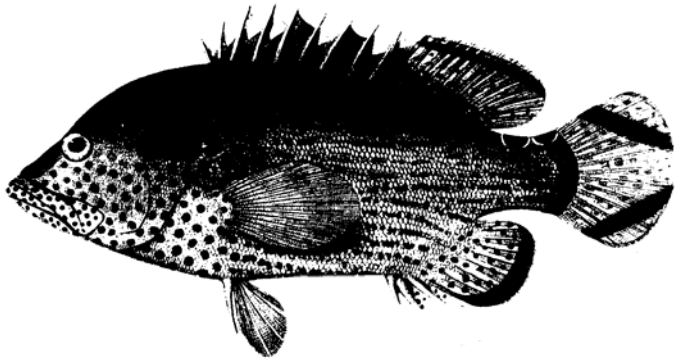
Coral Reef Fisheries

Literature Review and

Database Research Report



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EXECUTIVE SUMMARY

Background

1 There is a vast amount of information on coral reefs and the ecology of their associated communities. However, relatively little of it has been collected for purposes directly associated with the assessment and management of fisheries. While much of this literature may be of relevance, it is not easily interpreted.

2 A further problem is that much of the information is contained in 'grey' literature, such as internal reports, that are unpublished, unpublicised or difficult to obtain. Valuable case studies of management regimes in different areas often fall into this category. The number of published papers in easily accessed scientific journals is relatively small. This makes the task of gathering and interpreting the literature particularly difficult for isolated workers.

3 With these points in mind, the objectives of this project were twofold. First, coral reef fisheries literature references were to be obtained and organised into a computer database, which would be available for distribution along with an accompanying manual. Second, a comprehensive review article summarising and interpreting the disparate literature was to be written and distributed along with the database. The database and accompanying review should assist research and management of coral reef fisheries in developing countries.

The Coral Reef Fisheries Literature Database

4 A relational database, ODA_REEF, has been developed for storing and organising references concerning coral reef capture fisheries around the world. It offers facilities for adding, editing, printing and deleting selected references. The database can be run on any IBM compatible microcomputer with a hard drive and 80286 or better processor. The database is menu driven, and is designed to be easy to use and capable of being personalised and added to by individual users.

5 Key words are a vital part of the database. The categories covered by key words are region, country, study type, study data, data type, reef type, reef status, fishery type, and fishing method. In addition, text fields are available for the user to enter further details under the headings of specific targets, and content notes.

6 All key words have been standardised to avoid problems with misspelling or synonyms. In each category, key word fields can be left blank if that category is not relevant for a reference. Where a category is relevant, single or multiple key words can be entered.

7 References of relevance to the assessment and management of fin-fish fisheries on coral reefs have been collected by conducting an extensive search of the published literature, and through contact with organisations and individuals around the world who were likely to have access to reference material not published in the mainstream journals. A total of 355 literature references have been entered into the ODA_REEF database. While this is not an exhaustive collection, it is substantial and should prove a very useful initial collection on which users can build.

8 The database is available for distribution on two 720K floppy disks. A user manual has also

been written explaining how references in the database can be viewed or altered, and new references added.

9 The database contains references from all the main regions in the world. References based on catch and effort statistics dominate the literature, most are from the Caribbean, reflecting the long history of coral reef fisheries research in that region. Substantial numbers of papers relating to the Pacific, S.E. Asia and Australasia have also been entered.

10 The majority of references have 'Fisheries' as the primary study type. Ecological and management studies are also well represented, but there has been a general neglect of the socio-economics of coral reef fisheries, particularly where fisheries are being developed beyond their traditional management structures.

11 References based on catch and effort statistics are most common in the literature. Detailed work on growth, mortality, recruitment and yield-per-recruit models is rare. This is probably in part because such analyses, although often undertaken, are seldom published.

12 There is a small but growing number of publications concerned with productivity and energy flow through the reef community. At present these are largely theoretical studies based on the ECOPATH model, in which interest is increasing.

13 Sanctuaries have not been commonly discussed, although they are attracting growth in attention, the number of publications on fisheries reserves and zoning on reefs should rise in the future.

14 Most references are concerned with commercial or artisanal fisheries. That there are few publications concerned with subsistence fishing underlines how little is understood with regard to this activity. Since subsistence fishing is very common, it perhaps deserves more attention.

Coral Reef Fisheries Review Article

15 The review article covers the existing coral reef fisheries literature, the extensive literature on coral reef fish ecology and a number of management case studies.

16 Coral reef fisheries are widespread and often important to the local economy. Although other fisheries take multiple species and have many areas where stocks aggregate, no other fisheries have such diverse stocks or such extreme spatial heterogeneity.

Aspects of single species and community ecology

17 There is a large amount of life history information on coral reef fishes, however it tends to concentrate on small, generally territorial, species, rather than the larger and commercially important species. Although recruitment, growth and mortality can be studied for each species separately, the number of species on a coral reef and the range of behaviours exhibited make generalizations difficult.

18 An important issue is to define what constitutes a stock on a coral reef. If it is not possible to define distinct homogeneous populations, it will become necessary to include heterogeneity explicitly in population models, this will require a more detailed understanding of how fish and larvae disperse.

19 It is not known whether observed distribution patterns may be more closely related to numbers settling or post-settlement mortality. Experimental results and observations are conflicting.

20 Primary productivity and energy flow through food webs has been used to estimate potential yield from fisheries. It may however be difficult to reconcile the structure of such models with that underlying the ecological community and markets. The model structure is static, and may be a poor predictor of how the coral reef community, which is dynamic, might change under perturbation.

21 The ECOPATH model, a current application of trophic models, appears at present to be the only practical way to look at and use trophic relationships within the community.

22 Population models rather than trophic models are the most widely used basis for stock assessment. These can be easily extended to model communities by including terms describing the relationships between species. The wide variety of possible behaviours of these models however confer little predictive power on the general theory. It is nearly impossible to estimate the large number of parameters and test them properly.

