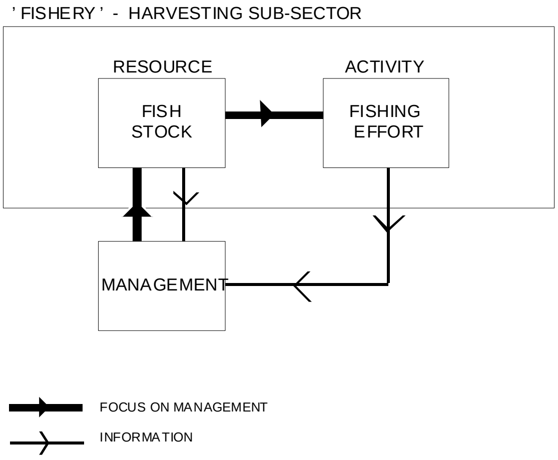

Figure 2.2 Conventional, or fishery science conceptualisation of the fishery and fishery management.

If we are optimistic about the use of the prevailing fisheries science approach in TCF management, we can say that its theoretical models can provide useful insights into what happens in the fishery under the impact of fishing effort and can suggest possible management objectives. Making those models operational, it can provide quantitative information about the fish stock and about possible management objectives - in so far as they relate to a particular state of the fish stock. It can say, for example, what the theoretical maximum economic yield (MEY) is and by how much effort must be reduced in the fishery to achieve MEY. A number of regulatory instruments can then be suggested through which managers of TCFs can achieve effort reductions and thus the selected management objective.

Such optimism has had the effect of equating the modelling activities of fisheries science with the act of fisheries management; but they are not synonymous. This has only gradually become apparent, as fisheries science has been widely seen to fail to achieve the objectives of fisheries management, both in TCFs and temperate fisheries (Bailey & Jentoft, 1990; Wilson et al, 1994).

The mechanics of and variations on these models have been extensively discussed in the literature (fn. main journals, ref. review articles). Indeed, this is the predominant theme in the academic fisheries literature. It is not our purpose in this brief review to summarise this literature. Instead, our purpose is to provide - in summary form - an assessment of the common conceptual, theoretical and operational issues facing these models and their ability to provide relevant management advice in the context of TCFs.

2.2.1.1. Conceptual Issues

Focus (resource)

Firstly, all models in the fisheries science paradigm conceptualise the problem as one facing a resource, as indicated in Figure 2.2. In biological models, the resource is a physical fish stock. In bio-economic and bio-socio-economic models, the resource becomes the monetised value of that fish stock. In each, the resource is the focus of the model and the focus of management. However, it is unlikely that this view reflects that of the fishers. The concept of a fishery resource is unlikely to be the prime focus of their decision making and behaviour. Even where fisheries have been successfully self-managed by communities, this success has not been based around a conceptualisation of the resource, but around social and cultural considerations (Berkes et al, 1989; Ruddle, 1996b). Thus, although bio-socio-economic models are moving in the right direction, the prevailing fisheries science paradigm conceptualises the fishery resource first and the society it is part of, second.

An alternative approach would be to conceptualise the society first. That is, look at the people who are or might use the resource, look at their cultural framework, their social organisation, and then the fishery resource as just one among multiple means they have of satisfying various cultural, social and economic goals. No models in this paradigm have attempted to include a cultural dimension, despite the fact that these may be of great importance in determining the behaviour of fishers in TCFs.

Level (aggregate)

The conceptualisation of the models of the prevailing fisheries science paradigm also differs from that of the fishers in terms of the level of aggregation. The available models all view the problem at the aggregate level of the whole fishery (however defined by species, area, gear). However, the fisher's view is likely to involve his actions as an individual, and as a member of a family, a fishing unit, and other social groupings, such as a village, etc. (for now, we will characterise this as the polar opposite 'individual' view, but see section 2.2.2, below. While the prevailing modelling paradigm posits this partial, individual view as an essential aspect of the management problem, it persists in modelling at an aggregate level while decisions about the fishery are made at individual level. This ensures a persistent rift between the logic and utility of the management advice provided by the models as perceived by the management and as perceived by the fishers. The management problem remains, therefore, the division between aggregate and individual level views.

Two possible solutions to this problem follow. One is to develop assessment models down to the individual level, to provide insights into decisions made at this level. The other is to develop means by which the decisions of the fishers with regard to the fishery can be made in aggregate. These represent polarities. Between these are intermediate solutions of assessment models at sub-aggregate levels and private decision making at supra-individual levels.

The key point is that until management models and fisher models view the problem at the same level, there will always be a difference in the solutions (advice/decisions) derived from those models, and an unsolvable management conflict.

Main assumptions (commons tragedy)

The prevailing fisheries science paradigm - and thus the models within it - is based on the assumptions of the 'tragedy of the commons' (a concept with an aggregate resource focus) (Berkes, 1985). These are:

- the resource must be collectively owned by society and freely open to any user[1]
- the users must be selfish and they must be able to pursue private gain even against the best interests of the community as a whole
- the environment must be limited, and there must be a resource use-pattern in which the rate of exploitation exceeds the natural rate of replenishment of the resource (Berkes, 1985)

The pertinence of all three assumptions is questionable to a greater or lesser degree in relation to TCFs. (Berkes et al, 1989; Feeney et al, 1990). Indeed, that these assumptions have been blandly yet mistakenly made in the case of many TCFs has lead to management advice and management strategies which have directly undermined existing ('traditional') management strategies. In time, this has lead to the fulfilment of the commons tragedy scenario on which the management advice was based and which it ostensibly seeks to prevent. That is, within the prevailing paradigm, they have become self-fulfilling assumptions (Catanzano & Mesnil, 1995).

Two alternative approaches follow. One is to revise these assumptions to be more in line with the actual situation faced in most TCFs , make these assumptions explicit, and continue to make generic models. Another is to cease making generic models, and to only undertake modelling on the specific situation of particular TCFs. In both cases, the specific assumptions or specifications may be different to those above, but they may still concern the same issues, vis:

- the ownership/access issue
- the fisher behaviour issue
- the exploitation pattern issue.

The issues remain analytically pertinent. The key point is how we specify them in models.

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[1] This is, in fact, the condition of 'open-access'. Hardin's phrase was an unfortunate inaccuracy, commons being far from open-access. The commons which Hardin described and many marine commons in tropical countries are subject to very detailed sets of users rights (see, for example, Feeny et al, 1990).

2.2.1.2. Theoretical Issues

Specification (partial)

While all modelling abstracts from reality in order to capture the main features of the thing being modelled, there is an obvious trade-off between simplicity and predictive accuracy in models. In the case of TCFs, this trade-off becomes strained due to the complexity of the system being modelled - TCFs may be thought of as representing a higher order of complexity than the temperate fisheries for which the prevailing fisheries science modelling approach was first developed (Appeldoorn, 1996; Wilson, 1982; Wilson et al, 1994).

In particular, the multi-species, multi-gear nature typical of many TCFs complicates the biological specification of the model. Firstly, knowledge of individual species characteristics is still partial in many cases. Secondly, the ecological interactions between species are not known, and even if they were, specifying them completely would make any model immensely complex. Neither are the technical interactions between non-discriminating gears and the target stock complex known. Appeldorn (1996) comments, 'At present, the standard stock-recruitment models can only be applied on the basis of faith'.

The main problem this presents for the application of models to TCFs is their low ability to accurately predict the variability of stocks. This is especially so in the case of non-random or evolutionary variability, which cannot be expected to even-out over time (Panayotou, 1982; Wilson et al, 1994).

Specification problems are also presented for economic and socio-economic models. The specification of a linear, rising total cost function may be less appropriate in the context of tropical developing countries, where the opportunity cost of labour may be negligible due to endemic un/underemployment and low occupational mobility (see section 2.2.1.3, below). Also, the cost and/or opportunity cost of capital inputs may be negligible, due to the simplicity of gear required in some fisheries and if excess capital stock can migrate from other over-exploited TCFs. Additionally, revenue functions will be difficult to predict over time due to often rapidly fluctuating prices and changes in catch composition of a heavily exploited TCF. Again, the main problem here may be caused by the consequent difficulty in predicting variability, especially where margins for small scale fishers are very low.

As an important corollary to this, there may also be a difference between the perceived (and advertised) predictive accuracy of a model and its objective predictive accuracy. This is partly because the mystique of scientific method can often lead to the assumption of objective accuracy (on the part of modellers, managers and fishers) and partly because models produce average results without estimations of variability or confidence limits.

Time (static)

Dynamic economic models have been specified, and these discount future yields to present values. However, it is debatable whether this is a justifiable procedure given the potentially very high discount rates of marginal fishers in conjunction with concepts of inter-generational equity.

Otherwise, models are specified for a particular exploitation pattern. Due to both the multi-species, multi-gear nature of many TCFs and to the number of actors taking decisions in the fishery, the exploitation pattern may vary considerably over time. That it does will be both cause and effect of a changing catch composition over time. Given then the ex-post nature of data in operational models and the lag between management advice and the impact of management measures, it is far from clear that the circumstances envisaged in the modelling exercise will still be relevant when the management measure takes effect. If this is so, it is impossible to predict the impact of the management measure.[2]

Goal (maximising)

The management goal assumed in current models is a maximising one. In biological models, maximum sustainable yield (MSY) is the presumed goal. In bio-economic models it is maximum economic yield (MEY), and in bio-socio-economic models it is maximum social yield (MScY) (a maximisation of rents and wages). The relevance of all of these is debatable in relation to TCFs.

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[2] However, see Tai & Heaps (1996) for an attempt to deal with this problem in a TCF by simulation.

Firstly, the problems noted under ‘specification’, above, in relation to biological models, lead Panayotou (1982) to conclude that “in tropical multi-species fisheries, MSY is not a meaningful goal for fisheries management”. In bio-economic models, while MEY provides better for ecological variability and conservation, it fails to take account of distribution, which is presented as an overarching policy concern universally. Bio-socio-economic address this problem with MScY. However, even maximising the social yield from a fishery may in some communities be less important than, for example, protecting the right of access for all members of the community, or avoiding conflict (White et al, 1994, Part 1).

Additionally, the possibility must be considered that maximising yield (whether biological, economic, or socioeconomic) may not concur with the preferences of the fishing community or the society involved has to be considered. In many tropical countries additional leisure may be highly valued, even where income levels and living standards are well below what would be considered minimal in the West. In this case, satisfising behaviour may be observed, where leisure is maximised subject to the constraint of a minimum target yield (catch, rent, rent + wages) (See, for example, Neiland et al, 1998).

2.2.1.3. Operational issues

The cost of management and TCFs

To be made operational, models in the prevailing fisheries science paradigm requires an on-going input of modelling expertise and time-series data on all the model variables. This presents a high cost of making the approach operational. This cost is higher the more complex the model that is to be made operational***.***

Figure 2.3 depicts a TCF in terms of the standard fishery science model. We will assume in this case that the TCF has suffered the ‘tragedy of the commons’ and is currently at point *a*, the open-access equilibrium, corresponding to level of effort OAE. All rent has been dissipated and total revenue only just covers total costs. From the point of view of the sustainability of the fishery and its efficient exploitation, there is a need to reduce effort back towards the level MEY. However, the management advice required to identify the initial position of the fishery, and to quantify and monitor its movement to a new and more efficient position is not costless. Thus, from the point of view of society, the total cost curve *with* public management now becomes TC’, lying above TC (it is assumed management costs represent a fixed addition to total costs at whatever level of effort in the fishery).

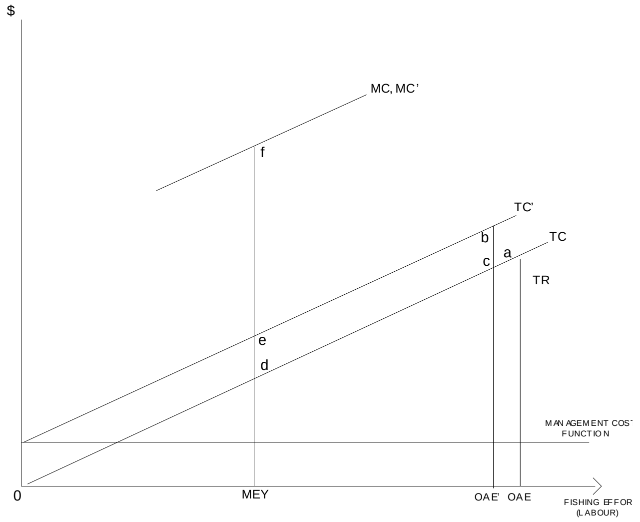

Figure 2.3 Cost of management endogenous to the model.

This implies a number of things. Firstly, on economic criteria, management has to move the position of the fishery to point *b* by reducing effort to OAE'. The resulting surplus *bc,* is required *simply to cover the costs of management and leave society no worse off.* Point *b* is effectively the new open access equilibrium. Secondly, in moving the fishery to *b*, management makes no gain for society as a whole, but simply transfers wages from fishers to fishery managers. On social criteria, in which $1 of wages to a small scale fisher would be valued more highly than $1 of wages to fisheries administrators, management actually makes society *worse off*. With a fixed management cost function, the situation is analogous if management is successful and reduces effort sufficiently to achieve the maximum economic yield at MEY. Society does not gain surplus *df*, as *de* is simply transferred from fishers to management.

The key point here, is that the benefits of management must outweigh its cost to be justified on economic and social grounds. It is clearly important then that management of TCFs be not only judged by its *effectiveness* in relation to management goals, but also by its *efficiency.* Providing least-cost solutions should be an internal goal of management. This is especially critical in the case of TCFs as educated, skilled manpower is invariably at a premium in tropical developing countries. This means that the opportunity costs of employing skilled workers in fisheries management i.e. their productivity in another employment, may be high. This is unlikely to be reflected in public sector wages. The cost to society of committing skilled manpower to fisheries management may therefore raise the total costs function above TC'. Moreover, the skilled manpower required of fisheries science approaches to TCF management may simply not be available. Thus, even if the private costs facing fishers are too great for them to organise efficient solutions in the fishery themselves, it does not necessarily follow that the costs of publicly brokered solutions are any less.

However, where fisheries managers are a distinct group from fishers - as is the case with public fisheries management - it is actually in their interests as a group to raise the costs of management, not lower them. The more resources fisheries management attracts, the better off management is individually and collectively. This was the case in at least one tropical country in which the author has worked, where the overwhelming beneficiaries of an increasing fisheries management and development budget, were the professional managers located in the capital city. This theme will be returned to in below.

The particular relevance this has to the modelling of TCFs is that while greater complexity in specification may be required to improve predictive accuracy of models, this raises costs. The benefits of increased accuracy must therefore be traded-off against costs, both on economic and social criteria. This point obviously has more relevance the smaller is the total value of the fishery being modelled. As many individual TCFs are not of high value, they will correspondingly only merit simple and cheap modelling approaches. Progress towards such modelling approaches has been attempted in two ways as part of this project. First, using simple catch data as a basis for assessing potential yield has been applied to large tropical marine ecosystems data in Chapter 3. Second, the use of life history parameter relationships has been investigated to develop the possibility of obtaining estimates of potential yield from simple and readily available data in Chapter 4.

2.2.1.4 An alternative proposal

Wilson et al (1994), take the concerns of this section one step further. They make the argument that the reductionist scientific approach pursued in fisheries to date has obscured, not illuminated, the nature of the resource. They argue that the behaviour of fish stocks is not only complex, presenting a massive information problem, but may actually be *chaotic*. That is, 'patterns of abundance in which the stock level of an individual species has no equilibrium tendency, but varies unpredictably within limits'. What becomes important to fisheries management in this case, is not a numerical approach focussing on fishing mortality, but a *parametric* approach, focussing on *how*, *when* and *where* fish are caught.

Three important implications of this conceptualisation of the resource, are that:

- it reduces the information problem (and so cost) as the basic parameters are stable over time and don't require constantly updated data
- the relevant scale of analysis and management is in many cases reduced to a lower level spatial awareness
- local level parameters are often well known by fishers, therefore raising the value of their knowledge *vis-a-vis* 'scientific' knowledge and providing a better basis for integrating knowledge systems.

Indeed, a parametric approach appears much more in line with the model used by diverse societies around the world in the self-management of there fisheries. In their survey of 31 studies (Wilson et al, 1994), general conclusions were that:

- rules were about *how* fish were caught, rather than *how many*
- management regimes were self-management at local/community level.

Other general conclusions relevant to this section were:

- systems of access/property rights exist, there is not open-access
- compliance was achieved through low-cost community pressure
- most rules have conservation in mind
- equity of access may be a more important goal than conservation or efficiency.

2.2.1.5 Conclusion

The issues raised in this section, provide sufficient cause for the applicability of models in the prevailing paradigm to TCFs, and their utility in providing adequate management advice, to be critically reviewed.

The need is not so much to peer deeper into the particular modelling problems presented by TCFs, but to raise our heads above the prevailing fisheries science paradigm and think critically about the whole enterprise of TCF management from first principles. In terms of Figure 2.1 (above), we should be thinking about the whole figure, and not only the modelling of the TCF resource.

2.2.2 The behaviour of fishers

> *TCF appropriation sub-systems have three basic components: resource, activity, actor. The latter has received little attention. The perspectives provided by economic anthropology can be used to more fully conceptualise the complex behaviour of 'the fisher' in TCFs. An indicative framework is provided to help describe his relationship with the resource.*

The issues raised above all result from the basic conceptualisation of fisheries science as presented in Figure 2.2. The semantic clues to the conceptualisation make it obvious: we are dealing with *fisheries* science, with *biological*, *bio*-economic, or *bio*-socio-economic models. We are dealing with fish. Whether our science of fish is good science or not is debatable (see, for; Rosenberg et al, 1993; against; Ludwig & Walters, 1993; Wilson et al, 1991). However, the critical point is that conventional fisheries science has widely failed because scientific optimism has set it a task which is beyond its proper capabilities; it is unreasonable to suppose that a science of fish can guide us through a *management* problem about *human behaviour*.

The conventional fisheries science approach reduces the whole vista of human behaviour to 'fishing effort' and reduces the whole management problem to a bland assumption that regulations can be introduced which will control fishing effort within the proper confines suggested by the model. Such an approach seems to miss the obvious, that *the management of TCFs is primarily a problem about the behaviour of people, not the behaviour of fish*. Fisheries science cannot therefore be expected to conceptualise the problem appropriately, let alone provide adequate management advice. Within the western scientific approach, the burden of advising on the management of TCFs therefore falls on the human sciences. Unfortunately, the contribution of the human sciences to the management of TCFs falls far behind the contribution of fisheries science (Charles, 1988; McManus, 1996).

Key to a human sciences approach to the problem, is that it provide a different way of conceptualising the TCF and its management problem at the outset. The corner stone for such an approach is summarised in Figure 2.4, below.

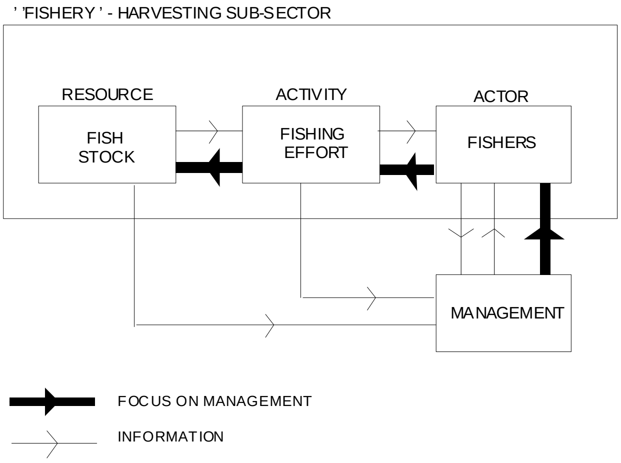

Figure 2.4 A basic human sciences approach to TCF management

The main differences between this and the 'conventional' fisheries science approach depicted in Figure 2.4 (above), are:

- the TCF harvesting sub-system has three - not two - basic components; the actor - the fishers themselves - are explicitly considered in the model,
- the actor is the prime focus of management.

Let us remove the actor from the mechanistic 'fishing effort' and take a look at who and what 'the fisher' might be.

2.2.2.1. The 'fisher'

TCFs have for some time be characterised in the literature as 'multi-species, multi-gear'. This characterisation has served to differentiate them from the temperate fisheries (single-species, single-gear) upon which the fisheries science approach has been based. The TCFs are characterised, therefore, as a more complex situation. However, the actor does not form an explicit part of this complexity. To the extent that he is included in the conceptualisation at all, it is in the form of the neo-classical microeconomic tradition. Thus, his most basic characteristics are:

(i) he is an individual
(ii) he is self-interested
(iii) he is rational - he prefers more to less
(iv) he is a maximiser

He is exactly the character imagined in Hardin's 'Tragedy of the commons' (Hardin, 1968) and he remains an unstated assumption underlying fisheries science approaches to TCF management. Thus, stating that assumption, TCFs are characterised as 'multi-species, multi-gear, *mono-behavioural*'. But is the behaviour of the actor really so simple and mono-dimensional in comparison to the resource he harvests and the gears he applies ? And if not, is this inadequacy in the conceptualisation of TCFs - of 'what constitutes the system?' - the root of the perceived failure of western management approaches to TCFs ?

If we wish fishers to behave in a certain way - that is, remain compliant in achieving a particular goal of fisheries management - it seems obvious that we need to understand what influences the way they behave. The insights provided by the various human sciences (economics, sociology, political science, anthropology) are usefully brought together in modern economic anthropology, which recognises three basic traditions of thought about human behaviour (Wilk, 1996). These are simplified and presented in Table 2.2, below.

Table 2.2 Human behaviour; economic anthropological perspectives with application to fisheries

Perspective	founding writers	application to fisheries	actor	prime motivation for behaviour	goal of behaviour
neo-classical microeconomics (economics)	Smith, Ricardo	Anderson (1986), Cunningham, Dunn & Whitmarsh (1985)	individual	self-interest	maximise utility
Social and Political Economy (sociology, political science)	Comte Durkheim Marx	Drache & Clement (1980), Jentoft, McCay & Wilson (1998), Ostrom (1995), Platteau (1989)	group, class	group interest	increase power of group
Cultural economics (anthropology)	Weber, Malinowski, Boas	Acheson (1981), Berkes (1977), Malinowski (1921, 1961), Robben (1989),	culture, ideology	moral	reinforce culture

In social and political economy, the actor is seen as the group, to which people belong and the interests of which they take on as their own. Thus, behaviour is essentially cooperative *within* the group, though it may be competitive *between* groups. The fisher may be a member of many different groups, the interests of each of which he may pursue with his actions: fishing unit, fishing group by gear/fishery, fishing cooperative, village, caste, class, tribe, joint-stock company, ethno-linguistic group, island/region, nation, etc.

In the cultural economics model, the actor is in effect the belief systems and values of the culture, and behaviour is determined (strong assumption) or guided (weaker assumption) by the desire to do right. The ‘right’ behaviour is learnt with all other aspects of culture as people grow up. Thus, in this model, the behaviour of the fisher is determined by the cosmology or ‘world view’ of the culture in which fish and peoples relationship to them forms an integral part. For the fisher to do ‘wrong’ (to break taboo, for example) causes internal conflict and ensures that culturally specified ‘right’ behaviour is reinforced.

