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9. ABSTRACT

Some tentative impressions are derived from available, scattered literature concerning the fisheries potential of coral reefs and adjacent shallow environments. The standing crop of fish populations on reefs is very high, sometimes as much as five to fifteen times higher than crops on representative North Atlantic fishing grounds and twice the average standing crop typical of temperate lakes, but obviously the reef crop is comprised of many forms dependent on surrounding areas. Harvests from four island fisheries on reefs and their surrounding range from 0.5 to 5.0 grams wet weight per square meter per year. Yield per unit effort may reach 5000 kg/man/year. Although the standing crop and harvests may be substantial around the reefs, the development of the fisheries is encumbered by the diversity of the species, the relative abundance of small fishes, and the restriction imposed on gear by the environment. There is a difference of opinion and a lack of substantive work on the sustained yields that might be harvested from reef environments which are notably productive but closed ecosystems. The possibliity that yields may be enhanced when the trophic pathways become rechanneled within the ecosystem in response to a fishery merits further consideration. Management schemes to prevent resource depletion should be the focus of further study.

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GENERALIZATIONS ON THE FISHERIES POTENTIAL OF CORAL REEFS AND ADJACENT SHALLOW-WATER ENVIRONMENTS

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SUMMARY

Some tentative impressions are derived from available, scattered literature concerning the fisheries potential of coral reefs and adjacent shallow environments. The standing crop of fish populations on reefs is very high, sometimes as much as five to fifteen times higher than crops on representative North Atlantic fishing grounds and twice the average standing crop typical of temperate lakes, but obviously the reef crop is comprised of many forms dependent on surrounding areas. Harvests from four island fisheries on reefs and their surroundings range from 0.5 to 5.0 grams wet weight per square meter per year. Yield per unit effort may reach 5000 kgs / man / year.

Although the standing crop and harvests may be substantial around the reefs, the development of the fisheries is encumbered by the diversity of the species, the relative abundance of small fishes, and the restrictions imposed on gear by the environment. There is a difference of opinion and a lack of substantive work as to the sustained yields that might be harvested from reef environments which are notably productive but closed ecosystems. The possibility that yields may be enhanced when the trophic pathways become rechanneled within the ecosystem in response to a fishery merits further consideration. Management schemes to prevent resource depletion should be the focus of further study.

I. INTRODUCTION

Experts tend to disagree in assessing the harvest potential of coral reef coasts and atoll environments. The reef sub-unit of such areas has inevitably attracted the greatest attention. In pioneering studies on reef dynamics, various workers, for example Odum and Odum (1955) and Johannes *et al.* (1972), have indicated that, though reefs are highly productive, they function as recycling, closed ecological systems. Thus, many analysts tend to assume that the abundance of fish congregating in rich reef areas could not be sustained under a substantial harvesting pressure. This view is bolstered by examples of depletion under exploitation and by numerous experiences in which some of the highly territorial fishes of reef habitats have been quickly fished out under localized fishing pressures.

The foregoing view essentially assumes that adjacent shallow areas, often with extensive seagrass beds and mangrove-bordered shorelines which are also highly productive (Qasim and Bhattathiri, 1971; Golley *et al.*, 1962), are similarly closed. Such pessimism overlooks the possible synergism of associated shallow habitats and fails to recognize that proportionately small releases from recycling systems may be appreciable when production is extremely high. Pessimism also overlooks the food chain reapportionments that may occur without upsetting a system where consumer populations are harvested. Champions of the suggestion that fisheries can be expanded in reef surroundings might argue that cases of depletion essentially reflect our lack of knowledge and corresponding inability to manage a reef area fishery.