23 The practical implications of results from studies of multispecies population models, are that managers should perhaps be a little more conservative with multispecies stocks. These models also suggest that yield may be increased by adjusting the relative catchabilities of different species as well as controlling effort.

24 Spatial heterogeneity is increasingly recognised as an important factor in coral reef ecology. However at this stage it is unlikely that it can be included in stock assessment until methods are developed to cope with this complex issue.

25 A number of authors have suggested that coral reef fish populations are relatively stable and are maintained by competition and predation between species in much the same way as has been proposed for temperate communities. Although predation is thought to have an important effect on population dynamics and community structure, little competition has been found.

26 As well as more general ecological theories, coral reefs have attracted a number of special theories to explain their high diversity. The intermediate disturbance hypothesis suggests that there is some level of random disturbance which maximises diversity. It only has application in the sense that large perturbations, which may be induced through fishing, will decrease the diversity of the reef, an empirical fact which has a wide support.

27 Since significant competition has not been found in reef fish populations, it has been proposed that adult stocks are limited by recruitment, fish densities on the reef are largely a result of previous settlement patterns. This theory is currently under test.

Coral reef stock assessments

28 Using results from coral reef ecological studies in fisheries models is problematic in that much of the theory is based on the study of a narrow range of species. These species are not important to the fisheries and have different population characteristics.

29 community model over another. In particular, there is no evidence that models other than those already used in stock assessments, such as yield-per-recruit on a species by species basis, will provide significantly better advice.

30 Nevertheless, for coral reef fisheries there are two important arguments against using single species stock assessments models. Firstly, predation rates are high on coral reefs, indicating significant trophic relationships. Secondly the problem of estimation is enormous, since the number of parameters required is very large.

31 At the other extreme, all species in the catches might be combined and assessed together. A

surplus yield model with undifferentiated biomass is robust and valuable in that it can provide a simple indication of the state of the fishery. However, data on catches at high effort levels are highly variable and often lacking, making MSY estimates unreliable. In addition, these models take no account of changing species compositions.

32 A more refined approach is to group only similar species together and treat them as if they were a single species. This approach relies on closely related species having similar dynamics. Such species grouping is common in tropical multispecies fisheries data and seems to give reasonably sensible results.

Management case studies

33 The lack of data for artisanal and subsistence fisheries is a particularly acute problem, yet these types of fishery dominate coral reefs.

34 Catches were highly diverse in all the fisheries examined in case studies. Species composition changed as fishing intensity increased, from large slow growing valuable fish to smaller fish with faster growth and lower market value.

35 Alternative sources of income, seasonal weather patterns and proximity of reefs to towns or villages often have the strongest and most immediate influence on levels of fishing effort. Prices may change with time of day, season, market, species, size and the pay cycles. These factors can also be important in driving supply.

36 Overfishing is a problem on many reefs. However, habitat destruction is of as much concern in many countries as direct overfishing. Much effort has gone into the creation of effective marine reserves. These also appear to increase stock sizes and catches. A key factor in the success of a reserve appears to be involvement of local people.

Management measures

37 Management regimes for coral reef fisheries in developing countries will have to be simple, require little data and be easy to enforce. A successful management system should protect the habitat, aid recovery if reef damage occurs, conserve vulnerable exploited species, and maintain the livelihoods of the fishermen. It should also deal with potential conflicts among users of the resource, most notably between fisheries and tourism.

38 Elimination of damaging fishing methods should have high priority. Subsequently controlling fishing gears and hence species selectivity is likely to be a key component of the management of a multispecies fishery. Limited entry and quota management are difficult to enforce in reef fisheries, and are likely to play only a small role.

39 Area closures are an important control that can successfully conserve both areas of reef habitat and fish stocks, and can be enforced relatively easily.

40 In many societies reef fisheries have been managed under customary marine tenure (CMT) systems, with family and clan groups possessing the rights to fisheries on reefs adjacent to their land. In these systems the community which uses the resources controls its exploitation. Although CMT management may slow development of resources and could hinder the implementation of national fisheries policies, it may well be as close to the optimum as could be achieved at present.

Future Work

41 Improvements in the database performance can be made, but that would be expensive and time-consuming. It should only be considered if many users were finding it difficult to run the database on their computers.

42 Each user is likely to have access to and be able to add to the database different sets of references. In several years, it may be useful to combine these databases to produce a new set of references which can be redistributed.

43 Effective management of coral reef fisheries requires a wide-ranging approach to deal with the many different issues it faces. Pure ecological research cannot be relied upon to solve all of these problems. Detailed scientific work on coral reef ecology will probably be useful in identifying appropriate models, but only in the long term as the structure of the coral reef community becomes better understood.

44 In the absence of reliable models of coral reef communities, assessments have frequently been based on a series of catch and effort data for species or species groups. Often only limited information can be gained from such data. Other aspects that deserve attention are studies aimed at understanding the dynamics governing the behaviour of fishermen, and studies of models and data which describe how catch species composition changes.

45 Adaptive management represents another powerful approach for dealing with fisheries and ecological management. It involves designing experiments to discriminate simultaneously between alternative ecological models and management actions, enabling managers to address their own research needs directly. It has been suggested that this approach is particularly appropriate for coral reefs, since different reef areas can be treated as nearly identical, independent experimental plots.

FINAL REPORT

1 Objectives of the Project

The objective of this project was to create, as a package available for distribution to interested scientists and government officials, (i) a flexible computerised database of literature references relevant to the assessment and management of coral reef fisheries, (ii) a user manual describing how to use the database and how to extend it by adding new references as they become available, and (iii) a comprehensive review article summarising and interpreting the literature.

In the original project memorandum, it was stated that initial emphasis would be placed on fin-fish fisheries. This emphasis has been maintained throughout the project

2 Work Carried Out in the Period

A relational database for storing and organising literature references concerning coral reef fisheries around the world has been constructed and written using R:BASE Runtime software. The database has facilities for adding, deleting, editing and printing selected references. In addition to a standard literature citation, each entry contains fields provided for the insertion of user notes, and is categorised by a number of sets of key words appropriate to the specific subject area. The database is menu driven, and designed to be easy to use and capable of being personalised and added to by individual users.