The neo-classical microeconomic position is given above. However, its basic assumptions about how individuals behave has been extended in two important developments, as theorists have sought to better reconcile the model with observed human behaviour. The first is the perspective offered by game theory, and the second, that offered by information and transaction cost theory. Both retain ‘economic man’ as the central pillar of analysis, yet lead him to different behaviour in more fully specified economic environments.

Game theory

Game theory represents an advance on neo-classical microeconomics by recognising that one individual’s behaviour affects and is affected by another (two person game) or other (*n* person game) individual’s behaviour. The field has developed since the 1940's, and provides formal mathematical tools for analysing human behaviour in different game scenarios (for a brief overview of the development of game theory, see Ridley 1996, chaps. 3 and 4).

Fishing strategies adopted by fishers can be seen as games, especially in respect of responding to regulation. Should the fisher act for immediate self gain and not comply with the regulation (defect), or should he cooperate and comply? His decision depends in part on what he expects other fishers to do, in part on how many fishers are involved in the game, in part on the perceived rewards and punishments of cooperation and defection, and in part on the sequence in which decisions are made in the game (whether it is a one-off or repeated game, whether decisions are consequent or simultaneous).

The great advantage of game theory is that it allows us to investigate the behaviour of fishers - which management actions seek to influence directly - rather than the behaviour of fish stocks - which management actions can only influence through the agency of fishers. If an equivalent amount of resources was committed to modelling fishers’ behaviour as is committed to modelling the behaviour of fish, the insights offered for successful management strategies might be far greater.

One of the most interesting possibilities is that in repeated games (under certain conditions) the most successful strategies for players to adopt are *cooperative* ones, not competitive ones (Axelrod, 1984;

Nowak, May & Sigmund, 1995; Kitcher, 1993). This is a powerful notion that challenges one of the fundamental propositions of neoclassical microeconomics, and provides a means by which the cooperative behaviour observed in social economy can arise from the assumptions of microeconomics. The successful cooperative strategies that game theory predicts have also been demonstrated in laboratory experiments (Ostrom, et al, 1992, 1994; Edney & Harper, 1978) in which the chance for players to communicate is seen as essential to the outcome. In reality, the chance to communicate may be circumscribed, the central theme of another body of theory.

Information and transactions costs (ITCs) theory

Conventional microeconomics *assumes* individuals make choices on the basis of perfect and costless information. Information and transactions costs (ITCs) theory begins from the observation that some very widespread and long-standing institutions (e.g. sharecropping, dealer contracts) could not be predicted by conventional theory, and were in fact rationale second-best solutions given the existence of imperfect and costly information (see for example Wilson, 1980).

Thus, the open access regime which conventional fisheries management sees as the underlying cause of fisheries problems, results from ITC's making it inefficient (the costs outweigh the benefits) for fishers to negotiate and maintain more efficient rights regimes. Open access regimes may thus be the most efficient regime in the given ITC environment. Wilson & Lent (1994) suggest, therefore, that the focus of fisheries management and research should be the ITC environment faced by the fishers with the aim of reducing the costs of fishers making bargains. Only then can institutions be negotiated that produce efficient behaviour.

The behaviour of fishers - conclusions

Ridley (1996) attempts to reconcile all the various perspectives on human behaviour by showing people to be self-interested individuals who are uniquely gifted in cooperating to achieve their ends, and thus produce (and are in turn a product of) a uniquely complex society and culture. The assumption of neo-classical microeconomics is thus an important part of, though an insufficient explanation for, human behaviour in a 'multi-dimensional' society.

Thus people can be seen to be pursuing their selfish interests at a number of levels. Their fundamental behavioural motivations are described by the biological perspectives. Their actions as individuals can be described by neo-classical economics. Social and political economy can illuminate group behaviour, from the level of small local groups to large national level aggregations. Cultural economy can explain behaviour with respect the cultural matrix in which individuals and groups interact.

In analysing TCFs, it is clear that each tradition of thought on human behaviour outlined above may be relevant to explaining the motivations and goals of fisher behaviour; fisheries managers are dealing with a complex problem. Fisheries managers are susceptible to analysis on exactly the same basis. It is also clear that the insights they offer suggest that there are more possibilities for management solutions than conventional fisheries management considers. Placing fisher behaviour firmly as the focus of management efforts within the fishery system is a crucial step for effective management of TCFs. We need models of *fisher* management that concentrate on the behaviour of fishers, not *fisheries* management that concentrate on the behaviour of fish.

2.2.3 The context of TCF systems

TCF appropriation sub-systems do not exist in a vacuum. They are only part of a fisheries sector, which in turn is part of a wider economy and society, all of which affects behaviour in the fishery. Most importantly, this wider context is of a dynamic, not a static, nature. An indicative framework is provided to assist contextualisation of TCFs.

Section 2.2.2 (above) placed the actor as the focus of the management problem, and made some general comments about how he might behave. However, in order to manage a particular TCF, we need to know more about the *relationship* between the actor and the resource, within the harvesting sub-system. We also need to know how the TCF harvesting sub-system articulates with the world outside its narrowly defined boundaries.

Describing the actor-resource relationship (depicted in Figure 2.4, above) reveals much about the likely incentives for behaviour of fishers and the relevant principles of social organisation on which a management approach may be based. It also helps to define the relevant boundaries of the problems presented by the fishery for management. For example, it seems unlikely that the same management structures and systems would be appropriate for the two caricature fisheries below:

- artisanal production, subsistence and local market, low capital, low value, village based, fishermen identify with each other as a group, high dependence, key part of livelihood strategy, family production relations, historical fishery, spatial perspective
- industrial production, for national or international market, highly capitalised, centralised port, highly competitive individual fishing units, industrial production relations, high value, lower dependency, new fishery, functional perspective.

Thus, the relationship between fisher and resource can be described by addressing a number of themes and asking basic questions. An illustrative scheme is presented in Table 2.3 below.

Table 2.3 Describing the relationship of fisher to resource

Theme	Focus of questions
Spatial	How are the fishers and the resource related spatially ? • location of fish/fishing ground • location of home port(s) • location of first distribution of catch
Institutional	What institutions relate the fishers to the resource ? • cultural institutions • institutions of social organisation • access/property rights • rules
Production	What are the production relations prevalent in the fishery ? • boat • gear • payment systems
Distribution	What does the fisher do with the catch ? • self-consumption / non-market exchange • local market • national/international market

Such an approach has been made operational by ICLARM, for instance, in their methodology for the Rapid Appraisal of Fisheries Management Systems (RAFMS) (Pido *et al.*, 1996). It suggests a set of 33 ‘attributes’ of fisheries systems (focus) which fall into 6 ‘contextual variables’ (themes).

Again, this doesn’t represent a hard-and-fast scheme, but is indicative of the questions we can ask about a TCF in order to illuminate the factors that affect how fishers behave in relation to the resource.

However, while such approaches are valuable and necessary, they produce a ‘snap-shot’ of a TCF system at a particular point in time. If time stood still, this would be a perfectly adequate basis on which to base management systems, and all the traditional management systems that ever existed would still exist and be functioning perfectly. But as the surveys of TCFs by Ruddle (1996b) and Wilson et al (1994) show, even the best adapted and long-evolved management systems break down as circumstances change over time.

One of the key aspects, then, to the relationship between the fisher and the resource, is the dynamic nature of the relationship i.e. it changes over time. Not only does this needs to form an explicit part of appraising TCF systems, it needs to be made the focus of such appraisals. Correspondingly, management is about managing a dynamic, not a static system. However, both authors above are vague as to the dynamics of change,

> ‘...traditional management techniques are destroyed under the pressure of modernisation’ (Wilson *et al*, *ibid*)
>
> ‘...traditional management systems have already disintegrated quite widely, and many factors have contributed to the decline, including processes such as colonialism,

> replacement of traditional local authority, education, commercialisation, and economic development' (Ruddle, *op.cit.*).

Thus, approaches such as illustrated in Table 2.3 (above) must be extended to make change the dynamic factor driving management. Examples of how this might be achieved is presented in Tables 2.4a&b below, for the fisheries of Misali Island, Pemba, Tanzania.

Table 2.4a Spatial characteristics - change dynamic and management implications

Theme	focus	Current status	Change dynamic	Management implication
Spatial	fishing ground	fringing, patch reef and bommies surrounding Misali Island	Destructive fishing methods (dynamite, *kigumi*) if extensive could drive fishers to other grounds	Convert *kigumi* fishers to non-destructive alternative method. Educate/coordinate on threat of dynamite fishing.
	home port	Fishermen from 30 *shehia* (local administrational level). Very important to fishermen from 10 *shehia.*	Large numbers of opportunistic octopus fishers from non-traditional *shehia*	Feedback function must continue strongly to **all** *shehia* to include potential entrants in management. Review current feedback activities.
	point of first distribution	Land in numerous sites. Main site Tengu, Chake Chake.	Octopus now sold to traders on the fishing grounds for export to Mombasa, Kenya.	Requires enumerator on Misali Island to quantify problem.

Table 2.4 b Distribution characteristics - change dynamic and management implications

Theme	focus	Current status	Change dynamic	Management implication
Distribution	self-consumption / non-market exchange	A small amount of catch is for fisher and fisher family self-consumption.	None known.	
	local market	Majority of catch.	Tourism development will rapidly increase demand and price for high-value species, such as grouper, parrot fish, lobster.	Higher SR returns for high value species will encourage more effort to be targeted at these species. Discuss issue and possible means of species specific regulation.
	national / international market	Lack of transport and post-harvest infrastructure, restricts market to local level only for most products. Holothurians exported to China.	New processing and export plant for octopus opened in near-by Mombasa. Attractive new export market.	Fishing effort in the octopus fishery may increase rapidly. Management should raise issue and seek solutions and rapid action.

Looking at the entries in the 'change dynamic' column in Tables 2.4a and 2.4b, shows that although we start by describing the relationship between fisher and resource *within* the TCF harvesting sub-system, some of the change dynamics are factors *outside* the harvesting sub- system which impacts on relations within it. In assessing TCFs therefore, we need to locate the harvesting sub-system within its wider context, and then deduce the dynamic interactions and assess their implications for management. A graphical representation of the wider system is suggested in Figure 2.5, below.

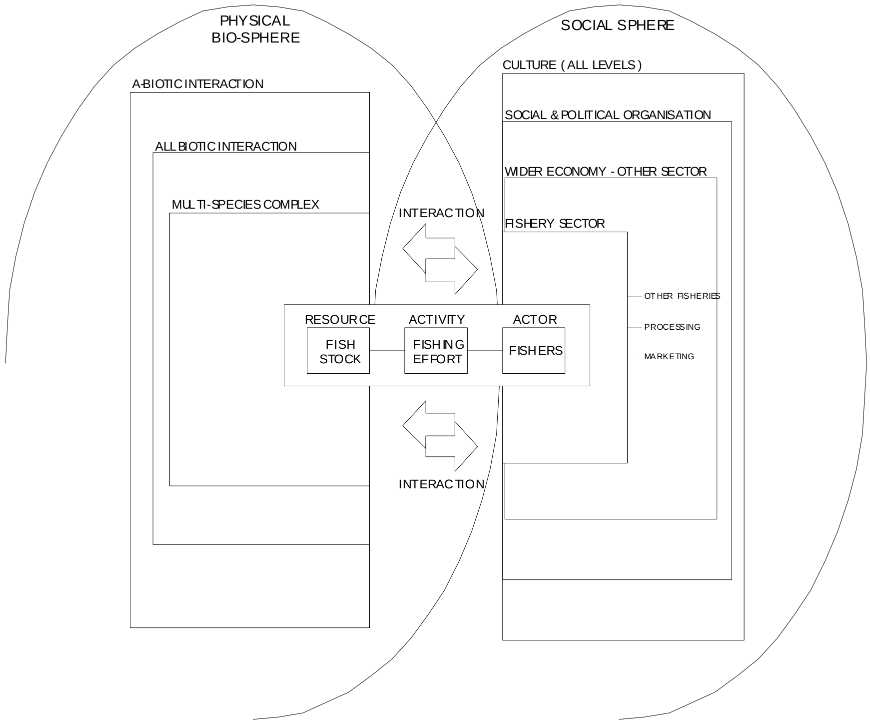

Figure 2.5 TCF in its wider context.

At the heart of the figure is the harvesting sub-system as presented in Figure 2.4 (above) of Resource, Activity and Actor. The ‘Activity’ of fishing effort is now seen as the focus of interaction between two general systems, the ‘Bio-physical sphere’ (or ‘nature’) and the ‘Social sphere’ (or ‘man’). We can see that the activities of conventional fisheries science - concentrated on the ‘fish stock’ and ‘fishing effort’ - take a very partial view of the total system. The behaviour of fish stocks is seen to be embedded in a much wider system of interactions in the bio-physical sphere. And fishing effort, through the behaviour of fishers, is seen to be embedded in a much wider system of interaction within the social sphere.

A similar systems approach is made in Catanzano and Mesnil (1995), in which they attempt to conceptualise fishery systems in a way comprehensible and relevant to researchers in different disciplines. The work of Charles (see for example Charles, 1995) also highlights the wider system in which TCFs are located, in a call for multi-disciplinary approaches to their assessment and management. The RAFMS methodology (ICLARM, op.cit) suggests ideally a team of eight experts for assessment of a TCF, the range of disciplines represented reflecting the system approach: fisheries biology, ecology, economics, sociology, anthropology, political science.

The implication of such system-wide approaches to TCF assessment, is that key relationships between the wider system and the harvesting sub-system need to be understood, if behaviour within the sub-system is to be understood, modelled and managed. The particular point of note in this section, is that these key relationships need to be understood in a dynamic, not a static context.

2.3 Management of TCFs

2.3.1 Re-stating the problem

> *The demand for management of TCFs is derived from the widespread perception that TCFs face a number of resource, economic and social problems. The basic problem, however, is one of surplus labour. Both development and management are advocated as a response.*

One of the key contextual perspectives of the system approach summarised in 2.2.3 above, is that TCFs are part of wider economies characterised by the dynamic process termed ‘development’. A development economics perspective is important to illuminate the relationship of the TCF to the wider economy and highlight to what extent potential solutions to perceived problems lie within the remit of management or development interventions.

In theory, in the medium and long term, returns in different sectors of the economy equalise, though in the short term they are in a constant state of flux, adjusting returns in response to differential incentives. Thus, the returns to effort in the fisheries sector will mirror that of other sectors of the economy. When returns in other sectors are low - the opportunity cost of labour in the fisheries sector is essentially zero - many people will enter the fisheries and returns in the fishery sector will reduce to become low (subsistence level or less). If, on the other hand, the returns in other sectors are high, then labour will leave the fishery for other sectors. This will reduce the returns in other sectors and raise returns in the fishing sector, all other things remaining equal, until a new, higher equilibrium return is reached across sectors. The process of labour leaving low-productivity, low-return, labour intensive production and being absorbed by higher-productivity, higher-return, more capital intensive production is a transformation in the nature of the economy characteristic of economic growth and development. That the modern industrial fisheries of the English Channel, for example, have undergone such a process, can be seen by Charles Fleet’s account of the Brighton fisheries in the mid 1850's (reprinted and edited in Durr, 1994).

TCFs are often located in economies characterised by a rapidly growing labour supply (high population growth, young population age structure). TCFs represent one possible employment. Others may be, for example, agriculture, mining, petty trade and commerce, government service, industrial employment. Labour - in the rational economics perspective - will assess what possible employment is open to it and make some evaluation of the net returns to be gained from entering that employment.

It is in this context that entry of labour into TCFs is often high. The key reasons for this are:

- TCFs tend to have widely scattered locations, often in rural areas, where other employment opportunities - especially ones with higher returns - are scarce or non-existent
- the costs of entering TCFs are often low, in terms of human and physical capital investment required
- expectations of returns are often inflated due to subtractability externalities not being taken account of in individual decisions

On the other hand, the ease of entry in TCFs is not matched by ease of exit (into other employment), such that the interaction between the fishery sector and the rest of the economy is a one-way valve, with labour accumulating in fisheries. This may be explained by:

- high cost of job search in relation to subsistence income
- inability to liquidate capital investment, when returns to fishing are low
- occupational ‘inertia’

Panayotou comments, ‘Lack of occupational and geographical mobility may result from long isolation, low formal education, advanced age, preference for a particular way of life, cultural taboos, caste restrictions, inability to liquidate ones assets, indebtedness or just lack of knowledge and exposure to opportunities. The consequence of immobility is that fishermen may continue fishing even if they earn far less than their opportunity cost’ (Panayotou, *op.cit.*). Clearly, the rational economics perspective only illuminates part of the problem.

Thus the key problem facing TCFs is an excess and immobility of labour. In simple technology, low-capitalised fisheries, labour is synonymous with fishing effort. Thus, the management problem is to reduce the amount of labour employed in the fishery. To do so, can be seen to lead towards achievement of a number of possible management goals: conservation of fish stocks, economic efficiency, higher incomes for remaining fishers.

For this to occur, various things have to happen:

- returns in other sectors must increase (through technological innovation, increased capitalisation, enterprise)
- fishers must be able to compare returns in other sectors to returns to fishing and must judge them high enough to cover the 'costs' of moving sectors and to compensate the risk of moving to something new.
- Within the fishery, for returns to rise, labour effort must not simply be replaced by other aspects of effort e.g. increased capital.
- Within the fishery labour must be held constant or reduced.

The first two points relate to the relationship between the harvesting sub-sector and the wider economy. Attempts to influence these two variables may be the subject of *development* interventions. While the first point is exogenous to the fisheries sector, the second point is the subject of interventions within the fisheries sector aimed at developing the fishers / the fishing community and its ability to integrate with the wider economy. This is not 'fisheries development' in the conventional sense - aimed at increasing catch in the fishery - and could appropriately be termed '*fisher development'*. This is referred to further in the next section.

Attempts to influence the third and fourth points are the subject of *development and management* interventions within the harvesting sub-sector. Thus, within the fishery sector, to reduce labour (effort) in the fishery, you have to:

1. stop more labour entering
2. reduce existing labour in the fishery over time
3. reduce the effort expended by the existing labour

1. Basic strategies to stop more labour entering the fishery are:

- create opportunities outside the harvesting sub-sector at the same rate as growth in the labour supply (development). This can be opportunities in fish processing and marketing, or non-fishery activities within the fishing community.
- gain agreement amongst existing fishers to close access to the fishery to all but the existing fishers and enforce the closed access policy (management).
- raise the cost of entering the fishery vis-a-vis other sectors so that the cost and the risk involved will dissuade new entrants e.g. introduce 'license' fees, training qualification, insurance contributions, rules favouring existing fishers etc. (management).

These are strategies aimed at maintaining the *status quo* in the fishery, a goal that in itself represents a considerable challenge.

2 Basic strategies to reduce existing labour over time are:

- create opportunities outside the harvesting sub-sector at a rate *greater than* the growth in the labour supply (development).
- reduce the costs and risks of moving sector for the fishermen and increase the potential benefits e.g. education, training, provision of information, subsidisation, insurance (*fisher* development)
- take advantage of 'natural wastage' e.g. when fishers retire, die, stop fishing for other reasons. (management).

3 Basic strategies to reduce the effort expended by labour in the fishery are:

- fishers agree to limit the time they spend fishing (management).
- fishers have less fishing or no fishing enforced on them (management).

The key thing is that these three different goals are pursued simultaneously. For example, it is pointless to pursue goal 3 through management while ignoring goal 1 and allowing new entrants to the fishery. Furthermore, you simultaneously have to control other aspects of effort, so that gains in reduced labour are not simply replaced by losses in increased capital.

Restating the problem in this way, a number of points become clear:

- management is largely required due to a failure of development. Thus, the best form of management is successful development
- both development and management have to be undertaken simultaneously if problems in TCFs resulting from surplus labour are to be solved
- the analytical and operational gap between development and management must be closed to produce a more integrated response to problems in TCFs.

2.3.2 Management of TCFs - a social and political process

> *Management of TCFs is a process, not a static, technical fix. The process is about communication between people within a dynamic social and political environment. The process itself can be the prime goal of management.*

In section 2.2.2 (above), we said that 'the management of TCFs is primarily a problem about the behaviour of people', and we placed the 'actor' - the fisher - in our conceptualisation of the TCF harvesting sub-system (Figure 2.4, above). Management was conceptualised as a separate entity that focussed its attention on the actor. In considering how we might conceptualise the management problem, this prescription has to be expanded. Such a scheme is presented in Figure 2.6, below.

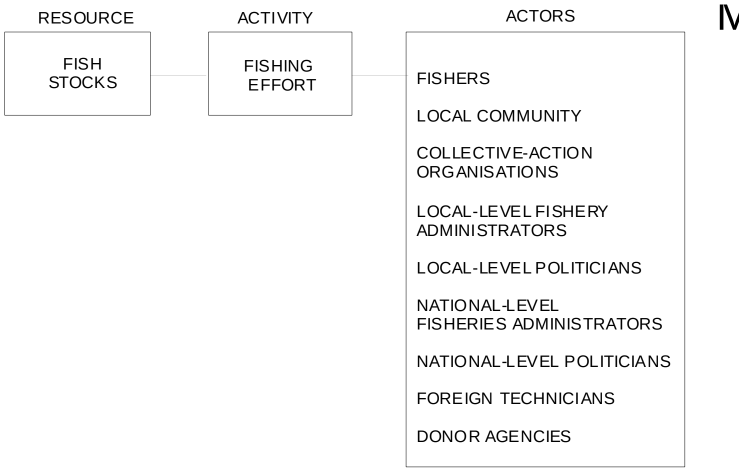

Figure 2.6 An inclusive scheme for TCF management

The key points to note about this scheme are:

- fishers are part of 'management'
- management involves a range of other people
- all these people interact in the function of management.

Thus, management of TCFs is first and foremost about *people* interacting. It is therefore susceptible to analysis in its own right, and within the western academic tradition, relevant fields of inquiry might include: management science, personnel management, organisation theory, social psychology, psychology, political science, conflict resolution. These fields lie outside the area of expertise of the current investigators, a situation typical within fisheries research, and one which could be fruitfully rectified in the future.

However, this isn't to imply that the only type of knowledge relevant and useful to the management process of TCFs is knowledge within western scientific epistemologies. Indeed, because of the implicit value bias of 'scientific' approaches over 'non-scientific' approaches in the prevailing fisheries management paradigm, it necessarily alienates and devalues the potential input of the fishers themselves and other local people without scientific training. In doing so, it also alienates and devalues the people themselves (Kurien, 1987). Thus, not only is their knowledge, their ideas and their energy wasted, but a division is created in the management function exactly where a bond needs to be formed. Community-management approaches are a direct response to this (see, for example, White *et al*,1994, for the case of coral reef management).

Knowledge systems are not the only difference between fishers and others involved in the management function. All will bring to the interaction within management their own interests, which will influence management outcomes in different ways. Gow and Morss (1988) provide an interesting insight into the 'agendas' and influence of actors in development interventions undertaken by USAID. The situation can be seen as broadly analogous to management interventions in TCFs. They summarise their findings in the table reproduced below as Table 2.5.

