OPTIMIZATION OF CORAL REEF FISHERIES PILOT PROJECT

Principal Scientists

Dr Gudrun Gaudian
Dr Paul Medley

Director

Dr Rupert Ormond

Research Assistants

Matt Richmond
Peter Hayward
David Wachenfeld

TMRU Ltd
University of York
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SUMMARY

Coral reefs form the basis of many small scale subsistence fisheries throughout the world and therefore are an important food source for coastal communities. The aim of coral reef fisheries management is to increase the sustainable yield. The objective of this pilot project was to explore a general experimental method which can ultimately be used to derive assessment techniques and improve benefits from these fisheries.

An experiment was carried out to monitor changes in fish populations before and after fishing within a study area. Transect counts were used to estimate fish abundance inside and around the fishing area. Detailed information was collected concerning the catches, including species, length and weight.

The preliminary analysis of the data concentrated on two species, *Lethrinus borbonicus*, which made up 50% of the catch, and *Chaetodon kleinii*, which is very rarely caught. As fishing progressed, there was a notable decline in catch per unit effort (CPUE) mainly caused by falling numbers of *L.borbonicus* in the catch. There was a distinct change in the catch species composition, because *L.borbonicus* declined at a faster rate than other species. Catches of *L.borbonicus* dropped during night fishing, suggesting that *L.borbonicus* dispersed from the reef during night hours, as do other lethrinids.

Analysis of the census data showed that there was a large difference between the abundance of fish at different sites in the study area. Numbers of *L.borbonicus* weree lower after fishing even outside the fishing area. In contrast *C.kleinii* showed no significant decline.

The analysis presented here is incomplete. It has, however, been demonstrated that the data from such experiments has an important role in developing new fisheries assessment techniques. The data would allow gear selectivity to be estimated, necessary to interpret catch species composition correctly and to estimate the impact of increased fishing effort on the coral reef community. It should also be possible to develop a model describing the effects of fish distribution and movement, a requirement for setting up fishing reserves as well as interpretation of catch data. However there is a clear need to develop some theoretical models and statistical methods to these data.

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TERMS OF REFERENCE

The terms of reference for this pilot project were defined in the form of objectives, described in section 8 of the MRAG Research and Development Grant Application and Project Memorandum document. They were as follows.

The scientific and technical objectives of this pilot project were to measure directly both decrease in stock density and the level of adult fish recruitment to the areas with a high fishing mortality. The methodology developed for this pilot project can then be used on larger scale long-term studies designed to eventually improve fisheries management on coral reefs.

The outputs of the project will be an assessment of the response of reef fish to intense fishing pressure over a limited area and time period with respect to adult recruitment.

INTRODUCTION

Coral reefs form the basis of many small scale subsistence fisheries throughout the world and therefore are a very important local food source for coastal communities. However, the low commercial value and the high complexity of the fish community has lead to this system being largely ignored in fisheries research.

Where fish represents a high proportion of income, albeit small, for coastal people and a high proportion of protein in the diet, the subsistence fisheries may well be more important in social terms than their commercial neighbours. Hence management objectives for subsistence fisheries should put greater emphasis on sustainability rather than maximising economic rent. To substantially improve the standard of living of those employed in these sorts of fisheries would probably require that the majority be pulled out of the fishery sector altogether, while at the same time the fishery is made more efficient. However the local fishery will always represent an alternative to other activities and hence give people a minimum income. Without this subsistence alternative, the risk that serious social problems will occur, as the economy develops, is greater.

The aim of coral reef fisheries management is to increase the sustainable economic yield from the fishery. At present the main methods used to measure the status of fish stocks and estimate maximum sustainable yield are length frequency based assessments. These methods consider each species as a separate population and attempt to estimate recruitment, growth, natural and fishing mortality from 'catch at size' data. Although these methods have many associated problems (Rosenberg and Beddington, 1989), they have some important advantages. They do not require the fish to be aged and they can be used with only samples from the catch rather than information on the total catch and effort. This has made assessments using length frequency particularly popular in artisanal fisheries. A major enhancement of these techniques would be to use species composition, which may provide important information on changes in the fish community.

There is a small, but growing literature describing the effect of fishing on the fish community as well as measuring yield. To date the major results indicate that there is a significant change in community species composition and sizes of fish between fished and unfished reef (Ferry *et al*, 1987; Koslow *et al*, 1988; Russ and Alcala, 1989; Alcala and Russ, 1990). These results confirm that coral reef fisheries do have a significant impact on the fish community, and suggest the rationale underlying length frequency is valid.

The other general result evident in the literature is the widely varying yield from different areas (Marshall, 1985; Alcala and Luchavez, 1981; Alcala, 1981). In all cases results come from simple direct observation of the fish assemblages, none have involved manipulation to isolate and measure particular effects. In understanding the impact of fishing, these studies are useful, but fall short of the information required for fisheries management.

A number of manipulative experiments on small fish species, notably damselfish, have been carried out on a small scale (Doherty, 1980; Eckert, 1984; Meekan, 1988). Based on results from such experiments, Munro and Williams (1985) give a number of research priorities for fisheries research. They suggest that direct experiments are needed to clarify how results observed for small reef species might relate to larger fish species. They emphasize spatial and temporal scale of experiments and the importance of gear selectivity, a pre-requisite for most assessment methods.

Coral reef fisheries present a number of characteristics which are poorly understood. The high diversity, and the nature of the presumably complicated ecology connecting the different species on the reef is a major hurdle both to fisheries management and research. A second major problem arises through fishing techniques which destroy the coral habitat. Where reef fishing is particularly intensive, fishing tends to be at the same time destructive. It is difficult to distinguish whether a drop in catches is due to overfishing, habitat destruction, or, most likely, a combination of both. Experimental design rather than passive data collection allows the spatial structure, substrate and other factors to be taken account of, while separating effects such as habitat destruction by controlling the fishing method.

Interpretation of length and species composition of catches requires an understanding of the dynamics of the resource. Production models, used to indicate where the maximum yield might lie, take some account of changes over time, but do not attempt to deal with distributions of populations in space. For most fisheries it is implicitly argued that the spatial component does not bias estimates and is unimportant in assessing the fishery dynamics. For some fisheries this assumption is inadequate and coral reef fisheries is likely to be an example of this.

For coral reefs one of the most important aspects is the spatial heterogeneity of the habitat. An understanding of how fish are distributed and how they move around within the reef as well as between the reef and adjacent habitats (such as seagrass beds, mangrove forests and the sea bed) is clearly important when considering recovery and recruitment to fishing grounds.

