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## *Ecological interactions between tropical coastal ecosystems*

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## PREFACE

Thirteen years ago the United Nations Conference on the Human Environment (Stockholm 5-16 June 1972) adopted the Action Plan for the Human Environment, including the General Principles for Assessment and Control of Marine Pollution. In the light of the results of the Stockholm Conference, the United Nations General Assembly decided to establish the United Nations Environment Programme (UNEP) to "serve as a focal point for environmental action and co-ordination within the United Nations system" (General Assembly resolution 2997(XXVII) of 15 December 1972). The organizations of the United Nations system were invited "to adopt the measures that may be required to undertake concerted and co-ordinated programmes with regard to international environmental problems", and the "intergovernmental and non-governmental organizations that have an interest in the field of the environment" were also invited "to lend their full support and collaboration to the United Nations with a view to achieving the largest possible degree of co-operation and co-ordination". Subsequently, the Governing Council of UNEP chose "Oceans" as one of the priority areas in which it would focus efforts to fulfil its catalytic and co-ordinating role.

The Regional Seas Programme was initiated by UNEP in 1974. Since then the Governing Council of UNEP has repeatedly endorsed a regional approach to the control of marine pollution and the management of marine and coastal resources and has requested the development of regional action plans.

The Regional Seas Programme at present includes eleven regions <sup>1/</sup> and has over 120 coastal States participating in it. It is conceived as an action-oriented programme having concern not only for the consequences but also for the causes of environmental degradation and encompassing a comprehensive approach to combating environmental problems through the management of marine and coastal areas. Each regional action plan is formulated according to the needs of the region as perceived by the Governments concerned. It is designed to link assessment of the quality of the marine environment and the causes of its deterioration with activities for the management and development of the marine and coastal environment. The action plans promote the parallel development of regional legal agreements and of action-oriented programme activities<sup>2/</sup>.

The idea for a regional South Pacific Environment Management Programme came from the South Pacific Commission (SPC) in 1974. Consultations between SPC and UNEP led, in 1975, to the suggestion of organizing a South Pacific Conference on the Human Environment. The South Pacific Bureau for Economic Co-operation (SPEC) and the Economic and Social Commission for Asia and the Pacific (ESCAP) soon joined SPC's initiative and UNEP supported the development of what became known as the South Pacific Regional Environment Programme (SPREP) as part of its Regional Seas Programme.

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1/ Mediterranean, Kuwait Action Plan Region, West and Central Africa, Wider Caribbean, East Asian Seas, South-East Pacific, South Pacific, Red Sea and Gulf of Aden, Eastern Africa, South-West Atlantic and South Asian Seas.

2/ UNEP: Achievements and planned development of UNEP's Regional Seas Programme and comparable programmes sponsored by other bodies. UNEP Regional Seas Reports and Studies No. 1. UNEP, 1982.

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## ECOLOGICAL INTERACTIONS BETWEEN MANGROVES, SEAGRASS BEDS, AND CORAL REEFS

Charles Birkeland

### Introduction

Coastal ecosystems have been of particular importance to tropical Pacific islanders because islanders have always depended upon coastal marine resources for at least 90% of their animal protein (Johannes 1977). The rational management of tropical coastal ecosystems should be of worldwide interest because mangroves, seagrass beds, and coral reefs are among the most productive ecosystems, marine or terrestrial (Table 1). In a literature review by Lewis (1977: Table 2), seagrass beds and coral reefs ranked higher in gross primary productivity per m<sup>2</sup> per year than other ecosystems, including sugar cane fields in Java and the nutrient-enriched Peru current. Mangrove ecosystems supplied with allochthonous nutrient input produce comparable levels of gross primary productivity (Lugo and Snedaker 1974: Table 2). These three coastal ecosystems are also of interest because of their geographic prevalence in the Pacific islands. These ecosystems provide or influence the important natural resources for Pacific islanders.

According to Adams et al. (1973), it is generally accepted that 75-90% of marine commercial and sport fish species depend on estuarine habitats during at least part of their life cycle. Even if the availability of estuarine habitats is critical for only one period in the life of an organism, the availability of the habitat is important for the success of the population. Estuarine habitats can be important for fishes and invertebrates either as nurseries for juveniles, as a source of food for adults, or both. Most of the productivity of estuarine habitats is a result of the production of marine vascular plants: mangroves, seagrasses or marsh grasses (Golley et al. 1962; Teal 1962; E.P. Odum 1961, 1971; Lugo et al. 1973a,b; and especially Heald 1971 and W.E. Odum 1971 which were cited in Snedaker and Lugo 1973). Since many commercial and sport fishes are dependent on estuarine habitats and since the major portion of the production of estuarine habitats is from marine vascular plants, one might expect that the primary production of marine vascular plants should be important for fisheries. However, this doesn't necessarily follow. The favorable influence of marine vascular plants on fisheries might not be a direct result of their large primary productivity but instead might be a result of their influences towards stabilizing the physical environment, providing habitat and refuge, contributing to the detrital food chain through bacteria and other microbes, or functioning in a role as substrata for epiphytic algae or bacteria. If this is the case, then the primary productivity possibly could be utilized more efficiently by Pacific islands and this is a major topic that will be addressed in this report.

Whether nearshore fisheries are mainly influenced by marine vascular plants through primary productivity or by some other factor, the effect is there. Skud and Wilson (1960); Darnell (1958, 1961, 1967); Sykes and Finucane (1966); Smith et al. (1966); Odum and de la Cruz (1967); Wood et al. (1969); Heald and Odum (1970); Cronin and Mansueti (1971); Odum and Heald (1972); Carr and Adams (1975); Snedaker and Lugo (1973); and Heald (1971) and W.E. Odum (1971), both cited in Snedaker and Lugo (1973).

documented the dependency of commercial and sport fisheries on estuarine systems in which the marine vascular plants were the major primary producers. Because of this, the estimates of the monetary value of marine vascular plant habitats are very high. For example, on the west coast of Florida alone, where the commercial fish production is dependent upon the productivity and organic export from mangroves, the wholesale value of commercial fish catches was worth \$10.4 million in 1971 (Adams et al. 1973). The estimated value of fisheries is several times greater when secondary economic benefits are taken into account. The mangroves which support the fisheries would therefore be found to have a large economic value if monetary estimates were made. If estimates were made for the potential monetary value of marine vascular plant communities to Pacific island economies, the value would be high in relation to the total economies.

The potential yield by artisanal fisheries of coral reefs and lagoons is of about the same magnitude as is the offshore tuna harvest, at least for Micronesia (Johannes 1977). For example, the potential harvest of reef fish in Palau by artisanal fishermen is between 2,000 and 11,000 tons per year while the commercial skipjack tuna fisheries of Palau harvested between 2,000 and 9,000 tons annually between 1965 and 1974 (Mitchell 1975; Johannes 1977).

There is a tremendous amount of literature on mangroves, seagrass beds, and coral reefs, but there is very little literature on interactions between these three coastal ecosystems. Bibliographies pertaining to mangroves (Thurgood 1968; van Tine and Snedaker 1974; Rollet 1981) include over 6000 references. Kent W. Bridges (Department of Botany, University of Hawaii) has a bibliography for seagrasses with over 2000 references. A comparable bibliography for coral reefs would be much larger. Despite this overwhelming mass of literature on these three ecosystems, nearly all the papers deal with particular ecosystems or with interactions between the particular ecosystem and terrestrial or offshore environments.