The objective of the present study is to see what might be gleaned from a probing of the scattered literature on abundance and harvests of fin fishes in such areas. Those familiar with reef and associated environments will realize that, in trying to generalize, we are glossing over an extreme diversity in physiographic and ecological settings and that specific considerations as to any given area might substantially alter the expectations. Those familiar with the literature referred to will also realize that it is often difficult to ascertain what habitats the reported fishery landings have come from, i.e. for a given site, does the indicated catch represent primarily lagoon populations, combined lagoon and reef crops, reef crops per se, or fishes taken from off the outer reef slope. For our purpose, which is to assess the composite potential of the demersal and meritic fishes of the reef plus its adjacent interacting environments, this is not too troublesome but we may have erred, unknowingly, in some cases where certain pelagic fishes, such as bonito occurring close to the reef and supported by the open ocean environment, are lumped indiscriminately with reef catch data.

The data we have compiled are presented under discussions of the gross productivity of coral reef and adjacent shallow areas, abundance of the fin fishes in such environments, and harvest experience on unit-area and other bases. These data are further interpreted in a discussion of reef area fisheries with some comments as to what is needed for managed development.

II. THE REEF-LAGOON-SHORELINE COMPLEX AND GROSS PRODUCTIVITY

The productivity of some of the major environmental types supporting the fisheries under consideration is extremely high as illustrated by recent studies as follows:

for coral reef tracts, including high, algal-covered reef expanses, (Johannes *et al.*, 1972), gross productivity = 4-10 gm. C / m^2 / day

for turtle grass beds (Qasim and Bhattathiri, 1971), gross productivity = 12 gm. C / m^2 / day

for mangrove swamps (Golley *et al.*, 1962), gross productivity = 8 gm. C / m. ^{2} / day

By way of comparison, we note that, for average cultivated land with a minimal energy subsidy (Odum, 1971), gross productivity = 4 gm. C / m^2 / day. While we don't have data on other supporting environmental types supporting these near-shore fisheries, for example the blue-green algae community covering the rocky shores or the benthic algal films on sediments, the generalization has been made (Johannes *et al.*, 1972, p.542) that high gross productivity may be characteristic "of any shallow, well oxygenated tropical benthic community situated in clear water on a stable bottom."

From the standpoint of harvest potential, the more significant considerations are those which point to a release from such high production systems, either as excess production, which might be utilized by consumers leading ultimately to harvestable products, or by routing more of the production into harvestable crops as these are exploited. As to the release, the extensive grazing by fishes on the reef and the consequent suspension of particulates from the mechanics of feeding and from defecation is well known. This is multiplied many times when the entire community plus inanimate forces, particularly breaking waves, are taken into account. There is a growing number of reports quantifying such release of substantial organic loads from the reef into the overlying waters (Marshall, 1965; Johannes, 1967; Qasim and Sankaranarayanan, 1970; Johannes and Gerber, in press; plus work in progress by Marshall and associates). Less extensive but similar work has been done on detritus from mangroves (Odum *et al.*, in press) and from seagrass beds (Zieman, 1968; Wood *et al.*, 1969).

The possibility that a harvested crop might benefit by a reapportionment of organic production from a relatively closed system is entirely speculative at present. As pointed out, for example by Marshall (1970), this may be common with respect to fisheries products in temperate estuaries. However, we must recognize that complex climax or near-climax communities like coral reefs are easily upset by re-routing the trophic structure. The latter point is probably the chief reservation held by those sceptical of higher expectations from reef area harvests.

Finally, of considerable significance in appreciating the production role of these systems are the advantageous interactions of the habitat types, for example, protective reef habitats often border rich seagrass feeding beds and the mangrove-grass-reef complex may function as a combination of habitats suited to large diverse populations and to certain demanding successional life history requirements.

III. ABUNDANCE OF FISHES

A number of investigators have noted and studied the diversity and species composition of fish from reefs and reef-associated habitats. Although Harry (1953) offered the general impression that the outer reef at Raroia Atoll supported fifty per cent of the fish population of the entire atoll, the more quantitative observations of abundance have been restricted to daytime studies on reefs (Table I) without accompanying observations on adjacent shallow-water environments. These population estimates, mostly by underwater census observations or from rotenone sampling, commonly include many species attracted to the reef from nearby shallow water during the day for shelter or for feeding purposes and give little indication of the overall abundance or carrying capacity of the entire coastal, reef-associated environmental complex or of its fishery potential.