While the complexity of the coral reef ecosystem is a major hurdle to fisheries assessment, their clear spatial distribution is a potential advantage in research. Fish populations may be isolated in patch reefs or be distributed in one dimension along a fringing reef. These comparatively simple spatial distributions can be exploited using manipulative experiments to assess how fish move along a reef. Adult recruitment to fished areas may be the most important aspect controlling catches. Where catch rates become unacceptably low to fishermen, at a point which lies below the stock size at the maximum sustainable yield (MSY), estimating MSY may not even be necessary, unless fishing efficiency improves.

On the practical side, an important advantage coral reefs have over other fisheries is the opportunity to carry out inexpensive surveys which do not affect the population. Divers on SCUBA apparatus or snorkel can carry out line transects estimating the abundance of populations independent of fishing. This is necessary to carry out controlled fishing experiments.

If results from research are to be used, some consideration must be made as to how they might be implemented in a management regime. Coral reef management has two major options in controlling fishing activity. Firstly, limiting the number of boats or fishermen, thereby limiting effort. Secondly, setting up zones where fishing is prevented or limited in some way. Other more sophisticated methods are not likely to be implemented, because the small commercial income from the fishery would not justify the input from the management regime.

There is a clear need to begin to understand the dynamics of reef fish populations. Coral reefs offer an opportunity to approach this problem by means of experimentation, making detailed observations as the state of the fishery is changed in some controlled way.

STUDY SITE AND METHOD

The study site chosen was situated at the southern end of Zanzibar Island, off the east coast of Tanzania (see Figure 1). The fringing reef opposite Kichungani was found to fulfil a number of criteria important to the success of the experiment.

1. There were no other reefs in the area - the fringing reef is bordered by open ocean.

2. The diversity and abundance of reef fish was high.

3. Fishing pressure was relatively low throughout the year. The fishermen could only fish from December to March because of the monsoon. The only fishing which had occurred near the study area was subsistence using hook and line, spears and traps.

The fringing reef within the study area was relatively shallow, not exceeding a depth of about 12m. The study site followed the contours of the coral reef, and avoided areas of gravel, sand and seagrass. This was to ensure that the fish encountered in the census were predominantly species dependent upon coral reef substrate.

Close liaison with the Fisheries Department of Zanzibar and discussions with relevant village elders and fishermen ensured that any fishing in the study area ceased while the experiment was in progress. Any boat observed near the area was recorded. The degree of co-operation was remarkable, and no problem was encountered in this respect.

Materials and Method

Experimental Design

Figure 2 shows the layout of the transects within the study area. Six 200m long transect lines were laid at each station along the fringing reef at a depth ranging between 6 and 9 metres, following the contours of the reef. Each transect was separated from its neighbours by an interval of 200m. Both ends of the 2.2km long study area were marked with large flags, easily recognisable to keep fishermen out of the study area. A 600m section, forming the fishing area, was marked with different coloured flags in the centre of the study area (stations 3 and 4).

The 200m transect lines were fixed to the substrate to avoid breakages and divided into 50m subsections. The ends of the transect line at each station were marked with buoys. Each subsection was marked by a small subsurface float, attached to the transect, held about 1.5m above the transect line and therefore easily visible to the divers. The four 50m subsections were labelled, for reference, from A to D.

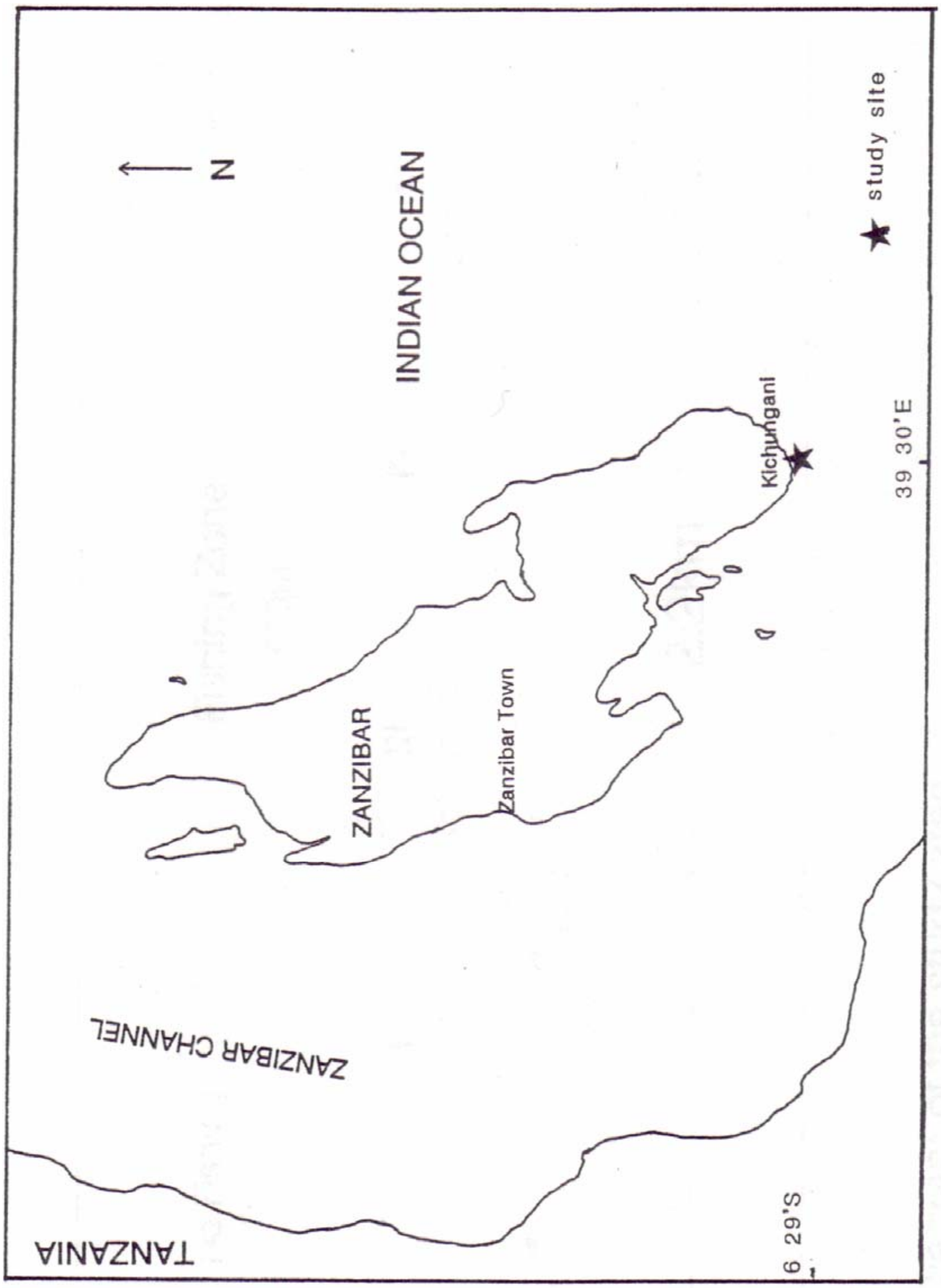


Figure 1. Map of Zanzibar including study site.

