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Editor's Preface

This volume is the fourth in a series that provides a record of UNEP-sponsored meetings held to encourage inter-regional co-operation and communication among people concerned with the three Regional Seas Programmes and their Action Plans[1] in the Pacific (South Pacific, South-East Pacific, and East Asian Seas). The first of the meetings was held at the XV Pacific Science Congress in Dunedin, New Zealand, in 1983[2]; the second at the XVI Pacific Science Congress in Seoul, Korea, 1987[3]; and the third at the VI Inter-Congress of the Pacific Science Association in Viña del Mar, Chile, 1989[4].

The meeting that forms the basis of this volume was held at the XVII Pacific Science Congress in Honolulu, Hawaii, 1991. William C. Clarke served as Chairman of the meeting and edited the volume. Paul F. Holthus of the South Pacific Regional Environment Programme (SPREP) represented UNEP's Oceans and Coastal Areas Programme Activity Centre (OCA/PAC) at the meeting and was its organiser/rapporteur. The agenda of the meeting focused discussion on a review of Programme activities in each of the Pacific regions and on the possibilities for inter-regional co-operation in the activities, particularly as these related to:

- climate change and sea-level rise
- marine-pollution assessment and control
- integrated coastal zone management
- coastal ecosystem monitoring
- conservation of marine biological diversity

Other agenda items brought forth discussion of environmental education in relation to marine issues, consideration of Pacific-wide issues to be brought to the attention of the UN Conference on Environment and Development (UNCED), and submission by the meeting of

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(1) CPPS/UNEP: Action Plan for the protection of the marine environment and coastal areas of the South-East Pacific. UNEP Regional Seas Reports and Studies No. 20. UNEP, 1983.

UNEP: Action Plan for the protection and development of the marine and coastal areas of the East Asian Region. UNEP Regional Seas Reports and Studies No. 24. UNEP, 1983.

SPC/SPEC/ESCAP/UNEP: Action Plan for managing the natural resources and environment of the South Pacific Region. UNEP Regional Seas Reports and Studies No. 29. UNEP, 1983.

(2) UNEP: Environment and resources in the Pacific. UNEP Regional Seas Reports and Studies No. 69. UNEP, 1985.

(3) UNEP: Co-operation for environmental Protection in the Pacific. UNEP Regional Seas Reports and Studies No. 97. UNEP, 1988.

(4) UNEP: Regional co-operation on environmental protection of the marine and coastal areas of the Pacific basin. UNEP Regional Seas Reports and Studies No. 134. UNEP, 1991.

recommendations to the Pacific Regional Seas programmes and to OCA/PAC, UNEP. The recommendations and further details of the meeting are provided by Paul Holthus in this volume's concluding paper.

As with the previous volumes in the series, the papers in this collection possess a great variety in approach, topic, and scale of coverage. Such variety is only natural amongst contributors so varied as to educational background, national origin, and career specialization, and who are united only by a shared concern with improving understanding and management of an area as vast and varied as the Pacific, its islands, and its contiguous continental shores.

It was initially intended that the papers in the volume be organised according to the five activity foci or topics discussed at the meeting and listed on the previous page. But not all the papers in the volume were prepared with the inter-regional seas meeting in mind -- although all were presented in some forum of the XVII Pacific Science Congress -- and the final collection available for publication did not divide easily into the five listed topics. As would be expected, all of the papers treat at least one of the topics, but a more significant division among the papers seems to be, on the one hand, an emphasis on basic investigative research (Sections I and V) and, on the other hand, a concern with developing or applying forms of protective management (Sections II, III, and IV). Many other categorisations could be devised, and in many of the papers the "pure science" component very much interpenetrates with management applications. In their separation of research from management as well as in their merging of research with management, the papers signify the two fundamental actions needed to attain protective management and sustainable resource use:

-- **learning more** about the Pacific's natural inventory, its processes, functions, and structure, and how it interacts with human-induced components and changes;

-- **managing better** on the basis of that information and knowledge.

All of the papers in the collection contribute to our understanding of one or the other or both of these basic activities.

The title of the volume stresses "coastal" because in almost all the papers the weight of attention is wholly or heavily on coastal or nearshore resources or systems. In terms of scientific content, there is a strong emphasis on mangroves, atoll lagoons, and the fishes of coral reefs and reef slopes. El Niño Southern Oscillation (ENSO) stands out as especially significant in the papers from the South-East Pacific, one of which uses ENSO as a surrogate for secular climatic change. Otherwise, climatic change as such is not a pervasive theme in the volume although one paper urges that an understanding of global warming and the processes of sea-level rise be better integrated into the education of the Pacific's youth, and another paper hints at the effects of global warming on corals by analogy with thermal pollution from a nuclear power plant in Taiwan.

Case studies of management issues include an analysis of the history of artisanal village fisheries of reef slopes in Vanuatu, pearl culture at Manihiki in the Cook Islands, the problems of tourism in coastal Thailand, and an examination of how traditional approaches to resource use might be used in attempts at sustainable development at remote Marovo Lagoon, Solomon Islands. There is also a more general consideration of the use of pricing of marine resources as a management tool. Both intra- and inter-regional cooperation are addressed in a paper on integrated coastal ecosystem monitoring in the East Asian Seas region. And even broader aspects of cooperation in monitoring and enhancement of education are contained in a paper that proposes a structured network of marine and environmental-science institutions across the South Pacific, Southeast Asia, and beyond to the north Pacific and southern Asia.

Special mention should be made of the long paper on marine ecosystem classification for the South Pacific that makes up Section V. In that paper, J.E. Maragos presents the progress to date of a widely cooperative and intensive programme to develop "an ecosystem classification of the insular tropical Pacific that would be useful in furthering resource inventories and conservation efforts in the region." The inter-regional seas meeting recognized the value of this work, both as basic inventory and as important in the process of determining conservation priorities. The paper and the work of the many scientists behind it provide a significant step in the efforts to move from *ad hoc* towards broader systematic classificatory schemes in a region and, in time, inter-regionally and globally. It should be mentioned too that the programme to develop this marine ecosystem classification also has a component covering inland waters (now available) and a component on terrestrial ecosystems (still undergoing revision).

As Chairman of the inter-regional seas meeting and editor of this volume, I would like to express thanks to Dr L.G. Eldredge (Executive Secretary of the Pacific Science Association) and the XVII Pacific Science Congress staff for facilitating so well the organisation of the meeting. I would also like to give thanks to Paul Holthus of SPREP for his many contributions to the meeting and the volume, to Professor John Morrison for his expert advice, and to all the authors for their valuable participation in the work of extending cooperation and environmental understanding across the wide Pacific.

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I. Investigating Coastal Resources and Systems

MANGROVE ASSESSMENTS ON YAP, KOSRAE, AND POHNPEI, FEDERATED STATES OF MICRONESIA

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ABSTRACT

Assessments of the general condition, stocking, composition, and growth of mangroves on the islands of Pohnpei and Yap and at one area on Kosrae were undertaken at the request of these states. Methods used included: reconnaissance on foot, by air and by boat; use of 1976 aerial photographs; remeasurement of forest inventory plots installed by the US Forest Service in 1983; and installation of new inventory plots, examination of public records, and reviews of published data (Pohnpei). Average annual increment of mangroves on all islands was 6.9 m^3 per hectare per year; increments on individual plots ranged from 0.9-16.7 m^3 per hectare per year. The wide variation in growth rates suggests that management could do much to boost productivity. Production appears adequate to meet present consumption except for a few specific locations and products. Problems affecting mangroves on these islands include uncontrolled exploitation, excessive sedimentation, and alteration of natural drainage. Actions to conserve mangroves are recommended.

INTRODUCTION

Yap, Kosrae and Pohnpei are three of the four states in the Federated States of Micronesia (FSM). The FSM lies east of the Philippines in the Caroline Islands, extending from Kosrae (5°19'N. latitude, 163° E. longitude) north and west to Pohnpei (6°54' N. latitude, 158°14' E. longitude) and Yap (9°33' N. latitude, 138°09' E. longitude) (Figure 1). Yap consists of four metamorphic, old volcanic high islands with a combined land area of 9,716 ha, plus about 15 coralline atolls. Kosrae is a single high volcanic island of 11,186 ha. Pohnpei is a high volcanic island of 35,493 ha, plus nine coralline atolls. This report treats only the high islands.

Mean annual temperature on the coasts of these islands is 27°C. Mean daily and monthly maximum and minimum temperatures differ by only 7-8°C. Mean annual rainfall ranges from 3028 mm on Yap to 4820 mm on Pohnpei and 5000 mm on Kosrae. Yap's rainfall is the most seasonal, with average monthly rainfall in the driest months, February through April, only 55 per cent of the average monthly rainfall in the wettest months, July through October. Pohnpei's rainfall is only slightly seasonal, with January and February drier than the

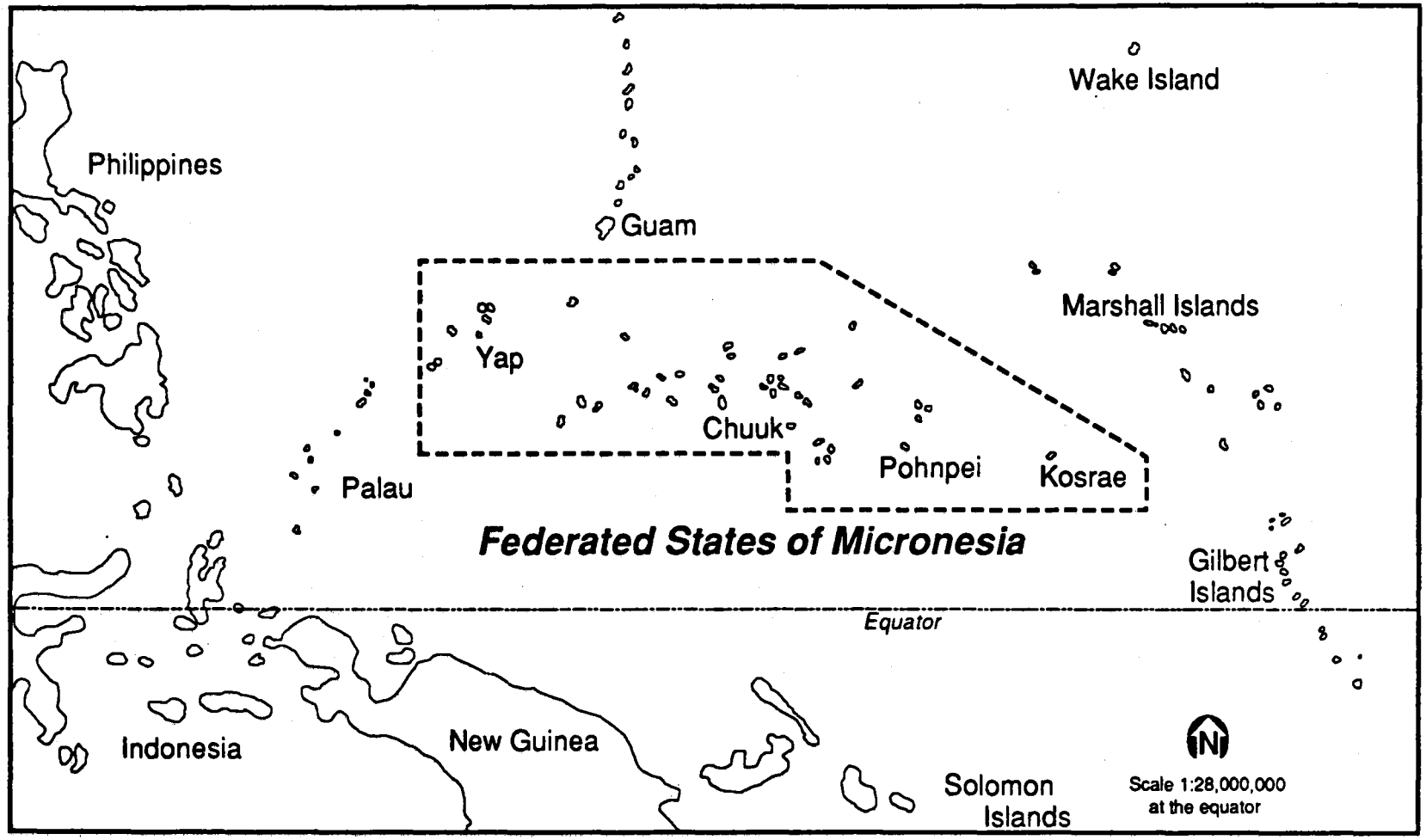

Wake Island
Philippines
Guam
Marshall Islands
Yap
Chuuk
Pohnpei
Kosrae
Palau
Federated States of Micronesia
Gilbert Islands
Equator
Indonesia
New Guinea
Solomon Islands
N
Scale 1:28,000,000
at the equator

Figure 1.

other months. Kosrae's rainfall is evenly distributed throughout the year. The highest point on Yap is 174 m; the other islands have more steeply sloping interiors with the highest point on Kosrae at 629 m and that on Pohnpei at about 800 m (MacLean *et al.* 1986, Whitesell *et al.* 1986, Falanruw *et al.* 1987). Mean annual rainfall in the interior of these latter islands is estimated to reach 7500 mm (Whitesell *et al.* 1986) and 9150 mm, respectively (Spengler 1990: 83).

Vegetation on these islands has been described and mapped (MacLean *et al.* 1986; Whitesell *et al.* 1986; Falanruw *et al.* 1987). Mangrove forest areas by tree-size class and density are shown in Table 1. Mangrove timber volumes were also estimated (MacLean *et al.* 1988) and are shown in Table 2. A second, more detailed, mangrove inventory conducted on Pohnpei reduced the estimated area of Pohnpei mangrove timberland to 4,855 ha while increasing the estimate of standing timber to 698,380 m^3 (Petteys *et al.* 1986).

Collectively Yap, Kosrae and Pohnpei have a significant mangrove timbershed; however, several factors suggest that if conservation measures are not taken now, the best of the resource may be lost. Mangroves are under constant development pressure because they occur in coastal and estuarine areas, where human settlement is concentrated on the scarce flat land (*cf.* Lal 1990 for Fiji). The FSM population has grown rapidly since 1950 and currently has an annual growth rate of around three per cent. Because 46 per cent of the population was less than 15 years of age in 1985 (Federated States of Micronesia 1988), this growth rate is expected to increase at least through the year 2000.

Growth of material expectations has perhaps outstripped population growth. More people, consuming and producing more than previous generations, are placing ever-increasing demands on the resource base. Mangrove forests are particularly subject to increased pressures in the areas of fisheries; of the use of timber for construction, furniture, fuel, posts, poles, and craftwood; and of alternative uses of the land itself. Mangrove forests have been and are disturbed by road-building, dredging, waste-dumping and the construction of homes, marinas, and other structures. These uses are expected to intensify with the expanding population and economic activity, especially in tourism.

Ecological services of mangroves include: protection of coastline and infrastructure from the action of wind and waves; filtration of upland sediment, thereby protecting lagoon and reef systems; critical habitat for larval and juvenile fishes; habitat for other wildlife, especially birds and bats, and conservation of germplasm.

On Yap, mangroves are privately owned; on Pohnpei they are state-owned; and on Kosrae they are held by the state but also claimed by individuals. Tenure affects the sorts of management that can be exercised and the types of restrictions on exploitation that can be maintained. Planning and allocation may enable the FSM to preserve representative areas of the mangrove ecosystem, and to provide for the sustained production of all benefits traditionally obtained from mangroves.

METHODS

Forest Inventory

In 1983, the US Forest Service conducted a region-wide vegetation survey and volumetric inventory of timberlands in the FSM, reporting species composition, stocking, and timber yields (MacLean *et al.* 1986, 1988; Whitesell *et al.* 1986; Falanruw *et al.* 1987). In 1991, for the assessment described in this paper, three mangrove plots on Yap, two on Kosrae, and three on Pohnpei were remeasured for the first time, for the purpose of examining mortality, ingrowth (*i.e.*, stems that grew into merchantable size or appeared for the first time), individual tree growth rates, and changes in stocking on a per-hectare basis. In addition, 15 new inventory plots were installed on Pohnpei. The same procedures were used in 1991 as in 1983 except that in the later work, exploitation was estimated by tallying stumps in addition to standing timber stock, and all mangrove areas, even dwarf stands, were included.

Plots were selected on a square grid using a random start. Grid intersections falling within areas mapped as mangrove were selected as field plots. Selected grid points were pinpricked on aerial photographs and located on the ground. Plots were permanently referenced for future remeasurement. For each plot, a cluster of five sample points was established, with the points distributed over approximately 1.4 ha. Two samples were taken at each point. The first sample included all trees greater than 2.4 cm and less than 12.5 cm diameter at breast height (dbh) within 2.36 m of point center. The fixed plot sample picked up stocking, growth and regeneration data on smaller trees not measured in the second sample. The second sample was a variable radius plot of all trees within the limiting distance of a metric basal area factor-seven prism (USDA Forest Service 1983).

Species, dbh, total height, bark thickness, crown ratio, crown class, azimuth, and distance from point center were recorded for all trees. Each tree greater than 12.4 cm dbh was visually divided into logical segments, and end diameters of these segments were measured or estimated. The segments were then classified as either sawtimber, poletimber, craftwood bolts, crotches, branches, or upper stems. Defective segments were identified as cull. Data from the field tallies were analyzed with an inventory program developed at the USDA Forest Service Pacific Northwest Research Station.

Yap State

On Yap, an additional sample of nine randomly-chosen transects was taken to fulfill a request for a qualitative assessment of the current condition of Yap's mangrove. Transects were walked for a distance of 200 m and a description of the stand including species present, estimated average tree diameter, estimated average canopy height, basal area (measured with a prism), and evidence of exploitation were noted. An overflight of Yap was made to observe the entire mangrove forest and near-shore environment. From these observations, a general description of Yap's mangrove was prepared (Devoe and Falanruw 1991).

Kosrae State

Reconnaissance and remeasurement of 1983 inventory plots were used to assess an area between the villages of Utwe and Walung on the south coast. This area of approximately 650 ha had already been identified as high priority for conservation, and municipal and state governments were reviewing options for tourism development. The mangroves were described, and management recommendations were prepared to support an ecotourism operation and the commercial timber production already underway (Devoe, in press a).

Pohnpei State

The investigation on Pohnpei has been the most complete to date, including (in addition to the inventory plots): extensive reconnaissance, bird counts, a market survey of sale of mangrove-associated fish, and examination of public records relating to wood consumption and land use in mangrove areas. This assessment was undertaken at the request of the state government of Pohnpei, to determine priority areas for preservation and for sustained-yield management. All mangrove areas were classed for either (a) preservation, (b) sustainable use, or (c) general-use not specifically reserved for (a) or (b) (Devoe, in press b). Criteria evaluated in the assignment of use categories were (1) presence of endangered or threatened species, rare species or particularly rich biota, and undisturbed, old growth communities; (2) the need to maintain intact mangrove to protect biotic resources from excessive wave action or sediments, or similarly, to protect cultural and economic resources; (3) presence of fisheries or forests of high productivity; (4) amount of timber stocking; and (5) proximity to processing installations and other infrastructure.

RESULTS

Results and Discussion: Yap

The Yap plots spanned the range of mangrove size classes, with corresponding extremes in volume from the smallest (28 m^3/ha) standing volume to one of the highest (209.7 m^3/ha) (Table 3). The plots with low and intermediate stocking are much more representative of conditions on Yap as a whole than is the one Okau plot, as can be seen from the area of these strata given in Table 1. In fact, the 1983 projections (Table 1) of the amount of area in each size class (dwarf, medium or large trees) underestimated the area of dwarf mangrove. There are at least 143 ha of dwarf mangrove on Yap, based on the transects covered on foot in 1991. The earlier timber inventory (MacLean *et al.* 1988) did not measure volumes associated with the dwarf areas because it was thought that these areas did not produce commercial quantities of timber. However, in the 1990-91 inventory on Pohnpei, it was found that standing volume of dwarf stands was almost equal to that of the medium-size stands (Table 8), although stem dimensions were much smaller. The standing commercial timber volume for Yap (medium and large size classes) should have been 63,736 m^3 or less in 1983, rather than 71,000 m^3, due to the expansion of dwarf at the expense of medium-sized stands. Based on the increments measured here, the current standing volume for Yap state, including the dwarf areas, is estimated at 118,290 m^3. The distribution of volume by species is shown in Table 4.

As seen from the ground samples and overflight, Yap's mangroves are not intensively exploited now. House timbers, posts, poles, and construction scaffolding are the major wood products. Fuelwood is being removed for lime production in the village of Maa, *Nypa fruticans* (nypa palm) is removed for thatch where it is abundant, and very small amounts of *Xylocarpus granatum* are harvested for handicrafts. Various foodstuffs such as fish, mangrove clams and crabs, and local medicines are also taken. The current level of exploitation appears to be well within the productive capacity of the resource, with the possible exception of nypa palm. However, because there is a tendency to extract wood from only the most convenient locations, which are along channels, roads and the shoreline, these areas are in some cases adversely affected. Regeneration is patchy but appears adequate for renewal of exploited and senescent individuals.

The greatest present threat to the mangroves and to the marine life protected by mangroves is the tremendous amount of earth-moving associated with road-building. The practice of bulldozing and filling, leaving uncompacted material exposed for months before the final road grading and surfacing, has resulted in the destruction of numerous taro patches, margins of roadside mangroves, clam beds, and the entrance of unacceptably high sediment loads into the waters surrounding Yap.

Results and Discussion: Kosrae

The inventory plots on Kosrae were both in the Utwe-Walung area (Table 5), the Yesron plot near Utwe, at the east end of a proposed park, and the Yemulil plot near Walung at the west end of the proposed park area. No new individuals were tallied on the Yemulil plot in the 1991 survey, while more than 200 trees per hectare had died during the eight-year period. Quadratic mean diameter of the Yesron sample went from 52 to 43 cm during the period 1983 through 1991, reflecting the mortality of large, senescing *Sonneratia alba*. The volume increments suggest that the Utwe-Walung area is rather better than average for the growth of mangrove forest. However, the volume increments reported here may be misleading in that much of the area has been cut and growing stock reduced; the two plots did not encompass any of the cut-over land. The structure of the existing stands also suggests that regeneration and production could be improved through selective thinning and better-timed harvesting. No regeneration was picked up on either of the fixed-plot inventory samples.

The distribution of species in the Utwe-Walung area, with *Sonneratia alba* close to the ocean shore, is not found elsewhere in Micronesia and is probably affected by the presence of a barrier island paralleling the shore. The forest is patchy in response to differences in substrate and in the small-scale history of human use. Four soil types are found in the area, varying greatly in depth, drainage, inundation cycles, and organic matter content (Laird 1983). Species tallied on the inventory plots are listed in Table 4. During reconnaissance of the area, other species were noted: *Heritiera littoralis* Dryand, found in the transition zone between the agroforest or lowland forest and the mangrove; *Pemphis acidula* Forst. f., *Cocos nucifera* L., and *Scaveola taccada* Gaertn., strand species occurring on the edges of the mangrove.

The reconnaissance disclosed intensive harvesting of *Sonneratia alba, Xylocarpus granatum*, and *Rhizophora apiculata* as well as some *Bruguiera gymnorhiza* and *Rhizophora mucronata*. The area around the Yesron plot was very heavily exploited, apparently for firewood and timber to feed the Utwe sawmill. One part of the area around the Yemulil plot was also harvested for fuel, local house timbers and poles, and mill timber. Because the cut stems did not occur in the inventory plots, the removal rate could not be quantified. The harvester(s) wasted a large proportion of the timber felled. Nypa palm (*Nypa fruticans*) is actively managed and harvested along the channels from Utwe to Walung, and crabs are caught over much of the area. At least one type of clams is removed from muddy banks. Another use of the area is the conversion of forest to house sites. How recently, or how extensively, this has occurred is not known.

Development of a park complex in the Utwe-Walung area would not adversely affect the ecological functions of the mangrove if the development were small-scale and sensitively done. Rather than being harmful, a park would very likely enhance the potential for conservation in this area of Kosrae. Currently, exploitation is uncontrolled and ecological values are threatened. A park is an alternative to the current use that would conserve the ecological services of the mangrove because an experience of the beauty and "naturalness" of the area is among the assets being sold. If a park is established and profitable, it could serve as a model for similar projects elsewhere, thus extending conservation benefits.

Results and Discussion: Pohnpei

The plots remeasured on Pohnpei (Table 6) did not include areas with trees in the largest size classes, which account for about a third of Pohnpei's mangrove (Table 1). The plots do suggest the range of increment values that obtains over areas of medium-sized trees. The larger, new inventory on Pohnpei has demonstrated a very wide range in stocking, from which it is inferred that site quality varies greatly.

The 1991 Pohnpei inventory was designed to estimate the average stocking (m^3/ha) by stratum within 20 per cent of its true value at the 82 per cent probability level for the 1 (medium-size trees) stratum and at the 95 percent probability level for the 2 (large trees) stratum. Based on coefficients of variation derived from the first four plots taken in each stratum (61 per cent for the 1 stratum and 42 per cent for the 2 stratum), 21 plots were required in the 1 stratum and 17 plots in the 2 (Dilworth 1970). The results presented here are based only on seven 1 and eight 2 plots.

Projections of total volume based on these preliminary data (Table 7) are about 40 per cent higher than values found in the previous inventory (Petteys *et al.* 1986). This probably results from a bias created by the order in which the plots in this study were installed. Because the first objective was to evaluate areas already identified from other reconnaissance as having the highest values for preservation and management, the plots that fell in these areas were installed first. No conclusions can be drawn from these data until the entire sample is taken, but the data do suggest some noteworthy trends. The range of volumes per hectare is larger

than previously thought, with more variation in site quality and stand response than has been noted before or elsewhere over such a small area of mangroves. Although stem dimensions are generally quite small, the 0 (dwarf) stratum is densely stocked, and standing basal area is nearly the same as that in the 1 stratum. Useful products do come from the dwarf mangrove (Table 8), and it provides the full range of ecological services.

Species tallied in the remeasurement plots are shown in Table 4; the larger inventory included the additional species *Lumnitzera littorea* and *Heritiera littoralis*. The species with the majority of volume varied by stratum (Table 8). The volume summations are only for growing stock trees, which have dbh greater than 12.4 cm. The results for the 0 stratum are thereby distorted, because the very small but numerous stems of *Rhizophora mucronata* and *R. apiculata* do not enter the calculation. *Lumnitzera littorea* dominated because only the largest trees were considered; *R. apiculata* followed. *Lumnitzera littorea* was found in this sample only in the 0 stratum. The species occurs outside the dwarf mangrove, but most of the large dimension *Lumnitzera*, Pohnpei's most valuable mangrove species, has been logged. None of the inventory plots fell in the cut-over areas. Replacing this population and stewarding what is left are high priorities for the Pohnpei forest management program. In the 1 stratum, *Bruguiera gymnorhiza* had the highest volume. In the 2 stratum, *Sonneratia alba* predominated.

As can be seen in Table 8, *Lumnitzera littorea* is harvested even as small stems. Commercial harvesting accounted for most of the exploited volume, with stump basal nearly 20 percent of the standing basal area/ha. Stump basal area/ha was 28 per cent of standing basal area/ha for *Xylocarpus granatum* in the largest size classes. *Xylocarpus granatum* is a high-value wood; branchwood is carved into handicrafts while larger stems are sawn for cabinetwork, flooring, and other interior construction. Harvests in the pole timber sizes were mostly of *Bruguiera gymnorhiza* (stump basal area/ha about six per cent of standing basal area/ha) and *Rhizophora apiculata* (stump basal area/ha approximately three per cent of standing basal area/ha). Cutting of these species as pole-sized stems is almost certainly non-commercial extraction for local house timbers. Smaller stems of these species are also taken for local uses such as fence posts.

Comparison of the exploitation observed in the field with the applications for permits to cut mangrove timber on file in the five municipalities of Pohnpei shows that considerably more wood than is officially sanctioned is being cut. Neither the records nor the exploitation are uniform, with some areas harvested more intensively than others and some municipalities keeping no records while others provide a reasonable estimate of activity in the woods. Three sawmills are operational on Pohnpei, although at the time of this investigation two were sawing only intermittently. It is noteworthy that so few permits for commercial milling are on file (Devoe, in press b) while three mills are operating on this small island. Other wood-consumers include furniture makers and a soap factory; no estimates of their consumption were obtained.

Though the records from 1985 through 1990 are disordered and incomplete, they show that at least 62 applications for development of mangrove areas were filed with Pohnpei State Department of Lands. Of the 62 permit requests on file, 57 were granted. Most of the requests

were for the filling and building or expansion of residential facilities on public land. Only three public works projects were officially sited in the mangrove. Of the 57 approved applications, 13 were for unspecified amounts of land. The area explicitly approved for conversion was approximately 10 ha; the actual area affected may have been much larger. Data from building and filling permits are too sketchy to reflect actual land use pressure. Viewed from the circumferential road, recent encroachment appears to be considerably greater than 10 ha. Mangroves are a popular location for piggeries and outhouses, presumably because of tidal flush. Because desires for some uses will have been frustrated (*e.g.*, cutting and building permit requests that were discouraged before an application was filed), demand must be underestimated and can be expected to increase, probably at a rate greater than population growth.

Preservation and conservation measures are necessary now. While the filling and building permit applications suggest that little mangrove is legally converted to other uses, field reconnaissance indicates that the active degradation of mangrove is extensive. Known clear-cuts (in addition to clearing for development) total only about 150 ha, but of all the mangrove covered on foot during 1990 and 1991, not a single site was without harvesting.

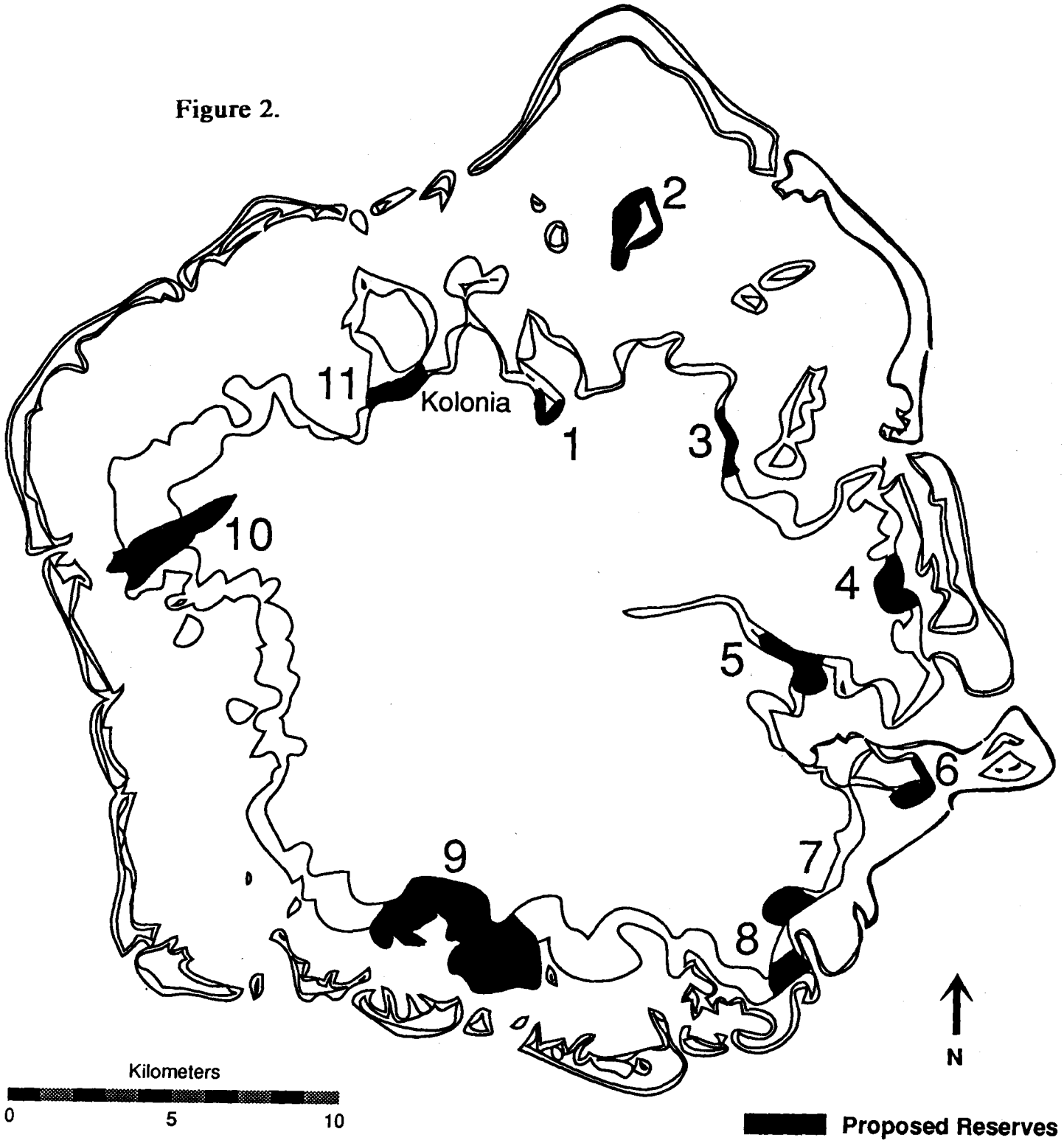
Eleven sites, totalling 1915 ha or 35 per cent of the total mangrove area, are suggested as those most important to reserve (Figure 2) (Devoe, in press b). Strict natural preserves account for 434 ha, parks for 176 ha, and production forests for 1305 ha. Before such a reserve system will become widely accepted and effectively enforceable, a public education program is needed to explain the costs and benefits of reserves and how these might be equitably distributed.

CONCLUSIONS AND RECOMMENDATIONS

Average annual increment, weighted by the area of the strata in which the plots fell, was 6.9 m^3/ha for the remeasurement as a whole. FAO (1982: 14) reported that "very little information is available concerning the growth rates of mangrove trees", quoting only three figures, 1.9 m^3/ha/yr in the Bangladesh Sundarbans, 8-10 m^3/ha/yr in Matang, Malaysia, both of these managed forests, and 16 m^3/ha/yr for *Rhizophora apiculata* plantations at Chanthaburi, Thailand. Other estimates in the literature are in units not directly comparable to those reported here. The range of values encountered here (0.9 - 16.7 m^3/ha/yr) is very wide; the average is reasonable in light of what is known about mangrove growth. The variability in growth rates suggests that management could do much to boost productivity.

Mangroves are exploited throughout the FSM but as yet they are nowhere managed. Consumption estimates are available only for Kosrae, and those estimates are only for the single use of cooking in underground ovens. Lal (1989) estimated that 105 m^3 per year was the total island consumption in underground ovens. If this were the only use of mangroves on Kosrae, present exploitation could be maintained without management in perpetuity. However, mangroves are harvested for other cooking, house poles, and sawtimber. The reconnaissance on Kosrae, Pohnpei and Yap suggest that exploitation is outstripping production in a few, specific locales and for particular products (nypa palm on Yap and Pohnpei, *Lumnitzera littorea*

Figure 2.



Darkened areas represent proposed mangrove reserves, Pohnpei, Federated States of Micronesia: (1) Dausokele, Nett; (2) Parempei Island, Nett; (3) from Nansalohi to channel north of Maramosok, Uh; (4) from the Lamaki to the Dien Outcrop, Madolenihmw; (5) Dauen Sapwalap, Madolenihmw; (6) Nan Madol, Madolenihmw; (7) land between Pilen Kihlid/Dauen Wapar and Dauen Lohd, Madolenihmw; (8) land between Kepindau Pohnahtik and Nan Diadi, Madolenihmw; (9) land between Dauen Semwei and Dauen Rakis, Enpein, Kitti; (10) Dauen Soundau, Sokehs; and (11) Dau Mwoakote, Sokehs. The island is surrounded by a barrier reef.

on Pohnpei). Until both demand and production are better defined, we can only guess as to the adequacy of the resource to meet the present and future needs of the people of the FSM.

Even more important than provision of resources are the ecological services of the mangroves that encircle the islands, for these protective forests are essential to a healthy lagoon and reef environment and to the maintenance of reef and pelagic fisheries. As Holthus (1987) argued, the prohibition of clearcutting of lagoon-side mangrove forests and in areas where the mangrove strip is less than 250m wide is the highest priority intervention in the management of coastal resources.

Damage to mangroves and deterioration of near-shore and reef habitats as a result of excessive sedimentation and alteration of natural drainage patterns is appearing on these three islands. Exploitation of only the most convenient mangrove areas, such as along channels, shorelines, and roadsides, has resulted in pockets of localized over-exploitation. Cutting of mangroves only at the most accessible locations should be discouraged because these are the areas that most require the protective role of mangroves as sediment traps and buffers against high wind and waves. Most of the damage and the larger, future threat is directly related to road-building. Bulldozing long stretches without grading, compacting, and surfacing should be prohibited, and the reduction of mangrove areas should be arrested. The clearing of mangroves between roads and shores should be prohibited where the mangrove strip is less than 250 m wide. Thinning (selective extraction) of the mangrove should be allowed only at distances greater than 50 m from roads or shorelines.

All exploitation and landscape modification should be conducted with a respect for existing drainage patterns so that channels and waterways are not blocked or impeded. Where water courses must be diverted, care should be taken to plan for the maintenance of water volume and quality. Mangroves are sensitive to changes in water depth, flow rates, mixing of fresh and salt water and sediment loads. The opening of the forest along waterways changes the conditions in the water by raising light levels and temperatures, which may be detrimental to aquatic life. No clearing or thinning of mangroves should be allowed within 50 m of any stream or river wider than 4 m across, nor within 50 m of any shoreline.

In many areas where exploitation was observed, trees were felled that were not removed. Such waste of wood should be discouraged by encouraging good logging techniques. Wood waste is also occurring when construction timbers are used once and discarded. The FSM should encourage the
recycling of prop timbers where possible by providing for the carting away of used timbers in sound condition. These can then be made available to builders at a nominal cost.

Most of the infrastructure and population in these states is now found in low-lying areas, a trend likely to persist and perhaps increase with further rural-to-urban migration. More stress will be placed on natural resources with the expansion of commerce. Now is the time to act to conserve mangroves, which support much of the FSM subsistence economy and which are essential to protection of shorelines and the near-shore environment. The task will only become more difficult and more urgent with time.

TABLES

Table 1. Mangrove forest area by size class and density on Yap, Kosrae, and Pohnpei.

State	Size Class[1]	Density Class[2]			
		Low	Medium	High	Total
			hectares		
Yap[3]	0	0	0	26	26
	1	16	143	944	1103
	2	0	17	35	42
Kosrae[4]	1	0	85	423	508
	2	0	526	528	1054
Pohnpei[5]	0	0	10	225	235
	1	8	53	3423	3484
	2	9	66	1731	1806

[1] 0 - short, shrub-like stands smaller than 12.5 cm in dbh.
1 - trees averaging less than 30 cm in dbh but larger than or equal to 12.5 cm in dbh.
2 - trees averaging 30 or more cm in dbh.

[2] Crown closure of main canopy: low = < 30 %; medium = 30-70 %; high = >70 %
[3] Source: Falanruw *et al.* 1987
[4] Source: Whitesell *et al.* 1986
[5] Source: MacLean *et al.* 1986

Table 2--Volume of mangrove timber on Yap, Kosrae, and Pohnpei

Tree Component	Yap	Kosrae	Pohnpei
Sawtimber:		----------1,000m^3----------	
Sawlog	-	40	65
Upper stem	6	7	22
Craftwood bolts	5	7	38
Branch and crotch	2	6	20
Tip	-	1	2
Roughwood	33	18	36
Total:	47	79	183
Poletimber:			
Poletimber	22	36	197
tip	-	3	13
branch	2	1	9
Total:	24	40	219
Total Volume:	71	119	403

Source: MacLean et al. 1988

Table 3--Standing timber on Yap plots 1983 and 1991.

	QMD[1]		Volume[2]		Basal Area[3]		Trees/ha		MAI[4]
Plot	1983	1991	1983	1991	1983	1991	1983	1991	1983-91
	— cm —		m^3 ha^{-1}		m^2 ha^{-1}				m^3 ha^{-1}
Okau	34	38	135.4	209.7	37.1	41.7	792	750	12.9
Tagareng	17	10	21.6	28.0	9.1	11.3	1630	2064	0.8
Lamear	29	22	85.4	124.9	30.4	25.6	2035	871	6.1

[1]Quadratic Mean Diameter is the diameter at breast height (1.3 m) of the tree of
[2]arithmetic average cross-sectional area.
Volume is net total volume (cull removed), including roughwood, sawlogs, tips,
[3]crotches, bolts, branches and poletimber, inside bark.
Basal area is the cross-sectional area of tree stems taken at breast height measured with a metric basal area factor 7 prism. Basal area indicates the amount of tree stocking, included are all live trees greater than or equal to
[4]2.5 cm in dbh.
Mean Annual Increment in net total inside bark volume of growing stock (live trees greater than or equal to 12.5 cm in dbh).

Table 4--Species[1] tallied by percentage of volume[2], 1983 and 1991.

	Yap						Kosrae				Pohnpei					
	Okau		Tagareng		Lamear		Yesron		Yemulil		Semwei		Panseiuh		Sokehs	
Species	1983	1991	1983	1991	1983	1991	1983	1991	1983	1991	1983	1991	1983	1991	1983	1991
Rhizophora apiculata Bl.	12	17	28	26	*	6	34	51	67	77	*	*	*	*	100	100
R. mucronata Lam.	-	-	-	6	-	-	-	-	3	2	-	-	*	16	-	-
Bruguiera gymnorhiza (L.) Lam.	30	24	61	54	17	13	13	13	-	-	11	15	21	25	*	*
Sonneratia alba J.E. Smith	55	58	-	-	83	81	53	36	30	21	46	41	-	-	-	-
Xylocarpus granatum Koen	-	-	11	13	-	-	-	-	-	-	43	44	79	59	-	-
Avicennia marina (Forsk.) Vierh.	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-

[1]Nomenclature after Fosberg et al. 1979.

[2]Net total inside bark volume, may not sum to 100 percent due to roundoff.

* = present, but stems too small to have commercial volume

- = not present

Table 5--Standing timber on Kosrae plots 1983 and 1991.

	QMD[1]		Volume[2]		Basal Area[3]		Trees/ha		MAI[4]
Plot	1983	1991	1983	1991	1983	1991	1983	1991	1983-91
	— cm —		m^3 ha^{-1}		m^2 ha^{-1}				m^3 ha^{-1}
Yesron	52	43	90.6	170.1	25.2	27.0	439	490	14.2
Yemulil	24	23	174.5	227.2	41.6	33.2	1377	1201	16.7

[1]Quadratic Mean Diameter is the diameter at breast height (1.3 m) of the tree of arithmetic average cross-sectional area.

[2]Volume is net total volume (cull removed), including roughwood, sawlogs, tips, crotches, bolts, branches and poletimber, inside bark.

[3]Basal area is the cross-sectional area of tree stems taken at breast height measured with a metric basal area factor 7 prism. Basal area indicates the amount of tree stocking, included are all live trees greater than or equal to 2.5 cm in dbh.

[4]Mean Annual Increment in net total inside bark volume of growing stock (live trees greater than or equal to 12.5 cm in dbh).

Table 6--Standing timber on Pohnpei remeasurement plots 1983 and 1991.

	QMD[1]		Volume[2]		Basal Area[3]		Trees/ha		MAI[4]
Plot	1983	1991	1983	1991	1983	1991	1983	1991	1983-91
	— cm —		m^3 ha^{-1}		m^2 ha^{-1}				m^3 ha^{-1}
Semwei	18	20	67.9	103.2	21.8	22.7	1623	2009	7.9
Panseiuh	13	12	71.7	73.6	23.9	28.4	2078	3115	0.9
Sokehs	13	17	31.2	58.3	16.7	19.6	1625	1631	3.9

[1]Quadratic Mean Diameter is the diameter at breast height (1.3 m) of the tree of arithmetic average cross-sectional area.

[2]Volume is net total volume (cull removed), including roughwood, sawlogs, tips, crotches, bolts, branches and poletimber, inside bark.

[3]Basal area is the cross-sectional area of tree stems taken at breast height measured with a metric basal area factor 7 prism. Basal area indicates the amount of tree stocking, included are all live trees greater than or equal to 2.5 cm in dbh.

[4]Mean Annual Increment in net total inside bark volume of growing stock (live trees greater than or equal to 12.5 cm in dbh).

Table 7--Pohnpei mangrove net volume by segment and stratum.

	Inside bark						Outside bark
Stratum*	Roughwood	Sawlog	Bolt	Branch	Pole	Total	Total
0	3,328	0	0	7,179	32,187	42,713	58,939
1	80,434	62,235	26,636	30,010	125,292	324,716	418,429
2	104,830	326,843	25,298	35,858	95,527	588,269	703,539
Total	188,592	389,078	51,934	73,047	253,006	955,698	1,180,905

*
0 Trees of small stature with average dbh less than 12.0 cm
1 Trees generally between 12.1 and 30.0 cm dbh
2 Trees with average dbh greater than 30.0 cm

Table 8--Pohnpei 1991 inventory: average net volume in m^3 and international board feet (IBF), quadratic mean diameter (QMD), and basal area per hectare (BAPH) by stratum and species.

Species[1]	Inside bark						Outside Bark				Stump
	Roughwood	Sawlog	Bolt	Branch	Pole	Total	Total	IBF	QMD	BAPH	BAPH
Stratum 0											
BR GY	.0	.0	.0	.0	.0	.0	.0	.0	.00	.11	.00
LU LI	6.1	.0	.0	11.4	53.9	71.4	101.5	.0	16.70	22.92	4.48
RH AP	.6	.0	.0	3.0	10.7	14.4	16.8	.0	14.49	4.14	.00
RH MU	.0	.0	.0	.0	.0	.0	.0	.0	.00	1.78	.00
SO AL	.0	.0	.0	.0	.0	.0	.0	.0	.00	2.15	.00
TOTAL	6.7	.0	.0	14.4	64.6	85.8	118.4	.0	16.41	31.10	4.48
Stratum 1											
BR GY	8.0	6.3	1.5	5.2	21.6	42.8	61.0	872.3	21.62	12.98	.73
RH AP	1.8	4.0	.0	.8	19.9	26.5	35.2	559.7	20.47	6.36	.00
RH MU	1.2	.0	.3	.4	7.6	9.4	13.2	.0	16.71	3.25	.00
SO AL	8.8	11.9	.5	.9	5.2	27.2	33.6	1,715.8	32.92	4.90	.00
XY GR	13.6	1.6	6.7	3.3	7.9	33.1	36.7	193.2	21.13	5.22	.23
TOTAL	33.3	23.7	9.0	10.6	62.3	138.9	179.7	3,341.0	21.72	32.71	.96
Stratum 2											
BR GY	14.8	23.9	.8	4.2	12.5	56.2	73.1	3,380.8	28.14	10.69	.35
HE LI	.0	.0	.0	.1	1.3	1.4	1.5	.0	.00	.31	.00
RH AP	6.3	22.2	1.0	2.9	11.8	44.3	52.8	3,527.0	27.98	5.41	.17
RH MU	2.3	.8	.0	.8	5.6	9.3	12.1	33.7	20.32	2.09	.00
SO AL	14.5	52.4	4.8	3.1	1.3	76.1	88.9	7,540.6	59.65	10.32	.00
XY GR	8.5	33.5	3.4	3.0	3.7	52.1	57.1	4,715.5	44.44	6.87	1.95
TOTAL	46.4	132.8	10.1	14.0	36.2	239.5	285.6	19,197.5	33.99	35.69	2.47

1/ BR GY = Bruguiera gymnorhiza; LU LI = Lumnitzera littorea; RH AP = Rhizophora apiculata; RH MU = Rhizophora mucronata; SO AL = Sonneratia alba; HE LI = Heritiera littoralis.

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EFFECTS OF SEA-LEVEL RISE ON ISLAND MANGROVE SWAMPS

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ABSTRACT

Stratigraphic records of island mangrove ecosystems during sea-level changes of the Holocene show that low islands will be particularly vulnerable to the loss of mangrove ecosystems during the rises of relative sea-level rise projected for the next 50 years. Mangrove ecosystems could keep up with a sea-level rise of up to 8-9 cm/100 years, but at rates of over 12 cm/100 years could not persist, as shown by palaeoecological reconstruction of mangrove response to sea-level rise in Tonga. Autochthonous low-island mangroves are more susceptible to impacts by rising sea-level than are high-island mangroves, where fluvial allochthonous sediment input from inland soil erosion should enable mangroves to keep up with sea-level rates of rise up to 25 cm/100 years.

A prototype to impacts on Pacific island mangroves is given by studies in Bermuda, a low limestone island subject to periods of more rapid rates of sea-level rise this century. There has been significant mangrove retreat, with mechanical erosion of peat from around root structures, causing trees to be susceptible to wind-throw. High losses of leaf litter from the swamp surface render impossible the peat buildup that allows mangrove ecosystems to keep pace with slower rates of sea-level rise.

Effective management is to reduce erosion of peat and leaf litter. In mangrove areas not yet affected by sea-level rise, monitoring should be established, with attention given to tidal patterns, mangrove substrate elevations with respect to the tidal prism, productivity and sedimentation rates, and changes in spatial patterns.

PAST RECORDS OF MANGROVE RESPONSE TO RISING SEA-LEVEL

Relationship between mangroves and sea-level

Mangroves are tidal forests that grow along sheltered shores in the tropics, with tree species characterised by adaptations such as aerial roots and salt regulation strategies for this stressful environment. Their close relationship with sea-level position renders mangrove swamps particularly vulnerable to disruption by sea-level rise consequent from the enhanced greenhouse effect (Ellison & Stoddart 1991).

Mangroves typically feature zonal organisation of constituent species. This results from different preferences of the component species for particular conditions of elevation, salinity and frequency of tidal inundation. Expansive mangrove ecosystems also accumulate vegetative detritus to form a mangrove peat, which may also contain allochthonous matter brought in by the tides and by rivers, depending on the tidal range and physiographic location.

The accumulation of peat under mangroves in the upper half of the tidal range gives mangroves some ability to keep up with rising sea-level. Rates of peat accumulation under mangroves are available from studies that have used mangrove peat as indicators of former sea-level, the data being available from coring coastal sediments and dating peat at different depths by radiometric techniques. Detailed work on mangrove stratigraphy of low, limestone islands has been carried out on Grand Cayman (Cayman Islands) and Tongatapu (Tonga). Studies of mangrove and deltaic stratigraphy of high Pacific islands have been carried out on Viti Levu (Fiji), Western Samoa and on Pohnpei and Kosrae (Caroline Islands). Mangrove stratigraphy on continental margins has been investigated in Florida and northern Australia. The results of these studies are summarised in Table 1, from detailed analysis in Ellison & Stodart (1991).

Low islands

The dated stratigraphy of globally distributed mangrove ecosystems during Holocene sea-level changes shows that on low islands mangrove ecosystems could keep up with sea-level rise of up to 8cm/100 years but could not persist at rates of over 12cm/100 years. For example, in Tongatapu a mid-Holocene mangrove forest established at Folaha from 7000 to 5500 years BP partially kept up with a sea-level rise of 12 cm/100 years. Then more rapid sea-level rise caused the forest to die and be inundated by the lagoon (Ellison 1989). In Grand Cayman, also a low limestone island, mangrove-derived peat deposits which underlie most of the present mangrove swamps have developed during a period of gradual late Holocene submergence, accumulating at a rate of 8.8 cm/100 years.

High islands

On high islands such as Viti Levu and Lakeba in Fiji and Kosrae in the Caroline Islands, sediment supply has been accelerated by anthropogenic soil erosion inland. This process gives the rapid sediment accumulation rates recorded in Table 1. These cases indicate that mangroves of high islands or continental coasts can be dominated by input of terrestrial sediment such that the effects of sea-level rise are lessened. Because of the allochthonous component in these sediments, mangrove substrates are accreting at a faster rate (up to 25 cm/100 years) than the peats of low limestone islands.

Analysis

Mangroves on low islands are more susceptible to disruption by rising sea-level because the only sediment available is produced by the trees themselves, giving relatively low rates of accumulation. Stratigraphy from high islands and continental coastlines, where more sediment

Table 1. Rates of mangrove peat accretion (from Ellison and Stoddart 1991)

Location (source)	Rate of accretion (cm/100 cal years)
Low Islands	
Tongatapu	
(Ellison 1989)	7.7
Grand Cayman	
(Woodroffe 1981)	8.8 - 9.0
High Islands	
Fiji	
(Southern 1986)	11.7
(Matsushima *et al.* 1984)	7.6
(Latham 1979)	13.1
Caroline Islands	
(Ward 1988)	13.4 - 14.0
(Matsumoto *et al.* 1986)	13.7
(Bloom 1970)	3.0
Samoa	
(Matsushima *et al.* 1984)	9.9 - 10.5
(Bloom 1980)	18.8

comes off the land into intertidal areas, indicates that these mangrove ecosystems will be better able to keep pace with sea-level rise.

Stratigraphic records indicate that in the earlier Holocene, when rates of sea-level rise were rapid as ice sheets melted, expansive mangrove ecosystems did not exist. Rather, mangroves occurred as disorganised, patchy individuals with dominant flushing of organic

material away from their roots, as seen today on more exposed or disturbed shorelines. As sea-level stabilised in the mid-Holocene the first expansive mangrove ecosystems established in sheltered locations. This is shown in stratigraphy by the appearance of mangrove peat, formed from organic accumulations beneath large mangrove ecosystems. Today, after a long period of stable sea-level or slow sea-level rise, expansive mangrove ecosystems are common in the tropics, useful in acting as sediment traps to stabilise sedimentary coastlines, in affording protection against hurricanes and storm surges, and in serving as a nursery for commercially exploited crustacean and fish species. They also provide timber and a large range of other economic products.

It would seem that under conditions of rapid sea level rise, mangroves undergo ecosystem collapse, and retreat into patchy, disorganised refugia. It is clear that low islands are the most vulnerable to loss of mangrove ecosystems during sea-level rise, but all mangroves will be severely threatened by the rates of sea-level rise projected for the future.

PRESENT RECORDS OF MANGROVE RESPONSE TO RISING SEA-LEVEL

Rising sea-level

Analyses of tide gauge records have shown that sea-level is rising at the present time. Using two different methods of analysis for 231 stations (excluding Fennoscandia), Gornitz and Lebedeff (1987) find an average rise of 12 and 10 cm/100 years. Most of the stations utilised in these analyses are located in Europe, North America and Japan, however, and thus lie outside mangrove areas.

Pirazzoli (1986) gives data for ten stations where mangroves and coral grow; these show a mean rise (over data sets ranging in length from 40 to 97 years) of 22 cm/100 years, though excluding Bangkok, which is affected by deltaic subsidence, the mean is 14 cm/100 years. Using slightly different data sets for six of these station, Barnett (1984) derives a mean rise of 23.6 cm/100 years. These rates, if real and persistent, are at or slightly higher than the rates shown by stratigraphy for the persistence of mangroves with sea-level rise.

Projections of future sea-level rise reviewed by the Committee on Engineering Implications of Changes in Relative Mean Sea Level (1987: 24-28), while uncertain, are summarised in a working expectation of a rise of 0.5-1.5 m by 2100. In the shorter term, a projected rise of 0.2 m by 2025 was utilised by Vicente *et al.* (1988), and 0.17 - 0.28 m by 2030 by the Commonwealth Group of Experts (1989). These projections give a rate of sea-level rise of 50 cm/100 years for the next half century.

Of low oceanic island locations, Bermuda and the Gulf of Mexico have experienced the most rapid rates of sea-level rise this last century, in excess of 20 cm/100 years (Gornitz *et al.* 1982; Pirazzoli 1989). Bermuda has a relatively long record of tidal recordings (since November 1932) that indicate a long term trend of sea-level rise at a rate of 28 cm/100 years (Barnett 1984; Pirazzoli 1986). The sea-level trend shows 10-12 year cycles of M.S.L., possibly

the result of meteorological causes (Wolfgang Scherrer, NOAA, Pers. comm. 1991), with rapid sea-level rise in the periods 1950-62, 1970-1974, and the late 1980s. We have identified a critical site in Bermuda with the first evidence of mangrove die-back with contemporary sea-level rise. Analysis and quantification of the problems experienced at this site are underway with the intention of offering a prototype of problems that may be experienced elsewhere in the future, hence allowing anticipatory management planning.

Hungry Bay, Bermuda

Hungry Bay is the largest mangrove area in Bermuda. The vegetation consists of two arboreal species, *Rhizophora mangle* (red mangrove) and *Avicennia germinans* (black mangrove), with no understorey shrubs or herbs, and extends over 7 acres. It is linear in shape, enclosed on three sides by limestone hills and open to oceanic exchange through one creek entrance. Bermuda has a microtidal range of 70-75 cm, a factor which causes change of mean-sea level to be of more significance to intertidal communities.

At Hungry Bay, the response of mangroves to rapidly rising sea-level as predicted from Holocene stratigraphy is occurring. The seaward edge of the mangrove swamp has been retreating in recent years, as noted by long-established local residents, and shown by stratigraphy. The shallow bay of 1 m depth seaward of the swamp was cored to show deep mangrove peat of 2 - 2.5 m beneath shallow calcareous sediment of 25 - 30 cm. The peat depths indicate that Hungry Bay is a long-established mangrove swamp, keeping up with slow sea-level rise of the Late Holocene of some 4 cm/100 years (Scholl and Stuiver 1967; Scholl *et al.* 1969).

From its position of at least 1000 years, the seaward edge of the swamp has died back in the last century about 80 m. In the open water of the bay, stumps of *Avicennia germinans* are common. At the seaward edge of the present swamp, 50 cm of peat have been eroded from root structures of the trees, leaving a little cliff in the soft sediment and exposing the mangrove roots. These trees are weakened, resulting in windthrows during storms.

An Interocean S4 current metre was used to measure current speed and direction, as well as water depth, temperature, conductivity, and salinity of water moving tidally in the main creek. Results show imbalance between flood and ebb current speeds on the ebb tide (~ 26 cm/s) being twice as fast as those on the flood tide (~ 13 cm/s). This leads to high loss of leaf litter and other macrodetritus with the ebb tides. Fine meshed fishing nets across the main creek were used to show that the swamp can lose around 8 kg dry weight of detritus on one ebb tide, while only a third of this is returned on the flood.

Expansive peat-building mangrove swamps such as Hungry Bay normally establish between the elevations of Mean Tide Level and Mean High Water. Using the 64 M.S.L. that defines Bermuda's Ordnance Datum, the swamp should occupy elevations of 0.000 at the seaward edge, and 0.500 m at the landward fringes. Detailed survey by TOPCON EDM tied to Ordnance Datum showed that the peat level in the northern back basin of the swamp is +0.1 to 0.3 m above OD, and the peat level in the southern front basin of the mangrove area is

around 0.1 m above OD. The edge of the mangroves at the creek mouth is -0.2 m below OD. South of the creek entrance, the mangrove peat at the seaward edge is between 0.0 and +0.1 m above OD. These elevations indicate that the swamp surface is lower than should be the case with respect to present sea-level. Disregarding erosion, present elevations of the peat indicate that the mangrove ecosystem was at equilibrium with sea-level around the 1930s.

The major problem for mangroves under conditions of sea-level rise would seem to be that the deeper water increases the efficiency of erosion, as is also seen in beach erosion (Bruun 1962; Schwartz 1967; Schwartz 1968). Both leaf litter and the peat surface at Hungry Bay are subject to erosion.

Management response

Several active management strategies could assist this threatened mangrove ecosystem:

-- The eroding edge could be stabilised and protected from further erosion by use of friction matting placed on the peat surface, or by using more natural fibrous material, such as woven palm fronds. Sediment could be taken from the bay and built up against the eroding edge, stabilised, and replanted with mangrove propagules. Creek banks could be stabilised and replanted with mangrove propagules in the same manner as the eroding seaward edge.

-- In order for the mangrove swamp to keep pace with rising sea level, leaf litter retention for breakdown to peat should be improved. It would be effective to put a floating boom across the creek entrance, or across the creek farther into the swamp, as most loss of organic matter from the swamp is in the form of dry floating leaves. If leaves could be retained by a boom and returned up the creek by the next flood tide, they would be more likely to remain in place because once wetted they are less buoyant. It is not possible to use a barrier to depth because it would disrupt fish movements.

-- Prohibitive management strategies are also necessary. Boats with motor propellers and jet skis must be banned from the creek and areas of the bay close to the mangroves. These kick up sediment and enhance erosion.

MONITORING STRATEGIES

In mangrove areas of the world that are not yet affected by sea-level rise, monitoring activities are indicated that can be started now, that will greatly assist identification of problems as they start to occur, and will help decisions regarding active management strategies.

Tide gauges

The understanding and prediction of global sea-level trends is only possible through a coordinated system of tide gauges, such as the UNESCO (Intergovernmental Oceanographic

Commission) Global Sea Level Observing System (GLOSS), or the National Oceanic and Atmospheric Administration (NOAA) network. The establishment of such tide gauges in areas with mangroves should be supported, as this will allow identification of trends of sea level that may cause problems to mangrove ecosystems.

Mapping

Mangrove areas should be mapped and remapped periodically, to show locations of different mangrove zones, and of seaward and landward fringes of the mangrove area. Older records from the mangrove area should be compiled into a database. Large scale colour air photographs should be taken.

Elevations

It is critical to determine elevation of the mangrove substrate with respect to the tidal spectrum, and preferably link surveys to the datum used by the nearest tide gauge. Such elevation surveys will indicate the preferred elevation of different mangrove species, information that will be of use should replanting become necessary with sea-level rise. Such surveys could also identify areas low in the tidal spectrum that may already be experiencing problems with erosion. Surveys over time would indicate this better, combined with monitoring of sedimentation rates. A permanent benchmark should be established close to each mangrove area, to which different surveys can be related for comparison.

Sedimentation rates

Sedimentation rates within the mangrove ecosystem should be monitored inasmuch as sediment accumulation is the natural process by which mangrove substrates can keep pace with sea-level rise. Litter fall should be quantified (see Brown 1984), as it is in the Caribbean as part of CARICOM, a program using low-technology standard techniques to monitor productivity. Substrate sedimentation can be most easily monitored by use of inserted pegs (see Spenceley 1982), though a standard methodology for this needs to be established.