A user manual has also been developed. It has been written with relatively inexperienced users in mind. Clear instructions are given on how to select references from the existing database as distributed and on how to add new references as they become available.

References of relevance to the assessment and management of fin-fish fisheries on coral reefs have been collected by extensive search of published literature and through contact with organisations and individuals around the world who were likely to have access to reference material not published in the mainstream journals. Hard copies were collected where possible. All literature collected that proved on reading to be suitable was entered onto the database, along with appropriate key words.
In addition, an article has been written reviewing the assessment and management of coral reef capture fisheries. As part of this review, the extensive ecological literature available on coral reefs was also reviewed from the point of view of fisheries management. Wider issues of fisheries management on coral reefs are addressed using case studies.

All planned inputs to the project have been achieved.

3 Results

3.1 Coral Reef Fisheries Literature Review, Database and User Manual

A relational database, ODA_REEF, has been developed for storing literature references relevant to the assessment and management of coral reef capture fisheries for fin-fish. The database can be run on any IBM or compatible microcomputer with a hard disk and an 80286 processor or better. The database is available for distribution on two 720K floppy disks.

A total of 355 literature references have been entered onto the ODA_REEF database. Each entry on the database is classified according to a number of key words, and additionally contains the appropriate

standard literature citation. The categories covered by the key words are: region, country, study type, study data, data type, reef type, reef status, fishery type, and fishing method. In addition, text fields are available for the user to enter further details under the headings: specific targets, and content notes. New references can be added as desired, and existing references can be edited.

A comprehensive user manual has also been written for distribution along with the database disks.

3.2 Coral Reef Fisheries Review Article

A review article has been written to accompany the database. Existing fisheries literature directly pertaining to coral reefs is reviewed, as well as the extensive literature on coral reef fish ecology. In the latter category of literature, attention is concentrated on the extent to which these studies could suggest improvements to existing assessment and management methods. Case studies from Papua New Guinea, the Philippines and the Caribbean are used to examine wider issues in management. These suggest that coral reefs are beset by a number of environmental and socio-economic problems that may well eclipse those of traditional fishery stock assessment in the short term.

The review covers the following subject headings: single species ecology, community ecology, models of the coral reef community, implications of models to stock assessment, coral reef stock assessments, management case studies, and management.

4 Implications of the Results

The specific objectives of the project have been achieved, in that the literature database has been developed, along with a user manual, and a substantial review article has been written. However, the true success of the project can only be judged properly in terms of how useful coral reef fishery scientists and managers in developing countries find them. To this end, it is important that careful attention be given to dissemination. In addition, possible follow-up work outlined in the next section, involving collation of additional references collected by individual users of the database in the field, could further enhance the usefulness of the database.

5 Priority Tasks for Follow Up

The following tasks should be accorded priority:

(i) The database, manual and accompanying review article should be given as wide as possible distribution to appropriate organisations and individuals.

(ii) A slightly shortened version of the review will be submitted to *Reviews in Fish Biology and Fisheries* for publication.

(iii) While it is believed unlikely that there are any serious gaps in the database arising from papers that have been published in the mainstream scientific literature, it is highly likely that individual users will have access to unpublished or difficult-to-obtain literature from their region that is not contained in the database. The overall value of the database could be considerably enhanced if in a few years users to whom the database was distributed were asked to send copies of their current databases back to ODA, with a view to developing a revised database consolidating new entries made by users. This revised version could then be redistributed.

(iv)If revision of the database as suggested under (iii) is contemplated, then consideration should also be given to rewriting the database in a high level computer language, such as Pascal, in order that its speed can be enhanced and that it may be used on less powerful computers than are currently needed.

(v) The review has highlighted several areas of future research that seem particularly promising.

OUTLINE OF RESULTS ACHEIVED

1 Coral Reef Fisheries Literature Review, Database and User Manual

1.1 Background

Within the published literature, there is a vast amount of information on coral reefs, but most of it has been collected for purposes other than the management of fisheries. Extracting and collating relevant literature in an appropriate form is an essential pre-requisite to any comparative study.

The database was developed to perform two functions. Firstly it was designed to organise coral reef fisheries literature, which was gathered to review current research and management interests. This was necessary not just because of the large amount of coral reef literature, but also because obtaining and organising studies covering different aspects of coral reef ecology, exploitation and management was particularly complicated. Much of this literature might be relevant, even though no specific mention is made of fisheries. For instance, a great deal of work has been carried out on pure marine ecology in the Caribbean and Pacific that is relevant to coral reef fisheries management, and is published in well-known scientific journals. There are probably fewer studies on fisheries ecology, although it must be recognised that many do not appear in the international journals, but are usually published regionally or recorded in internal reports. Similarly, descriptions and studies of coral reef management are rarely published. However references to the different management regimes pertaining to areas are often made in passing in many papers.

A number of organisations and individuals around the world were approached for potential reference material with varying degrees of success. Tracing publications and unpublished reports ('grey' literature) has proved difficult and time consuming. This perhaps underlines the need for easier access to papers and reports for researchers and managers in this field. The database should help in publicising work, particularly management case studies, which otherwise are not distributed.

1.2 The Database and its Scope

The database, ODA_REEF, is a relational database for storing and organising references concerning coral reef fisheries around the world. It offers facilities for adding, editing, printing and deleting selected references. The database is menu driven, which makes it particularly easy to use. In addition to a standard literature citation, fields are provided for the user's own notes, and standardised key words are provided to aid selecting references. The database application is written in R:BASE Runtime software (R:BASE Runtime is a registered trademark of MICRORIM Inc.).