From Table I we see that the means of the abundance of fish aggregating on and around reefs ranged from 38 g. / m.^{2} to 209 g. / m.^{2} (g. / m.^{2} = metric tons / km.^{2}). This excludes the limited high reef flat section observed at Eniwetok. The derived mean abundance estimates for all locations, except the reef flat at Eniwetok, are consistently high and indicate that daytime aggregations of fishes on coral reefs may reach densities four or five times the carrying capacity of U.S. lakes and twenty to thirty times the supporting levels of the two indicated temperate marine environments (comparison with Table II).

Abundance of fishes aggregating around an artificial reef in the Caribbean have also been included

Table I: Estimates of Abundance of Fish on Natural and Artificial Reefs

Location	Methods	Total Wet Weight (kgs.)	Reef Area Observed (m.^{2})	Wet Weight (gm./m.^{2})		Remarks
				Mean	Range	
[a]Offshore reef, Great Barrier Reef	Blasting	282	1,350	209	43–390	Range of blasting effect determined by rotenone sampling of 50m.^{2} on reef surface; samples taken from reef slopes and high reef areas; not fished.
[b]Fringing reef, Hawaii	SCUBA	2960	48,000	62	14–185	Eight transects in five locations with some coral growth; 3–27m. deep; variously fished; weights estimated from length observations.
[c]Reef flat, Eniwetok Atoll	Rotenone plus visual observations	2	240	9	1–20	Gms./m.^{2} biomass x 1.75 conversion to wet weight; six 46m.^{2} quadrats; not fished; large fish observed and counted under water; small fish poisoned.
[d]Patch reef, Bermuda	SCUBA and Rotenone	49	10,000	49	–	Shallow; not fished; weights of large fish estimated from length; small fish poisoned in 100m.^{2} quadrats.
[e]Fringing reef, Virgin Islands	Rotenone	143	900	160	–	Two shoreline reefs 3–5m. average depth; fished.
[f]Fringing reef, Virgin Islands	Rotenone	34	900	38	–	Reef 10m. deep; "routinely fished".
[e]Artificial reef, Virgin Islands	Rotenone	87	50	1750	–	Cement block reef in 9m. surrounded by seagrass; in fished area but catches prohibited over artificial reef; fish collected 28 months after reef was established.

[a]Talbot and Goldman (1972); [b]Brock (1954); [c]Odum & Odum (1955); [d]Bardach (1959); [e]Randall (1963); [f]Dammann *et al.* (1969)

Table II : Estimates of Abundance of Fish in Representative Temperate Areas.

Location	Methods	Weight (gms./m.^{2})		Remarks
		Mean	Range	
[a]English Channel	Catch data	5.6	–	Demersal fish only; rough estimates based on trawl catch rates and presumed abundance of fish which escape capture.
[b]Block Island Sound, U.S.A.	Swept area	9.2	2–20	One hour monthly trawl tows over three-year period.
[c]U.S. lakes	Variety of methods	34.3	$<$1–224	Weighted mean from 302 lakes calculated from frequency table; data for individual lakes not available.

[a] Harvey (1950)

[b] Merriman and Warfel (1947)

[c] Carlander (1953)

in Table I. In this case, after slightly more than two years, the daytime fish population was over ten times more dense than on adjacent natural reefs (see Randall, 1963) suggesting the potential of such structures for attracting fish from nearby shoal waters and not necessarily indicating a greatly increased carrying capacity for the overall environment.

As indicated in Figure 1, the majority of fish on coral reefs are quite small. Ninety percent or more of the fish collected or observed in two reef locations in the Caribbean were less than 0.1 kg. in weight; however, both of these samples were from shallow water and are not representative of the size distribution of fish in deeper water where some of the most successful fishery efforts are concentrated. Size distribution of captured fish as observed on an exploited reef are given in Table III.

