FINAL REPORT,
ODA FISHERIES MANAGEMENT
SCIENCE PROGRAMME

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'Responses of Reef Fisheries to Area Closure'

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1. OBJECTIVES OF THE PROJECT

The project aimed to gather accessible information on reef-fisheries management, and especially on effects of area closure (marine reserve establishment) on tropical reef fish populations and communities. It also aimed to collect new data on the effects of cessation of fishing on reef fish populations and communities at several sites throughout the tropics. The information obtained will be used to improve approaches to managing reef fisheries and to provide managers and local users of reef fishery resources with information as to the likely costs and benefits of reserve management of fisheries. An additional aim agreed at the end of 1991 was to begin modelling reef-fish population ecology, with respect particularly to the responses of populations to protection within reserves.

Work was to be undertaken in three separate phases:

i Review of the literature on the biological basis of reef-fish production and effects of area closure on reef fish populations, with specific reference to populations of commercial finfishes.

ii Field studies comparing reef fish population structure in protected and unprotected areas in the Caribbean.

iii Field studies as in (2) but in S.E. Asia. Computer modelling of effects of area closure on reef-fish populations.

2. WORK CARRIED OUT

Two scientific review papers were prepared during the first phase, one on the energetic basis of fish production on coral reefs (Polunin & Klumpp 1992, see section 5 of this report) and the other on effects of reserves on reef-fish local populations (Roberts & Polunin 1991, see section 5).

Choice of field-sites suitable for investigation was based on an assessment of established marine reserves by Mr Marek Gabrysch. The field-work in the Caribbean was completed according to plan during March to May 1991 by Drs Nicholas Polunin and Callum Roberts. This stage investigated the effects of reserve establishment on reef fish communities at two sites: Saba Marine Park in the Netherlands Antilles and Belize (Hol Chan Reserve at Ambergris Caye). The field-work involved close collaboration with staff of both reserves. The Saba Marine Park staff were able to provide substantial logistic support for the study, providing boat transport to sites and some diving equipment. In Belize, field-work was accomplished using boats and diving equipment from commercial sources.

Field-work in South-East Asia was planned to have been undertaken in peninsular Malaysia. However, delays in securing research permits within the time-frame of the project meant that this possibility was abandoned. Instead, the second phase was undertaken in the Egyptian Red Sea during November to December 1991 by Dr Callum Roberts. No difficulties were encountered in collecting the data. A computer model of effects of area closure on fecundity of reef-fish local populations was successfully put together by Dr Nicholas Polunin amd Mr Daniel Morton and simulations carried out using it.

3. RESULTS

Review of the use of marine reserves in reef-fishery management

The review of information on the effects of area closure on reef fisheries explored the theoretical basis for use of marine reserves in fishery management. It also examined the available evidence with which theoretical predictions could be tested. It summarised the problems inherent in applying conventional fishery management methods to highly complex reef fisheries. Such fisheries are characterised by high catch-diversity, use of many different capture methods, labour-intensive low-technology harvest and marketing, often-intensive exploitation and little or no management. Marine reserves appear to offer a simple management system which overcomes the need for detailed information on the biology of harvested species, are low cost and in theory easy to enforce. However, the effectiveness of protective management has not been properly evaluated. Effects of environemntal factors