Table 2.5 - Agendas and influence of different actors in development interventions.

Actors	**Agenda**	**Influence on intervention**
Donor agency	Programme monies for development activities that comply with substantive directives and procedural regulations	Intervention plan will be written to obtain approval; as a result, possible implementation problems will be suppressed
National ministries Lower-level government structures	Each wants to maximise control over resources and how they are used	Decision making not participatory; no networked collaboration - remains in remit of implementing agency
Lower-level politicians	Want to take credit for project and ensure that existing power structures remain intact	Distribution of benefits of intervention dependent on existing power structure
Foreign technicians	Want to perform in their chosen area of expertise	Ignore broader perspectives and higher orders of analysis, neglect capacity building and technology transfer, reduce chances of sustainability
Local project staff	Want career advancement and opportunities offered by the centre, no interest in the periphery	Rapid turnover, little motivation, reduces chances of sustainability
Intended project beneficiaries	Reluctant to adopt new techniques, concerned about existing local power relations	Resistance to change, intervention fails at point of delivery
Other members of the local population	Threatened by or envious of intervention activities and benefits	Constrains success of intervention, diminishes chance of widespread impact

Source: after Gow & Morss (ibid.), Table 3, p.1412.

That so many different agendas are present within the range of people involved in management, immediately brings us back to questions we raised in the introduction:

- what type of goals, what specific goals should management pursue
- who's goals, how are they decided upon ?
- who is controlling the TCF ?

How these questions are resolved will depend to a large extent on the mode of operation of management. Adams (1996) identifies two polar positions in the mode of operation of TCF management:

- *'Pre-emptive, or strategic, management*: This requires much knowledge about the biology of the target organism(s), about the fishing community, and about the effect it will have on the resource. It formulates a model of a fishery based on prior knowledge and applies management measures to the fishery designed (theoretically) to produce a particular result (usually a certain level of catch) at a future period.
- *Retrospective, or evolutionary, management*: This assumes no detailed initial knowledge. Fishing occurs under a certain set of rules and the result is observed. If catch rates decline, the rules are made more restrictive, and if they do not, the rules can be relaxed. Continued feedback provides (theoretically) an increasingly precise system of management.'

The first position is that we have already identified as the prevailing management paradigm based on fisheries science. We have already pointed out a number of problems with its application to TCFs in section 2.1 above.

The second position is a more ‘trial-and-error’ - thus non-scientific - approach. As such, it holds the potential to answer the criticism raised above about the exclusion of fishers and other local people from management. It also holds the potential to take account of other factors raised above in Section 2.2:

- a social **focus**, not a resource focus to management (2.2.1)
- common ground with respect to the **level** of fishers’ and managers’ views of the fishery (2.2.1)
- an alternative to the partial **specification** of highly complex fisheries (2.2.1.2)
- trouble avoiding rather than **goal** maximising (above, and 2.2.1.2)
- the high cost of pre-emptive approaches (2.2.1.3)
- the explicit inclusion of fishers as social and cultural as well as individual beings (2.2.2)
- a contextual focus (2.2.3)
- a dynamic, not a static approach (2.2.3, 2.2.1.2)

It would also be a mode of operation of management consistent with the parametric approach to TCF assessment highlighted in section 2.2.1.4, above.

However, such an approach to TCF management faces the problem of gaining currency and credibility in a climate presided over by a pre-emptive, scientific management paradigm. A viewpoint from the history and philosophy of science may be useful here,

> ‘History is full of “accidents and conjectures and curious juxtapositions of events” and it demonstrates to us the “complexity of human change and the unpredictable character of the ultimate consequences of any given act or decision of men”. Are we really to believe that the naive and simple-minded rules which methodologists take as their guide are capable of accounting for such a “maze of interactions”? ..Should we transfer to it [methodology, science] the sole rights for dealing in knowledge, so that any result that has been obtained by other methods is at once ruled out of court?...to these questions my answer is a resounding NO.’ (Feyerabend, 1975)

Various authors have proposed approaches to management which fall within the evolutionary management mode. Ramirez (1983) presents an ‘action learning approach’ to management. Action learning strategies have two distinct characteristics:

- there is agreement amongst stakeholders - however reached (political process) - that they need to cooperate in some way to solve intractable problems in conditions of turbulence (complexity and rapid change)
- all stakeholders (experts or laymen) learn together through taking actions to resolve the problem in a process where policy and implementation are simultaneous, not sequential.

The action learning approach changes the perspective of management and research:

- Management is re-framed from a control exercise to one of facilitating a co-learning process
- Research is re-framed from an answer-oriented endeavour to a problem-posing endeavour providing opportunities for learning

Within this approach, the management problem is seen to manifest itself as gaps between outcomes and expectations, termed ‘errors’. In the case of TCFs, one such error can be perceived in fishermen’s catches, created by the unaccounted-for externality of subtractabililty. Action learning is an approach to finding and correcting these errors - mainly through the agency of changing expectation.

> ‘Action learning strategies activate the ingenuity, curiosity, spontaneity, intelligence, self-reliance, confidence, and dignity of those who engage in them. As such, action learning reflects some aspects of folk wisdom and commonsense. In considering collaboration to be the higher logical type and competition the lower one, it returns us to some of our more indigenous forms of self-help and collegiality’ (Ramirez, ibid, p.739.)

Morgan (1982) suggests that systems which learn and evolve do so by avoiding undesirable states rather than pursuing those they actively desire. Thus an evolving TCF management system would not aim at some specific goal such as MEY or MScY, but instead, may seek to avoid, for example:

- a change in catch composition where most of the high-value species are removed from the catch

- damage to the environment on which the fisheries are dependent
- conflict over use of the fishery resources
- ‘overfishing’ (however this is defined).

Finger & Verlaan (1995) propose *Social-Environmental Learning* as an appropriate management strategy for current ecological crises, of which the state of TCFs is a good example. ‘Social-Environmental Learning is collective and collaborative learning that links the biophysical to the social, cultural and political spheres, the local to the global arenas, and action to reflection and research’. They argue that traditional problem solving approaches are bound to fail if these are pursued unilaterally and if the problems themselves are treated as discrete, separable units, approached only by specialists and experts. As such, it is an approach consistent with the findings of Section 2.2.

They employ three pedagogic techniques from adult education theory in their Social-Environmental Learning system:

- *Perspective transformation* - Requires, first deconstructing existing national and sectoral perspectives in order to come up with more inclusive perspectives and see the partiality of existing perspectives. They would also come to understand - explicitly - their own perspectives better. Perspective transformation is not an end in itself, but a means to informed action.
- *Collaborative problem solving* - called Action-Reflection Learning (ARL). Problems are collectively defined, impediments and solutions identified. Learning is individual but goes beyond skills acquisition.
- *Participatory Action Research* (PAR) - is collective and collaborative research used as an individual and group learning process, leading to the acquisition of skills and perspective transformation. Can also lead onto realistic action plans for the research area.

The differences between the two operational modes of management are summarised in Table 2.6, below.

Table 2.6 - Alternative operational modes for TCF management

Pre-emptive / strategic management	Retrospective or evolutionary management
‘fishery science management paradigm’	‘action-learning approaches’
• Atomistic logic • Hierarchical connections • Centralised authority • Formalised procedures • Rigid structure • Division of labour • Compartmentalised knowledge	• Contextual logic • Lateral connections • Decentralised authority • Low formalisation • Flexible/adaptive structure • Teamwork • Integrated knowledge

Conclusions

The conventional fisheries management paradigm based on fisheries science and practised by an elite core of specialist managers is an inappropriate approach for TCFs. An alternative approach, sees management as an evolutionary learning process involving diverse actors, especially fishers.

2.3.3 Management systems in TCFs

Management systems for TCFs should be designed as systems of social organisation able to achieve compliant behaviour. The choice of which of three analytically distinct systems to use and the level of decision making within the system are key determinants of compliance.

2.3.3.1 Systems of social organisation and compliance

The management system prescribed by the prevailing fishery science paradigm is based on threat - ‘if you don’t behave how I want you to, I will do something to hurt you’. Two points can be made here. First, it is, therefore, just a specific application of threat systems of social organisation (other examples are organised religion, law, the army) and as such, can be informed by that literature (see column I, Table 2.7, below). Secondly, it is just one of three basic systems of social organisation identified by diverse writers (Uphoff, 1993), and as such is a narrowly conceived prescription for TCF management systems (Dubbink & van Vliet, 1996). The three systems of social organisation are identified in Table 2.7, together with authors who have described them. To use Boulding’s terms, they are: threat systems, exchange systems, and integrative systems (Boulding, 1964).

Table 2.7 - Systems of social organisation in social science

Literature	**I**	**II**	**III**
Types of organisation Sociology - Etzioni 1961	Coercive	Remunerative	Normative
Types of power Sociology - French and Raven, 1959	Coercive power	Reward power	Referent power Legitimate power
Kinds of systems Economics - Boulding, 1964, 1989	Threat systems	Exchange systems	Integrative systems
Kinds of power Economics - Galbraith 1983	Condign power	Compensatory power	Conditioned power
Game theory outcomes - e.g. Rappoport 1969	Negative -sum	Zero-sum	Positive-sum
Relationships of utility functions Ecoonomics	Interdependent (negative)	Independent	Interdependent (positive)
Behavioural alternatives - Hirshman 1970	Exit (desired, but may be prevented by coersion)	Voice (critisism and bargaining)	Loyalty (acceptance of some disutilities)
Most strongly associated sector	State	Market (Collective action) (State)	Collective action (State)

Source: after Uphoff, 1993, table 1, p.612.

To these, the current authors add a fourth, ‘cultural systems’. This is really an extreme manifestation of integrative systems, but is worth making analytically distinct, especially in the case of TCFs. Various properties of the four systems are summarised in Table 2.8, below. They have their obvious counterparts in the different perspectives of human behaviour discussed in section 2.2.2 above. Indeed, they regard the same phenomena but from different ends of the spectrum of aggregation.

Systems of social organisation respond to different reasons why people do things. Thus, in the threat system, people do things because they are told to and in order to avoid punishment for not doing them. In the exchange system, people do things because they anticipate personal gain from doing them. In the integrative system, people do things in groups in the anticipation of gain for the group. And in the culture system, people do things because they are the ‘right’ things to do.

Threat systems

From the viewpoint of the biological sciences, the threat system can be seen as an updated, expanded and enhanced version of basic dominance behaviour over territory and social hierarchy (see for example Morris, 1967, chap.5). It works as a social organiser on the principle of ‘the dominant male’, who dictates behaviour on the basis that his authority is made ‘legitimate’ by physical strength. Thus, other members in the society are coerced into compliant behaviour. However, none *wish* to be coerced into compliant behaviour and all wish to be the ‘dominant male’. Thus, the system is constantly tested as members of the system react against coercion. This has the consequence, that if individual members of the society can ‘get away’ with non-compliant behaviour, they will. And once one member is seen to challenge the system and get away with it, then all other members will follow and the system will break down until, once again, one male dominates and the threat is re-established.

Locating solutions to TCF management problems in the threat system of social organisation, faces a number of problems. Firstly, is the problem of ‘instinctive’ dissent, which in the absence of an effective threat, will destroy the system - even if the desired behaviour is derived from the findings of science. Secondly, in the modern bureaucratic system, this instinctive resistence is exacerbated by the level of aggregation, which means that the rule maker and enforcer is easily seen as an outside entity, not even having the legitimacy of belonging to the group (see below). Thirdly, to locate management solutions exclusively in this system, wastes the potential for social organisation to be found in the other three systems.

Exchange systems

Exchange systems can be efficient social organisers. They work on the principle, ‘if you do something nice for me, I’ll do something nice for you’ - they create the chance for mutual gain. However, this relies on underlying institutions, especially law and property. Where property rights are assigned, exchange can lead to optimal resource allocation. Where property rights are not assigned - the open-access assumption of the fisheries science paradigm - exchange systems run into problems, hence the tragedy of the mis-named ‘commons’. Fisheries science prescribes the solution of reverting to a threat system, of directing and enforcing ‘correct’ behaviour by fishers. The other solution, of course, is to assign property rights to fishers where they don’t exist - and recognise and protect property rights where they do exist. Once property rights exist, exchange systems can act effectively as social organisers.

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Integrative systems

Integrative systems involve ‘a convergence in the images and the utility functions of the parties towards each other’, or a ‘meeting of minds’ (Boulding, 1964). Integrative systems are characterised by cooperative behaviour within groups. Thus, to the extent that the group is exclusively associated with a particular fishery resource, the coincidence of views and utility functions will suffice for the group to adopt efficient behaviour with respect to that resource. The great advantage of this is that the costs of achieving an efficient solution (i.e. information, regulation, surveillance, enforcement) are born by the group, along with the benefits of an efficient solution. It is in the group’s best interests therefore to ensure compliant behaviour in the least-cost way. Integrative systems require, however, that property rights to the resource be vested with the group and that the group can successfully defend those rights, in an analogous way to private property rights in exchange systems.

Many examples exist of fisheries that are effectively self-regulated by groups (see for example, Berkes et al, 1989. Wilson et al 1994 provide a summary of 31 different cases). Given the possibility of successful self-regulation of fisheries by groups, and the advantages of this with regards to the costs attached to compliance, it suggests that fisheries management and research be geared towards developing strategies and models for group forming behaviour and self-management. The social and political economy literature associated with the collective-action sector is an extensive general literature with this aim (see section 2.2.3 above). White et al (1994) provide examples for the case of tropical coral reefs.

Culture systems

Where societies have persisted over long periods of time in fairly stable environments, integrative systems will have developed to the stage that culture determines all behaviour, so that the ‘individual’ in the western liberal sense ceases to exist at all. Where such societies are associated with particular fishery resources, the use of the resource will be determined by the culture along with all other behaviour.

Examples of fisheries successfully regulated by culture have been widely documented, and are often associated with the epithet ‘traditional fisheries’ (see for example Berkes, 1977; Ruddle, 1996b). The long-term prospects for successful cultural regulation of fisheries appear to be diminishing, precisely because of the inexorable spread of ‘western’ culture, in which fish are simply a resource and behaviour amoral (i.e. rational). However, even within ‘mixed’ cultures, the local culture may still be an important determinant of behaviour in a fishery and may provide a key to successful local management.

Conclusions

Therefore, in seeking management solutions for TCFs, we can consider four systems of social organisation, not just the one, as has been commonplace. The system we choose must act to organise behaviour of people in the TCF in a way compliant with the management goals of the TCF - whether they be conventional goals or participation in a process.

Threat systems depend for compliance on the legitimacy and effectiveness of the threat. This is largely doubtful in the case of TCFs managed in state structures due to their dispersed nature and the thin resource base of the state from which to mobilise a threat. In any case, a threat does not change the underlying incentives for behaviour.

Exchange systems depend on allocation of private property rights or rights of access. These change the incentives for behaviour of the right holder and may produce an efficient solution. However, in the case of TCFs, an overarching concern of both fishers and policy makers is some measure of equality, especially equality of access, if not necessarily equality of return. Allocation of private property rights potentially creates a huge exclusion problem. If the allocation is seen to be ‘unjust’ by those excluded, defending property rights against ‘illegal’ fishing, or ‘poaching’ may present an intractable problem for the right holder.

Integrative systems also depend on the allocation of property rights or rights of access. However, the exclusion problem is minimised by the rights being vested in groups, and as such tend to ‘inclusivity’, not ‘exclusivity’. The rights must therefore be defended *vis-a-vis* other groups, but the integrative dynamics *within* the group should ensure compliance to group rules (see 2.3.3.2 below).

Finally, cultural systems depend for compliance on the integrity of the system, which in turn depends on its stability. Pure cultural systems are thus breaking down under rapid change. However, aspects of cultural systems may persist as powerful social organisers.

In practice, of course, systems combine these four types. A key requirement for successful management of TCFs is that the role each can play in a management system is considered, and the most appropriate combination is chosen. The current trend towards ‘co-management’ (however that is defined) involves a combination of integrative systems in the collective -action sector backed up at a higher level by threat systems in the state sector. This combination results, in part, as the ability of integrative systems as social organisers is dependent on the level of aggregation.

Table 2.8 - Properties of alternative systems of social organisation

	I	II	III	IIIa
Organising principle	Threat	Exchange	Integrative	Integrative
Principle institutions	Bureaucracies	Markets	Groups	Culture
Actor	Political leaders, technocrats, administrators	Individual/corporate producers/consumers savers/investors	Group, class (leaders and members)	Culturally imbued ‘individuals’
Prime motivation for behaviour	Coercion	Self-interest	Group interest	Moral
Goal of behaviour	Minimise disutility	Maximise utility	Advance interests of group	Moral correctness and cultural acceptance
Guides for behaviour	Regulations	Price signals and quantity adjustments	Agreements, group rules	Cultural norms, ritual, cosmology
Sanctions	State authority backed by coercion	Financial loss	Social pressure	Moral condemnation, excommunication
Mode of operation	Top-down	Individualistic	Bottom-up	Pervasive
Associated property right regime	State - *de facto* open-access	Private - individual/corporate	Communal - group/cooperative	Defined within cosmology
Main associated academic discipline	Political science	Economics	Sociology	Anthropology

Source: Derived from Uphoff (1993), Table 1, p.610, and Wilk (1996)

2.3.3.2 Integrative systems, compliance and the levels of aggregation

The motivation underlying fisher behaviour varies with the level of aggregation within society relevant to that behaviour. About ten levels of aggregation can be suggested. These can be seen, not only to provide a hierarchy of decision-making levels (Uphoff 1993), but also as a hierarchy of levels at which compliant behaviour is sought with respect to management goals for a TCF.

In integrative systems, compliance results from successful cooperation of the actors in a group in pursuit of management goals for the TCF system. In turn, cooperation within a group depends on developing *trust* between the members of the group (and between the members and the facilitators) and on developing *commitment* by the group members to achieving the group goal or participating in the group process.

The problem (and the cost) of developing trust within the group increases as the number of the people in the group increases. This is because the ease of communication between the members of the group diminishes as numbers increase. The problem (and the cost) of developing commitment within the group also increases as the number of people in the group increases. This is because the extent to which an individual's own self-interest is represented by the group interest diminishes the greater the number of people in the group. A graphical representation is presented as Figure 2.7, below.

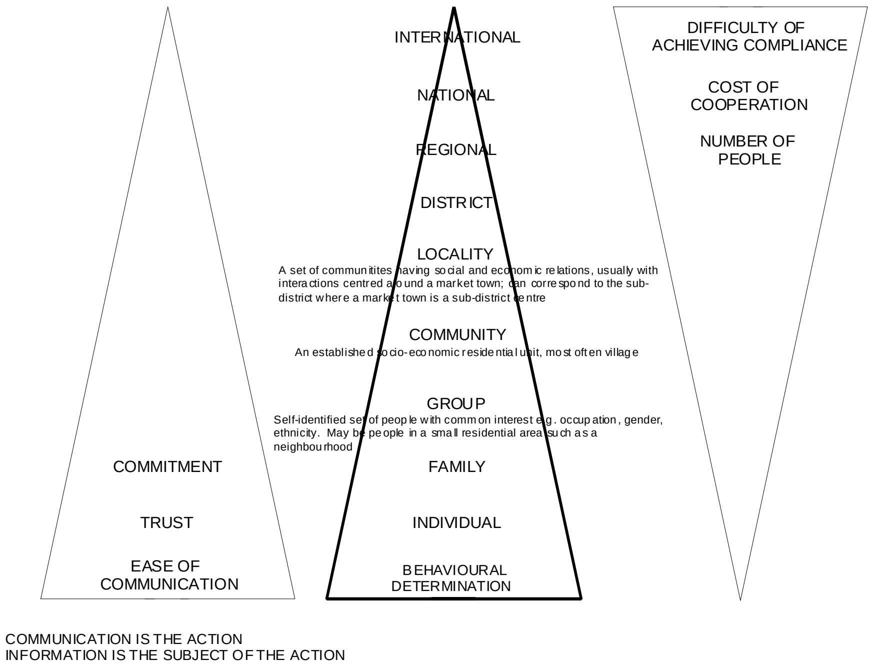

Figure 2.7 Integrative systems and the level of aggregation

The prospect for achieving successful compliance in relation to a management goal for a TCF, can be seen, therefore, to diminish the further up the hierarchy of aggregation the management problem is located, from 'individual' towards 'international'. It follows, that integrative solutions for TCF systems should be sought in accordance with Kohr's principle of subsidiarity - that is, at the lowest level of social aggregation possible (Kohr, 1978), both for reasons of effectiveness (achieving the management goal) and efficiency (achieving the management goal in the least-cost way to society). This provides strong theoretical justification for seeking cooperative solutions to TCF management problems at local levels and on a territorially defined, not functionally defined, basis.

For integrative solutions to work over wider systems and at higher aggregate levels, requires the development of 'networks' (see, for example, Carley, 1991; Carley & Christie, 1992; Sagasti, 1988).

Referring back to section 2.2 (above), one of the basic observations about assessment models for tropical fisheries, were that they had an aggregate level perspective, whereas fishers made decisions primarily from an individual perspective. This dichotomy of perspective has its organisational counterpart in the prevailing fisheries management paradigm in that management is primarily a function within the state sector (threat system), whereas fishers are organisationally in the market (exchange system) or collective action (integrative system) sectors. Putting the two together, we find that both the perspective, mode of operation and goals of fisheries managers are distinct from the perspectives, modes of operation and goals of fishers. It is little wonder, therefore, that within this paradigm, management successes are few. It suggests the need for a paradigm shift, rather than a refinement of existing solutions. Within the human sciences literature, that shift has been taking place now for some time.

'Management' therefore needs to move from the position of seeking to change individual decisions which are seen as 'wrong' at the aggregate level. It needs to move down to the individual level and seek ways of influencing the decisions that are made i.e. of internalising the externalities in individual decisions. Correspondingly, fishers need to move from making decisions that are right at the individual level but wrong at the aggregate level. They need to move up to that aggregate level and seek ways of making decisions that are right at that level.

This means that management needs to create conditions in which individual decisions *do* reflect aggregate level goals - fishers need to move towards a concept of management *as their aggregate level decision making*. This implies that fishers take on some responsibility for the management of the fishery i.e. that the social organiser changes from a threat system to an integrative system.

On a practical level what this means, is that forms of organisation have to found which overlap both in terms of the functions of the different sectors and the levels of decision making. It means creating organisational common ground. An example is shown in Table 2.9 for the fisheries of Misali Island, Pemba. The entries in the table in normal type are organisations existing prior to a management project. Those in bold type are organisations developed within the management project. They create an area of overlap between the perspectives and functions of managers and fishers. In this instance, organisation development was primarily in the collective action sector, though it could also be in the market sector through the formation of limited liability firms (Townsend, 1995b).

Table 2.9 - Closing the gap between managers and managed: an example.