IV. HARVEST EXPERIENCE

Fishing activities in these reef-lagoon-shoreline environments are very diversified, depending on the nature of the bottom and the type and abundance of fish present. Indigenous fishing traditions often control the pattern of the fishing activity which is generally characterized by the use of small, open boats and unsophisticated gear such as handlines, gill nets, seines and relatively simple, small traps and pots. Though fishing at first develops just inside the reefs and in the protected shallows, more advanced efforts are commonly focused on the outer reef slopes or on offshore shelf areas which may be enriched with reef patches. Such advanced practices often include attention to the pelagic oceanic fishes occurring close in but, as noted above, we have not intentionally lumped these in the present assessment of the supporting potential of the shallow-water environments. The mangrove swamps and the seagrass beds which are close inshore are generally too shallow to permit extensive fishing and the associated fishes are smaller than in the more seaward locations.

Table IV is a compilation of fishery information from reefs and their associated shallow-water environments in terms of annual catch, number of boats and fishermen, the amount of available reef and associated shelf area, and the harvest rates per unit area, also per unit effort. (Note: Unlike the abundance data of the previous section applicable only to measured or estimated reef areas, this tabulation relates to the best available estimate of the area of the total supporting shallow-water environment.) Relatively high effort fisheries are illustrated in the data for Jamaica, the Virgin Islands, Mauritius and Puerto Rico. The data from Lamotrek, Bermuda and Cuba are typical of low effort fisheries: in Bermuda during 1956, only serranids