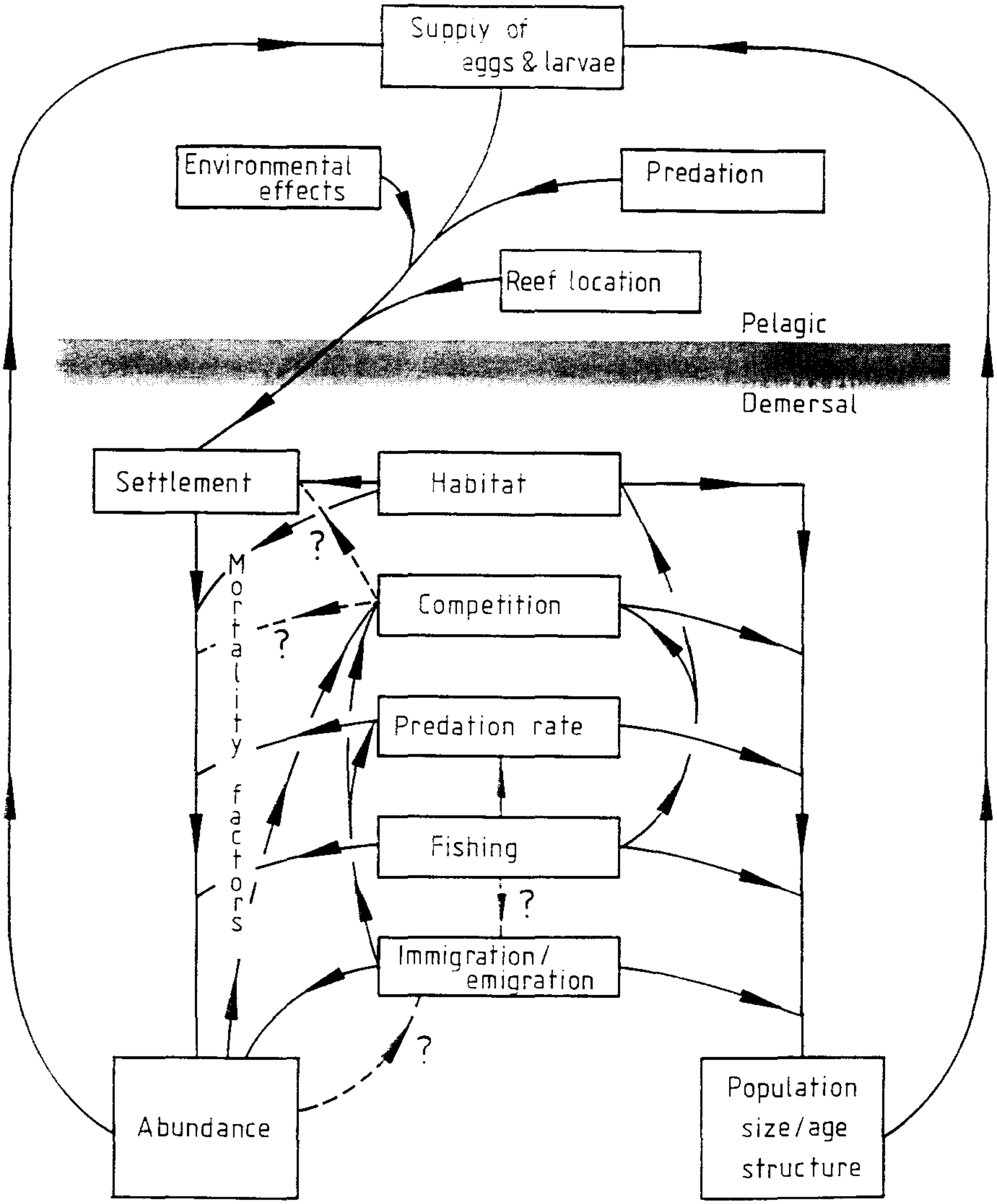

Figure 1. Flow diagram illustrating factors determining the abundance and size/age structure of populations of reef fishes and their relationships. Arrows show the direction of effects and solid links indicate those interactions supported by field evidence. Dashed links with question marks indicate expected relationships for which evidence is not yet available. Fishing mortality affects abundance and size/age structure both directly and indirectly. Removal of fishing mortality may thus be expected to result in pronounced changes in population structure.

including exploitation on fish populations were summarised (Figure 1) and field evidence to test fishing effects reviewed.

Key theoretical points established were that:

(i) closure of an area should result in increases in mean size and abundance of fished species,
(ii) marine reserves could act as supplies of recruits to fished areas,
(iii) local populations within reserves, particularly of larger carnivorous fishes, could act as buffers against overexploitation and recruitment failures in fished areas, and
(iv) reserves could play a role in conserving the genetic diversity of exploited species.