Research and Communication

Sea-level position is central to the functional ecology of a mangrove swamp. Rise in sea level will perturb every aspect of the ecosystem; hence, effective understanding and management require an applied direction by the different mangrove scientists, and communication among them. Effects of rise in sea level will vary between mangroves in different parts of the world and in different physiographic locations because of differences in productivity, species composition, and sediment supply. Here, also, communication between management personnel of different countries will allow separation and analysis of problems of local and regional scale.

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PRESENT KNOWLEDGE OF THE STRUCTURE OF CORAL REEF FISH ASSEMBLAGES IN THE PACIFIC

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ABSTRACT

Assemblages of coral reef fish in the Pacific are characterized by a large number of species and a great variability of species composition, density, or biomass over time and space. There is a gradient across the Pacific of the number of coral reef species but the gradient is poorly reflected by the number of species on a given reef. There is also a gradient across the Pacific of the trophic and life-history structure of the coral reef species pools. The pools can be clustered into two major groups: the Western Pacific group, which can be subdivided into the Central Pacific, the Great Barrier Reef-New Caledonia region, and the Central-West Pacific; and the East and South Pacific group, which can be subdivided into the Hawaiian-Polynesian region and the Norfolk-Lord Howe-Kermadec region. Data are still insufficient to correlate the structures of these species pools to the structure of the reef fish assemblages from the various regions. Variability of the trophic structure or life-history strategies of reef fish assemblages is usually low at a large scale if species composition is considered. Variability is greater when the structures are considered in terms of density or biomass. At a small scale in time or space, variability of these structures is usually important. The main cause of variability is likely to be random recruitment of juveniles to reefs. Within a region, assemblages on widely separated reefs of a particular type share more similarities than assemblages on reefs near each other but of different types. Within a given type of reef, only a limited number of species are ubiquitous, and only certain species are restricted to particular parts of the reef. Density and biomass are much more variable than species diversity although the sampling of non-territorial species is often a major problem in assessing these population parameters. The present review indicates that improved knowledge of the structure of coral reef fish assemblages will require (1) the development of testable hypotheses on the generation and maintenance of the organisation of coral reef fish assemblages, (2) the collection of standard data from various parts of the Pacific, and (3) the development of data bases on the growth, reproduction, and behaviour of the main species.

INTRODUCTION

Coral reefs in the Pacific support a very large number of fish species, with approximately 4,000 species known to be present in the aggregate (Myers 1989). It is likely that these species

are not distributed at random but are formed into assemblages that follow some kind of organisation. In order to understand how these reef fish assemblages function, it is necessary to *detect* and then to *explain* their organisation. Doherty and Williams (1988) have documented the various hypotheses now proposed to explain this organisation. I provide information on what has been detected about the organisation so far.

The character of what is detected is linked with the level of observation. Because the very high spatial and temporal variability of the fish populations in the assemblages make it difficult to detect any organisation at a small scale, it is mandatory to make observations at an adequately large scale. Otherwise, local variability blurs the observations to such a degree that it has often been concluded that the organisation underlying coral reef fish assemblages is very loose (Sale 1982). To facilitate understanding and analysis of the organisation, it is useful to partition it into what can be called structures. Because the structures are no more than analytical tools, there can be as many as are needed to answer our questions. The most frequently used structures are species structure, trophic structure, life-history structure, and space-utilisation structure. The main problem in using this approach is inadequacy of data. For instance, species structure implies the correct identification of each taxon; trophic structure requires knowledge of the diet of each species as well as the variations of diet with age or between different geographical locations; life-history strategy structure requires information on life-history traits (reproduction, growth, mortality . . .) of each species. At present, this kind of information, except for species identification, is limited and it is necessary to make many generalisations, which could lessen confidence in the results. Nevertheless, it is possible to detect the major trends described in this paper.

Explanation of assemblage organisation rests on both internal and external factors. Internal factors are linked to the traits of each species. Thus, larval dispersion, habitat or food preference of juveniles or adults, reproductive behaviour, and so forth may explain some of the characteristics of reef fish assemblages. Another internal factor is the available species pool. Given similar external factors but different species pools, different types of organisation may result. External factors are mainly physical and include temperature, salinity, currents, wave action, and turbidity as well as the nature of the substrate and the benthic organisms found there (coral, algae, invertebrates . . .). A major purpose behind the discovery of explanations of assemblage organisation is to be able to predict what kind of organisation would prevail under a given set of factors or what trajectory the organisation would follow if the factors are modified.

Although there are many sources of information on Pacific coral reef fish assemblages, only five areas have received more than superficial investigation: the Great Barrier Reef, Hawaii, French Polynesia, Micronesia (Guam, Saipan, Enewetak), and New Caledonia. Except for large scale variation, most of the present paper will centre on unpublished data from New Caledonia, with discussion of similar work done in other areas of the Pacific. I follow this approach because the New Caledonian data base is very extensive and covers most aspects of the organisation of reef fish assemblages. The only other work containing such detail is Galzin's (1985) for French Polynesia, though that study lacks biomass data.

LARGE GEOGRAPHICAL VARIATIONS

It is likely that the organisation of coral reef fish assemblages is in great part linked to the composition of the species pool available. This composition varies considerably across the Pacific, with the greatest diversity in the Indonesia-Philippines region. From this centre, there are two gradients of decline in species diversity. The sharpest gradient is eastward, the number of reef fish species declining from approximately 2,500 in the Philippines to 460 in Hawaii and 125 at Easter Island. The second path of decline is either northward or southward from the equator; this gradient is not as strong as the longitudinal one (Figure 1). How are these gradients in species richness reflected in the species diversity of fish assemblages for a given type of reef? The heterogenous information available from the literature (Table 1) suggests that there is no direct correlation between the diversity of fish observed on a reef and the number of species available to that reef.

Table 1a shows the variations in density and biomass estimates of coral reef fish across the Pacific. The existing data show no particular geographical trend. Excluding patch reefs, densities fluctuate between 0.2 and 11 fish/m^2, with most values between 1 and 5 fish/m^2. The range for biomass extends from 25 to 240 g/m^2, with most values between 80 and 200 g/m^2. Inshore or fringing reefs tends to have lower densities or biomass than middle lagoon or barrier reefs. The density and biomass estimates for patch reefs should be treated with caution because usually only the hard substrate is taken into account. If these estimates were calculated on the basis of all substrates present in a radius of 50m of these patch reefs, the densities or biomasses would be considerably lower. For example, in the Chesterfield islands, density estimates for patch reefs range from 5.6 to 127 fish/m^2 for hard substrates alone and from 0.15 to 1.5 fish/m^2 if all substrates are taken into account. These patch reefs are the refuge for many species that feed either in the water column (Caesionidae, Apogonidae, Holocentritidae, and a number of Pomacentridae) or on the nearby soft bottoms (Lutjanidae, Mullidae, Lethrinidae, and some Acanturidae). Also, a number of piscivores (Serranidae, Carangidae, and some Lutjanidae) forage on the fish concentrations formed on patch reefs but are usually found at much lower concentrations on extensive reef formations.

If there is no apparent relationship between fish-species richness of a given coral reef type and the species richness of the species pool available, there might still be a correlation between the composition of this species pool and the various structures observed for this assemblage. The first step in verifying this hypothesis is to look for cross-Pacific variations of the characteristics of the species pools. Trophic structure and life-history structure will be considered here. For 17 areas in the Pacific, reasonably accurate checklists of coral reef fishes were collected. For each of these checklists, data were gathered from the literature on the food habits and main life-history traits for as many of the species as possible. If no information was available on a particular species, data from the most closely related species were considered. Information was obtained on the diets or life-history traits of over 70 per cent of the species on the checklists.

Food items are divided into nine classes: fish, benthic macro-invertebrates, benthic micro-invertebrates, zooplankton, other plankton, macro-algae, micro-algae, coral, and detritus.

Table 1 : species diversity of coral reef fish assemblages in the Pacific. The number of species in the species pool are derived from figure 1. The first number gives the number of species, the second number is the sampled surface in m^2. In case of repetitive samplings of the same area or of undefined sampled area "ex" will be noted for the surface.

* : estimated

for the references see end of Table 1a

Area	Number of pool species	Type of Reef					Method
		Inshore/ Fringeing	Patch	Middle lagoon	Barrier	Outer	
Midway (1)	460		135 ex				Visual
Midway (1)	460		82 310 m^2				Rotenone
Hawaii (2)	460	155-187 ex					Visual
Hawaii (3)	460		76-81 1500 m^2				Rotenone
Hawaii (4)	460	81-84 1000-2000 m^2					Visual
Hawaii (5)	460		77 1800 m^2				Rotenone
Fanning (17)	550*	26 ex	62-102 ex	127 ex	88 ex	110 ex	Visual
Moorea (6)	630	54 ex		100-107 ex	160 ex	156 ex	Visual
Mataiva (7)	630			6-25 500 m^2	27-30 500 m^2		Visual
Tonga (8)	800*			46 1000 m^2			Visual
Chesterfield (11)	800	54-114 400 m^2	53-80 80-170 m^2				Visual
Chesterield (11)	800	112-132 500 m^2	117-145 80-170 m^2				Rotenone
GBR (13)	860		9-38 3-28 m^2				Visual
GBR (16)	860		25-50 50 m^2	50-75 50 m^2			Explosive
Saipan (14)	870	90 2000 m^2	74 2000 m^2		60-77 2000 m^2	61-86 2000 m^2	Visual
Guam (15)	870	80-119 ex					Visual
New Caledonia (9)	1200	168-252 ex		204-264 ex	201-219 ex		Visual
New Caledonia (10)	1200	35-53 1000 m^2		98-140 1000 m^2	120-135 1000 m^2		Visual
New Caledonia (10)	1200	106 600 m^2	50-120 40-150 m^2	224 600 m^2	227 600 m^2		Rotenone
GBR (12)	1300	110 1500 m^2		201 1500 m^2	163 1500 m^2		Explosive

Table 1a : Estimates of density and biomass for some reef types across the Pacific.

D : density in fish / m^2 B : biomass in g / m^2
* : value estimated from the data presented
+ : values for hard substrate only

Location	Inshore/ Fringeing		Patch reef		Middle Lagoon		Barrier reef		Outer reef		Method
	D	B	D	B	D	B	D	B	D	B	
Midway (1)			10.9/13+*								Rotenone
Midway (1)			1.4/10.3+*								Visual
Hawaii (2)	0.8/1.8										Visual
Hawaii (3)	3.1	106									Rotenone
Hawaii (4)	1.6/2.2										Visual
Hawaii (5)			2.6	102							Rotenone
Moorea (6)	2.7				1.4/1.5				2.2/5.8		Visual
Mataiva (7)					0.2/0.5		0.7				Visual
Chesterfield	2.0/3.2	37/43	5.6/127+	400/1400+							Rotenone
(11)	1.2/3.3	90/200									Visual
	3.3/5.3	110/231									Vis.+Rot.
GBR (13)			15.5+*								Visual
GBR (16)						17/195					Explosive
GBR (12)	7	92			8.4	237			3.2	156	Explosive
PNG (18)	2.6/4										Visual
Guam (15)	1.3/5.3										Visual
New Caledonia											
(9)	2.2/5.8	61/155			1/11	81/218	1.1/3.7	120			Visual
(10)	0.86	25			3.4	301	3.4	244			Visual
(10)	1.06	28			2.5	95	2.8	151			Rotenone

References

1 - Schroeder 1989 | 2 - Hayes et al. 1982 | 3 - Brock et al., 1979 | 4 - Walsh, 1983
5 - Wass, 1967 | 6 - Galzin, 1985 | 7 - Galzin et al., 1990 | 8 - Zann et al., 1984
9 - Kulbicki, unpub. | 10 - Kulbicki et al., 1991 | 11 - Kulbicki et al., 1990 | 12 -Williams and Hatcher, 1983
13 - Sale and Douglas, 1984 | 14 - Amesbury et al., 1979 | 15 - Molina, 1981, 1982 | 16 - Talbot and Goldman, 1972
17 - Chase and Eckert, 1974 | 18 - Birkeland and Amesbury, 1987

A discussion of this classification along with the findings for the species from New Caledonia are given by Kulbicki *et al.* (in prep.). Species were also grouped into six life-history classes according to the criteria given in Table 2. This life-history classification remains tentative because precise biological data are still lacking on most species. However, because the categories are broad, there will not be many misclassifications.

Figure 2 gives the distribution of the trophic composition of the checklists analysed. A cluster analysis (Figure 4a) indicates that these checklists may be grouped into two major clusters: the Western Pacific group, which extends from Papua New Guinea to Samoa and from Japan to the south of the Great Barrier Reef; and the other cluster, which includes the southern coral reefs (Lord Howe, Norfolk, Kermadec) and the Central Pacific islands (Polynesia, Johnson Atoll, Hawaii, Easter Island). To further divide these groups, in the west there is a major subgroup extending from Japan to Fiji and from New Guinea to the Marshall Islands. A second subgroup shows an antitropical association between Belau and the Great Barrier Reef and New Caledonia. Eastwards, there is a similar antitropical association between the Hawaiian Islands and the southern islands (Norfolk, Lord Howe, Kermadec, and Easter Island).

Table 2 : life history strategies of fish from coral reef fish assemblages.
life length can be considered as life expectancy (L50 after recruitment)

CLASS	SIZE	REPRODUCTION	BEHAVIOR	GROWTH	MORTALITY LIFE LENGTH
1	Large to very large > 50 cm usually > 1m	Very late in life Usually > 70% maximum size at first reproduction often ovoviviparous low gonado-somatic index	almost never schools except for reproduction	Very slow specially after reproduction	Very low > 12 years
2	Medium to large > 30cm usually >50cm	late in life Usually > 70% maximum size at first reproduction low gonado-somatic index	seldom schools often territorial	slow after first reproduction. Often rapid initial growth	low 7-12 years
3	Small to medium < 30 cm	late in life usually > 70 % maximum size at first reproduction medium gonado-somatic index	seldom schools often territorial	slow after first Initial growth often fast	low 7 to 12 years
4	Medium to large > 30 cm	2-3 years old at first reproduction high gonado-somatic index	often schools seldom territorial simple sexual behavior	rapid initially or through life	medium 3 to 7 years
5	Small to medium < 30 cm	1-3 years old at first reproduction high gonado-somatic index	often schools may be territorial sexual behavior may be complex	rapid initially	medium 3 to 7 years
6	Small to medium < 30 cm	very early in life very high gonado-somatic index	most species school simple sexual behavior	very fast	high 0.5 to 3 years

Figure 3 shows the distribution of life-history strategies of reef fishes across the Pacific. Similarly to the situation with trophic structure, a cluster analysis (Figure 4b) shows that there is a major difference between the western Pacific and the eastern and southern Pacific. In the western area are two subgroups, one encompassing the Great Barrier Reef, New Caledonia, New Guinea, and Belau to the west, and the other subgroup extending from Japan to Rapa. In the eastern and southern areas, no subgroups can be defined.

Cluster analysis of the combined information from life-history and trophic structures reveals remarkable geographical associations (Figure 5). Well marked is the separation between the western Pacific species pools of coral reef fishes and those of the eastern and southern Pacific. Within the boundaries of each of these areas, several subgroups can be defined. In the west, the three subgroups are the Great Barrier Reef region (the Great Barrier Reef and New Caledonia), the Central West Pacific (Japan to Fiji and Papua New Guinea to the Carolines), and a central Pacific area from the Marshalls to Samoa. In the south, the New Zealand group (Lord Howe, Norfolk, Kermadec) is separated from the eastern group of Polynesian archipelagoes.

This examination suggests that the species pools show significant differences across the Pacific. But are such differences reflected at the reef level? In other words, are the variations

in trophic or life-history structures between a coral reef fish assemblage in Polynesia and on the Great Barrier Reef linked to any extent to the variations of their species pools or to other factors. To answer this question would require a comparative study of similar types of reef under similar conditions in several areas of the Pacific. Such data are not now available. In any case, as will be shown in this paper, there is no simple answer because of the extreme variability of these structures in time and space -- a variability that has resulted in diametrically opposite conclusions being drawn from different levels of observation.

REGIONAL VARIATIONS

Coral reef fish assemblages in the Pacific have been studied at the regional level in French Polynesia, the Great Barrier Reef, and New Caledonia. Information is also available on other locations such as the Hawaiian islands, Guam, and Saipan, but these data are not designed for regional comparison.

The regional studies have shown that within a region the structure of a reef fish assemblage is mainly dependent on the type of reef or on the reef's position. Thus, Galzin (1985) in French Polynesia found greater similarity among assemblages on similar types of reef from five different islands than among different reef types of a single island. On the Great Barrier Reef, the work of Williams (1982), Russ (1984), and Williams and Hatcher (1983) indicates that the structure of reef fish assemblages had greater affinities among reefs of a similar type on a north-south gradient than among reefs of different types at the same latitude. Kulbicki (unpub. data) demonstrates that the structure of reef fish assemblages is linked to the position of the reef in the lagoon and therefore to the reef type (Figures 6 to 9).

However, depending on the type of data one analyses, the differences in structure between various reef fish assemblages may vary considerably, as is illustrated by data on the structure of reef fish assemblages in New Caledonia. Consideration of the trophic or life-history-strategy structures in terms of species (Figures 6a, 6b) shows that there is little variation across the lagoon either on a coast-to-barrier-reef axis or a north-south axis. Figures 7a and 7b show that in terms of density these structures are very different from the ones for species (Figures 6a, 6b), with gradients of the importance of the various trophic or life-history strategy classes along a coast-to-barrier-reef axis and a north-south axis. In terms of biomass, Figures 8a and 8b indicate different structures from those observed for density or species composition. As with Figures 7a and 7b, there are gradients along the coast-barrier-reef axis and the north-south axis but they involve different trophic or life-history-strategy classes. Combining trophic and life-history structures results in different clusterings depending on whether it is density, biomass, or species being considered (Figure 9). A similar result was found by Kulbicki and Wantiez (1990) for soft-bottom communities. Detailed analysis of the data presented in Figures 6 to 9 indicates that the species, trophic, or life-history-strategy structures are much more stable

between reefs than are density or biomass structures. This is so simply because a major change in species composition requires more disturbance than a change in density or biomass. Consequently, the detection of a difference between reef-fish assemblages in the trophic or life-history structures at the species level is likely to reflect larger dissimilarities in the functioning of these assemblages than would a similar difference at the density or biomass level.

Table 3 gives some idea of the variations observed in trophic structure on several reef types across the Pacific. Although disparate methodologies make comparisons between regions difficult, it is clear that at the species level there are only a few differences between regions or reefs of different types. In all cases, the invertebrate feeders are the most important group. The highest contribution to density is given by plankton feeders in the Great Barrier Reef-New Caledonia region, and by invertebrate feeders in Hawaii -- and probably also in French

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Table 3 : trophic structure of 5 types of reef across the Pacific. All numbers are percentages.
S : species D : density B : biomass
* : estimated ** : value given by Parrish et al. (1986)

Location	Trophic Groups	Fringeing S	Fringeing D	Fringeing B	Inner S	Inner D	Inner B	Middle S	Middle D	Middle B	Barrier S	Barrier D	Barrier B	Patch S	Patch D	Patch B
GBR (Williams and Hatcher, 1983)	Piscivores				13	2	11	10	1	6	3	1	2			
	Invert. feed.				63	7	34	51	6	12	55	6	26			
	Plankton feed.				13	88	45	23	90	71	25	67	43			
	Algae feeders				12	4	9	15	3	11	17	22	29			
New Caledonia Kulbicki (unpubl.)	Piscivores	10	4	9	12	2	9	12	5	9	10	3	10			
	Invert. feed.	52	17	32	49	18	27	51	21	30	53	23	36			
	Plankton feed.	14	59	21	16	55	26	14	51	33	11	48	9			
	Algae feeders	24	20	38	23	25	38	23	23	28	26	26	45			
Chesterfield Kulbicki et al. (1990)	Piscivores	9	4	9										12	4	24
	Invert. feed.	56	46	32										54	33	24
	Plankton feed.	12	23	12										17	50	31
	Algae feeders	23	27	47										17	13	21
Moorea Galzin (1985)	Large carnivores	2									5					
	Small diurnal carn.	8									30					
	Plankton feeders	3									2					
	Sessile invert.	7									9					
	Omnivores	52									5					
	Algae feeders	27									49					
Hawaii Brock et al. (1979)	Piscivores**													18	4	8
	Invert. feeders													53	62	18
	Plankton feeders													12	22	59
	Algae feeders													13	11	13
	Omnivores													3	1	2
NW Hawaii Parrish et al. (1985, 1986)	Piscivores													16*	6*	19*
	Invert. feeders													70*		
	Plankton feeders													8*		
	Algae feeders													16*		

Polynesia, where the "omnivore" category of Galzin (1985) consists mainly of invertebrate feeders. On the Great Barrier Reef, most of the biomass is accounted for by plankton feeders, whereas in New Caledonia, depending on the type of reef, it is either the algae feeders or the plankton feeders that are the most important trophic group in terms of biomass. In the eastern Pacific, the only information is provided by Brock *et al.* (1979), who indicate that plankton feeders had the highest biomass on the coral patch they studied.

WITHIN-REEF VARIATIONS

A single reef usually contains several zones. Moving from the windward to the leeward side, the usual, though not invariable, sequence is an outer reef, a reef crest, a lagoon, and a back reef. As a general rule, the density and diversity are greatest on the back reef and least on the reef crest (Goldman and Talbot 1976; Harmelin-Vivien 1977, 1989; Russ 1984; Galzin 1985). The difference is linked to wave activity, habitat diversity, and coral cover. Habitat diversity usually decreases with depth. The number of species restricted to one zone of the reef is usually low (5-15 per cent); similarly, ubiquitous species are rather rare (4-8 per cent). Birkeland and Amesbury (1988) and Thollet *et al.* (1991) have indicated that coral reef fish assemblages are usually not much influenced by nearby assemblages such as soft-bottom or mangrove-fish communities. Across a reef there are noticeable changes in the trophic structure (Goldman and Talbot 1976; Harmelin-Vivien 1989; Galzin 1985) and, as at the regional level, species trophic composition is fairly stable compared with density or biomass trophic composition. Usually plankton feeders are mainly found on the outer reefs and leeward side of the reefs, algae feeders prefer the reef flats and leeward side, whereas the piscivores and invertebrate feeders show no special distribution. Species composition and trophic structure change with depth, with grazers' diversity and density decreasing with depth (Galzin 1985; Harmelin-Vivien 1989).

Studies of the species composition of isolated patch reefs indicate marked differences in species composition, density, and biomass -- a diversity that has been mainly explained by random recruitment (Sale and Douglas 1984). It seems that in most instances, these small and relatively isolated reefs are not a system by themselves; the fish found on a patch reef do not represent an assemblage just as a bird assemblage often cannot be supported by an isolated tree.

LONG-TERM VARIATIONS

The few studies that have been done of long-term variations of coral reef assemblages show that over an area at least the size of an entire reef, changes at the species level or density level are not very important. This suggests that at these scales, coral reef assemblages show some stability. For instance, Galzin *et al.* (1990) at Mataiva in French Polynesia found no change over an eight-year period for the total number of species per habitat, the number of species per area unit, or for density (all species pooled). The classification of zones according to their fish assemblage remained the same over the eight years. Williams (1985), looking at the effects of *Acanthaster* on fish assemblages on the Great Barrier Reef, found that, at a given

time, variations within reefs was 2-29 per cent and between reefs was 46-82 per cent but that, for a given reef, variation through time of only 0.5 per cent. This study used a log scale, however, which is a rather coarse measure. Hobson (1983), using a limited number of samples, found no difference in densities of the ten major species after two years in Midway and three years in Kona Bay (Hawaii). Also in Hawaii, Brock *et al.* (1979) poisoned a reef twice, 11 years apart. Of the total of 112 species, 40 per cent were common between the two surveys. Density, biomass, and trophic structure remained similar. In a study that covered 23 months before a big storm over an Hawaiian reef and 16 months afterwards, Walsh (1983) found no decrease in abundance or species richness although he noticed some changes in the abundance of a few species.

There are also examples of changes over the long term and on a large scale. Galzin (1985) found in Mooréa (French Polynesia) that between 1976 and 1983, fish density increased 39 per cent on the fringing reef and 47 per cent on the barrier reef. During the same period, there had been a decrease in coral cover and an increase in algae cover, which were likely responsible for an increase in Labridae and Scaridae and a decrease in Chaetodontidae and Pomacentridae. In New Caledonia, the grouping of data into two periods of three years between 1985 and 1991 (Figure 10) indicates that on a regional basis there was no change in species composition but that the density of short-lived species (life-history classes 5 and 6 on Table 2), which are mainly plankton and microalgal feeders, had decreased drastically. Figure 10 also shows that the biomass of fish in life-history-strategy classes 2 and 5 had decreased between 1985-88 and 1989-91 whereas those of class 4 had increased. Because fish of class 2 are the most valuable commercially, they had been subjected to a great increase in fishing pressure during that period. At the moment, no explanation has been found for the variations of fish in classes 4 and 5.

Studies on patch reefs (Sale and Douglas 1984; Schroeder 1989) have shown important changes over time in species composition and density. The changes are attributed to large variations in recruitment, but most of the species taken into account during these studies are of life-history-strategy classes 4, 5, and 6 (Table 2). There is little evidence that similar changes occur for fish in strategy classes 1, 2, or 3 because their densities on patch reefs are usually too low for statistical comparison. Moreover, most of these species have a range that covers a larger area than a single patch reef. As already noted, most isolated patch reefs may not represent a sufficient unit of observation for the study of reef fish assemblages.

SHORT-TERM VARIATIONS

Coral reef fish assemblages show fluctuations of species composition, density, and biomass over short periods of time. In French Polynesia, Galzin (1985) examined three types of reefs over a 15-month period. On fringing reefs there were between 36 and 49 species per survey; 25 of these were permanent and formed 80 per cent of the density. On the barrier reef the number of fish species per survey fluctuated more (33 to 55 species), with 21 permanent species forming 74 per cent of the density. On the outer reef the surveys varied from 45 to 69 species, of which 36 were permanent and formed 94 per cent of the density. Variations in

density were highest on the outer reef and lowest on the fringing reef. A seasonal trend, which Galzin attributed to recruitment, appeared successively on the outer reef, barrier reef, and fringing reef. Molina (1982), who studied two of Guam's fringing reefs over a 15-month period, noted a marked increase in recruitment-related density. Carnivores had a peak in abundance - linked to recruitment - between April and June, whilst herbivores increased in abundance between October and December. The carnivores tended to show such peaks on the deepest stations (18 and 30 m), whilst herbivores had similar peaks on the shallowest stations (5 and 9 m). In New Caledonia, Kulbicki *et al.* (1991) have looked at the variations in species composition, density, and biomass of three different reef types (fringing, middle lagoon, and barrier) over a 12-month period (Figure 11). The number of species per station was fairly constant, as was overall density. In contrast, biomass and average weight showed marked variations, without any apparent pattern -- although the investigators believe that much of the fluctuation is related to non-resident species. The trophic structure was fairly stable with regard to species of invertebrate and algae feeders except on the fringing reef. Such stability was not apparent at the density or biomass levels, perhaps because of the variations in abundance on the transects of non-resident species. This emphasizes the significance of sample size (1,500 m^2 on each reef in this case) in that coral reef fish assemblages show such a diversity in space and time.

Variations of coral reef fish assemblages are known to occur at even shorter time scales, *e.g.*, monthly, daily, day/night. Galzin's (1985) investigations of this matter indicate that there are definite trends in the activity, and therefore the detectability, of most reef fish species. These trends are linked to the lunar cycle. There are also important differences between the fish active at night and during the day. Differences during daytime can be linked to tidal cycles. The trophic composition of the species active during the day and at night is also different. Algae feeders are all diurnal whereas a large percentage of the invertebrate feeders are nocturnal. All these variations in fish activity point yet again to the need for comprehensive sampling in the study of coral reef fish assemblages if we are to have more than a quite incomplete understanding of the assemblages.

CONCLUSIONS

Coral reef fish assemblages are derived from species pools that themselves show important variations across the Pacific in species numbers and in trophic and life-history-strategy organisation. The data now available are insufficient to determine the influence of these species pools on the structure of any particular coral reef assemblage.

The structure of coral reef fish assemblages show little variation at a large scale, either in time or space. Thus, reefs of a given type or morphology will support assemblages with comparable characteristics. On a long-term basis and at the scale of a reef, changes in species composition, density, or biomass are usually minor compared with the variations observed at a lower level, where species composition, density, biomass, or trophic structure are indeed heterogeneous and show significant variations through time -- variations that are mainly attributed to random recruitment.

The number of species found in a given assemblage depends on the type of reef, with the lowest diversity usually being found nearshore and the greatest diversity in the middle lagoon. Barrier reefs and outer reefs have intermediate values. This number of species is fairly stable over time. Within a given reef type, a limited number of species are ubiquitous (<20 per cent), and similarly few species are found in only one part of the reef (<10 per cent). Density and biomass are much more variable than diversity, but the sampling of non-territorial species is often a major problem in assessing these quantities. Trophic structure is usually very stable within a region when considered at the species level. Invertebrate feeders are the most diverse trophic group in coral reef fish assemblages across the Pacific. In the western Pacific, the plankton feeders tend to be the most abundant. The most important trophic group in terms of biomass varies with the region, the type of reef, and over time in such a way that no particular trend can be detected.

To improve our knowledge of the structure of coral reef fish assemblages, the following three approaches should be considered:

1. develop *testable* hypotheses about the generation and maintenance of the organisation of coral reef fish assemblages;

2. gather *standardized* information on species composition, density, and biomass of assemblages associated with selected types of reefs across the Pacific; and

3. develop databases on the life-history traits of Pacific coral reef fishes, in particular on growth, diet, age or size at first reproduction, reproductive effort, and recruitment patterns.

At present, the only hypotheses ruling the organisation of these assemblages have to do with the type of recruitment of coral reef fishes, food, and space allocation. It is unlikely that so few hypotheses can support all the contradictory information that has already been gathered on the assemblages. Other ideas need to be tested. For instance, to what extent is the organisation of these assemblages linked to the species pool available? Is there a unit of observation at which the structure of these assemblages show some stability? And so forth. To answer such questions it will be necessary to compare reefs from different regions of the Pacific. At present, such comparisons are difficult because of disparity in research methods. In addition, many regions of the Pacific have not yet been sampled so that any biogeographic study on the variation of the structure of fish assemblages can only be incomplete. To attribute a given structure to an assemblage requires data on the biology of all its species, whereas now our knowledge of the biology of coral reef fish remains limited, especially on growth, reproduction, and behaviour. Such studies are of course very time consuming and may be less attractive to the scientific community than broader theoretical studies. Unfortunately, it is difficult to build a house with only mortar (hypotheses) and no bricks (biological data).

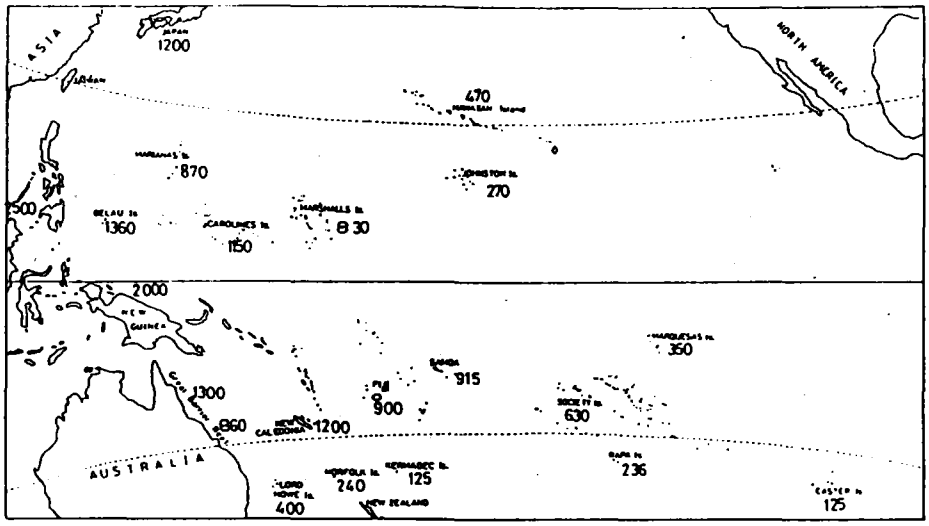


Figure 1 : Distribution of the number of reef fish species across the Pacific (adapted from Myers, 1989).

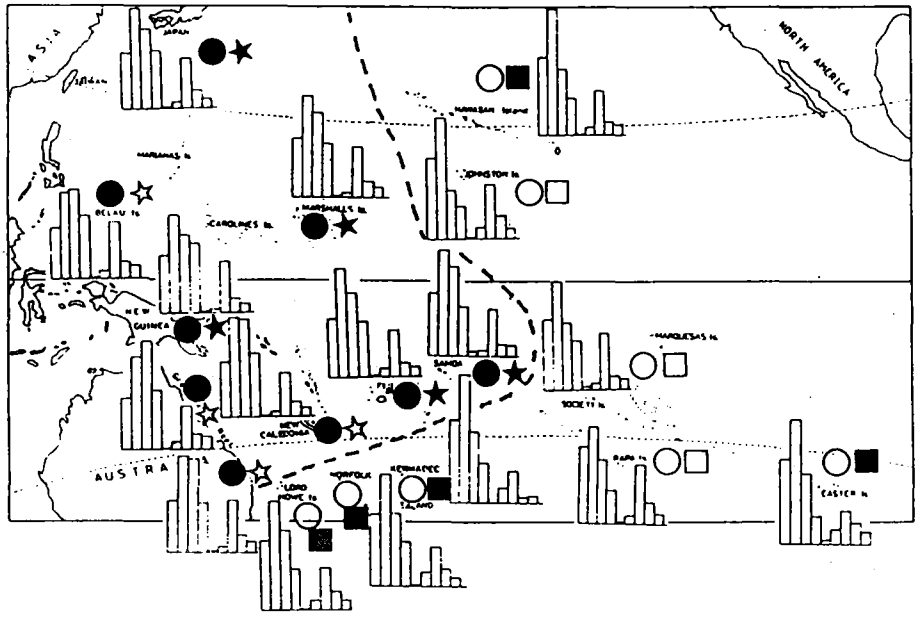


Figure 2 : trophic structure of the coral reef fish species pools across the Pacific. There are nine classes on each histogramm, from left to right : piscivores, macroinvertebrate feeders, microinvertebrate feeders, zooplankton feeders, other plankton feeders, macroalgae feeders, microalgae feeders, corallivores and detritus feeders. The symbols next to the histogramms are derived from the cluster analysis shown on figure 4a.

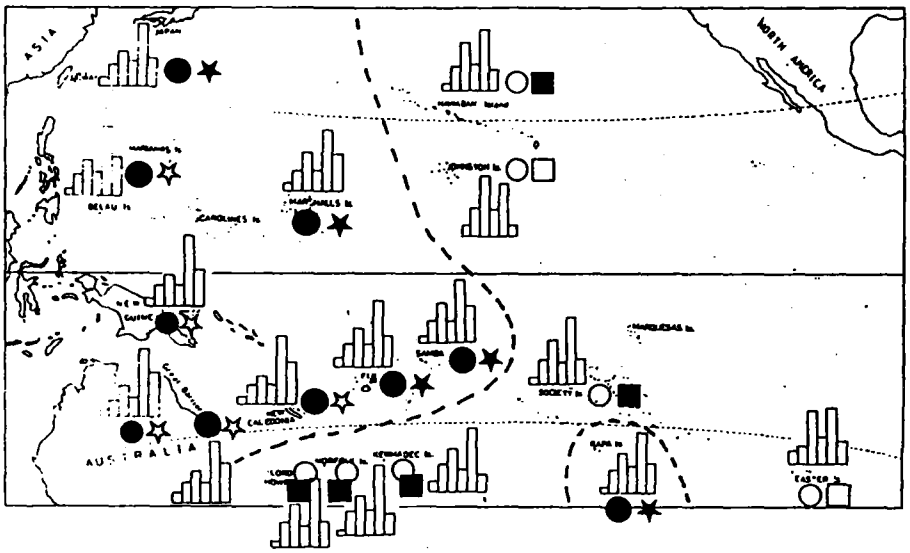


Figure 3 : Life history strategy structure of the coral reef fish species pools across the Pacific. The six classes on each histogramm are from left to right the classes 1 to 6 of table 2. The symbols next to each histogramm are derived from the cluster analysis illustrated on figure 4b.

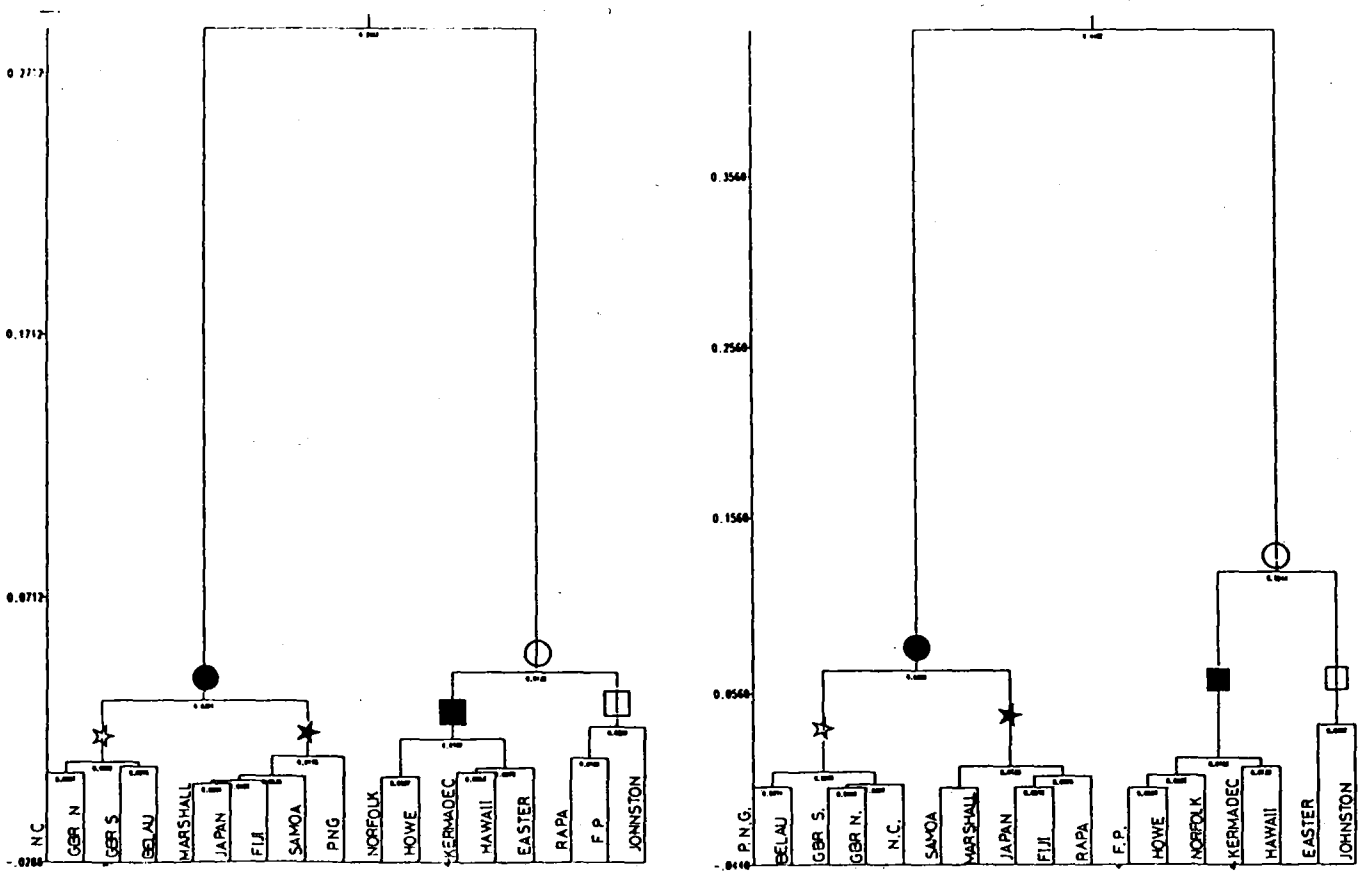
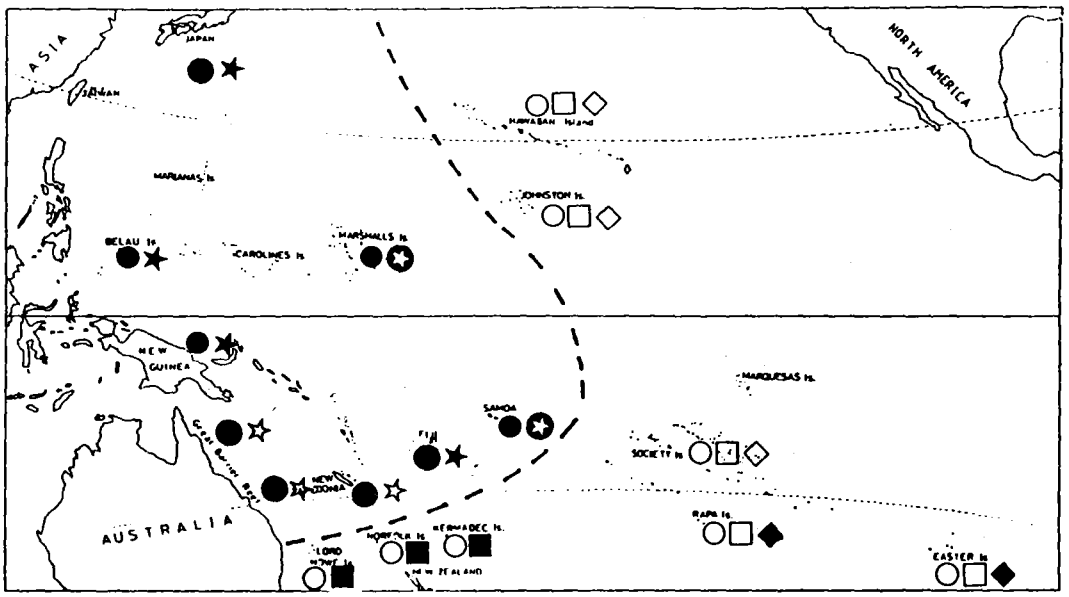


Figure 4 : a) Cluster analysis of the trophic structures of 17 species pools across the Pacific
b) Cluster analysis of the life history strategy structure of 17 species pools across the Pacific



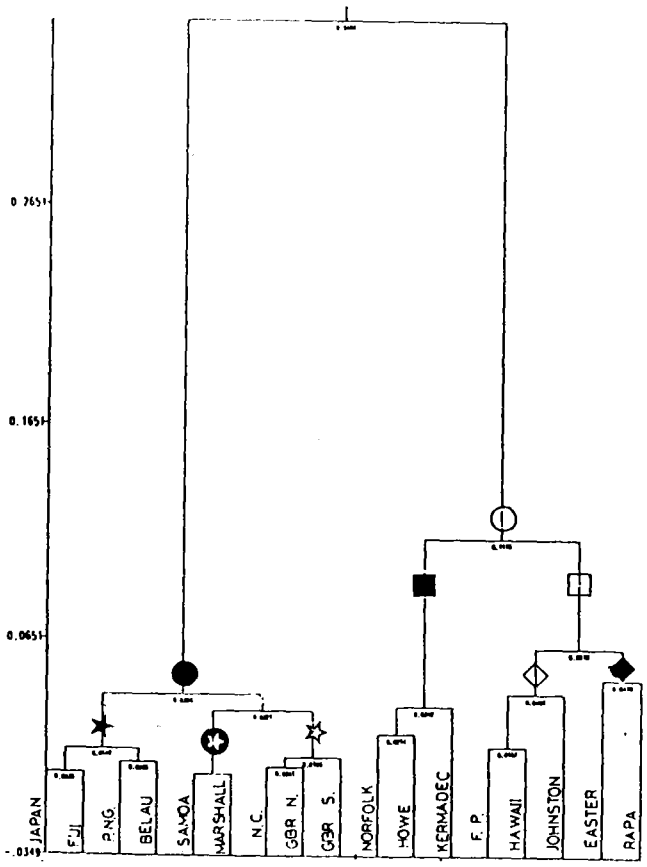
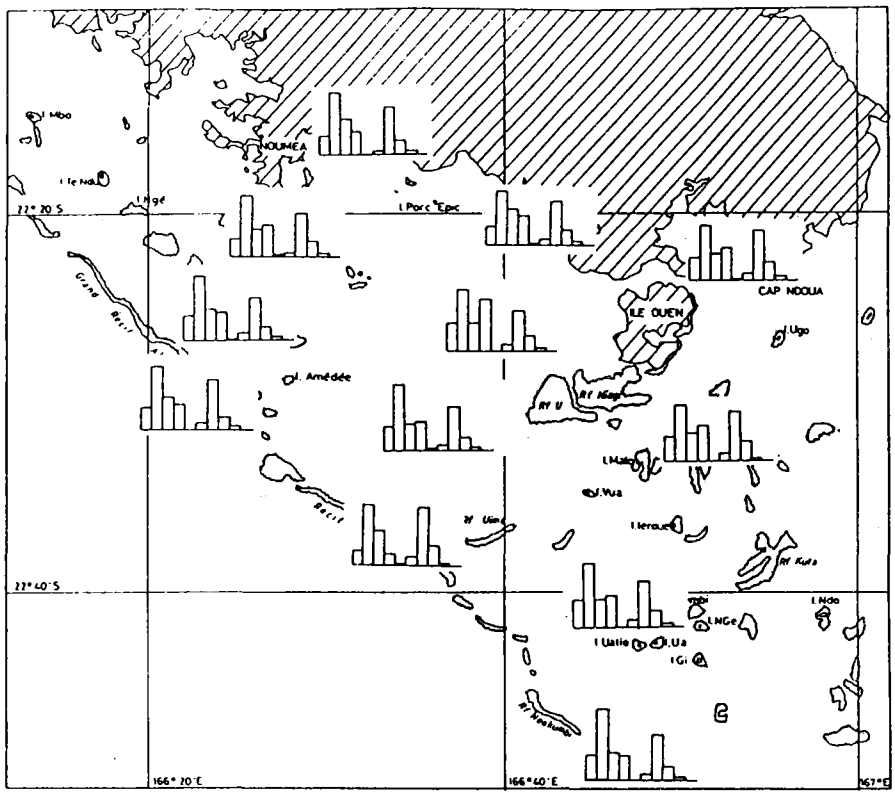
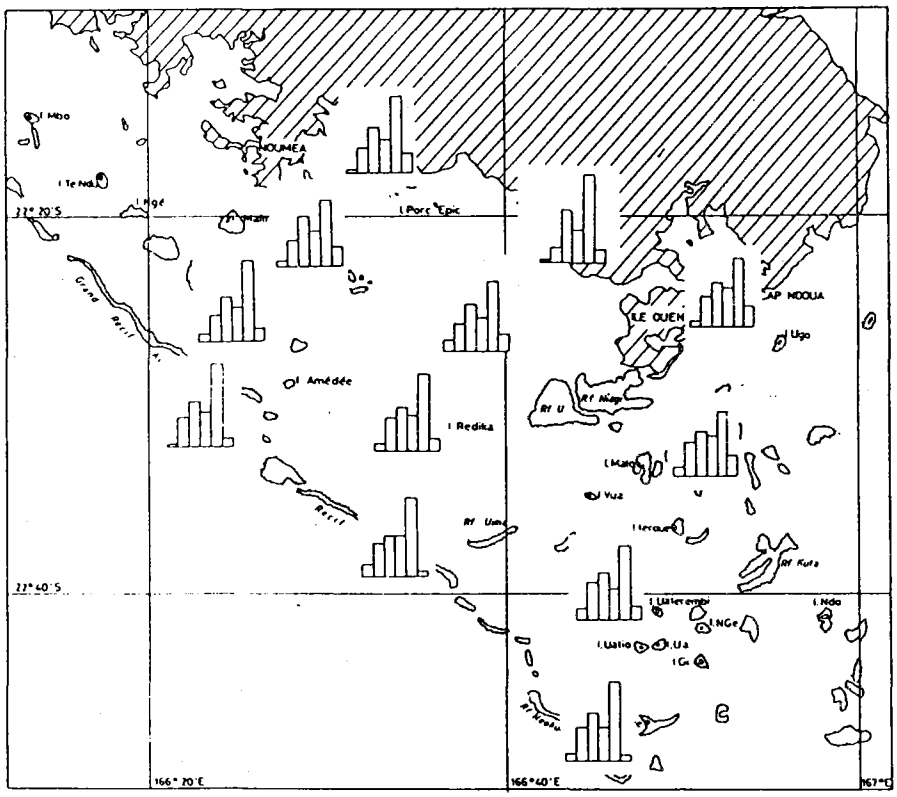


Figure 5 : Cluster analysis of the combination of the trophic and life history strategy structures of 17 species pools across the Pacific.



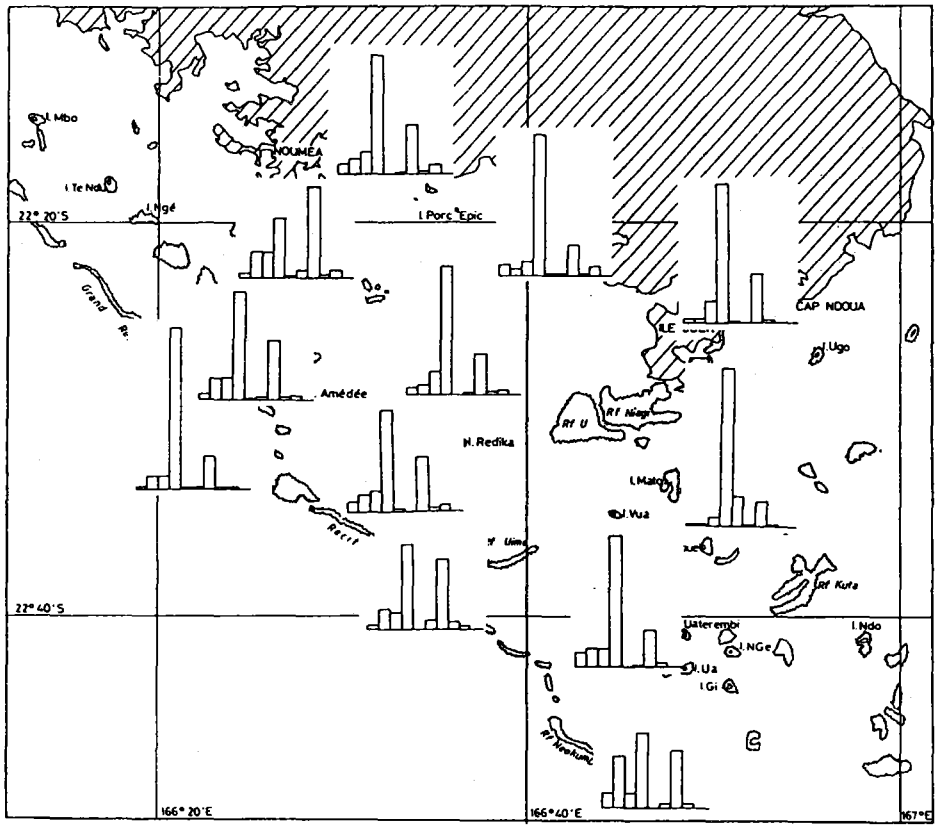
SPECIES TROPHIC



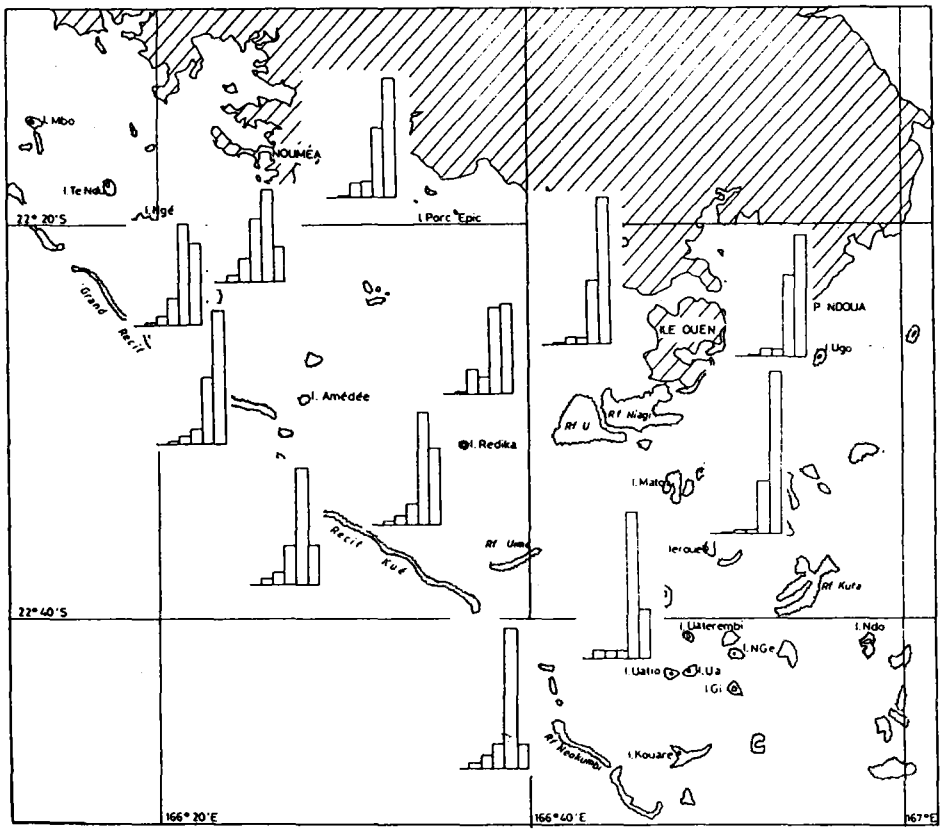
SPECIES LIFE HISTORY

Figure 6 : a) distribution of the trophic structure of coral reef fish assemblages at the species level across the S.W. lagoon of New Caledonia (approx. 2400 square nautical miles). The histogramms are arranged as on figure 2. Each histogramm is the average of 20 stations sampled over an area of 200 square nautical miles.

b) distribution of the life history strategy structure of coral reef fish assemblages at the species level across the S.W. lagoon of New Caledonia



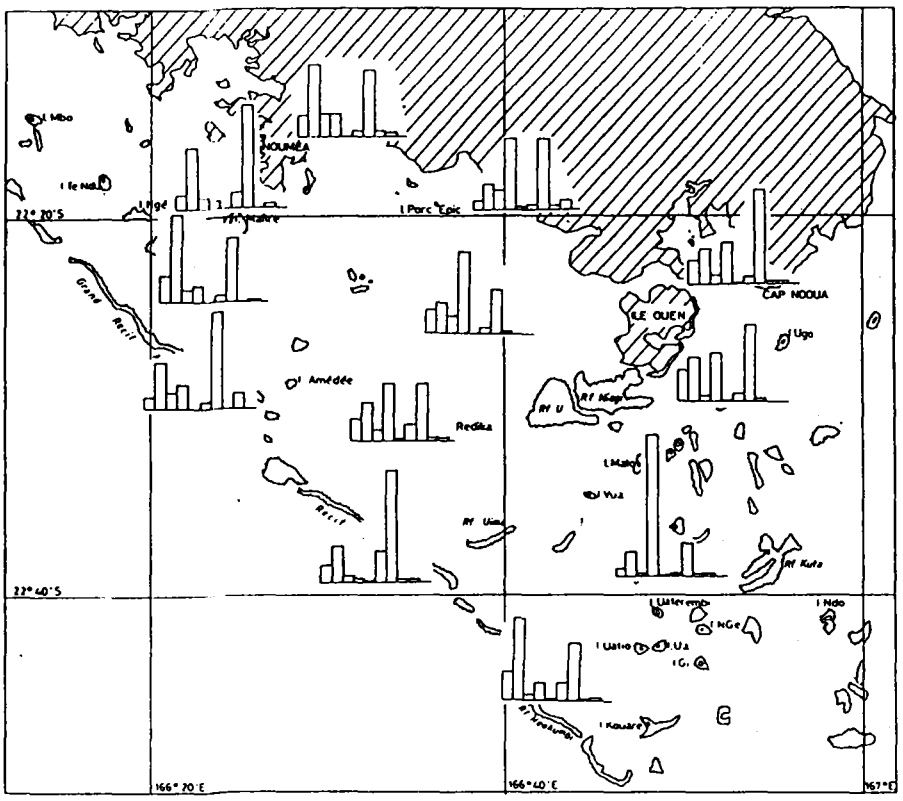
DENSITY TROPHIC



DENSITY LIFE HISTORY

Figure 7 : a) distribution of the trophic structure of coral reef fish assemblages at the density level across the S.W. lagoon of New Caledonia

b) distribution of the life history strategy structure of coral reef fish assemblages at the density level across the S.W. lagoon of New Caledonia



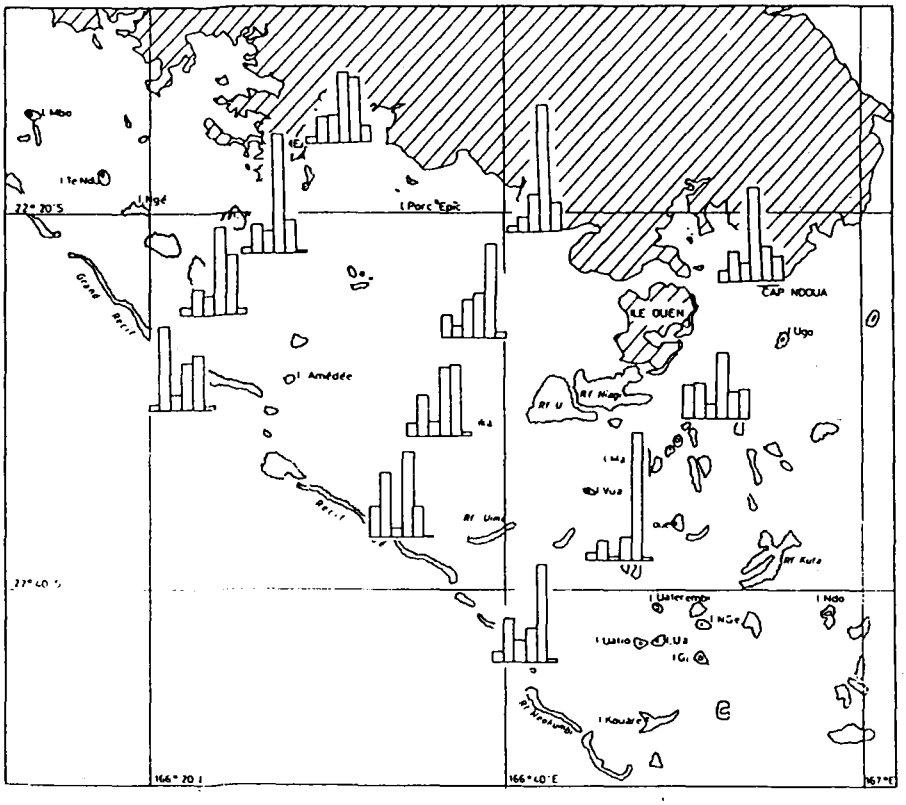
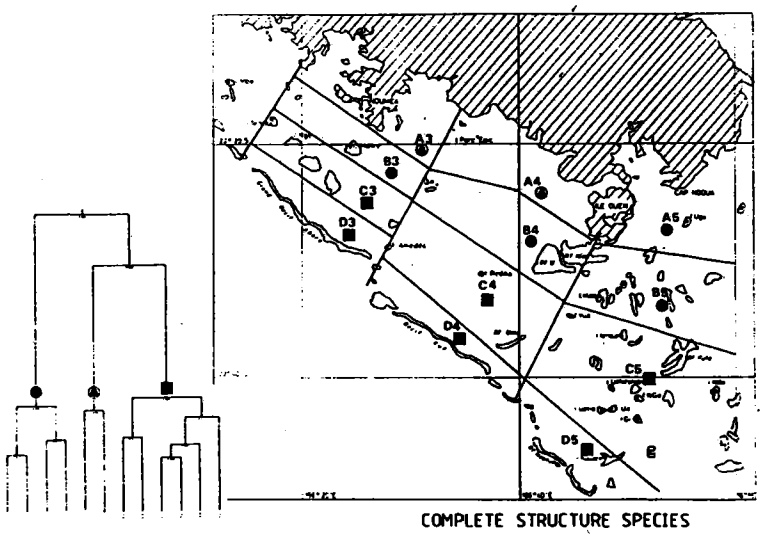
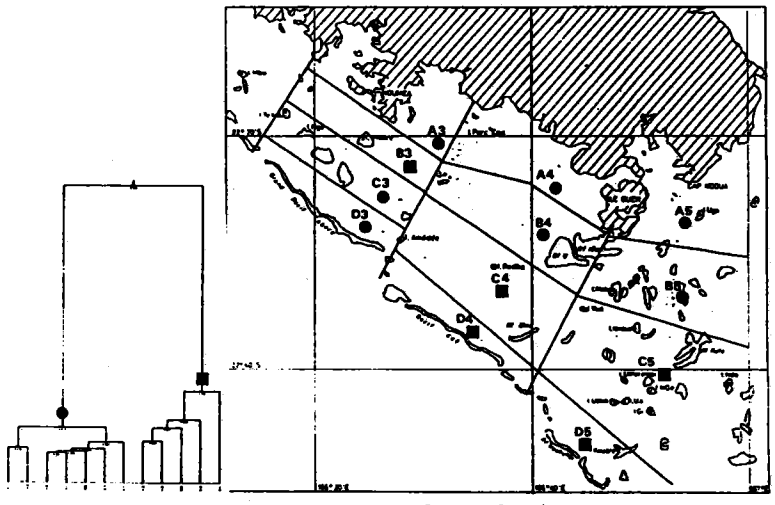


Figure 8 :a) distribution of the trophic structure of coral reef fish assemblages at the biomass level across the S.W. lagoon of New Caledonia

b) distribution of the life history strategy structure of coral reef fish assemblages at the biomass level across the S.W. lagoon of New Caledonia





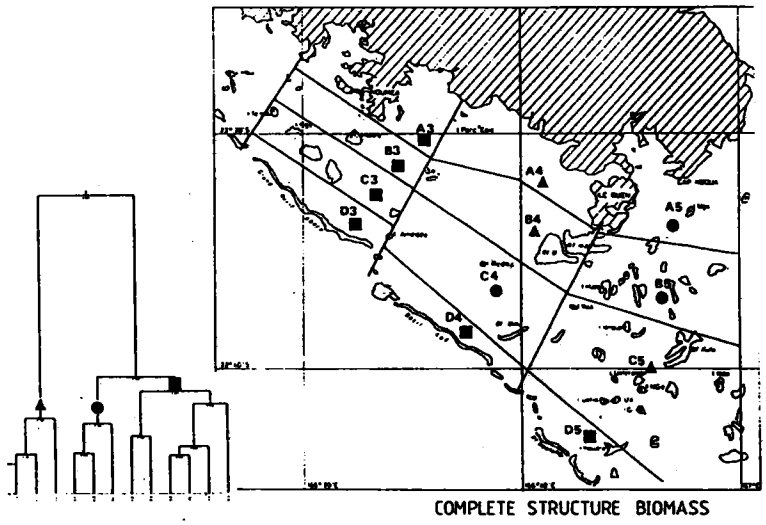


Figure 9 : cluster analysis of the combination of trophic and life history strategy structures of coral reef fish assemblages at the species, density and biomass levels on the S.W. lagoon of New Caledonia

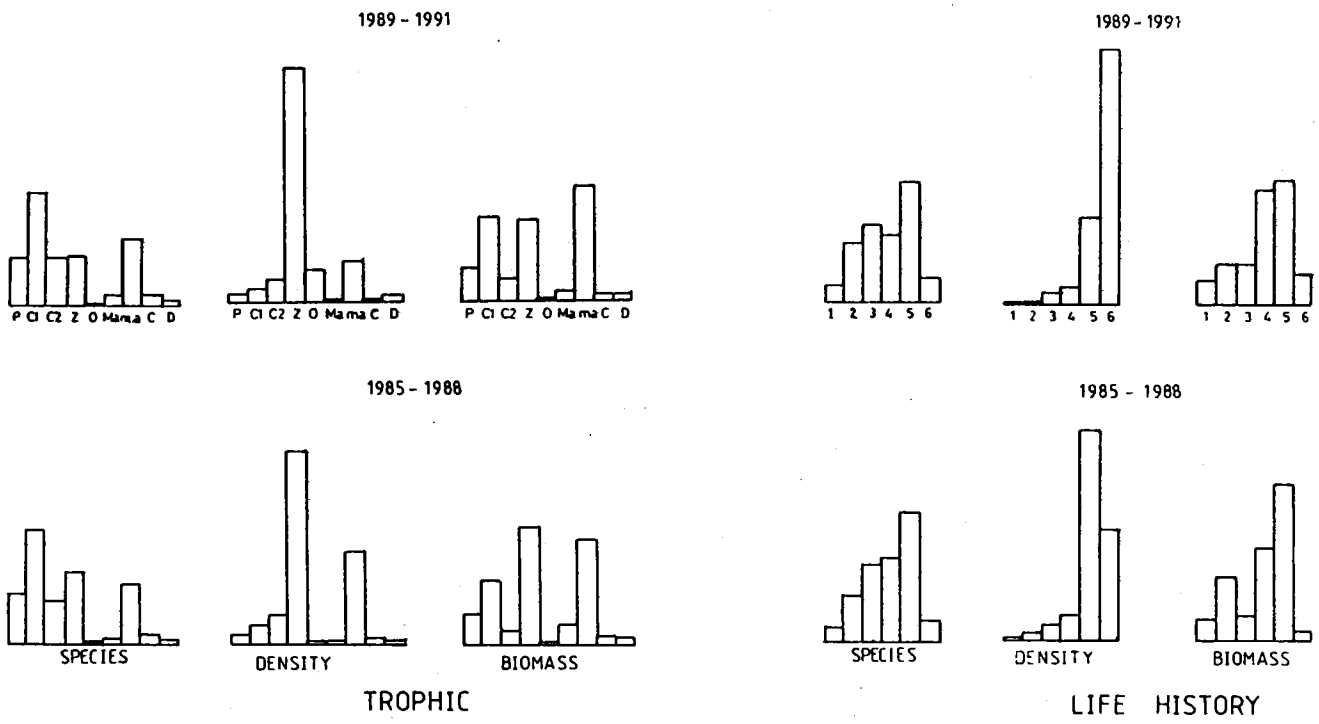


Figure 10 : temporal variations of the trophic and life history strategy structures of coral reef fish assemblages in the S.W. lagoon of New Caledonia. Trophic groups are arranged in the same order as on figure 2 and life history strategy groups are in the same order as on figure 3.