Because of the importance of these ecosystems to the peoples of the South Pacific islands as sources of protein and other resources as well as for logistic reasons, human settlement and urban development on islands has generally concentrated in coastal regions, especially in harbors where they exist, and along rivers which drain into coastal areas nearby. So while coastal resources are traditionally the resources most heavily utilized, they are also the areas which most directly and immediately feel the impact of man's developmental activities such as land-clearing and pollution. An understanding of how the coastal ecosystems function and interact with each other and with the abutting terrestrial and offshore areas is of primary importance as a basis on which to make sound rational decisions in developmental and coastal zone resource and land management matters.

McNae (1968) suggests that individual plants or species should be referred to as "mangrove" and the community as a whole should be referred to as the "mangal". This has acquired fairly wide acceptance among plant biogeographers (Mann 1982), but we still do not see it commonly in the

transport substantial enough to affect the reef community is provided by Meyer et al. (1983). They measured the growth rates of corals in areas where schools of juvenile haemulid fishes ("grunts") rested during the day, in areas where the haemulids were absent, and in areas in which the haemulids were present during the first year, then experimentally removed for the next eight months. During the first year of the study, two coral heads (*Porites furcata*) near fish aggregations grew significantly faster than did a coral head no more than 25 m away. Water samples were taken within a resting school of haemulids in a coral head and near a head in an adjacent area without the fish aggregation. A significantly greater concentration of ammonium was found in fish aggregations. No differences were found between the two areas in concentrations of molybdate-reactive phosphorous. Sediment traps were also placed under a coral head with an aggregation of fishes and under another head without an aggregation of fishes. A significantly greater quantity of nitrogen and phosphorous in addition to particles with significantly higher percentages of these nutrients were collected from sediment traps under schools of fishes. The results from the first year of the study thus indicated that juvenile carnivorous fishes excrete enough ammonium and defecate enough particles with nitrogen and phosphorous from seagrass beds to significantly affect the coral reef community.

The conclusions of the first year of the study by Meyer et al. (1983) were based on correlations between the locations of fish aggregations, nutrient contents of water and sediment, and growth rates of coral. An alternative explanation for this correlation could be that fishes aggregated where corals grew faster because the presence of nutrients from some source other than fishes was beneficial to both fishes and corals. To test this alternative hypothesis, the fish aggregation of 304 juveniles was removed from one of the corals with a fish aggregation. Results from this second set of tests did not support their original hypothesis rigorously. There was no significant difference in growth of corals with and without fish aggregations ( $t_{17} = 1.36$ ). The authors said this was probably because of a decreased number of grunts (haemulid fishes) over the coral with grunts, more squirrelfish over the coral without grunts, and weather-related factors were obscuring the effect of aggregations of grunts. Whatever the confounding factors were, the experiment did not support conclusively the hypothesis of fish aggregations in influencing the growth of the corals nearby. It would be worthwhile to repeat the experiment in the Caribbean in order to clarify the relative importance of the various factors in influencing the growth of corals.

Assuming that fish which forage over seagrass beds at night and rest over coral heads by day add a substantial input of nutrients to the reef community and can significantly influence the growth of certain coral heads in the Caribbean, we still cannot assume that this same relationship will be found in the Pacific. Initial impressions of fish community structure in the Pacific suggest that the interactions between coral reefs and seagrass beds may be less substantive than in the Caribbean. The aggregations of resting haemulids during the daytime on reefs in the Caribbean are spectacular and appear frequently in travel brochures and photographic books about Caribbean reefs. Although fishes such as *Gnathodentex*, *Monotaxis*, holocentrids and apogonids may forage

halos around reefs. In an elegant experiment (i.e., without the use of artificial materials such as cages), Ogden et al. (1973) removed over 7000 urchins from one patch reef and observed the rapid growth of benthic algae on formerly bare substrata on the patch reef. However, Ogden et al. (1973) and Ogden (1976) did comment that herbivorous fishes in the area of their studies were under intense fishing pressure and their abundances may be unnaturally low.

Hay (1981) and Hay et al. (1983) found that over 90% of the material grazed from Thalassia near coral reefs was taken by herbivorous fishes. Urchins removed less than 10%. In further work in widely scattered areas of the Caribbean, Hay (1984a, b) found that urchins were relatively influential on benthic plant communities in areas where fishing pressure by man was intensive and fishes were by far the most influential on benthic plant communities in more pristine or "natural" areas less heavily fished by man. Hay (1984a, b) concluded that much of the research on the influence of herbivores on benthic community structure in the Caribbean was done at marine laboratories in areas in which the resident scientists recognized severe over-fishing was occurring. Hay further warned that since much of the research in the literature on the effects of herbivores on shallow tropical marine communities was done in these overfished areas, we may have a misunderstanding of the functioning of these ecosystems because we assume these studies were done in communities in their near-to-natural states. Hay (1984a, b) conjectures that overfishing probably caused a drastic reduction in the abundances of predators of urchins (e.g., ballistids) and so urchins increased in abundance in overfished areas by several orders of magnitude. It is interesting to note the comparative scarcity of urchins in Micronesia as compared to the Caribbean (Table 2). Perhaps Micronesia is still in a relatively natural state as compared to the Caribbean. A multitude of alternative hypotheses could be invoked to explain this difference between oceans in urchin abundances, however, e.g., current patterns, phytoplankton densities, etc.

It is possible that as fishing pressure increases further on coral reef fishes in the Pacific, echinoids will be somewhat released from predation pressure and then become more abundant and influential. One of many alternative possibilities is that the abundances of urchins in the Pacific result from sporadic recruitment success (Ebert 1983) rather than predation pressure on adult urchins.

In addition to clearing or drastically reducing the abundance of seagrass blades in halos in the seagrass beds at the boundary of reefs, the size and morphology of seagrass blades within the halo is also altered by the action of herbivores. Within halos, the blades of Thalassia "form a flat curl and tend to lie flat on the bottom" (Ogden and Zieman 1977:379).

Although the influence of herbivores from a coral reef on seagrass communities is well recognized, the influences of the physical factors such as currents and wave action having been altered by the presence of a coral reef are not precluded. Ogden and Gladfelter (in Ogden and Zieman 1977) showed that the physical factors of water currents and wave action were clearly involved in creating a halo 1 m wide around an artificial reef made of construction blocks at a depth of 12 m. However, in



slightly deeper water (15 m), the currents and waves were not effective enough to create a halo; algae and grazed seagrasses grew right up to the base of the reef at 15 m (Ogden and Zieman 1977).

I have not found any direct evidence in the literature for the influence of herbivores in creating halos in seagrass beds in the tropical Pacific. Halos do exist in seagrass beds in the Pacific at the boundaries to patch reefs, but ripples and excavations in the sand in the halo at the base of the reef made the influence of currents and waves appear to be a more attractive explanation for the halo than the influence of herbivores.

Echinoids are generally less common in the Pacific, at least in Micronesia, than in the Caribbean (Table 2). Whether herbivores from coral reefs have a significant effect on the formation of halos, the morphology, size distributions, and abundances of seagrasses and/or the species composition of the associated algal communities in seagrass beds has not been documented to any extent in the Pacific. There may be significant qualitative differences between the Pacific and the Caribbean in the nature of interactions between seagrass beds and coral reefs and any research on this matter would be worthwhile.

While the transfer of nutrients is almost entirely from the seagrass bed to the coral reef (by urchins and carnivorous or omnivorous fishes that forage from the reef to the seagrass bed at night and by herbivorous fishes that forage by day), the effects of interactions on community structure are almost entirely in the opposite direction, from the coral reef to the seagrass bed by herbivorous fishes and urchins (Ogden and Gladfelter 1982). I have found no substantive evidence for interactions of this nature between mangroves and seagrass beds or between mangroves and coral reefs. Interactions between mangroves and the other two ecosystems appear to be mainly through alteration of the physical environment.