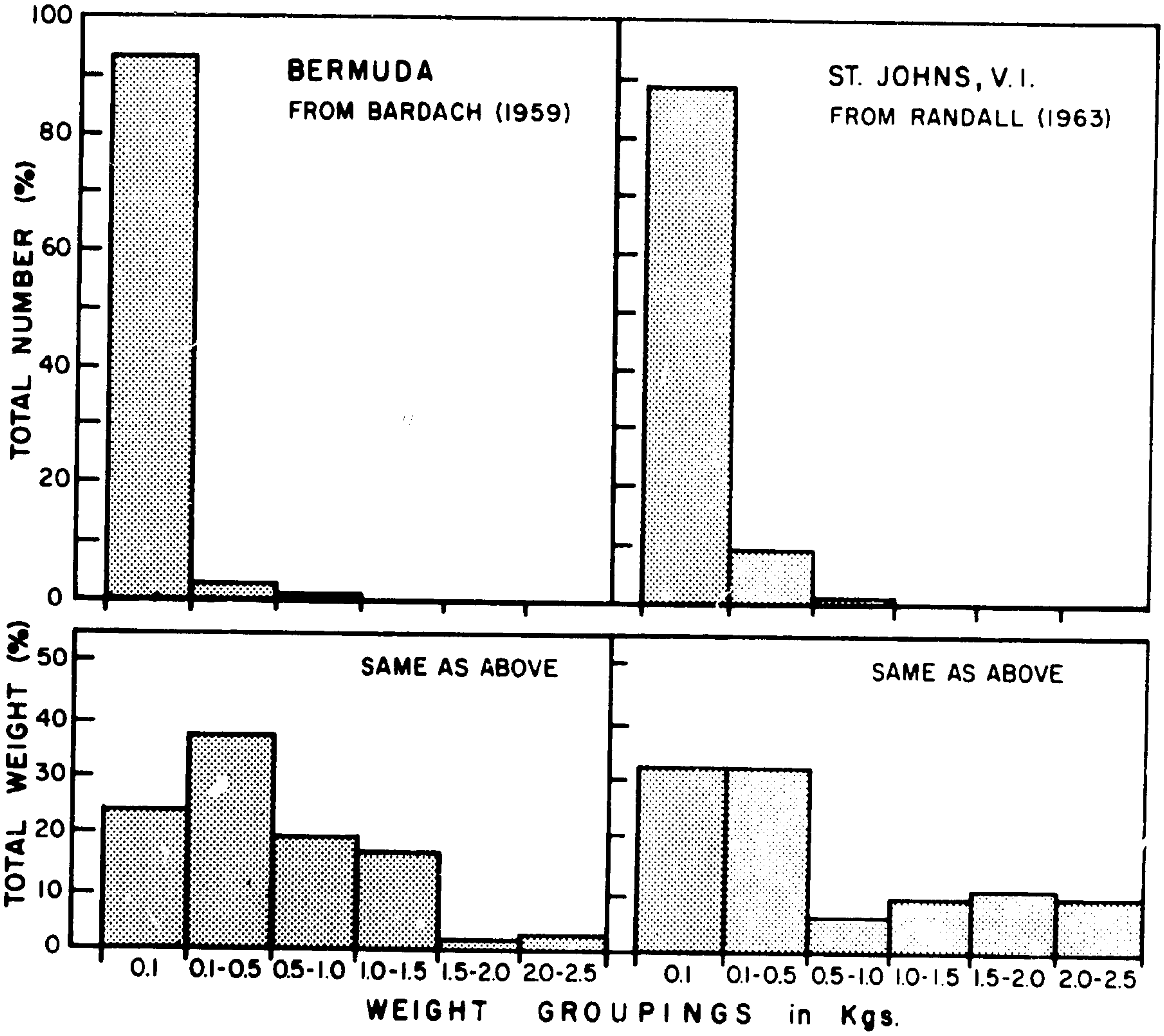

Figure 1: Weight frequency, expressed as per cent of total number and per cent of total weight, for two samples of reef-area shallow water fish populations.

were retained for marketing (Bardach and Menzel, 1957); at Lamotrek, the average man only fishes about 90 days a year (Alkire, 1965); in Cuba, large areas of the inshore shelf were underexploited (Buesa Mas, 1961).

A. CATCH PER UNIT AREA

Per area harvest rates from reef and adjacent environments ranged from 0.4 tons/km.^{2} to nearly 5.0 tons/km.^{2} in six locations for eight different years. The average yield per unit area for a more developed inshore reef fishery may lie between 2.0 and 5.0 tons/km.^{2} while some of the less developed, low effort fisheries harvest 1.0 tons/km.^{2} or less. To put this in perspective, we note that the harvest of bottom fishes in the North Sea and the surroundings of Iceland (Mortimer and Hickling, 1954) and on Georges Bank (Clarke, 1946) are generally appreciably below 5 tons/km^2/year.

B. CATCH PER UNIT EFFORT

Annual catch per man data in Table IV ranges from about 0.5 to 4.5 metric tons. In comparing catch/area data and catch/man data in this table, there is a suggestion that the catch in return for effort declines under intensive exploitation.

Table III: Average Weight, by Species, of Experimental Trap Catch, St. Johns, Virgin Islands[a]

Family/Species	Number of Specimens	Total Weight (kgs.)	Mean Weight per Specimen (kgs.)
Holocentridae			
Adiroyx coruscus	1	<0.01	<0.01
Holocentrus rufus	32	1.99	0.06
Myripristis jacobus	2	0.11	0.06
Serranidae			
Cephalopholis fulva	2	0.20	0.10
Epinephelus guttatus	1	0.29	0.29
Petrometopon cruentatum	2	0.77	0.38
Lutjanidae			
Ocyurus chrysurus	1	0.04	0.04
Pomadasyidae			
Haemulon aurolineatum	24	1.52	0.07
H. carbonarium	1	0.07	0.07
H. chrysargreum	23	1.87	0.07
H. flavolineatum	70	4.29	0.06
Sciaenidae			
Odontoscion dentex	1	0.05	0.05
Pomacentridae			
Chromis marginatus	1	0.04	0.0[illegible]
C. multilineata	14	0.48	0.03
Eupomacentrus leucostictus	4	0.08	0.02
E. planifrons	9	0.16	0.02
Microspathodon chrysurus	12	0.84	0.07
Totals:	200	12.80	–
Average:	–	–	0.064

Note: Sample taken from 900m.² of reef, 10m. deep, "routinely subjected to fishing pressure".