ODA_REEF is provided with 355 references pertaining to coral reef fisheries. This is not an exhaustive collection, but it is substantial and should prove a very useful initial collection on which users can build. Wherever possible, hard copies of the pertinent papers have been obtained and are held at MRAG. It has been designed so that additional references can be added and it can be personalised by the users to whom it will be distributed. The current reference collection concentrates on the fisheries for fin-fish.

Key words are an important part of the database. They have been standardised to avoid problems with misspelling or synonyms. The key words and their use is illustrated by the following analysis of the references already contained in the database. This analysis also demonstrates the areas on which the

fisheries literature has concentrated.

Table I shows the frequency of references concerned with each of nine regions in the world. The regions represent large scale divisions based upon both ecological and social factors. The greatest ecological division is between the Caribbean and Indo-Pacific, although the disparate forms of exploitation and social conditions within the Indian and Pacific oceans allow more specific and useful categories.

The key words and their use have been designed to be as flexible as possible. For each reference, key words have only been added where it was thought that a user of the database would want to extract that reference when searching on that key word. For this reason, it is possible for key word fields to be left blank, and for any combination of key words to be added, as they are not intended to be mutually exclusive. For instance, a theoretical paper which is not specific to any particular area would have no region key word. In contrast, a paper comparing countries in two regions would have two region key words. While this flexibility is highly desirable, it does lead to a certain amount of subjectivity by relying on the judgement of the person adding or editing the reference.

The Caribbean has a long history of coral reef fisheries research, and literature, and that region by far dominates the reference collection. Australasia would have been the dominant region if more ecological literature had been included. The majority of papers from S.E. Asia are from the Philippines, where concern for coral reef conservation and management is great. However it needs to be emphasised that many coral reef fisheries publications are internal reports and not widely available. In this sense, the relative frequencies reflect to some extent how easy it was to obtain literature from different areas, as well as the number of reports and publications written on those areas.

Table II gives the frequency of references for each study type, which classifies publications according to their main subject area. The predominance of publications concerned directly with fisheries should come as no surprise; that was the objective in developing the database. However, many other studies are relevant, although they are only concerned with fisheries indirectly. For instance, many ecological studies might be useful in formulating stock assessment models even though no fishery is mentioned. However the database also caters for references which cross over these divisions. Because key words are not mutually exclusive, they can be combined to indicate the subject area more accurately. Thus, socio-economic studies directed only at the fishery sector should have both '*Fisheries*' and '*Socio-economic*' as key words. The table illustrates the small number of studies which investigate socio-economics of coral reef fisheries. There has been a general neglect of this area, particularly where fisheries are being developed beyond traditional management structures.

Table III shows where the data used in the study came from and gives some idea of the type of study carried out. '*Data analyses*' is intended to suggest the analysis of quantitative data, while '*Descriptive*' suggests analysis of qualitative data. They are of equal importance in the literature. The frequency of '*Field study*', which only just exceeds the number of reviews, emphasises the difficulty in getting original data. '*Reviews*' use other literature as their source of information. Directly relevant '*Theoretical*' papers are relatively rare, mainly because data are lacking and because of the complexity of the coral reef ecosystem.

Table I

Region	References
Atlantic	12
Australasia	29
Caribbean	119
Pacific	66
S.E. Asia	42
Indian Ocean	23
Red Sea	1
Arabian Gulf	0
Global	37

Table II

Study Data	References
Data analyses	56
Descriptive	56
Field study	81
Review	76
Theoretical	19

Table III

Study Type	References
Ecological	87
Fisheries	207
Management	81
Socio-economic	25

Table IV

Data Type	References
Catch/cpue	102
Length/weight	51
Growth	25
Mortality	29
Yield per recruit	13
Migration	18
Productivity	6
Recruitment	14

Data type allows the user to specify in greater detail the data and analyses used. As shown in Table IV, references based on catch and effort statistics dominate the literature. More detailed work on growth, mortality, recruitment and yield-per-recruit models is rare. This is probably in part because such analyses, although commonly undertaken, are seldom published. Studies concerned with migration and movement are probably less frequently conducted, but more commonly published. There are a number of interesting papers indirectly concerned with fish movement, considering the use of trap catches in population indices. There is a small but growing number of publications concerned with productivity and energy flow through the reef community. At present these are largely theoretical studies based on the ECOPATH model, in which there is increasing interest. It is to be hoped that fisheries stock assessments using this model will be published in the future.

Table V

Reef Status	References
Managed	72
Unmanaged	6
Exploited	213
Unexploited	10
Damaged	16
Undamaged	2
Isolated	5
Sanctuary	10

Table V gives the frequency of references which have indicated the status of their reefs. Almost all of the references are concerned with the exploitation of coral reefs; few consider reefs in the pristine state before exploitation begins. Surprisingly few references deal explicitly with management on their subject reefs or indicate whether the reef habitat has been subject to significant damage from fishing or other activities. Note that these key words have only been recorded where it is the subject matter of the reference. So, for instance, it has been assumed that a user would only want to search references with the key word '*Managed*' where they are looking for specific case studies of managed reefs, rather than studies in which the reefs happened to be managed, but this has no bearing on the results or discussion. Isolated reefs have largely been unstudied, but should be unexploited and unmanaged. Sanctuaries again have not commonly been discussed, although they are attracting increasing interest, and the number of publications on sanctuaries and zoning on reefs should rise in the future.

The fishery type classifies fisheries on the basis of their economics, as shown in Table VI. Most references are concerned with commercial or artisanal fisheries. The distinction between these two is somewhat subjective, and depends largely on whether fishing is by companies or individual fishermen and the degree of capitalization involved. The few publications concerned with subsistence fishing underline how little is understood with regard to this activity. Since subsistence fishing is very common, it deserves more attention.

Table VI

Fishery Type	References
Artisanal	60
Commercial	62
Recreational	29
Subsistence	15
Global	39

As stated previously the main problem encountered in compiling the contents of the database is in obtaining the large amounts of 'grey' literature e.g. internal reports. The number of published papers in easily accessed journals is relatively small. The database provides a useful means by which these dispersed and disparate reports can be gathered together, particularly for case studies of management regimes in different areas, together with critical discussions of whether or not they worked. Increasing access to such studies could provide a valuable role for database.