Another form of interaction between coastal habitats occurs when one habitat serves as the nursery for a species which resides in another habitat as an adult. Ogden and Zieman (1977) stated that seagrass beds serve as nurseries for juvenile Diodon, Holocentrus, Ocyurus, Acanthurus, Mulloidichthys, and Halichoeres which apparently settle from the plankton into seagrass beds, spend time in seagrass beds growing as juveniles, then later take up residence on coral reefs. Ogden and Zieman (1977) report that Diodon juveniles are observed to arrive between June 15 and July 15 each year (for at least 3 years previous to 1977) as dense schools of thousands that presumably settle from the plankton. Gladfelter (in Ogden and Zieman 1977) says the schools are visible from an airplane as large dark spots.

Snappers (Lutjanidae), grunts (Haemulidae), and the great barracuda (Sphyræna barracuda) initially recruit to seagrass beds and mangroves. Snappers are particularly dependent on mangroves as a nursery. The great barracuda spends its first year in seagrass beds and its second summer among the roots in the mangrove swamp (de Sylva 1963). It is interesting to note that Sphyræna barracuda and the reef squid Sepioteuthis are circumtropical except for the Pacific coast of the Americas. Seagrass beds are essentially nonexistent along the Pacific coast of the tropics

production or nutrients or to interactions between their component species. Coral reefs, mangroves, and seagrass beds all form structures that influence water movements in a manner that stabilizes the physical environment. All three ecosystems produce sediment and, as a result of their modification of water movements, all three ecosystems retain sediments. The role of seagrass beds and mangroves as nursery areas may be more a result of the habitat morphology than productivity because the primary production that goes directly into the herbivore food chain may be production from epiphytic algae which use the seagrasses and mangroves as substrata rather than from the production of the seagrasses and mangroves themselves.

Coral reefs form barriers that dissipate wave energy. Lagoons would not exist without coral reefs. Mangroves and tropical seagrass beds are nearly always found in areas with reduced wave energy. Mangrove seeds have been found to attach and take root where they would not have otherwise because of the reduction in wave action brought about by small, stone, fish trap weirs (Saenger and Hopkins 1975). If mangroves have been able to take root where they would not have otherwise because of changes in water movement brought about by an artisanal, stone, fish weir, then it seems quite possible that coral reefs allow some mangroves to exist where they would not have otherwise by forming barriers which dissipate wave energy. By forming lagoons, coral reefs allow the existence of seagrass beds in some areas where they would not otherwise exist. However, mangroves and seagrass beds also exist in areas away from coral reefs, in natural harbors or in the leas of points of land.

Mangrove forests also occlude and absorb terrestrial freshwater runoff and thereby buffer large salinity changes in coastal waters. Both mangrove forests and seagrass beds trap and stabilize sediments, forming rich depositional basins for sediments and reducing the sediment load on coastal areas. Coral reefs produce calcareous sediments which accumulate in the lee of reefs. Mangroves and seagrass beds produce sediments by depositing leaves and blades. Epiphytic organisms on the prop roots and blades and infaunal organisms in the sediments also produce sediments.

All three ecosystems influence each other favorably by stabilizing the physical environment. Coral reefs, mangrove forests, and seagrass beds all stabilize the physical environment by dissipating wave action (mostly by coral reefs), buffering salinity changes (mostly by mangroves), and by stabilizing sediments. All three ecosystems also produce sediments.

#### Effects of land mass and water movement patterns

The ecological interactions between coral reefs, seagrass beds, and mangroves are complex and academically interesting. At some locations in the Caribbean, the effects of these interactions are measurable as documented in the previous sections. However, coral reefs can develop fully and survive in the absence of nearby seagrass beds or mangroves. Likewise, seagrass beds and mangroves can develop and survive away from coral reefs and away from each other. Therefore, interactions between coral reefs, seagrass beds, and mangroves are not always completely

particularly prevalent in developing areas where land is cleared for agricultural development (Moberly 1963; Fairbridge and Teichert 1948) and for housing and road construction (Fan and Burnett 1969; Van Eepoel and Grigg 1970; Van Eepoel et al. 1971; Maragos 1972; DiSalvo 1972; Wells et al. 1973; Dodge et al. 1974; Johannes 1975).

Coral reefs are the most susceptible of the coastal ecosystems we are comparing to damaging effects of siltation and terrestrial runoff of nutrients. Seagrasses have a greater tolerance of these factors and at low levels may even benefit from a slight increase. The mangrove ecosystem is the most tolerant and generally benefits from terrestrial runoff. It is clear that to make wise and rational decisions in the management of coastal ecosystems and resources, we should pay particular attention to understanding the influences of land masses, terrestrial input of materials and patterns of water movement on the nearshore coastal ecosystems.

The reason that chemical nutrients are generally sparse in tropical ocean waters is because phytoplankton and benthic algae take up and generally deplete the nutrients in the photic zone and the reservoir of nutrients in the water column below the photic zone is not generally available because the tropical seas are thermally stratified throughout the year. Despite these restrictions on nutrient availability, shallow tropical benthic communities are very productive (Table 1). The productivity of ocean waters is substantially increased near land masses (Doty and Oguri 1956; Jones 1962; Sorokin 1973; Gilmartin and Revelante 1974). This "island mass effect" must result ultimately from either an input or a prolonged retention of nutrients. There are at least nine mechanisms by which the presence of a land mass could produce an increase in input or retention of nutrients: terrestrial runoff, groundwater seepage, nitrogen fixation by benthic organisms, benthic nutrient regeneration, secondary productivity, internal waves, upwelling, eddying, and increased residence time of water. There may be additional ways in which the nature of the nearshore landmass can effect the productivity of nearshore habitats. How these factors interact with coral reef, seagrass, and mangrove ecosystems is of primary importance in understanding and managing the ecosystems.

Evidence for the importance of terrestrial runoff for nearshore fisheries can be found in Chidambaram and Menon (1945), Murty and Edleman (1966), Aleem (1972), Sutcliffe (1972, 1973). The effects of terrestrial runoff of nutrients on aspects of coral reef communities is discussed in Marsh (1977) and Birkeland (1982). An example of the influence of groundwater is presented in FitzGerald (1978). While influential groundwater seepage and terrestrial nutrient runoff may occur only at high islands, nitrogen fixation by blue-green algae is operational at both high islands and atolls. The importance of benthic nutrient regeneration and the magnitude of secondary productivity are presented in Johannes (1967), Johannes and Gerber (1974), Gerber and Marshall (1974 a,b), Sournia and Ricard (1976b), Sournia (1977), Scott and Jitts (1977), Lewis (1982), and Kropp and Birkeland (1982).

Internal waves, eddying, upwelling, and increased residence time of water are all influences on productivity that are brought about by alterations

the phytoplankton have undergone enough cell divisions to build up a standing crop sufficient enough to support larvae of A. planci. The dispersion of water could also thin out the concentration of A. planci larvae as well as the food supply of the larvae. Studies of fish larvae indicate that upwelling of nutrient-rich water leads to phytoplankton blooms, but the movement of the upwelling waters disperse food organisms so that the food particles are too low in concentration to support larval anchovy growth (Smith and Lasker 1978).