[a] Dammann *et al* (1969)

C. HARVEST IN RELATION TO NEED IN ISOLATED POPULATIONS

Estimates of the fishing effort and estimated harvests of isolated populations living on atolls (Table V) provide an insight into the potential of reef area fisheries to meet protein needs and the probable reliance upon such food sources by peoples living "harmoniously" with nature. In each case, entire protein needs may be nearly met with but little expenditure of harvest effort. Only at Ifaluk, with a limited shallow-water environment, does the necessary catch reach levels which, judging from catch/area harvest data in Table IV, might not be easily obtained.

V. DISCUSSION

Having noted that, in some instances at least, the catches of the reef and associated environs are quite impressive, it is important to point to the problems to be faced if we are to consider the further development and management of reef area fisheries. First, is the obvious fact that rough bottom topography is an obstacle to the development of large-scale, heavily capitalized fishery oper-

Table IV : Harvest Data for Selected Bottom Fisheries on Reefs and in Adjacent Shallow Water Areas.

Location	Year	Catch (Metric Tons)	Number of Boats	Number of Fishermen	Fishing Area (km.^{2})	Harvest (g./m.^{2}, Tons/km.^{2})	Catch per Effort	
							Tons per Man/Year	kgs. per Trap Haul
[a]Bermuda	1956	450		80–100	1035	0.4	4.5	1.6 (in 4–20m.) 3.2 (in 20–60m.)
[b]Jamaica	1945	5500			2860	2.0		
[c,d]Jamaica	1962	11,000	3000	7000	2860	4.0	1.4	
[c]Jamaica	1971	6350			2860	2.2		
[e]U.S. Virgin Islands	1967			400			2.1	
[e]British Virgin Islands	1967						3.3	
[f]Netherlands Antilles	1959	1000	803	1218			0.8	
[g, h]Puerto Rico	1971	1850	900	2000		0.8	0.9	2.5
[i]Cuba	1962	20,000	1700	6800	55,000	0.5	3.0	
[j]Mauritius	1945	1650		1150	350	4.7	0.[illegible] (in<20m.) 1.4 (in 20–240m.)	
[k]Lamotrek Atoll	1964	20		56	44	0.4	0.4	

Note: Fishing area variously calibrated by those presenting the data; in all cases it is represented as the inshore deep-area platform including part of the slope. When possible, spiny lobsters have been omitted from harvest data; figures for Jamaica, Netherlands Antilles and Mauritius probably include small quantities of lobster.

[a]Bardach and Menzel (1957); [b]Munro (1969); [c]Munro (1973); [d]Oswald (1963);

[e]Dammann (1969); [f]Zaneveld (1962); [g]Juhl and Suarez-Caabro (1972); [h]Juhl (1972); harvest/area calculated from the catch data applicable to a selected southwest coast fishing area measured out to the 20 fathom curve.

[i]Buesa Mas (1964; [j]Wheeler and Ommanney (1953); [k]Alkire (1965).

Table V : Comparison of Estimated Harvest and Protein Needs for Four Pacific Atolls.

Atoll	Population[a]	Number of Fishermen[b]	Area of Reef and Shallow Water (km.^{2})[c]	Estimated Annual Harvest[d] (Metric tons)	Estimated Annual Fish Harvest (tons) to Meet Protein Needs[e]	Harvest (tons) per Reef Area (km.^{2})
Lamotrek	201	56	44	20	22	0.45
Ifaluk	325	90	6	32	35	5.14
Kapingamarangi	490+	136	67	49	54	0.73
Raroia	350	98	400	35	38	0.09

[a] Data from Douglas (1969) for latter three atolls; Lamotrek figure from Alkire (1965)

[b] Equal to the number of adult males and given for Lamotrek by Alkire (1965); estimated for remaining atolls as the same proportion of the population as on Lamotrek.