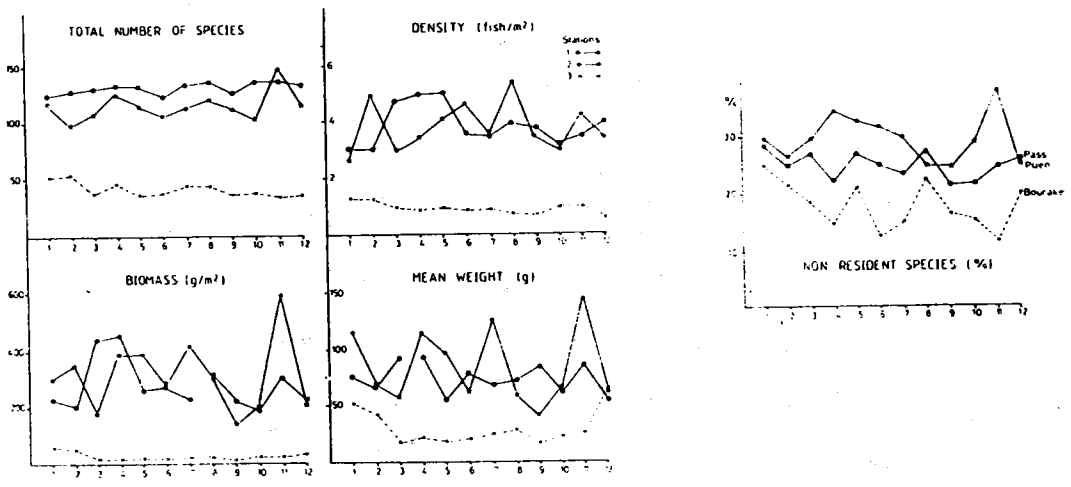


Figure 11 : annual variations of the species number, density, biomass, mean weight and percentage of non-resident species on three reefs in the S.W. lagoon of New Caledonia. Months are on the X axis. Station 1 (Bourake) is a fringeing reef, station 2 (Puen) is a middle lagoon reef and station 3 (Passe) is on the Barrier reef.

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ENDEMISM OF FISHES IN OCEANIA

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ABSTRACT

Only shore fishes, defined as those benthic or bottom-oriented species occurring in less than 200 m, or inshore surface-dwelling species, are considered in the present analysis of endemism of fishes at oceanic islands of the central and western Pacific. Most of the island groups of Oceania are not sufficiently isolated from one another to have many endemic species of fishes. The Marshall Islands and the Mariana Islands, for example, have about 1 per cent endemism. About 2 per cent of the fish fauna of the Society Islands, Tuamotu Archipelago, and Austral Islands combined is endemic. The Hawaiian Islands, with 536 species of shore fishes, have the highest percentage of endemic fishes, 25.0 per cent, which is not surprising in view of the geographic and hydrographic isolation of the archipelago. Next is tiny, remote Easter Island; of its total of only 125 shore fishes, 23.2 per cent are endemic. The island group with the third highest percentage is the Marquesas with an estimated 350 species of inshore fishes and an estimated 10 per cent endemism. Fourth is Lord Howe Island and Norfolk Island combined; of their 471 species of shore fishes, 7.2 per cent are restricted to one or both of these small islands. Fifth is Rapa, with 5.5 per cent of its 256 species of shore fishes endemic. With the exception of the Marquesas, all of these islands lie at subtropical latitudes.

The present report deals only with endemism of fishes of the islands of Oceania, *i.e.*, the oceanic islands of the central and west Pacific. West to east, these islands range from Palau to the Hawaiian Islands in the Northern Hemisphere and the Solomon Islands to Easter island in the Southern. Therefore, not included are Japan, Ryukyu Islands, Taiwan, Philippines, Indonesia, New Guinea, and New Zealand. Nearly all of the islands of Oceania occur on the Pacific Plate or at the margin of the Plate (Springer 1982: figure 2). Among those that are marginal at the western end of the Plate are the Ogasawara (Bonin) Islands, Mariana Islands, Palau Islands, New Caledonia, Fiji, and Tonga. Easter Island (Rapanui) is marginal at the eastern end. Although on the Nazca Plate, the fish fauna of Easter Island is dominantly Indo-Pacific, not eastern Pacific. Norfolk Island and Lord Howe Island lie well off the Pacific Plate but are part of Oceania.

The inshore fish fauna of islands of Oceania exhibits a striking diminution in the number of species to the east. In the Northern Hemisphere, the numbers range from 1,357 for the Palau Islands and Yap (Myers 1989), 844 for the Mariana Islands (Myers 1988), 800 for the Marshall Islands (Randall and Randall 1987), and 536 for the Hawaiian Islands (see below).

In the Southern Hemisphere there are about 1,650 shore fishes for New Caledonia (Jacques Rivaton and Michel Kulbicki, pers. comm.), 915 for Samoa (Wass 1984), 620 for the Society Islands (Randall 1985), 250 for the Pitcairn Group (Randall, MS), and 125 for Easter Island (DiSalvo *et al.* 1988) There is also a diminution with higher latitude in the western Pacific. The Ogasawara (Bonin) Islands, at 27-28°N, have an estimated 450 species of shore fishes (Randall *et al.*, MS), hence notably less than the Mariana Islands directly south. Lord Howe Island, at 31°S, has 427 species (Francis, in press).

Only shore fishes are here considered in computing the percentage of endemism. These are defined as benthic, bottom-oriented species that occur in less than 200 m; or surface-swelling species which are shore-oriented (belonids and hemiramphids are examples). Pelagic and deep-water fishes are widely distributed, in general, and their inclusion would only result in lowering the level of endemism. Also these fishes are not as well collected and documented as the shore fishes. If an area under comparison has had its pelagic and deep-sea fishes more extensively sampled than another area, its level of endemism will be lower. Some pelagic fishes such as certain exocoetids and scombrids venture close to coasts, but they are here not regarded as shore fishes.

Not everyone is in agreement as to what constitutes an endemic species. Should subspecies be regarded as endemics? Herein lies one of the major problems facing systematists dealing with insular faunas. What one person regards as a insular subspecies, another may call a species. For the present report, those forms consistently listed as subspecies (or sometimes elevated to species) qualify as endemics. An endemic should be an organism that occurs only at the area being considered. However, what does one decide when an endemic is found extralimitally but is very rare there, thus suggesting that it is a waif that has drifted in as a larva from another area. It is difficult to prove that a rare species is a waif; it may be represented at the area in question by a small breeding population and simply be rare. Or it may be more abundant in a habitat, such as deep water, that has not been well sampled, and thus only seems rare. Conversely, there may be stragglers coming from distant areas to the region for which the level of endemism is being determined. The more extensive the collecting, the more such wide-ranging species will be discovered, and the lower will be the percentage of endemism. For the present report, once a species is found elsewhere, regardless of its abundance, it is no longer considered endemic, and all species in the area of study, whether believed to be waifs or not, are regarded as part of the fauna.

A problem also exists with respect to the intensity of collecting at different areas for which comparisons of endemism are being made. Gosline and Brock (1960) and Randall (1976) noted that the most abundant fishes in an area tend to be the endemics. Therefore, when there is less collecting in an area, the percentage of endemism will be higher.

Most of the island groups of Oceania are not sufficiently isolated from other groups to have many endemic fishes. The Marshall Islands, for example, have only about 1 per cent endemic species of shore fishes (Randall and Randall 1987), and the Mariana Islands only 1.1 per cent (Myers 1988).

The Hawaiian Islands have the highest level of endemism of reef and shore fishes. Gosline and Brock (1960: 22) estimated that 34 per cent of the reef fishes have not been taken outside the Hawaiian chain (including Johnston Island which they correctly regarded as an outlier of the Hawaiian Islands). Randall (1976) reviewed the fish collecting in Hawaii since Gosline and Brock's book, pointing out additional endemic species, alleged Hawaiian endemics that turned up elsewhere, and taxonomic changes, all of which affected the level of endemism. Based on 442 species of Hawaiian reef and shore fishes, the new level of endemism was computed as about 29 per cent.

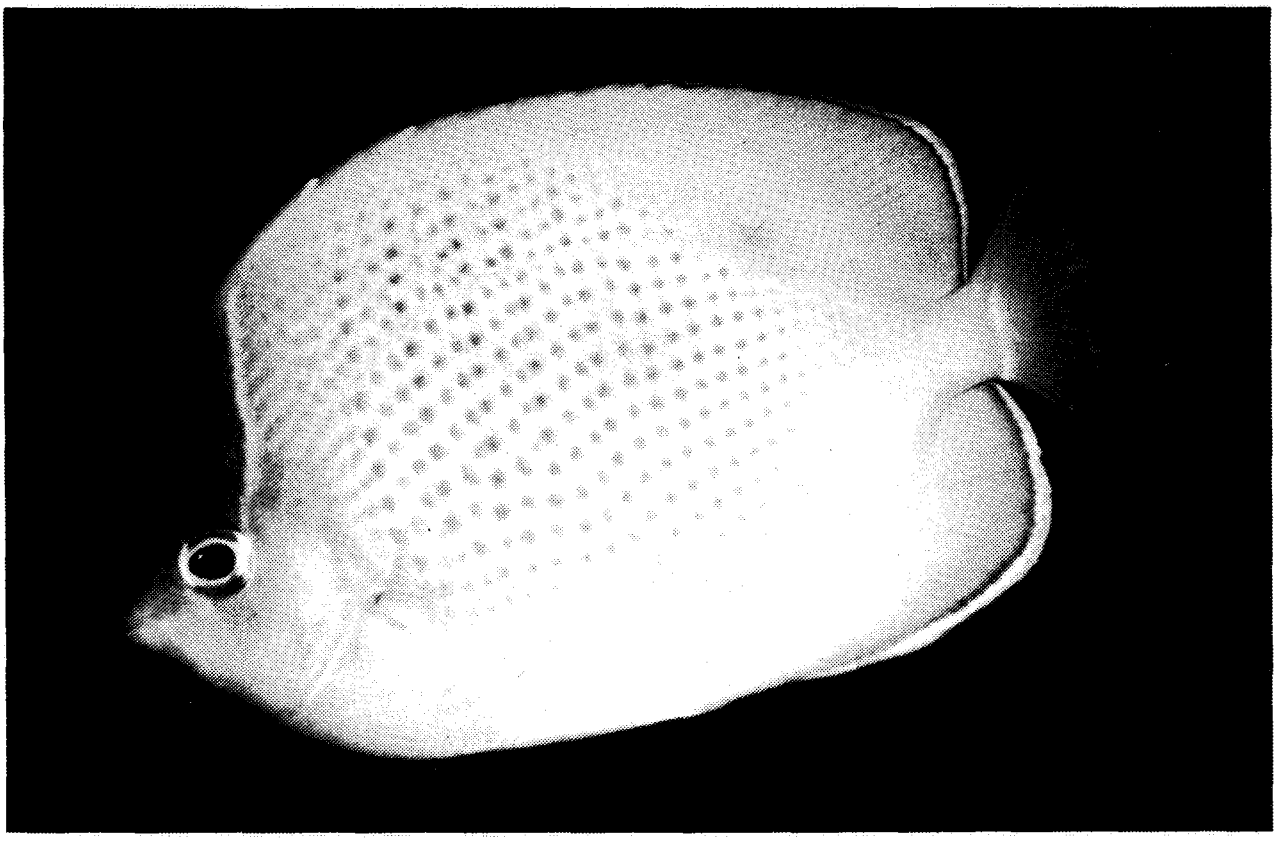
Randall (1976) also determined the level of endemism of the shore fishes of Easter Island. At that time only 109 species were known, of which 27 seemed to be endemic, thus a percentage of 27.3. In addition, he estimated the percentage of endemic shore fishes of Lord Howe Island, Elizabeth and Middleton Reefs, and Norfolk Island combined as about 12.

After spending a month collecting fishes in the Marquesas Islands, Randall (1978) estimated the total fish fauna at 350 and the level of endemism at about 10 per cent. A detailed analysis of all the collection of Marquesas fishes has yet to be made. More fish collecting is planned for these islands.

Springer (1982) reviewed the biogeography of the Pacific Plate, with emphasis on shore fishes. He noted that there is no family and very few genera of fishes endemic to the Plate, but many endemic species. He divided the Plate endemics into three types: (1) widely distributed endemics occurring in numerous island groups or in widely separated island groups; (2) endemics limited to a few islands or island groups within a limited area on the Plate; and (3) single-island or island-group endemics. Of the three kinds of endemics, he found type 3 to be the most common, particularly those from the Hawaiian Islands, Easter Island, and Marquess, all of which are high islands.

> The number of endemics present in these three island groups totals about 190, or about 14 per cent of the estimated total number of shorefish species on the Plate. . . . The total number of the three types of endemics (species only; subspecies excluded) mentioned or alluded to in the previous discussion is equal to about 20 per cent of the estimated nonmarginal Pacific Plate shorefish fauna. (Springer 1982)

In the ensuing 16 years since the 1976 analysis of the Hawaiian fish fauna, the number of native inshore fishes has been raised to 536. Some of the additions represent new records of shore fishes (Randall 1980; Randall *et al.*, MS), but most are deeper water fishes that have been found to occur in less than 200 m (even though their center of abundance may lie below this depth). Over the same period of time, additional collecting and recent revisions have expanded our knowledge of the fish faunas of other island groups of the Indo-Pacific region, and some species believed to be restricted to the Hawaiian chain have been found elsewhere. Examples are as follows: Heemstra and Randall (1977) identified *Erythrocles* sp. of Masuda *et al.* (1975) from Okinawa as *E. scintillans* (Jordan and Thompson), previously known only from the Hawaiian Islands, and Wrobel (1988) recorded it from Tahiti. McCosker (1977; 1979)



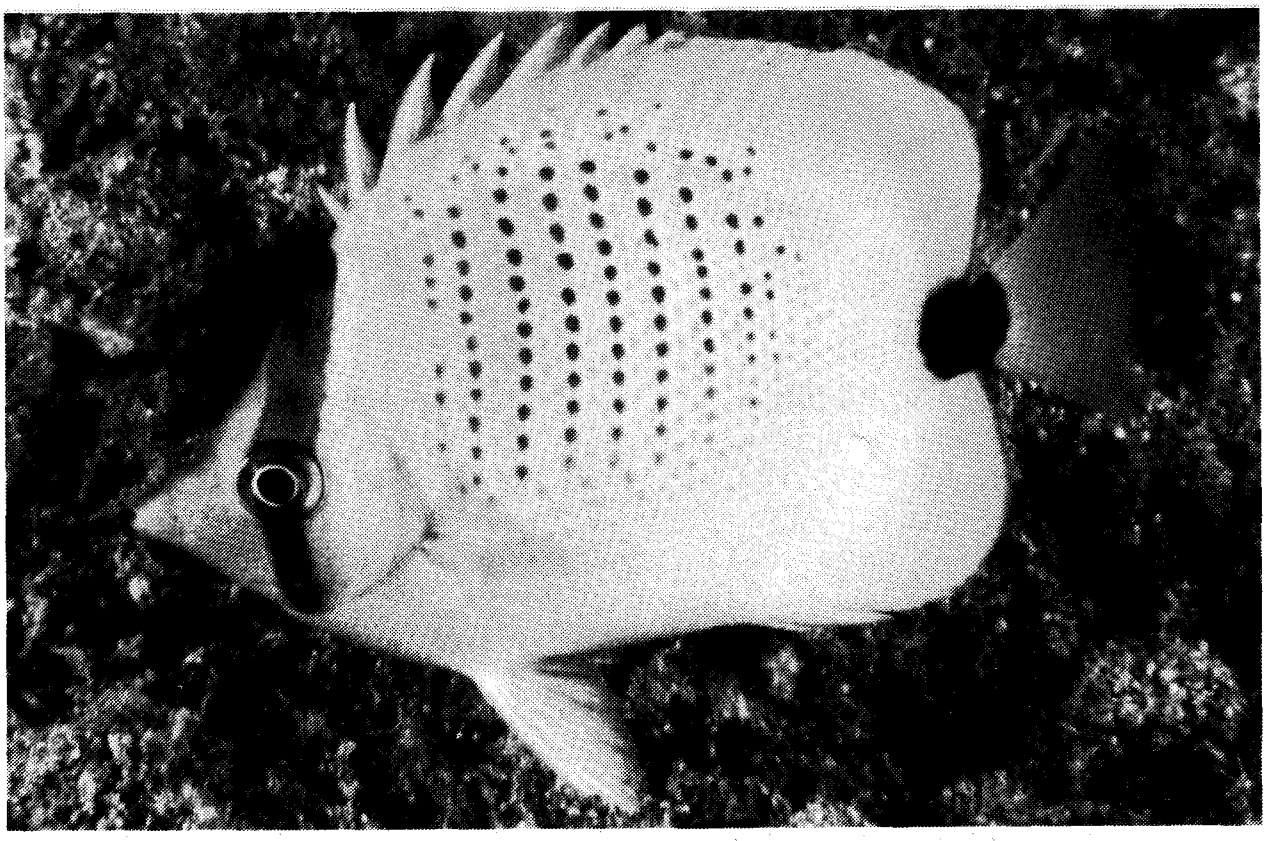


Figure 1. A. *Chaetodon guentheri*, about 105 mm TL, Komodo, Indonesia.
B. *C. miliaris*, about 105 mm TL, Oahu, Hawaiian Islands (night photograph)

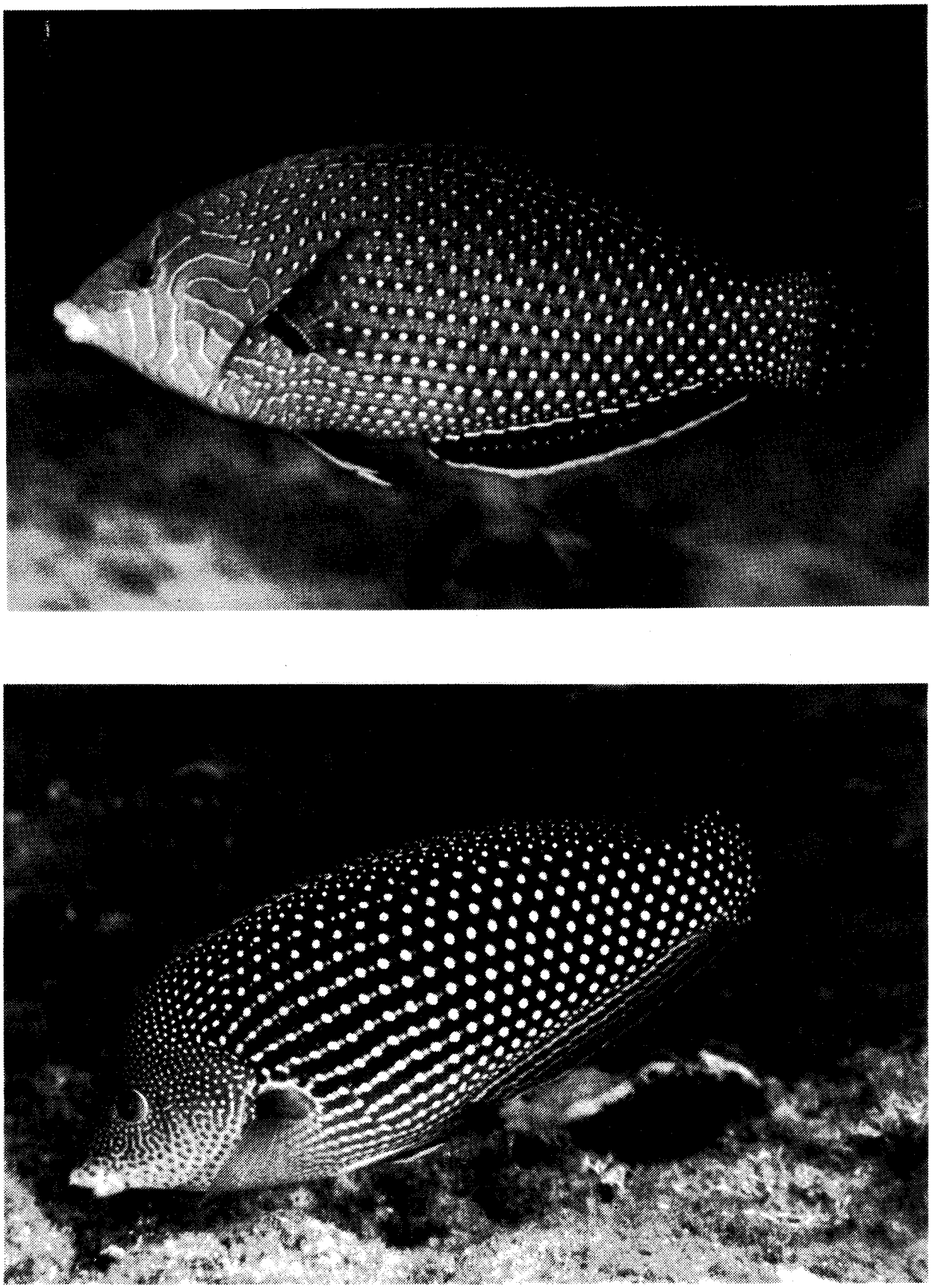


Figure 2. A. *Anampses caeruleopunctatus*, about 220 mm TL, La Digue, Seychelles. B. *A. cuvier*, about 210 mm TL, Oahu, Hawaiian Islands.

noted that the snake eels *Phyllophichthus xenodontus* Gosline and *Apterichtus flavicaudus* (Snyder), both named from Hawaiian material, are extralimital to Hawaii. He showed further that *Caecula platyrhyncha* Gosline is a synonym of *Ichthyapus vulturis* (Weber and de Beaufort), described from Sumatra (Sumatera). *Centropyge nigriocellus* Woods and Schultz, described from Johnston Island, was collected by the author at Tabuaeran (Fanning Island), Line Islands, and reported from this locality by Allen (1980); Myers (1989) listed it from the Mariana, Admiralty, Samoa, and Society islands. The Hawaiian shrimp goby *Psilogobius mainlandi* Baldwin was reprted from One Tree Island in the southern Great Barrier Reef by Randall (1982) and Russell (1983), hence antitropical in distribution. Two other examples of antitropical species first described from Hawaii are *Gymnothorax eurostus* (Abbott) and *Cheilodactylus vittatus* Garrett; the former was shown to be wide-ranging in the Indo-Pacific (Randall 1982); the later was reported from Lord Howe Island and New Caledonia by Randall (1982; 1983). Dawson (1985) showed that *Festucalex erythraeus* (Gilbert), described from a single specimen from Molokai, is a wide-ranging species with localities as far west as Mozambique. Randall (1986) illustrated a specimen of *Chaetodon tinkeri* Schultz from Enewetak, Marshall Islands. *Scorpaenopsis brevifrons* Eschmeyer and Randall, named from specimens from Oahu, was reported from Natal, South Africa, by Eschmeyer in Smith and Heemstra (1986). Pietsch and Grobecker (1987) regarded the Hawaiian *Antennarius drombus* Jordan and Evermann and *A. cunninghami* Fowler as junior synonyms of the wide-ranging *A. coccineus* (Cuvier) and *A. striatus* (Shaw and Nodder), respectively. The Hawaiian goby *Trimma unisquamis* (Gosline) was collected by the author and associates at Easter Island in 1986. *Cirripectes lineopunctatus* Strasburg described from Oahu, was listed by Williams (1988) as a junior synonym of *C. quagga* (Fowler and Ball), known throughout the Indo-Pacific region. Wrobel (1988) recorded the Hawaiian wrasse *Polylepion russelli* (Gomon and Randall) from French Polynesia. *Plectranthias helenae* Randall, known previously only from Oahu and Johnston Island, was recorded from Taiwan by Lee (1990). The Hawaiian razorfish *Xyrichtys niveilatus* Jordan and Evermann is a junior synonym of the widely distributed *X. aneitensis* (Günther) (Earle and Randall, MS). *Pseudanthias thompsoni* (Fowler), long regarded as a Hawaiian endemic, was recently collected by the author in the Ogasawara Islands.

The percentage of endemic fishes in the Hawaiian Islands, adjusted for the larger reef and shore fish fauna and the loss of endemics due to their turning up in other areas, is now 25.0 per cent.

As a result of further fish collecting at Easter Island in 1985 and 1986 (DiSalvo *et al.* 1988), the fish fauna of Easter Island was raised to 165, of which 125 are shore fishes; 29 are reported only from the island, hence the level of endemism is 23.2 per cent.

There has also been additional fish collecting at Lord Howe Island and Norfolk Island (Francis and Randall, in press). The total number of shore fishes for both islands has increased to 471 (Francis, in press), 34 of which are restricted to either or both of these islands; thus the percentage of endemism is now 7.2. The drop from the 12 per cent estimate by Randall (1976) is due to finding some of the supposed endemics at other localities, notably Australia, and the faunal additions being mainly wide-ranging species, many of which appear to be only waifs

from warmer northern localities (some of these probably do not survive their fist winter at Lord Howe or Norfolk).

The isolated island of Rapa, also know as Rapa Iti, lies at 27°36'S, 144°18'W. Extensive fish collections were made there in 1969 by C.L. Smith and in 1971 by the author (Randall 1974). Of the 256 shore fishes (Randall *et al.* 1990), 14 are known only from Rapa, hence a level of endemism of 5.5 per cent.

A glance at the chart of the Pacific, coupled with knowledge of the direction of surface ocean currents, will soon reveal that the islands with a high level of endemism of fishes are the most isolated geographically and hydrographically. More than 800 nautical miles separate the Hawaiian Islands and Easter Island from the closest island or reef (ignoring Johnston Island and Sala y Gomez which have essentially the marine fauna of Hawaii and Easter Island, respectively). The nearest reef to the island of Hawaii is Kingman Reef in the Line Islands, and the nearest island to Easter Island is Ducie Atoll in the Pitcairn Group. Furthermore, present-day current patterns are not directed toward Hawaii or Easter from these nearest localities. Fatu Hiva in the Marquesas is 275 nautical miles from the nearest of the Tuamotus, Tepoto Atoll, and the current runs from the Marquesas toward the northern Tuamotus. Lord Howe Island lies nearly 300 nautical miles east of Australia, but the surface current is primarly southerly. Rapa is 290 nautical miles from the nearest land, Raivavae in the Austral Islands. The current from Rapa has a strong westward component. It is clear from present insular locations and currents that it would be unlikely for a larval fish to reach any of these islands from the nearest shoal water.

With the exception of the Marquesas Islands, all of the islands of Oceania with a high level of endemic fishes are at subtropical latitudes, and the Marquesas at about 9°S have slightly cooler sea surface temperatures than other island groups at this latitude due to the effect of the westward-diverted Humboldt Current. This does not imply that there is a direct relationship between temperature and endemism. But there may be an indirect one. In his study of the blenniid genus *Entomacrodus*, Springer (1967) noted that nine of the 15 central and western Pacific species of the genus have their entire distribution on or near the boundary of the tropical and subtropical zones (see his Figure 4), and seven of the nine are endemics. He added, "A perusal of several recent revisions of Indo-Pacific fishes indicates to me that many species will be found whose distributions in the central and western Pacific are restricted to the periphery of the area". He cited the work of Matthew (1915), based mainly on mammals, who postulated the displacement of primitive forms from a central area by the development of more progressive forms there.

Analysis of the endemic species of the Hawaiian Islands reveals two types, ones which seem to be relatively recent derivatives of existing extralimital species, and relics. Examples of the former are as follows (Hawaiian member of the pair given last): *Priacanthus hamrur* (Forsskål) - *P. meeki* Jenkins; *Chaetodon guentheri* Ahl - *C. miliaris* Quoy and Gaimard (Figure 1); *Abudefduf saxatilis* (Linnaeus) - *A. abdominalis* (Quoy and Gaimard); *Dascyllus trimaculatus* (Rüppell) - *D. albisella* Gill; *Anampses caeruleopunctatus* Rüppell - *A. cuvier* Quoy and Gaimard (Figure 2); *Calotomus japonicus* (Valenciennes) - *C. zonarchus* (Jenkins);

Cantherhines pardalis (Rüppell) - *C. sandwichiensis* (Quoy and Gaimard); and *Canthigaster janthinoptera* Bleeker - *C. jactator* (Jenkins). These species could have arisen by the chance transport of larvae due to some unusal vagary of current to the Hawaiian chain. In the new environment, with little or no gene flow, the Hawaiian form evolved differently from the progenitor stock, or a common ancestor.

Because of their extreme isolation, the Hawaiian Islands and Easter Island are either totally lacking entire families of fishes or have few species of these families when it is known that the duration of their larval life in the plankton is short. For example, there are no opistognathid fishes (males incubate eggs in the mouth) or pseudochromids (lay demersal eggs). Groupers (subfamily Epinephelinae of family Serranidae), well represented in the Indo-Pacific in general, have only two native species in Hawaii (one of which is an endemic), and there are none at Easter Island. Those groupers for which larval development has been studied have a short larval life. Mito *et al.* (1967), for example, showed that *Epinephelus akaara* (Temminck and Schlegel) transforms to the juvenile stage only 26 days after hatching. The demersal egg-laying Gobiidae, much the most speciose family throughout tropic seas, is poorly represented at both the Hawaiian Islands and Easter Island, as is the mouth-brooding Apogonidae.

As would be expected, those families having species with a short larval life have a high percentage of endemics at oceanic islands. Five of the six species of Callionymidae in the Hawaiian Islands are endemic (hence 83.3 per cent). Most of the callionymids transform to the juvenile stage at a length of only about 10 mm (Hoede 1984). The Labridae and Scaridae, also with small size at metamorphosis and short larval life, are represented by 39 per cent and 43.7 per cent endemism, respectively, in Hawaii. Families with species laying demersal eggs and having a short larval existence also have a high number of endemics in Hawaii: Pomacentridae, 43.7 per cent; Blenniidae, 61.5 per cent; and Gobiidae, 40 per cent. The Syngnathidae, unique in the males rearing the ova in a ventral brood pouch or brood patch are 42.9 per cent endemic in Hawaii.

Families of fishes for which the duration of larval life is known to be long, such as the Muraenidae, Acanthuridae, Balistidae, and Diodontidae, are represented by few or no endemic species at oceanic islands of the Pacific.

Relics could result from the hypothesis of Matthew (1915). The progenitor stock for these species may have become extinct in the broad central part of the Indo-Pacific region due to superior competitors, increased predation, disease, or a combination of these. By not reaching Hawaii, the organisms responsible for the extinction cannot impact the species there, and a relic survives. Examples of Hawaiian endemic fishes that seem to be relics are as follows: *Pterois sphex* Jordan and Evermann; *Epinephelus quernus* Seale [closest relative seems to be *E. niveatus* (Valenciennes) of the western Atlantic and eastern Pacific]; *Cirrhitops fasciatus* (Bennett) (an apparent relic at Mauritius, Madagascar, and Hawaii) (Figure 3); *Chaetodon fremblii* Bennett (whose closest relative seems to be *C. blackburnii* Desjardins from Mauritius and southern Africa); *Genicanthus personatus* Randall (no close relative; postulated by Randall as the most primitive species of the genus)(Figure 4) ; *Centropyge potteri* (Jordan and Metz), *Desmoholacanthus arcuatus* (no close relatives; usually classified in *Holacanthus*); *Coris*

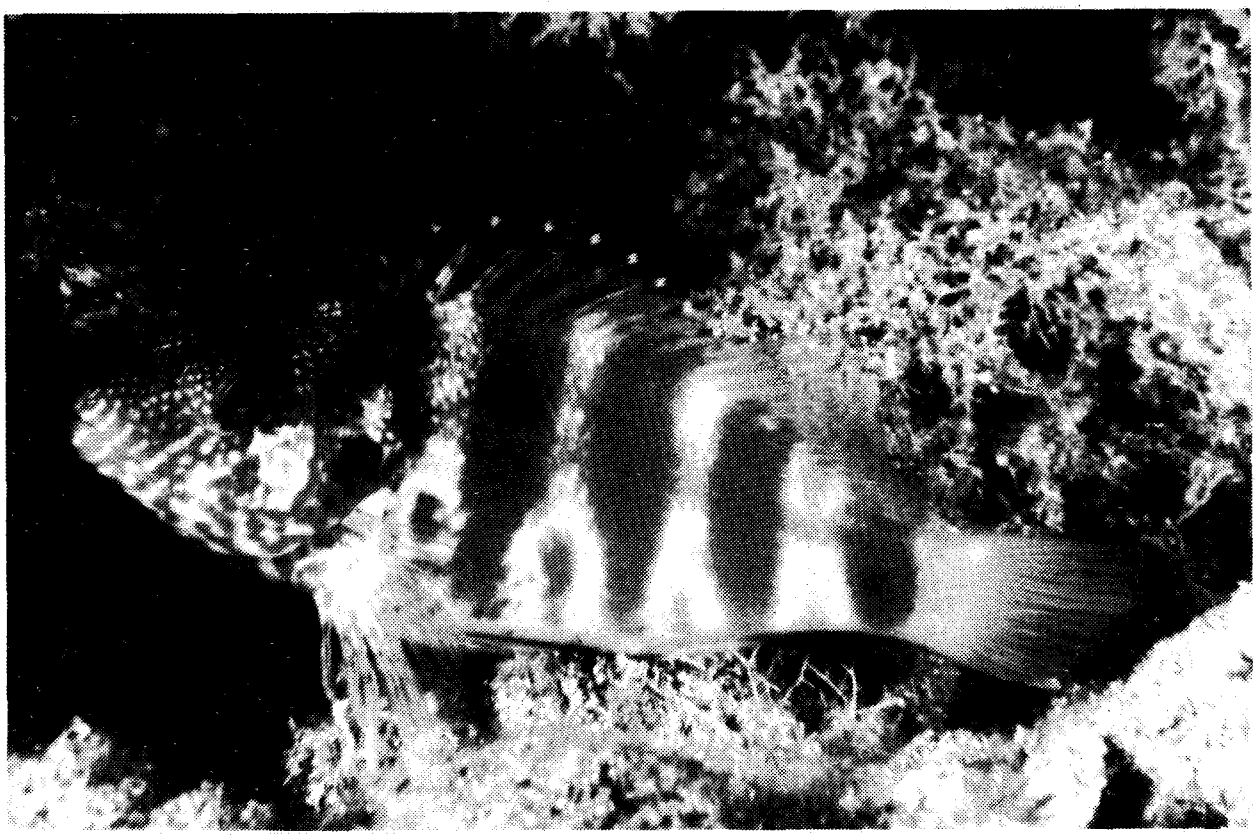


Figure 3. *Cirrhitops fasciatus*, about 85 mm TL, Oahu, Hawaiian Islands

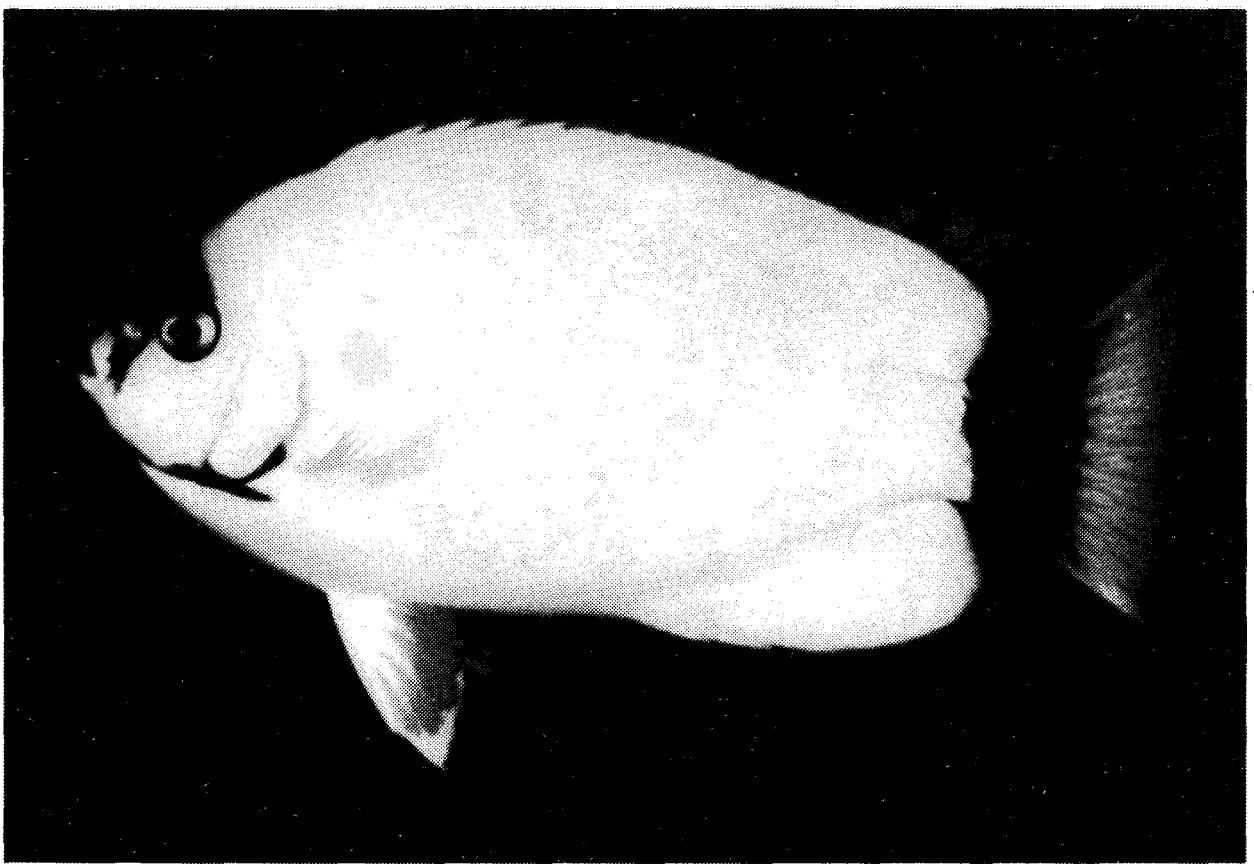


Figure 4. *Genicanthus personatus*, female, about 180 mm TL, Midway Atoll, Northwestern Hawaiian Islands

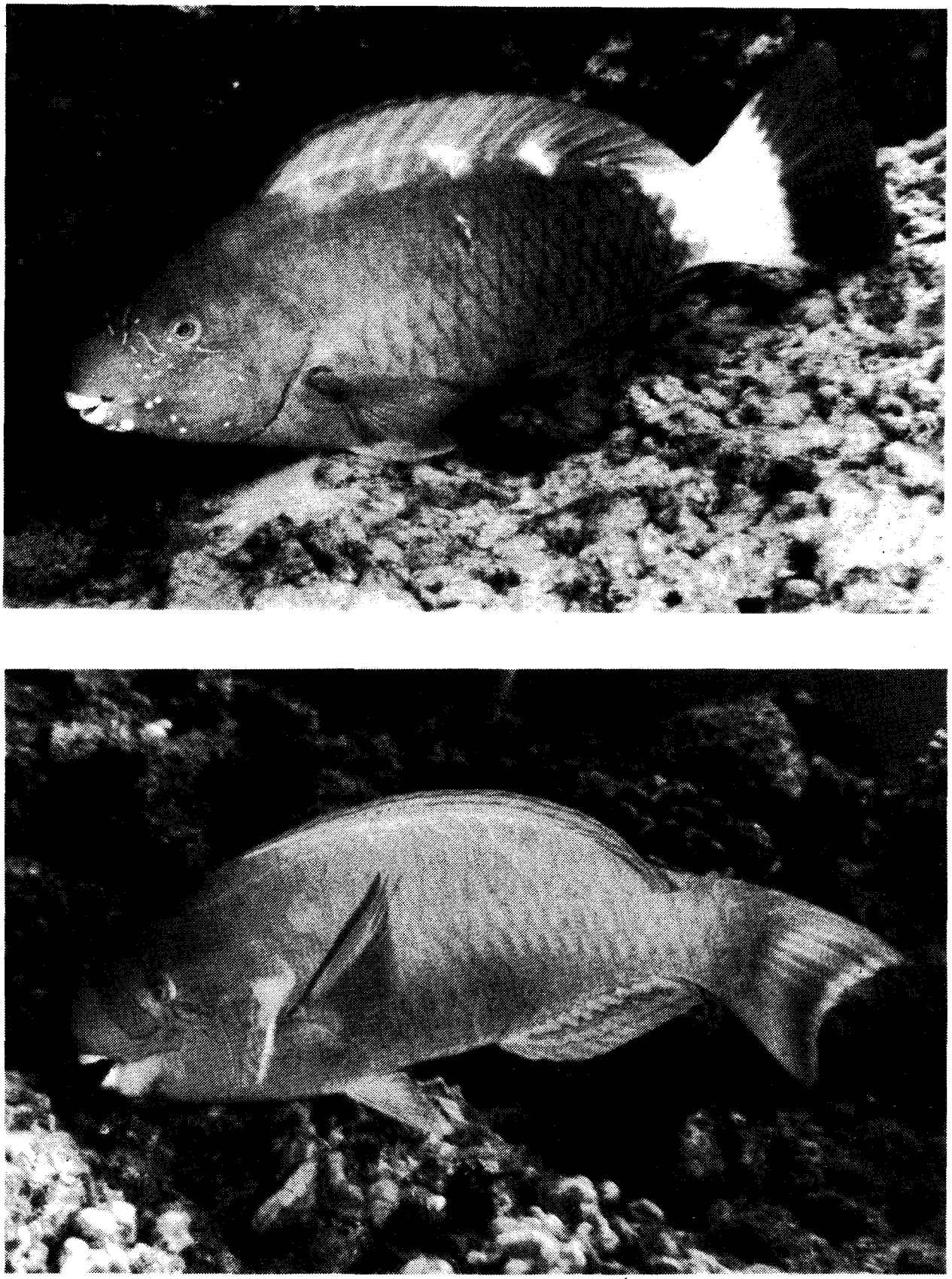


Figure 5. A. *Scarus perspicillatus*, initial-phase female (but starting to change sex to male), about 400 mm TL, Midway Atoll, Hawaiian Islands.
B. *S. perspicillatus*, terminal-phase male, about 600 mm TL, Oahu, Hawaiian Islands.

ballieui Vaillant and Sauvage, *Coris flavovittata* (Bennett), and *Scarus perspicillatus* Steindachner (Figure 5).

Mention was made above of the abundance of endemic species of fishes at Pacific Islands. Gosline and Brock (1960) first noticed this for the Hawaiian area and gave the following examples: *Thalassoma duperrey* (Quoy and Gaimard), *Muraenichthys cookei* Fowler, *Scarus perspicillatus* Steindachner, *Istiblennius zebra* (Vaillant and Sauvage), and *Acanthurus sandvicensis* Streets [I prefer to regard the last-mentioned as a subspecies of *A. triostegus* (Linnaeus)]. Two other presumed endemic species listed by Gosline and Brock as abundant have since been shown to range outisde Hawaii. Other noteworthy examples of abundant endemic Hawaiian reef fishes are *Sargocentron xantherythrum* (Jordan and Evermann), *Chaetodon miliaris* Quoy and Gaimard, *Chromis ovalis* (Steindachner), *Centropyge potteri* (Jordan and Metz), and *Canthigaster jactator* (Jenkins).

Randall (1976) also discussed the large populations of endemic fishes in Hawaii and at Easter Island and Lord Howe Island as well. He offered the following explanation of the abundance of these species:

> The endemics have either differentiated in their island environment over a long span of time, or, if relics, they may also have existed in the area for a long period. During this time they should have ample opportunity to become fully adapted to the environment. One manifestation of their success in adaptation would be their abundance.

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THE CYEL PROGRAM: ENERGY FLOW AND ORGANIC-MATTER CYCLING IN ATOLL LAGOONS

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ABSTRACT

Studies of the biochemistry of Polynesian atoll lagoons were begun in 1982 by ORSTOM scientists at Tikehau atoll in French Polynesia. Data obtained over five years made it possible to:

-- determine the water circulation and to calculate the residence time of oceanic waters in the lagoon;

-- establish a nutrient budget between ocean and lagoon waters; and

-- determine the trophic structure and productivity of lagoon communities.

This work raised new questions concerning the contribution of the following to organic matter cycles and energy flows in atoll lagoons:

-- hard substrate

-- sandy sediments

-- molecular nitrogen fixation

-- microbial loop

An investigation of each of these make up the four objectives of the CYEL program for 1991-1994.

DEVELOPMENT OF THE CYEL PROGRAM

Of the 84 atolls of French Polynesia, 76 constitute the Tuamotu Archipelago. The atolls' lagoons play an important part in the French Polynesian economy, with cultured pearls from

pearl-oyster aquaculture in the lagoons being French Polynesia's major export. In addition, the lagoons supply a major part of the local requirement for fish.

The aim of the CYEL Program is to determine the fluxes and the energy balance between trophic sources and energetic requirements of the exploited species (fish and/or pearl oysters). A model of the lagoon system will be developed to investigate these relationships.

An earlier ORSTOM program (ATOLL) was carried out at Tikehau atoll from 1982 to 1987. It revealed a great deal about (1) the productivity of many lagoon communities (Blanchot *et al.* 1989; Charpy and Charpy-Roubaud 1990a, 1990b, 1991; Faure and Laboute 1984; Intes *et al.* 1990; Le Borgne *et al.* 1989; Peyrot-Clausade 1984) and (2) the potential of fishery resources (Morize and Caillart 1988; Morize *et al.* 1990). However, this research left questions unanswered as well as raising new questions.

Specific issues that required further investigation were:

(1) the role of hard substrates in organic-matter production and transformation;

(2) the processes (i) whereby the organic matter, which is deposited at a high rate onto the existing lagoon sediments, is transformed by macroflora and microorganisms, and (ii) whereby the nutrients removed by diagenetic processes are returned to the water column by diffusion and bioturbation;

(3) the origin and trophic role of the high bacterial biomass and the associated "microbial loop"; and

(4) whether or not the non-balanced nitrogen budget between lagoon and ocean waters can be explained by nitrogen fixation in lagoon communities.

A greater understanding of these issues is necessary in order to construct models of energy and matter flows in lagoons. To facilitate this understanding, the CYEL program will focus on four themes.

Theme 1: The contribution of hard substrates to energy flow and organic-matter cycling.

In atoll ecosystems, hard substrates exist on the outer reef slope, the reef flat, and the coral pinnacles in the lagoon. The reef separates the atoll from ocean waters; in addition, the reef communities modify the characteristics of the ocean waters that enter the lagoon. Lagoon pinnacles may provide an important part of total lagoon productivity. Their biomass is high compared with that of bottom sediments, and the lagoon resources of pearl oysters and fish are mostly located close to the pinnacles. When water passes over the pinnacles, its characteristices are modified by the metabolism of the benthic communities.

The specific questions to be answered in relation to this theme are:

-- In what ways are ocean waters modified when they flow across the reef flat and through the reef-flat spillways?

-- Are lagoon pinnacles and reef flats a source or a sink for major nutrients?

-- How extensive is a pinnacle's influence?

-- What are the trophic webs of the pinnacles and reef flats?

-- What are the net and gross production and calcification of lagoon pinnacles and reef flats?

-- How much do fish contribute to organic-matter export from pinnacles?

Theme 2: The contribution of sandy sediments to energy flow and organic-matter cycling.

Sandy sediments cover much of the lagoon bottom. In shallow water, the benthic primary productivity is often higher than the productivity of phytoplankton, and this appears also to be the case if the Tikehau lagoon is considered as a whole. It must be noted, however, that organic matter produced in the water column and on the lagoon pinnacles is deposited on the existing sediments. Some of these organic deposits together with some of the bottom-produced organic matter are consumed or mineralized at the sediment-water interface; the rest is buried within the sediments and mineralized under anoxic conditions. The nutrients derived from this mineralization are returned to the water column by diffusion and bioturbation.

The specific questions to be answered in relation to this theme are:

-- How much organic matter is received by and is produced in these shallow-water sediments?

-- What is the contribution of nutrient fluxes from the sediments to the lagoon's primary-production requirements?

-- What is the trophic web in the sediments?

-- What is the role of macrofauna in the tranformation of the sedimented organic matter?

Theme 3. The contribution of the microbial loop to organic-matter cycling and energy flow.

The microbial loop is made up of small plankton: bacteria, phytoplankton, and their grazers, mainly protozoa. The loop displaces the commoner food web with differing results depending on environmental conditions. It may increase or decrease energy transfers to the upper trophic levels. The occurrence of an active microbial loop is favoured by the characteristics of the plankton in atoll lagoons: *i.e.*, very small phytoplankton ($< 3\ \mu$) and the dominance of bacterial biomass over phytoplankton biomass.

In order to model the functioning of lagoon ecosystems, it will be necessary to have answers to the following questions:

-- What is the biomass of the bacteria and protozoa?

-- What is their contribution to productivity?

-- What is the origin of the organic matter used by planktonic bacteria?

-- How much of this organic matter is transferred via the microbial loop to the higher levels of the lagoon's trophic chain, in particular to the pearl oysters?

Theme 4. The contribution of nitrogen fixation to energy flow and organic-matter cycling in lagoons.

During their residence time in the lagoon, oceanic waters become enriched in nitrogen (Charpy-Roubaud *et al.* 1990). The nitrogen has four possible sources:

(1) aerosols
(2) oceanic input of upwelled coastal waters (Charpy-Roubaud *et al.* 1990)
(3) endo-upwelling within the atoll coral structure (Rougerie and Wauthy 1986)
(4) N_2 fixation

The first source seems negligible; the second will be studied later; the third is under investigation by another ORSTOM program; the fourth is the subject of this theme.

Molecular nitrogen fixation has been shown to occur in many coral-reef areas. Large numbers of cyanobacteria, which are considered to be N_2-fixing organisms, were observed in the hard substrate, the sediments, and the water column of Tikehau atoll.

Thus, the questions for this theme are:

-- What is the rate of nitrogen fixation by plankton communities and communities of hard substrates and sediments?

-- What is the contribution of nitrogen fixation to the requirement for nitrogen in primary production?

-- What is the role of molecular nitrogen in the nitrogen budget between ocean and lagoon waters?

OUTLOOK FOR FUTURE RESEARCH

In order to most usefully conclude the CYEL Program, research should be extended to all of Polynesia so as to assess the aggregate contribution of atolls to ocean water productivity.

Three questions arise in this regard:

-- Is the operating system the same in all the atolls?

-- What is the influence of atoll typology on lagoon communities?

-- What is each atoll's influence on the surrounding ocean waters?

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II. Monitoring and Managing Coastal Resources and Systems

MARINE-ASSOCIATED PLANT COMMUNITIES IN INDONESIA IN RELATION TO GLOBAL ENVIRONMENTAL CHANGES

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ABSTRACT

Being a part of the world, Indonesia exerts its effect on global environmental conditions, and, in turn, the country's unique tropical flora and fauna are affected by global environmental changes. Marine-associated plant communities such as mangroves, seagrasses, and seaweeds are influenced by climatic and oceanographic features such as rainfall, temperature, tides, salinity, and water quality as well as by human activities. This paper attempts to evaluate the current status of marine-plant-community structure in Indonesia and to consider the conservation of marine-associated plant communities in the face of global environmental changes.

INTRODUCTION

Indonesia is a country of tropical waters containing 17,508 islands, which have 81,000 km of coastline. Two-thirds of the country's 11 million km^2 area is covered by sea (Buongiorno and Svanquist 1982). The forest area of Indonesia is about 120 million ha, of which 4.25 million ha are mangrove forests, which are largely located in the coastal estuaries of Sumatra, Kalimantan, Sulawesi, and Irian Jaya (Budiman *et al.* 1987). Of the mangrove area, 571 ha are declared as conservation areas (Darsidi 1987). Indonesia also has many coastal areas of coral reefs where seaweeds and seagrasses are commonly found (Figure 1). These estuarine and reef-associated plant communities are subject to severe disturbances under the impact of human activities and natural environmental changes.

Among the several plant communities that grow in marine habitats, we focus in this paper on mangroves, seagrasses, and seaweeds, and deal particularly with species richness, zonation, and habitat preference.

SPECIES RICHNESS

The most fundamental characteristic of vegetation is its susceptibility to change through succession, whereby the number of species present in a community increases or decreases, and

the mix of kinds of growth forms alters over time. Species richness (diversity) is a consequence of continually changing conditions. Research on species richness of mangroves in Indonesia

Table 1a. The number of seaweed species in some parts of Indonesia's waters (Atmadja 1991)

Location	Total	Composition			Common genera
		R	P	C	
Sunda Strait	115	54	24	37	Cl, Hl, Sg
Seribu Island	105	47	21	34	Ac, Hl, Sg
Pangandaran (Java)	50	25	11	14	Al, Gx, Lr
Karimun Jawa (Java)	64	21	20	23	Cl, Eu, Hl
Tj. Benoa (Java)	44	22	7	15	Cl, Gr, Hy
Nusa Kambangan (Java)	38	19	5	14	Cl, Gr, Hy
South & southeast Sulawesi	64	31	10	23	Ac, Hl, Sg
Geser & Makola (Moluccas)	48	27	9	12	Ac, Eu
Southeast Moluccas	86	42	17	27	
Tering Bay (Batam Island)	48	19	13	16	Ac, Gr, Sg

Notes:
R = Rhodophytes
P = Phaeophytes
C = Chlorophytes

Ac = *Acanthophora*
Cl = *Caulerpa*
Eu = *Eucheuma*
Gl = *Gelidium*
Gr = *Gracilaria*
Gx = *Galaxaura*
Hl = *Halimeda*
Hy = *Hypnea*
Sg = *Sargassum*

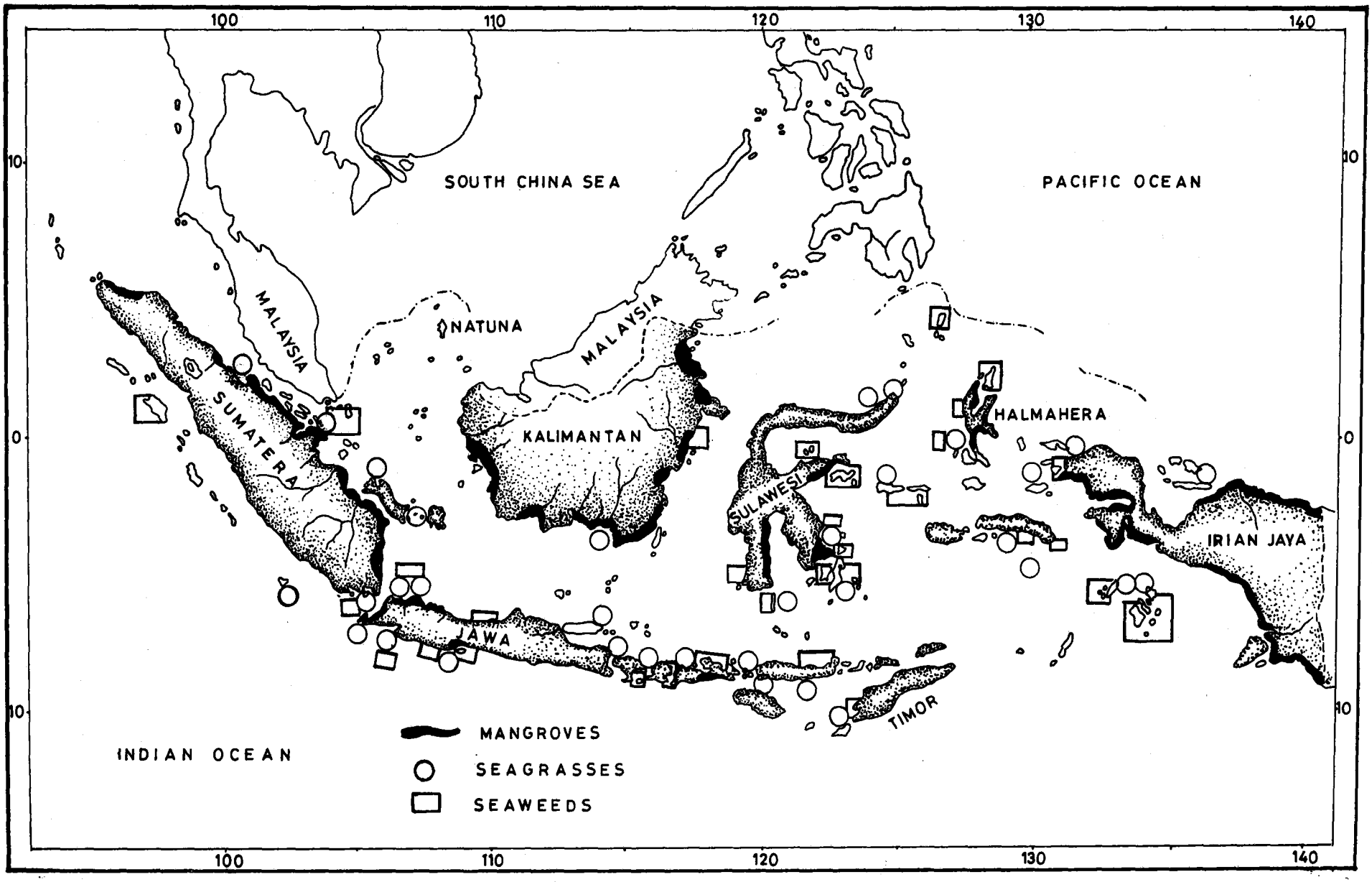

Figure 1. Distribution of mangroves, seagrasses, and seaweeds in Indonesia (Budiman *et al.* 1987; Hutomo *et al.* 1988; Soegiarto *et al.* 1978; Atmadja and Sulistijo 1988b; Atmadja and Sulistijo 1989)

reveals the natural occurrence somewhere in the country of 33 species of mangroves belonging to 14 genera(Budiman *et al.* 1987). Thirteen species of seagrasses have been collected from Indonesia (Kiswara and Hutomo 1985). Weber-Van Bosse (1928) listed 629 species of algae recorded in Indo-Malayan waters during the Sibogo Expedition of 1899-1900. Tables 1a and 1b show the species diversity of mangroves and seaweeds in various parts of Indonesia. In Ujung Kulon National Park (Sunda Strait, West Java), 15 mangrove species were found, with the commonest species being *Rhizophora stylosa, Sonneratia alba,* and *Lumnitzera littorea.* Eighteen mangrove species were collected from the Grajagan Reserve Forest in East Java, with the commonest species from that area being *Rhizophora apiculata, Avicennia officinalis,* and *Bruguiera cylindrica* (Data of Asean-Australia, Living Resources in Coastal Areas, 1987-1989).