#### LAGOONS

By enclosing water in a lagoon, the productivity of an otherwise oligotrophic body of water might be enhanced because of the increased residence time or cohesiveness of the water mass. A particularly striking example of biomass being supported under extremely oligotrophic conditions can be observed in the enclosed lagoons of the Tuamotus. Takapoto is a raised atoll with an enclosed lagoon that is approximately 16 km long, 4.5 km wide and averages 23 m deep. This  $1.6 \times 10^{10} \text{ m}^3$  (roughly) of water is connected to the sea by a couple of hoas that a person can easily wade across. Therefore the lagoon must be one of the most self-contained of coral reef systems with waters of particularly long residence time. Sournia and Ricard (1975) found the oceanic waters surrounding Takapoto to have low nutrient ( $0.36 \mu \text{ at g } \ell^{-1} \text{ NO}_3\text{-N}$ ;  $0.26 \mu \text{ at g } \ell^{-1} \text{ PO}_4\text{-P}$ ) and chlorophyll *a* ( $0.14 \mu \text{ g } \ell^{-1}$ ) contents. They also found that the waters within the enclosed lagoon have even lower nutrients ( $0.22 \mu \text{ at g } \ell^{-1} \text{ NO}_3\text{-N}$ ;  $0.12 \mu \text{ at g } \ell^{-1} \text{ PO}_4\text{-P}$ ) but much higher chlorophyll *a* ( $0.46 \mu \text{ g } \ell^{-1}$ ) contents. Yet the main industry of Takapoto involves the production of pearls by filter-feeding bivalves. Tons of bivalves (Pinctada, Arca, Iridacna) live in the lagoon despite the water being very sparse in nutrients. It may be that the enclosed lagoonal system is so self-contained that the nutrients are quickly recycled and contained in the biomass of the bivalves and fishes. The main effect of an atoll comes from its configuration which generally increases the residence time of water.

The way in which a lagoon functions leads us to a conclusion concerning a rational method of resource management in lagoons. Like the tropical rainforests, coral reef ecosystems may be able to withstand pruning and recycling but not harvesting and exporting because most of the nutrients are recycled and not imported. The removal of living materials from a coral reef community on a large scale might cause depletion at a rate at which the system would be unable to replenish and maintain itself. At Takapoto, the oysters are harvested but only the pearls are exported, the meat is eventually recycled into the lagoon. If we scrape a temperate shoreline of barnacles, we would expect the barnacles to return in a year or so; barnacles feed on imported suspended material. If we dredge or dynamite a reef, we might expect recovery to take a very great time because the nutrients have been lost and a substantial time may be required for the necessary processes to build up another stockpile.

seagrass virtually disappeared (e.g., the black brant, cf. Cottam 1934). However, the fishes and invertebrates generally did not decrease in abundance during the die-off of Zostera. Harrison and Mann (1975) suggested that this was because the accumulated detrital reserve of seagrasses decomposes so slowly that the foods and nutrients enter the food chain by decomposition at a fairly constant rate, relatively unaffected by any large year-to-year variations in productivity. In this way vascular plants of coastal ecosystems stabilize some food chains as well as some aspects of the physical environment.

#### Assimilation of vascular plant material by marine invertebrates and fishes

Detrital material from mangroves and seagrasses are often found in the stomachs of marine invertebrates and fishes (Gunter 1945; Darnell 1958, 1961; Springer and Woodburn 1960; Hansen 1969; Odum and Heald 1972; Carr and Adams 1973). These observations are used as documentation of the importance of mangroves and seagrasses for commercial and sport fisheries (Skud and Wilson 1960; Darnell 1967; Sykes and Finucane 1966; Smith et al. 1966; Odum and de la Cruz 1967; Wood et al. 1969; Cronin and Mansueti 1971). While mangroves and seagrasses are probably important to fisheries as providers of structural shelter and refuges for juveniles from predators, as substrata for epiphytic algae and bacteria which in turn contribute substantially to the food web, and as sediment stabilizers, there is evidence that calls to question whether much of the calories and nutrients in vascular plant material in the guts of invertebrates and fishes is actually being assimilated. Although mangrove forests and seagrass beds are among the most productive ecosystems in the world in terms of gross primary productivity (Ryther 1963; McRoy and McMillian 1977; cf. Table 1), it appears that over 90% of the net productivity is going into the detrital food web (Harrison and Mann 1975; Kirkman and Reid 1979) and less than 10% into direct herbivory, although a notable amount passes through the guts of marine invertebrates and fishes.

Even decomposers apparently process vascular plant material more slowly than they process algal or animal material. In temperate Atlantic waters, the kelp Laminaria longicruris decays rapidly and makes a quick substantial contribution to the detrital food web (Mann 1972a, b) while the eelgrass Zostera marina decays slowly, with only 35% loss of dry weight after 100 days at 20°C in the laboratory in the presence of abundant microorganisms and nutrients (Harrison and Mann 1975). Of this 35%, 82% was from leaching and occurred even under sterile conditions. Coastal sediments in eelgrass beds have accumulations of slowly decomposing eelgrass fragments as a reserve of organic matter which slowly becomes available for benthic consumers. In estuarine creeks of Georgia, over 90% of the detritus is from the marsh grass Spartina (Odum and de la Cruz, 1967). However, leaves of Spartina may enter the detritus slowly as they may die on the stalk and remain attached upright for long periods of time (Lopez et al. 1977). Similarly, the distal portions of tropical seagrasses such as Thalassia remain attached upright long after they become senescent. The great amount of Thalassia blades

was actually assimilated by the animals and also of giving the actual initial source of carbon regardless of the pathways through the food web.

Rodelli et al. (1984) analyzed the stable carbon isotope ratios for over 600 animals from Malaysian mangrove swamps, coastal inlets, and offshore areas. They found that carbon from mangrove trees was about equally important as carbon from algal sources in the diets of organisms from mangrove swamps. However, animals from collections made offshore showed almost no carbon from mangrove trees to be assimilated into their tissues although mangrove carbon was abundant as detritus at these sites. Rodelli et al. (1984) concluded that fragments remaining intact offshore were apparently quite refractory to metabolism.

Mangrove and seagrass leaves also appeared to be generally resistant to digestion by marine invertebrates even within the habitats (Rodelli et al. 1984). The stable carbon isotope ratio demonstrated that suspension-feeders (9 species of barnacles and bivalves) living on the prop-roots or low on the trunks of mangrove trees filtered water that contained a substantial amount of mangrove materials while the tissues of the suspension-feeders were generated mostly from algal sources. The tissues of snails that preyed upon barnacles and mussels (Thais and Murex) also was derived ultimately from algal sources two trophic levels below. Alpheus sp. and Upogebia sp. lived in the mud around the roots of mangrove trees, but the carbon isotope ratios indicated that they were either selectively feeding or selectively assimilating algal materials from the sediment (Rodelli et al. 1984).