[c] Lagoon plus outer reef; area computed from Hydrographic Office charts.

[d] Harvest = number of fishermen x 360 kgs./man/year catch rate given by Alkire (1965) for Lamotrek.

[e] Assumes 300 g. of fish are required to supply minimum daily protein requirements per capita.

ations. The diversity of fishes involved is also a deterrent to larger operations because of the difficulties in handling and processing highly mixed catches. As a result, participation in such fisheries tends to be restricted to the small operator with small rigs working "close to home." This, again, is a deterrent to resource utilization since reef area environments are widely scattered and small boats are not suited for long distance transport of catches to heavily populated demand areas.

The small size of the fishes around reefs is an added deterrent, often overlooked as we stress the harvest problems associated with species diversity. Often the size pattern is attributed to overfishing and, in a typically unregulated fishery, exploitation undoubtedly is involved in some locales. Still, the natural size distribution, particularly as noted for populations close to shore, is obviously unfavorable, discouraging large scale operations but not necessarily inhibiting the small operator. While handling, processing and marketing on such stocks may not unfold in a grand manner, the demand for little fish is surprisingly high amongst consumer populations of some tropical areas, encouraging the exploitation of catches which might be ignored elsewhere. Perhaps minimum size limits should be applied to the fishery, a point likely to receive little attention by people satisfied by eating small specimens; on the other hand, noting how easily the larger fish are skimmed off in reef harvests, the suggestion has been made (for example by C. Lavett Smith, personal communication) that management of these resources might benefit by practices designed to take all sizes, encouraging a balance in the size range of the fish supported by the environment.

Territorial and other limits to the range of many fishes of these environments is an added obstacle to reef area fisheries development inasmuch as the style of fishing easiest to pursue in these habitats, i.e. handlining, trapping, etc., tends to concentrate on limited areas quickly removing the home territory individuals. Systematically rotating fishing locations is often suggested as a counter measure but this is difficult to accomplish when managing a publicly owned resource.

Finally, all plans and hopes for expanding reef area fisheries are plagued with the occurrence of the toxin, ciguatera, in the flesh of reef area fishes, likely to be most troublesome in the large carnivores most desired in fishery development. Taking advantage of the tendency for this poison to be localized in distribution, fish from areas of interest can be checked and troublesome locales ruled "off-limits" to harvesting. The source and course of this poisoning is not clear; tests for its presence in fish flesh are cumbersome; and antidotes to the toxin have not been perfected. Obviously, the ciguatera problem is a large, complex issue which we are more or less sidestepping in concentrating on the gross potential which can be realized where areas are known to be relatively free of the problem.

From the foregoing remarks, we can readily understand why the fisheries around reef environments have been and will probably continue to be the province of the small operator. Prone to think on a grand scale, we have tended to overlook the potential of such activity; we have failed to appreciate that large numbers of relatively small operators can be highly significant both in terms of employment and cumulative catch; we have failed to realize that multiple small landing ports can help meet the food needs of millions of people. Such oversights suggest directing greater attention to these small operations. At present these are often subsistence in character but they are amenable to upgrading to an artisan status with modest improvement in methods, with realistic provisions for handling and marketing on a multiple small-scale basis, and with suitable fishery regulations. Furthermore, these fin fish harvest possibilities are generally enhanced by invertebrate and by other fishery resources, often very impressive, not touched upon in this presentation.

Reference to suitable management and regulation brings up the need for fundamental fishery biology information to accompany development efforts. First and foremost, we need such basic facts as harvest statistics, population estimates related to supporting environments, growth rate data, reproduction-recruitment data, etc. Fisheries biologists may react in despair to the thought of calculating maximum sustainable yields in settings where one must deal with numerous interrelating species and where the clues on growth rates may be obscure but some of the data are within grasp and new approaches may be considered (see, for example, Kutty, 1970). To be sure, it will be virtually impossible to study adequately the many scattered locales calling for regulated development; however, better information for a few representative areas will have high transferability.

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