2 Coral Reef Fisheries Review Article

A review article on coral reef capture fisheries has been prepared, based largely on the literature collected for inclusion in the database. It is intended that this review article should be distributed along with the database and manual. A shortened version will be submitted to *Reviews in Fish Biology and Fisheries* for publication. The following sections outline the main findings of the review article.

2.1 Introduction

Coral reef fisheries are widespread and often important to the local economy. Although other fisheries are multispecies and have areas where stocks aggregate, no other fisheries have such diverse stocks or such extreme spatial heterogeneity. Does this mean coral reefs require fundamentally different management methods to other fisheries? The review looks at this question, concentrating on stock assessment for capture fisheries for fin-fish. The extensive literature on fish ecology is reviewed briefly from the point of view of fisheries management and provides background for those not familiar with this area of research. The aim is to see whether studies can suggest any improvements to population models currently used in stock assessment. Using case studies, the wider issues of coral reef fisheries management are then discussed. These suggest that the coral reef environment is beset by a number of environmental and socio-economic problems, which may well eclipse those of traditional stock management in the short term.

2.2 Single Species Ecology

There is a large amount of life history information on coral reef fishes, although it tends to concentrate on small, generally territorial, species, rather than the larger and commercially important species. The potential sustainable yield from any population depends on three basic processes: recruitment, growth and mortality. These can be studied for each species separately, but the number of species on a coral reef and the range of behaviours make generalizations difficult.

An important issue is what constitutes a stock on a coral reef. Circumstantial evidence suggests that populations at the scales generally studied by ecologists are not individual stocks, since they are not exclusively self-recruiting populations. Managers will have to look to larger areas to identify independent stocks on the basis of recruitment. Part of the problem might be that discrete stocks do not exist on coral reefs, and fish are distributed in a continuum rather than as isolated populations. If it is not possible to define distinct homogeneous populations, it will become necessary to include heterogeneity explicitly in population models. Unfortunately this would require a more detailed understanding of how larvae disperse.

There is a great deal of evidence that suggests that many species at least have the ability to move into new areas even if under normal circumstances little movement occurs. In a number of experiments, recolonisation of reefs after individuals have been removed has been rapid due to immigration of adults and juveniles to the free area. This is almost certainly the way in which fishing sites recover in the short term, although it is not clear over what area fish will immigrate to a site. In interpreting catch per unit effort data for coral reefs it will not be possible to ignore movement of fish.

A major concern seems to be whether observed distribution patterns may be more closely related to numbers settling or post-settlement mortality. Experimental results and observations are conflicting, which is perhaps not surprising when considering the potential complexity of relationships between fish.

2.3 Community Ecology

There have been two basic approaches to modelling communities. Firstly models may use energy flow and productivity, which allow simplification of communities by combining species into trophic groups. Alternatively each species population can be modelled with explicit links between populations in the form of predation, competition and mutualism.

Primary productivity and energy flow through food webs has been used to estimate potential yield from fisheries. The main problems with trophic models result from the allocation of compartments, which must represent the major structural components of the community. A trophic chain imposes an artificial structure, which may be difficult to reconcile with the real community structure. For many communities aggregation of species to different compartments may be inappropriate, arbitrary or impossible. Even if the model structure does give a reasonable description of the community, it will be static, and therefore will ignore community dynamics and be unable to predict how the structure might change under perturbation.

The species groups may not capture significant differences in the value of the underlying components. Trophic models may capture some price differences since piscivores, which would form a separate group, tend to fetch a higher price than the herbivores and planktivores upon which they feed. Even so, the optimum management strategy suggested by these models may result in catches of lower value than ultimately could be achieved. Perhaps most importantly there is a practical application of trophic models available. The ECOPATH model can be obtained as a computer package from the International Center for Living Aquatic Resources Management for analysing ecological data. This model appears at present to be the only practical way to look at and use trophic relationships within the community.

Population models rather than trophic models are the most widely used basis for stock assessment. These can be easily extended to model communities by including terms describing the relationships between species. The simplest version of these models is based on the Schaefer model, with linear terms describing competition, predation and mutualism. This model provides when close to equilibrium a reasonable approximation to a wide range of possible deterministic models, but away from equilibrium may provide a poor description. Such linear and deterministic models assume homogeneous populations and have no external driving variables, such as seasonal environmental changes. Relaxing these assumptions can result in a wide variety of behaviours, giving the general theory little predictive power. A second criticism is that while its is simple to construct such models, it is nearly impossible to estimate the large number of parameters and test them properly.

Although community population models cannot be applied directly to stock assessment, there are some very general conclusions which can be drawn :

- the multispecies MSY is less than the sum of the single species MSY.
- the sensitivity of the system to environmental fluctuations increases as the level of exploitation increases.
- the models that do exhibit 'unexpected' and irregular behaviour normally are those that include strong nonlinear inter-species interactions.

The practical implications are that managers should perhaps be a little more conservative with multispecies stocks. These models also suggest that yield may be increased by adjusting the relative catchabilities of different species as well as controlling effort. This is most likely to be achieved by controlling fishing gears and the times and areas fished.

Populations in fisheries are never homogeneous. This can have a profound effect on population dynamics. Many fisheries models are age structured, but fewer are structured spatially. In theoretical

ecology, spatial heterogeneity has been put forward as a major stabilising factor, and hence very important to the dynamics. Spatial heterogeneity is increasingly recognised as an important factor in coral reef ecology. However at this stage it is unlikely that it can be included in stock assessment until methods are developed to cope with this complex issue.