Table 1b. The total area and species of mangroves in some islands of Indonesia (Budiman *et al,* 1987)

Island	Total area (ha)	Number of species
Sumatera	667,335	27
Java	49,935	23
Kalimantan	383,450	8
Sulawesi	99,833	6
Moluccas	100,000	25
Irian Jaya	2,943,000	18
TOTAL	4,243,553*	33

(* Not including Bali and Nusa Tenggara: 7,458 ha)

The recorded differences in species richness do not necessarily indicate that one site is actually richer than another. Rather, the differences could relate to differences in the intensity of research, length of research, and the size of the sampled area. However, we believe the recorded differences in diversity of these communities to be real and to reflect the kind and structure of habitat (including the dynamics of coastal sedimentation), zonation with regard to

tidal range, salinity, nutrients, water motion, and biological interactions. The annual temperature variation in Indonesia of about 5° C does not seem to have much effect on species diversity. Combinations of temperature, aridity, salinity, and the texture of the substrate are the controlling factors for mangrove distribution (Bird and Rosengren 1986). The few numbers of mangrove species in some places in Indonesia relates mainly to physical factors such as heavy surf, rough coastal topography, or limited sedimentation, as was observed by Frodin (1986) for the area of lowest diversity of mangroves in Nusa Tenggara Timur. Characteristically, seaweed diversity is determined by the site fertility, which in turn is influenced by the combination of temperature, radiation, water movement, substrate, and nutrients.

Indonesia's situation with regard to seaweeds is in accord with the global pattern of high numbers of seaweed species compared with numbers of mangrove or seagrass species. Species richness, however, has little bearing on the comparative significance of these plant communities within the environment or to human beings. All three communities enrich the marine environment and provide nursery habitats for many aquatic and terrestrial animals. The economic importance of managroves includes charcoal, firewood, and construction materials; seaweeds are harvested in Indonesia for export and for domestic consumption (Soegiarto *et al.* 1987; Soegiarto and Soemodihardjo 1987).

FLORISTIC ZONATION

Mangroves and seagrasses grow especially in large estuaries along the coast of North Java, East Sumatra, western to eastern Kalimantan, and southwestern Irian Jaya. In contrast, seaweeds commonly grow in areas of coral reefs, which are widespread in Indonesian waters. The zonation of mangroves depends on salinity regimes, the frequency and depth of inundation, substrate, and shoreline topography. Seagrasses are soft-bottom plants, usually growing on muddy or sandy substrates although a few species grow on hard substrates, for example, *Thalassodendron* sp. grows on a rocky substrate on the algal ridge facing the strong waves and surf movement at Tanjung Benoa, Bali. Zonation amongst seaweed species varies according to the limiting factors significant to each species, for example, tidal levels that determine emersion and submersion as well as spray are believed to be important in controlling algal zonation. Most seaweeds grow in the intertidal and subtidal zones. Interspecific competition does not appear to determine algal zonation. Clearly, marine-associated plant zonations within Indonesia are related not only to local conditions but also to global changes that will affect all the world's seas.

SUBSTRATE PREFERENCES

The texture of the substrate and its degree of hardness are important to mangroves, seagrasses, and algal growth. The chemical nature of the substrate is also important for mangroves and seagrasses but not for seaweeds.

Mangroves in estuaries and in association with coral reefs show evidence of distribution according to substrate preference. *Rhizophora apiculata* commonly grows on mud. *R. stylosa* is abundant on sand, whereas *Sonneratia alba* can grow on a sandy rubble of dead coral fragments. Accordingly, *R. stylosa* and *S. alba* are important members of mangrove communities associated with coral reefs, whereas *R. apiculata* and some other species such as *Bruguiera* spp., *Xylocarpus* spp., and *Avicennia ovalis* dominate estuarine or near-shore communities.

Seagrasses mostly grow on soft-bottom substrates, but some of them such as *Halophyla* spp. and *Cymodocea* spp. prefer sand, and *Thalassodendron ciliatum* commonly grows on rock.

Seaweeds have different preferences as to substrates. Most of them (for example, *Eucheuma* spp., *Sargassum* spp., *Turbinaria* spp., *Gigartina* spp., and *Gelidium* spp.) grow on hard substrates such as dead corals, limestones, shells of molluscs, and volcanic rocks. Other species such as *Caulerpa* spp., *Halimeda* spp., *Gracilaris* spp., and *Udotea* spp. can grow on sandy or muddy substrates (Atmadja and Sulistijo 1988a, 1988b, 1989). Epiphytic algae can attach onto algal thalli, seagrass leaves, or mangrove roots. Consequently, substrate characteristics -- which are mainly affected by topography, riverine sedimentation patterns, climate, tidal range, and long-term sea-level change (Thom 1987) -- directly influence plant growth. Substrate characteristics for mangroves are related to soil types, which are associated with variations in sediment composition, climatic conditions, local drainage, and rates of progradation of the shore line.

Natural or human-induced changes in the substrate will influence plant distribution. The effects of habitat destruction are even more profound, as in the conversion of mangrove and seagrass ecosystems for purposes of agriculture or aquaculture or else total reclamation for industry or settlement. In Indonesia, a total area of 298,210 ha of mangrove forests are proposed for fish ponds (Darsidi 1987). Similarly, the destruction of coral-reef ecosystems, as by removing corals and sand, also affects marine plant communities. Seagrass beds are depleted by human-induced thermal pollution, oil spills, toxic chemicals and sewage, and the increase of sediment input and water turbidity because of rainforest exploitation (Larkum and West 1983; Hutomo *et al.* 1988). Marine pollution caused by oil drilling and by industrial and agricultural activities have also been identified in Indonesia (Romimohtarto 1989). Several Government agencies working together with NGOs are now concerned with monitoring marine pollution in Indonesia; there is, however, a need to improve their capability and to provide them with sufficient equipment in order to achieve successful management for the maintenance of environmental quality. The Indonesian Government has established a legal framework to support these efforts. Positive actions to encourage the growth of marine plant communities include efforts to establish mangrove reforestation, seagrass restoration, seaweed farming, and the construction of artificial reefs.

THE NEED FOR CONSERVATION OF MARINE PLANT COMMUNITIES

If the valuable contribution made by marine plants to Indonesia's people and environment is to be sustained, it is necessary to use the plants more rationally, to protect them, and to conserve or preserve them. The Indonesian Government is working now to increase the very small marine- conservation area. It is planned that by the year 2,000 marine-conservation areas will have been increased to 30 million ha covering 200 localities -- that is, about ten per cent of Indonesian territorial waters (Dirjen PHPA 1988).

Mangrove forests are preserved as part of the terrestrial reserved forests (Table 2); seagrasses and seaweeds are included in the marine-conservation areas of coral reefs and estuaries (Tables 3 and 4). Marine-conservation areas established as Marine National Parks are still quite limited in Indonesia (Table 3). Table 4 lists other conservation areas, covering about 3,229,320 ha, that may be designated as Marine National Parks in the long run (Dirjen PHPA 1988). Indonesian marine-conservation areas now mostly have the status of protected seascapes and wildlife sanctuaries.

CONCLUSION

Marine-associated plant communities are widely distributed in Indonesia and cover a large area in the aggregate. Marine plants have been exploited heavily for economic purposes. Their condition as vegetation is related to environmental change -- both natural and human-induced -- at global, regional, and local scales. To ensure that these communities remain a productive part of sustainable development, efforts are being made to establish rational use of the marine plants and to include a significant part of marine-associated communities into conservation areas.

Table 2. Some areas of mangrove-forest conservation in Indonesia (Abdullah 1984)

No.	Name	Province	Area (ha)
1.	CA. Kelumpang Bay, Laut & Seku Straits	South Kalimantan	13,750
2.	CA. East coast of Jambi	Jambi	6,500
3.	CA. Muara Angke	Jakarta	15.4
4.	TW. P. Kembang	East Kalimantan	
5.	CA. P. Kaget	East Kalimantan	
6.	SM. Tanjung Puting	Central Kalimantan	11,000
7.	SM. Pleihari Tanah Laut	East Kalimantan	4,000
8.	CA. Lorentz Mountain	Irian Jaya	301,500
9.	SM. P. Dolok	Irian Jaya	99,000
10.	SM. Wassur	Irian Jaya	6,180
11.	CA. P. Sepanjang	East Java	2,430
12.	CA. Muara Kandawangan	West Kalimantan	
13.	CA. Estuary of Kahayan River	East Kalimantan	150,000
14.	CA. Adang & Apar Bays	East Kalimantan	128,000

Notes: CA. = Conservation Area; TW. = Taman Wisata (Protected Landscape or Seascape)
SM. = Suaka Margasatwa (Wildlife Sanctuary); P. = Pulau (Island)

Table 3. The Development Plan for Marine National Parks in Indonesia (Dirjen PHPA 1988)

A. In 1988.

N.	N a m e	Location	Total Area (Ha)
1.	Ujung Kulon	West Java	28,500
2.	Seribu Island	Jakarta/Java	108,000
3.	Karimun Jawa	Central Java	11,625
4.	Baluran	East Java	2,500
5.	Neru Betiri	East Java	10,000
6.	South Banyuwangi	East Java	14,110
7.	Krakatau	Lampung/Sumatera	14,700
8.	South Bukit Barisan	Lampung/Bengkulu Sumatera	10,000
9.	Way Kambas	Lampung/Sumatera	5,000
10.	Berbak	Jambi/Sumatera	5,000
11.	West Bali	Bali	5,700
12.	Kutai	East Kalimantan	10,000
13.	Tanjung Puting	Central Kalimantan	55,000
14.	Palung Mountain	West Kalimantan	30,000
15.	Komodo-Padar Rinca	Nusa Tenggara Timur	200,000
16.	Maumere Bay	Nusa Tenggara Timur	60,000
17.	Bunaken Menad Tua	North Sulawesi	90,000
18.	Semama and Sangalaki	North Sulawesi	10,000
19.	Banda Sea	Moluccas	100,000

Table 3. (continued)

B. To be developed until Year 2000

No.	N a m e	Location	Total Area (Ha)
1.	Siberut	West Sumatera	12,000
2.	Batu Islands	North Sumatera	75,000
3.	Balok Bay	South Sumatera	
4.	Belitung	Suth Sumatera	75,400
5.	North Lingga Island	Riau	
6.	Laut Kecil Island	Riau	400,000
7.	Tambelan	Riau	
8.	South Natuna	Riau	
9.	Segara Anakan, Nusa Kambangan	Central Java	4,717
10.	Atol Taka Bone Rate	Suth Sulawesi	531,000
11.	Rotan Island, North Manggar Waters	South Sulawesi	
12.	Sangihe-Talaud	North Sulawesi	156,000
13.	Grntal Bay	North Sulawesi	
14.	Samalona-Spermonde Island	South Sulawesi	5,000
15.	Togian Island	Central Sulawesi	135,000
16.	Peleng-Banggai Islands	Central Sulawesi	?
17.	Morowali	South-East Sulawesi	100,000
18.	Tukang Besi Island	South-East Sulawesi	?
19.	Muara Khayam	East Kalimantan	10,000
20.	Samarinda, Estuary of Mahakam River	East Kalimantan	?
21.	Kupang Bay, Kera Island	Nusa Tenggara Timur	?
22.	Halmahera	Molucas	85,000
23.	South -East Aru	Moluccas	80,000
24.	West Kei Island	Moluccas	?
25.	Ambon Bay	Moluccas	?
26.	Lorentz Mountain	Irian Jaya	10,000
27.	Wasur	Irian Jaya	4,000
28.	Dolok Island	Irian Jaya	10,000
29.	Membramo-Foja	Irian Jaya	40,000
30.	Cendrawasih Bay	Irian Jaya	80,000

Table 4. Proposed Marine National Parks in Indonesia (Dirjen PHPA 1988)

No.	L o c a t i o n	Number	Total Area (Ha)
1.	North Sumatera	1	75,000
2.	Riau	4	400,000
3.	Jambi	1	19,000
4.	West Sumatera	1	12,000
5.	South Sumatera	1	75,000
6.	Lampung	2	19,000
7.	Bengkulu	1	10,000
8.	Jakarta	1	108.000
9.	West Java	1	28,000
10.	Central Java	2	116,000
11.	East Java	3	28,150
12.	Bali	1	5,700
13.	Nusa Tenggara Timur	3	290,000
14.	Central Kalimantan	1	55,000
15.	West Kalimantan	1	30,000
16.	East Kalimantan	4	286,000
17.	North Sulawesi	3	156,000
18.	South-East Sulawesi	2	200,000
19.	Central Sulawesi	2	235,000
20.	South Sulawesi	4	636,000
21.	Moluccas	5	501,000
22.	Irian Jaya	5	144,000

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FOOD SECURITY AND VILLAGE FISHERIES IN VANUATU

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ABSTRACT

Produce from fishing plays an important part in the diet of the people of Vanuatu, meeting 16 to 18 per cent of yearly protein requirements. Three major consumer areas have been identified: urban, coastal, and inland rural. Each is affected by particular conditions of supply and demand. In the country as a whole, imported products (mostly tinned fish) account for 32 to 35 per cent of the fish supply. In order to increase the local supply of fish, the Government of Vanuatu introduced an ambitious development programme of small-scale fisheries at the village level.

In this paper, we examine whether or not this programme is likely to improve food security in the country, we assess the additional input in the light of changing patterns in subsistence living, and we outline prospects for increasing the role of fisheries in feeding the nation's people.

INTRODUCTION

Like most small island nations in the Pacific, Vanuatu faces powerful changes in its socio-economic, cultural, and demographic conditions. These changes affect nutrition through a combination of the following factors:

- a rapid increase in the number of consumers;
- a shift in consumer focus from a rural environment to urban areas, which is accompanied by a rapid change in dietary habits;
- a gradual but steady decline in subsistence production per capita, attributed in part to a decrease in soil fertility because of shortened fallow periods and in part to a change away from subsistence agriculture;
- inability of the commercial sector to offset this phenomenon; and

an increase in food imports, which jeopardizes the balance of trade, when it is already in deficit, and which increases the food dependency and food vulnerability of the country.

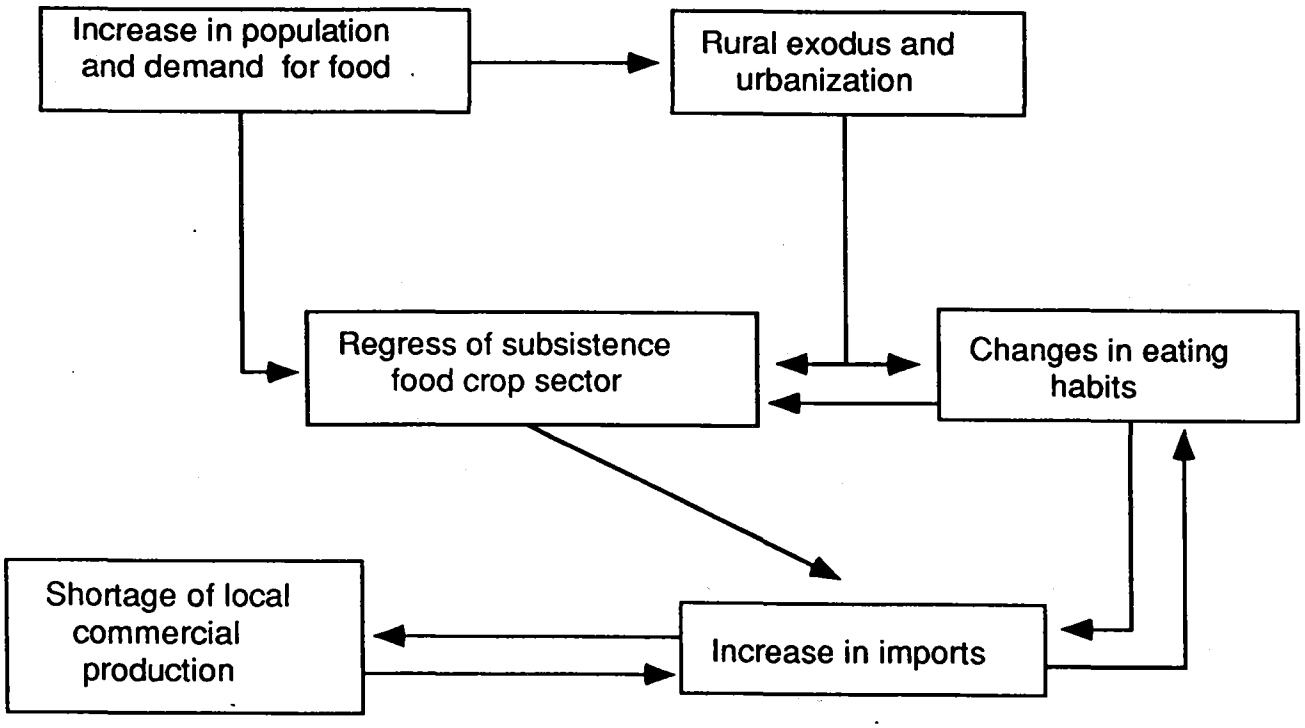

Figure 1. Factors jeopardizing Vanuatu's nutritional independence

According to Heywood (1991), "food dependence occurs when a country becomes dependent on imported food. The greater the proportion of total food consumption which comes from imported food the greater is the extent of food dependence." Food dependency, along with famine or malnutrition, is one of the components of nutritional vulnerability, which we define as: *the lack or inadequacy of adaptation responses and regulatory mechanisms of any food-production system to the constraints and imbalances occasionally generated by the environment.* At the opposite pole from nutritional vulnerability is nutritional security, defined as *the presence in a food-production system of adaptation responses to constraints and external imbalances, through which a population's nutritional needs can be guaranteed in a durable manner.* Nutritional security can be separated from food self-reliance, defined as *the durable provision of the population's nutritional needs through a rational exploitation of the country's natural resources.* A small nation such as Vanuatu with an economy dominated by agricultural

exports (particularly copra) and tourism, both vulnerable to world economic fluctuations, requires food self-reliance as an important component of food security.

Extending over 12,200 km^2, the Vanuatu archipelago is a chain of some 80 mountainous, volcanic islands, mostly with a narrow strip of fringing reef (Figure 2). Because there are few lagoons, and the outer reef slope drops rapidly, deep ocean is close to the coast. The country is well endowed with cultivable land (about 41 per cent), almost half of which is regarded as having good soils. According to the agricultural census of 1983, over 80 per cent of the people are dependent on agriculture for their food and as the main source of their income (Marshall 1986). In rural areas, each household has a garden that provides a large amount of starchy foods, such as yams, taro, and manioc, as well as green vegetables and fruits. Many rural people keep chickens and pigs and operate their own small coconut of cocoa plantations as a source of cash, although the cash economy still often plays only a minor role in rural villages.

Although subsistence agriculture plays the major role in providing the nation's food security, fishing is becoming an essential element, particularly for the supply of protein. Its significance derives in part from the length of the coastline (approximately 3,000 km) as well as the concentration of the population on the coast -- 74 per cent of the country's rural population was coastal in 1979 (David 1991).

Until 1986 a fleet of tuna-fishing long-liners operated out of a base at Pallicolo on the island of Santo. The fleet belonged to the South Pacific Fishing Company, with the Vanuatu government owning nine per cent of the stock. Most of the catch was put in cold storage and exported to canneries in Japan and the United States. Between 1978 and 1986, the exports amounted to 47,455 tonnes and accounted for 26 per cent of the total value of exports for that period (David *et al.* 1987). Since May 1986 the long-line fishing base at Pallicolo has been idle, and the tuna-fishing fleet has shifted to Pago Pago in American Samoa. Consequently, the only fishing activity in Vanuatu today is in coastal waters and is carried out only at a village scale and level.

Two types of village fishing can be identified. One derives directly from traditional fishing and is aimed at the wide range of fish species as well as shellfish, octopus, and crustaceans (notably lobsters) that are found in shallow coastal waters, usually within a depth of ten metres. The reef flat is the most intensively fished area, providing two-thirds of the catch. The handline, the hand spear, and the spear gun are, in declining order, the most common devices used. Gill nets and throw nets are still scarce (five per cent of the gear recorded in 1983) but are gaining in importance (David and Cillaurren 1988). Between 60 and 70 per cent of the fishing trips are done on foot, including underwater free dives. Expeditions by boat are undertaken in outrigger dug-out canoes, propelled by paddling. Motorized fishing craft are rare. This type of village fishing lacks any kind of structured commercial organisation and is referred to here as "small-scale unstructured village fishing".

The other type of village fishing is a more modern, commercial-sector activity. It relies on technical specialization, uses engine-powered vessels, concentrates on fewer species, and

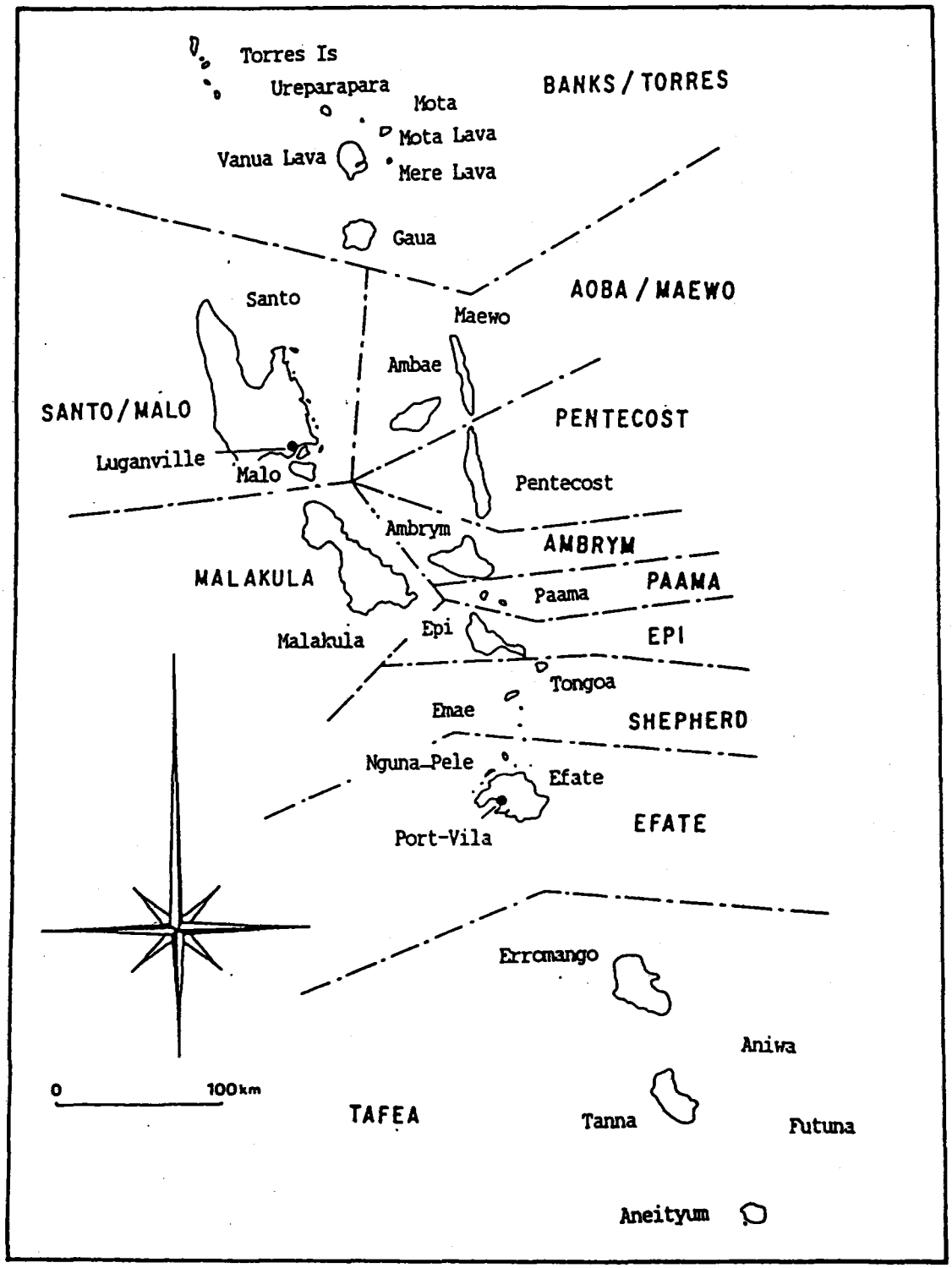

Figure 2 - Vanuatu and its eleven Local Government Regions

extends the fishing grounds beyond the traditional zone to the outer-reef slope at depths between 100 and 400 m. This fishing activity, which we will refer to as "artisanal commercial fishing" receives technical and financial assistance at both production and marketing levels from government agencies, as part of the country's fisheries development policy.

In this paper, we examine the ways whereby these two forms of village-level fishing contribute to the nation's food security. To begin, we discuss major trends in dietary habits in the urban and rural districts during the last thirty years. Next we look more closely at the consumption of foods from the sea, distinguishing differences in consumption patterns between urban areas, coastal rural districts, and landlocked areas. For each of these zones, we examine the constraints that apply to both supply of and demand for the fisherman's catch. Then, we address the issue of development policy in relation to commercial village fishing and examine how this activity can contribute to the country's food security. Lastly, we offer recommendations aimed at improving the contribution made by village-level fishing to national food security

Our analysis is based mainly on the results of various statistical surveys carried out in Vanuatu between 1983 and 1985, specifically, the agricultural census (Marshall 1986; David and Cillaurren 1988), the national nutrition survey (Hung 1983; David 1987), the Vanuatu/South Pacific Commission dietary study in 1985 (Lund *et al.* 1988), the family income and expenditure survey of urban areas (Anon. 1986; Singleton 1987; David 1991), and the monitoring of landings by village commercial fishers by ORSTOM and the Vanuatu Fisheries Department (Cillaurren 1990a).

MAJOR TRENDS IN THE EVOLUTION OF DIETARY HABITS

Rural/urban and urban/rural relationships

Dietary habits are different between the rural population and the urban dwellers because in town nutrition is an integral part of the cash economy, and a greater percentage of the food is imported from overseas. Outside Port Vila and Luganville, the two urban centres in the Vanuatu, nutrition remains linked to the traditional economy, and cash plays virtually no part in nutrition, which is based mostly on local produce. Despite these fundamental differences between urban and rural lifestyles, there are also powerful ties between the two.

- First, it must be remembered that town dwellers in Vanuatu are a fairly new breed, and most of them were born in rural areas. Their original dietary habits were, therefore, influenced by rural ways, and their current eating habits are a combination of this heritage and the nutritional changes brought about by urban living, which affects both the frequency of meals and the quality and quantity of food.

– Second, whereas the rural environment definitely affects the urban environment, the flow of influence goes the other way as well. As the cash economy has an increasing impact on the village economy, rural patterns of eating become infected with food originating from town, as is well exemplified by the way in which rural folk have taken to tinned foodstuffs. In the main missionary centres and Council headquarters in rural Efate and Santo (the islands that include the urban centres of Port Vila and Luganville respectively), the urban-to-rural food link extends well beyond tinned foods, for communications and the administrative or religious functions of rural villages play a major role in the development of dietary habits.

Changes in town

The main difference to be noted between rural and urban diets lies in the urban population's poor share of local produce, traditionally derived from the subsistence economy. These foods have been replaced by imported foodstuffs, products of Western and Asian agro-food industries. Rice has become the most common carbohydrate. Tinned fish or meat figure quite significantly in the protein intake, whereas the supply of fresh fish, molluscs, and shellfish is very irregular and costly, which explains the low priority given to these products. In the space of ten years of so, the consumption of fresh meat has increased by leaps and bounds because of its attractive price and its regular availability.

The changes in the diet have also seen a change in the pattern of meals during the day, reflecting a growing "specialisation" of meals: for instance, breakfast has lost its importance, now being more French in style, with bread dipped in tea or coffee as the major component (Jabre *et al.* 1976; Hung 1983). This meal is quick to prepare and swallow, no small factor in the case of families with several school-age children.

Although much more copious than breakfast, lunch is now also marked by the speed of preparation of its components (tinned meat or fish, rice). Supper, however, often includes traditional foods requiring longer cooking time, especially root vegetables, which are boiled or cooked in the earth oven. Where the housewife is not working outside the home, she may serve *laplap** . B. Jabre (1976) and his team observed, however, that because of the time it takes to cook, *laplap* is more often than not reserved for Sunday. Without doubt, the eating habits of ni-Vanuatu (indigenous Melanesian inhabitants of Vanuatu) are geared to gainful employment and school attendance, two key aspects of a Western lifestyle.

* Laplap is the "national" dish of Vanuatu. It is in the form of a big pancake and is made of grated vegetable mixed with coconut milk and cooked or braised in an earth oven.

T.G. McGee *et al.* (1980) provided seven explanations for the growing significance of imported food in the diet of ni-Vanuatu living in town:

a) lack of space for establishing family gardens in town, compelling urban households to buy most of their food;

b) high cost of local produce on sale at town markets;

c) low cost of widely consumed imported foodstuffs such as flour and rice;

d) variety of tinned food available in the shops;

e) children's schooling, which, on the one had, influences their tastes towards imported foods and, on the other, disrupts the daily pattern of life, inducing in particular the cutback on breakfast time;

f) working women, who have too little time to prepare traditional meals; and

g) urban lifestyles, which lead to a break with tradition and the introduction of a new diet consisting of a significant portion or foodstuffs that can be prepared rapidly, the best example being tinned food.

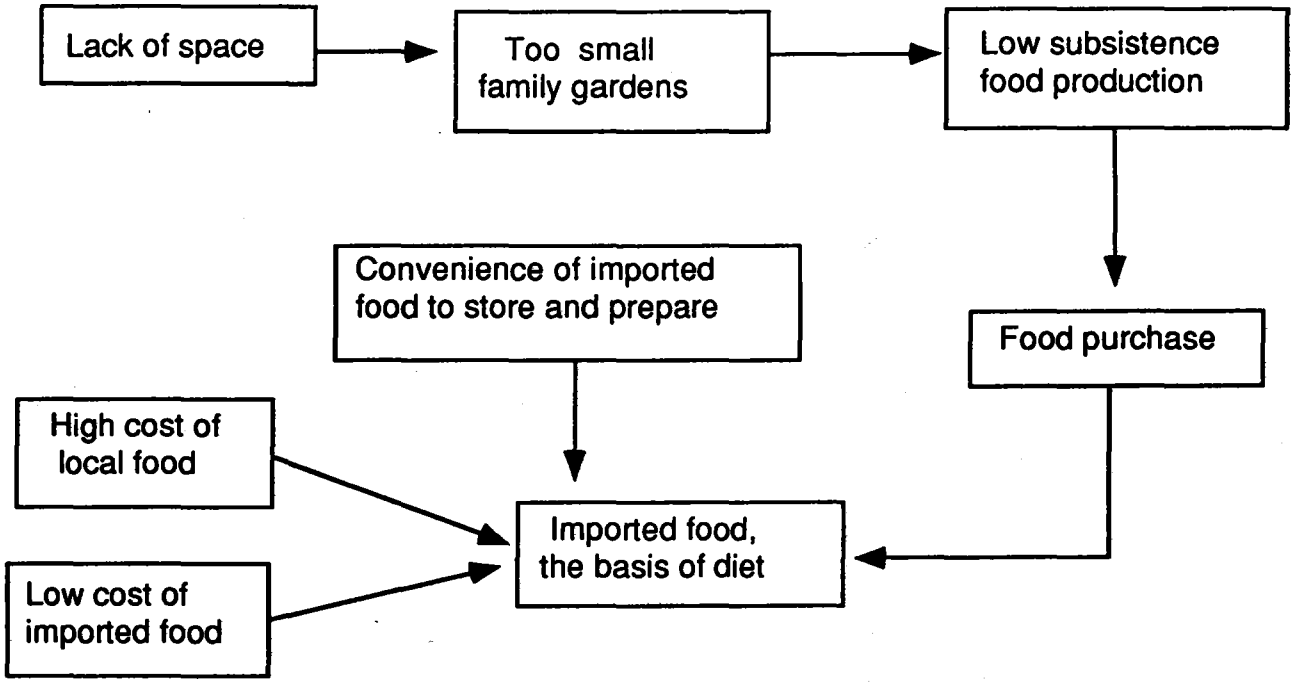

Figure 3. Factors leading to the significance of imported food in the diet of low-income urban families

The rapid increase of the urban population can only accelerate the process of change in eating habits. From 1979 to 1989, Port Vila and Luganville (the two urban centres in the country) went from 9,970 to 19,040 inhabitants and 5,150 to 6,900 inhabitants respectively, an increase of 90 per cent and 33 per cent respectively in ten years. In these circumstances, it is becoming more and more difficult for new arrivals to find space to plant their own subsistence gardens. Consequently, production of local foods for self-consumption by urban families is dropping.

Changes in rural areas

In rural areas, the proportion of imported foods in the daily diet is far less than it is in town. According to the National Nutrition Survey (Hung 1983; David 1987), tinned food accounted for 18 per cent of the meals where protein was consumed; in town, 30 per cent of such meals featured tinned products. However, the significance of tinned food it is increasing steadily, and gradually a diet of local produce combined with rice and tinned food is replacing the traditional source of protein, which was solely made up of fresh food, especially fish, served with vegetables, fruit, or root crops from subsistence gardens. Meat consumption has always been severely constrained by lack of supply because cattle, although common in Vanuatu, are only slaughtered locally on festive occasions or for custom ceremonies. Thus, the only source of fresh protein in regular supply comes from fishing.

The massive impact of urban consumer patterns is reflected in rural communities in Vanuatu in the shift toward imported foodstuffs and new eating habits. This change results mainly from the extraordinary influx of money into the islands over the last twenty years. The increasingly wide-spread use of money is reflected in the purchase of rice, tinned protein, and bread, foods that are known and enjoyed by the islanders through their contact with missionaries, European settlers, and American soldiers during World War II, and later through the school kitchens under the Condominium rule, where such foods figured predominantly on the menu (Figure 4).

As shown by Bonnemaison (1986), school and church, both described by the same term "skul", became a symbol of modern life in opposition to "custom" or tradition. The eating habits acquired at school took on the prestige attached to the establishment. In many instances, the desire for modernity was expressed, whether deliberately or unconsciously, by adopting "skul" foods. As Heywood (1991: 77) noted: "because of their association with expatriates, tourists and urban residents, imported foods my be regarded as superior goods even in rural areas. This will often be important in determining the positive attitudes toward imported items."

Two other factors will affect the future eating habits of Vanuatu's rural population. The first of these is population growth. Between 1979 and 1989, the country grew from 111,250 inhabitants to 142,630 inhabitants, an increase of some 31,500 people. The natural growth rate is 28 per thousand, with a birth rate of 42.1 per thousand and a death rate of 13.6 per thousand (Bedford 1989). Over this ten-year period, demographic pressure on cultivable land

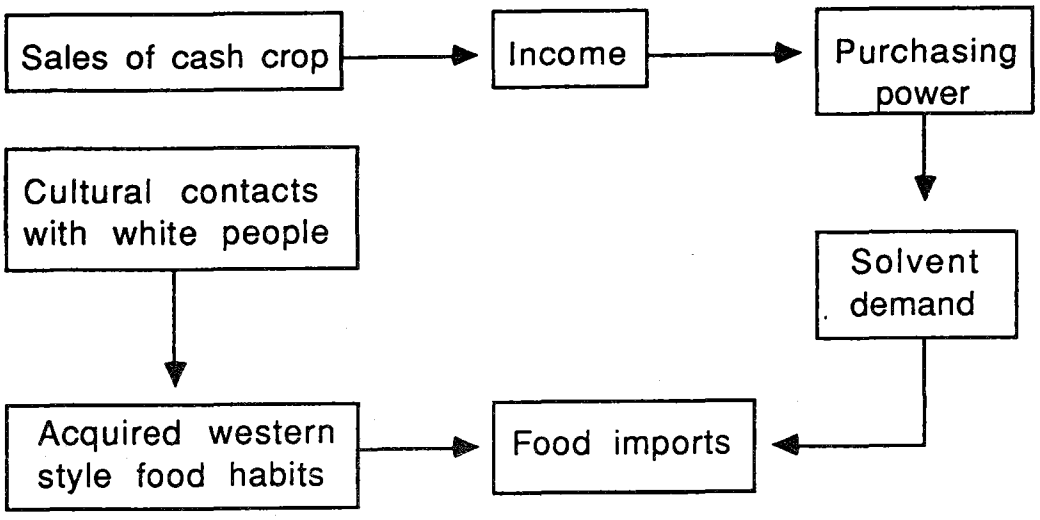

Figure 4. Factors influencing food imports to rural areas

increased to the extent that the average number of cultivable hectares has shrunk from 26 to 22 per household. In four of Vanuatu's 11 regions, the actual value is below the average, with each household having only five to nine hectares of cultivable land. In an increasing number of settled areas, population density now exceeds the carrying capacity of the traditional agricultural system, resulting in soil erosion and the beginning of undernutrition. In turn, these changes compel migration, which almost always means migration to town because movement into the numerous underpopulated rural areas are very difficult because of land-tenure systems and customs, whereby traditional land custodians refuse to allow outsiders to settle.

The other factor bringing dietary change is the extremely low price of copra, the production of which is the main economic activity of rural areas. Copra's price has fallen from US$600 per ton in 1984 to $300 in 1988 and 1989, and to an all-time low of $100-150 in the first quarter of 1991 (Anon. 1990). This decline has two consequences: one, a return to subsistence agriculture and a drop in cash flow to the rural areas, and, two, a search for other, more lucrative commercial activities. For instance, collecting trochus shells (*Trochus niloticus*), a mother-of-pearl shell in great demand on world markets, has risen significantly in coastal areas. Or the owners of mesh nets or cast nets are trying to develop small-scale commercial fishing activities.

CONSUMPTION OF FISHING PRODUCE, TYPOLOGY OF SPACE, AND CONSTRAINTS

Three patterns of consumption of fishing produce can be defined in Vanuatu:

- rural consumption in coastal areas,
- rural consumption inland, and
- urban consumption.

Table 1, which provides data on the supply of marine products in Vanuatu in 1984, shows the main quantitative aspects of these differences. However, although eating habits can be distinguished in terms of spatial distribution, not all distinctions can be reflected in this way. In urban areas, differences in income play a significant role in determining consumption so that spatial differences only apply to blocks of people of similar income dwelling in the same district. Following the classification used for budget surveys by the National Planning and Statistics Office (Anon. 1986), three classes of income need to be considered:

- households with incomes less than 45,000 vatu per month (*ca.* US$450),
- households earning between 45,000 and 100,000 vatu per month (*ca*, US$450 to US$1,000), and
- the wealthier households with more than 100,000 vatu per month.

The last class is further divided into ni-Vanuatu and expatriates, with the expatriates generally enjoying greater purchasing power than the ni-Vanuatu.

Urban consumption patterns

Five points need consideration (Table 1a):

- the significance of consumption by tourists in restaurants;
- the importance of shellfish in the tourism market, with consumption levels four to seven times greater than for fresh fish;
- the scarcity of molluscs and shellfish in the local-consumer market compared with fresh fish, which have a supply four to nine times greater;
- the significance of consumer income and product price as major factors determining local consumption, both in terms of quantities and type of product; and

Table 1 : Supply of marine produce in Vanuatu in 1984

a) Tonnage in urban areas

EXPORTS	IMPORTS			Local Consumption		Tourist Consumption		TOTAL
	Tin fis	Other Fish	Seafood	Fish	Seafood	Fish	Seafood	
3	127.5 - 199	37.5	16.4	144.3 - 183.3	15 - 45.16	40.8 - 85.1	295.6 - 343	677.1 - 909.5

b) Tonnage for the whole of the rural area

Imported products (tin fis)	Fresh Produce		TOTAL
	Fish	Seafood	
536 -568	1677 - 1774	1364.7 - 1659.7	3569 - 4076

c) Tonnage in the coastal zone

Imported products (tin fis)	Fresh produce		TOTAL
	Fish	Seafood	
476.5	1536 - 1774	1119 - 1659.7	2704 - 3505

d) Tonnage inland

Imported products (tin fis)	Fresh produce		TOTAL
	Fish	Seafood	
77.25	14.4 - 150	16 - 298.7	106.45 461.25

Table 2 : Main patterns of consumption of marine produce in Vanuatu

a) Nature and origin of the products included in the supply of marine produce [1]

Consumer Sector	Parameter	Nature of Products			Origin of Products		
		Imported	Consumed	Exported/ distributed	Imported	Consumed	Exported/ distributed
URBAN EXPATRIATE	1 2 3 4	Fresh fish Shellfish Tinned fish Mollusca	Fresh fish Shellfish Tinned fish Mollusca		Coast Overseas	Coast Overseas Local (Game fis.)	
URBAN NI-VANUATU	1 2 3 4	Tinned fish Fresh fish Mollusca Shellfish	Tinned fish Fresh fish Mollusca Shellfish	Tin. fish Fresh fish	Overseas Coast	Overseas Coast	Overseas
COASTAL	1 2 3 4	Tinned fish	Fresh fish Mollusca Shellfish Tinned fish	Shellfish Fresh fish Tin. fish	Overseas	Local Overseas	Local Overseas
INLAND	1 2 3	Tinned fish Shellfis.Mol. Fresh fish	Tinned fish Shellfis.Mol. Fresh fish		Overseas Coast	Overseas Coast	

b) Constraints

Consumer Sector	Parameter	Constraints affecting supply			Constraints affecting demand		
		Tinned fish	Fresh fish	Shellfish & mollusc	Tinned fish	Fresh fish	Shellfish & Mollusc
URBAN EXPATRIATE	1 2 3 4	Demand	Production Distribution Preservation means	Production Distribution	Competition from fresh products (fish, meat)	Lack of supply Competition from fresh meat	Lack of supply
URBAN NI-VANUATU	1 2 3 4	Demand	Demand Production Distribution Preservation	Demand Distribution	Price/Income Competition from fresh meat	Price/Income Competition from tin fish Lack of supply	Price/Income Competition from tin fish
COASTAL	1 2 3 4	Distribution Demand	Production Means of preservation Distribution Demand	Export to town Resources Demand	Lack of supply Lack of income (2) Price/income	Commercial supply Own consumption Lack of income	Lack of supply Resources Lack of income(2) Price/Income
INLAND	1 2 3	Demand Distribution	Demand Distribution Com. prod.	Demand Distribution Com. prod.	Lack of income Supply Price/Income	Lack of income Price/Income Lack of supply	Lack of income Price/Income Lack of supply

1) Each parameter is represented in decreasing order of importance, 1 (the highest) to 4 (the lowest).

2) The expression 'lack of income' means consumer income, not the earnings the fishermen generate from selling their marine produce commercially.

-- the local market's high demand for tinned sea produce, the consumption of which equals that of fresh fish. Most of the tinned produce is mackerel, known throughout Vanuatu as "tin fis".

Because differences in income between the expatriate urban population and the ni-Vanuatu urban population lead to totally different eating behaviours by the two group, we consider these two categories of people separately.

Expatriate urban consumption patterns. Because of their high purchasing power, expatriates, whether tourists or residents of Port Vila or Luganville, have access to a wide range of marine products whose prices are generally high. As shown in Table 2a, most of the products consumed come from the rural coastal areas as fresh fish, followed by fish, molluscs, and shell fish imported from overseas, either frozen or tinned. A small volume of tuna and deep-sea fish are obtained from small-scale game-fishing operations. Compared with fresh products, the consumption of tinned products is insignificant and comprises mainly highly priced goods such as tuna and shell fish.

The major constraint on consumer demand is the lack of availability of fresh fish and shell fish. Arrivals of fresh fish from the rural coastal areas are fairly erratic, and the quantities are often too small. Hotels and restaurants often suffer shortages, and the shelves are empty at Natai, the state-controlled fishmonger in Port Vila which markets the catch from the small-scale fisheries associations formed under the fisheries development programme. The main cause of this lack of supply is the low level of production and the inefficient distribution network, compelling the consumer to fall back on imported fish or more often to turn to local fresh meat, which is of excellent quality as well as regularly and cheaply available.

Ni-Vanuatu urban consumption patterns. The most distinctive trait of ni-Vanuatu patterns of consumption is the large amount of tinned mackerel used, and the definitely lower demand for fresh produce. Fresh products from the coastal areas are expensive, sold on the urban market at a much higher price than most ni-Vanuatu buyers can afford. The only products that ni-Vanuatu consumers may have access to are the smaller pelagic fish (mainly sardines) sold from time to time by an occasional fisherman from door to door, or reef fish that are available in stores once in a while. As for production for self-consumption, such is extremely limited because the waters close to urban areas have been more or less depleted.

Table 2b illustrates the situation. Demand is seen as the main, if not the only, factor constraining supply. The high price of fresh produce compared with the consumers' income means that lower-priced tinned fish is fiercely competitive. And now lower-quality fresh meat is competing strongly with tinned fish. In the last quarter of 1984, a large tin of mackerel (425 g contents) sold for 75 to 80 vatu in shops in Port Vila and Luganville, *i.e.*, 80 US cents. For the same amount of money, the urban consumer could buy from the Port Vila Government fisheries market 400 g of skipjack (Scombridae), 320 g of reef fish or grouper (Serranidae), 275 g of red snapper (Etelidae), or 265 g of shark fillet. Or, the meat lover could purchase

400 g of beef stew or 172 g of tinned meat, produced locally under the name "tin mit" or imported from Australia as corned beef.

Whilst all the mackerel in a tin is edible, the same does not apply to fresh fish, 55 per cent of the body mass being scales, skin, gut, or bone (Jardin and Crosnier 1975). In spending 80 vatu, the "tin fis" buyer ends up with three times as much food as the purchaser of red snapper (Table 3). In addition, depending on how the tinned fish is prepared (in oil, tomato sauce, or brine), the consumer is getting four to six times as many calories, two to three times more protein and vitamins, four to nine times as much iron and calcium. Of all the protein food from the sea available in Vanuatu, the mackerel is the best choice a consumer can make in terms of the ratio of nutritional value to cost. Given that tinned fish is a much more economical food than fresh fish and given that fifty per cent of the working Melanesian population in the private sector earned less than 16,000 vatu per month (*ca.* US$160) and twenty-five per cent received less than 9,000 vatu, it is no wonder that "tin fis" is so popular.

Of the fresh fish sold whole, the best value is skipjack. Compared with whole fish, fillets do have the advantage of being fully edible. At an average cost of 500 to 600 vatu per kilo, however, the price is too high for low-income families to buy fillets on a regular basis. The only fillets readily available to them are shark, at 300 vatu per kilo; but, in spite of its attractive price, shark is not much consumed because many ni-Vanuatu consider it a magic animal. Beyond such cultural attitudes and price, other factors decisive in determining demand are the number of outlets selling the product, its flavour, and how quickly and easily it can be prepared. Although fresh fish is usually better liked by consumers, there are a variety of other factors that make tinned mackerel more appealing.

Coastal rural consumption patterns

Table 1c shows the importance in coastal rural areas of marine produce caught locally compared with the situation in urban areas, but consumption of tinned mackerel remains significant, representing 27 to 30 per cent of the consumption of fresh fish. Compared with urban areas, consumer income is an unimportant factor in rural areas in determining the quantity of marine produce consumed although it does have a bearing on the choice of product; for instance, consumption of deepsea bottom-dwelling fish is closely related to availability of cash.

Table 2b shows that the constraints on supply are closely linked to the constraints on demand. Supply restricts demand, and demand always appears as the constraint impeding expansion of supply. Aggregate supply both commercially and for self-subsistence is considered to be quantitatively inadequate, especially with respect to fresh fish. Commercially, there are too few fishermen and their production is too low; with regard to subsistence fishing, often it is a matter of a limited fishing zone containing inadequate resources. Problems of preservation and distribution of marine produce also discourage fishermen from trying to improve their catch. The low volume of supply of shellfish along the coast results from sending all the lobster to urban markets. The main constraint on supply of tinned products stems from problems of distribution because of poor transport facilities in the islands.

Aside from supply, the main constraint on demand in coastal areas is low purchasing power. In 1984, the agricultural census gave an estimate of 78,540 vatu (US$785) as the average annual budget for rural households. About eight per cent of this was spent on tinned mackerel, 3.5 per cent on tinned meat, and two per cent on fresh fish (David 1991). Such an economic constraint hinders any improvement in commercial production.

Table 3 : Nutritious value (1) of some protein foods bought in Port Vila in 1984 for 80 vatu (2)

Product	Total weight (g)	Edible content (g)	Energizing content (kj)	(kcal)	Protein (g)	Lipid (g)	Glucid (g)	Calcium (mg)	Iron (mg)	Vitamin (mg)
Tin fis in brine	450	350	2580	620	70	35	0	133	4	29
Tin fis in oil	45	350	3240	775	65	55	0	665	9	31.5
Tin fis in tomato	425	320	2340	560	50	34	12	320	5	25
Skipjack	400	200	1475	350	40	20	0	75	2.5	16.5
Reef fish	320	145	630	150	30	4	0	40	1	9.5
Red snapper	275	125	545	130	25	3	0	35	1	8
Shark fillet	265	265	1155	280	50	6	0	75	2	17.5
Neck of beef	400	400	3065	730	70	50	0	40	10.5	36.5
Corned beef	170	130	1220	290	25	21	0	26	6	9.5

(1) The nutritious content was calculated with reference to the food composition tables prepared by FAO and used by JARDIN and CROSNIER (1975).

(2) The amount of 80 vatu represents the officially agreed purchase price of a large tin of macquerel.

Rural consumption patterns inland

Inland, as would be expected, there is almost no self-subsistence consumption of marine produce. Other inland traits are that the low levels of income lead to low consumption of marine produce, and tinned fish is substituted for fresh produce because of distribution problems. The constraint on demand because of lack of cash is particularly strong inland because of the scarcity of copra production there. The limited range of supply is another constraint. To improve the situation would require increasing production, developing ways of preserving the catch during transport, and organising better distribution networks. Making these improvements feasible will also require that the roads, which are few and far between and deteriorate rapidly during bad weather, be kept in reasonable condition. Frequently, because of financial constraints, road upkeep is neglected, and the Public Works Department only acts when a road has become completely unusable.

Summary of constraints

Our review of the several patterns of consumption of marine produce in Vanuatu shows that there are two main constraints on demand and three main constraints on supply.

a) Constraints on demand:

- low household incomes, and the small amount of their budget that householders are prepared to allocate for fresh fish;
- the availability and appeal of tinned fish compared with fresh fish.

b) Constraints on supply:

- low production, especially commercial production;
- lack of means of preserving fresh produce;
- poor distribution networks.

VILLAGE FISHERIES DEVELOPMENT PROGRAMME

Exploitation strategy and monitoring of production

The development of small-scale fisheries was one of the priorities of Vanuatu's first two Five Year Development Plans (1982-1986, 1987-1991). Implementation began in 1982 with the introduction of a development programme for commercial village fisheries, the Village Fisheries Development Programme (VFDP). The intention of the VFDP was to exploit unused fishing zones located along the reef drop, using motorised vessels fitted with reel-mounted lines extending to depths of 100 to 400 m. When Vanuatu became independent in 1980, these zones -- which mainly contained ichtyosarchotoxin-free fish (*i.e.*, without ciguatera contamination) such as red snapper (Etelidae), sea-perch (Lutjanidae), grouper (Serranidae), emperor (Lethrinidae), and bream (Pentapodidae) -- were virgin fishing grounds, being beyond the range of traditional canoes driven by paddles and far beyond the narrow stretch of fringing reefs where most of the "traditional" fishing activities had been concentrated where no lagoon was available. Because fish stocks on the reef slopes are not particularly abundant, their exploitation must be carefully supervised and managed. Brouard and Grandperrin (1984) have shown that the maximum sustainable yield (MSY) would be of the order of 760 tonnes per year for the whole of the country's reef-slope area, or an average of one kg/ha/yr. A total of 120 motorized vessels, each carrying three hand reels, and going out an average of 150 times per year, would be sufficient to produce these quantities, with each reel being in use four to five hours during each outing and bringing up an expected average of three kg of fish per hour.

The object of the Village Fisheries Development Programme (VFDP) was to set up, alongside the small-scale village unstructured fisheries, a structured, commercially-oriented sector that would exploit new resources, in a new fishing area, with new or upgraded techniques and modern equipment. To achieve this end required the creation of a group of professional fishermen, made up either of "traditional" fishermen attracted by the promise of profits or, less likely, of "small operators" attracted by the appeal of fishing.

Monitoring is an essential component of any strategy for developing fishing and marine-food production. Through monitoring, it is possible to determine the parameters for dynamic equilibrium, or MSY, which forms the basis of any rational management of renewable resources. Since the launching of VFDP in 1982, data concerning the development of fishing and production of deep-bottom-dwelling fish have been collected by ORSTOM, in close collaboration with the Vanuatu Fisheries Department. At present, the data-gathering process is divided into three levels, each corresponding to one of the stages of fish production: landings, rural fish sales, and the urban market. The three questionnaires/forms whereby these data are collected are shown in an appendix to this paper.

Monitoring of landings covers, depending on the year, 50 to 70 per cent of village co-operative fishing associations. This is the oldest part of the data-gathering system, having been in existence since 1982. It is also the most complete. Every time fishermen go to sea, they fill in a form indicating the area fished, the depth at which catch occurred, the duration of the trip, total catch, and the measurements of all fish belonging to 12 main species. In return, the fishermen receive tax-free petrol and an amount equivalent to 50 US cents. Between 1982 and 1989, some 13,000 fishing trips were recorded (Cillaurren 1990).

Gathering data on the marketing of fish in the rural districts is accomplished through the nation's seven fisheries extension centres and is mostly concerned with fishery development and fish production within the village fishing co-operative associations located in the vicinity of the extension centres. It also documents the production costs and the income gained by the fishermen from the sale of their catch. This system has been in place since 1989 and deals with many fewer village co-operatives than does the monitoring of landings.

Data-gathering in the urban zones is concentrated around the two government fish markets in Port Vila and Luganville. The data consist mostly of the tonnage sold and the selling price of the commercial species.

Together, these three systems of data collection provide information on the biology of the stocks. The entering and processing of the statistics is centralized and is organised as follows: entry of data, correction, detection of systematic and random biases, classification, evaluation of dynamic parameters, adaptation to existing models, and choice of appropriate predictive model.

Beyond the collecting and processing of these data a major question faces management of the reef-slope fish in Vanuatu and other Pacific archipelagoes: Does determination of a maximum sustainable yield for the whole archipelago provide an adequate method for

management of the resource? The fish targeted by VFDP are benthic dwellers living in the reef-slope environment of high islands separated by deep seas, which limit the movement of the fish from island to island. This may be the reason for the existence of separate stocks, each with distinct demographic features dependent on the particular area colonized (Carlot and Cillaurren 1990). This hypothesis needs to be tested, but its implications for management of the resource are clear: although fishing activity may decrease or remain unchanged at the scale of the whole archipelago, periods of intensive fishing may occur locally, leading to localised over-fishing because there can be no renewal of stock because of the limited pattern of migration.

Objectives and implications of the VFDP

The principal purpose of the VFDP was to develop commercial fisheries at the village level; four associated objectives were:

-- to improve the nutrition of rural and urban dwellers;

-- to reduce imports of tinned fish;

-- to develop a cash economy in villages (Crossland 1984; Legal 1986); and

-- to create employment opportunities in rural Vanuatu, thus decreasing the drift of rural people to Port Vila.

A closer examination of these objectives reveals two contradictory implications.

I. Village fisheries as an economic enterprise integrated into national and international markets. The high-value species exploited by VFDP hold a strong appeal for the urban tourist market and are subject to a potentially significant demand from overseas. To achieve and maintain profit, a high level of supply is required. Once a share of the tourist and the international market has been secured, the fishing operations can continue over the long term and ensure the long term development of the economy. This trend fulfills two of the four goals of the VFDP: the development of a cash economy and a decline in urban drift because of an increase in rural employment opportunities. The objective of improving nutrition has been met in a roundabout way. Because VFDP fishing production is geared to the external market, it makes no direct contribution to improved nutrition within the rural population, but the income generated enables families to increase their food expenditure and thus compensate for the lack of a supply of fresh fish from the VFDP. Ironically, "tin fis" is one of the imports to benefit most from the increase in demand for marine produce brought by the VFDP. The goal of reducing the imports of tinned fish is proving to be totally opposed to the logic of the development scheme.

The solution to this contradiction is simple: a model of dual development could have been planned, whereby a "modern", structured sector devoted exclusively to deep-sea fishing

for the urban and export market could co-exist with a commercial sector concentrating on small-scale fisheries intended to supply island populations with shallow-dwelling reef species. In contrast to deep-sea fishing, shallow-reef fishing is old-fashioned and inexpensive and requires little financial assistance to develop. Government action can be restricted to the duty-free sale of lines and nets and to encouraging simple and cost-effective methods of preserving the fish, such as by smoking or by a combination of smoking and salt-drying.

II. Village fisheries as a way to provide rural populations with protein and to reduce imports of "tin fis". This function of village fisheries is wholly in opposition to their function as a supplier of a high-value product to urban or international markets. Furthermore, if village fisheries are devoted to providing rural people with improved protein nutrition, the fisheries come to be "downstream" economically from agriculture, which is the source of rural income. Thus, fisheries would be very susceptible to any fluctuations in the agricultural sector, particularly to variations in the price of copra. Given such dependence on the health of the agricultural economy, fisheries would have virtually no scope for autonomous growth, their role in the development of the cash economy would be limited, and their contribution to controlling urban drift would be very marginal.

It should be noted that neither function (fisheries as externally directed economic enterprise or fisheries as a means to improve rural nutrition) bears on the improvement of nutrition among low-income, ni-Vanuatu, urban households. As these urban people have been left out of the fisheries development plan, it is hardly surprising that their consumption of fresh fish is insignificant compared with their heavy dependence on tinned fish. Nevertheless, there is no reason why the supply of fresh marine produce at low prices cannot be substituted for tinned fish unless the only aim of VFDP is to supply deep-sea, bottom-dwelling species, which are expensive to catch.

To meet the needs of low-income urban people, it is necessary to:

-- change target species, for instance, to shallow-dwelling reef fish, smaller deep-sea species (Clupeidae, for example), and the skipjack caught around the fish-aggregating devices;

-- restrict such production to areas around the islands of Efate and Santo, where the urban populations are; and

-- organise a mobile collection operation in rural areas so as to provide the fishermen with a regular outlet for their fish, which will stimulate their commercial fishing activities.

None of the objectives set out by the VFDP need to be opposed to the others. Contradictions arose solely because fisheries development focused exclusively on the exploitation of deep-sea, bottom-dwelling species along the reef slope. The bias of the development scheme towards export and the supply of high-priced urban markets, which was favoured by the

Fisheries Department in the early stages of the VFDP, has been slightly altered to include a form of local-centred development to meet the need to improve nutrition in rural communities while reducing the import of tinned fish. This combination has not proved fruitful so far, and the initial development scheme has gradually given way to a second scheme, which is now predominant.

Implementation of the Village Fisheries Development Plan (VFDP)

Set up initially to last three years, the Village Fisheries Development Programme provided for the creation of 25 Fishing Co-operative Associations, to which technical and financial support were guaranteed for the purchase of equipment as well as the provision of the training required for its handling and maintenance.

The European Development Fund (EDF) is the main funding source of the VFDP. As part of its aid to ACP countries between 1982 and 1985, EDF provided 73 million US$, or 53 per cent of the total budget (Crossland 1984). Canada also provided a substantial contribution, amounting to 18 million US$, in the form of salaries for the CUSO volunteers who were to carry out the technical training. Between 1982 and 1986, a dozen or so young Canadians followed each other, working on two-year contracts. British and Dutch volunteers are also involved with the VFDP; few in numbers during the early years, they are gradually taking over from the Canadians.

The location of the fishing co-operative associations is decided after an in-depth study. Along with the applications made by motivated candidates, several economic and ecological factors are taken into account, including the abundance of marine resources within a short distance of the village, good shelter for the boasts, and the proximity of a sufficiently wealthy market. Furthermore, applicants must have access to enough capital to buy a portion of their equipment, and they must be able to show other sources of income so that they can, if need be, repay a part of their bank loans. They must also agree to enroll in the training courses, lasting four weeks, which are provided at Fisheries Department headquarters in Port Vila.

Once selected by the Fisheries Department, each co-operative association is issued a boat, three or four wooden hand reels and their complete tackle, two outboard motors, one 25 hp, the other 5 hp to serve as a back-up. The boats are either 8.6 m catamarans or single-hulled boats 5 m long. In 1984, a catamaran, complete with motors and fishing tackle, was worth US$9,010, and the cost of the monohulls was US$5,380. The boats and the reels are made in the Santo shipyard, which was built in 1982 under the authority of the Fisheries Department. In order to preserve the fish caught, 14 refrigeration units were installed; ten of these were simple refrigerators, costing US$1,359 each, running on gas or kerosene. Two co-operatives have been equipped with ice-making facilities capable of producing 400 kg of ice per day; two other co-operatives had 22.3 m^3 walk-in freezers installed. The ice-making plants cost US$10,4000 each; the cost of each walk-in freezer was US$16,600. On average, all the equipment for a fishing co-operative association cost between US$9,000 and US$10,000. The EDF finances 51 per cent and the Vanuatu Development Bank loans 42 per cent in the form

of three-year loans to the fishermen at four per cent interest per year. The remaining seven per cent must be provided in cash by the users. Because it is difficult for an individual to find such a sum, most fishermen pool their resources, either as a family or as a village co-operative association. In the latter case, the whole village contributes financially to the creation of the association, of which everyone becomes a shareholder. The fishermen are chosen from among the volunteers by the chief or the elders of the village.