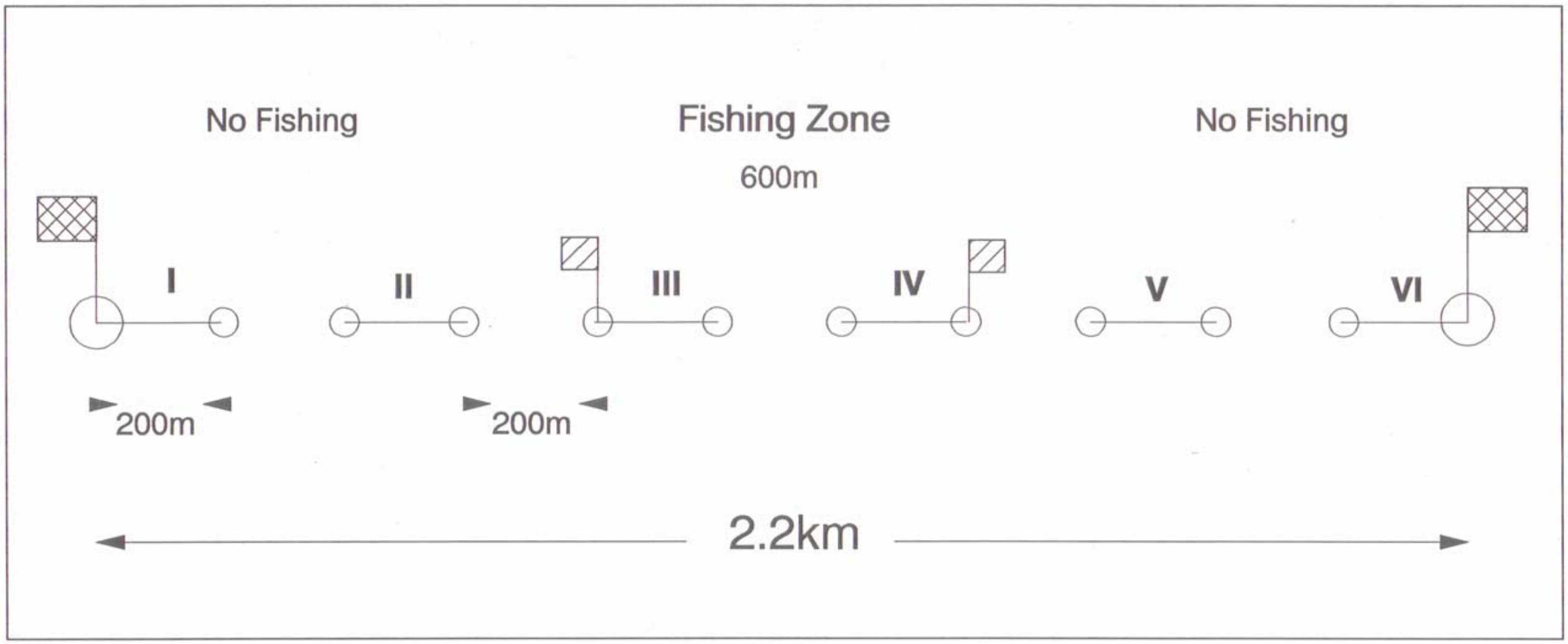


Figure 2 Diagram of the study area

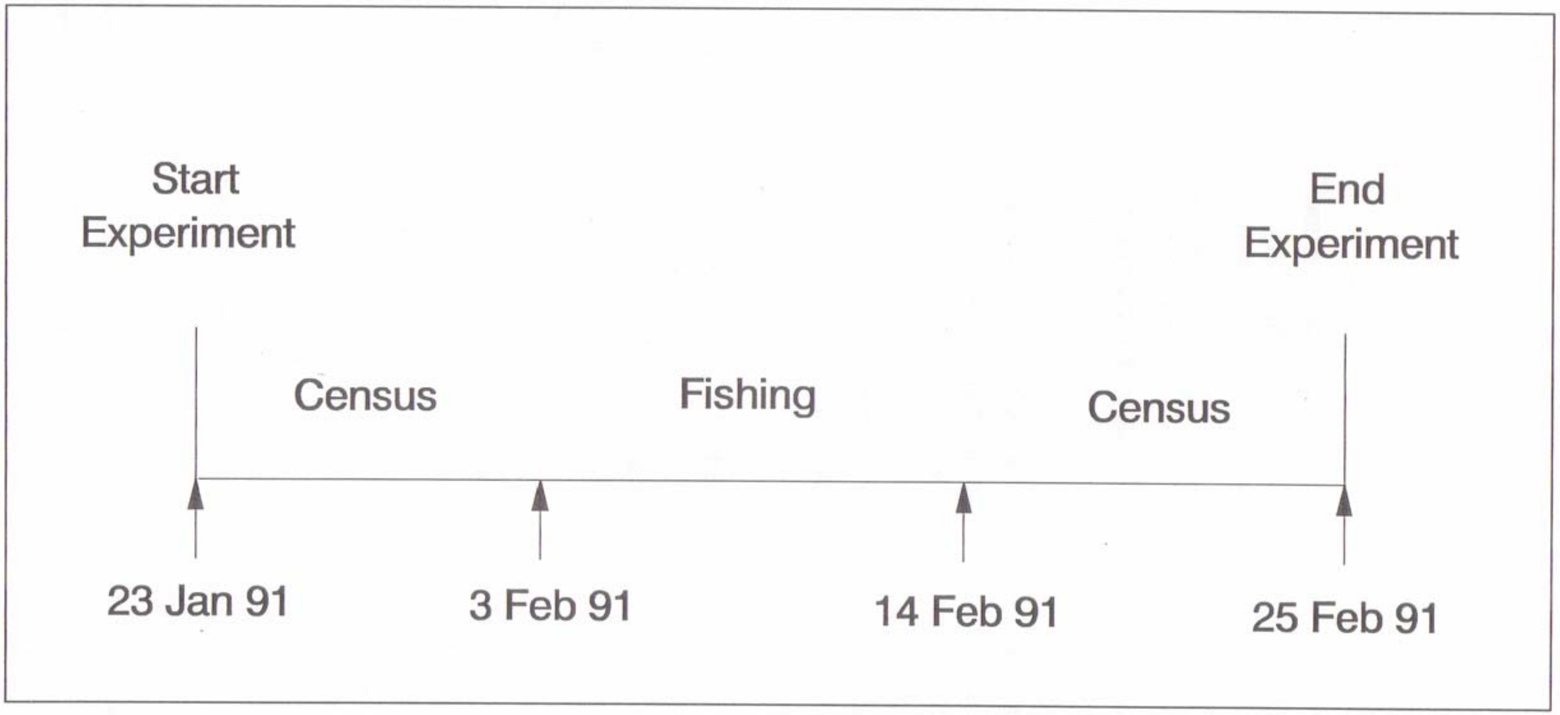


Figure 3 Diagram showing timing of experiment

Figure 3 provides a diagrammatic representation of the sequence of events. The first third of the experiment period was used to monitor the fluctuations in reef populations with no human interference. Each pair completed three counts at all six stations, each one consisting of 2 repeats. Fishing then continued for 11 days, during which the catch and effort of local fishermen were monitored. Counts then continued to detect any changes in fish abundance and monitor any recovery. Again each pair carried out 3 counts at each station. The original aim was to continue counts through the fishing period, but unfortunately this was prevented by the lack of resources.

Fish Counts

Before the census some time was spent in determining which reef fish species were caught by the fishermen in that area. Their catch was examined at the fish landing site at Kizimkazi Dumbani village as well as in their boats before the fish was sold or taken home. From these observations, a list of 40 species was compiled (see Appendix A), these making up the complete set of species counted during the experiment. It was found that the great majority of the catch were non-schooling species predominantly found within the vicinity of the reef. This is reflected in the list.

As well as a number of species common in the catch, several species which were rarely caught such as butterfly and angel fish were included in the counts. These were to be used as controls to assess possible changes in numbers of fish not due to increased fishing pressure, but some other factor, such as the weather. Strictly speaking, because species are affected by effects in different ways, they are not controls in the proper sense, but are useful for comparison.

Fish were counted inside and outside a 10m wide band along the transect line. To remind each diver of the 10m width, a rope was fixed perpendicular to the beginning of subsection A. Those fish encountered outside the 10 band were distinguished on the recording slate by circling the number.

The divers counted in pairs, a pair covering all 40 species, but each diver concentrating on 20 species only. The divers were swimming alongside each other, at a speed approximately covering a 50m subsection in 5 minutes.

The fish were recorded in terms of encounters (schools) and numbers of individuals per encounter (see Appendix B for an example data sheet). If an encounter contained more than 9 individuals, *ie* 2 digits, then the number was underlined on the recording slate to avoid confusion. Each column on the recording slate, as well as the data sheet onto which the recorded information was transcribed immediately after the dive, represents one 50m subsection. The divers were requested to treat each subsection separately during the dive, making sure that as far as possible, they took 5 minutes to swim each 50m section. If the current proved too strong, the count was aborted. The time taken to swim each 50m section was recorded to take account of any difference in time that did arise.

After reaching the end of the 200m transect line, the diving pair turned around and resumed the fish census from D to A, back towards the starting position. This could be treated as a repeat and used to measure observational error.

At the end of the dive the divers took a visibility reading. This was done using a tape measure, a distance reading being taken as soon as one diver could not see the other as that diver swam away. Hence corrections to the counts could be made where water turbidity changed from day to day.

Fishing period

A number of fishermen from two local villages volunteered to participate. In return each fisherman was given hooks, lines and weights. The hook size ranged from size 14 (small) to size 8 (large) and the line from 0.6mm to 0.8mm. The fishermen predominantly used the smaller sized hooks on hand lines. Their gear needed constant replacement because it tended to become caught amongst the corals. Up to 15 boats took part, mostly with one, but occasionally two or three, fishermen per boat. These boats were of local make and generally propelled by paddle and/or sail.