2.4 Models of the Coral Reef Community

A number of authors have suggested that coral reef fish populations are relatively stable and maintained by competition and predation between species in much the same way as has been proposed for temperate communities. Predation on larvae and post-settlement juveniles is thought to have an important effect on fish population dynamics and community structure. The coral reef food web is complex, with predation rates very different to the observed abundances of prey, making modelling of the system difficult. Fishing may be a source of community instability and could change community structure. Despite this potential problem, the complexity of reefs has prevented the development of food web models, most work being based on the analysis of single species, or species groups.

As well as more general ecological theories, coral reefs have attracted a number of special theories to explain their high diversity. The intermediate disturbance hypothesis suggests that there is some level of random disturbance which prevents domination of a community by a small number of species while not causing extinctions, hence maximising diversity. It only has application in the sense that large perturbations, which may be induced through fishing, will decrease the diversity of the reef, an empirical fact which has a wide support.

A special hypothesis for fish populations has been proposed based on work with territorial damselfish. In its simplest form the 'lottery' theory requires that there are a limited number of sites available to fish on a reef, and once a fish settles in a site, all other settlement there is prevented until it is released again. If all species have an equal chance of recruitment and the population is large enough, coexistence between species will be achieved. However, since it has been brought into question whether this model is a reasonable description of the territorial fish populations for which it is most appropriate, it would not seem fitting to apply it to more mobile fish which make up much of the catch.

Observations on settlement to patch reef and the inability to consistently find significant competition in reef fish populations has lead to the proposal that adult stocks are limited by recruitment, so that densities on the reef are largely a result of previous settlement patterns rather than interaction between and within adult fish populations. This hypothesis has received some empirical support through studies which have largely been directed at demonstrating that expected competitive interactions are not present or that observed densities can be directly related to known recruitment patterns. The theory does not address the possibility of a stock-recruitment relationship or interactions between pre-settlement populations.

2.5 Implications of Models to Stock Assessment

There are a number of problems with using the results from coral reef ecological studies in fisheries models. Perhaps the most obvious is the narrow range of species studied and upon which much of the theory is based. In general it is easier to undertake experimental work with the smaller less mobile fish species. This has led to significant amounts of work being carried out on, for instance, damselfish, but very little on species that are important in catches.

The conflicting results of ecological studies provide little clear evidence favouring one community model over another. In particular, there is no evidence that models other than those already used in stock assessments, such as yield-per-recruit on a species by species basis, will provide significantly better advice.

Choosing the model is an important management decision, since different models can give radically different results. For instance, single species models will obviously not lead to a recommendation to fish down the predators to reduce mortality on species lower down the food chain. Since there is no way to test models with the available information, the models used will probably continue to reflect the data available rather than theoretical considerations.

2.6 Coral Reef Stock Assessments

It would be reasonable to assume single species stock assessments to be the default analysis unless interactions between species are significant. For coral reef fisheries, there are several important arguments against using single species models. Firstly predation rates are high on coral reefs, indicating significant trophic relationships. However the impact of predation may not be so great if the sources of mortality are not additive. For instance, predators may selectively take diseased individuals that are likely to die anyway or there may be density dependent effects which will reduce the impact of predation. The effect of competition between species is even less clear. Competition is almost certainly greatest within guilds of species. For damselfish, growth has been shown to be density dependent, since at higher densities fish had to spend more time defending their territory and less feeding. If such competitive interactions are present within and between species, the impact of fishing will be significantly reduced and a higher fishing mortality might be attained before the total yield begins to decrease.

Even if it could be guaranteed that single species models would give an accurate description of the system, if none of the parameters are known *a priori*, the problem of estimation is enormous. Neglecting interaction parameters, the cost of obtaining accurate information for sets of single species models will be prohibitive. If it is assumed that 20 species make up the catch, and 5 parameters are needed to describe each species population changes (2 mortality, 2 growth and 1 for recruitment), the model would require 100 parameters. Allowing for interactions between species may require population models for species not present in the catch and these are simply impractical. This makes other simpler approaches, such as aggregating species in the catch much more attractive.

In general increasing complexity does not automatically increase accuracy. Very often simple models will result in better management advice than complex models, even if complex models are a more accurate description of the system. Considering the complexity of the coral reef community, it is likely that the best models will be very simple.

At the other extreme all species might be combined into a single catch. The surplus yield approach, where the biomass is undifferentiated, has been widely adopted. Although the method has shortcomings, it is robust and valuable in providing a simple indication as to the state of the fishery. However data on catches at the higher effort levels are often lacking, since there is an economic disincentive to fish at these levels. This effect together with increasing variability in catches with increasing effort makes the MSY estimate less reliable. Secondly the model only allows one control variable, effort, when there are a number of others, for instance species and size selectivity of gear, which may change the optimum fishing effort considerably.

A slightly more refined approach is to group only similar species together. The argument that this is valid makes use of the fact that closely related species tend to have similar parameter estimates for population models (e.g. growth and mortality estimates) and species guilds behave in a similar manner to single species populations in that larger slow growing individuals are replaced with smaller fish, whether of the same species or not. Such species grouping is common in tropical multispecies fisheries and by default, analyses are often forced to use these sort of data.

The main attraction of grouping species together lies in the low cost involved in data collection. The method also seems to give reasonably sensible results when using a robust surplus yield model. More detailed economic analysis would still require the species composition, however, unless the prices for all species were the same. A more subtle problem lies in the response of a heterogeneous population to fishing.

The estimate for catchability for a group of species combined may lead to under-estimates of the remaining population size as fishing progresses. More importantly for stock conservation, the recovery time from overfishing may be much greater. Species pushed close to local extinction may take many generations to recover, whereas a single species recovering from growth overfishing will take only one generation. Furthermore local extinctions in multispecies fisheries are a real possibility, since the catch rate may continue to remain high supported by alternative species, so there would be no economic constraints. Completely ignoring catch composition may not be a wise choice.

2.7 Management Case Studies

The lack of data for artisanal and subsistence fisheries is a particularly acute problem, and yet these types of fishery dominate coral reefs. Perhaps more fundamentally, managers do not always see stock assessment as the priority concern. To give some idea of the types of fishery and range of problems, case studies of fisheries in Papua New Guinea, Philippines and the Caribbean are discussed.