In mangrove swamps, shrimps, crabs, and fishes generally assimilated approximately equal proportions of foods from mangrove and algal sources while offshore populations only assimilated algal derived carbon (Rodelli et al. 1984). Note that we are discussing what is being assimilated into the tissues, not what is being consumed. Much of the detrital material available in the sediments and water column both offshore and in the mangrove swamp was derived from mangrove sources. It is most likely that much of the sediment consumed by crabs and shrimp living on mud around roots of mangrove trees and of the water filtered by suspension-feeders attached to roots of mangrove trees contains a substantial amount of material of mangrove origin. Apparently material of mangrove origin is usually resistant to the metabolic processes of marine invertebrates and marine fishes so these animals more easily assimilate material of algal origin. Since proportionately less of the available material of mangrove origin is assimilated by offshore populations of shrimp, crabs, or fishes, Rodelli et al. (1984) were led to speculate that mangrove materials become even more resistant with time during the offshore drift or transport. Studies by Colley et al. (1962) and Wiebe and Pomeroy (1972) also suggest that mangrove and Spartina material was metabolically refractory. Haines (1979) and Haines and Montague (1979) also used the stable carbon isotope method to trace the ultimate source of photosynthetic production in Spartina marshes. They found that Spartina was less important and planktonic and benthic algae were far more important than was previously thought. While insects (note that they had evolved in terrestrial habitats) and marsh snails had  $^{13}\text{C}$  values similar to vascular plants, mud-snails, bivalves, and crabs had  $^{13}\text{C}/^{12}\text{C}$  ratios similar to planktonic and benthic algae.

chemicals such as cellulose in vascular plants. The leaves of mangroves may be particularly difficult to decompose or digest because of tannins. Tannins are prevalent in mangrove leaves and are the basis of the economic value of mangroves to the leather industry (Swain 1965; Haslam 1979). Tannins are known to form complexes with protein and to inhibit the action of enzymes (Pridham 1963; Goldstein and Swain 1965). By this mechanism, tannins are known to inhibit the ability of microbes to break down leaves (Handley 1961). Tannins inhibit the growth of fungi (Williams 1963) and the transmission of viruses (Bawden and Kleczkowski 1945; Cadman 1960). The colonization and microbial degradation of mangrove leaves in seawater is delayed by the presence of tannins in the leaves and begins after the tannins are leached out (Benoit and Starkey 1968; Cundell et al. 1979).

The tannins released from decaying leaves and dissolved in the water can inhibit the growth of diatoms and presumably other phytoplankters and thereby reduce the phytoplankton productivity in waters in or near mangrove swamps (Smayda 1970; Kutner 1975).

Tannin-containing plants are also repellant to herbivores such as snails (Haberlandt 1914), locusts (Shpan-Gabrielfith 1965), and sheep (Wilkins et al 1953), and are actually toxic to cattle, goats, sheep, rabbits, rats and chickens (Dollahite et al. 1962; Kingsbury 1964; Glick and Joslyn 1966; Vohra, Kratzer, and Joslyn 1966). This toxic effect of tannins to herbivores is probably largely a result of formation of tannin-protein complexes in the gastrointestinal tract which results in a reduction of nitrogen assimilation. The proportion of dietary nitrogen that was egested increased by a factor of six compared to controls when 8% tannic acid was incorporated into the diet of rats (Glick and Joslyn 1966).

The inhibition of growth of moth larvae by tannins was also suggested to be the result of the formation of relatively indigestible complexes of tannin with available protein, thus reducing dietary nitrogen assimilation (Feeny 1969). Casein, when complexed with oak leaf tannin, is completely protected from hydrolysis by trypsin at pH 7.6 (Feeny 1970). As little as 1% fresh weight of tannin in the diet of moth larvae causes a significant reduction in larval growth rate and pupal weight (Feeny 1968). The degree of complex formation depends on the ratio of protein to tannin concentrations and on the time of contact between protein and tannin (Feeny 1969). In oak leaves late in the season, for example, the ratio of tannin to protein is about 1:3 and a caterpillar would have to ingest about 4 times the amount of leaf material that it would have had to if there were no tannins in order to obtain adequate nitrogen (Feeny 1970).

Plants store their tannins in vacuoles, separated from the rest of the plant cell by a membrane (Nierenstein 1934). If the membrane of the vacuole is punctured, the tannins can be released and bring about precipitation of protoplasmic proteins in the plant cell (Doby 1965). The synthesis of tannins is achieved through a complex pathway that requires a large quantity of sugars for both energy and structure (Haslam 1966; Feeny 1970; Zucker 1983). The effects of tannins in reducing metabolic efficiency of animals, fungi, and bacteria result from the general formation of hydrogen bonds, and perhaps covalent bonds, with

winter food of the black brant is eelgrass (Cottam 1934) and black brant and Canada geese consume about 17% of the summer standing crop of eelgrass in Alaska (McRoy 1966). When an eelgrass disease killed extensive areas of Zostera marina on the east coast of the United States in the 1930s, the black brant virtually disappeared (Cottam 1934).

Whereas gastropods, urchins, and fishes preferentially feed on the outer senescent portions of blades of seagrasses which are overgrown with epiphytic algae or microbes, green sea turtles (Chelonia mydas) selectively graze at the bases of Thalassia plants where they obtain the youngest, least overgrown portions (Bjorndal 1980, 1982; Mortimer 1981, 1982). After grazing an area, Chelonia mydas will return and recrop the same area, leaving adjacent areas of tall plants ungrazed (Bjorndal 1980). Regenerating blades have higher protein levels than untouched blades (Dawes et al. 1979; Dawes and Lawrence 1979) and by increasing turnover, grazing by green sea turtles might increase the productivity of the area. Thayer et al. (1982) presented evidence that green sea turtles speed up the process of decomposition of seagrasses. Although nutrients are absorbed from the seagrass material during the passage through the digestive tract of the sea turtle, the seagrass material is fragmented further and there is a two-fold increase in amino-acid content which facilitates rapid decomposition of the fecal material.

Unlike herbivorous invertebrates and fishes, green sea turtles avoid blades encrusted with epiphytic algae. However, Chelonia mydas will accept algae in areas where seagrasses are scarce (Mortimer 1981).

Dugongs (Dugong dugon) feed almost exclusively on seagrasses (Heinsohn and Birch 1972; Heinsohn et al. 1977). When seagrasses become scarce, dugongs will feed on algae (Heinsohn and Spain 1974), even consuming quantities of Sargassum (Spain and Heinsohn 1973). The West Indian manatee (Trichechus manatus) ranges more frequently between saltwater and freshwater and so its diet is more catholic (Campbell and Irvine 1977). In salt water, its main food is probably seagrasses (Bertram and Bertram 1968) but in freshwater they will eat water hyacinth, woody emergent reeds and cattails, and even terrestrial vegetation within one foot of the water (Anonymous 1976; Campbell and Irvine 1977). Unlike sea turtles which bite off seagrass above the substratum, dugongs root and dig up the entire plant, including the rhizomes. While feeding, dugongs leave trails 19-25 cm wide, 3-5 cm deep, and 1-5 m long (Heinsohn et al. 1977).

Clearly, marine vertebrates that reinvaded the sea from terrestrial origins evolved from a past association with terrestrial plants and have the metabolic pathways that allow the digestion of seagrasses while marine invertebrates and fishes generally find seagrasses difficult to process metabolically. Invertebrates and fishes generally do not feed on a major portion of the standing stocks of seagrasses and seagrasses do not decay as rapidly as algae. Despite the great primary productivity of seagrass beds (Table 1), much of this production is lost during the slow process of entering the detrital food web. If populations of green sea turtles and dugongs were allowed to recover from overexploitation, they might serve as a mechanism to exploit the production of seagrass beds directly through herbivory rather than indirectly through the detrital food web of invertebrates and fishes.



T. Fritts (pers. comm.) pointed out that while data on growth rates to sexual maturity in the natural environment are not solid, it appears that Chelonia mydas on the Great Barrier Reef and elsewhere in the Pacific generally show slower growth rates than do those around Florida. He suggested that perhaps a greater portion of the diet of C. mydas is algae in populations of slower growing individuals and is seagrass in populations of faster growing individuals. He commented that occasional mangrove shoots may be especially important in C. mydas diets in the Galapagos where they do not obtain other vascular plants. It would be most interesting to test the hypothesis that, on the average, Chelonia mydas grow significantly slower and have a significantly greater proportion of algae in their diets in the Pacific in comparison with populations in the Caribbean.