Decision-making level	**State sector (threat system)**	**Collective-action sector (integrative system)**	**Market sector (exchange system)**
International	Commission of the European Community	CARE	Italian processing company, Mombasa, Kenya; Dive boat operators, Mombasa, Kenya; octopus traders; sea cucumber traders
National	Government of Zanzibar, Ministry of Agriculture,	CARE	Tour operators, Zanzibar Town; Dive boat operator, Zanzibar Town
Regional	Commission for Natural Resources, Pemba; Fisheries Department, Pemba.	***Misali Island Conservation Association (MICA)*** (open to actors from all sectors, by voluntary association)	octopus traders; big hotels, Pemba;
	Misali Island Management Committee (a formally constituted committee with representatives from all sectors. the majority representation being of fishers through the collective action sector)		
District	District Officers,	***District Committees*** (district level committees of Mislai fishers)	Tenga market
Locality	Shehia (Masheha), Landing site officer	***Shehia Committees*** (local level committees of Mislai fishers)	market traders, boat operators Chake Chake - Misali
Community		boat cooperatives, gear cooperatives	Boat/gear owners - middlemen / owner - fishers
Group		Misali fishermen, Misali fishermen by gear/fishery, sharecrop fishermen.	fish traders, octopus traders, sharecrop fishermen
Individual (relationship to sector)	Citizen, voter, taxpayer	'Member'	producer, consumer,

Source: Soley (1998), originally adapted from Uphoff (1992), Figure 3, p.615.

2.3.4 Functions of TCF management systems

TCF management system is must fulfill a number of functions. These are divided into first and second order functions, and are hierarchical in importance to good management.

2.3.4.1 First order management functions

It follows that any management system for TCFs has some fundamental choices to make about its form before conducting any other management functions. These basic decisions will have the greatest influence over the behaviour of fishers in the TCF and thus over the outcome of the management process. As such, we will call these *First Order* management functions.

First order management functions involve management both *creating* and *maintaining/evolving* its basic form with respect to systems of social organisation, property/access rights, and forms of organisation / decision-making. A matrix of first order management functions is presented below as Table 2.10.

Table 2.10 First order management functions for TCFs

Social organiser	Property/access rights	Social organisation/decision making
1. None	open access	Individual (fishing unit) , private company, public limited company
2. Threat	State	State bureaucracy
3. Exchange	Private	Individual (fishing unit) , private company, public limited company
4. Integrative	Communal	Group, cooperative, limited company
5. Cultural	Defined by culture	Cultural leaders, cultural consensus

How management locates itself within the above matrix, determines its form in relation to two of the three issues of the ‘tragedy of the commons’, that is,

- ownership/access issue (see, for example, Feeny et al 1990; Christy, 1996)
- social organisation issue (see, for example, Townsend, 1995b; McCay, 1980)

The third issue - the exploitation pattern issue - is the subject of Section 2.5, below.

The ‘tragedy of the commons’ assumes situation 1 in Table 2.10, above. It may occur where first order management was never *created* (or never evolved), or where management failed to *maintain/evolve* its basic form. Either of these may be explained as a result of the information and transactions costs environment of the TCF being or becoming non-conducive to first order management functions. This may explain why many TCF management systems, though *de jure* are situation 2, *de facto* act as situation 1. This highlights the importance of first order management functions. If these are not fulfilled, second order functions will not be fulfilled either.

2.3.4.2 Second order management functions

Whichever first order situation (or combination) is relevant to the TCF, the management so defined has a number of second order functions to perform. Thus, the functions remain the same whether they are carried out by a state bureaucracy, a private firm, a cooperative, are culturally determined, or any combination of these. What will differ is the nature of the function depending on the first order decisions. The second order functions are:

- compile/communicate information
- set goals
- define rules
- gain compliance
- monitor itself

compile/communicate information
'Information' in this context, relates to both the assessment of the TCF covered in section 2.2, above, and the management of the TCF - covered in the current section. All forms of information can be considered here (not just western scientific forms) and the emphasis should be -as in Feyerabend's dictum - that 'anything goes'. However, information is only of use in the management process if it is *communicable* and *communicated* (Bennett & Hatcher, in prep.).

set goals
'Goals' in this context is not narrowly defined, and may refer to any of the following broad types,

- achievement of 'equilibria' solutions, characteristic of the fisheries science paradigm (e.g. achieve MEY)
- maintenance of system parameters, as advocated by Wilson et al (1994) and as practised in many 'traditional' self-management regimes (e.g. maintain spawning pattern of resource)
- avoidance of undesirable outcomes, (Morgan, 1982) (e.g. avoid conflict)
- maintenance of a process (ref.) (e.g. maintain usufruct system).

The way in which goals are set will depend on the social and political processes of management, the subject of section 2.2, above.

define rules
'Rules' will circumscribe the freedom of behaviour of stakeholders within the TCF system as a means of achieving management goals. Rules are the 'fine tuning' instruments of management and will be defined within the context of first order management functions and the second order functions of information communication and goal setting (all above). They are dealt with separately in section 2.3.5, below.

gain compliance
Compliance is sought in line with management goals and the rules through which they are pursued. The nature of this second order function will be determined largely by the choices made in first order functions. Thus, (from Table 9 ,above), situation 2 will require a formal surveillance and enforcement function within the state bureaucracy. In situation 3, the rights owner will not cheat himself, so surveillance and enforcement will only be necessary in the form of employer/employee relations. In situation 4, surveillance will be between members of the group, and pier/social pressure should in most cases be sufficient as enforcement. In situation 5, surveillance is internal to the person -seeking to do the 'right' thing - and enforcement will be through moral approbation. As in reality most TCF management systems will feature a mix of first order situations, the compliance function will form a mix of the above.

self monitoring
Lastly, whatever management system is in place, it must monitor itself with respect to *effectiveness* - fulfilling its first and second order functions - and *efficiency* - the costs of management compared to the benefits. Monitoring *effectiveness* is particularly important given the dynamic nature of the wider context of the TCF (section 2.2.3). Thus monitoring takes the form of continual assessment of the response of the management system to the contextual conditions. If changing conditions reduce effectiveness, management must be able to adapt itself by changing *whatever aspects of the management process or the first and second order management functions are necessary*. Monitoring is thus an important part of the information function (above). The importance of monitoring *efficiency* was covered in section 2.2, above. As a general principle, efficiency will be enhanced to the extent that the benefits and costs of management accrue to the same organisation. As such, first order decisions are crucial determinants of management efficiency.

2.3.5 Management rules for TCFs

> *Promulgating rules is a second order function of TCF management. Rules aim to influence the pattern of exploitation of the TCF in pursuit of management goals. The effectiveness of rules most crucially depends on management systems, processes and first order management functions.*

The TCF harvesting sub-system of Figure 2.3 (above) has three basic components: resource, activity, actor. First order management functions address two of these: the resource (property rights) and the actor (social organisation). The second order management function of rule setting addresses the third: the activity. While the exact rules management may promulgate will be case specific, a number of different *types* of rules, or instruments, are available by which management can attempt to influence fishing activity. These have been surveyed by, for example, Beddington & Rettig (1983)in application to different types of fisheries, Panayotou (1982) for 'small-scale fisheries', and by Ruddle (1996) in the case of traditional management regimes of tropical reef fisheries. A simple typology of rules is presented as Table 2.11, below.

Table 2.11 A simple typology of rules for TCFs

Rule affects	Rule type	Rule mechanism
who can fish	licences	boats, gear, fishermen, fishing units, with/without fees
	individual quotas	boats, gear, fishermen, fishing units
how to fish	gear specification	mesh size, pot size, no./spacing of hooks
	gear prohibitions	dynamite, poison, trawls, fish finders
how much to fish	fishing effort controls	vessel capacity, quantity of gears
	aggregate quotas	per fishery, as defined by species, gear, area
when and *where* to fish	time/area closures/rotations	seasonal closures, spawning ground closure, fishing spot rotation
	reserves	marine parks, reef sanctuaries
how much profit from fishing	economic controls	taxes/monopoly on inputs, taxes on landings/sales, price controls, monopsony

Within a TCF management system, a combination of different rules and different rule types is likely to be required to achieve specific management goals. This produces great complexity in the incentives facing fishers to behave in certain ways. The key point from the perspective of this paper, is that these various incentives are explicitly considered and that the management rules are not simply regarded in terms of an interaction of fishing effort and the resource.

However, an adequate discussion of the role rules can play in the management of TCFs has often been obscured in the literature of the fisheries science paradigm by a number of unstated assumptions. These are:

1. the rule can be implemented
2. fishers will comply with the rule
3. the rule has no further effects
4. the rule is effective in achieving its goal

All of these assumptions must be questioned in relation to TCF management.

The first assumption, is one about administrative feasibility. This is a key consideration in TCFs due to them being characterised as: small scale, widely dispersed, multi-species, multi-gear fisheries. This makes it unlikely that rules set by a central administration can be implemented. The chances of rules being implemented will increase if the administrative structure making the rules more closely matches the structure of the fisheries to which the rules apply. That is, they are small scale and widely dispersed i.e. they are decentralised and defined territorially along with the fishery.

The second assumption is about compliance, which is really the theme running throughout this paper. The main point that needs to be made here with regard to compliance, is that, contrary to the semantics of the literature, no rules are 'direct' in their effect on the resource; all operate through the agency of fishers. Thus, their behaviour is crucial to consideration of the rule.

The third assumption is also problematic. All rules circumscribe the behaviour of fishers to fish how they wish to. They may affect: how to fish, who can fish, how much to fish, when/where to fish, costs/returns to fishing. However, rules will not determine fishers behaviour completely and they still remain free to decide many things about their fishing activity. Thus, rules do not only have the intended effect, they also change the parameters facing fishers and so change fishers decisions about their fishing activity. These ‘secondary’ effects often act to undermine the goal of the rule in the first place. In particular, there has been a tendency to ignore possible economic and social impacts of rules. These are critical in determining whether fishers comply with a rule (2) and whether a rule is effective in achieving its goal (4).

The fourth assumption is problematic due to the limits TCFs place on the accuracy and utility of fisheries science (see section 2.2, above), especially in relation to their dynamic context (see section 2.2.3, above). It is far from certain that even if a rule can be implemented and complied with, that it will achieve its goal.

These four assumptions can, then, be made into criteria for judging potential rules. To these, we can add a fifth criterion of efficiency, whether the goal is achieved in the least-cost way.

- Can the rule be implemented?
- Will fishers comply with the rule?
- What secondary effects will the rule cause: economic, social?
- Will the rule be effective in achieving its goal?
- Will the rule be efficient in achieving its goal?

These criteria are presented with a number of guiding principles in Table 2.12, below.

Table 2.12 Criteria and guiding principles of rules for TCFs

Criteria	**Guiding principles**
Can the rule be implemented?	• Simplicity • ease of surveillance
Will fishers comply with the rule?	Compliance will depend on: • system of social organisation of the management system • first-order management functions • higher second-order management functions • fisherman notions of ‘fairness’.
What secondary effects will the rule cause?	• All rules have secondary effects. Effort should be made to recognise these when different rules are being considered in pursuit of a management goal, *before* any rule is selected and implemented.
Will the rule be effective in achieving its goal?	• Be realistic about the knowledge basis on which the rule rests, as the relationship between the rule and goal is likely to be incompletely understood. • The secondary effects of a rule may undermine effectiveness. • Will the effect of the rule be apparent, or can it be measured and demonstrated ? • Where multiple goals exist, a rule, while effective in achieving one goal, should not act to the detriment of another goal.
Will the rule be efficient in achieving its goal?	• An efficient rule creates benefits in excess of costs. If costs are greater then benefits, the rule should not be implemented. • The greater the excess of benefits over costs, the more efficient the rule. • Estimates (ex-ante) and measurements (ex-post) of costs and benefits are required to determine the efficiency of a rule. • Costs include opportunity costs and out-of-pocket costs to fishers of the rule, and all the costs of administering the rule (decision, surveillance, enforcement). Benefits are measured as the difference in value of the fishery *with* the rule over its value *without* the rule. Benefits must be positive. • The stream of costs and benefits created by the rule should be adjusted to account for the time value of money (discounting, compounding).

While the guiding principles apply equally to any rule, some comments can be made specific to the different rules in the simple typology of Table 2.12 (above).

Who can fish

Determining *who* can fish is an unavoidable corollary of determining *how many* people can fish. These rule types respond directly to the surplus labour problem of section 2.2.1. That is, they attempt to limit the number of people fishing. This implies choosing which people have access to the potential benefits provided by the fishery and which are denied those benefits.

Can the rule be implemented?

The manner in which this decision is made may be critical. In a threat system, an administrator will decide, on criteria of his choosing which may or may not be explicit. The potential for corruption is created here. In an exchange system, the market will allocate the right to fish and bids will be made based on the perceived future flow of net benefits from the right to fish. Clearly the ability to pay (e.g. access to credit) will critically determine who gains the right to fish. In an integrative system, *who* can fish will be agreed in a social and political process. Rights to fish can be expected to be allocated in line with power relations within the system. And in a cultural system, rights to fish will be defined within the culture. Thus egalitarian cultures will allocate rights equally to all and hierarchical cultures will allocate rights in line with the social status of people within that culture. Licence fees can potentially be used to help keep a fishery closed to new entrants from 'outside'. Fees for 'outsiders' to fish form part of many traditional community management regimes (see, for example, Ruddle, 1996b)

Will fishers comply with the rule?

The key point is that in limiting the number of people who can fish, in whichever system by whichever means, creates *insiders* - those allowed to fish - and *outsiders* - those not allowed to fish. Fishers (insiders) will comply by the rule, simply by fishing. The compliance problem is created by the outsiders, and manifests itself as 'poaching' or 'illegal fishing'. It is clear then that TCF management policies based on '*who* can fish' rule types should be critically concerned with the outsiders the rule creates.

What secondary effects will the rule create?

In creating a class or group of outsiders, the rule clearly disadvantages this group or class, *vis-a-vis* the insiders - they are denied access to the benefits of the fishery. In the absence of alternative income sources, the non-fishers and their dependents will become poorer than the fishers. In creating a disadvantaged group, the likelihood is that a situation of conflict will arise.

Will the rule be effective in achieving its goal?

This depends on the goal. If non-compliance can be contained, goals of fish stock conservation *may* be achieved, as may goals of raising fishermen's (insiders) income (though both will depend on many other factors). An over-arching goal of social equity will, however, be compromised.

Will the rule be efficient in achieving its goal?

This will depend on the cost of making the rule and the cost of maintaining it. This will be higher the greater the incentive the rule creates amongst outsiders for non-compliance and conflict. If this is high, the rule will either be ineffective or inefficient or both.

How to fish

If certain methods of fishing are banned outright - gear prohibitions - and if these gears are employed by particular groups/communities of fishers, the rule creates an outsider/insider situation analogous to the *who* can fish rule type above (see, for example, Buhat, 1994, on the case of sodium cyanide aquarium fishers).

Gear specification rules may similarly suffer from the outsider/insider problem within a multi-gear fishery, but to a lesser extent. This will be the case where a rule is applied to one of multiple gears, but not to the others. Those fishers using that gear may feel disadvantaged *vis-a-vis* other gear users.

Can the rule be implemented?

In a threat system, an administrator will announce a rule, may oversee withdrawal of gear, and will undertake surveillance and enforcement in accordance with the credibility of the treat he wields. In an exchange system, gear specification will be a voluntary act of a private operator made on the basis of calculation of their long-term profitability from the fishery. In an integrative system, a gear specification may be identified and agreed as a potential solution to a problem perceived and agreed within the group(s). The specification will then be voluntarily implemented by all members of the system. In a cultural system, gear may be specified and recognised as part of 'correct' behaviour with respect to the fishery.

Will fishers comply with the rule?
This will depend on the extent to which the fisher is 'bound in' by both the system and process in which the gear specification is implemented. From the view of game theory, whether the (individual) fisher will or will not comply depends on:

- the advantage to be gained by cheating together with the likelihood of getting away with it / the risk if being caught
- his perception of whether other fishers are compliant or not.

Game theory shows us that the result will depend on the circumstances of the game (see section 2.2.2.1, above).

What secondary effects will the rule create?
Gear specifications will impose costs on affected fishers, firstly of foregone income of withdrawn gear, and secondly of investment in compliant gear. These costs can be seen as an investment cost in a future stream of benefits i.e. increased resource productivity and so yields in the future. However, as returns in TCFs are often very low in the first place, fishers may not be able to bear this 'investment' cost in resource productivity. Non-compliance may therefore result, cheaper and more resource-destructive gears may be chosen, or production relations may change (fishers may become wage labourers).

Will the rule be effective in achieving its goal?
This will depend on whether the future benefits of gear specification accrue to the same fishers as bear the cost, whether they believe it will and whether it is shown to be so. If not, non-compliance is likely to result in all but the short-term. This will depend on first order management functions of property rights systems and second order functions of information gathering and communication systems as well as the nature of the resource.

Will the rule be efficient in achieving its goal?
Efficiency will depend on the value added to the fish stock by increasing size at first capture minus the costs of income foregone by fishers and enforcement costs appropriately adjusted for the time value of money.

***How much* to fish**
Can the rule be implemented?
Rules which limit aspects of fishing effort can be simple. Obvious aspects of effort e.g. boat size, motor powered or not, are relatively easy to monitor and at infrequent intervals. Rules which limit the quantity of fish landed require constant surveillance of landings. This is complicated to the extent that landings are made at many sites. There is also the potential problem that surveillance measures landings which may not be the same as catch.

Will fishers comply with the rule?
The game theory scenario is analogous to *how* to fish, above.

What secondary effects will the rule create?
Rules to limit aspects of fishing effort, create the incentive for fishers to innovate with respect to other aspects of effort not subject to rules to maintain their jurisdiction over effort. Rules to limit the quantity of fish landed create the incentive to upgrade the catch, resulting in dumping of lower value catch.

Will the rule be effective in achieving its goal?
The secondary incentives the rules create will act to undermine their effectiveness even if the rules are fully complied with. Both rules therefore require secondary rules to be effective in achieving their goals. A cycle of growing rule complexity is therefore set in motion. Both rules will only be effective if *all* aspects of effort or *all* aspects of catch are brought within the rule structure.

Will the rule be efficient in achieving its goal?
Given the complexity of the rule structure required of effectiveness in both cases, efficiency will be compromised (see, for example, Healey & Hennessey, 1998)

***When* and *where* to fish**

Can the rule be implemented?

When and *where* rules tend to be relatively easy to implement, with the ease of surveillance primarily dependent on the size of the area covered by the rule. The more sedentary fisheries associated with coral reefs are particularly apt for this type of rule, and it is a common devise in traditional community-managed reef regimes (see, for example, Ruddle, 1996b; Wilson et al, 1994). Many reef sanctuaries now exist around the world with the agreement of the local fishers.

Will fishers comply with the rule?

The game theory scenario is analogous to *how* to fish, above. If there is knowledge, belief or if it can be demonstrated that closing areas at certain times leads to long-run benefits, the likelihood of compliance will increase. Compliance can be achieved with reef sanctuaries once the benefits of the sanctuary to the affected fishers has been explained and demonstrated. Compliance problems tend to be from mobile ‘outside’ groups.

What secondary effects will the rule create?

Limiting fishing in one place at one time may simply lead to fishing effort locating to other areas/fisheries during the period of closure. This depends on the availability of alternative resources and the mobility of fishing units, both between areas and fisheries. The more mobile fishing units will be advantaged.

Will the rule be effective in achieving its goal?

The effectiveness will depend in part on the knowledge of the resource on which the closure is based.. Where more sedentary resources have been fished over many years, the closures can be effectively designed. Evidence is accumulating that reef sanctuaries are effective in increasing stock diversity and abundance over fairly short periods of time (see, for example, Roberts, 1995, 1997). The relationship to surrounding fishing areas is less clear as yet.

Will the rule be efficient in achieving its goal?

Small-scale closures clearly bounded geographically and by time are relatively easy and cheap to enact. If they are well designed with regard to the resource, they can be efficient rules.

***How much profit* from fishing**

By altering the returns fishers can expect from fishing, economic rules can alter the behaviour and decisions of fishers. In particular, fishing effort will tend to be reduced by measures that raise the costs of fishing and lower the revenues.

Can the rule be implemented ?

In TCFs, economic measures are likely to be hard to implement, especially in fisheries where rents have already been dissipated. Price controls, monopsony and taxes on landings and sales are all more easily implemented where marketing structures are centralised. Taxes / monopoly over inputs (e.g. fuel, nets) are possible on large scale but are unlikely to be applicable to particular TCFs.

Will fishers comply with the rule ?

The rule obviously creates the incentive not to comply. The ability for fishers to circumvent the rule will depend upon the pervasiveness of the rule, the alternatives marketing channels - for demand side rules - and alternative supply channels - for supply side rules, and the extra costs attached to using alternative marketing and supply channels. If there are alternatives which impose on them a cost less than the cost imposed by the rule, then they are unlikely to comply.

What secondary effects will the rule create ?

To the extent that compliance is achieved by the rule, it will cause a redistribution of income from fishers (and possibly fish traders) to the rule-making authority, most commonly the government. To the extent that the rule is circumvented, its leads to the creation of a ‘black’ market, whether for inputs or outputs, and thus a transfer of income from fishers to ‘illegal’ traders. In both cases, the rule is likely also to lead to a redistribution of income towards more efficient fishers, which may mean from artisanal to more capitalised fishers.

Will the rule be effective in achieving its goal ?

The rule may achieve effort reductions and efficiency gains, but will do so at the expense of poorer fishers, which in the context of TCFs will probably act against other management goals.

Will the rule be efficient in achieving its goal ?
Market-based rules tend to be relatively cheap and efficient to implement.

2.3.6 An illustrative example - Maluku Islands, Indonesia (Zerner, 1994)

Zerner takes an historical perspective and shows TCF management to be a continually changing response to unpredictable circumstances over time. Aspects of the example which illustrate points made in the text above are placed under section headings from the text.

In the central Maluku Islands, the institution of *sasi* is a historical community-based management system. 'To *sasi* means to place prohibitions on the harvest, capture , or theft of particular resources'. To place *sasi* restricts access to a resource until *sasi* is lifted. In relation to pelagic resources, Zerner comments;

> *'Marine sasi regulations were directed towards maximizing hunting success through the coordination of collective fish drives in bays and river mouths. When a school of fish entered the marine petuanan (controlled area) the ocean kewang (local official) dived and observed the movements of the school. Until the school was stable, he declared sasi closed, and no one - neither local residents nor outside villagers - was permitted to fish or enter the area.'*

In relation to a sedentary resource - trochus - Zerner comments;

> *'Sasi prohibitions against trochus harvest lasted from three to five years, which allowed populations to mature and reproduce at least once'.*

Assessment models in the fisheries science paradigm

> *'Because their [Moluccan fishermen] conceptions of nature and society's relationships to it are based on radically different models and metaphors of the world, it may be difficult for them to accept the causal models that underlie contemporary social and natural sciences.'*
>
> *'Careful attention to myths, stories, rituals, and personal narratives about the environment may reveal as much about community management or mismanagement as measurements of the number of trochus taken each year and descriptions of local communities.'*

The behaviour of fishers

> *'The story of community-driven overexploitation of trochus stocks in the 1980s and 1990s in the Maluku Islands cannot be understood without comprehension of the unique ways in which Moluccan men and women construct the idea of nature and society's relationships to it. Nor can reef management or mis-management be understood without comprehending how these ideas inform the Moluccans' daily acts of fishing and diving for trochus.'*

Dynamic context of TCF systems
The key contextual change has been the advent of an international market for trochus, whereas before it was mainly a minor subsistence resource. Zerner comments;

> *Emergence of the new trochus market resulted in new pressures on sasi community management institutions and practices throughout the Maluku Islands. Local governments and private exporters started competing with local communities and families for control of the rights to inshore reef resources.*
>
> *But local governments are not the only - nor are they invariably the primary - source of pressure for trochus extraction. Rapidly rising consumer desires, stimulated by television images of a growing Indonesian middle class and its commodities, are also pushing local officials (both government and customary) to shorten the intervals between sasi harvests. Increased population densities on isolated Moluccan islands also lead to a greater need for alternative sources of income. Despite evidence that*

> *shortened intervals result in drastically decreased stocks, some local officials claim that villagers' need for income - to perform religious festivals, pay school fees, and acquire consumer goods - is forcing them to reduce closed periods between harvests'.*

Management of TCFs - a social and political process

> *'Sasi is now being strategically edited and revised and is being integrated into contemporary environmental ideas and plans. In the 1990's, sasi purposes, institutions and rules continue to develop and evolve, fuelled by a dynamic mixture of changing environmental and social values as well as by economic development schemes'.*

Key organisations that contribute to the development of sasi come from all sectors:

- Department of Population and Environment (state sector)
- trochus trading companies (private sector)
- Indonesian Environmental Forum (an NGO umbrella), HUALOPU (an NGO) (collective action sector)
- Environmental Studies Centre, Faculties of Law and Fisheries - University of Patimura (research).