It is important to note that fishermen generally divided their time between fishing and farming, and that most of their catch was consumed directly by their families and neighbours. Some fishermen, however, managed to sell some of their catch either to local fish merchants, who transported it to Zanzibar town, or to an ice-boat which took it to Dar es Salaam. This involved only large commercial fish (emperors, snappers, groupers, rays, sharks, etc). The study area was known locally as an area where the predominant catch was small fish suitable only for local consumption.

The journey to and from the study site took the fishermen up to two hours, depending on prevailing currents and wind, and was a significant economic factor. Hence the state of the tides, currents and weather rather than the catch rate determined the length of time the fishermen remained in the area. If an unfavourable wind picked up, the fishermen would stop earlier to start their return journey home.

During the 11 day fishing period, the fishermen were asked to fish exclusively inside the 600m zone (stations III and IV) within the study area. In general, they fished from early in the morning until about 1400 hours, by which time the fishermen started to head back to their villages to tend their farms. In most cases the boats were positioned up-current, and then allowed to drift down while fishing, to the edge of the fishing area.

Two boats were necessary to patrol the area and check on the fishermen. Detailed notes were made as to the number of boats, number of fishermen in each boat, position of boats within the fishing area and time each boat spent fishing each day.

The catch from each boat was analyzed by identifying the fish, measuring weight and standard and total length. The fishermen presented for measuring only those fish which were caught in the study area, the rest of the catch, if any, was not inspected. The fishermen kept their catch.

In addition to hook and line, traps were also used. In total 21 locally bought traps were placed within the 600m fishing area. The traps were baited with a mix of algae and crunched-up sea urchins, and were checked between every 24 and 48 hours. If they contained fish, they were brought up into the boat, emptied, baited and placed back into the water. Care was taken to position the traps so that they lay flat on the bottom, surrounded by coral heads, the opening parallel to the prevailing currents.

The trapped fish was identified, weighed and measured (standard and total length) and then distributed among the fishermen.

Database

The results from the experiment have been set up in the form of a relational database in DBase IV, to run under both DBase IV command language and Standard Query Language (SQL). This allows the complicated structure of the experimental design to be represented within the database, so that specific data sets sufficient to carry out any particular analysis can be extracted. Any future statistical analysis should ultimately combine a wide range of different relationships between catch and count data, such as changes in school size, numbers and weight of fish. The design of the database also allows easy expansion to include future experimental data as they become available.

Theoretical Models

Linear models were used as the basic method to detect and test for changes in abundance. Encounters on a fish census, if the probability of encounter is constant, can be described as a Poisson process. Since fish aggregate, it will be necessary to use the quasi-likelihood assumption, that the variance is proportional, rather than equal, to the mean. Hence for all the following models, the error distribution is Poisson, the link function is the natural logarithm and the scale parameter is estimated from the data (see GLIM, 1985).