#### Summary and conclusions

Coastal marine ecosystems are particularly important to Pacific islanders because most of the animal protein of islands has traditionally come from coastal resources and because human settlements have tended to be in coastal regions for logistic reasons. An understanding of the functioning of coastal marine ecosystems is important both because the resources need more careful management as the human populations grow and because human activities will have the greatest effects on coastal environments where populations are concentrated.

Fishes and invertebrates forage out from coral reefs onto seagrass beds and return for shelter. In the Caribbean, field studies have indicated a flow of nutrients from the seagrass beds to coral reefs such that a greater biomass of fishes is found on reefs near seagrass beds. Also, coral colonies grow faster near the fish-aggregation sites on reefs (for fishes that forage in seagrass beds) than do coral colonies away from fish-aggregation sites. Seagrass beds and mangrove swamps serve as nursery areas for several species of reef fishes. While nutrients move from seagrass beds to coral reefs, the effects of species interactions on community structure are in the other direction. Coral reef herbivores influence the structure of plant communities in the seagrass beds near reefs. Pacific reefs may differ from Caribbean reefs in this regard. Echinoids are far less common in Micronesia than in the Caribbean.

The main effects of coastal habitats on each other are in stabilizing the physical environment by dissipating wave action (especially by coral reefs, which form lagoons), in buffering salinity changes (mainly by mangroves) and in stabilizing sediments (by seagrasses, mangroves, or corals). All three ecosystems also produce sediments and provide substrata for bacteria, epiphytic algae and animals. Seagrasses may provide a stabilizing effect on the detrital food web because the slow rates of decomposition provide a regular flow of nutrients during periods of fluctuation in primary productivity.

Although the ecological interactions between coral reefs, seagrass beds, and mangrove swamps are complex and academically interesting, the evidence in the literature indicates that these interactions are of negligible importance in comparison to the influence of the

## MANAGEMENT ISSUES REGARDING INTEGRATED TROPICAL MARINE ISLAND ECOSYSTEMS

Deborah Grosenbaugh

### Introduction

The management of marine resources traditionally has been an integral part of tropical Pacific island cultures. However, as growing populations approach the limited carrying capacity of island ecosystems and Western cultural influence places new strains on traditional management practices, choices often will have to be made between competing needs for economic development and resource protection. Although local perceptions concerning how to best allocate the available resources among competing uses may differ, user groups are equally constrained by the vulnerability of these resources to human exploitation. In many cases, the expansion of the local economy takes precedence over the observance of these limits, causing irreversible damage even before a problem is perceived. Unfortunately, for a variety of reasons, the lessons learned in one area are rarely applied elsewhere. It is this lack of understanding regarding the cause-and-effect that results in a limitation of future options, and the lack of information exchange relative to shared experiences that is addressed herein.

In devising regional management options, it must be taken into consideration that, while the Pacific Ocean unites the islands into a single environmental entity, great distances have promoted the evolution of a variety of political, cultural and economic factors that will require localized approaches to management problems.

In developing criteria, it must be realized that in an integrated approach to the management of coastal marine ecosystems, the object is not to manage the environment itself but to manage the use and development of that environment within limits that ensure maintenance and integrity of critical ecosystems. Unfortunately, tropical island ecosystems have been shown to have narrower limits than their continental counterparts, making them less tolerant of environmental perturbation and thus more sensitive to human activities. Management schemes that may have been successfully devised for temperate, continental systems cannot be directly applied to the islands of the tropical Pacific without first undertaking regional sensitive environmental assessment and monitoring programs. The kind of assessment and monitoring that would be required to arrive at quantitative criteria on which to base management decisions, however, is a luxury that can exceed the resources of developing island economies. In fact, the scope of such a project probably would far exceed the resources of the entire region. It is therefore necessary to develop flexible parametric guidelines based on the best available information and to monitor their effectiveness within reasonable limits. For example, Johannes (1980) notes that to determine maximum or optimum sustainable yield in a multispecies reef and lagoon fishery is an unrealistic goal. He suggests that a better approach would be to strive for a moderately stable increase in the yields of overexploited fisheries. This approach is the one we have tried to keep in mind in making our recommendations based on our assessment of current efforts to manage tropical coastal ecosystems.

Table 3. Summary of existing marine resource conservation and management legislation in the tropical Pacific region (see appendix).

	Comprehensive Environmental Legislation	Water Quality	Legislation Specific to Coastal Eco- Systems	Enabling Legislation for Reserves & Sanctuaries	Fisheries & Species- Specific Legislation	Outside Terrestrial Activities (Forestry & Mining)	Outside Marine Activities (Oil/Dumping)	EIA Provisions
American Samoa		x		x				x
The Northern Mariana Is.	x	x		x	x			x
Cook Is.	x			x	x		x	
Fiji		x	x	x	x	x	x	x
French Polynesia					x	x	x	
Guam		x	x	x	x	x	x	x
Kiribati				x		x	x	x
Nauru			x					
New Caledonia		x		x		x	x	
Niue		x			x			
Papua New Guinea	x	x		x	x	x	x	x
Pitcairn					x			
Solomon Is.		x		x	x	x		
Tokelau								
Tonga				x	x	x		
Trust Territory of the Pacific		x		x	x	x	x	x
Tuvalu				x	x		x	
Vanuatu					x			
Wallis & Futuna					x			
Western Samoa		x		x	x	x		

Table 4 (cont.)

4. Trochus Act, 1975. Establishes reserves at Aitutake, Farmerston and Manuae.
5. Territorial Sea and Exclusive Economic Zone Act, 1979. Provides for regulations for the protection of the marine environment and fisheries resources.

Fiji

1. Land Conservation and Improvement Act, 1953. Establishes the Land Conservation Board which is responsible for the supervision of water resources, stimulation of public interest regarding natural resources, and recommendations for conservation legislation.
2. National Trust of Fiji Ordinance, 1970. Provides for the development of parks and reserves.
3. Fisheries Act, 1942. Prohibits fishing in native customary fishing grounds without a license.
4. Fisheries Regulations, 1965-1972. Controls the use of fish fences, nets, poisons, and protects turtles and porpoise.
5. Provisions controlling the pollution of coastal waters are included in:
  - Native Land Regulations
  - Mining Regulations
6. Harbor Act, 1974. Prohibits the pollution of harbors and coastal waters.
7. Mangrove Regulations. A license is required for the exploitation or reclamation of mangrove stands.

French Polynesia

1. Fisheries Legislation. Provides for the protection and management of marine and coastal resources.
2. Forestry Regulations. Controls deforestation by clearing and bush fires.
3. Marine oil pollution is prohibited by law.

Guam

1. Applicable U.S. Federal Legislation. (See American Samoa, #1).

Table 4 (cont.)

3. Law No. 64-1331, 1964. Prohibits seawater pollution by hydrocarbons.
4. Decree No. 405, 1910 (as amended). Prohibits deforestation of certain hill slopes and river banks.
5. Decree 54-1110, 195. Authorizes the Mining Pollution Control Commission to determine pollution control measures.

Niue

1. Fish Protection Ordinance
2. Environmental Protection Ordinance

Papua New Guinea

1. National Constitution (Fourth Goal). Declares national policy to be the conservation of natural resources for the collective benefit of all and of future generations.
2. Conservation Areas Act, 1978. Provides for the establishment of conservation areas and the criteria therefor.
3. National Parks Act, 1966 (as amended). Places the administration of parks under the supervision of a National Parks Board.
4. Fauna Protection and Control Act, 1966 (as amended). Allows for the establishment of sanctuaries and protected areas for particular species.
5. Environmental Contaminants Act, 1978. Requires a license for the discharge of pollutants into coastal waters.
6. Environmental Planning Act, 1978. Invokes planning procedures when inadequate consideration has been given to environmental effects of development.
7. Timber Extraction Permits require the institution of reforestation programs.
8. Merchant Shipping Act. Contains provision for marine oil pollution of coastal waters.
9. Coral Harvesting Law. Controls the taking of coral.