Management system

The management system combines aspects of the cultural system and the threat system, all within a community-managed framework of *sasi*. Of the 'traditional' cultural system, Zerner comments;

> *'Many Moluccan farmers and fishers believe that the closing and opening of sasi prohibitions are witnessed by invisible spirits. Violators are believed to be observed by these spirit witnesses and punished through infliction of sickness or even death.'*

Of the threat system, Zerner comments;

> *'Violators of sasi are brought before village councils, and sanctions are imposed on them. Although the sanctions formerly included shaming of violators by binding them with signs of sasi and mandatory public protestation of their guilt, almost all sanctions now consist of monetary fines.'*

Management functions and instruments

Zerner shows that systems of property/user rights existed over coastal waters and that the resources of those coastal waters were not, therefore, open-access.

> *'Moluccan coastal communities historically possessed well-defined marine territories under the control of particular villages'*
>
> *'Several island communities claim use and control rights over submerged atolls..., which may be several miles from the island on which the community is located.'*
>
> *'the outer edge of community-controlled waters is usually located at the juncture between the coral reef and the drop-off.'*

Principles of TCF management

Zerner draws a number of lessons from the historical study and argues for case specific, not generic solutions to TCF management problems;

> *'The trajectory of new [management] projects may be assessed by taking bearings on factually grounded, historically dynamic, contextual analyses of particular cases rather than by referring to an imagined community that may never have existed'.*

2.4 Concluding remarks

This chapter has sought to define what is effectively a new research agenda for the management of TCFs. Such an agenda is based on more detailed assessment of the socio-economic motivations of fishers which go into the control of level of fishing. Clearly, such analysis in detail would need to be case specific, but there are potential generalities which have been briefly reviewed. This emphasis on socio-economic issues has properly been at the forefront of this project, however, the need for simple and cost effective ways of estimating the potential of resources to sustain fishing remains a major requirement for TCF management. Two approaches to this problem form the remainder of the project report.

References and Bibliography

Acheson, J.M. (1981) - 'Anthropology of Fishing', - *Annual Review of Anthropology*, 10: 275-316, 1981

Adams, T.J.H. (1996) - 'Modern institutional framework for reef fisheries management', pp.337- 360 - in - Polunin, N.V.C, and Roberts, C.M. - '*Reef Fisheries*', Chapman & Hall, 1996.

Appeldoorn, R.S. (1996) - 'Model and method in reef fishery assessment', - in - Polunin, N.V.C, and Roberts, C.M. - '*Reef Fisheries*', Chapman & Hall, 1996.

Bailey, C., Cycon, D. and Morris, M. (1986) - 'Fisheries development in the Third World: the role of international agencies', *World Development*, 14(10/11), pp.1269-1275.

Bailey, C. and Jentoft, S. (1990) - 'Hard choices in fisheries development', *Marine Policy*, pp.333-344, July 1990.

Beddington, J.R. and Rettig, R.B. (1983) - '*Approaches to the regulation of fishing effort*', FAO Fisheries Technical Paper 243, Rome, 1983, 39p.

Bennett, E. and Hatcher, A. (in prep.) - 'Fisherman's perceptions of fisheries regulations: the influence of information and communication on fisheries management efficiency'.

Berkes, F. (1977) - 'Fishery resource use in a sub-arctic Indian Community', *Human Ecology*, Vol.5., pp.289-307, 1977.

Boulding, K.E. (1964) - 'Towards a pure theory of threat systems', *American Economic Review*, 53, pp.424-434, 1964.

Buhat, D.Y (1994) - 'Community-Based Coral Reef and Fisheries Management, San Salvador Island, Philippines', - in - White et al (1994), op.cit., pp.33-50.

Caddy, J. (1998) - '*A short review of precautionary reference points and some proposals for their use in data-poor situations*', FAO Fisheries Technical Paper, No.379, Rome, 30p.

Carrier, J.G. and Carrier, A.H. (1983) - 'Profitless property: marine ownership and access to wealth on Ponam Island, Manus Province', *Ethnology*, 22:131-51, 1983.

Carley, M et al (1991) - 'A network approach to enhanced environmental management', *Project Appraisal*, 6, pp.66-74.

Carley, M. & Christie, I. (1992) - '*Managing sustainable development*' , Earthscan Publications Ltd, London.

Catazano, J. and Mesnil, B. (1995) - 'Economics and biology used in fisheries research or when social and natural sciences try to depict together the object of their research', *Aquatic Living Resources*, 8, pp.223-232, 1995.

Charles, A.T. (1988) - 'Fishery socioeconomics: a survey', *Land Economics*, Vol.64, No.3, pp.276-295.

Christy, F.T. (1996) - 'The death rattle of open access and the advent of property rights regimes in fisheries', *Marine Resource Economics*, Volume 11, pp.287-304, 1996.

Dubbink, W. and van Vliet, M. (1996) - 'Market regulation versus co-management ? Two perspectives on regulating fisheries compared', *Marine Policy*, Vol.20, No.6, pp.499-516, 1996.

Eythórsson, E. (1996) - 'Theory and practice of ITQ's in Iceland. Privatisation of common fishing rights', *Marine Policy*, Vol.20, No.3, pp.269-281, 1996.

Feeny, D., Berkes, F., McCay, B.J. and Acheson, M. (1990) - The tragedy of the Commons: Twenty-two Years Later', *Human Ecology*, Vol.18, No.1, 1990.

Finger, M & Verlaan, P. (1995) - 'Learning our Way Out: A conceptual Framework for Social-Environmental Learning', *World Development*, Vol.23, No.3, pp.503-513.

Healey, M.C. and Hennessey, T, (1998) - 'The paradox of fairness: the impact of escalating complexity on fishery management', *Marine Policy*, Vol.22, No.2, pp.109-118, 1998.

Jentoft, S.,McCay, B.J. & Wilson, D.C. (1998) - 'Social theory and fisheries co-management', *Marine Policy*, Vol.22, No.4-5, pp.423-436, 1998.

Kohr, L. (1978) - '*The Breakdown of Nations*', Dutton, New York, 1978, 2nd ed.

Kurien, J. (1987) - 'Knowledge systems and fishery resource decline: a historical perspective', - in - *Ocean sciences: their history and relation to man*, Proc. 4th International Congress on the History of the Oceans, Sept.1987.

Ludwig, C.H. and Walters, C. (1993) - 'Uncertainty, resource exploitation and conservation: lessons from history', *Science*, No.260, pp.17 and 36, 1993.

Malinowski, Bronislaw (1921) - 'The primitive Economics of the Trobriand Islanders', *Economic Journal*, vol 31, pp.1-16, 1921.

Malinowski, Bronislaw(1961)[1922] - '*Argonauts of the Western Pacific*', Dutton, New York.

McCay, B.J. (1980) - 'A fisherman's cooperative, limited: Indigenous resource management in a complex society', *Athropological Quarterly*, 53: 29-38, 1980.

McManus, J.W. (1996) - 'Social and economic aspects of reef fisheries and their management', - in - Polunin, N.V.C, and Roberts, C.M. - '*Reef Fisheries*', Chapman & Hall, 1996.

Morgan, G (1982) - 'Cybernetics and organisation theory: Epistemology or technique ?', *Human Relations*, Vol.35, No.7, pp.521-538, 1982.

Neiland, A., Weeks, J., Madakan, S.P., and Ladu, B.M.B. (1998) - 'Fisheries management in Lake Chad, the Upper River Benue and the Nguru-Gashua Wetlands (N.E. Nigeria); a study of fifty three villages', in - Final Report, DfID Research Project, R5471, pp.73-97,

Ostrom, E. (1995) - 'Designing complexity to govern complexity', - in - Beijer Institute of Ecology, '*Property rights and the environment*', EC and World Bank, pp.33-45, 1995.

Panayotou, T. (1982) - '*Management concepts for small-scale fisheries: economic and social aspects*', FAO Fisheries Technical Paper No.228, Rome, 1982, 53p.

Pido, M.D., Pomeroy, R.S., Carlos, M.B, and Garces, L.R., (1996) - '*A handbook for Rapid Appraisal of Fisheries Management Systems*', ICLARM Educational Series 16, 85p.

Platteau, J.P. (1989) - 'The dynamics of fisheries development in developing countries: a general overview', *Development and Change*, 20, pp.565-597.

Poggie, J.J.Jr. (1980) - 'Small-scale fishermen's psychocultural characteristics and cooperative formation', *Anthropology Quarterly*, 5(1):20-28, 1980.

Polunin, N.V.C, Roberts, C.M. and Pauly, D. (1996) - 'Developments in tropical reef fisheries science and management', pp.361-377, - in - Polunin, N.V.C, and Roberts, C.M. - '*Reef Fisheries*', Chapman & Hall, 1996.

Ramirez, R. (1983) - 'Action learning: a strategic approach for organizations facing turbulent conditions', *Human Relations*, 36, pp.725-742.

Reading (1976) - '*A dictionary of the social sciences*', Routledge & Kegan Paul, 1976.

Ridley, M. (1996) - '*The Origins of Virtue*', Penguin, 295p.

Robben, Antonius (1989) - '*Sons of the Sea Goddess: Economic Practice and Discursive Conflict in Brazil*', Columbia University Press, New York, 1989.

Roberts, C.M. (1995a) - 'Rapid Build-up of fish biomass in a Caribbean Marine Reserve', *Conservation Biology*, VOl.9, No.4, August 1995.

Roberts, C.M. (1997) - 'Ecological advice for the global fisheries crisis', TREE, Vol.12, No.1, January 1997.

Rosenberg, A.A., Sissenwine, M.P., Beddington, J.R. and Shepherd, J.G. (1993) - 'Achieving susteainable use of renewable resources', *Science*, No.262, pp.828-829 ***, 1993.

Ruddle, K. (1996a) - 'Geography and human ecology of reef fisheries', - in - Polunin, N.V.C, and Roberts, C.M. - '*Reef Fisheries*', Chapman & Hall, 1996.

Ruddle, K. (1996b) - 'Traditional management of reef fisheries', - in - Polunin, N.V.C, and Roberts, C.M. - '*Reef Fisheries*', Chapman & Hall, 1996.

Sharp, B.M.H. (1997) - 'From regulated access to transferable harvesting rights: policy insights from New Zealand', *Marine Policy*, Vol.21, No.6, pp.501-517, 1997.

Tai Shzee Yew and Heaps, T. (1996) - 'Effort dynamics and alternative management policies for the small pelagic fisheries of Northwest Peninsular Malaysia', *Marine Resource Economic*s, Vol.11, pp.85-103, 1996.

Townsend, R.E. (1995a) - 'Transferable dynamic stock rights', *Marine Policy*, Vol.19, No.2, pp.153-158, 1995.

Townsend, R.E.(1995b) - 'Fisheries self-governance: corporate or cooperative structures ?', *Marine Policy*, Vol.19, No.1, pp.39-45, 1995.

Uphoff, N. (1993) - 'Grassroots organisations and NGO's in rural development: opportunities with diminishing states and expanding markets', *World Development*, Vol.21, No.4, pp.607-622, 1993.

White, A.T., Hale, L.H., Renard, Y. and Cortesi, L. (eds) (1994) - '*Collaborative and Community-Based Management of Coral Reefs*', Kumerian Press, 1994, 134p.

Wilen, J.E. (1979) - 'Fisherman behviour and the design of efficient fisheries regulation programs', Journal Fish. Res. Board Can., Vol.36, pp.855-858, 1979.

Wilk, R.R. (1996) - '*Economics and Cultures*', Westview Press, 189p.

Willmann, R. (undated) - 'Economic information needs for small-scale fisheries management', FAO, pp.23-35.

Wilson, J.A. (1980) - ‘Adaptation to uncertainty and small numbers exchange: The New England fresh fish market’, *Bell Journal of Economics and Management Science* ***, 11(2):491-504, 1980.

Wilson, J.A. (1982) - ‘The Economical Management of Multispecies Fisheries’, *Land Economics*, Vol.58, No.4, pp.417-434, November 1982.

Wilson, J.A.(1990) - ‘Fishing for knowledge’, *Land Economics*, Vol.66, No.1, February 1990.

Wilson, J.A., Acheson, J.M., Metcalfe, M. and Kleban, P. (1994) - ‘Chaos, complexity and community management of fisheries’, *Marine Policy*, Vol.18, No.4, pp.291-305, 1994.

Wilson, J.R. and Lent, R. (1994) - ‘Economic perspective and the evolution of fisheries management: towards subjectivist methodology’, *Marine resource Economics*, Vol.9, 353-373, 1994.

Yamamoto, T. (1995) - ‘Development of a community-based fishery management system in Japan’, *Marine Resource Economics*, Vol.10, 21-34, 1995.

Zerner, C (1994) - ‘Tracking *Sasi*: The transformation of a Central Moluccan Reef Management Institution in Indonesia’, in - White et al (1994), op.cit., pp.19-32

3. Status and Production Potential of Large Marine Ecosystems

3.1 Introduction

Grainger & Garcia (1996) examined the status and production potential of 200 of the most important global fisheries resources on the basis of catch trend data aggregated according to various FAO reporting areas.

This chapter employs methodological approaches developed by Grainger & Garcia (1996) to re-examine the status and production potential of tropical fisheries resources from the perspective of Large Marine Ecosystems (LMEs). These large ‘global units’, geographically delimited by distinct bathymetry, hydrography, productivity and dependent populations, provide an ecologically more meaningful framework for studying global patterns of marine resource exploitation, and for developing appropriate management plans and interventions. Forty-nine LMEs have been delimited globally (Figure 3.1) supporting approximately 95% of the global annual catch (Sherman 1992).

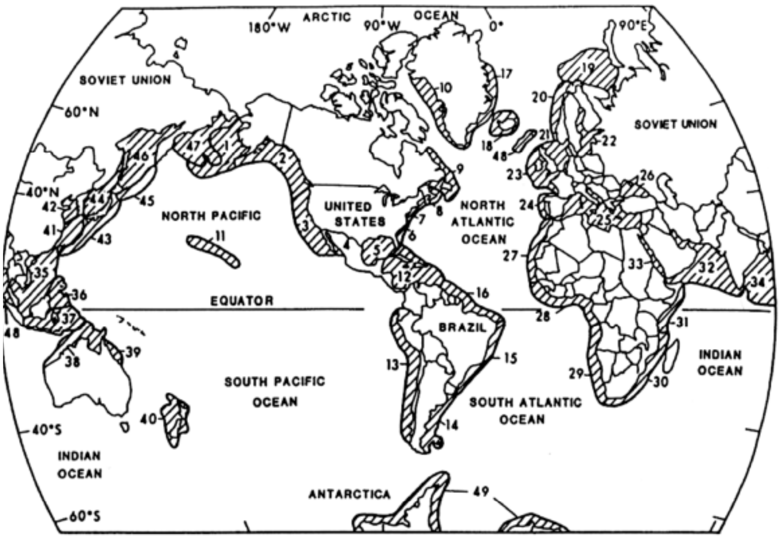

Figure 3.1 Location of Large Marine Ecosystems. (Key in Appendix 1). Source: Sherman (1992)

Perturbations in biomass yield among LMEs have been compared by several workers and ecosystem management is currently being applied to a number of LMEs including the Yellow Sea, Benguela current and the Great Barrier reef (see Sherman 1992 for further details).

3.2 Data and Data Structure

Comprehensive and detailed catch statistics (see below) are available (reported) only by country or FAO Statistical Area - not by LME. Catches from each tropical LME were therefore estimated as the sum of the catches reported by tropical countries[3] bordering the LME.

In cases where one or more country’s coastline or EEZ borders two LMEs (for example Brazil which boarders the Brazil Current and North east Brazil shelf, or Mexico and Cuba which border the Gulf of Mexico and the Caribbean Sea) catch statistics were combined across both LMEs (Combined LMEs). However, in cases where only a small proportion of the country’s coastline borders a second LME, (for example Tanzania boarders the Angulhas and Somali Coastal Current) catch data for that country

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[3] Lying or having borders within the Tropics of Cancer and Capricorn (± 23 ^{0} 27' of the equator).

were assigned only to the LME in which the majority of its border lie (in this example the Somali Coastal Current). Finally, in cases where a country borders two very large LMEs (for example India boarders the Arabian Sea and Bay of Bengal) catch data for that country was included in both LMEs. Overall the approach to assigning countries to LMEs was therefore subjective.

No account is taken of foreign fishing activities both by countries within and outside the LME in question. However, this omission should not have significant implications for the results of the analyses given (i) that catches taken by countries lying outside the LME may be balanced by catches taken by the foreign fishing fleets of the countries lying within the LME and (ii) the general decline in foreign fishing activities in recent decades, brought about by rising fuel costs and extended fisheries jurisdiction to within 200 mile EEZs,

A total of 104 countries were identified within the tropical region and assigned to 8 single and 5 combined LMEs and two oceanic regions: South Pacific and Indian Oceans (Table 3.1). In 1995, the combined catch of these 104 countries constituted 40%, 46% and 20% of the total world catches of marine fish, crustaceans and molluscs respectively.

Table 3.1 Allocation of national catch statistics to 15 tropical LMEs and Oceanic Regions

LME or Oceanic Region	Figure 3.1 Reference	Allocated National Catch Statistics (Country)
Canary & Guinea Currents	27 & 28	Morocco; Mauritania; Senegal; Guinea Bissau; Guinea; Sierra Leone; Liberia; Cote D'Ivore; Ghana; Togo; Benin; Nigeria; Cameroon; Equatorial Guinea; Gabon; Congo
Benguela Current	29	Angola; Namibia
Angulhas Current	30	Mozambique
Somali Coastal Current	31	Tanzania; Kenya; Somalia; Djibouti
Indian Ocean	-	Madagascar; Mauritius; Comoros; Seychelles; Maldives
Arabian Sea	32	Yemen; Oman; India
Red Sea	33	Sudan; Eritrea; Saudi Arabia
Bay of Bengal	34	India; Bangladesh; Myanmar
South China & Sulu-Celebes Seas	35 & 36	Thailand; Cambodia; Vietnam; Malaysia; Philippines
Indonesian Seas	37	Indonesia; Papua New Guinea
Northern Australian Shelf	38	Australia
South Pacific	-	Solomon Islands; Vanuatu; New Caledonia; Fiji; Tuvalu; Kiribati; Northern; Mariana Islands; Micronesia; Marshall Islands; American Samoa; Samoa; French Polynesia; Guam; Nauru; Palau; Tonga; Tokelau; Niue; Cook Islands
Gulf of Mexico & Caribbean Sea	5 & 12	Anguilla; USA; Mexico; Guatemala; Belize; Honduras; Nicaragua; Costa Rica; Panama; Colombia; Venezuela; Guyana; Suriname; French Guinea; Cuba; The Bahamas; Jamaica; Haiti; Dominican Republic; Puerto Rico; Antigua; Dominica; Martinique; St Lucia; Barbados; Trinidad and Tobago; Cayman Islands; Curacao; Aruba; Grenada; Guadeloupe; Montserrat; Netherlands Antilles; St Kits Nevis; St Vincent; Turks and Caicos; British Virgin Islands; US Virgin Islands
Brazil	15 & 16	Brazil
Humboldt Current	13	Ecuador; Peru

Time series of total annual catches for a 46 year period (1950 - 1995) by species/species group[4] were downloaded for each of the 104 countries from the FAO computerised catch and landing statistics database (FAOSTAT-PC)[5]. The Data were then aggregated across species/species group and countries assigned to each LME according to Table 3.1.

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[4] Species groups refer to aggregations of species typically landed unsorted and where no sampling of species composition is made (Grainger & Garcia 1996)

[5] These data are based upon reports from national authorities, supplemented with information from regional fisheries organisations and other sources. Where necessary unreliable or missing data are replaced with the best available information or in worst cases repeated figures from another year (Grainger & Garcia 1996).

3.3 Analysis

3.3.1 Status of Tropical LME Resources

Time series of total catches for individual species or species group within the main fish, mollusc and crustacean categories were plotted for each LME to reveal the historical pattern of exploitation. In total more than 900 individual time series were plotted and examined. Time series for the top10 species in each main category, ranked in descending order of average catch, are illustrated for each LME in Annex 2.

The time series of catches were used to identify the current state of exploitation for each species or species group categorised according to three of the four phases of the generalised fishery development model (GFDM):(i) Developing, (ii) Mature and (iii) Senescent (Figure 3.2) after Caddy (1984) and Grainger & Garcia (1996).

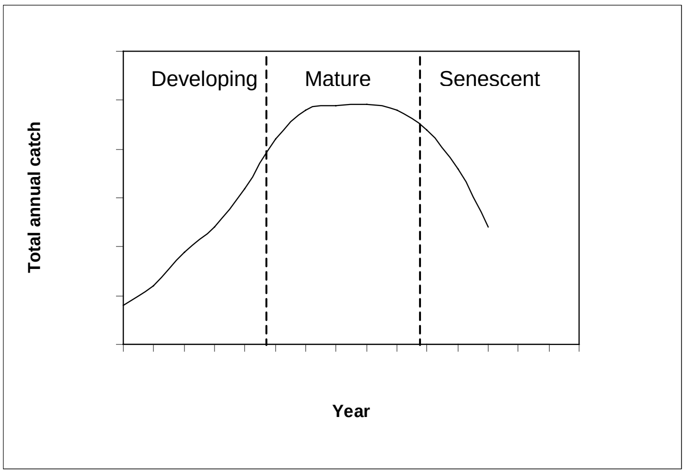

Figure 3.2 The Generalised Fishery Development (GFDM) Model

Catches increase rapidly as the fishery expands during the initial stage of development. Catches are maximum during the mature stage, before declining during the senescent stage as resources become depleted. The relative rate of increase in catch, *r* during successive time periods, *t*, during this cycle is given by:

$$r = C_{t+1} - C_t / C_t \qquad \text{(Eq. 1)}$$

where t = 1 year.