The experiment is designed to provide information for a variety of questions, both on the experimental design and impact of fisheries on the reef community. Firstly the scale in time and space must be adapted to the speed and distance that fish will move. Different species are likely to move at different speeds. If movement into the fished region was rapid or fishing mortality low, the effect of fishing would be lost in the variation in catches. Without any prior information, the study area was designed to cover the likely scale over which changes could be observed. The results will allow adjustment of these areas, if necessary.

Given a detectable decrease in the size of the population, the next problem is to formulate a mechanism for recruitment to that area, and estimate the rate at which recruitment occurs. The recruitment mechanism refers to the model describing the way in which fish leave the unfished population to enter the fishing area. The working hypothesis used and tested in this study assumes fish move randomly along the reef from location to location. The distribution of the fish can be described by the rate at which fish leave each location, the rate of leaving a location deciding the recruitment to adjacent locations. Hence the numbers at any discrete site may be written:

$$\frac{dN_i}{dt} = \frac{f(N_{i-1})}{2} + \frac{f(N_{i+1})}{2} - f(N_i) \qquad \textbf{(1)}$$

where N_i = Population in site i at time t and $f()$ defines the rate fish leave a site.

Equation 1 owes its simplicity to describing movement in one dimension. It is a deterministic differential equation describing immigration to and emigration from a discrete area. The biological principle is simply that fish will tend to leave a site they find attractive less frequently. This will naturally lead to a build up in numbers at attractive sites. The simplest form of function describing the departure rate is to assume the rate is proportional to the size of the population at that site.

$$\frac{dN_i}{dt} = \frac{\gamma_{i-1} N_{i-1}}{2} + \frac{\gamma_{i+1} N_{i+1}}{2} - \gamma_i N_i \qquad \textbf{(2)}$$

where γ_i is the instantaneous emigration rate from site i.

A low rate of departure indicates an attractive site to which fish will aggregate. Equation 2 defines a set of homogeneous linear differential equations of first order with constant coefficients. The solution will be in the form of a linear combination of exponentials. However, the key point is, after any perturbation the system will return to the same equilibrium, assuming a closed population, with the proportion of the total population at any one site being defined by the emigration rate parameters. So even where fishing reduces the size of the total population, the model predicts that each site will still have the same proportion of the total once the population has resettled. The rate at which fish redistribute will depend upon the size of these parameters, but the fact that the changes are exponential suggests they will be fairly rapid.

There are a large number of alternative models which might be proposed depending on the results of the fishing experiment. The proportion of the total population will be constant at any one site if the fish have food ranges, for instance. In this situation emigration will decrease more rapidly than the population size, as the site becomes more attractive, there being less competition for space. If the constant emigration rate model is rejected, it may be possible to propose and test a more appropriate model.

The model is important since it can predict how a reef will react to fishing and how populations will react to the positioning of fishing zones. For instance, if movement is governed by the constant emigration model, the positioning of reserves may be critical to the fishery. Assume that fishing ceases at some catch rate at which point fishermen switch to some other activity and the catch rate is proportional to the local population density. If fishing is permitted on an area which has the highest abundance of fish, the minimum catch rate will push the local population, and by extension the total population, down to a small proportion of the unexploited biomass. If only areas with low abundance are available, fishing will cease where abundance is a higher proportion of the unexploited population.

The theory presented here is inadequate for a full data analysis. Hence the aim of the remaining sections is to indicate the value of this type of work and the sort of results that would be available.

RESULTS

An important result is the data itself generated from the experiment. Only fraction has been analyzed for this report. The information collected is as follows:

1) Fish census
Numbers of individuals of 36 fish species before and after fishing.

2) Catch
Numbers of boats and fishermen involved in fishing experiment.
Numbers of lines and traps and times of operation throughout fishing period.
Catch data broken down to each vessel or trap catch on one day. Weight, length (standard and total length) and species for each fish caught.
Detailed position of traps and some vessels.

3) Lethrinus borbonicus
125 specimens of L.borbonicus were sampled in more detail for length, weight, sex, and maturity. For 75 of these specimens otoliths and scale samples have been taken as well.

4) General
Numbers and types of boat in fishing villages close to the study area.
Numbers of boats in the vicinity of the study area each day throughout the experiment.
Interviews with fishermen on their behaviour.

Fishing

Table I provides a summary of catch statistics. The dominant species, *L.borbonicus*, formed over 50% of the total hand line catch, and is considered separately alongside the rest of the catch in the following analyses. The traps, which it was hoped would target larger lethrinids and haemulids, were not so successful. The low catch rate was possibly due to a combination of factors, the most important being the general location which was probably unsuitable for this gear.

If catches are related to stock size and the stock size is decreasing, the catch per unit effort (CPUE) should decline. Figures 4 and 5 show a time series of the catch per hook hour in both numbers of fish and weight of catch, excluding night fishing. The results are somewhat difficult to interpret in detail due to the high variability in the catch rates. The low catch rate on the first day is likely to be due to learning by the fishermen, and the fish, which may initially be wary of hooks. It is noticeable that the CPUE for the total is driven by the *L.borbonicus* catch. However as fishing progressed other species formed an increasing proportion of the catch, mainly because the *L.borbonicus* catch declined at a faster rate.

These patterns are easier to discern using statistical models, which also indicate significance. Table II holds the results from the linear model fitted to the catch numbers excluding *L.borbonicus*. The model uses the Poisson error and a log link. Time and lines together give the fishing effort. Logarithms are taken making these covariates linear within the model. The model fitted defines the Poisson parameter with the following linear predictor:

Table I Summary of catch data from the fishing period

Catch using hook and line	
Number of days fished:	11
Average number of lines fishing per day:	13.1
Total number of fish caught:	4267
Total weight of fish caught:	544.4 kg
Total number of *L.borbonicus* caught:	2742
Total weight of *L.borbonicus* caught:	242.3 kg
Total catch /line /day:	3.8 kg 29.8 fish
L.borbonicus catch /line /day:	1.7 kg 19.2 fish
Catch using traps	
Number of traps used:	21
Total number of fish caught:	321
Total weight of fish caught:	80.81 kg
Total catch /trap /day:	0.35 kg 1.39 fish

The deviance for both the fishing time and number of lines is high, so variation in fishing effort explains much of the variation in the catch. The estimates suggest decreasing returns to fishing effort, since they are less than one. This might be due to a number of factors, for instance interference between lines or depletion of the local population. There was little difference between night and day fishing. The number of days since fishing started explains a small proportion of the variation. There is an overall decline in catches rates over time, but it is not significantly different from zero.