Pitcairn Island

1. Fisheries Zone Ordinance. Empowering legislation for the management of fisheries resource.

Table 4 (cont.)

3. Specific Legislation and Regulations

Code of the Federated States of Micronesia (FSM), 1982.

Establishes regulations for the taking of sea turtles, black-lip mother-of-pearl oyster shell, Trochus; prohibits the use of explosives and poisons; lists endangered species; creates the authority for the management of marine resources.

Ponape State (FSM). The Marine Resources Conservation Act of 1981 empowers the Director of the Department of Resources and Development to regulate the taking of Trochus, black coral, parrotfish, grouper and mangrove crab.

The Republic of Belau regulates the taking of fish (size limits), tridacnid clams, mangrove crab, lobster, and sea turtles. The taking of dugongs is prohibited.

Tuvalu

1. Wildlife Conservation Ordinance, 1975. Enabling legislation for the designation of wildlife sanctuaries.
2. Fisheries Ordinance, 1977. Forbids the use of explosives for fishing.
3. Prohibited Areas Ordinance. Provides for the declaration of "prohibited areas".
4. Harbours Ordinance. Prohibits the discharge of sewage or oil into harbours without permission.

Vanuatu

1. Constitution. Declares that it is the moral duty of every person to protect and safeguard national wealth and environment.
2. Fisheries Act. Contains provisions for the establishment of marine reserves.
3. Joint Regulation No. 17, 1968. Protects crayfish in coastal waters.
4. Joint Regulation No. 7, 1973. Prohibits night underwater fishing on the coast of the island of Efate.
5. Joint Forestry Regulation No. 30, 1964. Prohibits deforestation in declared forest areas except under permit.

Table 5. Provisions for the establishment of marine ecosystem sanctuaries throughout the tropical Pacific region.

	Enabling Legis- lation	Proposed Marine Sanctuaries or Reserves	Established Marine Sanc- tuaries or Reserves
American Samoa	X		X
Commonwealth of the Northern Marianas	X	X	X
Cook Islands	X	X	X
Fiji	X	X	X
French Polynesia	X		X
Guam	X	X	
Kiribati	X	X	
Nauru			
New Caledonia	X		X
Niue			
Papua New Guinea	X	X	X
Pitcairn			
Solomon Islands	X	X	X
Tokelau			
Tonga	X	X	X
Trust Territory	X	X	X
Tuvalu	X		
Vanuatu			
Wallis & Futuna			
Western Samoa	X	X	X

designation will require local acceptance through either vestigial traditional mores or conservation education:

1) Status Quo

The first task involved in considering management alternatives is to determine if the formulation, implementation and enforcement of a plan are cost-effective. In many cases, an analysis of traditional management measures will show that they provide the protection necessary to maintain designated environmental parameters within tolerable limits. Recognition and legal institutionalization of traditional laws such as reef tenure systems may be all that is required at this point in time. An example of a system that seems to ensure that environmental standards are met is the reef tenure system that remains in force in Yap Lagoon.

In a case such as this, where it can be shown that the traditional conservation system still protects the integrity of the lagoonal ecosystem, it should be left intact and simply monitored for serious departures from locally established criteria.

In some instances, though, reliance on existing traditional authority is not enough. Where Western economics and technology have made inroads, but have not seriously affected customary patterns of marine resource use, legislation legitimatizing traditional uses may be the answer.

2) Institutionalize traditional systems

Should it be determined that the most practical approach to resource management is legislation recognizing traditional exploitation practices, the success of such a program will depend on close coordination with the local users. Additionally, as Johannes (1982) points out, any legal authorities must be flexible and responsive to change, such that customs are not "locked in", preventing the natural evolution of the system.

This approach has been applied with apparent success in Papua New Guinea in relation to the management of certain wildlife species, most notably the dugong (Dugong dugon) (Hudson, 1980).

In most circumstances this type of species-specific management technique will not be cost-effective in dealing with tropical systems (Johannes, 1980). Because of characteristically high species diversity in the tropics, no one or two species dominates catches, even if effort is restricted to certain gear types. For this reason it is generally necessary to devise policies that anticipate environmental perturbations not only within, but outside, the entire coastal ecosystem, rather than the piecemeal, curative approach that dominates island management schemes.

It should be noted, however, that there are some particularly valuable species that may be responsive to a species approach. Where this is the case, traditional appreciation for the species and its need for management can possibly be used to engender a willingness to accept certain



pressure in the near future, rationalization of conservation and management options will require a different approach than that of a population that is capable of sustaining limited hunting pressure. One such approach could be to engender an appreciation for the beasts and the associated ecosystems as a tourist attraction for the growing number of divers that visit Palau.

Whereas species with limited migration patterns respond to local management schemes, a regional approach will be required for the conservation and management of another important marine herbivore, the green sea turtle (*Chelonia mydas*) throughout its range. Extensive migration of this species precludes a local approach to management issues. Table 6 illustrates the diversity of protective measures throughout the study area. A regional plan will have to be devised that considers a system of breeding, nesting and feeding sanctuaries combined with regional guidelines for the taking of turtles. Local plans that are responsive to traditional, subsistence taking could then be developed within these guidelines. Balazs (in press) suggests conservation measures for Tokelau that are reasonable for areas where it can be shown that turtle hunting is traditional and necessary.

Where traditional systems have completely broken down, such as generally is the case in the Mariana Islands, a different approach is required. A favorite food fish of the indigenous populations of the Marianas is the rabbitfish (*Siganus* spp.). These fish are harvested during all stages of their life cycle, including those times at which they are most vulnerable to exploitation: during recruitment when they come over the reef in dense aggregations (Kami and Ikehara, 1976) and during spawning when they again aggregate in a stupor-like state.

In the past, island populations were limited, and no more was taken than could be immediately consumed or preserved by traditional means. But given improved gear technology (monofilament, small-mesh nets) and better methods of preservation and storage, these fish appear to be exploited over the maximum sustainable yield as indicated by apparent population declines in recent years. The fact that these fish are also harvested during spawning gives credence to fishermen's observations that the number of adults on the reef is much lower than in the past.

Guam Fish and Game laws permit the use of small mesh nets for the "traditional harvesting of juveniles". This creates additional problems in that incidental catch of other species is unregulated and seasons are not established. Consequently, in practice, it is legal to use monofilament, small-mesh nets under any circumstances. In a case such as this, regulations should be enacted to permit the harvest of the juveniles only at designated locations and the use of small-mesh nets only be allowed during seasonal runs. It is interesting to note that attempts on the part of Guam's Division of Aquatic and Wildlife Resources to regulate juvenile fish harvest have met with resistance from those claiming the "traditional rights" to do so. Johannes (1982) has observed that villagers, even in remote areas, will invent "traditional rights" if it is advantageous.

Table 6 (cont.)

Tonga cont.