The value of *r* declines continuously as the fishery begins to develop, and eventually drops to zero when the fishery reaches its maximum production during the mature phase before becoming negative corresponding to the senescent stage as the stock is depleted or collapses.

Grainger & Garcia (1996) fitted polynomial functions to standardised catch time series trends for the worlds 200 most important species or resources. By calculating the slope of a fitted line for every successive pair of years, the catch trends were ‘sliced’ into segments corresponding to phases of increase or decrease or little change and thereby related to the phases of the generalised fishery development model.

Here, visual examination of the time series of catches was used to identify and categorise the current state of exploitation of each species or species group within each LME according to the GFDM. Although more subjective, this approach has two advantages. Firstly, each species or species group is categorised according to its own catch time series as opposed to being categorised from a polynomial function subjectively fitted to standardised catch data averaged across species exhibiting similar catch trends identified through cluster analysis. Secondly categorisation does not depend simply upon rates of change in catch during the last two successive years of available catch data but instead takes greater account of previous trends in catches.

3.3.2 Production Potential and Predicted Year of Achievement

Theoretical maximum production of global fishery resources has also been estimated by Garcia & Newton (1994) and Grainger & Garcia (1996) as the production corresponding to the year when the rate of increase in catch is zero, estimated from the abscissa intercept ($t_{\text{max prod}}$ = -a/b) of the linear regression of rate of increase in catch, *r* and year, *t*, (Eq .2) where the catch in year *t*, C_t is the three year moving average value (Figure 3.3):

$$r = (C_{t+1} - C_t) / C_t = bt + a \qquad \text{Eq. 2}$$

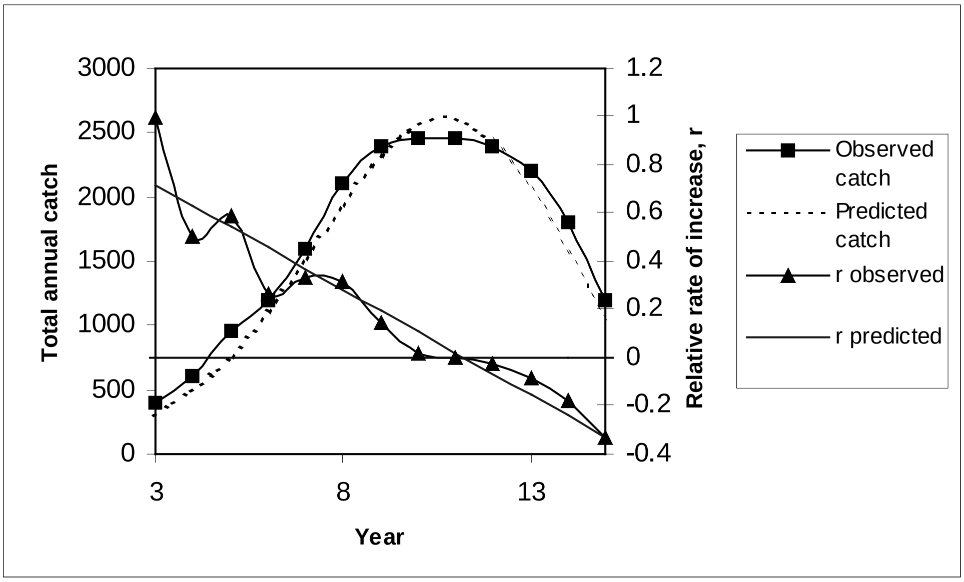

Figure 3.3 Estimation of maximum production potential and predicted year of achievement

Maximum production is estimated by predicting the evolution of catches with time iteratively, based upon the estimates of *a* and *b* of the linear regression model and the catch in the first year of the modelled time series, (in this case, the observed catch in 1952), using Eq.3:

$$C_{t+1} = C_t(bt + a + 1) \qquad \text{Eq.3}$$

This approach was used to estimate the combined potential production (millions of tonnes per year) of finish, molluscs and crustaceans in each LME, and the year corresponding to this predicted maximum ($t_{max\ prod}$). Predictions of production potential were compared with the mean value of recently observed landings (1991-1995) to assess the extent of remaining production potential, or degree of overexploitation. The analysis was then repeated using the following aggregated data sets:

(i) All tropical LMEs excluding the Humboldt Current
(ii) Tropical Pacific Ocean LMEs excluding the Humboldt Current
(iii) Tropical Indian Ocean LMEs
(iv) Tropical Atlantic Ocean LMEs

Catches from the Humboldt Current are significant and dominated by anchoveta whose catches and population abundance have fluctuated significantly with time in response to a rapid increase in fishing effort during the late 1950s and El Nino events during the last two decades. To prevent the overall picture from being overly distorted by these events, data from this LME were excluded from the analysis of catches from all tropical LMEs (ii) and the Tropical Pacific Ocean (iii). For (i) – (iv), predicted production potential and observed average landings (1991-1995), expressed both in terms of per unit shelf area and per unit surface area, were also compared.

3.4 Results

3.4.1 Status of Tropical LME Resources

Although highly variable among individual LMEs, the visual examination of the time series of catches indicates that about 28% of the 860 tropical resources which have been exploited for 10 or more years are senescent, 36% are mature and equal proportion are at the developing stage (Table 3.2). In other words, almost 60% of all tropical resources are either at the mature or senescent stages of exploitation. The remainder are, however, still at the developing stage and therefore potentially offer scope for increased production. Strikingly similar conclusions were reached by Garcia & Newton (1994) and Grainger & Garcia (1996) for the top 200 global fishery resources.

Table 3.2 Numbers (and percentage) of tropical resources categorised according to the three stages of the GFDM.

	Stage of development			
Resource	**Developing**	**Mature**	**Senescent**	**Total**
Fish	222 (33%)	240 (36%)	203 (30%)	665
Molluscs	40 (44%)	33 (36%)	18 (20%)	91
Crustaceans	48 (46%)	35 (34%)	21 (20%)	104
Total	310 (36%)	308 (36%)	242 (28%)	860

3.4.2 Production Potential and Predicted Year of Achievement

Despite attempts to smooth interannual variations in catch by means of a moving average, the relative rate of increase in catch, *r* exhibited a wide degree of variation with time for all 15 LMEs and oceanic regions. No significant ($P>0.05$) declines in *r* were found in 7 of the 15 LMEs. Significant declines in *r* were found for the Canary and Guinea Currents, the Angulhas Current, the Red Sea, S.China and Sulu-Celebes Seas, the South Pacific, Brazil, Humboldt Current. (Figure 3.4 and Table 3.3) For these LMEs, the GFDM explained a maximum of 28% of the variation in *r*. For the aggregated data sets, significant models were fitted for the tropical Pacific Ocean LMEs (excluding the Humboldt Current) and for all Tropical LMEs combined, including and excluding data for the Humboldt current (Figure 3.5, 3.6 and Tables 3.4 and 3.5).

For those models found to be significant, maximum production estimates exceeded, in all cases, the mean landings reported during the last five years of the time series, indicating scope for further production (Table 3.5). LMEs ranked in descending order of scope for further production are: Humboldt Current; South China and Sulu-Celebes Seas; Canary and Guinea Currents; South Pacific; Red Sea, Brazil, and the Angulhas current, amounting to nearly 22 million tonnes per year.

Further scope for increased potential may exist from many of the LMEs for which model fits were found not to be significant. Indeed, when catches for all LMEs are combined (excluding the Humboldt Current), the fitted model predicts an additional 47 million tonnes of finfish, molluscs and crustaceans may be available each year. This scope for increased production is significantly lower if landings from the Humboldt Current are included in the analysis (Table 3.5). The other aggregated data sets suggest that an additional 5 million metric tonnes may be achievable from Tropical Pacific LMEs, equivalent to an additional 0.6 t km^{-2} of shelf area or 0.04 t km^{-2} of surface area (Tables 3.6 a and b, respectively). Model fits to the aggregated data from tropical Atlantic and Indian Ocean LMEs were not significant ($P>0.05$) (Table 3.4).

Due to the imprecise nature of the data employed and the large residual components of the fitted models from which they are derived, these predictions should with treated with caution. Potential yield predictions based upon this method also appear particularly sensitive to catch variability during the initial three years of the time series. However, the general pattern emerging from this analysis suggests that scope does exists for increased yield from tropical LMEs. Remedial measures, in the form of effort reductions, may however, be required in the cases of Angulhas Current, Somali Coastal Current, Brazil and the Humboldt Current which are predicted to have already exceeded their maximum production potential.

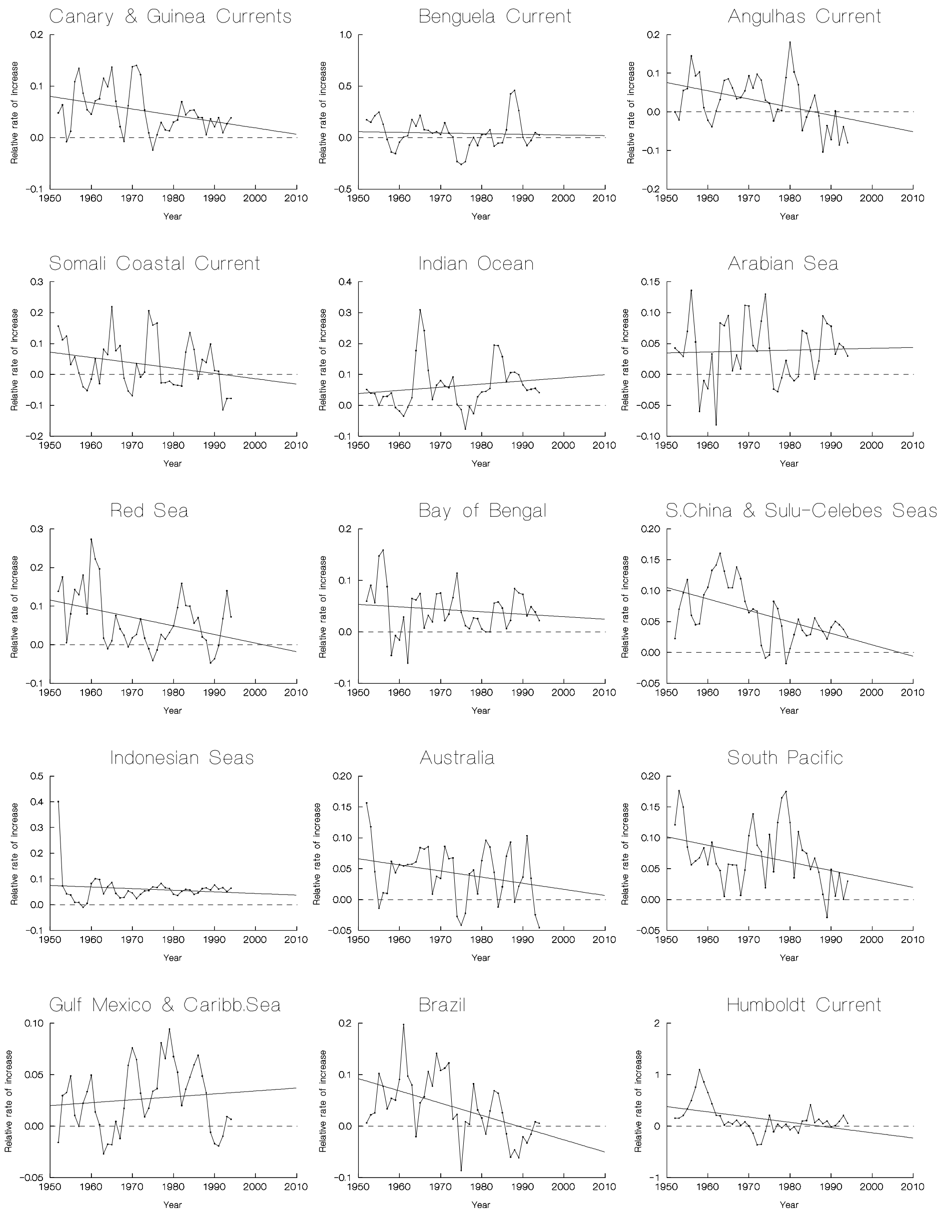

Figure 3.4 Time series (1952-1995) of rate of relative increase, *r* of total landings of finfish, molluscs and crustaceans in the 15 LMEs (Table 3.1) with fitted GFD model.

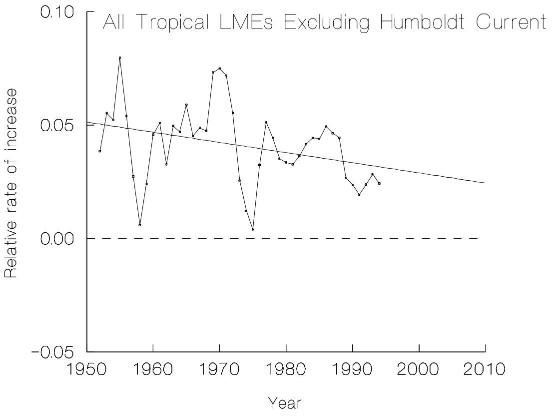

Figure 3.5 Time series (1952-1995) of rate of relative increase, *r* of combined total landings of finfish, molluscs and crustaceans from all LMEs (excluding the Humboldt Current) with fitted GFD model.

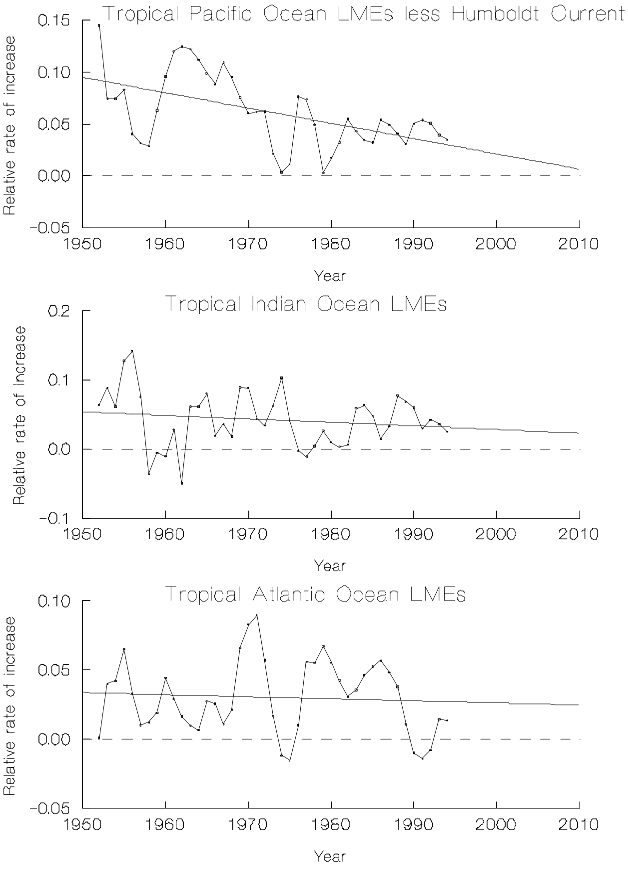

Figure 3.6 Time series (1952-1995) of rate of relative increase, *r* of combined total landings of finfish, molluscs and crustaceans from tropical Pacific LMEs excluding the Humboldt Current (top), Indian LMEs (middle) and Atlantic LMEs (bottom) with fitted GFD models.

Table 3.3 Parameters of the GFD linear regression model, estimated maximum production and year in which the maximum production is reached ($t_{\text{max. prod.}}$). The time series is shortened to 1952-1994 by the processes of calculation and smoothing.

LME	Parameters *a,b* (Eq.2)	R^2	P	Max Prod. $\times 10^6$ t	Fully fished in ($t_{\text{max. prod.}}$)
All[3]	3.06, -0.00153	0.10	0.04	38.26	2005
All [3,4,5]	0.92, -0.000448	0.11	0.03	70.99	2063
Canary & Guinea Currents	2.47, -0.00123	0.13	0.02	2.47	2015
Benguela Current	-2.57, 0.00132	0.01	0.58	0.16	NA
Benguela Current[4]	2.47, -0.00123	<0.01	0.74	2.18	2040
Angulhas Current	4.22, -0.00212	0.18	<0.01	0.02	1985
Somali Coastal Current	3.43, -0.00172	0.07	0.08	0.08	1992
Indian Ocean	-1.94, 0.00102	0.03	0.28	NA	NA
Arabian Sea[2]	-0.25, 0.00015	<0.01	0.81	NA	NA
Red Sea	4.47, -0.00223	0.14	0.01	0.07	2002
Bay of Bengal[2]	0.97, -0.00048	0.02	0.38	11.49	2063
S. China & Sulu-Celebes Seas	3.73, -0.00186	0.28	<0.01	7.86	2007
Indonesian Seas	1.30, -0.00063	0.02	0.39	23.5	2069
Australia	2.00, -0.00099	0.08	0.07	0.30	2016
South Pacific	2.77, -0.00137	0.13	0.02	0.28	2024
Gulf of Mexico & Caribb. Sea	-0.54, 0.00028	0.01	0.47	NA	NA
Brazil	4.73, -0.00238	0.25	<0.01	0.61	1989
Humboldt Current	20.17, -0.0101	0.20	<0.01	29.41	1987

[1] Total annual landings of marine finfish, molluscs and crustaceans.

[2] Total landings by India included in both Bay of Bengal and Arabian Sea LMEs

[3] Landings by India included only once.

[4] Includes all landings of *Trachurus tracae, Merluccius capensis, Sardinella spp, Engraulis capensis, Sardinops Ocellatus, Trachurus capensis, Engraulidae, Caranx hippos* and *Scomber japonicus* reported by Spain and Russian Federation.

[5] Dataset excludes catches from Humboldt Current (Peru and Ecuador)

Table 3.4 Parameters of the GFD linear regression model for LME data pooled by major ocean, estimated maximum production and year in which the maximum production is reached ($t_{\text{max. prod.}}$).

Ocean	Parameters *a,b* (Eq.2)	R^2	P	Max Prod. x10^6 t	Fully fished in ($t_{\text{max. prod.}}$)
Tropical Atlantic [1]	0.33, -0.000151	<0.01	0.64	106.9	2172
Tropical Indian Ocean [2]	1.05, -0.000513	0.03	0.30	10.1	2054
Tropical Pacific [3]	2.97, -0.001475	0.29	<0.01	15.1	2014

[1] Includes all landings of *Trachurus tracae, Merluccius capensis, Sardinella spp, Engraulis capensis, Sardinops Ocellatus, Trachurus capensis, Engraulidae, Caranx hippos* and *Scomber japonicus* reported by Spain and Russian Federation.

[2] Landings by India included only once.

[3] Dataset excludes catches from Humboldt Current (Peru and Ecuador)

Table 3.5 Comparison between estimated potentials and average landings[1] (x 10^6 t)of the last five years (1991-1995) (all figures have been rounded)

LME	Estimated Potential (A)	Landings 1991-95 (B)	Difference (A-B)
Canary & Guinea Currents	2.47	1.86	0.61
Benguela Current	0.16	0.35	-0.19
Benguela Current[4]	2.18	0.61	1.57
Angulhas Current	0.02	0.02	0
Somali Coastal Current	0.08	0.07	0.01
Indian Ocean	NA	0.21	NA
Arabian Sea[2]	NA	2.76	NA
Red Sea	0.07	0.05	0.02
Bay of Bengal[2]	11.49	3.38	8.11
S. China & Sulu-Celebes Seas	7.86	6.85	1.01
Indonesian Seas	23.5	2.94	20.56
Australia	0.30	0.22	0.08
South Pacific	0.28	0.14	0.14
Gulf of Mexico & Caribb. Sea	NA	7.06	NA
Brazil	0.61	0.59	0.02
Humboldt Current	29.41	9.22	20.19
All[3]	38.26	33.20	5.06
All[3,4,5]	70.99	24.24	46.75

[1] Total annual landings of marine finfish, molluscs and crustaceans.

[2] Total landings by India included in both Bay of Bengal and Arabian Sea LMEs

[3] Landings by India included only once.

[4] Includes all landings of *Trachurus tracae, Merluccius capensis, Sardinella spp, Engraulis capensis, Sardinops Ocellatus, Trachurus capensis, Engraulidae, Caranx hippos* and *Scomber japonicus* reported by Spain and Russian Federation.

[5] Dataset excludes catches from Humboldt Current (Peru and Ecuador)

Table 3.6 (a) Comparison of recent landings (1991-1995) and estimated production potential per shelf area and (b) per surface area for tropical waters.

(a)

Ocean	Shelf area (10^6 km^2)	Recent Landings (x10^6 t)	Recent Productivity (t km^{-2})	Estimated Potential (x10^6 t)	Estimated Potential Productivity (t km^{-2})
Tropical Atlantic[1]	4.6	10.1	2.2	106.9	23.2
Tropical Indian Ocean [2]	4.6	3.9	0.8	10.1	2.2
Tropical Pacific [3]	8.4	10.2	1.2	15.1	1.8

(b)

Ocean	Surface area (10^6 km^2)	Recent Landings (x10^6 t)	Recent Productivity (t km^{-2})	Estimated Potential (x10^6 t)	Estimated Potential Productivity (t km^{-2})
Tropical Atlantic[1]	64.7	10.1	0.16	106.9	1.65
Tropical Indian Ocean [2]	60.1	3.9	0.06	10.1	0.17
Tropical Pacific [3]	139	10.2	0.07	15.1	0.11

[1] Includes all landings of *Trachurus tracae, Merluccius capensis, Sardinella spp, Engraulis capensis, Sardinops Ocellatus, Trachurus capensis, Engraulidae, Caranx hippos* and *Scomber japonicus* reported by Spain and Russian Federation.
[2] Landings by India included only once.
[3] Dataset excludes catches from Humboldt Current (Peru and Ecuador)

References

Caddy, J.F. (1984). An alternative to equilibrium theory for management of fisheries. *FAO Fisheries Report.* No. **289**, Supplement 2. 214pp.

Garcia, S.M. & Newton, C. (1994). Current situation, trends and prospects in world capture fisheries. A paper presented at the Conference on Fisheries Management. Global Trends. Seattle, Washington, USA, 14-16 June 1994.

Grainger, R.J.R & Garcia, S.M. (1996). Chronicles of Marine fishery Landings (1950-1994): Trend analysis and fisheries potential. *FAO Fisheries Technical Paper*. No. **359**, FAO. 51pp.

Gulland, J.A. (1983). Fish stock assessment. A manual of basic methods. Chichester: John Wiley & Sons 223pp.

Kirkwood, G.P., Beddington, J.R. & Roussow, J.A. (1994). Harvesting Species of Different Lifespans. *In* Proceedings of the Large-Scale Ecology and Conservation Biology Symposium 1993. Blackwell Scientific Publications.

Pauly, D. (1980). On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. *J. Cons. Int. Explor. Mer.* **39**(3): 175-192.

Regier, H. A., Welcomme, R. L., Steedman, R. J. & Henderson, H. F. (1989). Rehabilitation of degraded river ecosystems. In *Proceedings of the large river symposium* (Dodge, D. P. ed.) **106** pp. 86-97. Canada: Department of Fisheries and Oceans.