Published studies indicated that:

(i) data were insufficient at all levels to test theoretical predictions adequately,
(ii) available data tended to support predictions of increased mean size and abundance of fished species when exploitation ceases, although these predictions were not universally upheld, and
(iii) evidence for enhancement of catches in areas adjacent to reserves was suggestive but equivocal.

Marine reserves are considered a promising approach to reef-fisheries management in developing countries, but their precise mechanisms and roles are still incompletely understood. This affects their design and deployment, and critical investigations of the effects of cessation of fishing on local populations are necessary.

Results of field studies

Study sites

In the Caribbean, field work was centred on the Saba Marine Park and the Hol Chan Marine Reserve in Belize. In both areas marine reserves had been established in 1987 and parts of them closed to fishing since then. Fishing restrictions had been effectively policed at both, and this was a major criterion for their selection for study.

In Egypt, field work was centred around the Ras Mohammed Marine Park, all of which has been closed to fishing and effectively policed for approximately 15 years.

Methodology

The same approach was used at all sites to allow comparability among studies. Fish populations were enumerated using a standard point count visual census method developed in the Caribbean. On each count a circular area of approximately $70m^2$ (5m radius) was censused and fishes within or passing through the area counted during a fifteen minute period. The lengths of individuals from selected families were also estimated visually. In addition, counts were made of pelagic piscivores passing through the area using a modified procedure developed in Australia for such species. The counts provided data on abundance, species composition and size structure of both target and non-target species. Inter-observer error of length and abundance estimates were calculated using standard objects of known length and repeat counts of the same areas, respectively. Agreement between observers was high in both cases. For Caribbean sites, all species of fish within the areas censused were counted. However, in Egypt counts were restricted to families considered to be favoured targets of fishermen. Estimates were also made of habitat characteristics of the sample areas, so that ecological differences between sites other than level of fishing could be evaluated.

In Saba and Belize counts were made at two depths (5 and 15m in Saba, 2 and 15m in Belize). In Egypt, counts were only made at 15m due to more limited field time, manpower and time available for data processing.

At all locations fish populations were censused in areas closed to fishing, and in areas where fishing was not restricted, the object being to establish whether there were differences among areas which could be attributed to the effects of fishing. In Belize and Egypt, lightly-fished areas were also incorporated into the sampling design. Data overall were analysed using ANOVA and pair-wise comparisons made using the Student-Neuman-Keuls Test.

Results from Caribbean studies

Data for differences in abundance between fished and unfished areas were analysed for all species observed. Data for mean length were analysed for species from the following

Table 1. Exploited fish species and groups showing significant (P<0.01) differences in abundance between fished (F) and unfished (UF) areas around Saba

(Depth) Habitat Fish	Statistical Significance	Order of Abundance
(5m)		
Benthic		
Haemulon carbonarium	P<0.0005	UF>F
Anisotremus virginicus	P<0.002	UF>F
Lutjanus apodus	P<0.002	UF>F
Scarus taeniopterus	P<0.005	UF>F
Haemulidae (grunts)	P<0.0001	UF>F
Overall numbers	P<0.0001	UF>F

families: Acanthuridae (surgeonfish), Scaridae (parrotfish), Serranidae (groupers), Lutjanidae (snappers) and Haemulidae (grunts). In addition biomass data were calculated for species from the above families using mean length figures and length-weight relationships obtained from the literature.

Abundance : Data for abundance are summarised in Tables 1 and 2. At Saba, significant differences in abundance

Table 2. Exploited fish species and groups showing significant (P<0.01) differences in abundance between fished (F, two sites), lightly-fished (LF) and unfished (UF) areas at Ambergris Caye, Belize