Few artisanal or subsistence fisheries collect data on a permanent basis, because of the difficulty in implementing a fishing log-book system to measure catch and effort. This means that data has to be obtained through specific surveys. If any stock assessment is undertaken, it may often be based on length-frequency samples, which are relatively easy to obtain. The stock assessment information in many studies is obtained from specific surveys.

2.7.1Papua New Guinea

The catch was highly diverse in all fisheries. Alternative sources of income and seasonal bad weather had the strongest influence on fishing effort. Species composition was observed to change as fishing intensity increased. The catch changed from being dominated by large herbivorous acanthurids to smaller predatory lethrinids, and then to small herbivorous siganids. In all cases there was a consistent decline in the value of the catch, from slow growing valuable fish to smaller fish with higher fecundity and lower market value. The actual abundance of small fish, such as siganids, had increased despite the increased fishing mortality as a result of reduced predation and competition.

A common feature of most coral reef fisheries is that fishing effort concentrates around towns or villages. This is presumably because it is more costly and difficult to fish further away from home. There are a number of other factors that influenced the behaviour of the fishermen. Prices may change with time of day, season, market, species, size and the fortnightly pay cycle, so that these factors may well be important driving forces in supply. However, maximising the catch rate may not be the main objective for subsistence fishermen. Since the subsistence fishery operates without a market, there are no observable prices. This makes it difficult to assess fully the value of subsistence fishing, so it will be even more difficult to understand subsistence fishery dynamics.

2.7.2Philippines

Coral reef fisheries in the Philippines are much more developed than those in Papua New Guinea, and face a different set of problems. They are particularly intensive and provide income for a large number of people. As well as the usual hand lines, nets, spear and trolling, the Philippines have a particularly large fishery gathering invertebrates in the lagoon and reef flat.

Habitat destruction associated with deforestation, damaging fishing methods and other forms of exploitation is of as much concern in the Philippines as direct overfishing. Fishing using explosives, poisons and breaking up the reef to scare fish into nets reduces live coral cover which has, independent of fishing mortality, a large impact on the fish community.

Because of deterioration of reefs in the Philippines, much effort has gone into the creation of effective marine reserves. Where these have been successfully implemented, they appear to increase stock size and catches. The basic principle on which community reserves that have recently been established in the Philippines are based, is that there is a small area in which fishing is prohibited, surrounded by a larger area in which fishing is allowed, but only with ecologically sound gears. A key factor in the success of a reserve appears to be involvement of local people, which in turn depends upon their perception of the benefits they obtain from the reserve.

As well as stock reduction through habitat loss, reef fish are being harvested well beyond the optimum. Overfishing is a problem on many reefs and that there are no adequate stock assessment tools to deal with a fishery in this state. In particular it has been found that when fishing mortality is high, there are too few length frequency classes to obtain reasonable estimates of growth and mortality parameters. Species composition and magnitude of yields vary considerably among reefs and with season.

2.7.3Caribbean

In the Caribbean reef deterioration and overfishing are equally of great concern. However, compared to other areas, there is a much longer history of interest in reef fisheries and consequently a greater literature on stock assessments and the biology of commercially important species. In this region, fishery regulations have been largely orientated towards improving the economic efficiency of the fishery. Protection and management of the reef habitat is seen as the responsibility of agencies concerned with establishing national parks and reserves. The Caribbean also provides examples of the problems caused when there is open access to fisheries.

2.8 Management

It is clear from the case studies that management of coral reef fisheries is beset by a number of social, economic and biological problems. Methods are required to cope with the limited resources available in developing countries. Realistically management regimes will have to be simple, require little data and be easy to enforce. This probably rules out many of the management controls developed for industrial and commercial fishing, which has a major influence on how results from stock assessments can be used in management.

Any successful management system would have to solve two important problems. First, it would have to provide for the protection the habitat, recovery should reef damage occur and protect vulnerable exploited species. Secondly the regime will have to protect the livelihoods of the fishermen, and if possible, increase their income from the resource. More generally, coral reef management must also deal with conflicts among users of the resource, most notably between fisheries and tourism. These objectives will require a combination of management approaches, the selection of which will depend on the characteristics of the fishery, including the socio-economics of the community involved.

Limited entry and quotas are difficult to enforce in reef fisheries, where many species are being taken with a variety of gears and landed at numerous points. Quotas may be inappropriate where gears are unselective, since fishing may have to cease once the first quota is reached, even when other species remain virtually unexploited. Effort control through limited entry is likely to lead to overcapitalisation where fishing power is able to increase. In the context of reefs, these methods are used mainly in recreational fisheries or fisheries targeting high value invertebrates, such as lobster or conch. However, effective enforcement can be costly. Furthermore, in subsistence fisheries it is simply inappropriate without providing alternative sources of food for those excluded from the fishery. This is the case in many fishing villages in the Philippines.

Elimination of damaging fishing methods should have high priority. If alternative methods of equal efficiency are not available, enforcement may be extremely difficult. Gear controls, for instance trap mesh size limits can be used to control both size and species selection, and are essential for

implementing recommendations from most stock assessments. Gear controls for commercial fisheries can be enforced at sea or at landing sites, if there are relatively few.

Controlling species selectivity is likely to be a key component of a multispecies fishery. Food web multispecies models suggest that the sustainable yield can be increased by adjusting the fishing mortalities for each species. This can be achieved through changing their catchabilities, which will be dependent on gear as well as time and area fished. Without strong theoretical support, adjusting catchabilities among species to improve yields will be a major challenge. However the immediate management concern appears to be conservation, so the more subtle problems of species selectivity will probably only be resolved in the long term.