Table III shows the same analysis for the numbers of *L.borbonicus* caught. Surprisingly the time spent fishing accounts for little of the total deviance. However this term becomes more important when all other parameters have been fitted, hence fishing effort is only important as a correction within other dominating effects. The parameters also emphasise the diminishing returns of fishing, so doubling fishing time results in less than twice the catch.

The most significant effect is the drop in *L.borbonicus* catches during night fishing. This suggests that *L.borbonicus* disperses from the reef to feed during dark hours, as do many other lethrinids. The decline in catches over the period of assessment is significant. Note that the fishing date term is not logged, so the effect is exponential.

Table IV gives the result for the model fitted to the total catch weight data. The same model was appropriate, since even for weight the variance appeared to be proportional to the mean. There is a clear relationship between catch and effort, although again the returns diminish.

The night fishing catch is significantly higher. The catches at night were made up of larger fish, as well as a different species composition. Finally, as fishing progressed, the decline in catches was highly significant. This was due not only to decreasing total catches, but changing species composition, as different species were selectively removed.

Table II Analysis of Deviance : total catch weight

Term	Deviance	Variable	Estimate	S.E.
Total	384990	Const	8.047	0.268
df	102			
Time	116976	ln(Time)	0.603	0.149
df	1			
Lines	69880	ln(Lines)	0.401	0.163
df	1			
Night	11097	Night(2)	0.853	0.205
df	1			
Fishing date	35797	Date	-0.078	0.016
df	1			

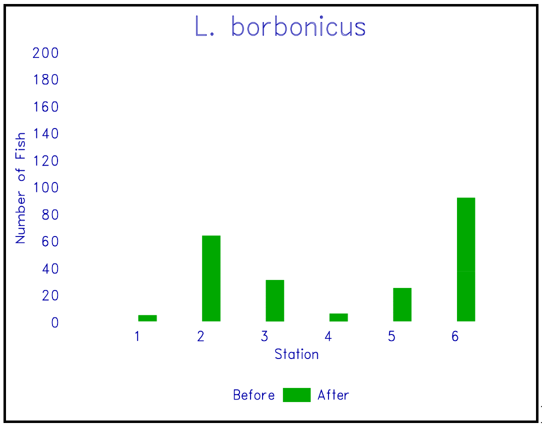
Parameter estimates are for the complete model. ln() indicates the natural logarithm of variable was used. The factor level is indicated by the integer following the variable in brackets.

Census

The preliminary analysis of the data concentrated on two species, *L.borbonicus*, an important constituent of the catch, and *C.kleinii*, which was taken rarely and only as by-catch.

The most important objective was to measure the decline in abundance as a result of the fishing. Figure 6 shows the abundance of the two species, *L.borbonicus* and *C.kleinii*, at each station before and after fishing. As the times spent on counts are the same at each station, and before and after fishing, the numbers of fish counted are directly comparable.

There was a large difference between the abundance of fish at the different stations. Although both species appear to be most common at the eastern edge of the study area (station 6), *C.kleinii* has a much more uniform distribution. There also appears to be a different response to fishing. In each case the numbers of *L.borbonicus*, which dominated the catch, are lower after fishing. In contrast *C.kleinii* shows no consistent decline in the counts.



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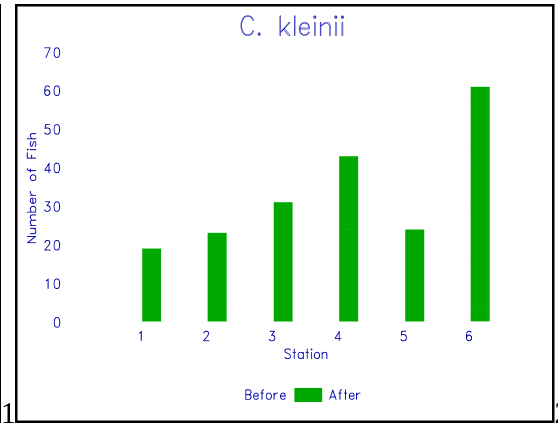

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Figure 6 shows the change in numbers of fish counted for the two species, *L.borbonicus* and *C.kleinii*, before and after fishing at each station.

Figure 7 shows the census data for *L.borbonicus* as a time series before and after fishing. The stations have been pooled together in terms of west unfished (I and II), central fished (III and IV) and east unfished (V and VI). In general the numbers of fish decreased after the fishing period. However the figures suggest different stations might be affected by different amounts. The west unfished stations showed little change, fish numbers remaining low after fishing, but there was a significant decrease in fish numbers after fishing in the central fished area as well as in the east unfished area. The decrease in numbers after fishing may suggest that fish have moved into the central fishing area during the fishing period. There is also some indication that numbers of individuals are beginning to pick up again in the east unfished area after the fishing.

Table V gives the results of fitting a linear model to the census data for the most abundant species in the catch, *L.borbonicus*. The most important factor is clearly the station. Station VI at the eastern end of the experimental area appeared to have considerably more individuals than any other station, whereas stations I and II consistently had fewer. Although it is possible that there was a simple decline in abundance from east to west, the parameter estimates suggest that the distribution of *L.borbonicus* may be more complicated than this.

The other factor estimates the difference in catches after fishing. There was a clear decline in numbers observed between the two fishing periods. However the interaction term (station.after-fishing) is not significant, hence it must be assumed that the numbers at all stations have been reduced by the same proportion. This agrees with the simple model proposed in the Theoretical Models section above, and suggests that it provides a reasonable approximation. This aspect is considered in greater depth in the discussion.