(Depth) <u>Habitat</u> Fish	Statistical Significance	Order of Abundance
(2m) <u>Benthic</u>		
Haemulon plumieri	P<0.0001	LF>F=F=UF
Lutjanus jocu	P<0.0001	UF>LF=F=F
Scarus guacamaia	P<0.001	UF>F=F=LF
Scarus taeniopterus	P<0.003	LF>F=F=UF
Sparisoma viride	P<0.001	LF>UF=F=F
Sparisoma aurofrenatum	P<0.001	UF=F>F=LF
Acanthurus chirurgus	P<0.002	UF>F=F=LF
Lutjanidae (snappers)	P<0.01	UF>LF=F=F
Serranidae (groupers)	P<0.005	UF>LF=F=F
Scaridae (parrotfishes)	P<0.0001	LF>UF=F=F
(15m) <u>Benthic</u>		
Ocyurus chrysurus	P<0.005	UF>LF=F=F
Mycteroperca bonaci	P<0.005	UF>F=F=LF
Acanthurus bahianus	P<0.005	F=F=LF>UF
Lutjanidae (snappers)	P<0.005	UF>F=F=LF
Serranidae (groupers)	P<0.002	UF=LF>F=F
Scaridae (parrotfishes)	P<0.01	UF>F=LF=F
Acanthuridae (surgeonfishes)	P<0.001	F=F=LF>UF
(2m) <u>Pelagic</u>		
All fishes	P<0.0001	UF>F=F=LF
Tylosurus crocodilus	P<0.0001	UF>F=F=LF

between fished and unfished areas were detected for 26% of species (6 in all) considered favoured or occasional targets of fishermen (see Table 1 for details of species and groups which exhibited highly significant differences). In the majority of cases (7 of 8), there were significantly greater abundances in the unfished than in the fished area. There were significant differences between fished and unfished areas also for 17.5% of non-target species (8.5spp).

Table 3. Fish species for which highly significant differences were found in mean or maximum length at Saba and Ambergris Caye, Belize between unfished UF), lightly-fished (LF) and fished areas (F)

AREA (Mean or Max) (Depth) <u>Habitat</u> Fish	Statistical Significance	Order of Length
SABA (Mean)		
(5m)		
<u>Benthic</u>		
Cephalopholis fulvus	P<0.005	UF>F
(5m)		
<u>Pelagic</u>		
Caranx ruber	P<0.01	UF>F
BELIZE (Mean)		
(2m)		
<u>Benthic</u>		
Scarus iserti	P<0.0005	UF=F>LF=F
Sparisoma viride	P<0.002	UF=LF>F=F
Acanthurus coeruleus	P<0.003	UF>LF=F=F
(15m)		
<u>Benthic</u>		
Acanthurus bahianus	P<0.0005	F>F=UF=LF
BELIZE (Maximum)		
(2m)		
<u>Benthic</u>		
Sparisoma viride	P<0.0001	LF>UF=F=F
(15m)		
<u>Benthic</u>		
Ocyurus chrysurus	P<0.005	UF>F=F=LF
Acanthurus bahianus	P<0.005	F=F>LF=UF

In Belize significant (P<0.05) differences among areas were detected for 33% of target species (see Table 2 for species with highly significant differences) compared with 24% of non-target species. Of the favoured and occasional target species 12 out of 15 were more abundant within the unfished (Hol Chan Reserve) or lightly fished (Basil Jones Cut) areas,

compared with 3 of 15 more abundant in the more heavily fished areas (San Pedro Cut and Mata Cut).
Length of fishes : Cases where mean and maximum size differences were highly significant are shown in Table 3. In Saba, significant ($P<0.05$) differences in size were evident in only six species. Of the four considered favoured or occasional targets of fishing, all were larger in the unfished area. Twenty-three percent of target species showed an effect of fishing on size, compared with 8% of non-target species.

In Belize only 7 target and occasional target species showed significant ($P<0.05$) size differences among areas (Table 3). Of them, 5 were significantly larger in the unfished or lightly-fished areas, while two species were larger in the more heavily fished areas. Twenty percent of species considered fishing targets, compared to 12% of those considered non-target species, showed effects of protection.