Closed areas are a important control in coral reef management and are being used to conserve both areas of reef habitat as well as stocks. It has also been found that catches in the vicinity of the closed area can improve. An important advantage lies in the comparative ease with which they might be enforced. There are a variety of closed areas, ranging from sanctuary areas in which fishing is totally banned, to zoned areas in which fishing is permitted, but only under certain conditions or using certain gears. Closed areas could be beneficially established in many reef fisheries immediately, spurred on by the urgent need for habitat protection for reefs in most parts of the world.

In many societies reef fisheries have been managed under customary marine tenure (CMT) systems, with family and clan groups having the rights to fisheries on reefs adjacent to their land. These systems are only now being fully documented and show much variety in detail, but have the common characteristic that the community which uses the resources controls its exploitation.

The extent to which societies recognised the problems of free and uncontrolled access to reef fish and expressly implemented such measures to limit this appears to vary. Community managed systems have provided a good basis for dealing with contemporary problems in coral reef management. There are some disadvantages to the CMT systems. CMT management may slow development of resources where they are not allocated to those who might make best use of them. It may hinder the implementation of national fisheries policies where this is important to the management of fish stocks as a whole. For instance, the protection of spawning areas may be of wide interest, but the sites may lie in CMT areas whose owners may be unwilling to accept such controls.

The role of stock assessment within community managed systems is not clear. It is assumed that the owners know best how to harvest the resource. Given the complications of the ecosystem it is unlikely that fishermen will be able to find the economic optimum, so a central fisheries body may have some role in providing advice and education. Perhaps the greatest value of community based management is the devolution of the decision-making to a level where people are familiar with the fish, fisheries and socio-economic realities. Given our present understanding of coral reef ecology, community management may well be as close to the optimum as could be achieved at present.

3 Future work

Possible areas of follow-up work on the database and the review that have been identified are indicated below.

3.1 Database

The database could be improved further mainly by rewriting it in a high level language (e.g. Pascal). This would bring about major improvements in performance and size, making the database more widely available to users with poorer hardware. However, this would be expensive and time-consuming, and should only be considered if large numbers of users trying to use the package were finding it difficult to run on their computers.

If the database comes into wide use, and references are added by the users, it may be useful to

combine all these databases at a later date to produce a new set of references which can be redistributed. This would allow users to learn about reports and publications which otherwise have no publicity. Should feedback from users be such that an update of the database is considered appropriate, that would need to be undertaken as part of a separate research project.

3.2 Review

The review suggested a number of research areas which need to be addressed. The dynamics governing the behaviour of fishermen has been rarely studied, but is necessary to understand how a fishery operates. For instance, a particular problem in coral reef fisheries management is the spatial distribution of fishing effort and local overfishing. A consistent observation has been that the heaviest fishing takes place close to areas of human habitation. Predicting how the distribution of fishing effort will change as a fishery's infrastructure or gear changes will be valuable in the economic analyses and interpretation of catch data. There may be some value in using models for this purpose in the management of artisanal fisheries, but it is unlikely this approach will be effective in subsistence fisheries without a better understanding of their economic structure.

A second fruitful area of research may be in investigating changes in species composition within a fishery, which may provide additional useful information for monitoring stocks. It is widely accepted that under increasing fishing pressure the catch will become dominated by small, faster growing species. However there are no quantitative estimates of these changes, so these observations at present are of little use in interpreting catch data. There is a need to study models and data which describe this process and may lead to improved multispecies stock assessment methods.

As well as specific research, coral reef management requires a general approach to deal with the wide variety of issues it faces. It would seem that pure ecological research cannot be relied upon to solve the problems of stock assessment and management. Existing ecological research is not advanced or specific enough to answer questions posed by fisheries management. Detailed scientific work on reef ecology will probably be useful in identifying models, but only in the long term, as the structure of the coral reef community becomes better understood. Although most innovations are likely to come from this source, ecological research cannot be expected to provide answers for more immediate management questions, or be specific enough to apply to individual fisheries.

The obvious alternative is to use past catch and effort data, and look for relations between different time series variables. Models using catch and effort information can be improved to some extent, but ultimately they are limited by two fundamental problems. Firstly, good parameter estimates require wide variation in the independent variable, which is rarely available. Secondly, other factors of which there are no records might be changing and affecting the catch independent of fishing effort, so that these analyses may provide a poor estimate of the degree to which variables, like effort, control catches.

A third alternative, adaptive management, represents a powerful approach for dealing with fisheries and ecological management and has been suggested as particularly appropriate for coral reefs. It involves designing experiments to discriminate between a range of models and therefore, by extension, management actions. The essence of this approach is that instead of relying on research from outside, management takes it upon itself to identify and answer problems directly.

Adaptive management is not a simple recipe for success, but is a highly flexible approach that tailors regulation to current needs and encourages constant improvement in management. There are four basic areas involved in the designing of adaptive management strategies. First, problems, objectives and the limits on what management can achieve need to be defined. This should avoid wasted research effort on areas that management is unable to control or problems which are considered relatively unimportant. Second, quantitative models representing the current understanding of the fishery dynamics need to be proposed. This should produce explicit assumptions and predictions about the fishery so that current thinking can be tested. Third, uncertainty should be introduced, both in the form of observation and process errors for the current model, and alternative models against which the current

model can be tested. The data obtained from monitoring the fishery can be used to constantly update models and therefore alter policies through learning. Finally policies should be designed not just for sustainable production, but also to test models and find ways in which production can be improved.

The particular advantage of adaptive management for coral reef fisheries lies in the low cost of obtaining accurate information, if different reef areas can be treated as nearly identical, independent plots. Differences between reefs are probably not critical since this can be taken into account in the design of the experiment. The inter-dependence between plots is a more difficult problem. It will be affected by larval recruitment and migration, and hence the experiment's time and spatial scales. Careful experimental design will be able to account for some interaction between different areas, but such interactions will reduce the amount of information obtained, and suggest the method will not be easy to implement. It still needs to be demonstrated that adaptive management is appropriate to the needs of coral reef management in developing countries, but it has the potential for providing guidance on problems which have so far defeated other methods.