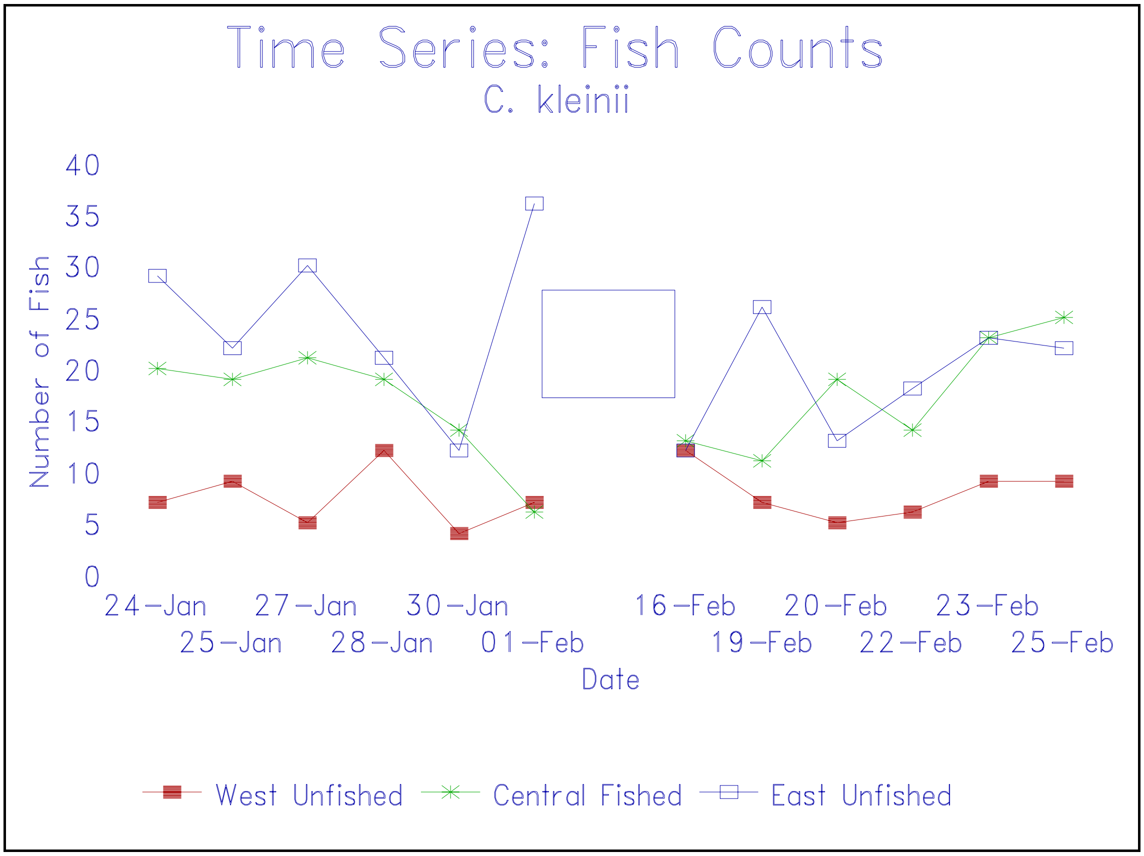

Figure 8 Time series of *C.kleinii* counts over the experimental period.

Figure 8 shows a time series of the census data for *C.kleinii* before and after fishing. Overall, there appears to be little or no decrease in *C.kleinii* after the fishing event.

Table VI shows results from the same model, as applied to *L.borbonicus*, but fitted to the butterfly fish *C.kleinii*. From the size of the deviance it is clear that the variability in counts is considerably lower than for *L.borbonicus*. As observed in figure 6, although *C.kleinii* has an aggregated spatial distribution, it is more uniform than that for *L.borbonicus*. The results also demonstrate that there was no significant decline in abundance after fishing, the counts remaining stable over the whole period. Since *C.kleinii* did not appear in the catches, this result supports the proposition that the observed fall in the counts was due to the impact of fishing.

DISCUSSION

Perhaps the most significant result of the study was to demonstrate that it is possible to carry out this form of manipulative experiment on coral reefs. The value becomes more obvious when considering what the data might be used for, and the relevance this has for coral reef fisheries management.

The data collected may help in two ways. Firstly, it may help generate the state of a fishery, the state being some index which can be used to monitor the resource. Secondly, it can be used to define the optimum state of a fishery. Using a number of input controls, such as effort, management can then attempt to move the fishery towards this optimum.

Often the fisheries state variable used is catch per unit effort (CPUE), assuming that it provides a relative index of the size of the resource. Although simple, CPUE has a number of drawbacks, in particular it ignores biological necessities, such as reproduction and growth. One of the major objections to using CPUE indices for coral reef artisanal fisheries is the lack of accurate data on catch and, in particular, effort. This has led to the widespread use of length frequency methods, which have an advantage in that they require only a sample of the catch. In a population of growing animals, a higher mortality will increase the proportion of smaller individuals in the catch and this result is used in length frequency methods.

In principle there is no reason why the fishery state variable cannot be extended to represent a number of species. There are two effects such an index will be able to take advantage of. In the short term with a heavy fishing mortality, species which are vulnerable to the fishing gears being used will tend to form a decreasing proportion of the catch. This effect was noticed in the experiment, and was probably due to the abundance of *L.borbonicus* decreasing at a faster rate than the other species. However it is possible that other effects such as decreasing competition or predation will serve to increase these changes in species composition as time goes on. Also in the long term it might be expected that slow growing large species (K-selected) would tend to form a decreasing proportion of the catch while faster growing small species (r-selected) will tend to form a larger proportion. Dealing with species independently in a multispecies catch ignores these important sources of information.

In all cases, however, the variable which defines the fishery's state must ultimately be related to the abundance of fish. This requires knowledge what the fishermen are trying to catch and of gear selectivity. Experiments, such as designed here, can provide estimates on gear catchability for each species for each size. Given the catch removed from a closed population and relative indices of abundance are known, the relationship between absolute abundance and the index can be generated by linking the change in the index to the numbers of fish in the catch. This knowledge will not only be necessary for meaningful interpretation of fisheries data, it will also provide information on the likely impact of increasing effort on the fish community and hence how the catch species composition will continue to change.

It should be possible to use the data set obtained in this experiment to generate useful first estimate for the selectivity of the gear used. The main problem is the potential leakage from the population at the edges of the study area. In this respect the visual census has been useful. Since there is little indication of a change in the local population size after fishing, it might reasonably be assumed that immigration rate is negligible. However as *L.borbonicus*, for instance, appears to be capable of moving a distance of at least half the length of the study area within the fishing period, it is unclear over how large an area the population distributes itself. Of greater importance is the question of what the index is measuring. If CPUE is used, it at best measures the abundance in the fishing area. To relate that to the stock size requires a model of fish movement.

The model proposed here, chosen on the basis of simplicity rather than biological theory, suggested that fish would redistribute themselves so that all areas would reflect the decrease in population size equally. If this is correct, CPUE data from one site would provide a suitable index for the stock size. Using the visual census data from outside the fishing area will help validate this assumption. In practice CPUE information would come from a number of areas. In this case it is envisaged that although the variability in catch rates would increase, the average decline in catch rates from all areas would still provide an unbiased estimate of the size of the stock. Simulations and controlled experiments might be used to test this assumption under different scenarios.