Biomass of fishes : Table 4 shows the results for differences in biomass in Saba and Belize. Biomass was only calculated for species considered targets of fishing and for all 7 species showing significant ($P<0.05$) differences at Saba there were greater biomasses in the unfished area. When biomasses were calculated at the family level for the five families considered major fishing targets, four of them had a significantly greater biomass in the unfished compared to fished area. The Serranidae did not show a significant difference. The total biomass of the five families combined in the unfished area was approximately double that in the fished area at 5m deep, but only 20%

Table 4. Significant ($P<0.01$) differences in biomass (g fresh-weight /count) between species and families of fishes in unfished (UF), lightly-fished (LF) and fished areas (F) at Saba and Ambergris Caye, Belize

AREA (Depth) <u>Habitat</u> Fish	Estimated Mean Biomass (g fwt/count) in area that was : Unfished	Lightly Fished	Fished	Fished
SABA (5m) <u>Benthic</u>				
Lutjanus apodus	308	-	0	-
Scarus taeniopterus	300	-	87	-
Haemulidae	655	-	110	-
Scaridae	941	-	476	-
All fishes	3525	-	1843	-
All predators	1414	-	394	-
All herbivores	2111	-	1449	-

Table 4, contd

BELIZE				
(2m)				
Benthic				
Haemulon plumieri	141	351	98	146
Lutjanus jocu	487	46	47	46
Cephalopholis fulvus	78	1	52	18
Scarus guacamaia	544	0	46	0
Sparisoma viride	180	166	46	48
Lutjanidae	1345	679	410	388
Scaridae	1208	953	808	447
All herbivores	1590	1205	1022	734
(15m)				
Benthic				
Ocyurus chrysurus	1171	444	323	294
Acanthurus bahianus	61	117	176	179
Lutjanidae	1946	444	378	445
Acanthuridae	130	243	345	401

greater at 15m. This reflects fishing pressure, which appears to be greater in shallow water.

In Belize there were significant (P<0.05) differences for 8 target species, of which biomass was greatest in unfished or lightly fished areas for 6, and in more heavily fished areas than in protected or lightly-fished areas for 2. When grouped at the family level, biomass was greatest in the unfished or lightly fished areas for Serranidae, Haemulidae (grunts) and Lutjanidae (snappers), and for the overall total biomass of these families. Only highly significant differences in biomass are shown in Table 4.

Results from Red Sea investigation

Abundance : Abundance of 11 of 45 species differed significantly among fishing levels (Table 5). There were greater numbers on unfished reefs for four, little-fished for three and fished for four. Some differences were probably due to fishing but others are more difficult to understand. At the family level, the Acanthuridae (surgeonfishes) were significantly more common on unfished reefs. A non-significant trend towards higher abundance on fished and little-fished reefs was apparent for the Serranidae (groupers).

Mean size of fishes: Significant differences in mean size among fishing levels were detected for seven species (Table 6). All increased in size with decreasing fishing intensity.
Biomass of fishes : Biomass of 14 species differed significantly among fishing levels with higher biomass in unfished sites for five, in fished sites for four and equivocal results for five (Table 7). At the family level,

Table 5. Exploited fish species and groups showing significant (P<0.01) differences in abundance between fished (F), lightly-fished (LF) and unfished (UF) sites at Sinai, Egypt

Fish	Statistical Significance	Order of Abundance
Cephalopholis miniata	P<0.001	UF=LF>F
Aethaloperca rogaa	P<0.001	LF>UF=F
Epinephelus fasciatus	P<0.005	F>LF=UF
Hipposcarus harid	P<0.002	F=LF>UF
Scarus ferrugineus	P<0.01	UF=LF>F
S. niger	P<0.001	LF>UF=F
Zebrasoma veliferum	P<0.0001	UF>LF=F
Acanthurus nigrofuscus	P<0.0001	F>LF=UF
Naso lituratus	P<0.01	UF>LF=F
N. unicornis	P<0.0001	F>LF=UF
Acanthuridae	P<0.0001	F>UF>LF

there were significant differences for Scaridae (parrotfishes) and Acanthuridae with the former greatest on little-fished reefs and the latter on fished. However, for the Acanthuridae this was due only to the schooling *Naso unicornis* being more abundant on fished reefs. Serranid (grouper) biomass was 1.4

Table 6. Exploited benthic fish species showing significant (P<0.01) differences in mean length between unfished (UF), lightly-fished (LF) and fished (F) areas at Sinai, Egypt