Sherman, K. (1992). Large Marine Ecosystems as Global Units for Marine Resources Management - An Ecological Perspective. *In* The Large Marine Ecosystem Concept and its application to regional Marine Resource Management pp 3-13. Gland: IUCN.

Appendix 1: Key to Figure 3.1 - Large Marine Ecosystems

1. Eastern Bering Sea
2. Gulf of Alaska
3. California Current
4. Gulf of California
5. Gulf of Mexico
6. Southeast U.S. Continental Shelf
7. Northeast U.S. Continental Shelf
8. Scotian Shelf
9. Newfoundland Shelf
10. West Greenland Shelf
11. Insular Pacific-Hawaiian
12. Caribbean Sea
13. Humboldt Current
14. Patagonian Shelf
15. Brazil Current
16. Northeast Brazil Shelf
17. East Greenland Shelf
18. Iceland Shelf
19. Barents Sea
20. Norwegian Shelf
21. North Sea
22. Baltic Sea
23. Celtic-Biscay Shelf
24. Iberian Coastal
25. Mediterranean Sea
26. Black Sea
27. Canary Current
28. Guinea Current
29. Benguela Current
30. Angulhas Current
31. Somali Coastal Current
32. Arabian Sea
33. Red Sea
34. Bay of Bengal
35. South China Sea
36. Sulu-Celebes Seas
37. Indonesian Seas
38. Northern Australian Shelf
39. Great Barrier Reef
40. New Zealand Shelf
41. East China Sea
42. Yellow Sea
43. Kuroshio Current
44. Sea of Japan
45. Oyashio Current
46. Sea of Okhotsk
47. West Bering Sea
48. Faroe Plateau
49. Antarctic

4. The Estimation of Potential Yield and Stock Status Using Life History Parameters

4.1 Introduction

Fisheries science has developed substantially in the last two decades, primarily due to the large increase in computing power which enables complex statistical procedures to be performed relatively cheaply. The central problems of the science are:

1. The estimate of the potential yield of a stock or stocks.

2. The estimate of the current state of a stock or stocks.

3. The estimate of the effect of different patterns and levels of exploitation on the future behaviour a stock or stocks.

The scientific apparatus for solving these problems is well developed. The potential yield of a fish stock can be readily estimated from the demographic parameters of the stock and these in turn can be estimated by well-understood methods of sampling and experimentation.

The current state of a stock can be estimated by a variety of methods, both direct via research surveys and indirect using a series of information of catch size and age or sex composition and the effort levels associated with that catch.

The effect of different levels of exploitation on the future behaviour of a stock can be evaluated by computer simulation procedures which enable likely trajectories of stocks to be evaluated with associated levels of uncertainty.

It is important to emphasise that there are still many unsolved problems and the uncertainties associated with the estimation procedures and predictions are widespread and constitute the paradigm of fisheries research. Nevertheless, it is fair to say that failures of fishery management which are well known and ubiquitous are more a fault of the economics and socio-economics of management regimes, rather than failures of science (although there are some major exceptions to the rule. A recent example being the collapse of the N W Arctic cod stocks where scientific errors are clearly implicated).

However, this is a picture of science that is relevant to developed world temperate and high latitude fisheries, it has little relevance to the operation of tropical fisheries in the developing world where even when the scientific methodology is applicable, its use is enormously constrained by the lack of resources. Institutions in developing countries, with few exceptions, do not have the resources to conduct the substantial sampling and research which is necessary to apply the methodology and much work is conducted which, although properly executed is fundamentally flawed because it is incomplete.

What is needed is a development of a scientific methodology which is tailored to the requirements of developing country fishery management and in particular can be based on data and research findings that are within the capability of their fishing institutions.

In this review, two of the key problems of fisheries are addressed within this framework: the estimation of potential yield and the estimation of stock status.

4.2 The estimation of potential yield

This is not an abstract problem of interest only to fisheries scientists and biologists, it is arguably the most important problem for fisheries management in the developing world. The reason is that once an estimate of potential yield can be made, the key management information on the capacity of the fishery can be deduced. Knowledge of a fisheries capacity is crucial to its management, whether in small scale localised artisanal fisheries or larger commercial ventures. Management needs to know how many fishers (and their families) can be supported by a fish stock or stocks without eroding the productive capacity of the resource. For it is a commonplace that stocks can be overexploited and become less productive or disappear and be replaced in the ecosystem by other less valuable (or edible) species.

4.2 Estimating potential yield from life history characteristics

The remainder of this section develops the underlying scientific analysis which is aimed at allowing the estimation of potential yield directly from the parameters of size and growth. Such parameters are readily estimated from relatively simple data obtained by standard sampling and estimation procedures. The LFDA software developed under the FMSP Programme by MRAG describes a number of standard procedures for estimating the two growth coefficients of the standard growth model of Von Bertalanffy which is in widespread use through both the developed and developing world.

The results mean that armed with estimations of growth (in the jargon K and L_∞ of the Von Bertalanffy growth curve) and an estimate of stock abundance, potential yield and hence capacity can be calculated. Other key parameters, and in particular the sustainable rate of exploitation, follow from such calculations.

The analysis is developed in two phases, initially the theory that leads to estimates of potential yield from standard demographic parameters is reviewed. Secondly, using two different approaches, it is shown that either empirical relationships between life history parameters or using the theory of evolution of life history characteristics, the standard procedures can be simplified to allow potential yield to be predicted from size and growth.

4.2.1 Review of standard methodology

The standard methodology was developed under FMSP Project R.4823 and published as Kirkwood et al (1994). The derivation largely follows this analysis with some extension in Beddington & Basson (1994). Kirkwood et al argued that:

"It is an intuitively plausible idea that long-lived, slow-growing species have less potential to provide a sustainable yield than short-lived, fast-growing species. This idea was first encapsulated in a simple formula by Gulland (1971). This formula directly related the potential yield of a species to its natural mortality rate in the equation:

$$Y = 0.5MB_0$$

where M is the natural mortality rate and B_0 is the unexploited population biomass.

Gulland's argument was a simple mix of a theoretical consideration, that the biomass level at which maximum sustainable yield can be obtained occurs at half the unexploited level in a simple logistic model, and an observation from experience of fisheries worldwide that indicated that the maximum yield appeared to occur when the level of fishing mortality was roughly equal to that of natural mortality."

In this development, the mathematical derivation of Kirkwood et al (1994) is assumed, interested readers are referred to this paper. It is nevertheless essential to define the parameters used as an aid to concentration on the main results.

Definition

l_c = *length at first exploitation (as a proportion of* L_∞*)*
l_m = *length at sexual maturity (as proportion of* L_∞*)*
t_c = *age at first exploitation*
t_m = *age at sexual maturity*
M = *instantaneous rate of natural mortality*
L_∞ = *asymptotic length*

K = growth rate
l(t) = length of fish of age t
W(t)= weight of fish of age t

Growth is given by:

$$l(t) \ = L_\infty(1 - e^{-k(t)})$$

$$w(t) = W_\infty(1 - e^{-k(t)})^3$$

SSB = spawning stock biomass
R = recruitment which can be either constant or a function of spawning stock biomass
B_0 = total equilibrium biomass of stock
ExB_0 = exploited equilibrium biomass of stock ie biomass of stock above age tc
F = instantaneous fish mortality
Yield = equilibrium level of catch for a particular level of fishing mortality

In terms of the other parameters:

$$Yield = FRW_\infty(1 - l_c)^{m/K}\left(\frac{1}{F+M} - \frac{3(1-l_c)}{F+M+K} + \frac{3(1-l_c)^2}{F+M+2K} - \frac{(1-l_c)^3}{F+M+3K}\right) \qquad (1)$$

B_0 and ExB_0 are defined similarly from:

$$Yield = FExB_0 \qquad (2)$$

and

$$B_0 = ExB_0 \ \text{where } l_c{=}0 \qquad (3)$$

The yield can then be further defined as maximum yield as a proportion of unexploited stock size:

$$\frac{MaxY}{B_0} \qquad (4)$$

or the maximum yield as a proportion of exploited stock size of age greater than t_c:

$$\frac{MaxY}{ExB_0} \qquad (5)$$

Both expressions can be written as fractions of F M K and l_c and can be maximised with respect to F to find the potential yield.

Constant recruitment

For a constant recruitment, provided *M*/*K* and l_c are fixed, the maximum (potential) yield as a proportion of unexploited stock size (*Y*) is proportional to *M,* the constant of proportionality being given by the maximum solution of the yield equations with respect to fishing mortality, *F*. Values of this constant of proportionality for different values of *M*/*K* and l_c are given in Table 4.1.

Table 4.1 Constants of proportionality for estimating maximum potential yield (a) as a proportion of exploitable biomass, and (b) as a proportion of total biomass, from Kirkwood et al (1994) [Table 9.1].

(a)

	M*/*K				
l_c	**0.5**	**1.0**	**2.0**	**3.0**	**4.0**
0.2	0.30	0.25	0.22	0.22	0.23
0.3	0.32	0.28	0.26	0.28	0.30
0.4	0.35	0.32	0.33	0.36	0.42
0.5	0.40	0.37	0.41	0.48	0.55
0.6	0.45	0.44	0.52	0.61	0.68

(b)

	M*/*K				
l_c	**0.5**	**1.0**	**2.0**	**3.0**	**4.0**
0.2	0.30	0.25	0.22	0.21	0.22
0.3	0.32	0.27	0.25	0.26	0.27
0.4	0.35	0.31	0.30	0.30	0.29
0.5	0.39	0.35	0.33	0.31	0.28
0.6	0.43	0.39	0.35	0.28	0.19

The effect of delaying fishing to a particular size (and age) is illustrated in the table and is well understood, but in many developing country fisheries is often unachievable. Different gears select fish in different ways and the smaller and younger fish may well be exploited by one gear eg seiners, while larger fish are caught only in traps.

Prudence would indicate that such effects are allowed for in assessing the potential yield so that a low l_c value is used for the estimation of potential yield. Such commonsense prudence is also supported by some analysis performed by Pauly and Soriano (1986).

The assumption of constant recruitment is very strong and implies that density dependant responses to fishing are marked. Beddington and Cooke (1983) looked at this issue and assumed that the constant recruitment assumption was reasonable for stocks which were exploited at a rate that meant that the spawning stock was not reduced beyond around 20% of its unexploited level. Kirkwood et al (1994) followed a different procedure and incorporated explicitly a stock recruitment relationship.

The effect on potential yield of the relationship between stock and recruitment

There is an enormous literature on stock and recruitment and a plethora of models have been proposed. Kirkwood et al (1994) used a modified form of that of Beverton and Holt (1957). They argue that the various stock and recruitment relationships vary between extreme density dependence Ricker (1954) and through constant recruitment to the more conservative forms of Beverton and Holt. This seems sensible in the context of developing country fisheries and is a prudent choice.

The estimation of stock - recruitment relationships is an exercise fraught with difficulty due to the often highly variable nature of recruitment. However, some insight can be gained from simple observations of where recruitment can be seen to have declined under exploitation.

Beverton-Holt SRR (standard)

According to the Beverton and Holt SRR, the number of recruits first increases rapidly as the SSB increases from zero. As the SSB increases further, the rate of increase in the number of recruits declines, until for very high SSBs, recruitment approaches an asymptotic value.

The standard formulation of the Beverton and Holt SRR is

$$R = \frac{\alpha B_t}{\beta + B_t} \tag{6}$$

where R is the number of recruits arising from an SSB of B_t, and α and β are the two parameters. In this formulation, $\alpha\beta$ is the asymptotic number of recruits, and α measures the rate at which this asymptote is reached.

This formulation is particularly useful when pairs of corresponding estimates of SSB and recruitment are available, as it is a relatively simple matter to estimate the parameters using regression techniques. Estimates of the parameters α and β are also often reported in the literature when stock-recruitment relationships have been fitted to stock and recruitment data.

Beverton-Holt SRR (steepness)

The standard formulation is ideal when recruitment data are available. In most cases, however, such data are absent, and it is difficult to find realistic values for the stock-recruit relationship. One popular alternative is the "steepness" formulation. This formulation requires a value for "steepness" in addition to estimates of B_0 and R_0. (where B_0 is defined here as the unexploited spawning stock biomass, and R_0 is constant annual recruitment) B_0 can be easily calculated from R_0, and vice versa, so the user needs only input either B_0 or R_0. Steepness (h) is defined as the recruitment (as a fraction of R_0) that results when spawning stock biomass is 20% of B_0. When h approaches 1, the Beverton-Holt SRR approaches the form of the Constant SRR; when h is close to 0.2, recruitment is linearly related to spawning stock biomass.

We know that in an unexploited population, from equation 6.

$$R_0 = \frac{\alpha B_0}{\beta + B_0} \tag{7}$$

Substitute the definition of h into equation 6.

$$hR_0 = \frac{\alpha(0.2B_0)}{\beta + (0.2B_0)} \quad 0.2 < h < 1 \tag{8}$$

After some algebraic manipulation of equations 7 and 8, we get the Beverton-Holt Steepness SRR:

$$R = \frac{4hR_0B_t}{B_0(1-h) + B_t(5h-1)} \tag{9}$$

This formulation is related to the Beverton-Holt Standard SRR as follows:

$$\begin{aligned} \alpha &= \frac{0.8hR_0}{h-0.2} \\ \beta &= \frac{0.2(1-h)B_0}{h-0.2} \end{aligned} \tag{10}$$

The analysis presented by Kirkwood et al (1994) found that the relationship between potential yield and natural mortality rate was not strictly linear but for large areas of parameter space was approximately so. The stronger the density dependence, the higher the potential yield as a fraction of M in the limit, with constant recruitment the results of Table 4.1 are recovered. When a stock recruitment relationship is considered a further parameter, the length at maturity (as a proportion of asymptotic length) is needed.

The results presented by Kirkwood et al (1994) are given for a range of values of M, M/K and l_m the population parameters of the stock and a range of values of the parameter l_c the length at first capture which can to an extent be determined by management.

In summary, they show that potential yield considered as a proportion of unexploited stock biomass

1. Yield is higher for higher M.
2. Yield is higher for higher K (M fixed).
3. Yield is higher for larger length at first capture l_c.

They also show that the results are a reasonably robust guide when recruitment fluctuates and when there is a variation of mortality rate with age. With these results it is possible to assess the potential yield with information only on natural mortality rate, the growth rate, the length at maturity and the asymptotic length.

4.3 Estimation of parameters

The major difficulty in applying these results to developing country fisheries is that for very few fisheries has it been possible to directly estimate the parameter M, the natural mortality rate. Other parameters have been routinely estimated for many stocks, but the sampling necessary and the complexity of estimation mean that estimation of natural mortality is beyond most fishery institutions (a remark that also applies to the developed world). This is a serious problem as from the results derived it can be seen that yield is in fact proportional to natural mortality and if it cannot be estimated then neither can the potential yield (at least using this methodology).

Two approaches to this problem are developed here, the first using empirical relationships between mortality and other parameters of growth, the second using optimal life history strategy techniques.

4.3.1 Deriving mortality rates from growth parameters

The key life history parameters that determine the potential yield of fish stocks can be see by the above analysis to be:

the instantaneous natural mortality rate M
the age at sexual maturity t_m
the length at maturity l_m
the parameters of growth K, and
the asymptotic (maximum) length L_∞ of the Von Bertalanffy growth equation

These life history parameters of fish species have been measured for a reasonably large number of species and various authors have noticed that there appear to be some rather simple relationships between these parameters which appear to be similar across different species and for different populations of the same species. The pioneering work in this area was done by Beverton and Holt (1959) and was largely empirical in its analysis. In effect, Beverton and Holt and a number of subsequent authors eg Pauly (1980), have used simple statistical techniques to derive empirical relationships between the parameters. That such relationships exist is surprising in that the parameters have been estimated from an enormous variety of sampling methods and sample sizes and from many different estimation techniques. They are thus subject to different kinds of statistical uncertainty (including statistical bias) and the existence of clear empirical relationships of high statistical significance imply that there are fundamental evolutionary and ecological processes involved.

Estimating mortality and potential yield from growth parameters

The most difficult parameter to estimate for all fisheries is the natural mortality rate *M*. This is particularly so for fisheries in developing countries where the detailed age sampling necessary for estimation is both too difficult (age readings are often impossible) and too expensive. A way around this problem that has been used by many authors is to use an empirical equation derived by Pauly from data on several hundred fish species. The equation is:

$$\ln M = 0.6543 \ln K - 0.279 \ln L_\infty + 0.4654 \ln T - 0.0152 \tag{11}$$

where T is mean annual water temperature (^{o}C).

The attraction of this equation is that the parameters K, L_∞ and the water temperature are easily measured. The potential yield can thus be calculated from these parameters for different values of the length at first capture l_c and length at maturity (where a stock recruitment relationship is involved).

Constant Recruitment

In the constant recruitment case there is an approximately linear relationship between the potential yield and the growth parameter K of the form

$$Y = aK \tag{12}$$

Different values of the length at first capture l_c give different values of the parameter a. However, the value of L_∞ enters via the Pauly equation and as a scaling on l_c. The results, for different values of K, are illustrated in Figure 4.1.

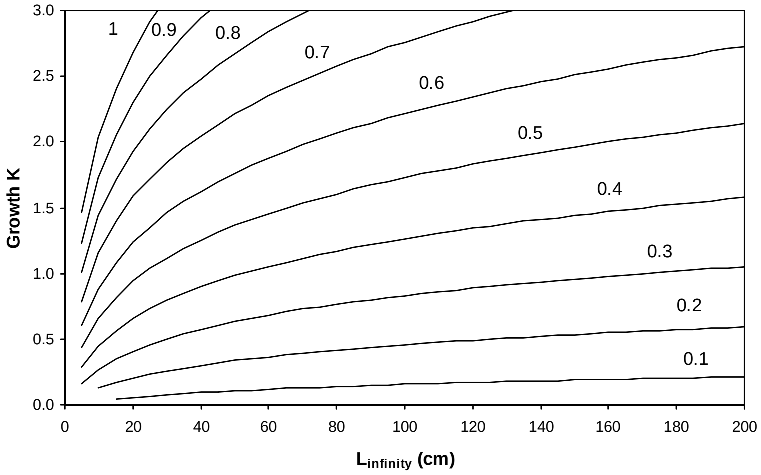

Figure 4.1. Isopleths of MSY/B0 as a function of L_∞ and K (from the von Bertalanffy equation). The B_0 values are the average exploitable biomass over the course of a year, in an unexploited population. Simulations were performed with length-at-capture equal to 30% of L_∞ and length-at-maturity equal to 66% of L_∞ (theoretical value reported in Jensen 1996). The stock-recruit relationship is assumed to be constant. The MSY values were obtained by estimating natural mortality from L_∞, K and environmental temperature (assumed to be 27°C), using the equation in Pauly (1980).

Incorporation of a stock recruitment

Where there is a stock recruitment relationship there is a need for the further parameter l_m, the length at sexual maturity. This parameter has been studied for a relatively restricted number of species and methods used to estimate it are often ad hoc and with no clear statistical properties. Published data examined in this study indicate that l_m scaled to L_∞ varies from around 0.4 to 0.9 with a mean value of around 0.6.

The potential yield is then a function of the parameters K and L_∞ and the values of l_c, l_m water temperature and the degree of density dependence in the stock recruitment relationship. A typical relationship is illustrated in Figures 4.2 with high levels of potential yield per unit of exploitable biomass predicted for small fast growing species such as anchoveta, whilst lower yields per unit of biomass are predicted for larger, slower growing species, such as snappers. The dependence on *K* being particularly strong.

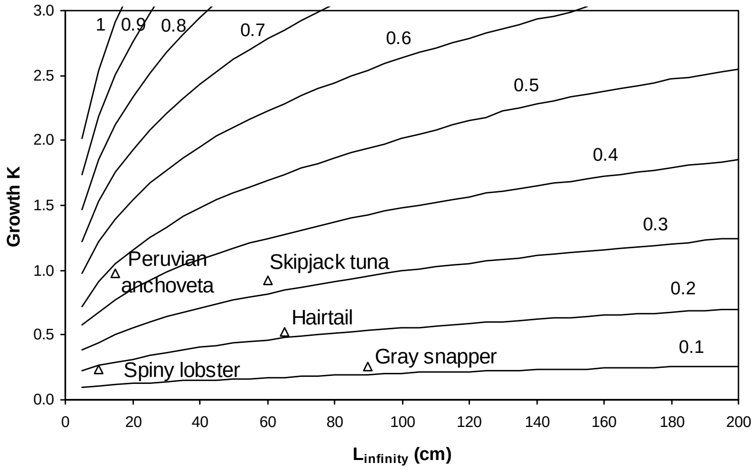

Figure 4.2 Isopleths of MSY/B_0 as a function of L_∞ and *K*. The B_0 values are the average exploitable biomass over the course of a year, in an unexploited population. Simulations were performed with length-at-capture equal to 50% of L_∞ and length-at-maturity equal to 66% of L_∞ (theoretical value reported in Jensen 1996). The stock-recruit relationship was a Beverton-Holt with *d* = 0.5, after Kirkwood et al. (1994). The MSY values were obtained after estimating natural mortality from L_∞, *K* and environmental temperature (assumed to be 27°C), using the equation in Pauly (1980).

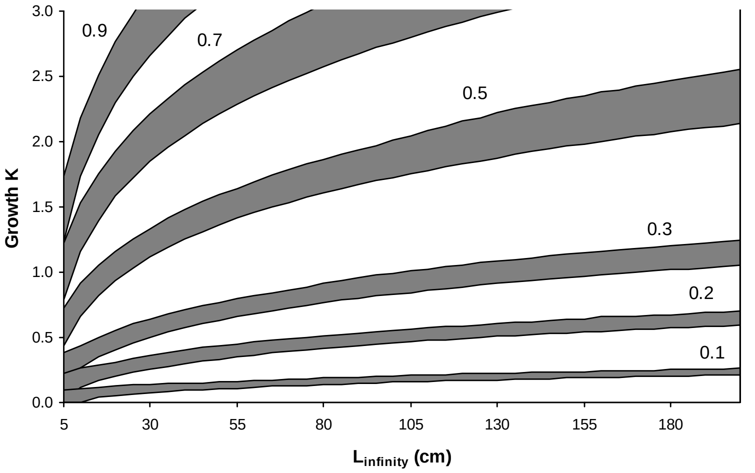

Figure 4.3 Variation in calculated MSY when constant recruitment and Beverton-Holt recruitment is used in the model to calculate MSY. The upper value in the bands is for Beverton-Holt recruitment. Note that bands represented MSY/B0 = 0.4, 0.6, 0.8 and 1.0 have been omitted to ease representation.

Although there is a difference between the constant recruitment and a stock-recruitment relationship, the difference is not particularly marked. Figure 4.3 illustrates this for typical values of the Beverton & Holt recruitment function.

These results illustrate that a straightforward calculation of potential yield can be made from relatively few parameters which can be estimated with comparative ease in developing country fisheries. The results, however, are critically dependent on the empirical relationship derived by Pauly. Data analysed in this study indicated rather different relationships and clearly there is a significant level of uncertainty associated with it.