To sell the catch, two fish markets equipped with substantial cold-storage capacity were opened in Port Vila and Luganville by the Government of Vanuatu in 1983 (Crossland 1984).

During the first year of VFDP's operation, the fishing associations caught 49 tonnes of fish. Two years later, the catch had doubled to 97 tonnes. Of this catch, 55 to 60 per cent was sold in the fishermen's own villages or in nearby communities. The selling price varied between US$1 and US$1.35 per kilo. The rest of the catch was sent to Port Vila or Luganville fish markets, where it fetched US$2 to US$3 per kilo. The fish was transported by road from the village to the nearest airport, whence it was flown to the airports of Port Vila and Luganville and then delivered by truck. During transport, the fish are kept cold in insulated sacks holding 40 kg. Through agreements between Air Melanesie, the national airline, and the Fisheries Department, the air-freight rates are reasonable: the equivalent of US$0.30 per kilo, regardless of the distance travelled.

VFDP's first three years have been considered a success (Legal 1986). The programme was meant to end in December 1955, but given its popularity -- with the Fisheries Department receiving two or three applications per week for new associations in 1985 -- it was decided to extend the programme for another four years to mid-1989, when a new structure called "Extension Services" was inaugurated.

By 1983, eleven fishing co-operative associations were in operation, producing 49 tonnes of fish, *i.e.*, almost 4.5 tonnes each, generating turnovers of between US$4,500 and US$5,000. This is a substantial amount for rural areas, bearing in mind that during the same year the average annual budget for a family was US$785. Fishing, therefore, appeared to be a particularly viable activity, an impression that led political leaders on each island of Vanuatu to bring pressure to bear on the Fisheries Department to grant VFDP assistance to their constituents and electors. By 1984, the initial planned figure of 25 associations was exceeded; since then, over 200 fishermen's associations have been formed. However, these figures should not be taken to indicate that the VFDP was a success. Since 1983, the average production per association has steadily declined. Whereas the number of fishing associations may have increased 15 times in six years, the fishing yields per association have not. Table 4 shows the landings of commercial village fisheries as monitored by ORSTOM and the Fisheries Department. The production figures shown are probably 30 to 50 per cent below actual yields because the survey only took into account 50 to 70 per cent of the operational associations, which was no mean feat given the geographical dispersal of the associations and the lack of auction centres where landings could be grouped. In 1983, the 11 associations produced on average 4.46 tonnes each. By 1988, the average yield had dropped to 1.06 tonnes per association, with 75 associations landing a total of 79.3 tonnes.

Table 4 : Development of fisheries production supported by the VFDP (Ref.: Vanuatu Fisheries Department)

	1983	1984	1985	1986	1987	1988
No. of associations	11	23	50	72	59	75
Total yield (ton)	49.1	87.9	97.5	128.9	93.5	79.3
Average production per association	4.5	3.8	1.9	1.8	1.6	1.1

Table 5 : Average duration of fisheries projects (1)

Duration (Years)	Number of projects (in %) n=138
7	0,5
6	0,5
5	3
4	4
3	13
2	26
1	53
Mean 1,8	Total 100

(1) Survey done on a sample of 138 projects monitored by ORSTOM between 1983 and 1989.

Very few village fishing co-operative associations manage to operate for more that three years (Table 5), and the pool of professional fishermen who were supposed to ensure the long-term success of the fisheries development programme contains only a few dozen persons. The VFDP very early on suffered from its own popularity. According to its design, the programme required a strict follow-up of the fishermen in order to teach them fishing techniques, equipment maintenance, fish preservation, and management procedures. The young professional fishermen sent by the NGOs to assist the original 25 associations never exceeded a dozen people, and most of the fishermen groups dissolved after a few months of operation because of the lack of technical assistance and appropriate advice.

This failure has been diagnosed as a reflection of the lack of profitability of the associations, and of the impossibility of ensuring their economic viability (Shepard 1987). The government has endeavoured to take this into account during the implementation of the second stage of the small-scale fisheries development policy, already in place now. This new programme, which is funded by the EEC, has three objectives:

-- Training of fishermen. A fisheries school has been operating in Luganville for the past year, and seven training centres have recently be inaugurated in the main regions of the country.

-- Implementation of a "leasing programme" for fishing vessels. In lieu of the previous funding programme (51 per cent in donations, 42 per cent in bank loans, and seven per cent own capital). As the EEC withdrew from direct funding of equipment and tools in order to assist with the infrastructure and budget requirements of the programme, the fisheries school and the new Fisheries Department in Luganville were total funded by the European Development Fund.

-- Diversification of the fishing fleet, with a view to tailoring the vessels more to the fishermen's needs. Now, sailing outriggers fitted with 5 hp outboard engines are being offered to part-time fishermen living along coasts sheltered from the tradewinds. For the few motivated and expert fishermen, who are keen to take up fishing as a full-time occupation, there will be vessels more than 10 m long, which will be safer at sea and have an extended fishing range and a capacity to remain longer over the fishing grounds.

Under this programme, it is essential that the seven training centres be established and placed under the direction of qualified professional fishermen who can advise the fishermen and help them maintain and repair their gear. These centres must be equipped with ice-makers and cold-storage space to provide the fishermen with ice; and the centres also need to be in a position to purchase the catch. This support should enable nearby associations to begin again on a better footing. These arrangements can really be considered as a return to the original plan, on a somewhat smaller scale.

The results of the development plan

After nine years of commercial fisheries exploitation by villages in Vanuatu, fishing activity is in decline, and the deep-bottom stocks are generally underfished. In 1987 and 1988, the level of production in Efate was about 50 per cent of the maximum sustainable yield (Cillaurren 1989). Given that yields on the whole archipelago have never exceeded 200 tonnes and have had a tendency to drop off over the last few years, the main objectives set by the VFDP have not been met.

Although the creation of over 200 fishing co-operatives meant numerous employment opportunities in rural Vanuatu, the jobs have been too short-lived to reduce urban drift. It may even be that young fishermen who enjoyed productive fishing expeditions during the first successful years of VFDP became accustomed to a good income and are reluctant to return to subsistence agriculture or
fishing and decide to migrate into town.

Unlike unstructured village fishery, structured commercial village fishing never really played its role in providing a substitute for imported fish, either in town or in rural areas. A large portion of the catch was sent to the urban market, where it was consumed mainly by expatriates and tourists -- two sections of the population who normally do not eat any or much "tin fis". The supply of fresh fish in rural areas has always been small and has not been a serious competitor to tinned fish.

In the early years of VFDP, shipments of fish to Port Vila and Luganville certainly contributed to an increase in cash available locally. Because of problems with air freight and the price paid to fishermen by "Natai", this era is now over, and commercial village fishing gains only a small share of the influx of currency to the islands. But it is still a source of outflow through payments to replace fishing tackle and for fuel. Under present circumstances, therefore, commercial village fishing actually increases the deficit in the balance of trade in those islands where there are associations.

The assessment of the VFDP is no brighter in the field of nutrition. As we have noted, part of the production is exported to the urban centres where it contributes hardly anything to those people most in need it: the low-income ni-Vanuatu population. In rural areas, the lack of transport infrastructure led to fish-distribution networks developing mostly within coastal areas only. The additional supply of fish has probably most benefitted households who did little or no fishing for their own consumption. But the people living inland, who of all the people in Vanuatu suffer most from protein deficiency, have benefitted little or not at all.

CONCLUSIONS AND RECOMMENDATIONS

The 4,322 to 4,885 tonnes of fish caught in Vanuatu in 1984 (Table 1) provided 377 to 415 tons of protein, *i.e.*, 16 to 18 per cent of the population's yearly protein requirements, estimated to average 50 g per day. Small-scale unstructured village fisheries supply 61 to 65 per cent of protein needs compared with three to five per cent from commercial village fishing

and game fishing, and 31 to 34 per cent from tinned fish (Table 6). Clearly, unstructured village fisheries, carried out essentially for local subsistence, play a major role in supplying the population of Vanuatu with marine food products. By comparison, artisanal commercial village fishing, supported most strongly by the Government, plays a negligible role. The importance of imported tinned fish in meeting the nation's protein requirements reflects the failure of the country's fisheries to supply adequate fresh marine products. Reducing this shortfall remains one of the unaccomplished goals of the VFDP.

Table 6 : Composition of protein supply in the whole range of marine produce for Vanuatu in 1984 (in tons)

Unstructured small-scale fishing			Commercial fishing		Game fishing	Imports	TOTAL
Fish	Shellfish	Mollusc	Fish	Shellfish	Fish		
145-159.9	43.8-54	38.9-49.3	11.5-12.5	0.155	5.54-6.88	131.3-131.96	376.6-414.7

Overall	Fish	Shellfish	Mollusc	TOTAL
	293.2 - 310	44.5 - 55.4	38.9 - 50.5	376.6 - 414.7

Strangely, the large part played by tinned fish in the nutrition of the population serves to emphasize the importance of the role of the small-scale unstructured village fishing in providing substitutes for imports. If all marine food products are considered, this type of fishing provides 228 to 263 tonnes of protein for consumer needs. Had these small unstructured fisheries not existed, the country would have had to import 1301.5 to 1504 tonnes of tinned fish in order to provide an equivalent amount of protein – requiring an expenditure 1.6 to 2 times greater than the whole 800 tonnes of tinned fish imported in 1984 (Anon. 1986b). With the landed cost of tinned fish averaging US$1.2 per kg, the unstructured village fisheries saved the national economy 1.57 to 1.81 million US$ in imports in 1984.

The inability of the Village Fisheries Development Programme to fulfill the objectives for which it was created leads us to query the exclusive support given to catching deep-bottom

species. This activity calls for techniques and gear that are too new and too foreign to Vanuatu's village society. The simple addition of large amounts of capital is not enough to spread these new practices. In coming years, it would be desirable to integrate the small-scale unstructured village fisheries into development policies for coastal fishing.

Small-scale fishing offers potential for development and could play an essential role in supplying local island markets, in improving nutrition, in creating jobs, and in generating cash incomes. It appears feasible to increase its production at no great cost -- for instance, by the distribution of mesh nets and cast nets. However, the production potential of Vanuatu's narrow fringing reefs could be reached fairly rapidly along densely settled shores. Therefore, effort should concentrate more on resources available on the reef slope at depths between 10 and 100 m. Sheltered leeward coastlines would be most suitable for these activities as fishermen can fish from an ordinary outrigger canoe, although production might be increased by encouraging the use of sailing canoes like those used in the Maskelyne islands south of Malekula, equipped with one or two handlines fitted onto reels, and eventually a small engine for travel to windward.

Another means to encourage fishing would be to introduce simple, low-cost methods of preservation, such as smoking or salting, which would enable fishermen to take advantage of the occasional surplus catch. The process of smoking or salting is also a key to the distribution of fish farther inland; smoked or salted fish will keep for several days, sometimes weeks, at ambient temperatures and can be transported by back where roads are poor or absent. There seems no reason to believe, as Schoeffel (1985) also puts it, that the Melanesian population would "disdain" smoked fish, provided that appropriate information is provided. The product is no more exotic than tinned fish and has some of the same advantages: low price, easy and quick to prepare, long-lasting, and a strong flavour for seasoning root vegetables, rice, soup, or laplap. In most tropical countries where smoking and salting is done on a small scale, the women are in charge of both processing and marketing. The processing can be done at home and would provide ni-Vanuatu women with a gainful activity -- something generally lacking for them in rural Vanuatu.

Small-scale unstructured fishing could also help meet the needs of poor urban families by supplying inexpensive products such as small pelagic species (*e.g.*, Clupeidae) and mullets. However, this type of fishing will not be able to supply the urban market with highly priced deep-bottom fish, which can only be caught by a structured commercial sector using larger boats capable of staying more than one day at sea. In view of the current inter-island transport situation, it is recommended that such a sector be confined for now to Efate and Santo. To supply the urban market, the structured commercial sector could also exploit pelagic fish, mainly tuna. The constraint arising from the extreme mobility of these fish and the consequent large amount of time needed to locate them can be solved by establishing fish aggregating devices (FADs) (Cillaurren 1990b). The viability of fishing around a FAD is related to its location, especially with regard to the time required to reach it (Cillaurren). The species most commonly caught around FADs in Vanuatu are skipjck (*Katsuwonus pelamis*) and the yellow-fin tuna (*Thunnus albacares*). Whereas the yellow-fin is a high-priced fish, which can be sold to the urban expatriate and tourist market, skipjack sells for less than one US$ per kilo, and a large proportion of the co-operative associations' catch is kept to be used as bait for fishing

deep-bottom fish. If landings of skipjack could be increased and its price maintained at a low level, it could provide urban markets with a highly nutritious food at affordable prices.

Given the importance of fishing within the economy, the activity should be included in any development plan for coastal regions. Fishing is not simply catching marine foodstuffs; it includes numerous economic inter-relationships that, together, form a complex system. An alteration of one element of the system is likely to affect the other elements, directly or indirectly, as is shown schematically in Figure 5. Monitoring these alterations becomes a fundamental concern for the decision maker whose task is to prepare or assess a fisheries development plan. Several of the 13 elements affecting the fisheries system can be measured

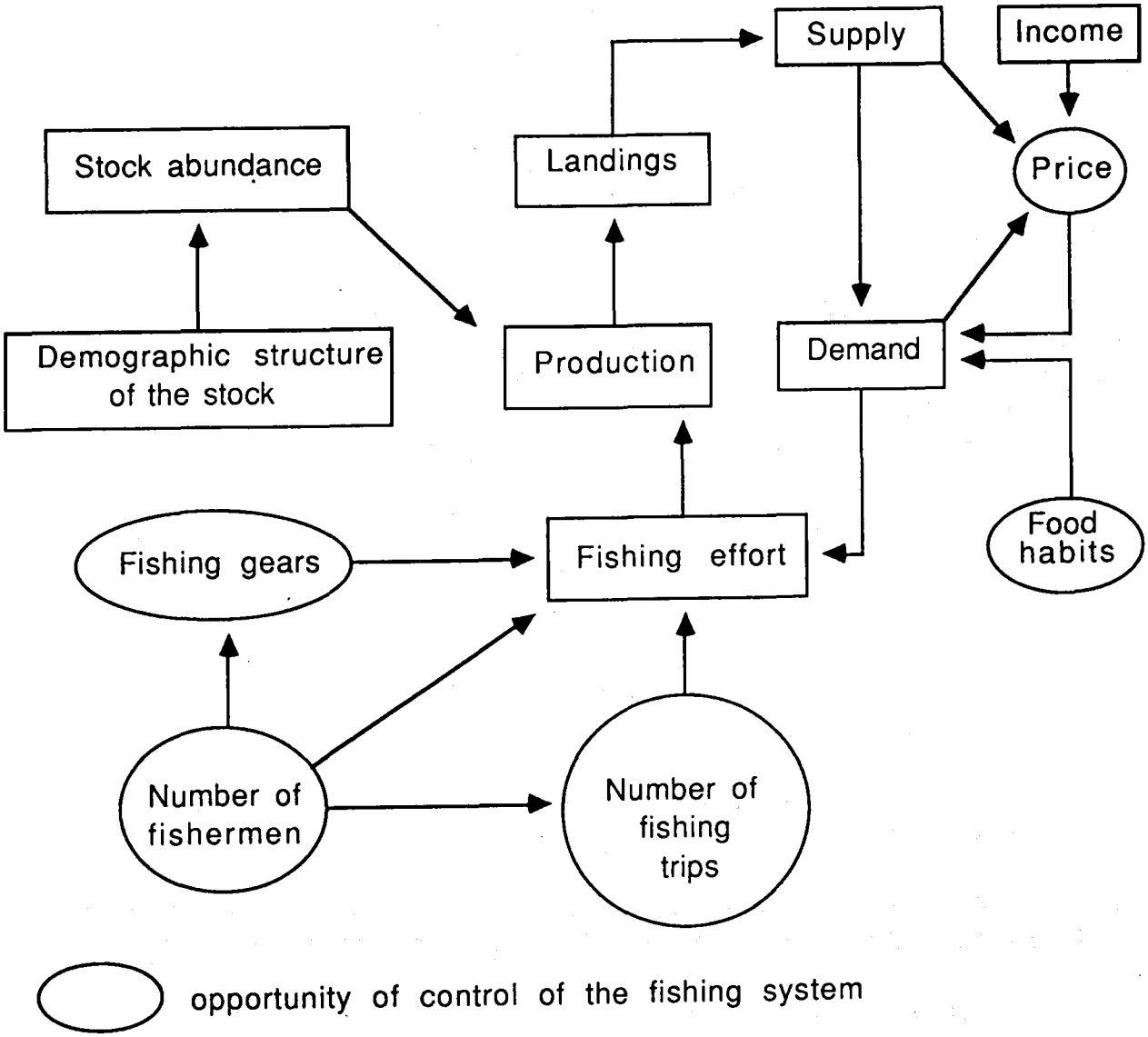

Figure 5. Monitoring the evolution of the fishing system

in the field and constitute indicators as to changes taking place in the system. Some of the indicators can also be manipulated in order to control the evolution of the system. Thus, by making use of taxes or grants, the planner can affect the selling price of fish. By spreading relevant information through the media, the planner may also be able to change dietary habits. Through legislation, particularly through the issuing of fishing licenses or establishing quotas, some control may be exercised over the number of fishermen and the frequency of fishing trips. Finally, through control of available bank credit, the evolution of fishing equipment can be directed.

We are convinced that in Vanuatu and other Pacific nations, village-level fishing offers a real potential for development. The resources are there, as are the men and women capable of innovation and adaptation. This potential must be tapped to improve the nutritional security of the country by developing fishing as well as farming and cattle production. Taking into account the specific socio-cultural aspects of small Pacific Island nations, any development model that rigidly fosters specialization among the fishermen, and that aims at an in-depth and rapid alteration of their social and economic organization through massive capital investment is doomed to failure.

Any innovation proposed by planners can only be successful if it fits with the aspirations and strategies of individuals and communities to be developed. Development programmes must be conceived around the existing forms of village-level fishing activities. Such programmes also need to be kept flexible and adaptable so that their goals and their means of execution can be modified according to the responses of the existing village fisheries to their application.

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NOTE

The Appendix on the following four pages shows copies of the questionnaires/forms used by ORSTOM and the Vanuatu Fisheries Department to monitor the production of deep-bottom-dwelling fish, which are the target of the VFDP. As described above on page 109, the data-gathering process is divided into three levels, each corresponding to one of the stages of fish production: landings, rural fish sales, and the urban market.

VILEJ FISING PROJEK

REKOT BLONG FISING LONG WAN TRIP

Nem blong kampani : .....

Nem blong bot : ..... Hamas man i stap long bot : .....

Deit yu ko aot : ..... Taem yu ko aot : .....

Deit yu kam bak : ..... Taem yu kam bak : .....

Fising eria : ..... Fising depth : .....

Hamas line yu usum : .....
long dip solwota

Hamas line yu usum : .....
long trolling

Hamas kilo fis yu kasem : ..... kg
long dip solwota

Hamas kilo fis yu kasem : ..... kg
long trolling

Taem yu start bottom fising : ..... Taem yu start troll : .....

Taem yu stop bottom fising : ..... Taem yu stop troll : .....

Wanem kaen beit yu usum : ..... Hamas kilo beit yu usum : ..... kg

---

INCOME

Hamas mane yu kasem long fis sales : ..... VT Nara income : ..... VT

HAMAS MANE YU USUM

Benzene/oel : ..... Repair mo maintenance : .....

Samting blong fising : ..... Freight : .....

Pay : ..... Ol nara expense : .....

Nem blong fis	Mesament blong fis (length long cm)
Etelis coruscans	
Etelis carbunculus	
Etelis radiosus	
Pristipomoides multidens	
Pristipomoides filamentosus	
Pristipomoides flavipinnis	
Epinephelus magniscuttis	
Epinephelus morrhua	
Epinephelus septemfasciatus	
Lutjanus malabaricus	
Aphareus rutilans	

REMARKS

REPUBLIC OF VANUATU

FISHERIES EXTENSION SERVICE
RESEARCH UNIT ORSTOM - FISHERIES DEPARTMENT
GOODS RECEIVED NOTE

GRN Nº 2951

Extension Centre ..... Date .....

Fishing Project ..... Procode .....

Fishing Area ..... Trip Length ..... Hours

PIECES	SPECIES		KILOS	PRICE	VALUE
.....	E. carbunculus	(Red Short Tail)	.....	.....	.....
.....	E. coruscans	(Red Long Tail)	.....	.....	.....
.....	E. radiosus	(Silver Jaw)	.....	.....	.....
.....	P. multidens	(Large Scaled Jobfish)	.....	.....	.....
.....	P. flavipinnis	(Yellow Jobfish)	.....	.....	.....
.....	P. filamentosus	(White Poulet)	.....	.....	.....
.....	L. malabaricus	(Red Snapper)	.....	.....	.....
.....	A. rutilans	(Green Jobfish)	.....	.....	.....
.....	S. rivoliana	(Amberjack)	.....	.....	.....
.....	E. magniscuttis	(Spotted Loche)	.....	.....	.....
.....	E. morrhua	(Brn. Striped Loche)	.....	.....	.....
.....	E. septemfasciatus	(7 Banded Loche)	.....	.....	.....
.....	G. unicolor	(Dog Tooth Tuna)	.....	.....	.....
.....	T. albacares	(Yellow Fin Tuna)	.....	.....	.....
.....	K. pelamis	(Skipjack)	.....	.....	.....
.....	T. alalunga	(Albacore)	.....	.....	.....
.....	C. hippurus	(Mahi-mahi)	.....	.....	.....
.....	M. seheli	(Mullet)	.....	.....	.....
.....	S. crumenophtalmus	(Mangreau)	.....	.....	.....
.....	Clupea sp.	(Sardine)	.....	.....	.....
.....	Mixed Reef Fish		.....	.....	.....
.....	Other Species		.....	.....	.....
		TOTAL			

Received from Fisheries Extension Service ..... VT.

Signed .....

"NATAI"

PORT VILA FISHERIES LIMITED
P.O. Box 883, Port Vila — Telephone : 23344
P.O. Box 211 — Luganville, Santo — Telephone : 36841

GOOD RECEIVED NOTE № 11563

Date : ....

Received from : ....

AWB No : ....

Bag No's : ....

CODE

Grade A - First Grade
B - Second Grade
C - Third Grade
IKE - Killed
HIG - Headed & Gutted
H/G - Head Off
G&G - Gilled & Gutted
WH - Whole
L - Live
D - Dead
F - Frozen

Description of Goods	Code	Kgs	Price	AMOUNT Vts

Void 24.1.92.

Total Kgs | **Sub Total**

Goods Received Signed : .... **Freight Ded**

Approved Payment Signed : .... **Other Ded**

Till Cash .... Cheque No. .... **Total Payable**

EFFECTS OF CLIMATIC CHANGES IN THE SOUTH-EAST PACIFIC REGION

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ABSTRACT

This paper reports the views of regional experts called together by the Comisión Permanente del Pacífico Sur (CPPS) to consider the implications of climatic change in the South-East Pacific region. The great variety of natural and human conditions in the region has led to the formation of many areas that will be sensitive to climatic and sea-level changes. Because the "El Niño" phenomenon is such a significant regional event -- even though episodic rather than secular -- it is used as a case study to establish the implications of change on regional ecosystems and socioeconomic structures. Particular attention is given to the sensitive marine and coastal ecosystems of coral reefs, mangroves, temperate salt marshes, and estuaries. The implications of the strong vertical tectonic activity characteristic of the South-East Pacific are examined. Consideration is then given to the effects of change on coastal pelagic ecosystems, the benthic environment, and fisheries; and an approach is made to an evaluation of the impacts of change on socioeconomic conditions.

INTRODUCTION

Within the framework of the UNEP Regional Seas Programme, the Permanent Commission for the South Pacific (Comisión Permanente del Pacífico Sur/CPPS), which is the Regional Co-ordinating secretariat for the Action Plan for the South-East Pacific, held meetings of regional experts in Bogotá (1987) and Santiago (1991) to prepare a report on the effects of climatic change in the South-East Pacific region. The group of regional experts initially adopted the Villach estimates of change as a basis for preparing the regional report -- *i.e.*, an increase of sea-surface temperature of 1.5°C by the year 2025 (with latitudinal variation); and an increase of relative sea level of 20cm by the year 2025. Following the Second World Climate Conference (Geneva, 1990), the group agreed to modify the figures to a temperature increase of 2-5°C for the next century and a sea-level rise of 65 ± 35cm for the same period.

Because the changes brought by El Niño events exert such a significant impact on regional climatic and marine environments, the CPPS group included the 1982-83 El Niño phenomenon in their report as a case study of short-term effects of climatic change in the South-East Pacific. While recognizing that El Niño is an episodic rather than a secular change, the group believes that understanding the causes and effects of El Niño may provide insight into

the longer-term effects of changes in the global heat balance. Although the large-scale anomaly in ocean-atmosphere interaction that is El Niño (Wyrtki 1982) involves most of the world's regions (Rasmusson and Wallace 1983), its influence produces particularly dramatic results in the coastal regions of the South-East Pacific, where temperatures increase, and mean sea level rises up to 40cm, with a maximum of 50cm, as recorded during the 1983 event (Fonseca 1985). The group assumed that impacts sustained by various regional ecosystems and socioeconomic structures under the influence of El Niño may reflect changes taking place in the year 2025 because of longer-term climatic change.

PHYSICAL ASPECTS

The strongest impact of a sea-level rise is the flooding of areas situated just above the previous water level. Because the elevation of these wetland areas is usually below the highest annual tide but above mean sea level, wetlands account for the largest land areas located at less than one metre above sea level. The extent of flooding depends on the slope value of the supratidal area. According to Bruun's Rule, a sea-level rise produces a modification in the equilibrium profile of the soft sedimentary shores so that a part of the sediment from the supratidal area is eroded to re-establish the previous bottom depth prior to flooding (Bruun 1962). The outcome of this process is a coastline retreat, with each rise of 1 cm in sea level bringing a landward retreat of 1 m. Also, deeper water allows the onshore arrival of higher-energy waves, which erode the shoreline, particularly during storm surges and tsunami. The inland penetration of salt water can be expected to have significant effects is some environments, *e.g.*, estuaries.

Inasmuch as coastal areas are influenced by hinterland as well as marine processes, an increase or decrease in precipitation inland will affect coasts, *e.g.*, modification of sedimentary input to fluvial systems because of climate change will affect sandy shorelines. In addition, a change in elevation of the snow line will change watershed reception of precipitation, which is turn will successively affect fluvial behaviour and coastlines. In the interfluvial areas, climate change will affect erosion and solifluction, again altering fluvial sedimentary inputs to the shoreline zone. Aeolian influence on coastal terraces will also change. In spite of these potential changes flowing from land towards the shore, most researchers have focussed their concern upon the flooding of coastal lands and the landward retreat of the coastline under the impact of rising sea level.

Because of the high level of variability that characterizes natural processes in the South-East Pacific, the most sophisticated models currently in use have been unable to pinpoint local or regional anomalies resulting from predicted anthropogenic changes in temperature or sea level. Because of its location in a plate convergence zone, the South-East Pacific coastline is characterized by great vertical mobility, which makes place-specific predictions regarding effects of sea-level rise particularly tentative. The magnitude of the tectonic movements may surpass the sea-level changes expected because of the global warming. As these tectonic movements include both uplift and subsidence, they may either intensify or diminish the effects of sea-level rise.

IMPLICATIONS FOR KEY MARINE ECOSYSTEMS

Coral Reefs

Coral reefs occur frequently in the eastern Pacific, especially along the coasts of Costa Rica, Panama, Colombia, and the oceanic islands of Cocos, Malpelo, and the Galápagos. Generally, reefs in this part of the Pacific have a low biodiversity. They are also small and discontinuous because of the character of the region's environment. Reefs near the low-temperature limit for coral (such as those of the Perlas islands in the Gulf of Panama or the reefs of the Galápagos) will be favoured by a temperature increase and can be expected to expand. Reefs near the high-temperature limit (Gorgona Islands of Colombia or Secas, Uvas, and Contreras Islands in the Chiriqui Gulf) may suffer damage if temperature increases, a calamity already suggested by the coral bleaching reported in some reefs during the 1983 El Niño.

With regard to the effects of sea-level rise, there is evidence of adaptation to such changes during the Pliocene and Quaternary. Therefore, a 20-cm rise does not foretell irreversible change; on the other hand, no estimate has been made for the effects of a rise of 65cm or more, which may be associated with augmented wave energies.

Mangroves

The South-East Pacific mangrove ecosystem generally comprises *Rhizophora* and *Avicennia* in various combinations. In Panama, Colombia, Ecuador, and northernmost Peru, the mangrove forest runs parallel to the coast in a zone of varying width, being particularly extended in some parts of Guayas, northern Ecuador, and southern Colombia. The mangrove ecosystem covers over 283,775ha in Colombia and 177,555ha in Ecuador.

During the 1982-83 El Niño, sea level reached heights more than 2m above normal. The high temperature, the extremely low salinity (associated with high precipitation), and the increased sediment input resulted in a high mortality among filter molluscs and mangrove crabs. On the other hand, catch rates of penides from the mangrove increased from 10 to 20kg/fisherman/day before El Niño to 80 to 100kg/fisherman/day during the event. Given the usual range of temperatures in which mangrove species develop, predicted increases in temperature should not a have a direct effect although species composition and productivity may be altered.

Temperate Salt Marshes

On the temperate-latitude coast of Chile, tidal marshes of the Gulf of Ancud (42-43° S. latitude) are similar structurally to marshes of the temperate zone in the Northern Hemisphere. The few studies carried out on the floristics of the marshes in the Gulf of Ancud record the presence of the halophytes *Triglochin martitum, Cotula coronopifolia, Eleocharis*

melanostachys, Salliera radicans, Spartina densiflora, and *Salicornia* sp. among others. These particular marshes presently

show evidence of erosion by the sea because of a relative sea-level rise caused by tectonic subsidence. A rapid climatically-induced sea-level rise would doubtlessly endanger the intertidal ecosystems, particularly as in many cases they have no opportunity to migrate upslope because they are located just seaward of coastal bluffs.

Estuaries

Estuaries, which are one of the less studied ecosystems in Latin America, are complex, diverse, open systems, which, together with a high level of productivity, offer short trophic chains. Between the central and southern areas of the Chilean coast (34° to 42° S.), estuaries are linked to large- or medium-sized rivers, some of which are severely affected by urban and industrial pollution. The significance of estuarine demersal resources is increased along the waterways and fiords supporting shellfish fisheries. In Colombia and Ecuador, most estuaries are associated with mangrove ecosystems.

An increase in sea level would produce a deeper inland penetration of the salty wedge, producing changes in the prevailing distribution of plants and animals in the estuaries. Changes recorded during the El Niño event have been associated with high precipitation, which resulted in flooding, alteration of patterns of sedimentation, and massive mortality of estuarine animal life.

Coastal Pelagic Ecosystems

The outstanding biological productivity of the coastal pelagic ecosystem of the South-East Pacific depends upon the upwelling to the surface of colder, deeper waters high in nutrients. These support the phytoplankton, in turn eaten by the fish. El Niño processes bring a deep surface layer of warm equatorial water, so preventing the cycling of nutrients from the colder depths, which reduces the density of phytoplankton, as shown by a decline in chlorophyll values. This change at the lower trophic level diminishes the catch of the region's pelagic fisheries.

Serious alterations in the physiological state of marine species during El Niño should also be taken into account. Body weight falls because of a decline in fat content, and there are changes in the spawning season and in larvae and juvenile mortality that affect the reproductive cycle and influence recruitment figures in later years.

It is possible that the effects of a long-term increase in temperature could produce oceanic conditions similar to those produced in the short term by El Niño.

The Benthic Environment

Most benthic species in the region are adapted to low temperatures. When warm conditions develop as a result of El Niño, these species are greatly reduced in numbers because of migration as well as depredation by immigrant species from warm waters. It has also been reported that during El Niño, most native crustaceans in the upwelling area sustain massive mortality.

A temperature increase of 1.5° C would not, however, be expected to bring a sudden alteration of the species composition of benthic ecosystems as most of the species are eurythermal within that range of fluctuation. The effects of a 5°C increase have not been evaluated.

An increase in temperature would generally entail:

-- adaptation of subtidal organisms;

-- migration of stenothermal subtidal organisms to higher latitudes;

-- unimportant effects of intertidal organisms, given their eurythermal character; and

-- increases in the matabolic processes of growth and spawning.

FISHERIES

Although the 1982-83 El Niño conditions may be used to simulate longer-term environmental changes, study of the region's fisheries activities indicates that the impact of each El Niño event since 1958 differs from the next. The 1957-58 event affected the distribution and behaviour of the anchovy (*Engraulis ringens*); the 1965 event introduced new changes in the distribution and the vulnerability of the species, and catches were seriously impeded, with harmful effects on the fisheries; the effects of the 1972-73 event were even more serious and lasted much longer so that the anchovy population was greatly reduced. The 1983 unloading of fisheries produce in Peru was about 1.5 million tons, the lowest on record since industrial fishing began in 1959. Average catches in years of normal climatic conditions were 6 to 8 million tons per year. In 1983, loss of income because of the decline in fish production was estimated to be about US$100 million.

Artisanal fisheries are also affected by El Niño conditions, not only because of changes in the biomass of some species but also because some species migrate, and artisanal fishers cannot follow the displaced prey, be they demersal or coastal, or be they crustacean, fish, or molluscs. High rates of mortality have also affected some algae, birds, and mammals.

SOCIOECONOMIC IMPACTS

The strength of socioeconomic impacts depends on the rate of onset of temperature and sea-level changes. Gradual changes will allow time to introduce countervailing infrastructure. Sudden changes will bring more acute dislocations to local economies and societies.

Uncertainties as to the rate and strength of the changes make evaluation of impacts tentative. Possibilities include the retreat of sandy coastlines, which will affect tourism. Other possibilities, which have occurred in association with El Niño events, include severe droughts, high rainfall, flooding, erosion, sedimentation, and so forth, all of which result in socioeconomic damage.

Evaluation of the harmful effects of the 1983 El Niño in Ecuador and Peru shows that 12 to 15 per cent of Ecuador was affected by climatic change, and some 950,000 people suffered heavy material loss from torrential rainfall, flooding, landslides, and storm surges. Some 5,700 slum dwellings were totally destroyed, and 8,000 more were severely damaged. Morbidity increased, 90 hospitals were affected, and the waterworks in 29 towns were damaged. Damages to the educational infrastructure was calculated to be US$6.6 million. Loss of income from agriculture, industry, and fisheries amounted to US$22.7 million. The total cost of material damages to the social sector was US$23.6 million.

In Peru, persistent and extreme drought affected 20 per cent of the country and 460,000 people. The coastal region was subjected to heavy rainfall and storm surges, which brought large-scale flooding affecting some 830,000 people, 41 waterworks, 875 schools, and 10,800 dwellings. The damage to social services was calculated to be US$133 million; the loss of income by the agricultural sector amounted to US$297 million; and irrigation infrastructure showed a loss of US$60 million.

CONCLUSION

The CPPS group's review of possible impacts of global climatic change and sea-level rise establishes that the South-East Pacific region has many areas sensitive to such environmental modification. Even though not all possibilities have been mentioned, it is clear that global climatic change will have serious consequences that will affect not only the natural environment but also the whole society and economy.

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INTEGRATED MANAGEMENT OF THE COASTAL ZONE (Chile, Perú, Ecuador, Colombia, Panamá)

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ABSTRACT

In the context of facilitating the regional management of the sensitive coastal zone of the eastern Pacific from the north of Panamá to the south of Chile (the coastal area included in the South-East Pacific Action Plan), this paper reviews the zone's main features, its resources and their uses, the conflicts arising from multiple uses, the natural hazards of the area, and the legal framework necessary to achieve compatibility between the goals of the various users and nations.

SOUTH-EAST PACIFIC COASTAL LANDS: THE SETTING

Physical geography

Generally, the Andes fall sharply into the Pacific Ocean except in Colombia and northern Ecuador, where the slope is gentle and there are a series of estuaries and wide alluvial plains formed by the San Juan, the Patia, the Mira, the Esmeraldas, and the Guayas rivers. The Baudó mountains of Colombia's northern Pacific coast are narrow and low, rising only to altitudes between 560 and 800 m. Along Chile's shore, the coastal cordillera stretches for 3,000 km, forming a high wall in the north, with few coastal flatlands; to the south of the Aconcagua River, the altitude is not higher than 1,000 m, and finally the mountains disappear in the Taitao Peninsula.

The South-East Pacific coastal region exhibits a large variety in climate and vegetation type, given its great latitudinal extent, its varied orographic structure, and the strong influence of variations (both spatial and temporal) in adjacent sea-surface temperatures. A long stretch of the coast centring on about 20° S. latitude has a desert climate and xerophytic vegetation. Farther north in the equatorial latitudes, more humid tropical climates and vegetation types occur, whereas southward in middle and southern Chile there is a sequence towards Antarctica of steppe, Mediterranean, and humid temperate climates and vegetation types extending virtually to tundra.

Table 1. Coasts of South-East Pacific Countries

Country	Length of Coastline *km*	Coastline/ land area *ratio*	Population	Population on coast *per cent*
CHILE	6,452	0.0087	11,682,000	20.0
PERU	2,414	0.0019	18,707,000	43.0
ECUADOR	2,869	0.0081	9,251,000	45.0
COLOMBIA	2,414*	0.0031	27,515,000	5.9
PANAMA	2,490*	0.0329	1,910,000	61.0

* Total length of coast, Pacific + Caribbean

Human settlement

Chile. Given the extreme aridity of Chile's north and the cold and wet of its far south, the country's population is concentrated in the central and central south parts (30° to 43° S.). Because of the unusual linear shape of the country as well as the inhibiting presence of the Andes in the eastern interior, Chile's population and urban centres when not on the coast are not far away from it.

Peru. Peru is divided into 25 administrative departments. According to the 1981 census, 58 per cent of the population of the then total population of 17,005,210 lived in the ten coastal departments, a percentage influenced in part by the heavy migration of interior peoples to Lima, the country's administrative, cultural, and commercial centre, located just inland from the port of Callao.

Ecuador. The four coastal provinces of Esmeraldas, Manabí, Guayas, and El Oro contain over 40 per cent of Ecuador's total population, derived in part from a strong migration, starting in 1970, to the coastal provinces, especially El Oro and Guayas.

Colombia. The Pacific littoral of Colombia is a sparsely settled part of the country, with only the two urban centres of Buenaventura and Tumaco.

Panamá. The geography of Panamá makes the country a virtual island, and, as with many islands, its population is concentrated in the coastal areas, particularly in the country's largest city, Panamá, which is located at the Pacific end of the Panamá Canal.

COASTAL RESOURCES OF THE SOUTH-EAST PACIFIC

Fisheries

Some of the most important pelagic fisheries of the world are located along the Pacific coast of South America because of the nutrients supplied to the bottom of the food chain by the upwelling of cold, deep waters along the Chilean and Peruvian coasts. An intensive aquaculture devoted to red algae, salmon, and prawns further increases the landing of marine products. When recurrent El Niño events take place, the nutrient supply from depth is lessened, provoking drastic reductions in the volume of catch, especially for Peru with its high dependence on the single species *Engraulis ringens*, which is heavily affected. On the other hand, the increases in sea-surface temperature associated with El Niño encourage production of crustaceans and molluscs.

The most important species in the Peruvian and Chilean fisheries are sardine (*Clupea strangomera bentincki*), mackerel (*Trachurus murphy*), anchoveta (*Engraulis ringens*), and Spanish sardine (*Sardinops sagax*). Ecuador's main catches are derived from pelagic species such as Spanish sardines, the mackerel *Scomber japonicus*, and prawns. There is also a mariculture concentrated on prawns (*Penaeus vanamei* and *P. stylirostris*). During 1985 the pelagic catches amounted to 1,466,488 tons; by contrast, the 1983 catch was only 176,000 tons because of the 1982-83 El Niño. Ecuador's tuna industry is important because of its high value: an income in 1985 of $US68,633,639. Fishing is of slight importance on Colombia's Pacific coast. Information for 1984 shows products landed through the only two ports of Buenaventura and Tumaco amounting to 18,500 tons, of which prawns (*Penaeus occidentalis* and *Xiphopenaeus rivetii*) contributed 3,480 tons, and oysters and squid contributed 350 tons. The potential may be somewhat higher.

Special coastal ecosystems

Coral reefs. Abundant from Costa Rica to Colombia and around the oceanic islands of Cocos, Malpelo, and the Galápagos, coral reefs of the eastern Pacific are characterized by a comparatively low number of species (eight to ten) per reef and not a rich diversity overall.

Mangroves. South-East Pacific mangroves generally consist of Rhizophoraceae and *Avicennia* and *Laguncularia* in a close association. Along the coasts of northern Peru, Ecuador, Colombia, and Panamá, a strip of mangrove forest parallels the shore, intruding extensively inland in Guayas, northern Ecuador, and southern Colombia. The mangrove ecosystem of Ecuador covers about 177,755 ha and that of Colombia about 283,775 ha. Panama's mangrove forests cover some 500,000 ha.

Agriculture, Forests, Grasslands

In the South American Andean region more than 391,500,000 ha are devoted to coastal agriculture or forestry or a combination of the two. Woody growth predominates, covering

more than three-quarters of the total; only 82,000,000 ha are agriculturally developed lands, of which 22,000,000 are dedicated to annual crops and pastures, and 60,000,000 ha given over to permanent native grasslands.

Agriculture. Given the geographic variation of the region together with cultural and economic differences, there is a great variation in crops and agricultural systems over the region, ranging from low-technology self-subsistence farming to agro-industry. In Ecuador, the emphasis on export of agricultural products (particularly bananas) has meant the loss of agricultural land for production for national consumption. Colombia's agricultural development is mostly in the valleys and uplands of the country's central Andean zone, away from the Pacific coast.

Forests. Southern and central Chile's climate allows forests, which are composed both of native species as well as, over considerable areas, exotics such as *Pinus radiata* and *Eucalyptus* spp. The coastal areas of northern Chile and Peru are too arid for forests. Information is scant on the forest resources of the humid Ecuadorian coastal area (PMRC 1989). The natural vegetation of Colombia's wet, little-developed Pacific coast is rain forest. Panama has a total forest cover of 40 per cent, with the most important sector located in the lowlands of the Pacific slope. Species include *Cavanilesa platanifolia* and *Prioria copaifera*. *Mora oleifera* occurs on lands subject to brackish waters.

Grasslands. Chile's extensive livestock industry depends on a variety of natural grasslands and developed pastures, some of which are coastal. Many of Peru's grasslands and pastures are found in the Andes but some are also present in the northernmost coastal departments of Tumbes, Piura, and Lambayque. Grasslands and pastures continue northward in the coastal regions of Ecuador but are of little importance on the Pacific coast of Colombia. Panamá's grasslands are dominated by *Hyparrhenia rufa*.

Parks and Wildlife Protection

Chile has a long tradition of nature protection, dating from a 1873 law regarding the felling of trees. Fifteen national parks or reserves have a specified coastal component; three more contain coastal areas within their boundaries (Table 2). In Peru, protected areas can be categorised variously as national parks, restricted areas, historical sanctuaries, protected forests, and so forth. Areas falling under protection include:

- National mangrove sanctuary in Tumbes (northernmost Peru) covering 6,000 ha
- Virillá estuary covering 1,500 ha containing specialized estuarine flora and fauna and bird breeding sites
- Lachay National Reserve, 105 km north of Lima, covering 5,070 ha with a high diversity of plants and animals as well as archeological sites

Table 2. Protected Areas in Chile

Name	Region	Year Established
Pan de Azucar	Antofagasta/Atacama	1986
Fray Jorge*	Coquimbo	1941
Juan Fernández Islands*	Valparaiso	1935
Rapa Nui (Easter Island)	Valparaiso	1935
Chiloé Island	Los Lagos	1938
Guaytecas	Aysen	1938
Guamblin	Aysen	1967
Isla Magdalena	Aysen	1983
Laguna San Rafael	Aysen	1959
Katalalixar	Aysen	1984
Bernardo O'Higgins	Aysen/Magallanes	1969
Alacalufes	Magallanes	1969
Los Pinguinos	Magallanes	1966
Alberto de Agostini	Magallanes	1965
Cabo de Hornos (Cape Horn)	Magallanes	1945
Alerce Andino	Los Lagos	1983
Queulat	Aysen	1982
Cinco Hermanas	Aysen	1964

* Biosphere Reserve

- Paracas National Reserve, the first natural protected area with a marine component, it covers 335,000 ha, including 217,594 ha of coastal waters containing concentrations of fin fishes, molluscs, crustaceans, birds, and mammals

- Lagunas de Mejía National Sanctuary, a lake of 69 ha located near the coast and possessing a special flora and fauna related to the presence of migratory birds

Ecuador's coastal zone contains four protected areas: Machalilla National Park, Churute Ecological Reserve, a protected forest along a branch of the El Salado river, and a protected mangrove forest. Colombia manages Gorgona Island as a protected or restricted area and is concerned to maintain the mangroves along its Pacific coast.

Tourism

Chile's extended coastline offers many huge sandy beaches, although some of these located near main ports or coastal cities are polluted. During 1987, almost 560,000 foreign tourists visited Chile, 36 per cent of them spent time in the coastal zone. Income from tourism in that year amounted to more than $US175,000,000. During 1985, the number of tourists visiting Perú was about 300,000, but coastal tourism is not significant and is concentrated in Lima. The large beaches of the north coast have potential for tourism. Tourism in coastal Ecuador is recent and is concentrated around Guayaquil. Tourism is insignificant along the Pacific coast of Colombia, and existing facilities offer little scope for development.

Mineral Resources

Chile's major mineral resource copper, produced in open-pit mines. is very significant in the country's economy, along with iron, molybdenum, and other minerals. Coal mining has been developed under the sea floor as well as in open-pit mines. Offshore production of petroleum is also important. Perú has reserves of copper in various coastal areas, and extensive resources of some 40 other minerals including iron, manganese, coal, silver, and gold. Oil and gas occur on the continental shelf as well as in the desert north and the Amazon basin. Oil is produced in Ecuador near the coast on the Santa Elena peninsula, and there are plans for further exploration there and under the waters of the Gulf of Guayaquil. Colombia's cordilleran system is rich in a variety of minerals such as gold, silver, coal, copper, iron, zinc, and others. Petroleum is found on the Pacific coast in the Tumaco vicinity.

Ports and maritime infrastructure

The geographical characteristics of Panamá and the Pacific-coast countries of South America make maritime activity very significant, with the ocean often being the only pathway for bulk cargo. Chile has six main ports scattered along its immense length from Iquique in the far north to Punta Arenas in the far south. Argentina and landlocked Bolivia also make use of some of Chile's ports. Since 1970, Peru has had a National Port Authority (ENAPU)

to coordinate the operation of all Peruvian ports and to expand facilities and to improve efficiency in all aspects of shipping and landing. The country has 18 maritime terminals, with a trade greater than 10,000,000 tonnes. Callao is the major port, followed, in order of importance, by Matarani, Chimbote, and Salaverry. Ecuador's coast has six main ports. Esmeraldas in the north deals with a range of products and is the site of the Balao oil terminal, which exports oil piped in from the east. Other specialist ports in Ecuador are El Oro, with over 90 per cent of its exports being bananas, and Puerto Bolívar, used by artisanal fisheries. On Colombia's Pacific coast Buenaventura is the major port, dealing with 51 per cent of the country's maritime trade. Tumaco in the south is much less important. There are no other ports of any significance on Colombia's Pacific coast although important ports may be developed in the north (Gaitán 1984). Panamá's maritime significance is well known, but the great volume of shipping traffic associated with the country mostly consists of international cargo passing through, not national freight.

NATURAL HAZARDS

Many natural hazards impede economic activity in the coastal area or cause large amounts of damage or destruction to the human settlement and industrial development that is concentrated near or on the coast. The Andes and associated deep Perú-Chile Trench running parallel to the coast are manifestations of the subduction zone that separates the oceanic Nazca Plate from the American Plate. Consequently, earthquakes are a common occurrence, and the risk of tsunami is high. Another singularly important natural component of economic risk in Chile, Perú, and Ecuador arises from the consequences of the El Niño events, which bring a great decline in the yield of fisheries as well as onshore flooding from high rainfall. On the other hand, El Niño improves the yield of scallops, prawns, and some other marine products. Because the phenomenon is recurrent, governments must include the consequences of El Niño in their development plans.

POLLUTION

Taken as a whole, the countries of Chile, Perú, Ecuador, Colombia, and Panamá do not have their populations concentrated on the Pacific coast. However, along or near the immense stretch of coast belonging to these countries live some 20,000,000 people, whose urban centres and industrial activities discharge garbage and wastes, much without any treatment, directly into the sea or into rivers and streams, polluting that water and its final destiny, the ocean. Marine pollution, originating mainly from terrestrial sources, is the greatest problem to be faced in a coastal management plan, whether national or regional.

Chile. Along the Chilean coast between Arica and Puerto Montt the few indentations or bays that exist have become centres of industry and human settlement, whence garbage and sewage are dumped into the sea, making the bays the most polluted areas of the littoral. In the north, population is small, but industrial residues from fisheries and mining find their way

into the sea directly or through low-volume streams (0.12 m^3/sec - 12.0 m^3/sec). The areas most affected are Iquique, Antofagasta, and Coquimbo. In the central and central-south coastal zone, where the population is much larger, wastes equivalent to 296 tons/BOD/day are deposited in torrential rivers (8 - 100 m^3/sec) that empty into Valparaíso and Concepción bays. Industrial waste is also large, originating from a variety of industries such as fisheries, chemical plants, abattoirs, breweries, paper factories, mines, and so forth. In the far south, the sparse population contributes an organic discharge of 16 tons/BOD/day, and industrial pollution is limited by the absence of industries, except for oil.

Perú. The sources of marine pollution in Perú are similar to those in Chile: untreated sewage, domestic garbage, and industrial wastes from fisheries, mines, oil refineries, oil landing and shipping, and a variety of factories.

Ecuador. All of Ecuador's coastal cities and towns discharge domestic and industrial waste into adjacent waters. The most badly affected area is the Gulf of Guayaquil, which receives discharges from Guayaquil through the Guayas River and which is bordered by the provinces of Guayas and El Oro in which only one out of three houses has sewage treatment (PRMC 1989). The northern city of Esmeraldas discharges sewage directly into the sea 1,600 m out from the shore at a depth of 20 m. In the province of Manabí between Esmeraldas and Guayas, only three out of 20 houses treat sewage. Wastes originating in the interior highland city of Quito reach the sea through the Machangora and Guayillabamba rivers. Coastal pollution also results from the fishing industry, mines (*e.g.*, mercury in the Amarillo River), oil refining, and, along the coast of El Oro Province in the south, pesticides and fertilizers from the banana plantations.

Colombia. Because of its low population density, the Colombian Pacific coast has the least pollution of the region, with significant amounts of garbage and sewage found only in the vicinity of the two port towns of Buenaventura and Tumaco.

Panamá. By far the worst affected area is the Bay of Panamá, which receives sewage and other wastes from the city of Panamá, the country's major urban centre. Oil pollution associated with shipping is also present.

LEGAL FRAMEWORK

Because the coastal zone has not been defined in the legislation of the CPPS countries, we follow here concepts commonly put forward in the literature and define the coastal zone as "that part of land influenced by its proximity to the sea and that part of the ocean affected by its proximity with land" (Ketchum 1972). Some CPPS countries define the maritime and continental boundaries of their coastal zones (Table 3) but only in order to deal with certain restricted uses of the zones. To deal with problems resulting from multiple uses, it is necessary to have a broader definition as well as basic scientific information about the problems in order to support a legal framework and to plan for the integrated management of the coastal region.

Table 3. Definitions of Coastal Zone Boundaries

COUNTRY	TERRESTRIAL	MARITIME
CHILE	80 m inland	Outer boundary of the continental shelf
PERU	800 m elevation	Outer boundary of the upwelling area
ECUADOR		
COLOMBIA	50 m inland	Two km wide, parallel to the coast
PANAMA		

At the national level, different ministries, secretariats, commissions, and other agencies have partial authority over different aspects of the coastal zone, territorial seas, or EEZ, but there is no study of the management of the whole zone and no holistic planning initiatives. The basic question has to do with the mutual compatibility of uses of the coastal zone. Not all uses can be compatible, but consideration of the conflicts can minimize damage. Another major issue in the development of a coastal zone management plan must be provisions for dealing with the consequences of natural hazards.

As described by Cabrera (1991: 11), a legal framework for a strategy to prevent and control marine pollution in the South-East Pacific Region does exist in the form of four legal instruments developed within the framework of the Action Plan for the Protection of the Marine Environment and Coastal Areas of the South-East Pacific. These four instruments entered into force in 1987 and form the basis for future regional cooperation among CPPS countries in addressing the issues of coastal and marine pollution. Further expansion of legal agreements is required, however, if the CPPS member states are to deal adequately with existing and potential environmental problems of their coastal zone (Llanos Mansilla 1991).

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THE PRICING OF MARINE RESOURCES

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ABSTRACT

One element of the process of management of marine resources is the question of the pricing of the interests granted to enable the resource to be developed. The paper looks briefly at the context in which such interests are granted and at the nature of the interests entered into. It goes on to consider the experience of several Pacific countries and states in their policies towards the pricing of leasing and licensing arrangements for the development of the resource.

The paper addresses two issues that are currently under wide consideration in the field of pricing: the question of how to specify the price that is to be charged, and the question of how to fix the price on the basis of a given specification. The paper concludes with an examination of the impacts of different policies in respect of pricing and of prospects for the future.

INTRODUCTION

In looking at the pricing of marine resources, I consider the different approaches adopted towards leasing and licensing, and towards pricing and valuation of those resources for which there is a market in marine areas. I do not include any consideration of ownership and jurisdiction or of planning and conflict resolution, although these are both important issues in the Pacific in the last decade of the twentieth century. For reasons of space, only uses and developments that are predominantly coastal or near shore are treated. There has been significant and rapid development in offshore exploitation of hydrocarbon prospects; considerations relating to these, to offshore polymetallic nodules and crusts, and to other more experimental uses are not examined here. There have also been important changes in the ways in which erstwhile "free" resources, particularly fisheries and shellfisheries, are managed. Except insofar as these impinge upon the leasing and licensing of coastal marine areas for development, considerations relating to these are likewise excluded.

Research for the paper has been in progress since 1988 (Munro-Faure 1991) and has involved visits and meetings with individuals and agencies in fourteen states, including the following from the Pacific and Pacific rim: British Columbia (Canada), the states of Washington

and Hawaii (USA), Fiji, New Zealand, New South Wales and Queensland (Australia), Singapore, Malaysia, Hong Kong, and Japan. The information on which the paper is based is derived primarily from more than 210 interviews held in the states visited and from unpublished documentation on existing lease and licence arrangements. The persons interviewed were all connected with some aspect of the administration and management of the marine resource at levels ranging from local to international, and were drawn from both the public and private sectors.

Such a survey is inevitably restricted in its nature; however, the specific instances are more or less directly relevant to coastal marine areas in different parts of the Pacific that are being affected by rapidly growing pressures, interest, and concern.

The pressures include population growth and the accentuation of its effect on marine resources because of population drift to urban areas, which are often located in the coastal zone. The struggle for economic growth and higher standards of living compounds pressure on existing resources and encourages technological developments enabling such resources to be exploited more successfully.

These pressures lead to the development of marine resources, including uses such as reclamation for agricultural, aquacultural, or urban uses, or for port development; dredging for minerals, sands, and gravels; tourism development; jetties, moorings, and marinas; aquaculture of finfish, shellfish, and seaweed; power-generating projects using tides, winds, or waves; hydrocarbon exploration and extraction; oceanic thermal energy projects; pipelines, cables, and bridges; conservation, marine parks, and reserves; and many others. Such developments in most cases involve the granting of some sort of lease or licence by the owners of the resource, generally the state, and of permission by others who may have jurisdiction in these areas.

THE LEASING ISSUE

The requirements of a prospective user of the marine resource are not fundamentally different from those of a prospective lessee or licensee of property on dry land.

The interest that the user is granted must be reasonably certain, both as regards its legal standing and as regards the definition of the interest granted. It must adequately identify physical boundaries to satisfy legal and practical requirements, not necessarily an easy task because of tidal fluctuations, slack lines at low tides, currents, and other difficulties. The length of time for which the interest subsists must be included together with any rights to extension, assignment, or sub-leasing that the lessee or licensee may have, and any rights to determine all or part of the interest that the parties may reserve. The rent or licence fee and any premia to be paid must also be specified, together with a clear basis for reviewing the rent if there is provision for review.

Further requirements are:

- identification of responsibilities under the agreement for such matters as repair and insurance and for compliance with legislation during the term of the agreement;

- inclusion of details about the treatment of any performance bond;

- specification as to what is to happen at the conclusion of the interest granted with regard to, for instance, any improvements that have been undertaken;

- specification of the nature of the interest granted, whether it provides for exclusive possession with the corresponding lessor's covenant for quiet enjoyment, or otherwise; in what, whether sea bed and/or water column; and for what purpose.

The elements thus identified determine the extent and value of the interest granted and may well have a significant impact on the viability of potential uses of marine areas. This may be the case quite apart from any other controls be available to other agencies or individuals through the various policies and procedures that exist to resolve conflicts of interest.

The term and extent of the interest granted out of the state's ownership of sea-bed and foreshore are frequently governed by the legislature, whether directly through constitutional definition or legislative specification, or indirectly through administrative regulation. In some cases, where direct control is subordinated through a head lease or a grant of control over a specific area, such constraints will be further determined by the terms of the agreement. Examples of the latter include the province of British Columbia which grants 30-year leases to the Fraser River Harbour Commission and the North Fraser Harbour Commission. The New Zealand Department of Conservation issues grants of control of foreshore and the adjacent sea-bed to local authorities for up to 21 years, out of which may be granted licences for the use of foreshore and sea-bed of up to 14 years.

The leasing and licensing system thus created by the state varies considerably and has a resultant effect on development in marine areas.

At its most potent, the state may effectively suspend the operation of the system and place further development of particular activities under a moratorium. The rapid growth of mariculture has concerned some states because of potential adverse impacts, and this has led to the temporary imposition of moratoria on the granting of new leases or licences for such purposes, as, for example, with salmon farming in Washington State's Puget Sound.

In more normal cases the state administration works through specified limits as to the duration of interests granted. These limitations stem from different, often historic, circumstances and may prove more or less of a constraint to development.

Where a substantial lease term, such as the 100 years maximum permitted in Singapore, is available, this will not present major problems to the lessee in amortising the investment, nor will it pose a constraint in terms of providing a mortgageable interest as the basis for external funding.

In other situations, however, policies towards the maximum duration of interests may have a considerable impact. A fairly common delegated policy limit under normal circumstances for a leasehold term is of the order of 30 years. Such a limit may be extended, in some cases, by the executive agency referring proposals to the prime decision-making agency from which the delegated powers are derived, particularly where large capital investments require longer amortisation periods. In other cases, as in New Zealand, licences beyond the statutorily provided maximum of 14 years for foreshore and sea-bed areas require an enabling act of parliament.

It is not, however, always possible to achieve a longer lease period. In the case of Washington State, for instance, the maximum duration of leases in harbour areas is fixed at 30 years by the State's 1899 constitution. This was a reasonable period for amortising the then prevalent piled timber jetty structures. This restriction, when major sources of funding such as life offices may be unable to grant mortgages on terms exceeding four-fifths of the unexpired portion of the lease, is, however, not conducive to modern development in harbour areas. Those wishing to facilitate such development are left with the options of lobbying to change the constitution, or of trying to change the designation of the area.

Issues of this kind are often complicated as ports and their associated boards, commissions, or authorities are frequently solely charged with traditional transportational and associated port responsibilities, which, in many cases, history has well endowed them with the powers to fulfil. This may lead to a distinction being drawn between water-dependent and non-water-dependent uses, with considerably shorter terms being granted, where permitted, to the latter.

At the other end of the scale, many uses of coastal marine areas are undertaken on the strength of annually renewable licences. This is true of most licences for sand and gravel dredging and for certain types of mariculture; it is the interest on which development of all kinds in marine areas is undertaken in some countries.

The leasing and licensing of coastal marine areas is additionally determined by the nature of the interest granted when direct control is subordinated through a head lease or grant of control; as the head lease wanes so does the possible term of any sub-lease. In the cases of the Fraser River ports' leases mentioned earlier, the 30-year leases contain options to renew for a full term half way through the term. Arrangements of this kind limit the port to granting the balance of the remaining term, although in practice the federal port commissioners will grant a longer term with the balance beyond the remaining term being conditional upon renewal of the head lease by the province.

The viability of any given proposal may depend not only upon the duration of the legal interest offered, but also upon the other terms and conditions attached. These latter, it is probably fair to say, are in various stages of review around the Pacific to bring them up to date in the context of a resource which is under rapidly increasing pressure. It is not, however, unusual for leases and licences as at present offered to be sufficiently unspecified as to be a considerable act of faith on the part of one or both parties. A lease, for instance, which has no covenant for quiet enjoyment from the landlord, and no right for a mortgagee to remedy a tenant's default within a given time period to avoid forfeiture may prove of limited value as security for a loan.

The viability of a proposal will, of course, also depend upon the cost of securing an appropriate lease or licence for the purpose required. The costs include licence fees or lease rents which comprise only part of the total expenditure to secure a legal interest. The costs will also include the costs of applications and of compliance with the planning framework in marine areas. The former may involve survey fees, together with legal and valuation advice. The latter may include referrals to many governmental and other agencies for appropriate permits, with possible requirements for environmental impact assessments of various kinds. The costs relating to these matters may be measured both in terms of time and money, and may be very substantial.

THE PRICING ISSUE

The assessment of lease rents and licence fees, and thus of the price of the legal interest granted, is under active review in several of the states visited. The nature of the review is not simply the periodic review of values that is part of almost every leasing and licensing system. In several cases the basis by which the dues under such agreements are fixed is being fundamentally reappraised.