Fish	Statistical Significance	Order of Length
Cephalopholis miniata	P<0.01	UF>LF=F
C. hemistiktos	P<0.005	UF>LF=F
Variola louti	P<0.01	UF>LF=F
Scarus sordidus	P<0.0001	LF>UF=F
Acanthurus nigrofuscus	P<0.0001	UF=LF>F
Ctenochaetus striatus	P<0.0001	UF=LF>F

to 1.6 times greater on unfished reefs than sites subject to fishing but this was not significant. Total biomass of all species combined (excluding *N. unicornis*) did not differ significantly among fishing levels although mean biomass was 1.2 times greater on unfished than fished reefs.

Table 7. Fish species and groups showing significant (P<0.01) differences in mean biomass (g fresh-weight/count) between unfished (UF), lightly-fished (LF) and fished (F) areas at Sinai, Egypt

Fish	Estimated Mean Biomass (g fwt/count) in area that was :		
	Unfished	Lightly Fished	Fished
Cephalopholis miniata	588	440	119
Aethaloperca rogaa	0	162	8
Epinephelus fasciatus	19	2	56
Hipposcarus harid	0	262	277
S. niger	150	444	211
Zebrasoma veliferum	207	77	62
Ctenochaetus striatus	365	365	248
Naso lituratus	318	42	32
N. unicornis	116	0	4676
Scaridae	5176	637	5152
Acanthuridae	1752	1156	6041
All fishes	6404	5897	9751
All herbivores	2937	2832	6997

Conclusions from field studies

The results for abundance and size of species support, but to a limited extent, the prediction that fishing targets will be more abundant and larger in unfished compared to fished areas. However, with a few exceptions the sizes of effects detected were generally small. It was only when species were grouped at the family level that marked effects of reserve protection could be demonstrated, with biomass of fished families usually being greater within reserves than in fished areas. The magnitude of differences varied substantially among families.

Some fished species were more abundant in fished areas perhaps for reasons of release from competition with, or from predation by, other species depleted by fishing. Indirect effects of fishing may be common in such multi-species communities.

These results provide some support for the view that marine reserve establishment has been effective in protecting stocks. However, fishing levels in the northern Red Sea and Saba are low and use of reserves to manage fisheries may prove most effective in regions where fishing intensities are high or damaging fishing methods widespread.

Effects modelling

Because increase in length is one of the most prominent effects of closed areas on local fish populations and fecundity is logarithmically related to length, dramatic increases in population fecundity are to be expected as a result of the cessation of fishing. Modelling therefore focussed on this important effect.

Methodology

Mathematical descriptions of fecundity as a function of length, of length-growth over time in the form of the Von Bertalanffy Growth Function, of the cumulative fecundity of individuals of varying length within a size class and of mortality were combined into the model. This has permitted effects of varying time, growth characteristics, size composition, and natural and fishing mortality to be combined. Simulations employed actual or likely values for the modelled parameters derived from the literature.

Results of modelling

The model has emphasised the substantial effect on egg output expected from growth-overfished local populations when they are protected within reserves. It has provided a basis for predicting the magnitude of the response, given data on growth, fecundity in relation to size, mortality, age-class composition and other variables. Larval survivorship and dispersal, however, are considered to be very variable processes so that the fate of the extra egg production promoted by closed-area management can still not be predicted. Available information suggests that above a certain stock size, there is only a very weak, if any, relationship between stock size and recruitment. In severely-depleted stocks, however, the increase in fecundity can be expected to have a discernible positive effect on stock size. There is insufficient information at present on the biology of larvae and juveniles to predict the recruitment effect of enhanced fecundity in any particular case.