Given the present state of the fishery, it is necessary to know where the optimum state lies, so that action can be taken to manoeuvre the fishery in that direction. One approach is to estimate the position empirically. The state at which a set of performance criteria maximises can be estimated from data collected from the fishery. This optimum state is then maintained by adopting a feedback policy. An example of this is where a fishery might try to estimate MSY by plotting total catch (performance variable) against CPUE (state variable). Management then adopts a policy (usually catch or effort control) to maintain the fishery at the required state. It is clearly important that the state variable represents the true state of the fishery. Theory is valuable in defining both the appropriate state variable and indicating where optimum states lie.

For single species fisheries, the theory for defining the maximum catch or profit is well defined. One approach for a multispecies fishery is to treat each species as a separate population, and maximise the yield from all species combined. This ignores relationships between species which may be important. It has long been recognised that removing predators or competitors, should increase the yield from other target species by decreasing their natural mortality (May *et al*, 1979). There may also be implications for the fish distribution. If predators or competitors (eg for space) are removed from an area, a species may well move and aggregate there.

Fish aggregation is fundamental to the existence of most fisheries. Pockets of high density increase catch rates, making the fishery economically more efficient. Much of the fishermens' skill lies is locating these areas where catch rates are particularly high. Aggregation is likely to be important in fish population dynamics, increasing fecundity and reducing mortality.

An important measure of efficiency is the catch rates that fishermen are experiencing. The rate at which high density areas are restocked may well define the optimum fishing effort. The results from the experiment suggest, at least for *L.borbonicus*, restocking from the immediate area is rapid. This result may be species specific. *L.borbonicus* probably disperses to feed off the reef at night. On returning to the reef the population may redistribute itself, so a new equilibrium is reached rapidly.

The optimum state is only of use if it can be reached using the management tools available. It has already been mentioned that tools available to coral reef fisheries are limited. The total effort, in the form of numbers of boats, will be set by the optimum catch rates, subject to the maximum sustainable yield constraint. Setting up reserves will need to consider fish movement and distribution so that their effects can be predicted. In addition it might be possible to control fishing gear, which may be valuable in improving species composition in the catches. This will require detailed knowledge of gear species selectivity.

Finally there is an aspect of pure research to this work. Although it is not possible to say whether such results will have any value, there is a chance of important discoveries as with any pure research. The mixed nature of this work has the advantage that results of some value are guaranteed.

The discussion has touched on a number of areas, but has not given an exact account of what would be done. This is mainly because there is no adequate methodology for dealing with these sorts of data. For instance, using the estimated numbers of each fish species in the community as the state of the fishery gives a variable with a very large number of dimensions. Dealing with such a variable requires the development of new computer based statistical techniques, as well as a theory defining its behaviour under harvesting. The priority, before continuing a programme of field work, must be therefore to use the present data set to generate theories and statistics in this vein.

Appendix A

Table III Fish Species in Census

Commercial Fish Species

Lethrinidae (emperors)

Lethrinus ramak	L. barbonicus
L. mahsena	Monotaxis grandoculis
L. harak	P. playfairi

Haemulidae (grunts)

Plectorhinchus schotaf	P. flavomaculatus
Diagramma pictum	

Balistidae (triggerfish)

Balistoides viridescens	Pseudobalistes fuscus
Balistapus undulatus	Sufflamen bursa
S. chrysopterus	

Serranidae (groupers)

Variola louti	Cephalopholis argus
Epinephelus fasciatus	E. spilotoceps
E. chlorostigma	E. caeruleopuncatus
Anyperodon leucogrammicus	

Acanthuridae (surgeonfishes)

Naso lituratus	Acanthurus nigricaudus

Lutjanidae (snappers)

Lutjanus bohar	

Mullidae (goatfishes)

Parupeneus bifasciatus	P. barberinus

Labridae (wrasse)

Cheilinus lunulatus	C. trilobatus

Scaridae (parrotfish)

Scarus sordidus	

Non-commercial fish species (controls)

Chaetodontidae (butterfly), Pomacanthidae (angel fishes)

Chaetodon auriga	C. trifasciatus
C. kleinii	C. lunula
C. unimaculatus	Heniochus acuminatus
H. monoceros	Pomacanthus chrysurus
Apolemichthys trimaculatus	

Appendix B

REFERENCES

Alcala, A C, 1981. Fish yield of coral reefs of Sumilon Island, Central Philippines. Natural Research Bulletin of Philippines, 36 (1).

Alcala, A C, Luchavez, T,1981. Fish yield of the coral reef surrounding Apo Island, Negros Oriental, Central Visayas, Philippines. Proc. 4th Int. Coral Reef Symp., Vol 1: 69-73.

Alcala, A C, Russ, G R, 1990. A direct test of the effects of protective management on abundance and yield of tropical marine resources. J.Cons.Int.Explor.Mer: 46

Doherty, P J, 1982a. Coral reef fishes: recruitment limited assemblages? Proc. 4th Int. Coral Reef Symp., 2: 465-470.

Eckert, G J, 1984. Annual and spatial variation in recruitment of labroid fishes among seven reefs in the Capricorn/Bunker Group, Great Barrier Reef. Marine Biology 78: 123 - 127.

Ferry, R E, Kohler, C C, 1987. Effects of trap fishing on fish populations inhabiting a fringing coral reef. North American Journal of Fisheries Management, 7: 580 - 588.

GLIM 1985. Generalised Linear Interactive Modelling. Manual, release 3.77. Payne C.D. (editor). NAG, Oxford, UK.

Rosenberg, A A and Beddington J R, 1989. Length based methods of fish stock assessment. In: Gulland, J A (editor), Fish Population Dynamics. John Wiley and Sons.

Koslow, J A, Hanley, F, Wicklund, R, 1988. Effects of fishing on reef fish communities at Pedro Bank and Port Royal Cays, Jamaica. Marine Ecology Progress Series, 43: 201-212.

Marshall, N, 1985. Ecological sustainable yield (fisheries potential) of coral reef areas, as related to physiographic features of coral reef environments. Proc. 5th Int Coral Reef Symp. Vol 5: 525 - 530.

May, R M, Beddington, J R, Clark, C W, Holt, S J, Laws, R M, 1979. Management of multispecies fisheries. Science 205(4403): 267-277.

Meekan, M G, 1988. Settlement and mortality of juvenile fishes at Lizard Island Northern Great Barrier Reef. Proc. 6th Int. Coral Reef Symp., 2: 779-784.

Munro, J L, *et al*, 1985. Seminar C: Assessment and management of coral reef fisheries: biological, environmental and socio-economic aspects. Proc. 5th Int. Coral Reef Symp., Vol 4: 543-581.

Russ, G R, Alcala, A C, 1989. Effects of intense fishing pressure on an assemblage of coral reef fishes. Marine Ecological Progress Series, 56: 13-27.

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