4.3.2 Estimating potential yield from life history parameters using the Beverton and Holt invariants

A completely different approach to the relationship between the life history parameters has been taken by a number of authors who have sought an explanation of the relationship using life history optimisation techniques, Charnov (1990 and 1993), Roff (1984) and more recently using ecological theory by Jensen (1995).

The implications of these studies are that three fundamental relationships are to be expected amongst the parameters, these are known as the Beverton & Holt invariants and are

- The product $M.t_m$ is constant
- The ratio M/K is constant
- The ratio l_m/L_∞ is constant

Following the development in Jensen (1995) it is possible to show that when growth is of the Von Bertalanffy form

$M.t_m = 1.65$
$M/K = 1.5$
$l_m/L_\infty = .66$

Jensen checked these relationships empirically using data published in Pauly (1980) and other sources and they are largely corroborated by this statistical analysis. This study, using substantially more data, comes up with a similar level of corroboration. Jensen also showed that similar results could be obtained for different growth functions, although the empirical estimates of the invariants were slightly different.

The implications of these results for the estimation of potential yield in developing countries is encouraging. What the results imply is that if estimates of growth can be obtained using standard techniques so that an estimate of K and L_∞ are obtained, the simple manipulation of the invariant relationships above give the other parameters necessary to estimate potential yield. The natural mortality rate M is simply equal to $1.5K$, the length at maturity is equal to 0.66 of the asymptotic length, L_∞ and the age at maturity can be readily calculated from the growth curve.

With these results it is possible to revisit the analysis of Kirkwood et al (1994). In the constant recruitment case it will be recalled that Kirkwood et al derived a simple expression for MSY in terms of M/K and l_c and showed that when M/K and l_c are fixed, the relationship is linear with potential yield proportional to natural mortality:

$$Y = aM \tag{13}$$

A simple manipulation of the equations using the Beverton & Holt invariants, specifically M/K = 1.5 means that the equation can now be written as:

$$Y = a_{l_c} \; K \tag{14}$$

where the parameter $a l_c$ is a constant for a particular value of the length at first capture l_c (Figure 4.4)

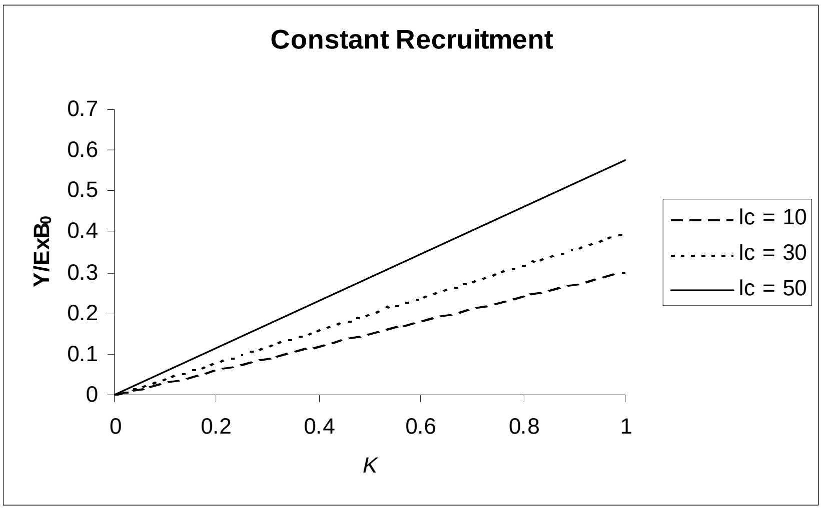

Figure 4.4 Yield as a proportion of exploitable biomass plotted as a function of *K* for l_c = 10cm, 30cm and 50cm.

Constant recruitment is effectively the limiting case of strong density dependence[6]. A more conservative approach is to assume that recruitment is dependent on stock size and that the degree of density dependence is characterised by a parameterisation of the steepness of the Beverton & Holt form discussed earlier. In particular, we have the steepness parameter *h* which is illustrated in Figure 4.5.

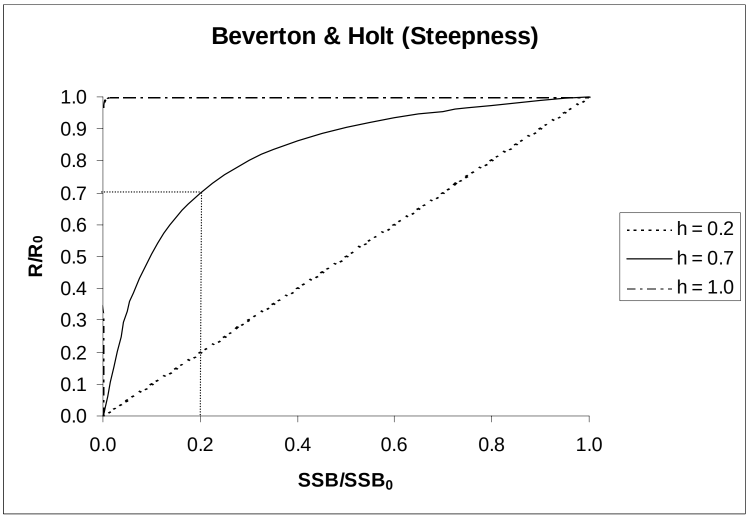

Figure 4.5 The characterisation of the Beverton & Holt SRR using the steepness parameter, *h* for values of *h* = 0.2, 0.7,and 1.

A further parameter is needed for this analysis l_m scaled to L_∞ or, more simply, l_m/L_∞. This, it will be recalled, is the third Beverton & Holt invariant: l_m/L_∞ = 0.66. Kirkwood et al (1994) had illustrated a relationship between potential yield and natural mortality which was almost linear for large cases of parameter space but varied with l_m, *M*/*K*, and the degree of density dependence and the age at first capture (t_c).

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[6] The domed stock and recruitment relationships of the Ricker form which imply stronger density dependence has been ignored for these purposes as evidence of species with such forms is rare.

The use of the Beverton & Holt invariants significantly simplifies the analysis so that, as in the constant recruitment case, the potential yield is given by a linear relationship:

$$Y = a_{l_c,h} K \tag{15}$$

where $a_{l_c,h}$ is determined by the length at first capture l_c and the degree of density dependence (steepness) in the stock recruitment relationship h. The results are illustrated in Figures 4.6, 4.7 and 4.8.

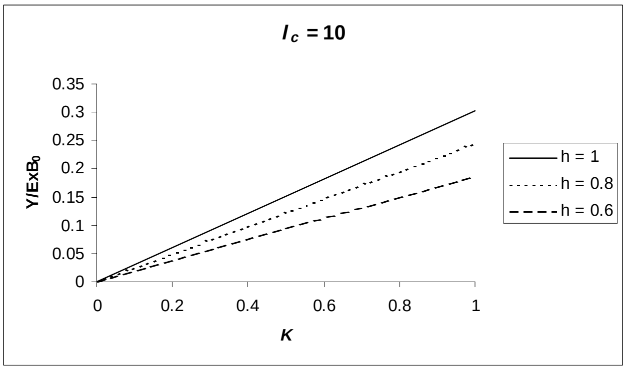


Figure 4.6 Yield as a proportion of exploitable biomass plotted as a function of *K* for l_c = 10cm, and *h* = 0.6, 0.8 and 1.

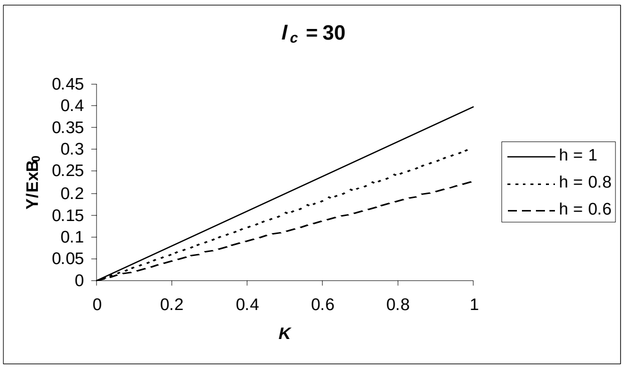


Figure 4.7 Yield as a proportion of exploitable biomass plotted as a function of *K* for l_c = 30cm, and *h* = 0.6, 0.8 and 1.

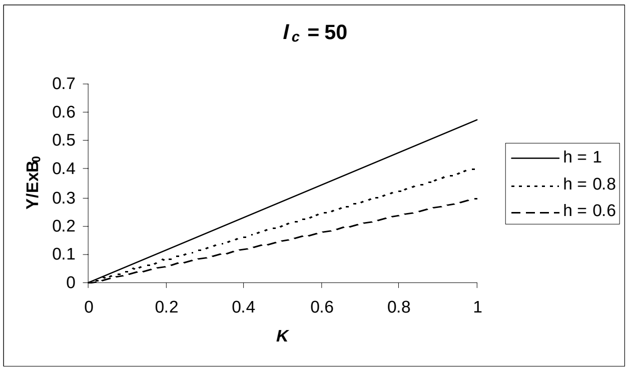


Figure 4.8 Yield as a proportion of exploitable biomass plotted as a function of *K* for l_c = 50cm, and *h* = 0.6, 0.8 and 1.

The results are as expected, the constant of proportionality increases with delayed length at first capture and with the degree of density dependence (with the constant recruitment being the limit as the steepness parameter $h = 1$.

Even for quite weak density dependence $h = 0.6$ the difference between this and the case of constant recruitment is relatively slight. Clearly, it would be prudent in assessing yield to take lower values of h (weak density dependence) until data accumulate to provide evidence to the contrary.

These results now affect the possibility of assessing the potential yield of any stock of which growth curves have been obtained. This thus affords both a cheap and robust way of estimating potential yield.

4.4 Stock status and the estimate of fishing mortality at the level of maximum yield

In their pioneering work, Beverton & Holt (1957) had observed that in many situations the level of fishing mortality that generated the maximum yield $F_{\max}$ was often related and indeed often very close to the level of annual instantaneous natural mortality rate M.

The analysis above implies that if this is correct, then there are two issues. First, the relationship can only hold for a particular length at first capture l_c or where l_c has been determined to provide a maximum overall yield. Second, that the relationship between $F_{\max}$ (for particular l_c) may be a simple fraction of the growth parameter K.

It can be shown that for a wide range of parameter space, a simple linear relationship between $F_{\max}$ and K appears to hold; specifically:

$$F_{\max} = a_{l_c} K \tag{16}$$

Where the coefficient $a l_c$ varies with the length at first capture. This appears to be the case both for constant recruitment and for the typical forms of the stock recruitment relationship explained above. However, in this case the equation is

$$F_{\max} = a_{l_c,h} K \tag{17}$$

Where $a_{l_c,h}$ is a constant depending on the values of l_c and the degree of density dependence h. The values of the parameter and the relationships derived are illustrated in Figure 4.9. As expected, $F_{\max}$ is higher for higher l_c.

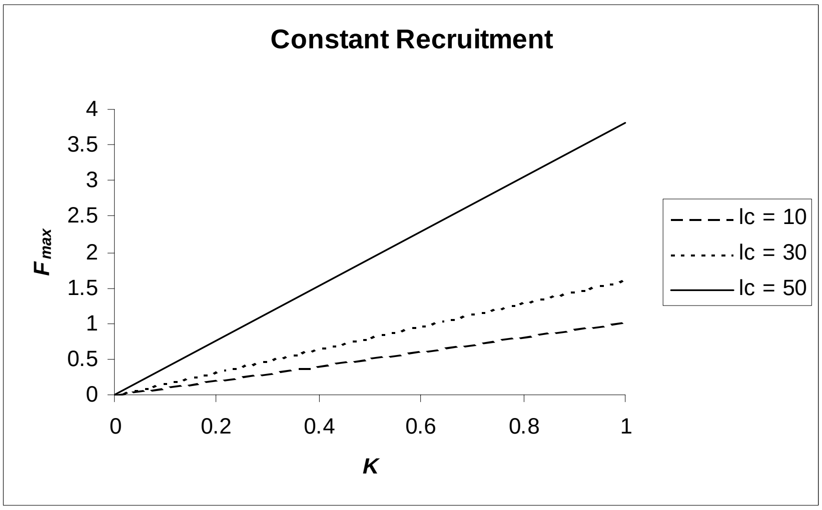
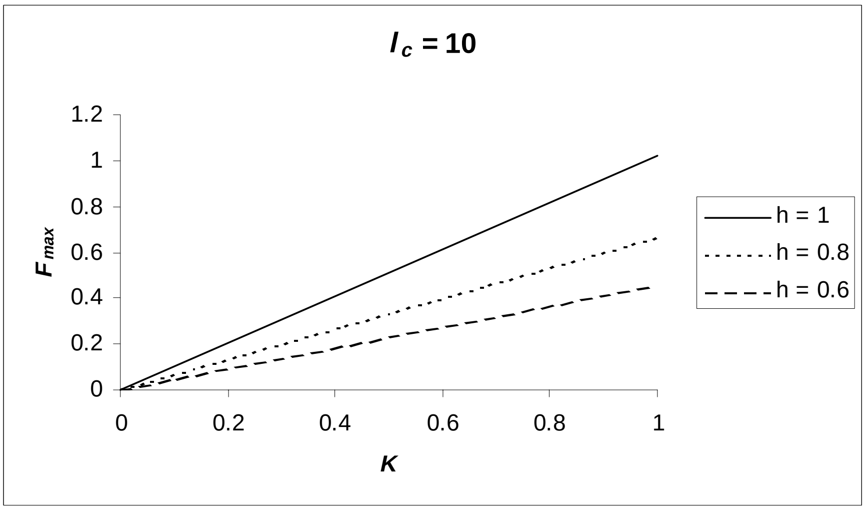
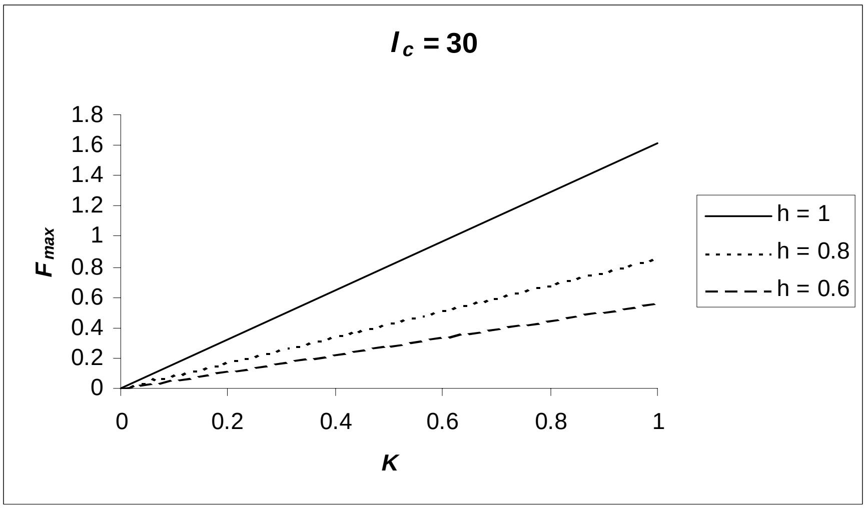


Figure 4.9 F_{max} as a function of K for l_c = 10, 30 and 50cm when recruitment is assumed constant.

Figures 4.10 to 4.12 illustrate the relationship between $F_{\max}$ and K for three values of l_c and different values of the steepness parameter h.





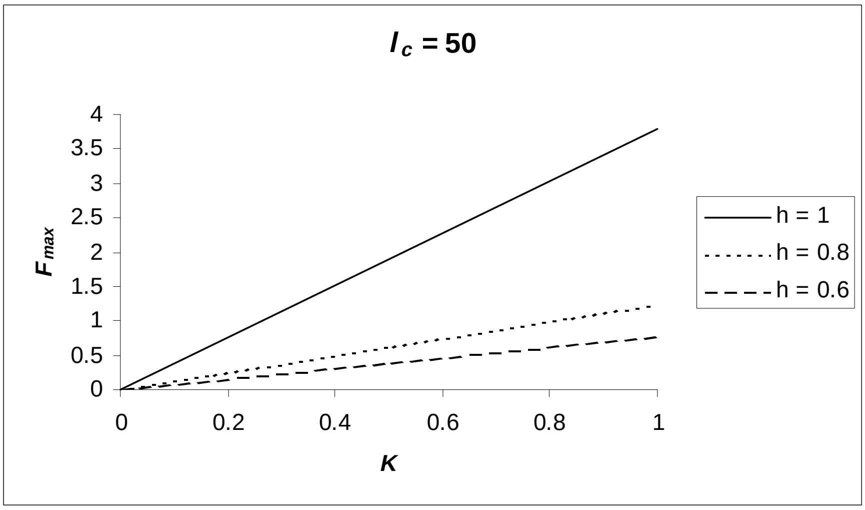


Figure 4.10 (top), **4.11** (middle) and **4.12** (bottom) illustrating the relationship between $F_{\max}$ and K for different values of the steepness parameter, h = 0.6, 0.8 and 1, for l_c = 10cm, 30cm and 50cm, respectively.

4.4.1 Implications for stock status

The results above have a useful practical implication for the assessment of the status of fisheries where data are sparse. Given an estimate of growth for the species concerned, an estimate of $F_{\max}$ can be obtained by simple application of equation [16]. Estimates of the current level of fishing mortality can be obtained in a number of ways, but most simply by looking at the ratios of catch, C to stock biomass, B, F is given by the relationship:

$$F = \frac{C}{B} \tag{18}$$

If the value of F is significantly higher than $F_{\max}$, then the stock is clearly being overexploited and some action may be needed to avert a collapse. If it is close, then any increase in fishing effort should be discouraged. In the situation where the estimate F is well below the $F_{\max}$ estimate, then some simple guidelines for expansion of the fishing may be given. Increasing catch levels by increasing effort can be permitted as long as the new ratio of C/B (for biomass will also change) leads to a level of the new F that is below $F_{\max}$. Clearly prudence will require that it is a reasonable level below.

4.4.2 Caveats

The analysis presented above has omitted certain areas of parameter space where complications can occur. Most importantly, the situation where l_c is larger that l_m, ie that length at first capture is greater than the length at maturity. This is problematic from an analytical perspective as in these cases the level of fishing mortality needed to obtain the MSY level is infinite. Such situations are rare and simple ad hoc methods can be used, for example by assuming l_c is some significant proportion say 0.95 of l_m.

A more important constraint is when density dependence manifests itself in a decrease in l_m as the stock is exploited. This is potentially most important for relatively large slow growing species, an investigation of this is in hand, project R.6465 ‘Growth parameter estimates and the effect of fishing on size composition and growth of snappers and emperors: implications for management’ MRAG (1999).

4.5 Fluctuating environments

The analysis in this chapter will appear to the reader to be ignoring the ubiquitous nature of fish stocks, namely that they fluctuate constantly. Such fluctuations are difficult to quantify and in most circumstances usually impossible to predict. However, the deterministic analysis derived above can be shown to be an excellent guide to the average behaviour of stocks that are exploited in fluctuating environments. There is clearly a need to understand for management purposes what are the implications of different levels of fluctuation in the environment as it often affects recruitment and other demographic parameters. An elaboration of this is planned in project R.7041.

4.6 Multi-species effort issues

Only very rarely is it the case that a single species is exploited. By far the most common situation is where a complex of species are harvested by a number of different gears. Appropriate ways of dealing with such situations have been reviewed by project R.5484, Management of multi-species topical fisheries, MRAG (1996).

The methodology set out in the analysis presented in the MRAG (1996) report is significantly enhanced by the applications presented. The key parameters for estimating appropriate policies and estimating yields are the same as for the single species case. It is thus possible to simplify the analyses once there is sufficient information on the growth of the individual component species of the harvested complex.

Such analysis is applicable where species interaction are relatively weak. Situations where there is a strong interaction with significant changes in the abundance of one species in response to the harvesting of another are not covered by this type of analysis. Hence prey release following depletion of a predator, or indeed predator decline following exploitation of a prey, are difficult and as yet unsolved problems. Only theoretical approaches have been used eg Beddington & May (1980) and Beddington & Cooke (1982). Detailed analysis of such problems relevant to fisheries does not currently exist and data to examine the issues empirically are rare. Such issues are beyond the scope of this study.

4.7 Concluding remarks

Chapter 2 has highlighted the difficulties and requirements needed for a sensible socio-economic fisheries management regime. A prerequisite of such a regime is an understanding of the limits to which the resource can be fished and an idea of the direction in which management actions need to be taken. The analysis in this chapter enables these key resource issues to be addressed in a simple and straightforward manner using relatively modest amounts of data. Clearly more work is needed, but in the interim, the broad guidelines that can be derived from the above analysis, interpreted cautiously, form a good and relatively robust basis for assessment for management.

References

Beddington, J. R. & Basson, M. (1994). "The limits to exploitation on land and sea" *Phil. Trans. R. Soc. Lond B* **343**: 87-92.

Beddington, J.R. & Cooke, J.G. (1982). "Harvesting from a prey-predator complex" *Ecological Modelling* **14**: 155-177.

Beddington, J.R. & Cooke, J.G. (1983) "On the potential yield of fish stocks" *FAO Tech. Papers,* **242**: 1-47.

Beddington, J.R. & May, R.M. (1980). "Maximum sustainable yields in systems subject to harvesting at more than one trophic level" *Math Biosciences* **43**: 64-85.

Beverton, R.J.H. & Holt, S.J. (1957) “On the dynamics of exploited fish populations” *MAFF Fisheries Investigations, London, Series 2* **19**: 1-533.

Beverton, R.J.H. & Holt, S.J. (1959) “A review of the lifespans and mortality rates of fish in nature and the relationship to growth and other physiological characteristics” *Ciba Found. Colloq. Ageing* **5**: 142-177.

Charnov, E.L. (1993). “Life history invariants” *Oxford University Press, New York*.

Charnov, E.L. & Berrigan, D. (1990). “Dimensionless numbers and life history evolution: age of maturity versus the adult lifespan” *Evol. Ecol.* **4**: 273-275.

Gulland, J.A. (1971). “The fish resources of the ocean” *Fishing News Books, West By Fleet, Surrey.*

Jenson, A.L. (1995). “Beverton & Holt life history invariants result from optimal trade-off of reproduction and survival” *Can. J. Fish. Aquat. Sci* **53**: 820-822.

Kirkwood, G. P., Beddington, J. R. & Rossouw, J. R. (1994). "Harvesting species of different lifespans" .P J. Edwards, R. May and N R Webb (ed). *Large-Scale Ecology and Conservation Biology* pp 199-227, Blackwell Scientific Publications.

Pauly, D. (1980). “On the interrelationships between natural mortality, growth parameters, and mean environmental temperture in 175 fish stocks” *J. du Cons. Int. pour l’Explor.de la Mer,* **11**: 559-623.

Pauly, D. & Soriano, M.L. (1986). “Some practical extensions to Beverton & Holt’s relative yields-per-recruit model”. *The First Asian Fisheries Forum* pp.491-495 Asian Fisheries Society, Manila, Philippines.

Ricker, W.E. (1954). “Stock and recruitment” J*ournal of the Fisheries Research Board of Canada* **30**: 1965-1976.

Roff, D.A. (1984). “The evolution of life history parameters in teleosts” *Can. J. Fish. Aquat. Sci* **41**: 989-1000.