4. IMPLICATIONS OF THE RESULTS FOR ACHIEVING THE OBJECTIVES OF THE PROJECT

The data collected in this study were intended to test several of the theoretical predictions of closure of areas of reef to fishing. The study was designed to make comparisons among unfished and fished areas in a more rigorous way than has been achieved in other similar studies to date. Despite this rigour the results have revealed a high level of complexity which makes interpretation difficult. This is perhaps to be expected from such diverse and complex assemblages as reef fishes. A critical problem with studies of this type is the difficulty of controlling for differences among areas other than that of fishing. Consequently, differences detected could be due to a variety of other factors. This problem could be overcome to a large extent in future studies if the opportunity is given to make observations of areas before they are closed to fishing and follow changes over time in these and comparable areas where fishing continues unrestricted. Such an approach will require a commitment to fund for a period longer than the present study, with four years being a suggested minimum. Modelling has conceptualised, and provided a basis for predicting, fecundity effects on protected local populations of reef fishes. This work has underlined the potential recruitment effect of closed areas on surrounding fished sites, but this ultimate effect requires information on larval and juvenile biology and this is not yet available.

5. PRIORITY TASKS FOR FOLLOW-UP

Dissemination of findings

In order to be of most value to fishery and reserve managers in developing countries it is important that our work be widely reported. The results are therefore being published in scientific journals, in literature available to a greater range of people involved in reef fishery management and in more popular publications. Publications resulting from this project, or which are expected to arise from it, are listed below.

Polunin, N.V.C. & D.W. Klumpp (1992). A trophodynamic model of fish production on a windward reef tract. pp213-233 In: D. M. John, S. J. Hawkins and J. H. Price (eds), Plant-animal interactions in the marine benthos. Systematics Association Special Volume 46. Clarendon Press, Oxford.

Polunin, N. V. C. & R. D. Morton. Model of fecundity effects of the cessation of fishing on local reef-fish populations. [Scientific journal to be decided]

Polunin, N.V.C. & C.M. Roberts. Can marine reserves act as ecological reference sites? For IVth World Congress on National Parks and Protected Areas, Venezuela, 1992. Abstract only.

Polunin, N.V.C. & C.M. Roberts. Effects of area closure on reef fish stocks in two Caribbean reserves. In preparation. To be presented verbally at the 7th Int. Coral Reef Symposium, Guam.

Roberts, C.M. & N.V.C. Polunin (1991) Are marine reserves effective in management of reef fisheries? Reviews in Fish Biology and Fisheries 1: 65-91.

Roberts, C.M. & N.V.C. Polunin. Effects of marine reserve establishment on reef fish populations. For IVth World Congress on National Parks and Protected Areas, Venezuela, 1992. Abstract only.

Roberts, C.M. and N.V.C. Polunin. Marine reserves: simple solutions to managing complex fisheries? In preparation for submission to the journal Ambio.

Roberts, C.M. & N.V.C. Polunin. Effects of marine reserve protection on northern Red Sea fish populations. To be presented verbally at the 7th Int. Coral Reef Symposium, Guam. Paper submitted.

Roberts, C.M. & N.V.C. Polunin. Marine reserves and fishing. In press in Saba Marine Park News (Newsletter of the Friends of the Saba Marine Park).

Roberts, C.M. (1991) Problems with proving the obvious: Do marine reserves protect fish? Tropical Coastal Management News (Newcastle Univ.) 4: 14.

In addition a book is in the planning stages which will draw heavily on work undertaken during this project. It has a working title of 'Protective management of reef fisheries'. This should ensure the widest possible dissemination of the results and continued development of the subject.

Further work

The ability to predict effects of area closure on local reef-fishery populations is hampered in two major ways. Lack of before-and-after information means that it is difficult at present unequivocally to substantiate abundance, size and other responses to reserve establishment. An obvious recommendation from this is that there should be controlled monitoring of protected sites in contrasting areas from the time of their inception. This is the subject of a project-concept already submitted through MRAG Ltd.

The other important gap is in the knowledge of pre-recruitment stages, namely the fate of larvae and juveniles. The most urgent matter to improve upon in this area is the relationship between spawning stock size and level of recruitment on spatial scales similar to those of effective reserves. This is a focus of the Fish Management Science Programme project now beginning on 'Multi-species responses of reef-fisheries to exploitation in the Pacific'.

6. SUMMARY OF FINANCIAL EXPENDITURE

This has been provided separately by the Finance Department, University of Newcastle upon Tyne.

Nicholas V.C. Polunin ....
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