-no sale or export of shells less than 35" (89 cm) in length  
-no taking of eggs

Trust Territory  
of the Pacific  
Islands

Endangered Species Act of 1973 applies with subsistence provisions for green sea turtles; however it is not being strenuously enforced pending political status negotiations. Local regulations apply:

Code of the Federated States of Micronesia, 1982  
Republic of Belau Fish and Game Regulation, 1982

-no taking 1 June to 31 August, and 1 December to 31 January  
-no taking on land  
carapace length must be greater than 34" (86 cm) for green sea turtles and 27" (67 cm) for hawksbills  
-no taking of eggs

preserve, coral harvesting was prohibited. When an attempt was made to close the area to net fishing, several fishermen put pressure on their senators to repeal the law on grounds that it was discriminatory. Thereupon, a prohibition on all taking of marine life was enacted by public law for a trial period of one year. During the course of that year, enforcement proved to be so difficult that a continuation of sanctuary status was not pursued.

The acceptance of the concept of sanctuaries by the local users is of paramount importance in predicting the success of any regulatory attempt. Governments must be able to demonstrate some discernible benefits of establishing reserves. The speculation that they will serve as seed areas for desirable species and maintain genetic diversity of the whole integrated ecosystem does not translate into higher fisheries yields and improved standards of living. Benefits must be concrete: legal recognition of local village authority, lease payments, protection from outside encroachment, tourist dollars, etc. Only then can the system function.

#### Conclusions and general recommendations

Devising a regional approach to the management of tropical coastal ecosystems presents some unique problems. All of the islands of the tropical Pacific share a common dependence on marine resources. However, the existence of a diversity of political, cultural and economic factors makes the development of a universally applicable management strategy impractical. Add to this the biological implications inherent in the association of these ecosystems with different island types, and the task of making recommendations that are relevant to the entire region is further complicated. Therefore, the recommended approach is to devise a set of meaningful regional management objectives with which to guide the development of local plans.

Prerequisite for any management program is a set of well-defined objectives that can be clearly understood. In the absence of such objectives, decisions tend to be ad hoc, disorganized and contradictory. Even when management objectives are defined, as is the case in some of the jurisdictions studied, an effective administrative mechanism must be in place and have the support of those affected by the proposed management scheme. It must also be remembered that approaches to management may vary significantly according to differences in the nature of the ecosystem's association with the land mass, traditional patterns of resource exploitation and local perceptions regarding the continued availability of these resources. Little cooperation with respect to quotas, for instance, can be expected in an area where a resource is not perceived to be on the decline. It should also be noted that for any set of management objectives that can be proposed, some may be in direct conflict with others. This situation results from the disparity in interests between various levels of a developing economy. It is under these circumstances that local users, given the alternatives and their consequences, will initially have to set development priorities.

## RECOMMENDATIONS

### Recommendations for further research on interactions between coastal ecosystems

Projects of most basic and immediate importance in forming a foundation on which to base decisions on management of coastal resources are listed below.

1. Coastal habitats as nurseries for fauna of other marine habitats
  - a. Adams et al. (1973) claim that 75-90% of marine commercial and sport fish species in Florida depend on estuarine habitats for at least part of their life cycle. Is this approximately applicable to commercial and sport fishes of tropical Pacific islands? This is an important piece of information for coastal management policies or decisions. An estimate of the dollar value of estuarine and other coastal habitats in terms of fisheries and second order economic benefits would be a useful figure to obtain. The first part of this question must be answered before it will be possible to answer the second part. This study should apply to crustaceans and molluscs as well as to fishes.
  - b. Are seagrass beds or mangrove swamps necessary as nursery areas for any coral reef fishes? A study should be made to determine if any coral reef fishes in the Pacific require other coastal habitats as a nursery. Does the coral reef fish community structure near seagrass beds differ from coral reef fish community structure far from seagrass beds as a result of recruitment? Alternative factors such as food for adults should be controlled or accounted for.
2. Effects of land mass and water current patterns.
  - a. The effects of terrestrial runoff, groundwater seepage, internal waves, water current patterns, and water residence time on coastal nearshore communities are the most important factors to study if we desire an understanding of the island ecosystem that would allow us to make rational decisions in matters of coastal zone management. While it has been shown that mangroves display a tenfold greater rate of production where influenced by terrestrial nutrient runoff, the influences of location in terms of the nature of the nearby land mass, current patterns, and allochthonous nutrient supply has not been so well documented for seagrass communities. A direction for future studies to take should include assessing the standing stock and the rates of productivity of seagrass beds at various sites and relating these measures to availability of allochthonous nutrients, to water movement patterns, and to the substratum and topographic characteristics of the nearby land mass.
  - b. Comparative studies between relatively pristine coastal areas and coastal areas affected by human activities nearby (such as reclaimed wetlands or forests cleared for

- g. Traditional methods of resource management should be documented and assessed.
- h. The various traditional and present uses and materials obtained from each ecosystem, including the contributions of each ecosystem to fisheries as nurseries or nutrient supply, should be evaluated in terms of an economic unit of measure. This information is often needed to document coastal zone management plans and proposals.

#### 4. Nutrient transfer by foraging animals

- a. In the Caribbean, juvenile haemulid fishes ("grunts") feed on invertebrates and small fishes in seagrass beds by night and return to rest on the reef by day. Although some species in the Indo-Pacific may sometimes follow this pattern as individuals or small groups (e.g., perhaps Gnathodentex, Monotaxis, Macolor, apogonids, holocentrids), are there any fishes that forage at night in seagrass beds then aggregate on the reef in groups of hundreds during the day, repeatedly at particular sites? The patterns of movements of fishes between coral reefs and seagrass beds has yet to be documented in the Pacific.
- b. If daytime aggregations of fishes which feed in seagrass beds at night are found on coral reefs, do excretions and defecations of these fishes have a measurable affect on the reef community? Are there greater concentrations of ammonium in the water and nitrogen and phosphorus in the sediments and do corals grow faster at sites of these fish aggregations? This is apparently the case in the Caribbean (Meyer et al. 1983), although the evidence available to date for this process is not conclusive. Furthermore, there is no evidence available to date to indicate that this process is of any significance on Indo-Pacific reefs.
- c. Do areas of coral reef bordering on seagrass beds or mangroves support a larger biomass of reef fishes than comparable areas of reef margin bordering on other areas? If so, is the increase in biomass mainly accounted for with species of fishes that forage from coral reefs into the mangroves or seagrass beds? Edge effect, patch size, and habitat border effect per se should be controlled in the design of this study. These questions could also be asked about lobsters and other organisms.

#### 5. Biological interactions between habitats

- a. In the Caribbean, juvenile haemulids feed on seagrass beds by night and return to rest, defecate and excrete on coral reefs by day. Are there any fishes that follow this pattern of behavior on Pacific reefs (perhaps Gnathodentex, Monotaxis, Macolor)?

Recommendations for management action

1. Institutionalize any traditional reef tenure systems or management practices that are effective, where they exist.
2. Develop a "framework" regional plan based on regional standards that are flexible enough to account for cultural and environmental differences. A regional plan should include management objectives giving performance standards and guidelines by which they can be attained, criteria for the development of fragile ecosystems, provisions for environmental impact assessments, and regional standards for such parameters as water quality, relative species diversity and biomass based on baseline data.
3. Each jurisdiction should then develop a local plan within the guidelines of the regional plan which should include administrative mechanisms and legal authorities necessary to achieve regional management objectives.
4. Establish a system of marine reserves, especially in areas readily accessible to academic institutions.
5. Create a regional advisory board consisting of a cadre of those familiar with tropical ecosystems to aid in local decision-making by administrators and resource users.
6. In jurisdictions where traditional hunting is an important cultural activity, link valuable species to environmental management through conservation education.
7. Map ecosystems throughout the region determining regional environmental standards relative to environmental status and the current uses.

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