The latter is a function of several pressures that have been evident during the 1980s and seem set to continue through the 1990s. The first of these is that there is now far greater pressure on marine areas than there has been in the past. These pressures include those on what are often regarded as traditionally free uses such as fishing, navigation, environment, and recreation. In most cases these are public rights but in some cases, particularly in the Pacific where customary rights in marine areas are recognised, these uses may be exercised exclusively by virtue of private or communal rights. In some cases customary rights overlay the states's ownership of the seabed, as is the case in Fiji, for instance. In these cases, pressures on marine areas derive from an extended range of sources. For most other uses a charge may legitimately be made by the owner of the resource; in nearly all cases this is the state. Pressure for more effective management of the former, more traditional uses, and for more extensive areas to be exclusively available for such uses take effect as a constraint on the supply side, at least as far as the latter, other uses, are concerned. Simultaneous growth in demand for these latter has resulted in many cases in an increase in the market value of the resource. The monopolist situation of the state puts it in a particularly strong position to realise the results of these

changes in market forces. It should be said, however, that in none of the Pacific states visited has there been any suggestion that advantage has been taken of this *de facto* position.

With this increase in value of the resources in real terms has come the view that resources should be utilised efficiently and that the market may present a useful mechanism for so doing. If the approach supplements government revenues more effectively by following this route then that is often regarded as a welcome bonus. This may also be viewed as a positive development by those who would prefer not to see profligate development in marine areas. When the user pays the full value of the resource, the incentive to use marine resources that have been generally regarded as undervalued in the past will be seen in a proper balance with dry land alternatives. If the user can be seen to be paying a reasonable price for the use of the resource, and the income is then directed to funding improvements in the marine and coastal environment, as is the case in Washington State's Aquatic Land Enhancement Account, then so much the better.

The range of attitudes underlying the philosophy applied to the valuation of coastal marine areas varies both between states and within states. In the latter case, different agencies responsible for administration may use different criteria for fixing rents or license fees, even for the same uses. In a given state different philosophies may underlie the treatment of different uses; some being regarded as free or appurtenant to an existing ownership, such as private jetties and moorings; others as straightforward market propositions, such as port reclamation schemes. Between states the range is at least as wide with some states being predominantly oriented to market value and others being almost wholly restricted to charging minimal administrative fees. It is possible to identify a broad continuum within which these pricing policies lie. At one extreme there is simply the free use of the resource. This philosophy has been widespread on a *de facto* basis, whatever the policy makers' views have been, because of the resource's dispersed, low-value, extensive, and often relatively inaccessible nature outside areas with special suitability. At the other extreme is the charging of maximum rent using the market position of the monopolist.

The range in between covers the fixing of rents based on offsetting administration costs, through various degrees of market assumptions.

It is not only the underlying philosophy that distinguishes state from state in its attitude to the value of coastal marine resources. It is also the attitude towards practical problems of valuation and the fixing of rents and fees.

There is a very real problem underlying the fixing of market or market values and that is simply that by the very nature of the resource there is often a basic lack of market evidence to support appraisals. The approaches adopted in the valuation of these interests necessarily reflect this.

In many situations it is the practice to set administrative fees as an arbitrary but minimal rental or licence fee. This does not comprise a significant element of expenditure for the lessee or licensee. Such was the case, for instance, with submerged land lease fees in

Florida, characterised in the past by the state governor as "blue light specials" following the cut-price marketing term of a major chain store in the state (MacFarland 1986). It is not uncommon for such arbitrary sums to be adjusted by reference to the retail prices index to provide some linkage with current prices. Where this is the practice the granting of a lease or licence may confer a substantial windfall asset upon the lessee or licensee. This can be substantiated by market evidence of the subsequent transfer of such interests.

Where the approach adopted is to try to assess the market value of the interest granted a number of approaches are typically used in practice. In a very limited number of cases a market for the resources exists and it is possible to analyse sales in order to establish comparative values. This is frequently the case with, for instance, yacht moorings.

Where this is not possible, perhaps most commonly where commercial undertakings reclaim or build over marine areas, the adjacent upland value may be taken to represent the most appropriate basis for comparison and a specified portion of this value is taken. This is closely related in principle to the residual or hypothetical development approach, which is often used, particularly in such circumstances. In this approach the broad rule-of-thumb percentage of upland value is more closely analysed by looking at the value of land as reclaimed or of the platform as constructed and deducting all of the costs associated with its construction, thus leaving a residual value for the marine land leased. For a given area with broadly comparable reclamation costs, the fact that the land reclaimed will probably equate in value to the adjacent upland lends some support to the percentage-of-upland-value approach. In cases such as these where a capital value is appraised an appropriate annual value is derived by the application of an appropriate discount rate.

Where such an approach is not appropriate or such evidence is not available, another approach adopted is to look at the productivity or profitability of the enterprise to be carried out, be it salmon farming, sand and gravel dredging, marina development or whatever and to assess how much of the net profit, after allowing for fixed and variable costs, should be paid as rent. This may result in a general rental figure being defined on a unit basis: per hectare, per square metre, or per cubic metre extracted, for example. Alternatively, it may be felt more appropriate to identify the rental on a turnover basis as a percentage of gross turnover having regard to the production or profit of the specific enterprise. The former approach may take account of locational differences in profitability by dividing coastal areas into different rental zones, as is the case in British Columbia with its finfish and shellfish lease rents. The latter may cater for profitability differentials depending on how the agreement is structured, but will necessarily suffer from problems of accountability. Productivity is an issue in the valuation of compensation claims where customary rights are interfered with as has been the case with native fishery rights in Fiji when marine areas have been taken for reclamation. In such cases a resource survey of the area has been undertaken and the capitalised value of the sustainable harvest taken as the value for compensation.

In sum, all of the usual methods of the valuer or appraiser are appropriate; whatever the method chosen, however, the fixing of value is not an easy process.

M.R. Grover, a partner in Grover, Elliott and Co. Ltd. in Canada, provided an entertaining paper on the topic of submerged land valuation, as true today as it was at the 1980 Annual Convention of the Appraisal Institute of Canada (Grover 1980). Having commented on the problems of valuations for rental purposes in a general context, he went on to say:

> Take away a big chunk of the evidence that might be available, replace with a fair amount of monopoly, and sprinkle generously with terms such as riparian, littoral and avulsion, submerge the whole thing below several feet of water, and there you have a recipe for water lot valuation. If you accept that a problem is no more than an opportunity in disguise, then by all means tackle the valuation of submerged lands.
>
> It has been said that a good appraiser has to sit on the fence and keep both ears to the ground. The valuation of water lots introduces an intriguing new dimension into that suggestion.

CONCLUSIONS AND FUTURE PROSPECTS

There is every likelihood that the pressures for leasing and licensing of marine areas will increase substantially as the decade of the 1990s sweeps into the 21st century. Environmental issues are going to intensify. Coastal marine areas are going to bear the brunt of many difficult, if not insoluble, problems, particularly if sea levels change in accordance with current expectations.

The limitations imposed by current leasing and licensing arrangements are significant in some cases, and in spite of improvement are likely to remain a problem for some time to come. The increasing acknowledgement of those seeking such interests and those granting them that they are dealing with a valuable property and that the legal title is a vital determinant of value and use should, however, ensure that greater specification of terms and conditions results. The state as landlord is likely to become more concerned to offer interests that will enable the maximisation of current returns and yet protect the reversionary interest. Where low-lying atolls such as those of the Marshall Islands have doubt cast over the prospect of their long-term future as the result of possible sea-level increases, it is perhaps not surprising that the emphasis has tended to be on current returns with serious consideration being given to proposals to accept the use of atolls as waste disposal sites. These longer-term interests are likely, however, to be increasingly lobbied for through the planning regime and environmental organisations. The South Pacific Regional Environment Programme's recent development as a funded regional organisation is already starting to undertake important work in marine areas.

The greater awareness of value has been commented on; the real pressure on the resource is likely to increase, thus forcing up values. These increases in value are likely to accentuate the realisation of those involved in marine areas that they are dealing with a valuable resource. There will be fewer and fewer "blue light specials".

The difficulties of valuation notwithstanding, the value attached by policy to submerged land is an important determinant of whether and how the resource is used. At its most simple, if marine areas can be reclaimed at minimal cost for the submerged land element, then they will be reclaimed in preference to dry land as offering a cheaper and more financially profitable alternative. Not only does this undervalue the interest granted in commercial terms, thus transferring a public resource to a private purse in an inequitable manner, it also undervalues the resource in a broader environmental context. The margins of the sea include some of the most organically prolific areas on earth; the substitution of a vertical sea wall for a gently sloping productive mudflat or reef has obvious implications.

The hydrological cycle -- whereby water is continuously transferred between the oceans, the atmosphere, and the land -- provides an example of a system crossing the boundaries of the land and the sea. It is difficult to envisage the sea returning to its erstwhile position as a free resource taken in isolation and all but taken for granted. It would be a positive step forward if the pricing and leasing of mining areas were to be seen in the future as an integral part of the system that determines the use of coastal and marine areas, rather than as an administrative chore. This would help to promote sound resource management and use in the context of a systematically based sustainable development rather than the simple plundering of a free resource.

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CHANGES IN LAGOON TENURE AND MANAGEMENT WITH THE DEVELOPMENT OF PEARL CULTURE IN MANIHIKI, COOK ISLANDS

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ABSTRACT

This paper examines the roles of traditional and modern fisheries management in the lucrative black pearl culture industry in Manihiki, Cook Islands. The causes of conflicts and dissension within the community, and with the government are discussed. Progress towards management through consultation and consensus is outlined.

The changes in tenure that accompanied the development of pearl culture in Manihiki occurred at three levels: small-scale tenure patterns evolved for farming and spat-collecting; there was increased control of the industry at the local Island Council level; and these changes have been incorporated into a new, national Fisheries Bill.

The issues surrounding traditional tenure and modern forms of ownership are examined. Entry must still be controlled to prevent over-exploitation. A management plan for the industry has been drafted to accommodate these needs.

INTRODUCTION

Lagoon aquaculture is expanding in the Pacific. Commercial seaweed culture is established in Kiribati and Fiji, for example, and subsistence and commercial giant clam culture is being developed. Pearl culture is established in French Polynesia, Fiji, and the Cook Islands, and is the subject of trials in several other countries. These developments all have an impact on established lagoon tenure and management systems. Conflicts inevitably result. An understanding of the forces of change at work may help to alleviate these conflicts.

Pearl culture on Manihiki represents a good example of how traditional systems can evolve to fit the modern framework. A review of the progress and problems in Manihiki might also be of help in solving similar problems elsewhere. In Manihiki, the management of pearl culture has evolved out of traditions, and meshed with the modern demands, rather than one replacing the other (Sims 1990 a, 1990 b; Newnham 1990). This evolutionary type of change could be fostered in other situations throughout the Pacific (Baines 1982, 1985; Zann 1985; Wright 1985; Teulieres 1990; Toloa *et al.* 1991).

The Manihikian pearl culture experience further reinforces the need for traditional management and tenure systems to be considered when planning and implementing lagoon-aquaculture developments (Johannes 1982; Sims 1990b). It also demonstrates that the traditional systems should not, and cannot, be protected from change.

The changes in Manihiki occurred at three levels:

changes in small-scale tenure patterns;

increased emphasis and control at the local level of management; and

formal structuring and ratification of the changes by incorporating them into a new, comprehensive Fisheries Bill at the national level.

BACKGROUND

The Cook Islands are located between French Polynesia on the east and Samoa and Tonga on the west. The Northern Group islands are atolls with few development opportunities because of their isolation and their limited resources. Their greatest asset lies in the natural stocks of black-lip pearl oysters (*Pinctada margaritifera* L.) found on Manihiki, Penrhyn, and the uninhabited atoll of Suwarrow. Manihiki has all of the best natural attributes for a resilient stock of oysters, and it has managed to bounce back after repeated bouts of over-fishing (Sims 1990a).

Pearl culture began on Manihiki in the late 1970s, when a small Australian venture was set up, only to fail during the early part of the 1980s. Local farmers then began setting spat-collectors and farming oysters, with the first seedings occurring in 1987. At the same time, a French Polynesian company set up a large pearl farm. The industry has continued to expand ever since. In June, 1991, in Rarotonga, 39,000 black pearls were presented at auction, with an estimated worth of NZ$6 million (about US$4 million).

In the Cook Islands, the term "traditional" often refers not to pre-contact traditions but rather to what has become established over the last 150 years of Western contact. By their nature, however, these traditions are still resistant to change. As an example, an open-access lagoon system was introduced to Manihiki and Penrhyn some 70 years ago, against strong local resistance. Now, some pearl shell divers will vehemently defend this open-access as their "traditional" right (see also Baines 1985: 47).

This fundamental resistance to change, this commitment to retaining what are modified or only recently established traditions is possibly linked to the threat that aquaculture and other commercial developments offer to the established power structure. In Manihiki, there was a long-running dispute between the Island Council, which favoured granting exclusive pearl-farming rights to a large French Polynesian company, and the central government's Ministry of Marine Resources, which sought to foster independent local pearl farmers (Dashwood 1991).

The Island Council and other conservative elements within the community were perhaps more comfortable with foreign-owned and foreign-controlled pearl farms dominating their lagoon because it was the least threatening option -- being less destabilising to the community as a whole. It may also have fitted some Manihikian expectations of what economic development was supposed to be: large-scale, capital-intensive, and requiring a high level of technical expertise.

Eventually, the gathering momentum was so strong that local pearl farms had to be officially condoned. Initially, the Island Council attempted to keep the activity largely confined to a "communal farming" basis. This was apparently an attempt to limit the scale of free enterprise, to secure the distribution to the established social and political structures, and to lessen the loss of controls to the central government. After further conflicts, however, permits were eventually extended to all farmers.

Flexibility is not inherent in traditions, but has grown out of the pressure for change. These pressures are evident in reviewing the changes that occurred in traditional and established tenure prior to the pearl culture developments.

CHANGES IN "TRADITIONAL" SMALL SCALE TENURE

Adaptations of traditional tenure

Pre-contact tenure systems were not well documented. Manihiki-Rakahanga appears to represent an especially interesting case. The islands are merely 26 nautical miles apart, and they were inhabited by one society. The people travelled from one island to the other as a means of conversation. Terrestrial resources were more abundant in the better soils of Rakahanga; fish were more readily available in the lagoon in Manihiki.

There was a division down the middle of Manihiki lagoon, between Tukao and Tauhunu. Clan-groups had access to parts of the lagoon as an extension of their land holdings, with jurisdiction over finfish and shellfish (Raymond Newnham, pers. comm.).

The establishment of the commercial pearl shell fishery reinforced the strict lagoon tenure. Even up into the early part of this century, permission was required before a diver could take pearl shell from another family's waters.

Tenure breakdown

In the 1920s, the New Zealand colonial authorities enforced the adoption of an open-access system over Manihiki and Penrhyn lagoons. This was the source of continuing controversy over many years, and led to considerable resentment of the colonial government. The opening and closing of pearl shell seasons were regulated by the central government. The locally-elected Island Councils were considered merely divers' representatives.

With self-government in 1965, the central government in Rarotonga assumed the role of external administrator of the pearl shell industry. With the development of pearl culture, however, there were several tentative calls for re-establishing traditional lagoon tenure rights, usually by people who had yet to begin farming.

This question was examined as part of the drafting process for the Pearl Oyster Resource Management Plan. The author conducted extensive consultations with pearl shell divers and farmers in Manihiki, Rakahanga, and Penrhyn on a range of issues concerning lagoon access and farming controls (Sims 1990c). The prospect of reinstating small-slices of "traditional" lagoon tenure, once it had been erased, was widely recognised as presenting a number of problems. These were :

i. Most Manihikians recognised that the long period of disuse and inadequate documentation of the tenure systems would lead to endless disputes.

ii. Manihikians also felt that the traditional 'mana' (authority) was too weakened; other forms of enforcement are necessary.

iii. The central government felt that small parcels of permanent tenure would make it difficult to administer and manage the industry, and to collect revenues (as governments like to do).

iv. Many farmers felt that the inequitable access to farm sites inherent in traditional lagoon divisions would be disadvantaging to some clans or villages (Sims 1990b).

v. Everyone (farmers, Island Councillors, and government) regards most long-erased traditions as inappropriate. They are not "theirs" anymore. Their "traditions" are those they have come to know. (See also Baines 1982: 290).

Recent evolution of tenure

As the pearl culture industry has developed, so have lagoon tenure concepts evolved where necessary.

Before pearl farming was introduced, "banks" of hoarded undersize pearl shell were the most active form of marine tenure in Manihiki. This practice was widely accepted, but not legally condoned. Divers established banks where they pleased, and enforced their ownership through an unwritten code.

In the early 1980s the first farmers laid spat-collector lines in the lagoon without Island Council permits (Dashwood 1991). Spat-lines only became regulated after the French Polynesian pearl farm began operating, and pressure on the farming areas increased. Issuance of these permits was not controlled -- a farmer generally went out and set his spat-line, then went to the Island Council office and marked its location on a map held there. Farmers were not limited to any length or number of lines. Indeed, the lines were not considered to confer

any rights to the farmer. Unofficially, divers were supposed to keep away from the lines to prevent pilfering, but this was not enforced.

Farm-area permits were initially granted only to those farmers with oysters seeded by the French Polynesian company, with the oysters then held on a communal farm area. Many of the more committed farmers were reluctant to place their oysters under a communal system, and accepted an alternative arrangement of cash or oyster exchange for seeding. Conflicts also ensued over the communal area demarcations, but permits were eventually issued to all farmers. Again, however, the Island Council generally approved the location of the individual farms after they had been established.

The farm permits were not leases, but merely granted permission to farm in a certain area. This was in compliance with the lagoon still being "owned" by the Crown, but with the 1982 Act which vested control of aquaculture activities in the Island Council. Nevertheless, a farm was considered a virtual lease, and the farmer held exclusive control over the area. Others could not dive or fish within the permit area, or within a 25 m buffer zone on any side. An interesting exception was that the farmer did not control the wild pearl oysters on the lagoon floor beneath his farm. These were still subject to Island Council regulations, and were protected from SCUBA divers working on their farms.

LOCAL EMPHASIS: ISLAND-CENTRED TENURE AND MANAGEMENT

The island is the inherent unit of lagoon management. The lagoon contains a single pearl-oyster population (Hynd 1960). In small islands of Polynesia, the island is also one of the strongest, most basic units of tenure and identity. The island is the level where resource ownership is most strongly perceived, and where management is most appropriate. On Manihiki, this has been re-affirmed and strengthened as the pearl culture industry has developed.

This is significant to the Manihiki situation because the people there were for a long time dis-enfranchised of their lagoon rights. Since the dissolution of traditional tenure, all management decisions had been made in Rarotonga.

The control of Manihiki's lagoon only reverted to Manihikians in 1982. There had been considerable resentment on the island over the exclusive permit which had been earlier granted to the Australian pearl company. After the company left in the early 1980s (largely because of the problems caused by such resentment), the government decided to hand the authority for pearl-oyster management back to the Island Councils. This was achieved by a Bill which referred specifically to pearl oysters and pearl culture.

Manihikian access

Today, access into Manihiki for pearl farming is limited exclusively to those of Manihikian descent. Long-standing residents of the island who are married to Manihikian

women must have the permit issued in their wife's name. Companies or partnerships must be wholly Manihikian-owned. Rarotongan businesses are thereby precluded from formal involvement in the industry. Farm permits also cannot be used as collateral for loans. This may slow the pace of developments in the early years, as farmers struggle to establish sufficient operating capital for farm materials and seeding-technician services, but it ensures that Manihikians continue to retain control of the industry.

Problems of access were encountered with returning migrants from Rarotonga, New Zealand, and Australia. They would sometimes obtain farm permits and stake a farm claim over an area before leaving Manihiki again. The Island Council moved to limit absentee permit-holders by imposing residency stipulations in the farm permit. It is noteworthy that Rakahangans are permitted to hold permits, as they are of the same line of descent, but they must also take up residence on Manihiki.

Need for entry limitations

The open-handed policy of providing permits to all Manihikians as their birthright is admirably generous, but cannot be sustained. Pearl-culture industries have demonstrated limits to growth. The French Polynesian, Australian, and Japanese pearl-culture industries have all suffered from disease problems and stock collapses because too many farms held too many oysters.

At some stage, the Island Council will have to begin to limit entry into farming, either by imposing a ceiling on the number of farm permits issued or by limiting the number of oysters held on farms, or both. This is perhaps the greatest challenge facing the industry on Manihiki, as the sense of island identity and birthright will come into conflict with the need for stability in the industry for the benefit of established pearl farmers.

Weakening of island-centred enforcement

The island unit has been weakened in one important way: continuing erosion of traditional authority has weakened communal enforcement mechanisms (Sims 1990b; Toloa, *et al.* 1991). Commercialisation is often disruptive of traditional fisheries management (Johannes 1982; Wright 1985; Sims 1990b). The process in Manihiki has been hastened by the dramatic increase in the value of the resource from pearl shell to pearl culture.

Pearl Shell Inspectors appointed by the Island Council are also considered politically biased, self-serving, and ineffectual. Manihikian divers and farmers prefer inspectors or other officials to be from other islands -- they would be viewed as more objective, and therefore better respected and more effective (Sims 1990c).

THE FISHERIES BILL: EVOLUTION, CONSENSUS, AND CONSULTATION

The weakening of communal enforcement has increased the need for formal incorporation of industry management into the modern legal framework. The evolving, island-centred management strategy has been used as the basis for a recent redrafting of fisheries legislation into one comprehensive Fisheries Bill (1990). It is explicitly stated in this Bill that each island's Lagoon is primarily the responsibility of the Island Council. The central government is to act in a purely facilitative manner, by providing advice, co-ordinating policies between islands, and establishing the legal back-bone to regulations.

Management Plan

Management Plans for each "designated" fishery lie at the crux of this legislation. The Plans are designed to integrate traditional perspectives with development initiatives, to reconcile local concerns with central government control, and to bring island-centred management under a national legal framework.

A management plan for pearl oysters is currently being drafted (Sims 1990c, and in prep.). Once completed, it will come under regular review in order to maintain an inherent flexibility. Drafting and review is a long and protracted process requiring consultation and consensus among fishermen, farmers, local authorities (elected Island Councils, and appointed Fisheries Committees), and the Fisheries Department and other government authorities.

CONCLUSIONS

Rigid traditional tenure and fisheries management present inherent constraints to commercial aquaculture development. And yet, aquaculture can strengthen and reinforce lagoon tenure and management systems. The traditional perspectives will then still be respected, even as they are being challenged and changed.

Both the tenure systems and the modern management regulations need to be flexible. Only then can the appropriate tenure evolve. If real, tangible benefits are recognised by the community, the system will be supported by them.

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COASTAL TOURISM IMPACTS: LESSONS LEARNED FROM PATTAYA

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ABSTRACT

Tourism is of great importance to Thailand's economy. The boom in the tourism industry has led to an increasing number of people visiting the country's attractions, which in turn has led to serious environmental problems. Pattaya, which is the best known seaside destination in Thailand, serves as a case example of the national phenomenon of over-development and poor planning. Even though Pattaya attracts tourists because of the natural beauty of its coastline, its environmental assets have been allowed to deteriorate to meet the demands of the fast-growing tourism industry.

The success of tourism is usually measured in terms of how many tourists visit and how much foreign exchange is earned. But no matter how successful Thailand's tourism industry may appear, there is a dark side to its development.

INTRODUCTION

Tourism is the largest generator of foreign currency in Thailand, having surpassed the earnings from major exports such as rice, tapioca, rubber, and tin in 1982 (TDRI 1986). The country's tourism income rose from 511.04 million US$ in 1980 (TAT 1984) to 4,880 million US$ in 1990.

Because Pattaya is the largest tourism destination in the country after Bangkok, its good reputation as an international resort has played a vital role in national economic growth. Pattaya is endowed with several advantages that supported its rapid growth. Its closeness to Bangkok, its good access, and the variety of its activities serve to maintain it as the top beach resort area.

Pattaya developed from a small fishing port to a major tourist resort in the brief space of 30 years, during which the sharply increasing numbers of tourists and associated large investment to meet infrastructure requirements led to disorderly land development and serious urban problems, which now threaten Pattaya's reputation. In this paper, I examine the past development of Pattaya, the resort's present situation, and future trends and plans in the light of the lessons learned at Pattaya.

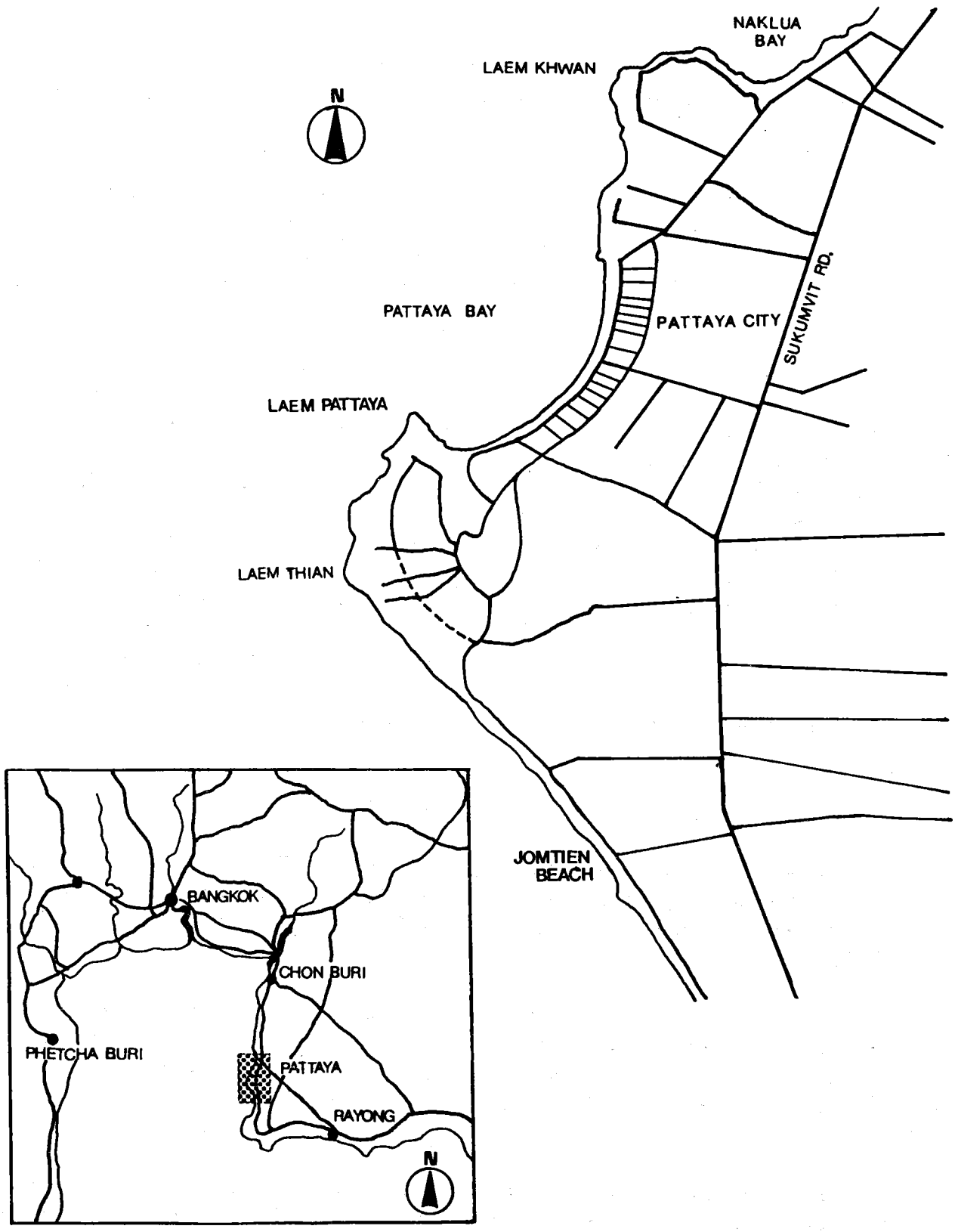

Figure 1 Location map of Pattaya

PATTAYA IN THE PAST

In the early 1960s, Pattaya was still a small fishing village, blessed with a sandy beach three km long, a calm sea, and tropical vegetation backing the beach. The spot had been used domestically by Thais as a recreation area for some years but came to be appreciated in the mid-1960s by the USA military personnel who were based in Thailand or who went there for rest and recreation during the Vietnam War. The first international-class hotel was established in 1964, and significant international tourism began in the late 1960s and early 1970s (Dobias 1989).

The number of tourists visiting Pattaya increased rapidly, it being estimated that 280,000 tourists spent at least one night in Pattaya in 1973, some 360,000 in 1974, and about 400,000 in 1975. Of these numbers, slightly over half are estimated to have been international tourists (JICA 1978). According to a survey carried out in 1975 by the Office of the National Environment Board (ONEB), in that year Pattaya had only 12 hotels, with 1,903 rooms, and many bungalows, mostly located farther inland, with a total of 359 rooms. Although the sea and beachfront remained acceptable for recreation in 1975, building encroachment was congesting the seaside, and sewage was contaminating the sea (Ludwig 1975).

By the late 1970s, degradation of beaches and nearshore waters was deemed a serious problem, resulting from unplanned and largely unrestrained construction of hotels and affiliated structures. Building laws had largely been ignored as hotels, bars, and entertainment complexes had sprung up to serve the increasing numbers of foreign tourists. By the early 1980s, the number of foreign tourists visiting Thailand reached two million and continued to increase steadily at an average of ten per cent per year (Bongsadadt 1989). Arrivals at Pattaya stabilized at 20 per cent of the total arrivals in Thailand (IMRSDS and K & E 1986). To meet the increasing demand, the number of hotel rooms increased in Pattaya at an annual rate of 8.1 per cent from 7,642 rooms in 1982 to 11,262 in 1987 (TAT 1984; 1987). In 1987 it was estimated that revenue generated by foreign tourists in Pattaya was equivalent to 31 per cent of the total revenue from the tourist sector in Thailand or 5.1 per cent of the value of Thailand's total exports (JICA 1990). Clearly, for decades tourism has been the mainstay of Pattaya's economy, providing many job opportunities and bringing income to the area.

PATTAYA TODAY

By 1990, Pattaya had over 20,500 hotel rooms, more than 60 per cent of them first class. Aside from the stimulus and effects of tourism, Pattaya's environment has changed because the city has been the focus of the Eastern Seaboard project, the Thai government's first major intervention for planning and managing the development of an emerging urban/industrial region, intended to decentralize development from Bangkok and vicinity. As the city has grown and there has been rapid industrial development in the Eastern Seaboard (ESB) region along the coast of Thailand's upper Gulf, pollution problems have caused a decline in the tourism industry, with the number of visitors to Pattaya decreasing from 1.72 million in 1988 to 1.69 million in 1989.

Coastline and beach

Pattaya's bay and beach are extensively used for recreation, including sunbathing, swimming, sight-seeing, boating, water skiing, skin diving, sport fishing, and coral viewing. The boats in the bay are mostly excursion vessels, speed boats, water scooters, and pedal boats. Over-utilization of the waters of the bay and an ineffective demarcation between activities has led to severe congestion, potential conflict, and a heightened risk of accidents.

At the south end of the bay, the "entertainment area" is made up of restaurants, bars, and night clubs built over the water on timber piling, an encroachment of construction beyond the natural shoreline that is interfering with normal coastal functions and leading to erosion.

Water pollution

Because of the lack of an adequate sewage system, water pollution and sea-bed pollution are so serious at Pattaya that sea bathing and diving are no longer possible. Pollution measurements taken in November 1988 in the bay water of South Pattaya revealed a most probably number (MPN) of coliform bacteria 160 times greater than the maximum safety level, and at North Pattaya the contamination level was 1.4 times greater than the maximum safety level, set for swimming at a coliform bacteria count of not more than 1,000 MPN/100 millilitres (ONEB 1989).

The major cause of pollution is overload of the treatment plant and an insufficient collection system. Over 200 hotels in the resort and many condominiums do not have to comply with official environmental standards. Some major hotels that do have water-treatment facilities keep them switched off to reduce costs. Pattaya City does not have an effective monitoring system for businesses and restaurants, which contribute to the waste-water problems.

Urbanization

The accelerated construction at Pattaya of restaurants, hotels, boutiques, insurance companies, and small shops has worsened traffic congestion, noise, and overcrowding until, in the eyes of visitors and hoteliers, Pattaya has become a "concrete jungle" of buildings crammed too tightly together. Water shortages have threatened the resort during the summer for several recent years as demand for water has rapidly increased. Garbage collection is inadequate to deal with all the solid waste generated within the city, and all natural drains and sewers discharge into the immediate sea.

PATTAYA'S FUTURE

Because Pattaya is the centre of the ESB region, attention has been focussed on the city's expansion and the growth of commerce and industry there. When the industrial

development of the ESB is completed, failure to control pollution problems could become disastrous for the popular seaside resort. In view of this situation, the Royal Thai Government decided to implement a water-quality plan (ONEB 1990) and to initiate a study that would lead to a master plan for development of the Pattaya area (JICA 1990).

Water-quality plan

In January 1990, the Cabinet took steps to solve Pattaya's water-pollution problem by approving plans proposed by ONEB through the Ministry of Science, Technology, and Energy.

Short-term aspects of the plans include:

-- Expansion of the present water-treatment facilities by the Civil Works Department, for completion during 1991.

-- Orders are to be issued by city authorities to ensure effective management of water-treatment facilities already present in large buildings, including hotels on the outskirts of Pattaya. Building owners, under the control of city authorities, will see that treatment is carried out.

-- Water quality in the Pattaya canal will be controlled, and the efficiency of the canal's drainage system will be improved by a project due for completion within two years.

-- Research is to be carried out on the possible impact on sea-water quality of the proposed water-treatment plans. An allocation of 1.6 million dollars was provided to the ONEB to complete this research within one year.

-- Cooperation will be encouraged between ONEB and City authorities to control sea-water quality in Pattaya Bay.

-- A special committee is to be established by the Interior Ministry to oversee the operations of the plans to solve Pattaya's water-pollution problems.

-- The Pattaya City Administration Act 1987 on water treatment is to be strictly enforced.

-- Water drainage from buildings and other operations are to be controlled in accordance with standards to be laid down by ONEB. The controls are to be implemented three months after the ONEB sets the standards.

-- Controls will be placed immediately on construction and the expansion of buildings.

-- Attempts will be initiated within six months by Pattaya City to solve the water-pollution problems caused by the trespass of Pattaya South into the sea.

Long-term aspects of the plans include:

-- Water-treatment facilities are to be installed within three years in buildings outside the range of City facilities.

-- The City is to assume control of water treatment in South Pattaya.

-- A monitoring programme of the City's water quality is to be implemented immediately in accordance with a plan by ONEB. A budget of some 16,000 US$ a year has been allocated for this operation.

Master Plan Study for the Development of Pattaya Area

This JICA plan has as its objective the drawing up of guidelines for developing a multi-function city with one focus on tourism and another on the function of Pattaya as ESB regional centre including commerce and business. Priority projects proposed for implementation include: South Pattaya land reclamation and development of port facilities; beach restoration and development of beach promenade; improvements to sewage treatment, rainwater drainage, and the canal; development of water-supply pipeline and treatment plant; improvements in sold-waste disposal; and road development. Goals of the plan include not only the acceleration of infrastructure development in order to catch up with urban development but also the conservation of an agreeable natural environment and the enhancement of the artistic and cultural environment. Acceptance of the plan is now being sought from several Royal Thai Government agencies before it is submitted to Cabinet for approval.

LESSONS LEARNED FROM PATTAYA

Pattaya serves well as an example of the national phenomenon of over-development and poor planning. In the case of tourism, Thailand has made good progress in gaining a share of the market, but now tourism promotion and expansion are blamed for natural-resource degradation.

Non-implemented tourism and environmental plans

Over the past decade, various documents have been prepared as a basis whereby the ONEB and the Tourism Authority of Thailand (TAT) could tackle environmental problems and tourism development at Pattaya. These documents have included environmental guidelines for coastal zone management (Ludwig 1975), the ESB environmental management plan (ONEB 1986), and a master plan for tourism development (JICA 1978). However, the ONEB and the

TAT lack the authority and jurisdiction to compel implementing agencies to carry out the recommended strategies (TDRI 1986; Kiravanich and Bunpapong 1989). Because the integrated, comprehensive plans have not been implemented, a serious imbalance has developed between the supply of and need for facilities, particularly infrastructure.

Impacts of tourism's growth

The rapid growth of tourism results in crowding and a lack of privacy on the beach, and excessive littering during peak-use periods. High-rise buildings dominate Pattaya while scenery and nature -- "green space" -- are diminished. The cost of living rises rapidly in the "concrete jungle", and local people sell their land and move out, giving way to tourism development. Social and cultural disharmonies such as crime and prostitution become more and more obvious. As a result of these changes, Pattaya faces an uphill battle to retain its lucrative share of the tourist market, a share that has declined from 23 per cent in 1983 to 16 per cent in 1988 (JICA 1990). The visitors clearly recognize that Pattaya is no longer a peaceful place, and its natural environment is so spoilt that it has lost its attraction. Many overseas travel agents worried by the pollution problem recommend other destinations.

Trends in the development of beach tourism

The history of tourism at Pattaya has set the pattern for the development of coastal resort tourism in Thailand. During the first stage, small bungalows owned by local people dominate the resort, which mostly attracts domestic visitors. As the tourism volume increases, the second stage begins when outsiders start buying land and establishing their own operations. During the third stage, hotels are constructed without being subject to proper zoning plans or environmental-protection controls. Most local owners are replaced by outsiders with superior management skills and financial backing. The economic benefits begin to leak out of the community.

During the fourth stage, most hotel and restaurant owners are outsiders, and more tourist income flows out of the area. Massive hotel developments adjacent to the shoreline spoil the scenery. Pollution of the sea becomes so serious that swimming is abandoned. During the fifth stage, which Pattaya is entering, the volume of tourists falls off because of environmental degradation. The other popular Thai coastal resorts of Phuket and Samed are now following Pattaya into stage four (ONEB and URI 1991), while Samui begins to move into stage three (White and Dobias 1991).

The need for assessments of environmental impacts, recreational carrying capacity, and limits of acceptable change

The Tourism Authority of Thailand has prepared master tourism plans for all well established coastal resorts in Thailand (Wongkomolshet 1988), but these plans have lacked adequate environmental assessment (EA) and have contained too little knowledge or concern with recreational carrying capacity (RCC) and the limits of acceptable change (LAC). The master plans focus mainly on development of facilities and services, an approach that cannot meet the objective of preserving pristine coastal scenery while at the same time catering to an ever-growing number of tourists.

EA of physical, social, and economic impacts on both macro- and micro-levels should be included in the earliest stage of tourism planning so that there is (1) clarification of the impacts of large tourism developments on the whole community, and implementation of appropriate city planning; (2) identification of physical constraints that might limit the potential of the locale to service tourism; and (3) mitigation of unacceptable degradation of resources during construction and operation.

Estimation of RCC should carried out prior to developing the master plan so that the potential of the locale to carry recreational activities and to absorb the pollution generated by the activities can be quantified (TISTR 1988). Formulation of RCC requires that consideration be given to absorptive capacity when only low technology is in use and also after high technology is implemented (Bongsadadt 1988).

A planning system including LAC is required so that consideration is given to what resource and social conditions are acceptable and what management actions should be prescribed to maintain conditions within those limits.

CONCLUSION

By the year 2000, the number of tourists visiting Thailand could reach 12 million, according to at least one estimate. Yet, in 1990, with only about three million tourists visiting Thailand, the existing degradation of the resources attractive to tourists was already causing concern about the future, as the case of the sea coasts of Pattaya illustrates.

What Pattaya needs now is environmental preservation, not further promotion and development. Deplorably, however, the course of development that happened at Pattaya is now being followed elsewhere in the country, as for example at Samed Island where too many bungalows and food vendors are destroying the beauty of many beaches. Each of the major coastal resorts is taking similar unsound steps along the road to increasing environmental degradation while the costs of rectifying the mistakes increase substantially as the resort enters each successive stage of development.

Success in tourism has usually been measured in terms of the number of foreign visitors and the amount of foreign exchange they bring into the country. But no matter how successful Thailand's tourism is by these measures, there remains a dark side to the development. The Pattaya experience shows that Thailand cannot any longer afford, economically or environmentally, to be complacent about the exploitation and destruction of its natural resources for immediate economic gain. Instead, if the country is to maintain economic benefits from coastal tourism, it needs to commit itself to rehabilitating the resource base.

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ARTICULATING ATTITUDES AND ASSETS FOR SUSTAINABLE DEVELOPMENT, MAROVO LAGOON, SOLOMON ISLANDS

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ABSTRACT

Marovo Lagoon is an isolated region of Solomon Islands where people maintain a largely traditional subsistence lifestyle. Marovo villagers who participated in 1987 in a survey of environmental attitudes and awareness expressed the desire to maintain their way of life and the existing levels of community control in decisions over the use of natural resources. The thesis of this paper is that existing environmental and socio-economic conditions in Marovo suggest that benefits are to be gained by a small-scale, slow-paced rate of economic development guided by the desires of the Marovo community, and underpinned by principles of sustainability.

INTRODUCTION

In June and July of 1987 a brief survey of environmental attitudes and awareness was conducted in fourteen villages in Marovo Lagoon, Solomon Islands (Figure 1), as part of the "Marovo Lagoon Resources Management Project", which was coordinated through the Solomon Islands Ministry of Natural Resources with support from the Commonwealth Science Council's South Pacific Region Coastal Zone Management Programme. The programme's objectives were:

- to define and describe the resources and environment of Marovo Lagoon and its islands;
- to describe the various development activities under way in the lagoon area, and the actual and potential threats to the resource base;
- to identify the development of a local community capacity in assessment, monitoring, and sustained use of lagoon resources;
- to build on appropriate traditional arrangements to devise a coastal resource management regime for the area;

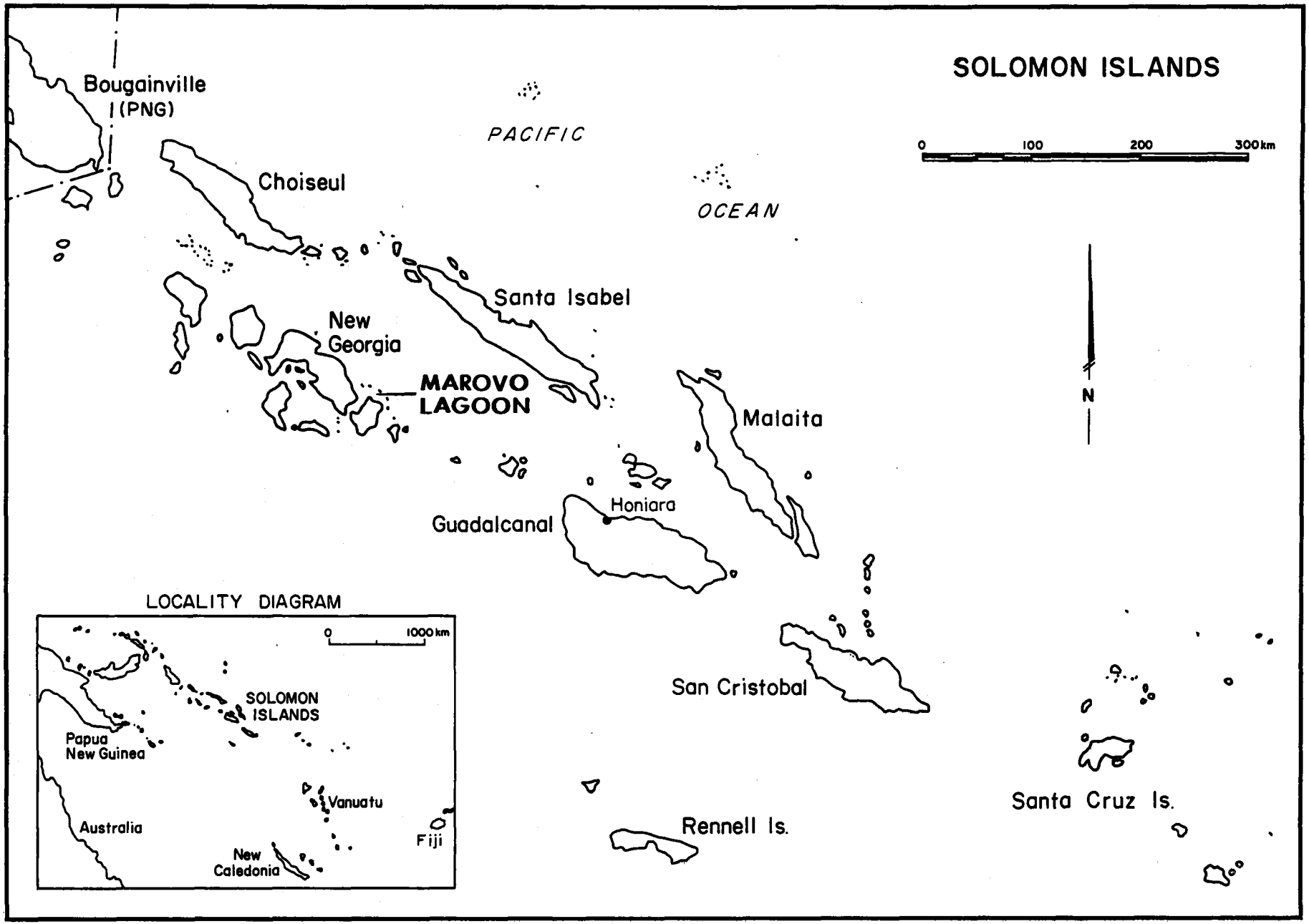

Figure 1. Solomon Islands and the Location of Marovo Lagoon.

- to make available knowledge and understanding gained from the project to other communities and agencies of Solomon Islands and other countries of the South Pacific island region.

The argument of this paper is that Marovo Lagoon is an ideal locale in which to operationalize the concept of sustainable development. The World Commission on Environment and Development (1987: 8) concluded that "humanity has the ability to make development sustainable -- to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs." Although this definition may be criticized for its imprecision, the Commission's recognition that sustainable development "must rest on political will" is most significant, for it affirms that the attainment of these lofty goals, while not impossible, is improbable without considerable consensus, capital investment, and coercion.

Brookfield (1988, 1990) has made a significant contribution to the promotion and clarification of the concept of sustainability, including its implications for economic development and environmental management of small islands. He unabashedly and quite rationally locates environmental management at the center of the issue of sustainability because "the environment is the most important of all social goods" (Brookfield 1990: 23). He, like the Commission on Environment and Development, pragmatically advocates neither unbridled growth nor a steady state, recognizing that economic growth is necessary to improve the condition of those millions of humans now trapped in poverty.

In elaborating on the contribution of Pearce and Turner (1990), Brookfield (1990: 13) states that sustainable development "involves maximizing and optimally distributing the net benefits of economic development, so far as these can be achieved while establishing and reaffirming the conditions of security under which the services and qualities of natural resources can be maintained, restored or improved in the foreseeable future." The formidable challenge, therefore, is to erect social structures that can ensure that dysfunctional environmental (see Blaikie and Brookfield 1987) and social (Bookchin, 1990) processes may be readily identified, and remedies applied to prevent long term or irreversible environmental *and social* degradation. Although, as Brookfield (1990: 19) argues, much hope and capital investment will need to be placed in the emergence of an ecologically responsible and productive "diversified post-modern agriculture", the deficit really lies in the absence of political will to establish transformative structures for operationalizing existing and ecologically functional agricultural systems.

Brookfield (1990) specifies how the general goal of environmental sustainability may be attained, drawing upon Perrings (1987) and Solow (1971), who have suggested that management for sustainability of the natural and manmade environment will demand: (1) a political economy embracing a principle of common property; (2) an interventionist state enlightened in ways of ensuring private accountability and encouraging private initiatives for achieving sustainable development; and, perhaps most importantly, (3) a strong civil society knowledgeable about and supportive of measures necessary for maintaining environmental integrity. Although this is a contentious proposal, which may be incompatible with dominating ideologies in many parts of the world, I hope to demonstrate how Brookfield's proposal might be compatible, and necessary, in the Marovo setting.

MAROVO LAGOON: PROSPECTS FOR SUSTAINABLE DEVELOPMENT

The harmful effects of global material production and consumption are increasingly thrust upon the underdeveloped world as the developed world exhausts its own stock of natural resources. Low-impact tribal subsistence economies in South America Southeast Asia, Africa, and the Pacific are being transformed by the extractive industries of mining and logging, which destroy subsistence modes of production and draw once isolated and largely autonomous societies into the orbit of global capitalism. Invariably, these peoples lose their high degree of control over resource-use decision-making in the changed context of a diminished resource base and growing economic dependency (Bodley 1988; S. P. Juvik 1987). For small, underdeveloped and peripheral countries the cost of incorporation in the global economy is likely to be increasing relative deprivation and environmental degradation. Because Solomon Islands is still relatively autonomous -- politically and economically -- a pressing task for local individuals is the identification of existing characteristics of the society that can mediate between the negative effects of Western over-production and the desires of local communities.

Marovo: Society and Economy

Marovo Lagoon is an area of outstanding natural beauty. The Lagoon extends over 8,000 km^2 adjacent to New Georgia and Vangunu Islands and contains some 200 islands, islets, and cays (Figure 2). The Lagoon is a vital part of the region's resource base, which is being extensively exploited both for local subsistence needs and for commercial baitfish for the tuna fish industry operated by Solomon Taiyo Ltd., which is jointly owned by the government and Japanese interests. Because of its scenic beauty and its scientific values, the entire lagoon has been proposed for inclusion within the UNESCO World Heritage Areas (McKinnon, 1990).

Although the lush terrestrial and marine environments of Marovo appear rich in timber, minerals, fish, and other land and lagoon resources, there is an absence of scientific appraisal of the natural endowment or of the human carrying capacity of the area. Nor is the complex system of relationships and interactions between Marovo society and its environment and resources well understood (but see Hviding 1988).

Marovo society is traditional in the sense of being relatively unimpacted by western technology. Each of the small coastal villages of Marovo is home to a clan group (*butubutu*) of 200 persons on average. Each *butubutu* is an autonomous group which enjoys ownership and control over considerable land and lagoon areas (see Hviding 1988 for land/lagoon ownership arrangements).

The regional population of approximately 8,000 persons is a small fraction of the national total of 285,176 enumerated at the 1986 Census (Solomon Islands Government 1989). The population density in Marovo is estimated to be close to six persons per km^2 (not including lagoon and reef areas). The low population density has fostered the perception, at least in the villages included in this study, that there is an abundance of land resources, in particular

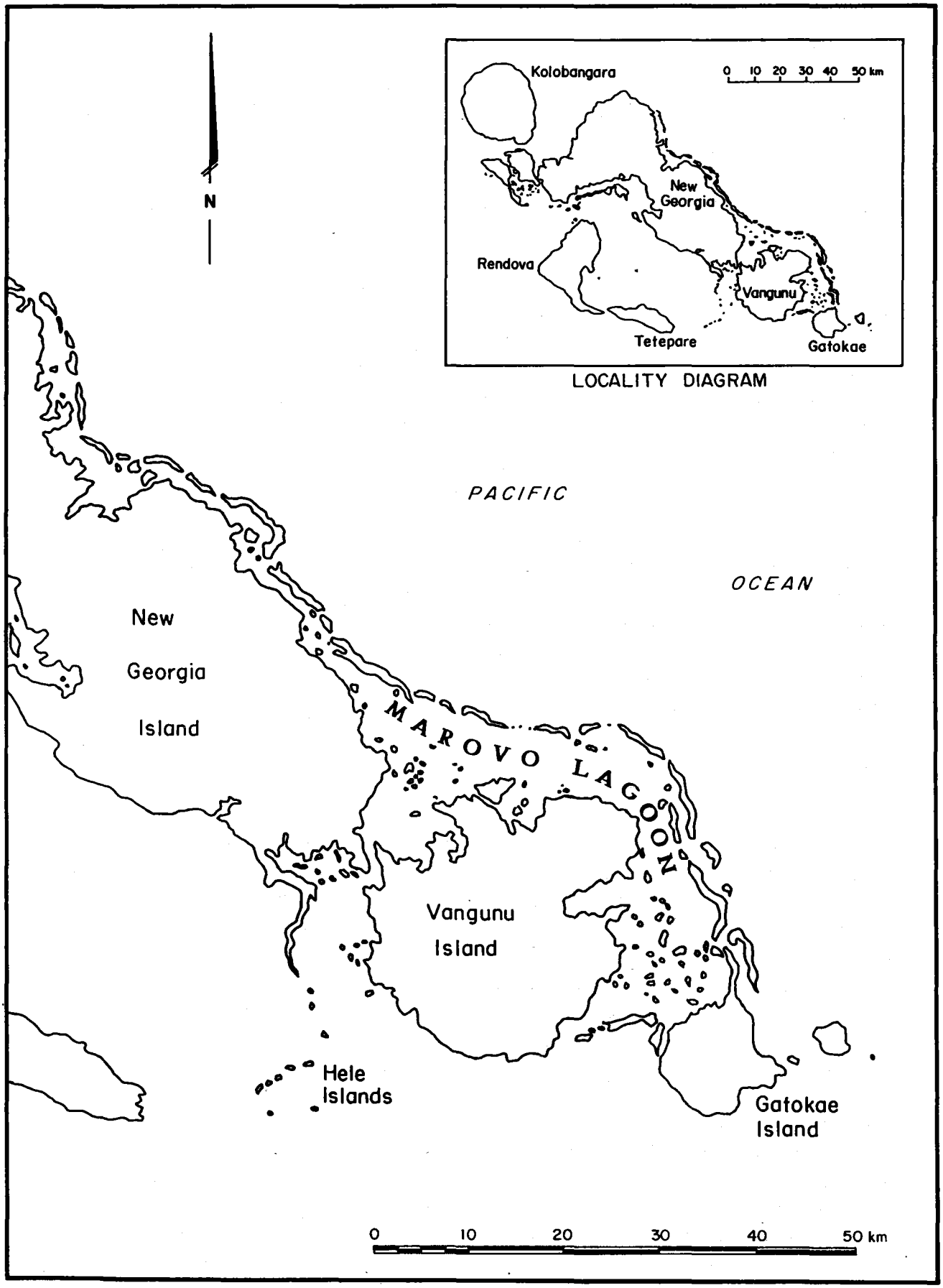

Figure 2. Marovo Lagoon.

particular plenty of good garden land for future generations (data from 1987 field survey). However, with a population doubling time of less than twenty years (natural increase is over 3.5 per cent per year) rapid buildup of demand for land could soon present necessities for human adjustment as the fixed resource base becomes stressed. Obviously any strategy for sustainable development must put as much emphasis on controlling population growth as on managing environmental resources.

The traditional economy is one of low-intensity subsistence shifting cultivation with occasional surplus for market exchange. Private employment opportunities are non-existent within the villages studied so that individual entrepreneurial talent is the basis for any cash earnings. Cash is obtained from the sale of handicrafts and surplus food (primarily sweet potatoes). Copra, while potentially the most important cash crop in the region, is generally underproduced, for the most part because of low prices and lack of transport. (Throughout the 1980's copra production in the Marovo region as a whole was low, with between 10-19 per cent of households said to be producing copra at the time of the 1986 Census).

The environmental stresses resulting from the self-sufficient subsistence mode of production are low at present, permitting an adaptive rate of change in the physical environment and the society. This is because a shifting-cultivation regime, in a sparsely populated area, allows enough time for restoration of the productive capabilities of the land after use in food production (Nye and Greenland 1960). Thus, for a start, the rate of future economic change in Marovo should be moderated to avoid the alienating and dislocating impacts of what Harvey (1990) terms "time-space compression" produced under conditions of rapid socio-economic change. Second, slow-paced, small-scale economic development will best ensure the kind of community development that is a necessary concomitant to the retention of the kind of mastery over resource-use decisions that is so highly valued by Marovans.

People in Marovo, young and old, express a need for money. But they are also acutely aware that most of their material needs can be obtained from the extensive land and lagoon areas to which they have access as members of a *butubutu*. Furthermore, the absence of private employment opportunities in Marovo has not stimulated any widespread village support for new government or outsider development proposals, at least in the villages studied. To the contrary, the attitude of the majority of villagers reflects the fear that development "will destroy our custom ways", and for this reason villagers generally express anti-development sentiments. The opinion that "money is bad" and development brings "dead money" was voiced by a group of elite professionals (government workers, health-care professionals, and businessmen) interviewed in Honiara. Dead money may be compared with the Nietzschean concept of creative destruction, the process of development that even as it creates capital destroys the environment and the individual's participation in the environmental transformation process. The individuals who express these attitudes are not out of touch with the realities of village life, for they frequently return on leave to their home villages in Marovo. Table 1 summarizes the development preferences expressed by this elite group of Marovans; and their attitudes are no different for the majority of villagers (n=386) who participated in the study.

Table 1. Marovo Non-Resident Elite Preferences for Marovo Economic Development (n=10)

Type of Development	Scale of Development % of Respondents			Development by Whom % of Respondents		
	Small	Medium	Large	Local	Govt.	Outside
Cattle Projects	20	10	40	0	0	0
Logging	70	10	0	70	0	10
Fishing	50	40	10	90	10	10
Mining	40	10	10	40	10	20
Tourism	30	10	10	30	0	0
No development	0	0	0	0	0	0
Other*	10	10	10	20	0	10

* Other includes manufacturing

Resource Constraints

Whether economic development in Marovo be slow-paced, small-scale, or some other style, it is imperative that it be based on an environment-sustaining strategy that includes a harmonious relationship between ecosystems and socio-systems. The harmony is required because (1) the land-lagoon ecosystem is fragile; (2) the socio-system is almost entirely dependent on subsistence food gardens and is likely to remain so in the foreseeable future; and (3) the absence of any institutionalization of land tenure arrangements creates a high degree of uncertainty that is bound to result in conflicts amongst insiders as well as between Marovans and outside investors. Other constraints on development relate to the underdeveloped state of social capital (such as in education and sanitation) and a near total absence of physical infrastructure.

Fragile land-lagoon ecosystem.

Ecosystem fragility must be seen as a serious limiting factor in the future economic development of Marovo Lagoon. "Fragile" as used here refers to the range of arguments that assumes environmental vulnerability and susceptibility to degradation because of small size, the possible existence of unique or rare biological species, humid tropicality, and so on. More specifically, the argument in support of the fragility of the whole Marovo Lagoon ecosystem

derives from the interplay of the physical structure of the land-lagoon system plus the complex structural and functional relationships between the land-lagoon ecosystem and the social system. The heritage of Marovo's people is intimately tied to land *and* lagoon, and their future economic security and cultural identity are dependent on the maintenance of a careful balance between resources use and preservation.

Both McLean (1980) and Brookfield (1988) have emphasized that small high islands, typically within in the humid tropics, are extremely susceptible to erosion because they have small catchment areas so that a high proportion of eroded material is usually carried to receiving waters -- which in Marovo is the nearby lagoon. The processes of mass wasting and overall land degradation are exacerbated when the soil's vegetative cover is removed by agricultural, logging, or mining activities. Water quality then becomes degraded from soil load and debris carried in streams and surface runoff. For any of the extractive industries, the magnitude of the environmental insults in the Marovo land-lagoon ecosystem is going to be dependent on the production/extraction process employed. Agriculture that is dependent on large quantities of fertilizers and pesticides will quickly result in eutrophication or toxic contamination of near shore lagoon waters and mangroves; while clear cut logging exposes soil to erosion and destructive physical alteration (Carpenter, 1983).

Juvik and Juvik (1984) have taken the argument about vulnerability of island ecosystems even further by stating that for many small high islands in the tropics the "multiple use" strategy of resources management may be entirely inappropriate due to limited size of some species habitats and the inability of certain ecosystem components to prevail in the absence of refugia and pressures exerted by multiple users.

Pearce's (1990) account of logging in Sarawak (with a climate similar to Marovo's) emphasizes that the "hit and run" nature of logging enterprises, even well-managed projects, causes irreparable damage results to vegetation, land surface, and traditional economy of the tribal societies dependent on forest resources. Pierce's account is illustrative of the gap that exists between the theory of sustainable forestry and the reality -- at least in humid tropical areas -- for he further observes that while sustainable forestry requires selective cutting, massive destruction takes place in all but one per cent of the world's tropical forests. It is not irresponsible, therefore, to say that there "will always be a large percentage of tropical forests in which the goal of sustained yield probably will not be attainable" (Budowski 1988: 34). Likewise, it is not irresponsible to conjecture that large areas of Marovo are unsuited to logging especially since people and the environment in such an isolated setting would be hard pressed to rebound from any form of "hit and run" economic activity.

Protection of Marovo food production system.

Marovo people like their present way of life and desire to maintain their traditions as far as possible. To a large extent they can if they so choose. Estimating land requirements for subsistence farmers is fraught with difficulty if for no other reason than that carrying capacity shifts with changing technology and application of human artifice. But a kinship group or

village or even a family needs a considerable area of suitable forest land in order to grow their subsistence food requirements and allow for proper regeneration of the forest. In turn, this requires the identification of clearly defined territorial boundaries that exclude outsiders from food garden sites. Even if we assume that in Marovo dependence on subsistence food gardens will lessen in the future, at present there is a dearth of knowledge concerning the distribution and productive potential of agricultural lands. The proper assessment of this resource is urgently needed in order to avoid foreclosure of future agricultural options.

In Marovo harmful land-based production processes will also threaten village drinking water quantity and quality. Since the Marovo population is entirely dependent for potable water on surface flow, potential contamination of streams or change in stream flow regimen, as described in Carpenter (1983), would have serious negative impacts on village life.

Institutionalization of land tenure.

Laissez faire land use within an informal traditional land tenure system is likely to emerge as one of the most problematic and explosive areas of resources management in Marovo (McKinnon, 1990). Only when land tenure becomes formally agreed upon by Marovans and guaranteed through government legislation can some of the potentials for conflict within and between the range of "other sides" described by Hviding (1988) be substantially reduced.

PLANNING A SUSTAINABLE FUTURE

Clearly, there are some compelling reasons to be sympathetic to the anti-development stance exhibited by the majority of Marovans participating in the attitude-and-awareness survey. If a framework for sustainable development is to be established in Marovo, it will require the specification of the roles of key players whose actions or inactions can affect the future integrity of Marovo economy, society, and physical environment. The interaction and interrelationship between players at different levels of the decision-making hierarchy also need to be identified and circumscribed to the degree necessary for the achievement of sustainability.

Role of the State

The Solomon Islands economy is relatively underdeveloped and dependent on outside owners of capital and technology. There are pressing needs within the society for infrastructure and for a range of expanded public health and welfare services; all of which point to the need to increase revenue-generating activities. These overarching requirements of the economy point to the necessity for Government support of resources development by outside capital investors. Given this reality, to take a stance for ecologically responsible economic development is to give voice to a minority position. But, as with any minority position, the advocacy and intervention

of the state (international, national, or local) will be crucial to secure the principles or corrective actions demanded by the local community. Therefore, without strong advocacy by Government, Solomon Islanders in Marovo, or elsewhere in the country, cannot be assured the necessary structures of support to ensure future environmental sustainability. The situation presents a problematic whose resolution calls for careful management of the pace of change in order for Marovans to build trust in government and in outsiders, including expatriate outsiders and outsiders from neighboring villages and provinces. Here, Baines's (1989: 273) assessment of the development dilemma confronting Pacific Island governments is pertinent to the situation in Marovo. His perception of the dilemma is summarized in the questions he asks:

> To what extent can the traditional systems accommodate further change? Will serious efforts be made to adjust approaches to economic development so as to ease those disruptions to traditional resource-management systems which are eroding Pacific Island societies themselves?

Until there is sufficient information to answer these questions satisfactorily, some interim policy initiatives directed at sustainability for Marovo include:

1. Evaluation of land suitability for various land uses; and safeguarding of valuable agricultural lands.

2. Specification of development guidelines appropriate for initiatives emerging from inside and outside Marovo.

3. Implementation of appropriate programmes for community development, including the public information and participation that are vital to build trust in government and others and to achieve social cohesion. (The corollary of this is that an informed and discerning public can more wisely select options appropriate to their own needs.)

4. Support for individuals who may wish to take advantage of opportunities for family planning.

5. Clarification and formalization of the existing land tenure arrangement.

6. Surveying and recording of *butubutu* property boundaries.

Although this list of issues in need of government intervention is by no means exhaustive it is sufficient to demonstrate the relative political and economic isolation of Marovo society. And it is for this reason that it is impossible to overemphasize the potentially disruptive effects of changes, the pace of which are revolutionary rather than evolutionary.

The elaboration of development goals and specification of policies and strategies for their achievement must remain the prerogative of Solomon Islanders, and more specifically, in

this case, of Marovans. In this regard two conclusions drawn from the literature on rural development are instructive. The first is taken from a recent report of The World Bank's experience with rural development projects. In a 1988 report, World Bank reviewed the performance of rural development projects funded (in the amount of US$157.2 billion) from 1965 to 1986. The results from only 32 per cent (184) of 574 projects funded over the years indicate a high rate of failure, based on which the Bank indicated a large number of "lessons learned" (World Bank 1988: xvii-xx). Many of these lessons are apropos to future economic development activity in Marovo; the lessons most relevant to this discussion are:

1. *Scale*: The World Bank's experience with rural development indicates that a focus on smaller scale projects might have achieved more stable results in the long run. Small-scale development projects are likely to be more adaptive in Marovo society and environment for the ecological and socio-cultural reasons indicated above.

2. *Government commitment*: The World Bank review concluded: "It is now clear that rural development projects were more successful (as were other projects) when government commitment to the projects was strong." They urge that full commitment of a government to a project should be assured at an early stage. In addition, they found that legal covenants in projects have proved to be an ineffective substitute for genuine commitment. The results revealed how critical a role government commitment plays in successful rural development; when national policies are absent, the ability to sustain even successful projects is doubtful.

3. *Involvement of impacted local community*: Representatives of potential beneficiaries of development projects should be involved more closely in project identification and design from the start to ensure that project objectives are fully supported by beneficiaries. A corollary of this finding is that expatriate technical assistance is a poor long-run substitute for local capability, even if the external expertise seems to enhance efficiency. A shift to reliance on local rather than overseas expertise will necessitate the development of human capital rather than swift implementation of physical projects..

I draw the other broad conclusion from the literature on the social impact of rural development planning in the Third World (Derman and Whiteford 1985) and emphasize the concept of "growth with equity" (Schwartz and Eckhardt 1985: 89), which expands the argument in (3) above. It advocates empowerment of rural communities through some form of client control and participation.

> The literature indicates that what begins as the empowerment of local groups and small communities readily becomes negative structural penetration, institutional transformation, and increased inequality. Local level empowerment by itself is inadequate to realize the intended goals, and it must be combined

> with some form of regional heteronomy, some structure that mediates between the central state institutions and small communities so that members of the latter can participate in projects without self-defeating consequences (Schwartz and Eckhardt 1985: 89).

Schwartz and Eckhardt draw attention to Friedmann's (1981) "agropolitan district" as a good illustration of the sort of "mediating structure" needed to confront the creation of inequality and other destabilizing effects of political-power relations and elite domination. In the main, the primary goal of a mediating structure, however constructed, is the achievement of economic self-reliance and efficient economic planning through a political authority that is genuinely "capable of speaking for and acting on behalf of local people" (Friedmann 1981: 248-249). This assumes, however, that at the local level there is clear agreement of which actions must be taken, and what strategies are capable of achieving the conditions sought by local residents. Although Friedman's agropolitan district may be more appropriate to the Asian rural development he is discussing specifically, the general idea of a regional political authority with the explicit role of mediating negative impacts of structural penetration could well be adapted to the local Solomon Islands situation. This assumes that there is clear understanding of what actions must be taken and which strategies are capable of achieving the conditions desired by local residents.

Role of Citizens

Marovo society possesses social relations that can greatly advance the achievement of sustainability goals. The traditional values of reciprocity, and consensual decision-making should predispose village people towards implementation of structures to achieve equitable distribution of benefits from resources development. Similarly, retention of existing common-property principles will fulfill yet another important requirement of environmental sustainability as constructed by Brookfield (1990) and Perrings (1987: 160-167).

On the other hand, changes will also be necessary since stasis or a steady-state economy can be seen as counter-productive to self-sustaining "independent" economic and social development. It will be the responsibility of Marovans to agree on the pace of change adaptive for their social and physical environment. The prospect of achieving the goals set by Marovo people presupposes a state of continued and enhanced participation in decision-making for resources development. In sum, the citizens' role will be to work hard to actualize desires, which includes realizing the means to power as well as initiating and enhancing local entrepreneurship.

Role of capital investors

In expressing their preference for an autonomous Marovo society, Marovans have put themselves at variance with the conventional procedures of investors. It has been the nature of profit-driven, resource-extraction industries to be large-scale, to use high technology, and generally to disregard community views. These approaches have alienated local communities like Marovo from natural-resources developers and the State and have reduced access to their own

resources. The rejection by the today's Marovans of the consequences of the conventional development *process* is clearly demonstrated by data obtained on villagers' attitudes towards development of logging, mining, and tourism on their lands. Over 82 per cent (82.46%) of adults surveyed (n=213) said they "would not be happy" if a company wants to do logging on their *butubutu* lands. There is, however, much less opposition to tourism development since only 60 per cent of the adult respondents were opposed to tourism, with 20 percent agreeing that tourism would be "a good business for Marovo". These data give the developer an opportunity to search for the underlying causes of the attitudes, and to adjust future behavior as indicated by the findings. The product of this process would be a more sensitized investor-partner who is involved in overall community development. The dividends of this ought to be increased community trust and cooperation.

It appears that for the foreseeable future, developers wanting access to Marovo resources must be willing to conform to the wishes of the resource owners. For a start, developers will need to limit the scale of their projects and adopt technology that is appropriate to the maintenance or enhancement of the land-lagoon ecosystems and that is constructive, rather than deconstructive, with regard to the integrity of Marovo culture. Marovo society already possesses a mechanism for ensuring developer responsiveness in that the basic land resource has not been alienated from the traditional owners. Land owners can therefore withhold approval until their demands are agreed to by the developer and sanctioned by the Government. A weakness in this arrangement, quite apart from that of enforcement, is that there is the possibility, and indeed reality, of local elite domination, manipulation, and control of land-use decisions. It is necessary, therefore, to find ways to disarm this threat -- a process that may require State intervention in the form of regulatory guidelines that specify procedures for validating consent agreements obtained by investors.

CONCLUSION

In an age when terms like "post-modern", "post-industrial", and "over-developed" are apt descriptors for societies experiencing crises of high unemployment, poverty, resource depletion, and waste buildup, the existence of pristine places, and self-sufficient (or nearly self-sufficient) societies like Marovo present a wonder and a challenge. The challenge may lie entirely in protecting the existing natural environment and enhancing the integrity of the socio-cultural system. The villagers surveyed in Marovo do know what they want to achieve and, as expressed, their desires are entirely consistent with the ideals of ecological sustainability. Therefore, all that is needed is the cooperation of the national and international communities in recognizing how decisions made outside of Marovo can foster or impede the attainment of sustainable economic development in Marovo.

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INTER-REGIONAL CO-OPERATION IN INTEGRATED COASTAL ECOSYSTEM MONITORING

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ABSTRACT

Studies of marine ecosystems in the East Asian Seas are gaining better integration regionally because of efforts to standardise methodologies for monitoring. Success has been achieved in terms of quantifying the community structure of coral reefs, mangroves, sea grass beds, and other shallow-water ecosystems. Inter-comparable data (between countries) are now available and could yield the first insight as to the unifying characteristics of these habitats located in the East Asian bio-geographic region. Current attempts focus on the monitoring of functional aspects with the same objective of uncovering a possible unifying theme (or themes) in terms of ecosystem function. Monitoring ecosystem function has an added advantage in that community metabolism is known to respond more quickly to environmental forcing than do structural components of an ecosystem. This then could provide a more effective monitoring system for environmental stress, including pollution. The East Asian Seas experience could indicate directions for inter-regional cooperation in integrated ecosystem monitoring, especially where the early detection of pollution stress is essential.

INTRODUCTION

The attempt to integrate coastal ecosystem monitoring by standardising methodologies has a relatively long history. An example comes from coral-reef studies, where a notable step was the compilation by prominent researchers of widely used techniques (as of that time) into an easily accessible compendium (Stoddart and Johannes 1978). This volume served as a basis for further refinements and recommendations of various methods in succeeding years.

The case for evolving a more universal system of coral-reef monitoring by combining the best elements of different methodologies (if at all possible) has been elaborated several times in the past (*e.g.*, Gomez and Yap 1984, 1986; Unesco/ROSTSEA 1984). In such efforts, serious attention was paid to the ability of a particular technique to convey the "true" picture of the state of an ecosystem, but also to the costs and levels of convenience involved.

The attempts mentioned above are apparently meeting with success, since ecosystem-monitoring programmes have certainly transcended national boundaries (Gomez *et al.* 1981) and

assumed more regional dimensions. An example is the recent establishment of the Caribbean Coastal Marine Productivity Program (CARICOMP), which has the following objectives (Birkeland and Eldredge 1991): (1) long-term ecosystem monitoring and research; (2) education and training; (3) central data management and exchange; and (4) application of research to management. Plans are now being laid to develop a similar programme for the Pacific basin, "PACICOMP" (C. Birkeland, pers. comm.).

My paper describes experience with respect to a relatively successful regional programme in Southeast Asia, the ASEAN-Australia Marine Science Project "Living Coastal Resources". The project is funded by the Australian International Development Assistance Bureau (AIDAB). Joint efforts by scientists from Australia, Indonesia, Malaysia, the Philippines, Singapore, and Thailand have led to the publication of a methods manual (Dartnall and Jones 1986), which currently serves as the guide for region-wide investigations of the structure of coastal nearshore ecosystems such as coral reefs, mangrove forests, sea grass beds, and certain soft-bottom environments. A package of standardised techniques covers the range of field surveys all the way to data storage and analysis. This manual is currently being revised and a second edition will soon be published.

The Southeast Asian-Australian experience might show the way for efforts aimed at a wider geographic area. In other words, the next logical step is to widen the coverage from the regional perspective to a network of inter-linked regions. But as with any undertaking, there must be a reason why inter-regional attempts at integrated coastal ecosystem monitoring are desirable, and this must be expressed in clear-cut objectives. One possible reason would be the need to elucidate natural patterns in structure or activity that may be universal, *i.e.*, have global significance. Such a finding would have great value for management as well as for prediction. In this day and age, when the planet is everywhere vulnerable to human impact and technology, and global change has become an immediate reality, this is a compelling enough reason.

MONITORING ECOSYSTEM STRUCTURE

The initial phase of the ASEAN-Australian project "Living Coastal Resources" is completed; it saw the development of methods for evaluating the structure of the most important coastal and nearshore ecosystems of Southeast Asia: coral reefs, mangroves, sea grass beds, and soft bottoms. During the project, representative sites throughout the region have been investigated using standardised techniques as compiled in the project manual edited by Dartnall and Jones (1986).

Field Investigations

Coral reef ecosystems. Reefs are visited for the purpose of either a broad survey to gain an initial impression, or monitoring over a relatively long period of time to gain insights on stability and change. For purposes of broad surveys, the project has made use of transects laid parallel to the shore at selected depths. The transect length and number of replicates depends on the characteristics of a particular reef and the demands of statistical rigour, and this has

been largely a matter of judgement by the investigator concerned, although the manual specifies some minimum criteria.

The coral reef benthos is characterised not in terms of species, but in terms of "life forms" or physiognomic-structural categories. This approach achieves two purposes: the need for highly specialised taxonomic skill is done away with, and structural attributes are quantified, which may yield the most sensitive information with respect to environmental forcing, such as growth form, cover, and type of substrate. Broad taxonomic categories are of course included.

For coral reef monitoring over the long-term, permanent quadrats at selected sites are recommended. Growth, mortality and recruitment are recorded, as is any type of damage that may be recognised. In this way, the most important aspects of population dynamics and environmental change are documented, and used to elucidate long-term reef dynamics.

Coral reef fish are described and quantified as an integral component of the reef ecosystem. The project manual specifies a visual census technique which involves a SCUBA diver swimming along a "corridor" above the coral reef transect line. In addition to species, fish lengths are estimated, as is abundance based on a log 4 scale.

Mangrove forests. Traditional methods are used to evaluate the community structure of vegetation in mangrove forests. Two techniques are specified in the manual, namely, the standard "transect line plots methods" or a quicker, plotless "angle-count cruising method" making use of a relascope. Either way, some quantification is made of the more common tree species, their distribution, and their biomass, which is estimated from "diameter at breast height" (dbh). Potential primary productivity is derived from an estimate of average chlorophyll content of the entire forest, which in turn is measured by the attenuation of light though the canopy. A variety of soil characteristics, including grain size and certain chemical parameters, are analysed to complement data on productivity. The faunal component is considered essential, consisting mainly of fish and prawns. These are determined by using methods prescribed in the manual.

Sea-grass beds. These are also evaluated in terms of vegetation community structure and biomass, as well as their associated major faunal groups. The latter are dominated by fish and juvenile prawns.

Soft-bottom communities. A suite of techniques are recommended for the study of soft-bottom communities. These centre on the use of a grab which collects replicate samples along a transect perpendicular to shore, following some environmental gradient of interest. Tows to collect sediment epifauna making use of a sledge and/or a trawl may be conducted to augment grab sampling. It is specified that sediment fauna be identified at least to family level, and sorted according to standard size categories.

Remote sensing. Field investigations are accompanied by the use of remote sensing to gain broader geographic perspectives. The "Living Coastal Resources" project employs a particular microcomputer-based tool developed in Australia call "microBRAIN" (for **B**arrier

Reef **I**mage **An**alysis). Satellite images such as Landsat and SPOT are analysed for selected information using microcomputer software. The usual limitations with respect to satellite imagery exist, such as interference by clouds and by turbid water. But where satisfactory images are available, they have proved immensely useful in categorising broad topographic features and coastal processes such as sediment input. Present efforts concentrate on "ground-truthing" to verify satellite-derived information. If consistent and reliable correlations are found between satellite signals and features on the ground (*e.g.*, seas grass cover, coral cover), field surveys would receive a significant boost in terms of area coverage and general efficiency.

Database Management

The same degree of effort has been devoted to improving techniques of data storage and management as to refining field methods. Due consideration is given to the level of technology available in most developing countries, so that emphasis has been placed on microcomputer-based systems which would have potential access to more powerful computing centres.

Raw data are stored according to standard formats. At the moment, the universal system adopted is the data management system "dBASE." The original recommended formats in the project manual have been further modified (Chou and Boto 1988; Licuanan and Tangjaitrong 1989) to respond to needs arising under conditions in different countries, and generally to incorporate greater flexibility.

In addition to the storage and formatting of raw data, secondary programmes developed by project personnel link the data base to statistical packages for analysis. The presently designated regional data centre is at Chulalongkorn University in Bangkok, Thailand.

Results

Results of structural investigations of coastal and nearshore ecosystems in Indonesia, Malaysia, the Philippines, Singapore, and Thailand have been published as the proceedings of a regional symposium sponsored by the project (Alcala 1991). Additional data for Singapore are compiled in another volume (Chou 1990).

For the Philippines, published papers outside of those mentioned above are those of Licuanan and Gomez (1988), Hilomen and Gomez (1988) and Gomez *et al.* (1988) for coral reefs, reef fish, and coral-fish association, respectively; Yap and Nacorda (in press) for soft-bottom communities; and Fortes (1991) for mangrove and sea grass ecosystems.

Because methods employed are nearly common to all countries involved, the intercomparability of data is realised. It thus becomes possible to detect emerging patterns that may be true for the region as a whole. Examples are the typical or dominant species in each of the researched habitats. When taken further, analyses also indicate common features in terms of distribution with respect to distance from land, major environmental gradients, or even with respect to the influence of climatic factors (rainfall, typhoons, *etc.*). If confirmed, such

patterns may help towards classifying coastal and marine habitats on the basis of larger geographic scales, and would enable the prediction of future dynamics or responses to perturbation. It is precisely this point that might justify the broader activity of inter-regional ecosystem monitoring.

MONITORING ECOSYSTEM FUNCTION

The current phase of the "Living Coastal Resources" project concentrates on the functional attributes of ecosystems. This focus provides the logical follow-up to the structural investigations of the preceding phase. In other words, since we now know (more or less) what ecosystems are present, what they look like, and what their major components are, the next step is to find out what they do. The present phase also addresses one of the most important questions in ecological research, namely, the nature of productivity, and how it may be harnessed on a sustainable basis.

Again, the guiding theme is standardisation of methodology and approach, so that data will be intercomparable, and unifying patterns of ecosystem function would be detectable.

The first major activity to launch the present phase was a workshop on "Energy Transfer and Nutrient Flow" (Chou, in press). The merit of functional studies is that they focus on parameters that integrate almost all metabolic processes, thus providing a synoptic picture of the productive state of a particular ecosystem. Methods already exist to produce results that are able to provide a fairly reliable indication of the over-all mass balance of a system (production versus consumption). Results may also be of diagnostic value, which is important in a monitoring program. For example, some idea may be gained as to whether a system is perturbed or stable. Finally, the assessment of some metabolic parameter, if sensitive enough, may help gauge the degree of response to a stress factor.

The first step in the monitoring of ecosystem dynamics would be a determination of total function, for which methods are available (*e.g.*, Kinsey 1985). This is fairly easy in submerged habitats such as certain coral reef zones, sea grass beds and soft-bottom areas because the water column is an excellent medium for the integrated measurement of metabolites (nutrients, organic compounds, or dissolved gases such as oxygen and carbon dioxide).

Some investigations may call for breaking a system down further into its components (Yap, in press). This is relevant, for instance, when it is essential to identify the most productive entity for purposes of management. Such information is also necessary in deliberate attempts to enhance productivity, as in fertilisation experiments. Examination of an ecosystem in terms of its parts yields further insight into inter-connections and energy pathways, information which would eventually serve as a basis for either manipulation or prediction.

The proceedings of the workshop on "Energy Transfer and Nutrient Flow" mentioned above (Chou, in press) contain a package of recommended techniques and approaches in the study of energy and nutrient fluxes in nearshore and coastal habitats, with a view to existing

or potential capabilities of developing countries. If studies using the package are carried out, their results would certainly benefit a wide range of users, with purposes ranging from resource conservation, coastal zone management, rational exploitation of fisheries, to the prediction of the possible impacts of global climate changes.

CONCLUSION

The ASEAN-Australian Marine Science Project "Living Coastal Resources" is probably the first of only a few successful instances of co-operative ecosystem research on a regional scale making use of standardised methodologies. Useful data on structural characteristics of the most important habitats are now available either in the literature or at the regional database centre. Functional investigations are presently underway to complete the regional picture of ecosystems that is emerging.

Attempts at inter-regional co-operation might build on the Southeast Asian-Australian model, though it is acknowledged that it is by no means perfect, and will certainly benefit from expertise and experience from other regions.

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NONBIOLOGICAL FACTORS ASSOCIATED WITH CORAL BLEACHING IN SHALLOW WATER NEAR THE OUTLET OF THE THIRD NUCLEAR POWER PLANT, SOUTHERN TAIWAN

Che-Chung Huang[1], Tsu-Chang Hung[1,2], and Kuang-Lung Fan[1]

ABSTRACT

Since the two generating units of the Third Nuclear Power Plant began full operation in January 1987, two incidents of coral bleaching have been reported, in July 1987 and July 1988, in a shallow bay near the west side of the plant's cooling-water outlet. Immediately after the first event (July 1987), we found that thermal effluent was the major cause of coral bleaching. Our study investigates nonbiological factors associated with the coral-bleaching event: nearshore ocean currents, physical and chemical properties of the sea water (temperature, salinity, pH, dissolved oxygen, biochemical oxygen demand, total oils and greases, heavy metals, nutrients, chlorophyll a), and biological parameters, including primary productivity and coral growth.

Except with regard to temperature, sea-water quality, as sampled in the shallow bay, met the marine-water criteria set by Taiwan's Environmental Protection Administration. In summer, the temperature of the 3-metre surface-water layer near the outlet usually exceeds 30°C. The growth rate of corals in thirteen marked colonies in the shallow bay decreased gradually during the period July 1987 to October 1988. Since the cooling water intake/discharge rate was increased by ten per cent in May 1989, the decrease in growth rate lessened after the summer of 1989. At no time during the survey period were significant changes found in coral coverage in the control group of marked colonies near Nanwan village.

INTRODUCTION

Taiwan, like a ship in the midstream of the Kuroshio current, is located between latitudes 21° 50' N and 25° 21' N. The mean water temperature around Taiwan is over 20°C. Nanwan Bay, which is a part of Kentin National Park, is located at the southern tip of Taiwan. A branch of the warm Kuroshio current passes through Nanwan Bay and flows northward

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along the western coast of Taiwan (Liang *et al.* 1978; Fan and Yu 1981). The warm, clear water brought by the branch of the Kuroshio current nurtures a well-developed coral-reef community fringing Nanwan Bay (Jones *et al.* 1972; Yang *et al.* 1976; Yang *et al.* 1977; Yang *et al.* 1982).

The Third Nuclear Power Plant, which has two generating units, started operating on Nanwan Bay in November 1984 and achieved full output in January 1987. In its operation, a nuclear power plant takes in a large amount of cooling water, discharging it as thermal effluent. Decolouration or bleaching of corals under the influence of high-temperature stress or heated effluent has been reported (Jokiel and Coles 1974, 1977; Oliver 1985; Kato 1987; Su *et al.* 1988). Stony and soft corals taken from Nanwan Bay and exposed to a thermal stress of over 33°C became pale and bleached or lost colour (Yang *et al.* 1980). Two events of severe but localized bleaching of coral colonies were recorded in July 1987 and July 1988 in the shallow water near the thermal-effluent outlet of the Third Nuclear Power Plant. This decolouration and the corals' growth response to thermal-stress conditions are described in this paper.

MATERIALS AND METHODS

The focus of investigation was on nonbiological factors that influence coral decolouration. The flow speeds and directions of ocean currents were monitored with a self-recording current metre (Aanderra RCM-4). The mooring stations for the current metre are shown in Figure 1. The diffusion of thermal discharge from the power plant was studied by two methods: (1) the fluorescent dye (fluorecein sodium) diffusion-tracing technique and (2) temperature measurements taken by a diver with mercury thermometers, digital thermometers, a Conductivity-Temperature-Depth (Neil Brown) instrument, reversing thermometers attached to Nansen bottles, and self-recording thermometers (Peabody J-180).

Water samples were collected at different depths with metal-free Van Dorn bottles by the research vessel, Ocean Researcher 1, and by fishing boats. The sampling locations are shown in figure 1. Immediately after collection, the water samples were analyzed for salinity, pH, dissolved oxygen, biochemical oxygen demand (BOD-5), total oils and greases, nutrients (nitrite, nitrate, phosphate, and silicate), chlorophyll a, and primary productivity, using the same analytical methods as those reported previously by Su *et al.* (1980).

For the coral decolouration study, the underwater photographic technique was applied (Yang *et al.* 1982). Since May 1988, colour photographs have been randomly taken with a Nikonos III or IVA underwater camera at or around stations X, Y, and Z at depths, respectively, of 3.3 m, 4.4 m, and 4.8 m (Figure 1). All coral colonies in the photographs were classified in the laboratory into six categories: Acroporidae, Pocilloporidae, Poritidae, Faviidae, Alcyoniidae, and others. To study coral growth, a stainless-steel square frame 50 x 50 cm was used for photography on the reef. Transparent section paper was used to estimate the coral coverage on the photograph.

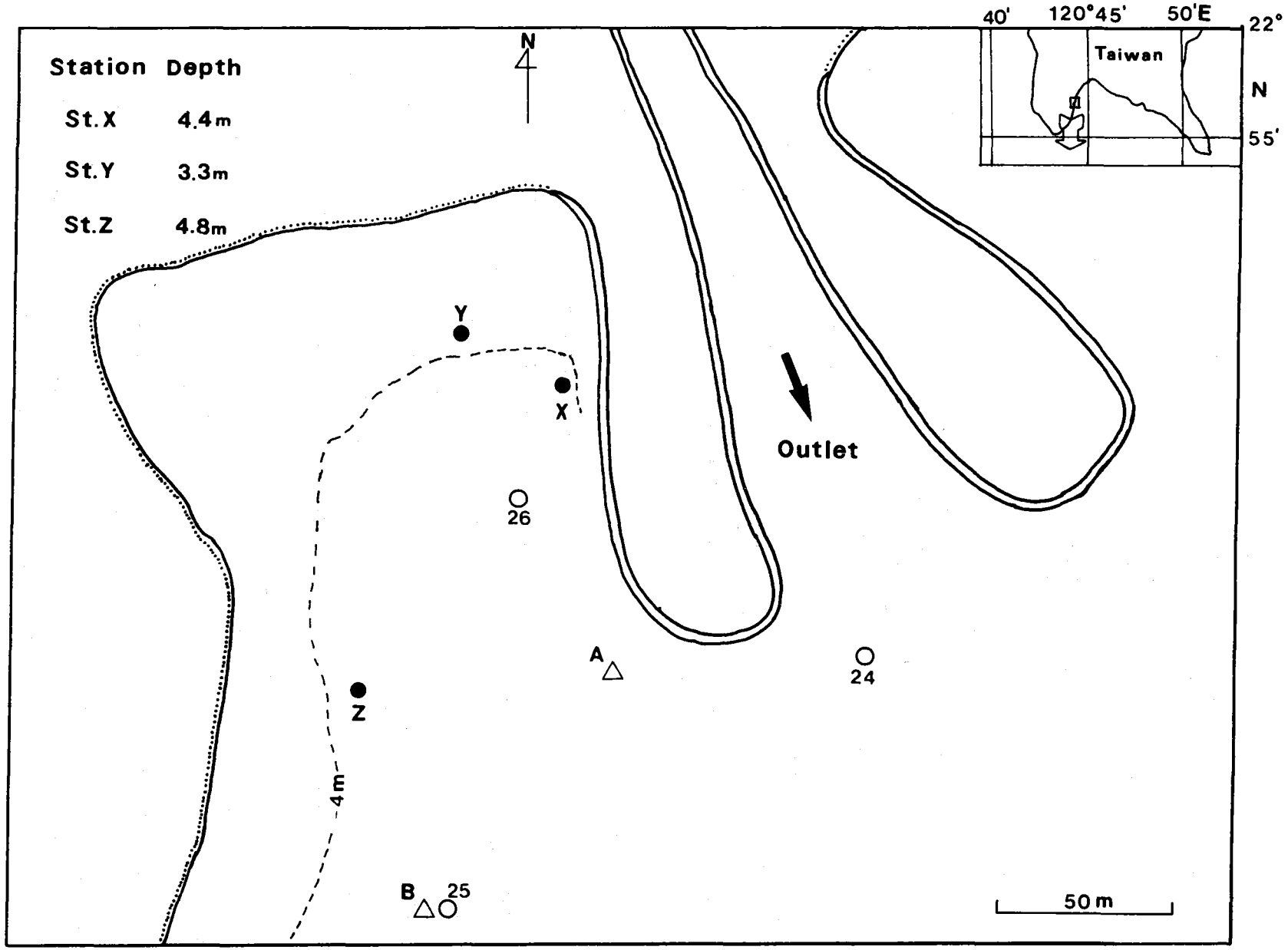


Figure 1. Distribution of stations in shallow water near thermal-effluent outlet of Third Nuclear Power Plant

Water-sampling stations: 24,25,26
Current-measuring stations: A, B
Coral-bleaching study stations: X,Y,Z

For the study of long-term changes in coral coverage in the shallow bay, four coral colonies (one of *Acropora*, one of *Sarcophyton*, and two of *Lobophytum*) were observed in the bay from 7 October 1986 or from 21 December 1987. In addition, as a control, two colonies of *Lobophytum* in the shallow waters near Nanwan Village (over three km away from the influence of the thermal discharge) were observed from 8 October 1986 through 7 January 1990. All of these coral communities are at depths of 3 to 4.8 m.

RESULTS AND DISCUSSION

Ocean and tidal currents

Figure 2 shows the general pattern of ocean currents around Taiwan. During summer, water from the South China Sea flows into Taiwan Strait and Nanwan Bay. During winter, the branch of the Kuroshio current passes by Nanwan Bay and flows into Taiwan Strait (Fan and Yu 1981). Examining Nanwan Bay, Liang *et al.* (1978) and Yip (1984) found that diurnal and semidiurnal tides dominate the current patterns in the Bay. Near the thermal outlet the current flows towards the southwest most of the time during flood tide; during ebb tide, the flow is sometimes to the southwest and sometimes to the northeast (Figure 3). The predominantly southwestward direction of the current prevents the thermal effluent from flowing back to the cooling-water intake, which was the basis for TAIPOWER's choice of the locations of the intake and outlet.

Physical and chemical properties of the sea water

Figure 4 shows temperatures near the outlet on 3 July 1987 (Fan 1988). The data, which were supplied by the Radiation Monitoring Laboratory, TAIPOWER, were collected from 0810 to 0830 during the flood tide, when the surface-water temperature at the station near the intake was 27.9° C. The temperature rise ΔT of > 4°C covered an area extending from the outlet for 300-400 m to the south and west. The temperature of the surface water in the shallow bay on the western side of the outlet exceeded 31.9° C, and in some places the temperature exceeded 34° C, which would definitely hurt or kill corals in shallow water near the shore (Yang *et al.* 1980). During summer, the southwest monsoon, strengthened by the on-shore wind during the day, can push the heated water into the little bay, jeopardizing the coral in the shallow water. It was this that happened in early July 1987, the first incident of its kind in Taiwan, occurring during the first summer that the two major reactors of the Third Nuclear Power Plant were operating simultaneously. During the summer of 1988, damage occurred over a more extended area.

Table 1 shows the surface- and bottom-water temperatures at stations X, Y, and Z in the shallow bay (Figure 1). Surface-water temperatures of over 33° C were recorded during the summers of 1988 and 1989 but not the summer of 1990. Temperatures over 31° C were recorded frequently during the summer of 1988 but not often during the summer of 1989 and on only a few occasions during the summer of 1990. Figure 5 shows that the bottom-water temperature of the shallow bay varied concordantly with the outlet-water temperature of the

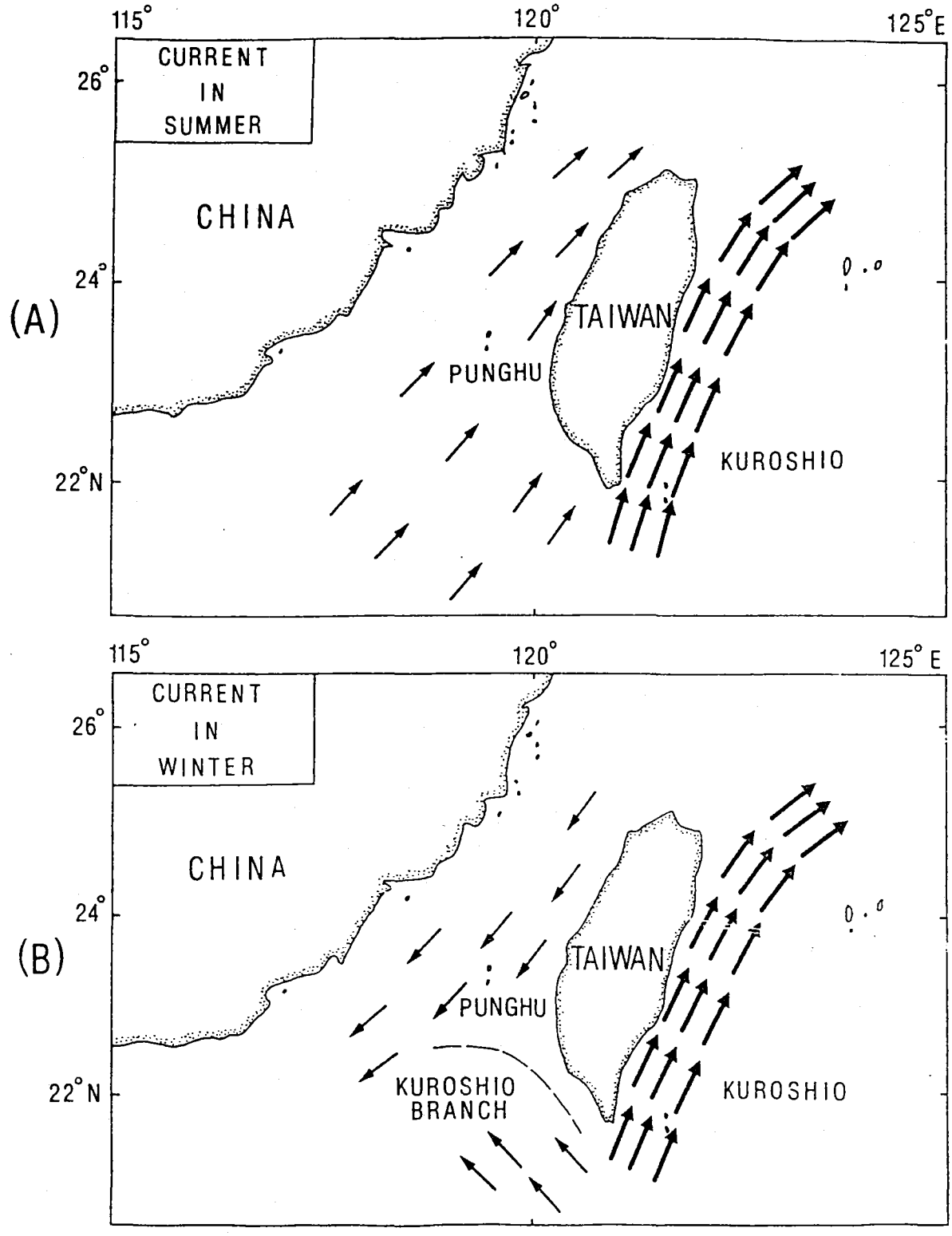


Figure 2. Current patterns around Taiwan in (A) summer and (B) winter

plant. The water temperature of the shallow bay (Figure 6), mainly at stations 25 and 26, varied from 24.5° C to 32.3° C in the bottom layer and from 25.6° C to 34.2° C in the surface layer, thus reaching temperatures much higher than the 31° C upper limit for coral survival (Yang *et al.* 1980). However, the distributions of salinity (32.444 to 35.445 ppt), pH (7.76 to 8.38), dissolved oxygen (4.31 to 8.18 ppm), nutrients (nitrite 0.11-1.35 μmol/L, nitrate 0.73-8.55 μmol/L, phosphate <0.03-4.17 μmol/L, and silicate 1.62-33.06 μmol/L), chlorophyll a (0.04 to 0.78 μg/L), and primary productivity (0.21 to 1.15 μgC/L/hr) varied with season and location (Su *et al.* 1988). The water quality of the shallow water on the western side of the outlet can be classed as "A" marine water according to the criteria set by Taiwan's Environmental Protection Administration. Measurements showed the following levels: total oils and greases (n-hexane extractable matters 1.2 to 13.0 mg/L, Figure 6), BOD (0.2 to 0.5 ppm, Figure 6), and heavy metals (mercury <0.05 μg/L, chromium 1.36-3.18 μg/L, zinc 0.50-48 μg/L, cadmium <0.01-0.98 μg/L, lead 0.2-12.4 μg/L, and copper 0.16-17 μg/L, Figure 6). Class "A" marine water should meet the standards of BOD-5, mercury, chromium, zinc, cadmium, lead, and copper content of less than 2000, 2, 50, 40, 10, 100, and 20 ppb, respectively.

Effects of thermal stress on the coral community

1. Mass coral bleaching events in the shallow bay. Mass coral bleaching was recorded in the shallow bay in July 1987, occurring from the shoreline to a depth of 3 m over an area of about 0.012 km^2, which is 0.1 per cent of all the coral coverage in Nanwan Bay (Figure 7). Over 90 per cent of corals on the fringing reef were bleached in this event. Conspicuous coral bleaching was reported again in July 1988. As shown on Figure 7, the range of coral bleaching expanded from 3 m to 5m in depth in the shallow bay and extended along the coast from the shallow bay to Mao-pi-tou, an area of about 0.035 km^2 (30 x 1,500 m), which is 0.3 per cent of the total coral cover in Nanwan Bay. About 30 per cent of the corals living between 3-5 m deep in the shallow bay were bleached in this event, but no mass mortality of corals was found along the coast of the shallow bay to Mao-pi-tou. The staghorn coral *Seriatopora hystrix* was recognized as the most sensitive local species.

2. Percentage of decolouration in corals in the shallow bay. The photographic data were classified into three levels of decolouration: complete decolouration with over 80 per cent of the coral colony bleached, partial decolouration with 20 to 80 per cent bleached, and normal with less than 20 per cent bleached (Table 2). The percentage of normal colonies decreased from 82.9 per cent on 30 May 1988 to 32. 1 per cent on 17-19 August 1988. The percentage of coral colonies with complete decolouration increased from 3.8 per cent to 52.2 per cent during the same period. During the summer of 1989, the percentage of normal colonies was 85.2 per cent on 22 June, dropping to 69.7 per cent on 27 September, but rising to 92.5 per cent by August 1990. The percentage of coral colonies with complete decolouration was 3.3 per cent on 22 June, increasing to 7.0 per cent on 27 September 1989, and decreasing to 2.3 per cent on 9 August 1990.

3. Long-term changes of coverage in observed colonies. Figure 8 shows changes in the coverage of four coral colonies in the shallow bay and two colonies near the coast at Nanwan

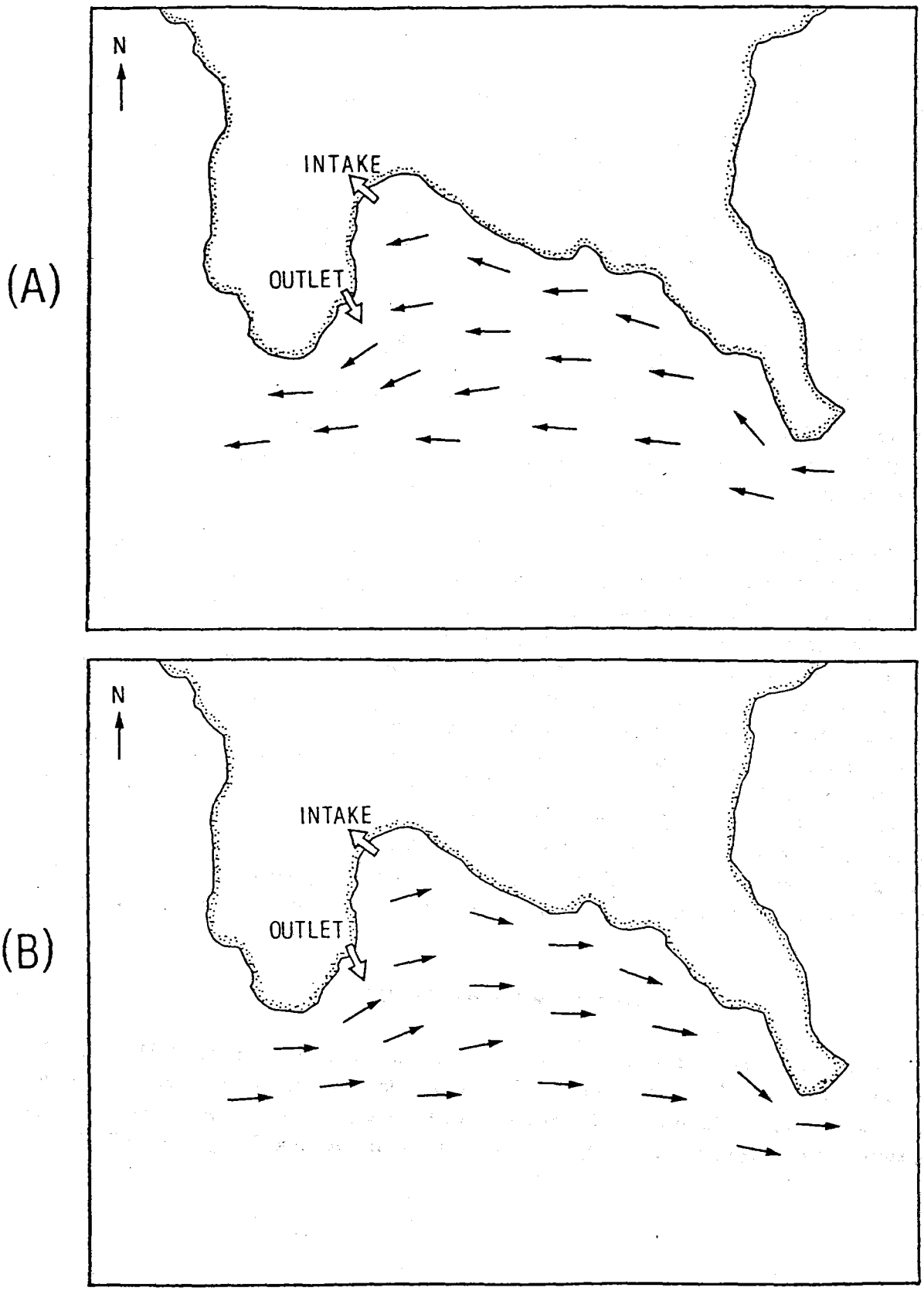


Figure 3. Generalized patterns of tidal currents in Nanwan Bay for (A) flood tide and (B) ebb tide

village. Conspicuous changes of coral coverage throughout the survey period were found on the three colonies numbered 1, 2, and 5, all of which are in the shallow bay. The coverage of number 5 was 1676.8 cm^2 on 13 April 1988; by 4 November 1988 it was only 891.2 cm^2. All of the observed colonies of soft corals in the shallow bay showed a decrease in coverage after the summers of 1987 and 1988, but the decrease was less after the summer of 1988. No significant changes of coverage were found in the observed colonies near Nanwan village during the survey period.

4. Mortality of the coral. Of the 21 coral colonies shown in Figure 9, only one in the shallow bay and two near Nanwan village were lost during the survey period. Besides the observed colonies, four colonies near Nanwan village were wiped out by a typhoon. The aggregate mortality rates of the coral colonies were 75 per cent (6/8) and eight per cent (1/13); mortality from the typhoon was 50 per cent (4/8) and zero per cent (0/13), respectively, for those in the shallow bay and those near Nanwan village.

Extensive bleaching of corals caused by the synergistic stress of high temperature and high light was observed on the Great Barrier Reef (Oliver 1985). Extensive coral bleaching occurred in the Java Sea during sea-water warming caused by El Niño Southern Oscillation (Brown and Suharsono 1990). A sub-lethal coral bleaching in response to seasonal variations in water temperature was studied in Jamaica (Gates 1990). Kato (1987) indicated that the branchlets of poritid coral had a mortality rate of 19 per cent under the stress of water temperatures at 32° C over a period of 48 hours; the mortality increased to 57 per cent if the temperature was 33° C for the same period. Jokiel and Coles (1974) found that the lethal temperature was 32° C for Hawaiian corals. For the Nanwan corals, laboratory experiments produced estimates of 31° to 32° C as the upper temperature limits for 14 coral species (Yang *et al.* 1980). The bottom-water temperature in the shallow bay frequently reached 31° to 32° C during the summers of 1987 and 1988, confirming that the upper lethal temperatures for Nanwan corals is 32° C in accordance with the limits for Hawaiian and Okinawan corals.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to Mr. Charley C.H. Tsai, Mr. C.C. Lin, and Miss L.C. Wang for their assistance in fieldwork and in the preparation of the tables and drawings. Thanks are also extended to the reviewers who have provided critical comments and corrections. The study was supported by the Atomic Energy Council, ROC.

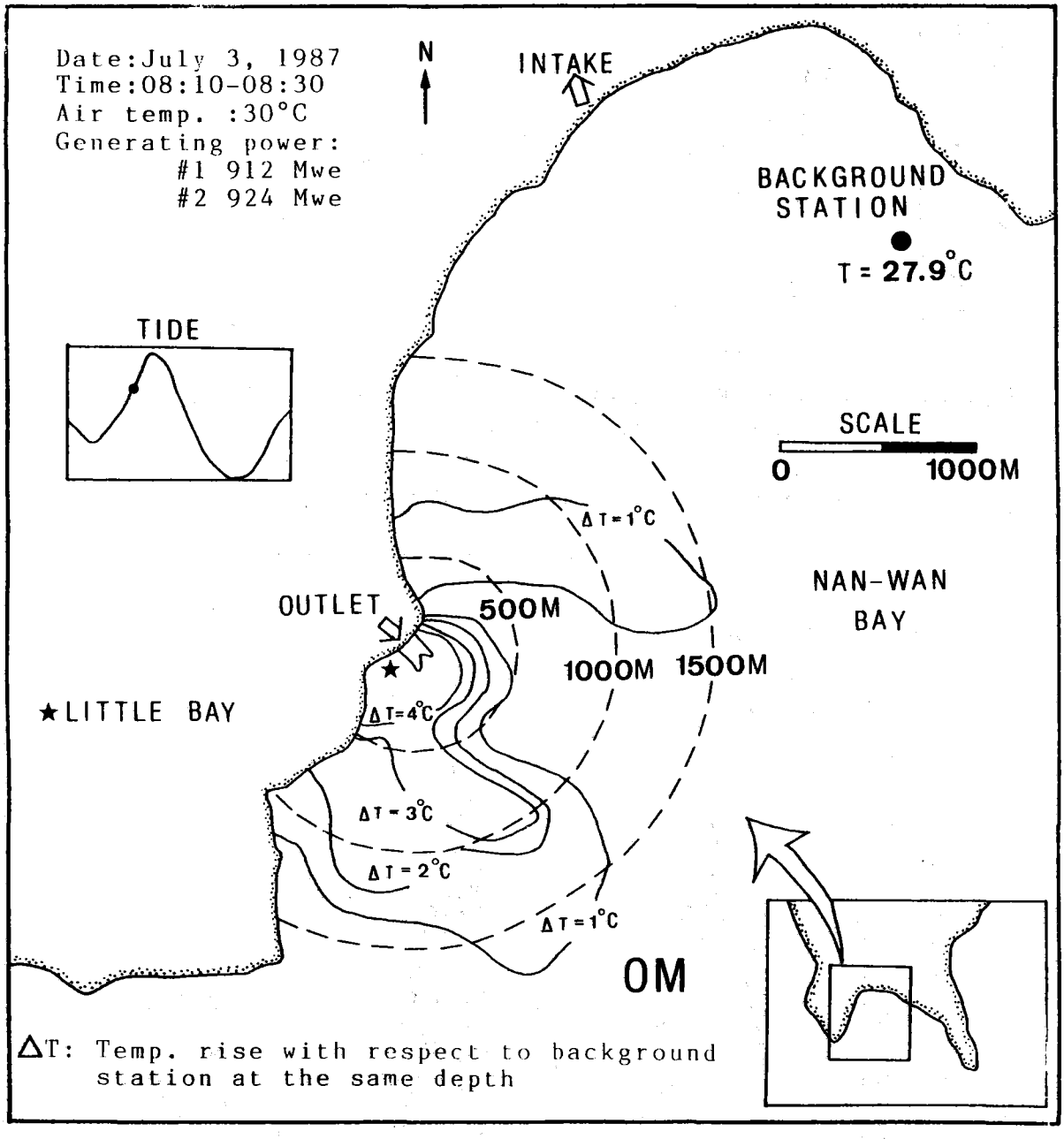


Figure 4. Temperature increases of sea water near the thermal outlet on the morning of 3 July 1987 (*Source:* Fan 1988)

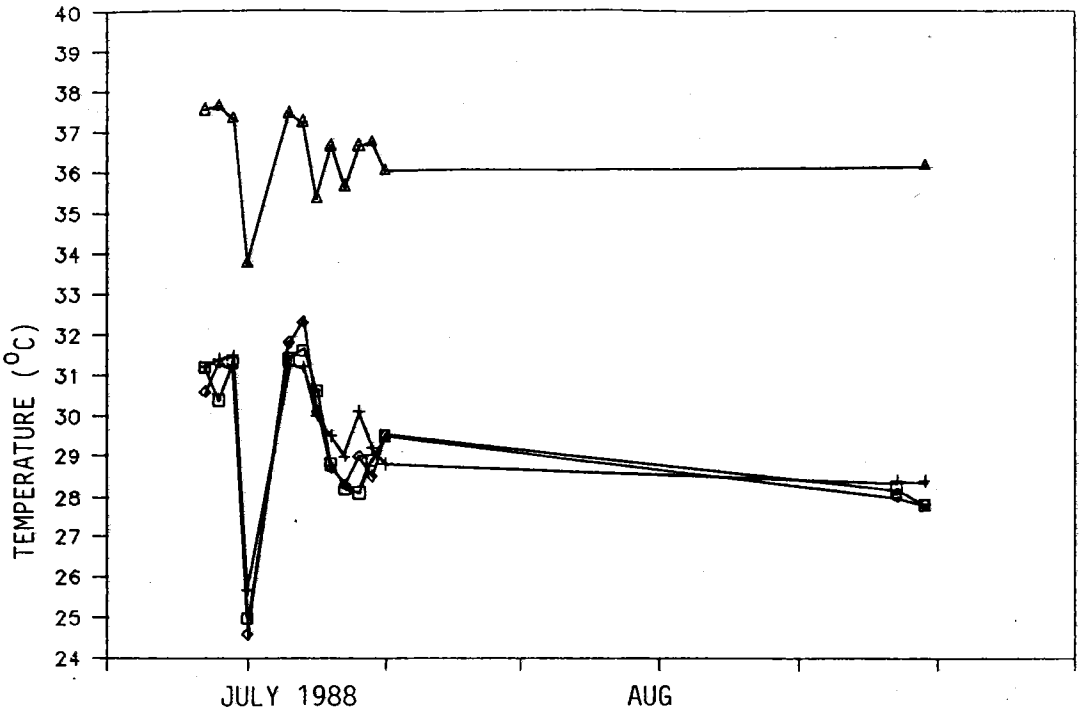


Figure 5. Bottom-water temperature in the shallow bay of the Nanwan coastal area and in the outlet of the Third Nuclear Power Plant

□ : Station X, + : Station Y, ◇ :Station Z, △ :Outlet

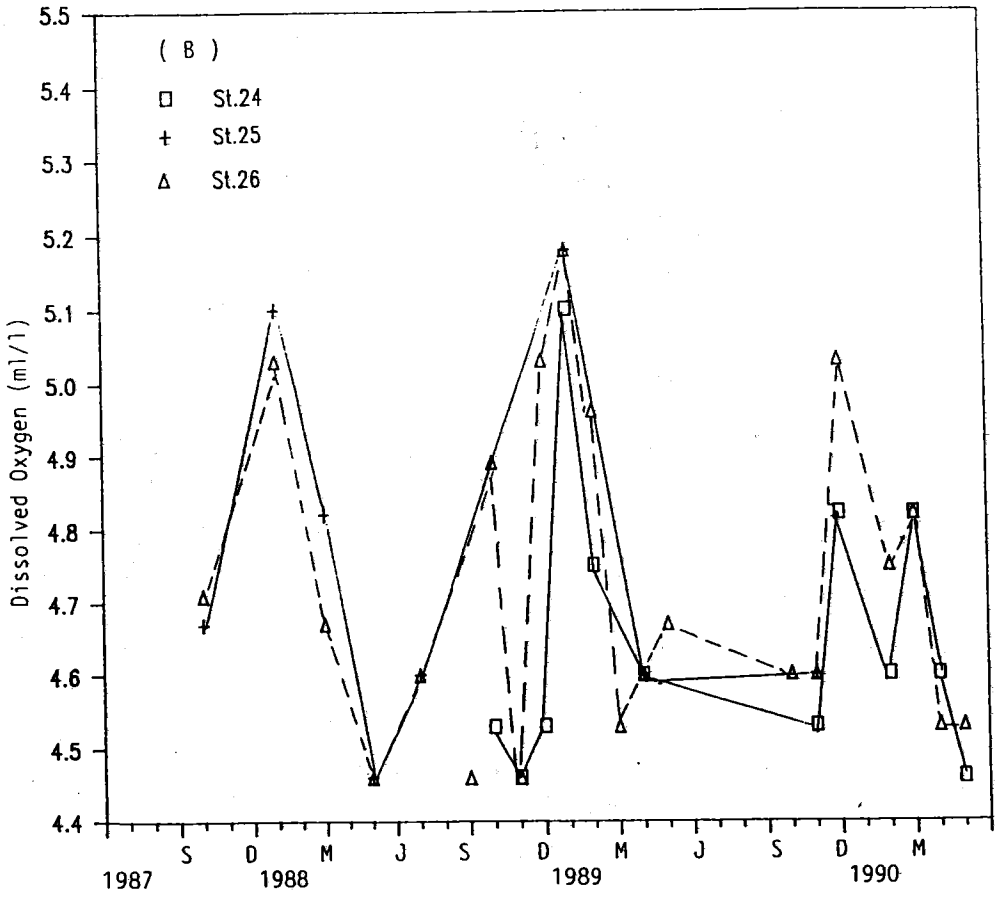
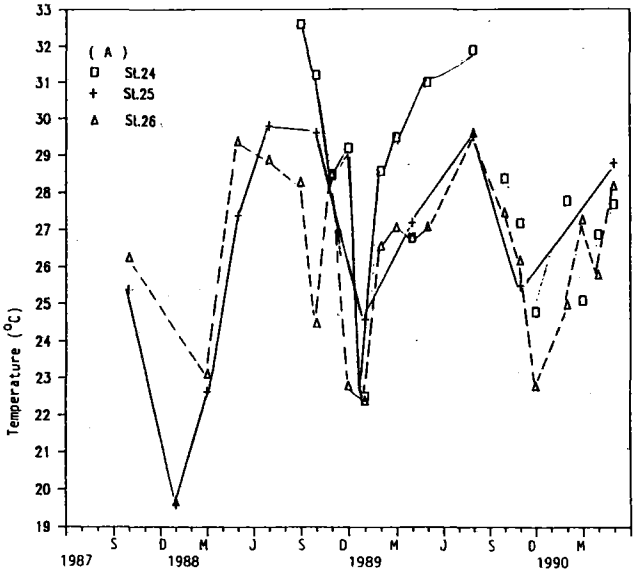
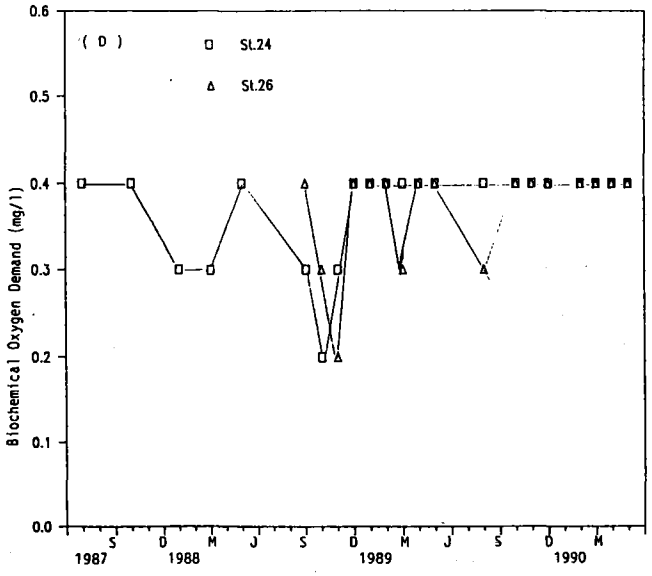


Figure 6. Seasonal distributions of hydrographical and chemical parameters in waters of the shallow bay in the Nanwan area (Stations 24, 25, 26 shown on Figure 1)

Figure 6, *continued.*





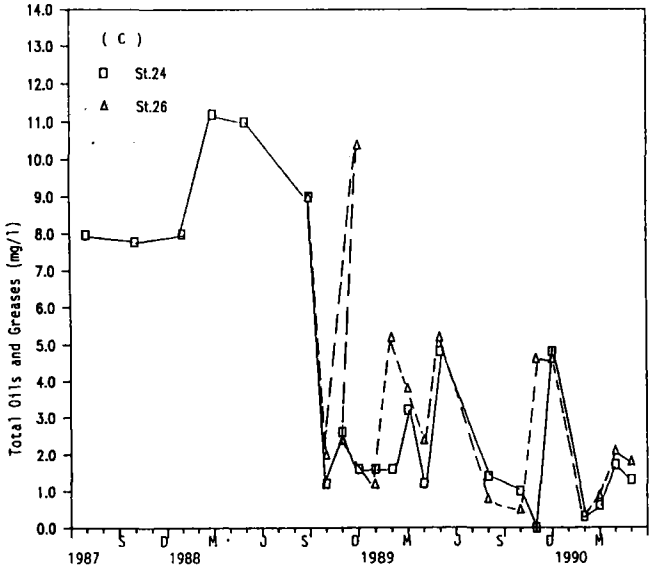
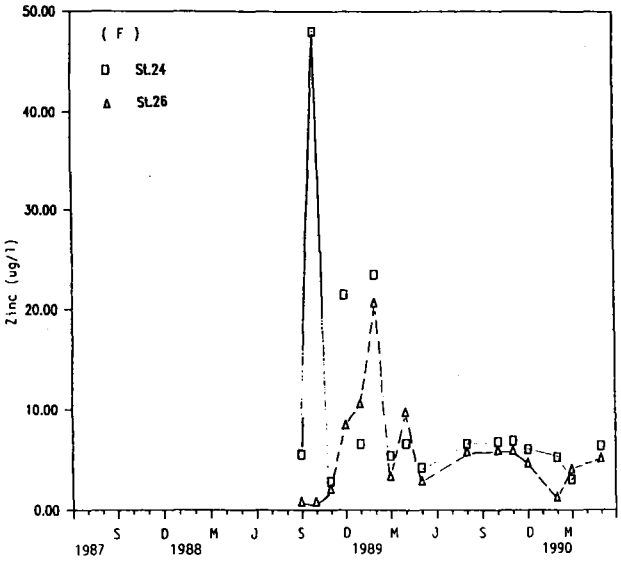
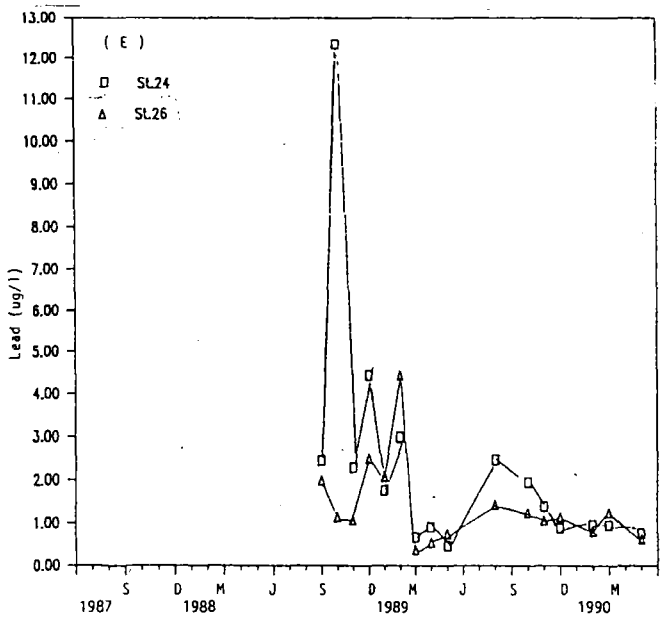
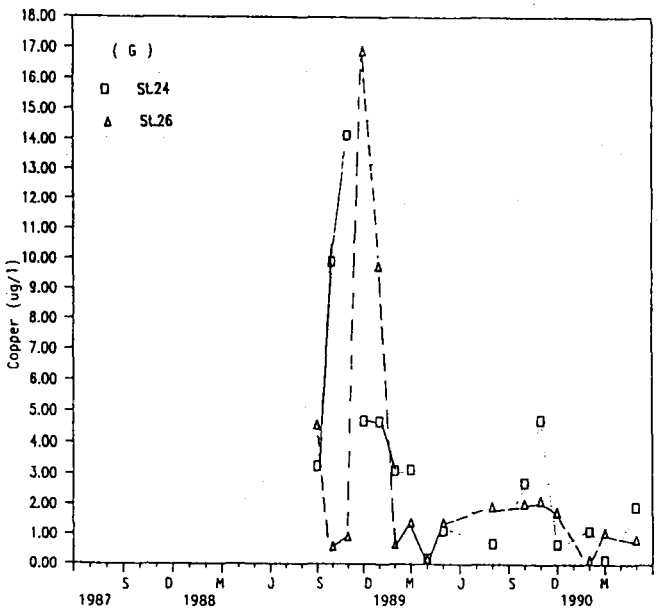


Figure 6, *continued.*







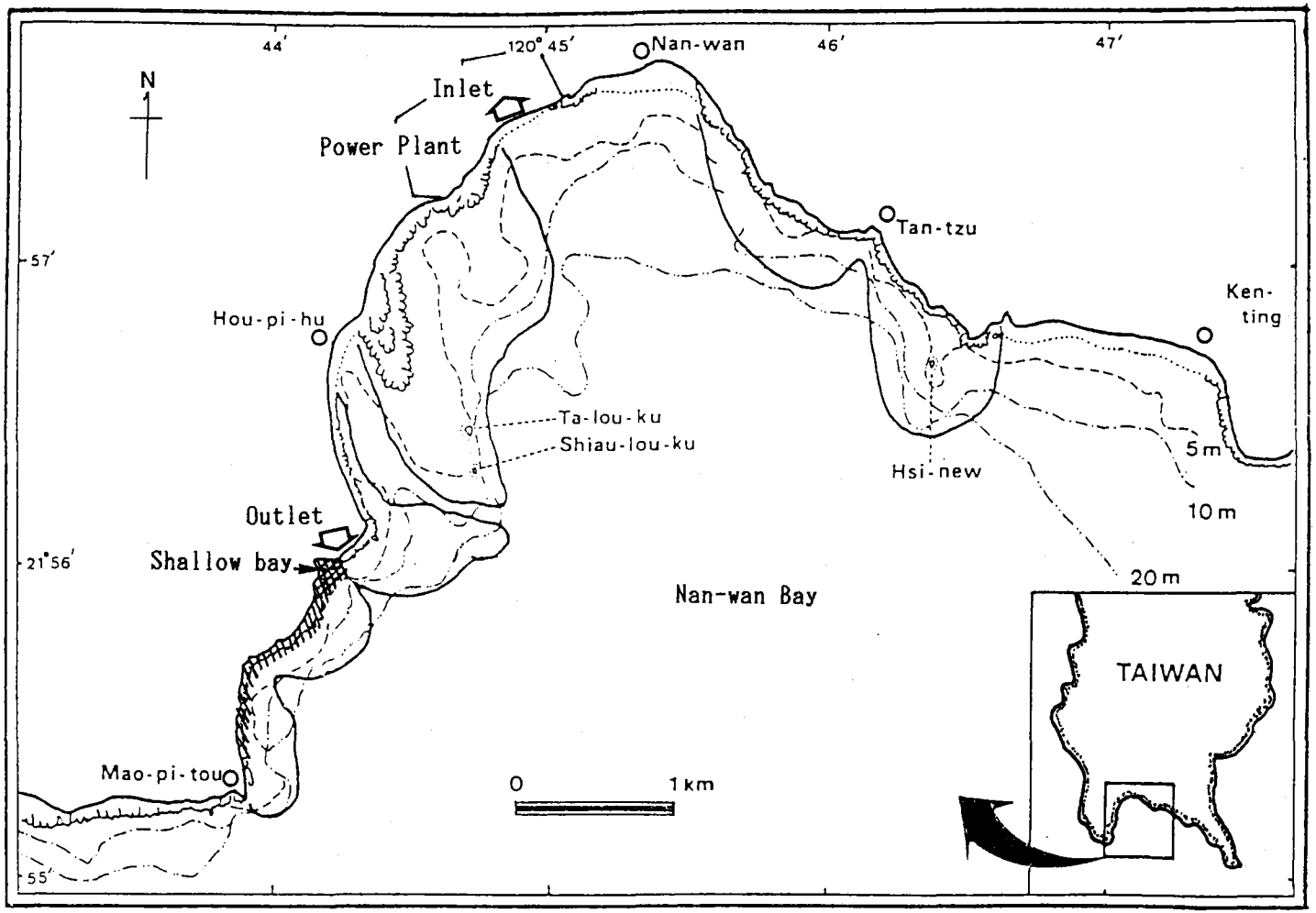


Figure 7. The distribution of coral reefs and the area of coral bleaching in Nan-wan Bay.

Area of coral bleaching in summer 1987

Area of coral bleaching in summer 1987

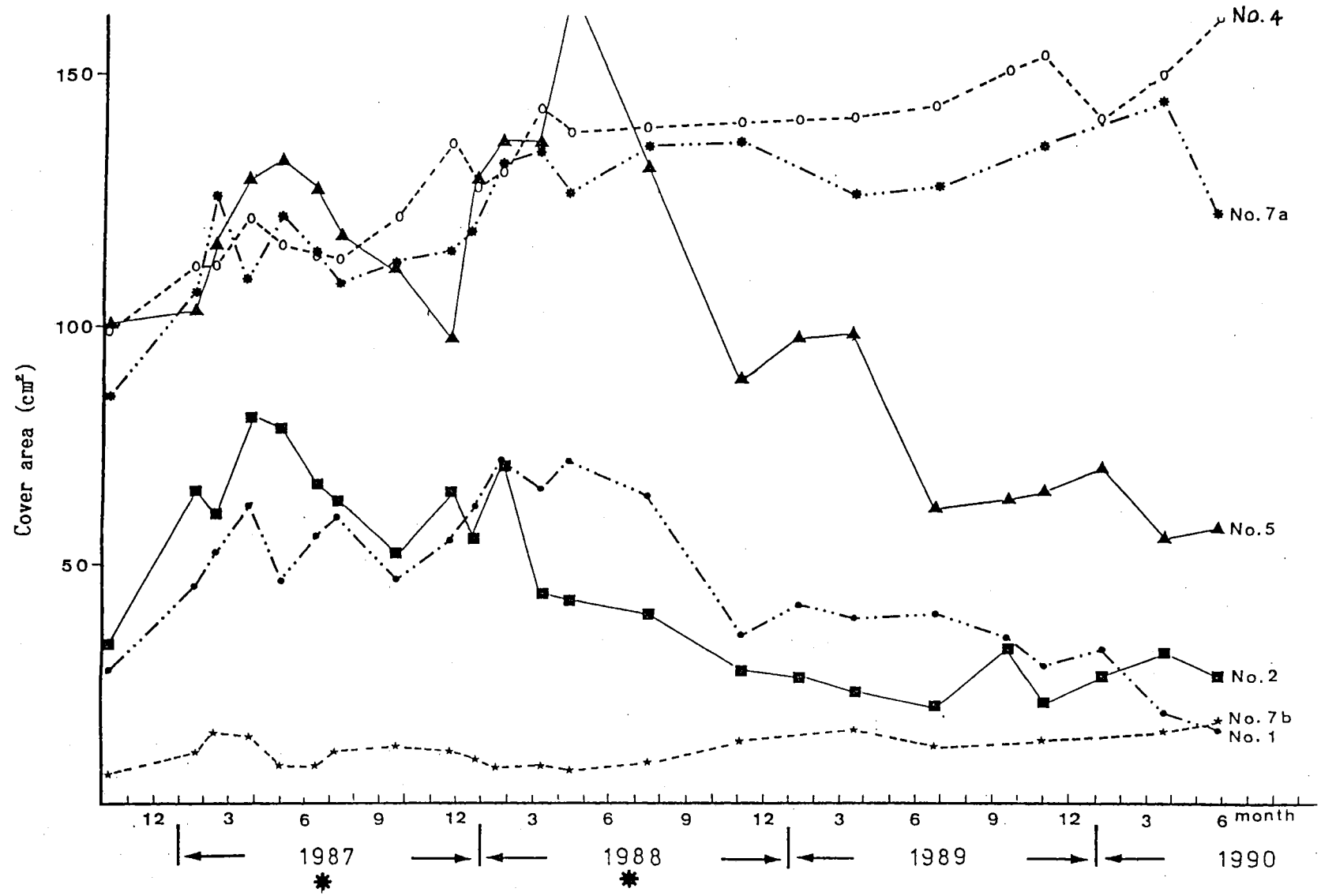


Figure 8. Changes in the coverage of coral colonies in the shallow bay near the thermal outlet (nos. 1, 2, 4, & 5) and near Nanwan Village (nos. 7a & 7b). Colony no. 1: *Sarcophyton*; Colonies 2, 5, 7a, & 7b: *Lobophytum*; Colony no. 4: *Acropora*.

ASTERISK indicates periods of coral-bleaching events

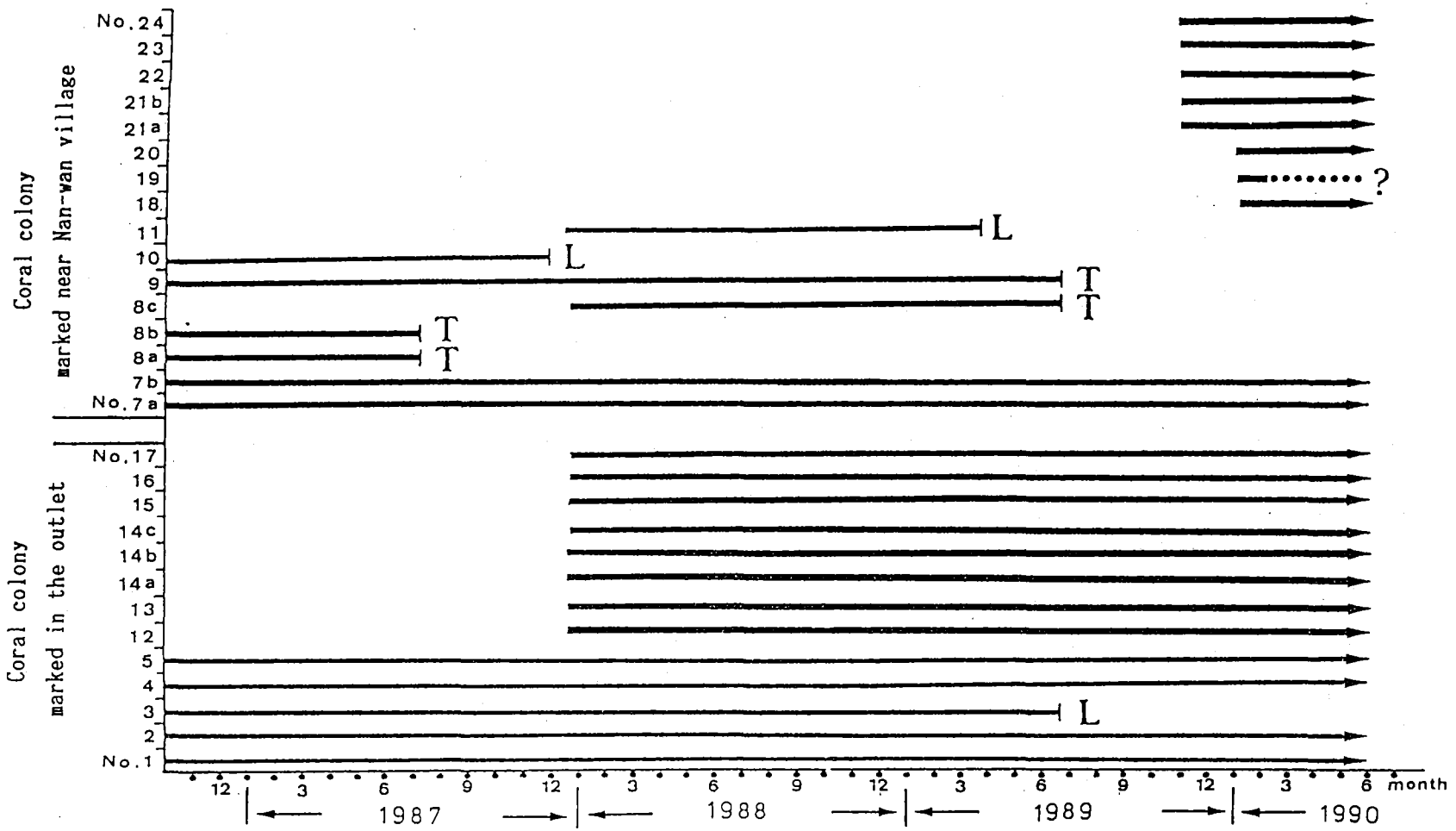


Figure 9. Survival span of coral colonies in the shallow bay and near the coast at Nanwan Village (T: disappeared or dead, covered by sand during typhoon; L: lost or unknown)
Colonies 1, 14, 18, 23, & 24 are *Sarcophyton* genus
Colonies 4, 10, 11, 13, 16, 19, 20, & 22 are *Acropora* genus
Colonies 2, 3, 5, 8, 9, 12, 15, 17, & 21 are *Lobophytum* genus

Table 1. Water temperature (℃), at three stations (Sts.X, Y & Z) in the Shallow Bay and Nanwan village in summer of 1988 to 1990.

DATE	St.X		St.Y		St.Z		Nanwan
	S*	B*	S	B	S	B	S
Jun. 27,1988	32.1	31.2	31.6	31.2	31.8	30.6	--
28,	31.2	30.4	31.8	31.4	32.4	31.3	--
29,	32.1	31.3	31.7	31.5	32.2	31.2	27.3
30,	25.7	25.0	26.1	25.7	25.6	24.6	27.3
Jul. 3,	33.2	31.4	33.4	31.2	33.3	31.8	31.5
4,	33.7	31.6	34.0	31.2	34.2	32.3	31.2
5,	32.3	30.6	32.4	30.0	31.5	30.1	28.1
6,	30.8	28.8	30.8	29.5	30.7	28.7	29.4
7,	31.9	28.2	31.0	29.0	32.1	28.3	29.2
8,	31.0	28.1	30.9	30.1	32.0	29.0	29.2
9,	32.1	28.9	31.4	29.2	32.3	28.5	28.4
10,	30.2	29.5	30.0	28.8	31.5	29.5	28.2
Aug. 17,	29.5	28.2	29.2	28.4	30.4	28.0	28.1
19,	29.0	27.8	29.2	28.4	29.5	27.8	28.2
Jun. 20,1989	29.6	28.6	29.5	29.0	29.8	28.6	26.0
21,	29.3	28.5	29.0	28.8	30.0	28.9	26.2
22,	29.4	29.2	29.4	29.2	30.0	28.7	26.4
23,	29.4	28.8	29.2	29.3	28.9	27.7	26.4
24,	30.0	29.2	30.0	29.3	31.0	29.1	28.1
25,	29.1	28.4	28.5	28.3	31.2	28.4	27.8
26,	31.6	30.0	30.6	30.1	31.6	28.8	27.5
27,	31.3	28.6	31.0	30.8	30.7	28.6	28.6
28,	28.3	28.1	28.2	27.9	28.9	27.2	27.4
29,	27.9	26.9	27.3	26.7	28.1	26.4	26.6
30,	27.7	27.2	27.4	26.9	27.4	26.7	27.0
Jul. 1,	28.4	24.5	28.3	26.4	28.2	24.5	26.6
2,	29.5	26.4	29.6	28.3	29.8	25.1	27.2
3,	29.4	28.8	29.5	29.1	29.7	28.5	28.8
4,	28.4	24.9	28.1	26.4	29.6	24.6	28.2
5,	31.5	25.5	31.5	26.5	31.2	24.8	28.8
6,	29.9	27.4	29.8	28.9	29.4	25.4	28.0
7,	30.5	29.2	30.6	29.2	29.4	28.8	28.2
8,	32.4	30.0	32.6	30.6	32.7	29.6	28.8
9,	29.9	28.0	30.7	30.3	30.2	27.6	27.8
10,	31.2	29.2	31.5	30.7	31.0	28.9	28.0
11,	30.8	28.9	31.8	30.8	31.0	28.4	28.4
12,	32.8	30.3	32.5	31.6	33.0	29.8	28.8
13,	33.3	29.8	33.2	31.6	33.5	29.4	29.0
14,	32.3	30.5	31.8	31.4	32.7	30.0	28.8
15,	31.8	31.0	31.7	30.2	31.8	29.4	28.6
Aug. 9,	31.8	29.2	31.3	30.6	32.1	28.3	28.2
10,	32.0	29.2	32.1	31.0	31.9	28.9	28.3
11,	32.1	29.7	31.6	31.2	32.3	29.4	27.8
12,	31.8	29.4	31.4	31.1	32.0	28.8	27.8
13,	31.6	29.3	31.2	30.8	31.8	28.6	27.7
14,	32.6	29.3	32.2	30.9	32.9	29.2	28.2
Jun. 26,1990	27.4	27.1	28.0	27.8	27.6	27.4	27.2
27,	27.2	27.0	27.6	27.5	27.3	27.1	27.0
28,	27.3	27.2	27.6	27.5	--	--	27.1
30,	29.2	28.7	29.3	29.0	29.1	28.4	27.2
Jul. 01,	29.8	28.0	29.7	28.6	30.6	27.8	27.8
02,	30.6	27.8	30.4	29.2	31.2	27.0	27.2
03,	30.7	28.2	30.6	29.3	31.5	27.9	27.8
04,	29.8	28.0	30.2	28.8	30.8	27.8	28.2
05,	31.7	29.0	31.6	29.8	32.8	28.5	28.8
06,	32.8	29.9	32.0	30.2	32.9	29.1	29.2
07,	32.3	31.3	31.9	31.4	32.1	30.6	29.8
08,	30.9	30.3	31.2	30.8	31.5	30.4	29.6
09,	30.0	29.6	30.4	28.6	29.9	29.2	29.2
10,	29.8	28.4	29.1	28.5	29.4	28.2	29.0
11,	30.0	28.4	29.3	28.4	29.7	28.1	28.9
12,	29.9	28.6	29.4	28.5	29.8	28.2	28.8
Aug. 05,	28.2	27.4	28.0	27.5	27.9	27.1	27.6
06,	28.5	27.6	27.9	27.6	28.0	27.1	27.8
07,	28.0	27.2	27.9	27.4	27.8	27.1	27.4
08,	28.1	27.3	28.2	27.7	28.3	27.1	27.4
09,	27.8	25.4	27.2	25.9	27.4	25.6	27.6
10,	27.6	25.7	27.5	25.9	27.6	25.4	27.7
11,	27.8	26.0	27.7	26.2	27.6	25.3	32.0
12,	28.2	26.6	28.3	27.0	27.9	26.2	28.0

* S:surface, B:bottom.

Table 2. Number of the decoloration of coral colonies in the shallow bay from May in 1988 to August in 1990.

	May 30, 1988			June 12, 1988			June 30, 1988		
	C*	P*	N*	C	P	N	C	P	N
1. Acroporidae	17	39	540	9	5	106	24	75	207
2. Pocilloporidae	25	125	216	9	25	10	4	22	55
3. Poritidae	0	1	17	0	0	4	0	7	27
4. Faviidae	4	13	174	0	4	10	3	12	16
5. Alcyoniidae	1	3	129	0	0	3	0	1	24
6. Other	11	24	201	4	6	22	6	19	27
Total colonies	58	205	1277	22	40	155	37	136	356
(%)	3.8	13.3	82.9	10.1	18.5	71.4	7.0	25.7	67.3
	July 7-9, 1988			July 22-23, 1988			August 17-19, 1988		
	C	P	N	C	P	N	C	P	N
1. Acroporidae	65	159	350	294	258	182	667	165	320
2. Pocilloporidae	29	72	115	11	21	75	79	38	74
3. Poritidae	2	3	45	2	2	33	9	1	5
4. Faviidae	11	25	59	14	24	26	33	26	60
5. Alcyoniidae	2	12	46	1	9	36	12	20	39
6. Other	11	41	67	49	23	58	114	24	63
Total colonies	120	312	682	371	337	411	914	274	561
(%)	10.8	28.0	61.2	33.1	30.1	36.8	52.2	5.7	32.1
	June 22, 1989			July 6, 1989			August 6, 1989		
	C	P	N	C	P	N	C	P	N
1. Acroporidae	14	39	272	18	44	290	14	72	202
2. Pocilloporidae	9	33	31	7	23	53	5	25	48
3. Poritidae	0	0	31	0	3	25	0	0	24
4. Faviidae	0	1	109	0	2	216	0	1	185
5. Alcyoniidae	0	2	95	0	0	69	0	0	83
6. Others	1	9	82	0	4	109	2	14	75
Total colonies	24	84	620	25	76	762	21	112	617
(%)	3.3	11.5	85.2	2.9	8.8	88.3	2.8	14.9	82.3
	August 14, 1989			September 27, 1989			July 1, 1990		
	C	P	N	C	P	N	C	P	N
1. Acroporidae	14	66	214	43	103	218	0	2	199
2. Pocilloporidae	11	24	29	10	26	24	0	3	20
3. Poritidae	1	2	17	0	4	32	0	0	7
4. Faviidae	0	6	144	1	30	145	0	0	88
5. Alcyoniidae	0	1	72	0	7	78	0	0	65
6. Others	1	10	27	0	10	42	0	0	34
Total colonies	27	109	503	54	180	539	0	5	413
(%)	4.2	17.1	78.7	7.0	23.3	69.7	0	1. 2	98.8
	July 10, 1990			August 5, 1990			August 9, 1990		
	C	P	N	C	P	N	C	P	N
1. Acroporidae	1	18	233	2	9	232	10	16	231
2. Pocilloporidae	1	7	32	2	8	24	4	14	28
3. Poritidae	0	0	29	0	0	18	0	0	17
4. Faviidae	0	0	145	0	0	131	0	0	170
5. Alcyoniidae	0	0	83	0	0	67	0	0	76
6. Others	0	5	62	0	1	49	0	2	50
Total colonies	2	30	584	4	18	531	14	32	572
(%)	0.3	4.9	94.8	0.7	3.2	96.0	2.3	5. 2	92.5

* C: Complete decoloration colonies; P: Partial decoloration colonies; N: Normal colonies.

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ASSESSMENT AND CONTROL OF MARINE POLLUTION IN SOUTH PACIFIC ISLANDS

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ABSTRACT

The characteristics and causes of problems of marine pollution in the South Pacific are briefly described. The current state of knowledge regarding the region's pollution situation is considered, and current assessment and control activities are discussed. The purpose and activities of SPREP POL, the marine-pollution component of the South Pacific Regional Environment Programme (SPREP), are described.

MARINE POLLUTION IN THE SOUTH PACIFIC

Problems of marine pollution in the South Pacific islands can be summarised under four headings (SPREP 1990):

- destruction of coastal ecosystems;
- lowering of water quality;
- changing ocean properties and processes; and
- climate change and sea-level rise.

The marine-pollution component of the South Pacific Regional Environment Programme (SPREP POL) addresses the first three of these issues.

The primary causes of pollution are the disposal of domestic waste (including sewage), the disposal and management of non-domestic waste (*e.g.*, agricultural chemicals, oil, tyres), increased sedimentation (resulting from changing land use, forestry, and mining), coastal development (tourism, port construction), over-exploitation of living marine resources (reef fish, shellfish, mangroves), and natural disasters such as volcanic activity, earthquakes, and cyclones (Brodie and Morrison 1984; Brodie *et al.* 1990; Morrison 1991).

Secondary causes include inadequate waste disposal facilities, inadequate legislation or ineffective application of existing legislation, lack of awareness of the seriousness of the problems, the sectoral separation of many national planning activities, and the lack of adequate data for the preparation of legislation and mitigating actions.

The knowledge gaps that have been identified include the following:

(a) A lack of long-term data to facilitate the recognition of temporal and spatial trends. There are one or two notable exceptions discussed below.

(b) A knowledge of the behaviour of toxic contaminants (*e.g.*, pesticides) in critical environments is unavailable.

(c) There is no basis for estimating the health impacts of the microbiological contamination caused by uncontrolled sewage discharges.

(d) Few baselines exist for the development of programmes studying ecosystem changes as pollution indicators.

(e) Apart from certain fish species, information on the extent of use of marine resources is lacking.

Existing assessment and control activities include limited research carried out by national, regional, and international agencies, localised but often overloaded waste-treatment and disposal facilities, varying levels of environmental-management planning, suitable environmental legislation in many countries, and a rapidly expanding program of environmental legislation.

Resources to carry out marine pollution assessment and control activities are very limited. Trained manpower is lacking, and there is a general trend of out-migration or transfer within government of such specialists. Facilities and funding for these activities are often inadequate. What equipment is available is often inoperative (because of poor servicing) or under-utilised because of the lack of supporting services (electricity breakdowns, poor water supply). Even the use of low-level technology or community monitoring is restricted because of the lack of staff to provide training and compile/analyse the data produced.

THE MARINE-POLLUTION COMPONENT OF THE SOUTH PACIFIC REGIONAL ENVIRONMENT PROGRAMME (SPREP POL)

The overall goal of the SPREP POL programme is to assess the extent of pollution and to provide a basis for recommendations to control such pollution. The objectives include:

(a) the provision of information on types of pollutants;
(b) generation of time series of data;
(c) analysis of the causes of pollution;
(d) contribution to UNEP's Global Environment Monitoring Systems programme (GEMS); and

(e) enhancement of indigenous capability in assessment and control of marine pollution.

These objectives will be achieved by a combination of monitoring programmes, baseline studies, and research activities.

The monitoring will focus initially on ocean properties and processes -- including the South Pacific components of Joint Global Ocean Flux Study (JGOFS) and World Ocean Circulation Experiment (WOCE) -- as well as on heavy metals, pesticides (particularly organochlorines), sewage, and other potential contaminants such as hydrocarbons and surfactants. Standard methods will be used to ensure comparability of data, and quality assurance will be emphasised at all times. A few of the monitoring activities will be long term so as to provide a basis for assessing changes on a global scale. Most will, however, be of relatively short duration (1-2 years) initially, studying areas of known or suspected pollution.

The baseline studies will include a region-wide, land-based pollutants survey. Since virtually all of the pollutants in the South Pacific are land-derived, the survey will provide the data necessary for determining what pollutants are likely to be found in any given locality. Atmospheric transport of pollutants may be important in certain parts of the world, but recent studies have shown that the South Pacific atmosphere (apart from certain industrial areas) is the cleanest so far studied (Riley *et al.* 1989). A section of the land-based pollution study will focus on sediment inputs to the South Pacific ocean via rivers. This will also provide a valuable baseline for assessing the impact of future land use changes, including logging and mining.

The research activities include the development (by ORSTOM) of a computer simulation circulation model for coastal lagoons. This is important as many major population and industrial centres in the region are located on or near lagoons. Knowledge of the behaviour of pollutants discharged into these zones of limited mining and/or fishing is important in planning pollution control programmes. Another activity utilises data from the major long-term marine monitoring program in the region -- that of the Guam Environmental Protection Agency. The Agency has been asked to review its 12-year data set and consider the selection of sites and parameters in the light of the original objectives. From this exercise it is hoped that other regional governments will be able to design better monitoring programmes, avoiding mistakes that might otherwise waste limited resources.

In addition, national marine pollution programmes will produce supporting data. For many countries this work will be extremely limited or non-existent, but Australia, New Zealand, Guam, and French Polynesia will provide valuable local information. Some bilateral projects (*e.g.*, the USAID project in Tarawa lagoon, Kiribati) will generate useful information. International programmes such as JGOFS and WOCE will provide valuable support in the study of ocean processes and properties.

Training activities are a part of SPREP POL and will facilitate the enhancement of the indigenous capability essential for long-term control of marine pollution. An emergency

response fund will be available to governments so that events like chemical spills and fish kills can be quickly investigated. Funding has been provided by UNEP, with complementary activities supported by the Canadian International Development Agency/International Centre for Ocean Development (CIDA/ICOD). Several other aid agencies have expressed an interest in supporting aspects of SPREP POL.

Marine pollution problems in the South Pacific have expanded significantly in the last decade. An efficient, effective programme of assessment and control is essential to prevent the situation becoming even more serious. SPREP POL represents an integrated, multi-faceted, multi-agency attempt to reduce these problems and maintain or improve the quality of the marine environment for the benefit of the peoples of the region.

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IV. Marine Science Education

INTEGRATING GLOBAL WARMING/SEA LEVEL RISE PHENOMENA INTO THE SCIENCE EDUCATION OF PACIFIC CHILDREN -- A CASE STUDY Of MICRONESIAN EDUCATION

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ABSTRACT

Even though the Pacific Islands face extraordinary environmental challenges, the quality of environmental science in the elementary and secondary school curricula of Pacific children has never been systematically analysed. Global warming/sea level rise phenomena represent one class of environmental challenge facing Pacific Island people. All of the low-lying islands of the Pacific are at risk of inundation or damage by these effects, yet few children or adults in the islands have a rudimentary understanding of these or other environmental phenomena and processes. The purpose of this paper is to explore environmental-science education for school children as it relates to the global warming/sea level rise phenomena in that part of Micronesia where schools follow the USA format, that is, Guam, the Commonwealth of the Northern Mariana Islands, the Republic of the Marshall Islands, the Republic of Belau, and the Federated States of Micronesia.

CURRENT STATUS OF SCIENCE EDUCATION IN MICRONESIA

Curriculum policy

The eight school systems of Micronesia have been very active in the past five years in developing curriculum policy and curriculum frameworks for various school subjects. The frameworks generally specify philosophy, goals, learning objectives, specific educational activities, materials, and methods of assessing competence. These elements of curriculum are divided up across all grade levels with some degree of overlap between the educational matter at the end of one grade and the material at the beginning of the next grade. Many times, the curriculum framework is derived from an examination of one or more textbooks on the subject for a particular grade, adjusted downward to meet the limited English proficiency of students. In the language arts, a small collection of first-language materials have been developed in Micronesia on math or science. Of these, health topics have been predominant. Some educators debate whether or not the indigenous languages of Micronesia can communicate scientific ideas. Where the effort has been made, the Micronesian languages have proven capable, borrowing technical terms from English or Japanese where needed.

In some places the development of curriculum framework is incomplete for some topics. Teachers have usually not yet received training that will lead to classroom implementation of the curriculum frameworks. The majority of teachers in Micronesia receive their teacher preparation at the community colleges of Micronesia and at the University of Guam. Although a science instructional methods course is on the University roster, it is frequently taught at the same time and in the same classroom with other methods courses. There is no science-education specialist on the faculty of most of the community colleges or at the University. Inservice training provided to teachers rarely addresses science education, although some integrated language arts and science workshops have been held in the past year.

Instructional materials for science education in Micronesia are usually science textbooks from the USA. Some school systems have chosen materials from Hawaii such as the Hawaii Nature Program (University of Hawaii 1980), which covers Pacific plants, and the FAST program (University of Hawaii 1978), which is designed for hands-on activities and work with reference materials. In Yap, parts of the science curriculum and accompanying materials were developed by local specialists and are squarely centred on the environmental science of Yap state and Micronesia (Falanruw, 1987). There have been a few efforts to create supplementary contextualized science materials (*e.g.*, Merlin & Keen 1990). However, there are problems with these since they have been produced completely outside the realm of the curriculum framework, and are written at a level more suitable for post-secondary education.

An examination of the concepts covered by most of the science-curriculum frameworks in Micronesian schools would bring some satisfaction to advocates of a strong science education. Many frameworks also incorporate context based on the island environments, although content lists could be improved by the addition of more explicit coverage of environmental impacts actually facing specific Micronesian islands. However, the implementation of these curriculum frameworks in the schools and classrooms of Micronesia is disappointing because:

(1) in spite of the inclusion of science in the daily or weekly class schedules of grades 1 through 12, science is actually taught irregularly and infrequently;

(2) the content covered in classrooms does not correspond to what is outlined in the frameworks;

(3) students cannot understand what is written in their text materials, and very little experiential activity occurs because of the lack of science equipment and lack of lesson plans based on what equipment is at hand;

(4) most teachers have not received training in how to teach science or environmental science;

(5) available materials and approaches are frequently irrelevant to the environments and issues of the students' own islands;

(6) the rich ethnoscience of Micronesia is almost completely ignored or discounted, with no effort made to weave in local knowledge or methods; and

(7) even when science is taught, there is often no attention to the development of attitudes (feelings, values, beliefs, and appreciations) supportive of scientific knowledge and its application.

If the concerns above were rephrased slightly, they would describe concerns about science education in many other parts of the world. It is important to recognise that some advances in science education in Micronesia have been made in recent years; for example, curriculum frameworks have been developed; science education has been discussed at two major regional conferences in the past four years; and science centres have emerged in some of the Micronesian schools. But much more attention should be devoted to improving the quality of classroom science education in Micronesia if public understanding of environmental problems is to be heightened, and if the number of Micronesian students interested in and prepared to begin careers in science is to surge ahead.

TRENDS IN SCIENCE EDUCATION IN THE UNITED STATES

Traditional science teaching in the USA has been described as packed with facts and as unfocused, didactic, and overly dependent upon rote memory at the expense of thinking skills. The failure of American students to measure up to the science achievements of students in many other parts of the world has spurred reform efforts (American Association for the Advancement of Science 1989). Both the traditional and the reform approaches affect Micronesian students because the slim experience of Micronesian students with science education comes from an American philosophy of science education, from teachers influenced by this philosophy, and from materials produced by US publishers.

Roth (1989) describes four major American perspective on science education. In response to the *traditional* format, the *inquiry movement* in science education emerged in the 1960s and 1970s. It views students as little scientists who learn by engaging in hands-on activities, developing and using the conceptual skills of predicting, hypothesising, observing, recording data, making inferences, and drawing generalisations. Although advocates of the inquiry approach acknowledge the value of science content, they place greater emphasis on science process, particularly scientific thinking skills. There is a naive tendency to expect that content knowledge, conceptual understanding, and an affective orientation toward science will develop naturally out of the process skills. Roth (1985) and Smith and Anderson (1984) compared the understanding of concepts and student attitudes during a unit on photosynthesis in a traditional instructional setting and in an inquiry instructional setting. After eight weeks of hands-on activities, students in the inquiry program still failed to grasp the fact that plants manufacture their own food. They liked some of the hands-on activities, but did not seem to understand why they did them.

Two other science education reforms are the *science-technology-society* (STS) perspective, and the *conceptual change* (CC) perspective. Yager and Hofstein (1986) have described the goals of the STS perspective. Current problems and societal issues are the core of the curriculum. Concepts and processes useful on a daily basis to students are emphasised at the expense of those more relevant to scientists. Consumer decision-making and environmental awareness are nurtured, as are values and ethical or moral considerations. Like inquiry methods, the STS approach concentrates on process skills more than on content, but the process skills of STS (use of scientific knowledge) are defined differently from those of the inquiry process (creation of new scientific knowledge). Roth (1989) speculates that an STS photosynthesis unit might focus on the effects of deforestation and industrialisation the warming of the Earth's atmosphere due to the greenhouse effect. Science concepts would include absorption of solar energy by the Earth's atmosphere and the changing balance of $0_2/CO_2$ in the Earth's atmosphere because of the use of fossil fuel and the widespread cutting of rain forests. Students would be helped to assess the severity of the problem and to think of possible solutions to the growing danger of the greenhouse effect.

The CC approach holds that scientific knowledge is used by learners only when it is useful in making sense of their own worlds. (Anderson and Roth, in press; Driver 1987). The power of this kind of scientific knowledge stems from its connection with the student's personal experiences, their schema, and by the internal organisation of the ideas. Science literacy is seen as a sense-making enterprise. Whatever the science concepts studied, the richness of the understanding enhances the student's appreciation of scientific learning and activity. CC encourages motivational strategies such as abandoning traditional disciplinary-bound curricula in favour of societal issues and popular contemporary science topics. Process skills are not to be practiced in isolation from genuine understanding and interest.

THE MATERIAL CURRICULUM - A SELECTIVE REVIEW

Because science education in Micronesia is mainly based on US science textbooks, a review of this material curriculum might help answer several relevant questions:

1. How does the material curriculum cover the foundation concepts essential to the Micronesian child's understanding of global warming-sea level rise (GW-SLR) phenomena?

2. Where are the points of entry into the material curriculum for enrichment study of either the foundation concepts or more focussed study of the GW-SLR phenomena?

3. Given the existing material curriculum, and the instructional approaches employed, what recommendations can be offered for creating curriculum supplements and more stimulating or effective instruction?

4. How should instruction and curriculum be differentiated in view of student characteristics such as age, language proficiency, motivation, and stage of cognitive development?

Six science textbook series were reviewed in an attempt to discover how useful this methodology would be. The effort was hampered by the absence of any comprehensive list of science text books used in Micronesian schools. Further, marketing of US science textbooks in the region may soon lead to changes, and there is no centralised collection of these materials. The review included three grade one to six (primary) science textbook series (Laidlaw, 1976; McGraw-Hill, 1979: and Silver Burdette Science, Centennial Edition, 1985), and three junior-high-school (secondary) series (Science Worship Series, Globe, 1988; Globe Series, 1986; and Globe Work-A-Text, 1987). Selected materials were also examined from the Hawaii Nature Program (University of Hawaii 1980) and the FAST Program (University of Hawaii 1978). All these materials have been used in Micronesian schools. The copyright dates of these materials show that it is not uncommon to find old science textbooks used in Micronesian schools, with the age varying from one to 15 years. Some language arts books purchased just this year were 10 or more years old at the time of purchase (see Spencer, 1990, for a discussion of unethical bookselling practices in Micronesia).

The review process was constructed as a broad-gauged content analysis. The few concepts focused on are important to an understanding of the GW-SLR phenomena: *carbon dioxide*, *ozone*, *fossil fuels*, *pollution*, and *human impacts on the environment*. Inspection of the table of contents, glossary, index, and a page- by-page perusal were applied to each book in each series to glean understandings of the rationale of the material structure, formatting, content depth, instructional approaches, and hands-on activities. Findings were:

1. GW-SLR concepts receive little or no coverage in many of the science books in the grade 1 to 6 textbook series.

2. The older elementary series are very inadequate in coverage. The single newer series reviewed (Silver Burdette, Centennial, 1985) is markedly better.

3. The junior-high-school materials address more of the concepts, address them more often, and in more depth.

4. The junior-high-school materials designed for below-level students were particularly weak in coverage of the concepts, as well as in explanation of science material in general.

5. Although the rationale for hands-on science activity as an effective instructional method is often espoused in the material, many of the materials that use this approach are weak. The few activities offered are often uninteresting, are poor demonstrations of the phenomena, and often require chemicals or equipment that are not available in Micronesian schools. They lack appealing photographs and illustrations.

6. None of the materials examined took into consideration the limited English proficiency of the Micronesian students.

7. In spite of an effort to use below-grade readability levels, most of the material seemed ill-designed relative to the cognitive development of students at the grade level of the

materials. Little care is taken to establish connections between the students' experience and the scientific concepts; the information is not presented in a logical sequence from a concrete foundation to more abstract materials; and little is done to encourage students' intrinsic motivation.

8. In general, the coverage of the GW-SLR is slight -- nonexistent in some primary-school materials. And some of the points made are questionable, as, for example, the observation that fossil fuels are important because modern society needs an increasing supply of them, making the discovery of more fossil fuels a necessity.

9. None of the series cover oceanic and coastal concerns sufficiently, considering the importance of these ecosystems to children of the Pacific.

INTEGRATING GW-SLR PHENOMENA INTO SCIENCE EDUCATION IN MICRONESIA

Prior to the review, it seemed that two possible strategies might be selected as ways to deepen Micronesian children's understanding of GW-SLR. First, curriculum materials and instructional approaches could be selected that already strong in this area. Second, supplementary materials and activities could be developed, and strategies designed for inserting them into the existing curriculum.

Selecting appropriate textbooks and materials

The review shows that most existing materials have little or no coverage of GW-SLR, but a few commercially produced science education supplements are now available which address GW-SLR. Publishers representatives report that new science textbooks are likely to expand treatment of the Greenhouse Effect. In addition, the ICSU Committee on the Teaching of Science reports that it has decided to engage in its first major curriculum development project, targeting 16- to 19-year-old students, using global change issues to introduce and illustrate scientific principles and to demonstrate that science is an international endeavour. With new and improved materials on the horizon, there is reason to recommend the development of guidelines for future textbook review and adoption that will ensure that new textbooks increase student access to GW-SLR information.

1. The first step in reviewing science textbooks for GW-SLR coverage is to assemble a comprehensive collection of materials. This can be done by compiling a list of major publishers and sending each a carefully written letter that clearly defines the boundaries of the review.

2. The second step in the review is to specify the key GW-SLR concepts, then to inspect the textbooks' table of contents, and to identify by a page-by-page perusal how the key concepts are treated in *each* text of the science series. Sometimes publishers will agree to provide this service to potential customers free of charge, supplying a list of page

numbers showing where to find each target concept. Points to keep in mind in seeking useful texts include:

-- phenomena underlying GW-SLR should be introduced from the earliest primary levels;

-- information should be introduced in an orderly, coherent manner, leading from fundamental concepts (connected with the students' own experience) to new and more abstract concepts;

-- hands-on, experiential activities are very useful in teaching students with limited proficiency in English, but the hands-on activities presented in the texts need to be assessed carefully as to their practicality and their relevance to local island life;

-- "dumbed-down" texts need careful inspection as some of them have been found to be very unsatisfactory in quality of explanation, visual and graphic material that could potentially have substituted for narrative explanation, and introduction of key GW-SLR concepts; and

-- it is important to check copyright dates because some US publishers sell old materials in the Pacific for current year prices. (Many educators believe that any science textbook more than five years old is obsolete. In the selection review done here, this proved to be true in that even materials only two years old were disappointing in coverage of GW-SLR. Publishers' catalogues indicate that new textbooks will give more attention to GW-SLR. These should be used!)

3. Reviewers should give the issue of students' motivation serious consideration. The way science education is presented in childhood will *set* children's motivational pattern for absorbing science information for the rest of their lives. New, highly visual materials, dealing with natural phenomena that children recognise as part of their own lives or that take them into direct exploration of the wonders of their own environment are likely to build life-long motivation for understanding and protecting the natural world. The materials may not explicitly cover GW-SLR, or may not cover it in much detail, but if they motivate children to explore nature, the materials have merit. The technical material in science textbooks is vulnerable to becoming outdated, which will require changes in subsequent texts. But if the child's habit of appreciating and exploring the world has been enlivened, she or he will catch up on new developments as new information becomes available.

Creating Supplementary Materials

Because of the shortage of funding facing most school systems in Micronesia, old materials will continue to be the most available for some time. Therefore, it is imperative that

Pacific scientists and educators develop GW-SLR lesson plans and activities geared to several different age levels for teachers and students to use now with whatever curriculum materials they happen to have. But developing supplementary materials in a haphazard way will waste scarce funds for material development. The preliminary guidelines below for GW-SLR supplementary material development are offered in the hope that they may be of use to the South Pacific Regional Environment Programme and other science-education organisations.

1. Any plan for development of supplemental materials should be preceded by a careful examination of the science-curriculum policy and framework in the specific school system for which the materials are intended. The supplemental materials should be designed for insertion into specific entry points in the official curriculum. Clear explanation should be designed to inform teachers how and where to interface the supplementary materials with the existing materials.

2. Any plan for developing supplemental materials should be preceded by expressions of interest and commitment to use them by the curriculum policy makers in the school system for which they are being designed. Pacific teachers often do not have the autonomy to use materials they like in their classrooms, even if the materials are provided free of charge.

3. Guidelines for developing supplemental materials can incorporate many of the features already discussed as important to the review of science textbooks. Additional points that should be kept in mind include:

   -- The need for compatibility with learning styles and discourse styles of children from varying Pacific cultures. This may mean, for example, learning activities which can be done by student teams.

   -- The need to provide teachers with information that allows the utilisation of the child's culture and first language. First-language materials may need to be provided.

   -- The need to guard against crowding too many concepts into a single lesson or activity. Allow for incremental and hierarchical concept building.

   -- The need to create explanations for teachers that are clear, illustrated with the line drawings and diagrams, that show exactly how to carry out supplementary activities and lessons. Many teachers have not received training in science education and may be new to the process of teaching science.

4. Students' existing schema for environmental science should be explored by engaging them in a variety of writing activities on GW-SLR. For example, they could make a classroom newspaper of the GW-SLR target concepts. They could write personal journals which include observations on a particular target concept. Essays and mini-

research papers on the environmental hazards facing their own islands could lead students to incorporate more technical information into their existing understanding of issues;

5. Pacific children should be helped to develop a sense of empowerment to counteract pollution, as by:

   -- creating activities in which student themselves develop mini-lesson plans and teach environmental protection concepts;

   -- fostering environmental awareness and self-expression by having students draw, paint, or use traditional art forms to depict their observations of GW-SLR concepts;

   -- fostering a strong sense of involvement by organising students to write letters to the leaders of the industrialised countries, describing the beauty and fragile environments of their islands and asking the leaders to take responsibility for reducing their countries' high consumption of fossil fuels, which worsens the GW-SLR phenomena; and

   -- conducting a lesson on how the Montreal agreement to ban chlorofluorocarbons came about. This lesson could include helping students to make their own official agreement based on this or other GW-SLR related documents and then allowing them to circulate the agreement around the community, explaining the problems and obtaining signatures. The final, signed documents, should be sent to government officials at local, national, or international level, with a letter from the students explaining why they gathered the signatures.

More and more books, articles, and pamphlets on GW-SLR are becoming available to the lay public (*e.g., A Climate of Crisis: Global Warming and the Island South Pacific* by Peter Hulm 1989; Is our World Warming?, *National Geographic*, by Samuel Matthews 1990). Some scientists have asked if these and similar materials, if translated, could become appropriate supplemental materials for Pacific schools. The answer is that most could be used as resource materials in high schools -- and need not be translated at that level -- but the effectiveness of the materials may be slight unless students have benefited from the building of a foundation of key concepts related to GW-SLR before they are given these advanced materials. For these teenage students, it may be well to precede lessons with a video or film as a motivating device, then go on to work on foundation concepts, and eventually to full blown GW-SLR phenomena.

It is at least as important, however, to give attention to building foundation concepts during grades 1-8. For this, environmental scientists need to provide ideas and lesson plans for educational activities that teach the fundamental science of GW-SLR, help both younger and older students grasp the impacts of GW-SLR on their own islands, and empower them to protect their islands. It will be important for environmental scientists to collaborate with professional educationalists who understand how to develop curriculum for children of different

ages and varying language proficiencies. Too often, individual scientists spend money on projects that result in products that are unusable in the classroom because they have ignored issues of cognitive development in children and principles of curriculum development.

Pacific scientists and educators are advised that the services of Project BEAM, the Bilingual Education Multifunctional Resources Centre for the Micronesian Region, and the Micronesian Language Institute, both at the University of Guam, are available as collecting centres for ideas and sample lesson plans on GW-SLR for children. Specifically solicited are hands-on activities that demonstrate basic phenomena, using classroom and school yard materials readily available in Pacific schools. Preferred focuses include the atmosphere , its components and their relationships; pollutants, their nature and how they cause environmental damage; human environmental behaviour, positive and negative; the chemistry and mechanics of the greenhouse effect; and ideas for empowering Pacific youth to prevent and cope with damage to their islands by GW-SLR.

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NETWORKS FOR MARINE SCIENCE EDUCATION IN ASIA AND THE PACIFIC:

A Report on a Session Convened at the XVII Pacific Science Congress

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ABSTRACT

UNESCO/ROSTSEA* (Jakarta) has developed a proposal to organise an Indo-Pacific network of marine and environmental science institutions to collaborate on enhancing education and monitoring programmes, with special reference to global change. More than 80 participants from 25 countries throughout the region met at the XVII Pacific Science Congress to review the proposal. Suggested changes were incorporated into a revision that will be submitted to UNDP for funding. Individual presentations were made about existing marine science education programmes in Indonesia, the People's Republic of China, and India. An organising committee was formed, and a tentative program outlined for a marine curriculum workshop to be held in India in 1992.

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* UN Acronyms

ESCAP =	UN Economic and Social Commission for Asia and the Pacific
ESSD =	Environmentally Sound and Sustainable Development
ROSTSCA =	UNESCO Regional Office for Science and Technology for South and Central Asia
ROSTSEA =	UNESCO Regional Office for Science and Technology for Southeast Asia
UNCED =	United Nations Conference on Environment and Development (1992)
UNDP =	UN Development Programme
UNESCO =	UN Education, Scientific, and Cultural Organization
WESTPAC =	Western Pacific Region, Intergovernmental Oceanographic Organization (IOC) of UNESCO

HISTORY OF NETWORK PROPOSAL

In 1986 UNESCO organised a brief planning meeting in Bangkok for a major inter-regional meeting on marine science curricula to involve countries represented by ROSTSEA (Southeast Asia and the Pacific) and ROSTSCA (Western and South-Central Asia) (UNESCO 1986). The matter was further discussed by a group at the XVI Pacific Science Congress (PSC) in Seoul in 1987. The major curriculum meeting was held in Qingdao late in 1987; it incorporated the findings of a curriculum/employment survey designed by the Bangkok group, and the Qingdao experts advanced the recommendation that a network be established to enhance marine science education at the tertiary level throughout the region (UNESCO 1989). ROSTSEA in 1989 contracted one of the Qingdao participants to draft a funding proposal for UNDP consideration. During a six-month period he travelled extensively throughout the region visiting marine science education institutions, and he conducted a further mail survey of potential network members. A small meeting of experts in Jakarta in August of 1989 provided additional guidance for proposal development. At a curriculum workshop sponsored by ROSTSEA in Jakarta in March 1990, faculty participants from the network region critiqued the proposal. A draft of the proposal was reviewed by a workshop of invited experts at the Fourth Pacific Congress on Marine Science and Technology (PACON) in Tokyo, July 1990 (Maynard *et al.* 1990). These comments were incorporated in the first draft of the proposal published for dissemination outside of ROSTSEA (UNESCO 1990). The proposal was also tabled before ESCAP meetings in 1990 and 1991. A subsequent revision (UNESCO 1991a) was circulated to potential participants in the session scheduled to review the proposal at the XVII Pacific Science Congress in Honolulu. The most current version of the proposal was completed just prior to PSC XVII and incorporated comments received by ROSTSEA in correspondence and in a March 1991 meeting with the aforementioned consultant (UNESCO 1991b). After ROSTSEA considered the PSC XVII comments, the proposal will be forwarded to UNDP. It will be discussed also at the December 1991 WESTPAC meeting in Penang and at UNCED in June 1992 in Brazil.

OVERVIEW OF NETWORK PROPOSAL

Objective

The project objective is to develop an inter-regional network to support and enhance existing educational organisations and structures for marine studies to prepare present and future generations with an understanding of marine and associated systems as they relate to ecologically sound and sustainable development in a continually changing world.

Geographic Coverage

As presently envisioned, the network would encompass the Indo-Pacific region from Iran in the West to Hawaii in the East and from the former U.S.S.R. in the North to New Zealand

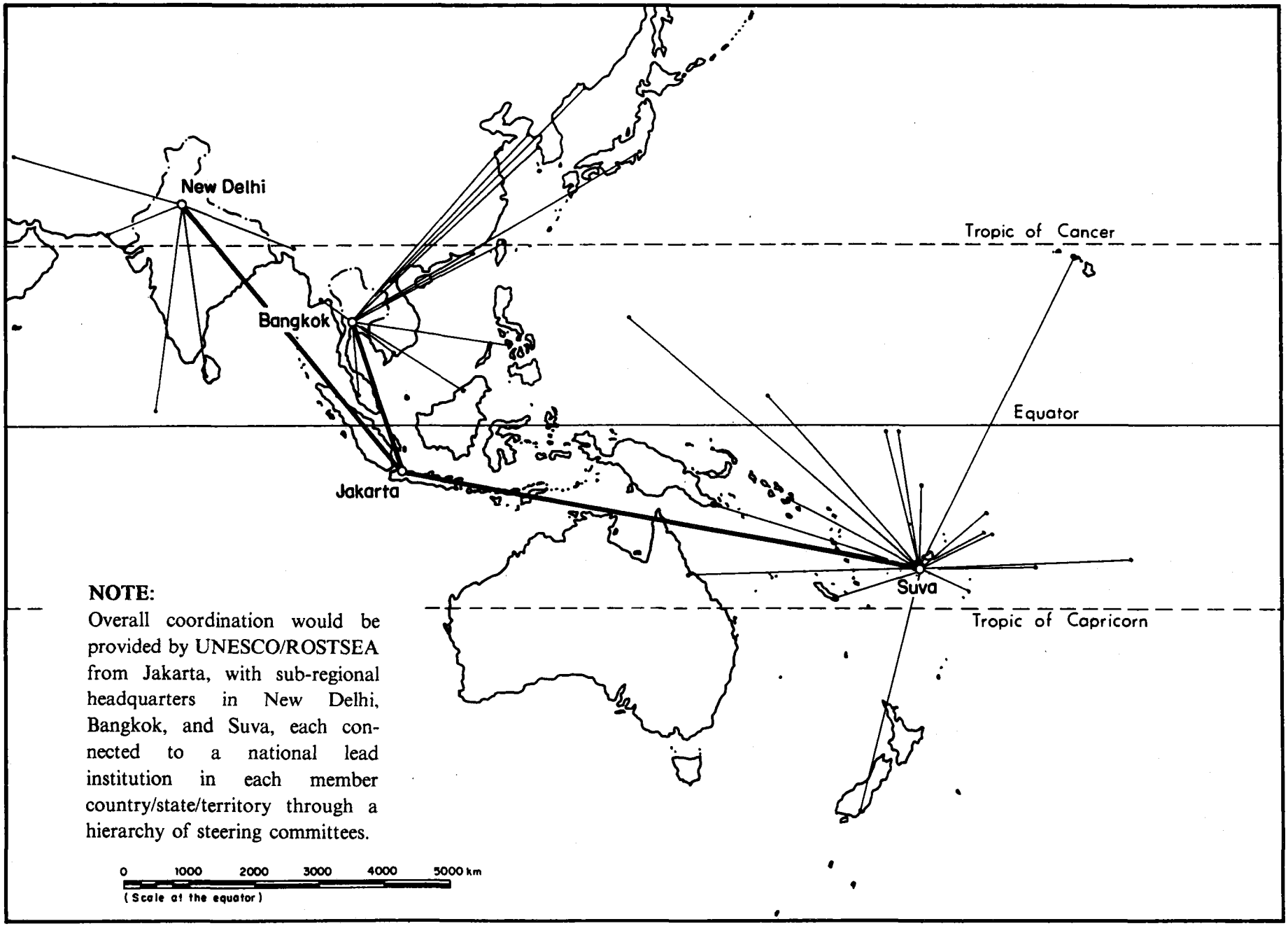

Figure 1. Proposed UNESCO Indo-Pacific Network of Marine Education Institutions.

in the South. Inclusion of the East Coast of the Pacific Basin (from the U.S.A. to Chile) was proposed at PSC XVII and is under consideration. Developing, newly industrialising, and developed countries may all belong (Figure 1).

Organisation

To facilitate management of the network and to assure better sensitivity to local needs, the country and state members would be organised into three sub-regions: West and South-Central Asia, East and Southeast Asia, and Pacific Islands. The composition of membership for each sub-region is still being worked out. Overall coordination would be based at the Jakarta office of ROSTSEA. Each of the three sub-regions would identify one institution to which a secretariat and teaching resource centre would be attached. Policies and programme priorities would be established by a steering committee for each sub-region. This committee would meet at least annually and consist of one representative from each national steering committee within its region. The national committees would be comprised of front-line education staff (faculty, teachers, training officers, *etc.*) of representative marine education institutions (colleges, universities, schools, marine resource departments, research facilities, oceanaria, environmental protection agencies, NGOs, *etc.*) from throughout the country or state.

Funding

The proposal is designed to secure at least five years' worth of start-up funding from the UN Development Programme. It is intended that others with interests in the region will also support the network, *e.g.* Asian Development Bank, World Bank, UN Environment Programme, U.S.A.I.D., J.I.C.A., A.I.D.A.B., I.C.O.D., E.E.C., IGBP, IOC, ESCAP and others. The preliminary five-year budget totals about US$ 30 million.

Programmes

The network will bring together individuals and institutions in the region to undertake activities grouped into nine areas. Global change and environmental stewardship will be core themes.

1. Organise the network administration, including the secretariats, steering committees, and institutional membership.

2. Through periodic training/curriculum workshops, keep faculty up to date on the latest developments in the field and on improvements in teaching technologies.

3. Co-ordinate faculty exchange programmes for teaching, curriculum development, and research.

4. Place tertiary students in other regional institutions for specialised training, for short-term research projects, for long-term matriculation in programmes not available at home institutions, and for participation in an annual regionwide symposium of student projects.

5. Conduct field-training workshops for secondary teachers to prepare their students to collect and analyse environmental data in conjunction with monitoring and ground- truthing programmes.

6. Develop, maintain, and publicise an information base/directory about the programmes, facilities, and personnel expertise of member institutions.

7. Act as an information clearinghouse for marine-education programmes, materials and services, training sessions, funding opportunities, employment, meetings, and ideas.

8. Establish sub-regional teaching resource centres which will collect, develop, and disseminate relevant, locally/regionally-based curricula and support materials.

9. Regularly submit proposals which support marine education programmes in the region and to serve as a point of co-ordination for external aid in marine and environmental sciences.

PSC WORKSHOP PARTICIPANT COMMENTS

More than 80 participants from 25 countries attended the PSC session. There was general agreement that the network and its programmes as conceived were worthwhile and that implementation should proceed without further delay. Some reservations were expressed about the scope, target audience, organisation, and size of the undertaking. Particular concerns were expressed about securing sufficient funding to underwrite the programmes. A number of questions were raised about which countries should belong to which sub-region. Concern was also expressed about whether adequate co-ordination could be achieved with other programs already working in the region.

Participants endorsed a resolution that was subsequently approved by the Pacific Science Council and ratified by the Pacific Science Association as "Resolution--4" arising from the XVII Pacific Science Congress:

.....

Resolution--4
NETWORKS FOR MARINE SCIENCE EDUCATION

Whereas the development of networks for marine science education in Asia and the Pacific is deemed to be important,

Be it resolved that the Pacific Science Association endorse the UNESCO/ROSTSEA "Proposal for an Indo-Pacific Marine and Environmental Science and Technology Education, Training and Monitoring Network at the Secondary as well as Tertiary Levels and Beyond -- A Link in a Strategy for Managing Global Change in the 21st Century "; and,

Be it further resolved that the Association commends UNESCO/ROSTSEA for developing this timely proposal and urges UNESCO to move it forward as expeditiously as possible for funding and implementation.

.....

In addition, participants agreed to the following:

Recommend that UNESCO present the proposal as an education programme/project to UNCED

Request UNESCO to draw the attention of IGBP to the similarity between this project and the START proposal and invite them to consider unification

Ask UNESCO member states to officially request the UNESCO secretariat to proceed with asking UNDP to fund network

Request UNESCO member state delegations to raise the requirement for this project at the UNESCO general conference in October 1991

Request UN member states to include mention of the project as an appropriate action for ESSD attainment in their country reports to UNCED (Brazil 1992)

Request UNESCO/IOC member states to pass a resolution at the upcoming WESTPAC scientific programme meeting in Penang, Malaysia, in December 1991 to support the project through UNDP

POST-CONGRESS DEVELOPMENTS

ROSTSEA is preparing a revised proposal accommodating input from Congress participants. This will be forwarded to UNDP via UNESCO Headquarters (Paris), with funding possibly starting as early as January 1992. A curriculum workshop is being planned for December 1992 at Andhra University in India.

ACKNOWLEDGEMENTS

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V. Marine Ecosystem Classification

A MARINE ECOSYSTEM CLASSIFICATION FOR THE SOUTH PACIFIC REGION

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ABSTRACT

In 1991, the South Pacific Regional Environment Programme (SPREP), the U.S. Agency for International Development, The World Wildlife Fund, The Nature Conservancy, the East-West Center, and the U.S. Fish and Wildlife Service all collaborated and sponsored a program to develop an ecosystem classification of the insular tropical Pacific that would be useful in furthering resource inventories and conservation efforts in the region. The steps followed in developing the classification included: 1) preparation and distribution of review papers (in February 1991) summarizing past efforts at classifying ecosystems, especially those applicable to the South Pacific, 2) sponsoring workshops at the East-West Center in Honolulu (in March 1991) to assemble scientific experts to review past efforts and develop an ecosystem classification applicable the South Pacific, 3) presentation of the draft ecosystem classification before a broader scientific audience at the Seventeenth Pacific Science Congress in Honolulu (in May 1991) in order to solicit suggestions and revisions, 4) preparation of a revised classification for formal scientific review (in September 1991), 5) sponsoring another workshop in Vanuatu (held in October 1991) to solicit feedback from the 22 member countries of SPREP and to "test" the ecosystem classification, and 6) to finalize the ecosystem classification (in December 1991) so that it can be used for field inventories and other conservation efforts that are now being planned throughout the region. This report covers progress to date on the marine component of the ecosystem classification. A second component covering inland waters is being published separately by Polhemus *et al.*, and a third component (terrestrial ecosystems) is still undergoing revision while this report is being prepared. Collectively these three components (marine, terrestrial and inland) constitute the entire ecosystem classification developed for the South Pacific, and the classification has been structured to allow it to be incorporated into a larger global ecosystem classification if or when one is eventually adopted.

Considerable effort is being placed on establishing the ecosystem classification to ensure that future field work can follow standardized guidance and a more widely accepted system. In addition the classification is intended to ensure a more systematic evaluation of biodiversity in the tropical Pacific and to establish priorities for future conservation efforts including planning, inventories, on-site protection, monitoring and educational efforts. Figure 1 presents the basic structure of the proposed marine ecosystem classification; the fully developed classification is included at the end of the text as Table 22. There is widespread recognition that the ecosystem classification will require periodic revision and updating as investigators begin to use it.

INTRODUCTION

> Since biosphere preserves are to include representative and unique areas of the world's biomes and their subdivisions, it is essential that their establishment be based on a knowledge of the nature and extent of the important biotic communities of the biosphere. This involves international and national support for development of mutually acceptable classifications of the world's biomes and for the required surveys and inventories of biotic communities to determine their nature and extent. (Man and Biosphere Programme, UNESCO, 1974)

> A classification is at the heart of the work of marine conservation, research, and monitoring. It is to be highly recommended that a workshop be convened in the very near future for the purpose of refining this scheme or replacing it with another which is more reflective of marine ecosystems. (Ray 1975)

The foregoing quotes succinctly and accurately reflect the value of both a marine classification system and the need for a proper forum to help devise it for the purpose of inventory and conservation of biological and related natural diversity. The present effort will focus on a marine classification system for the tropical Pacific that was developed as a result of the cooperative efforts of a working group of marine scientists (refer to the acknowledgements for a listing of the participants) and three workshops held in 1991.

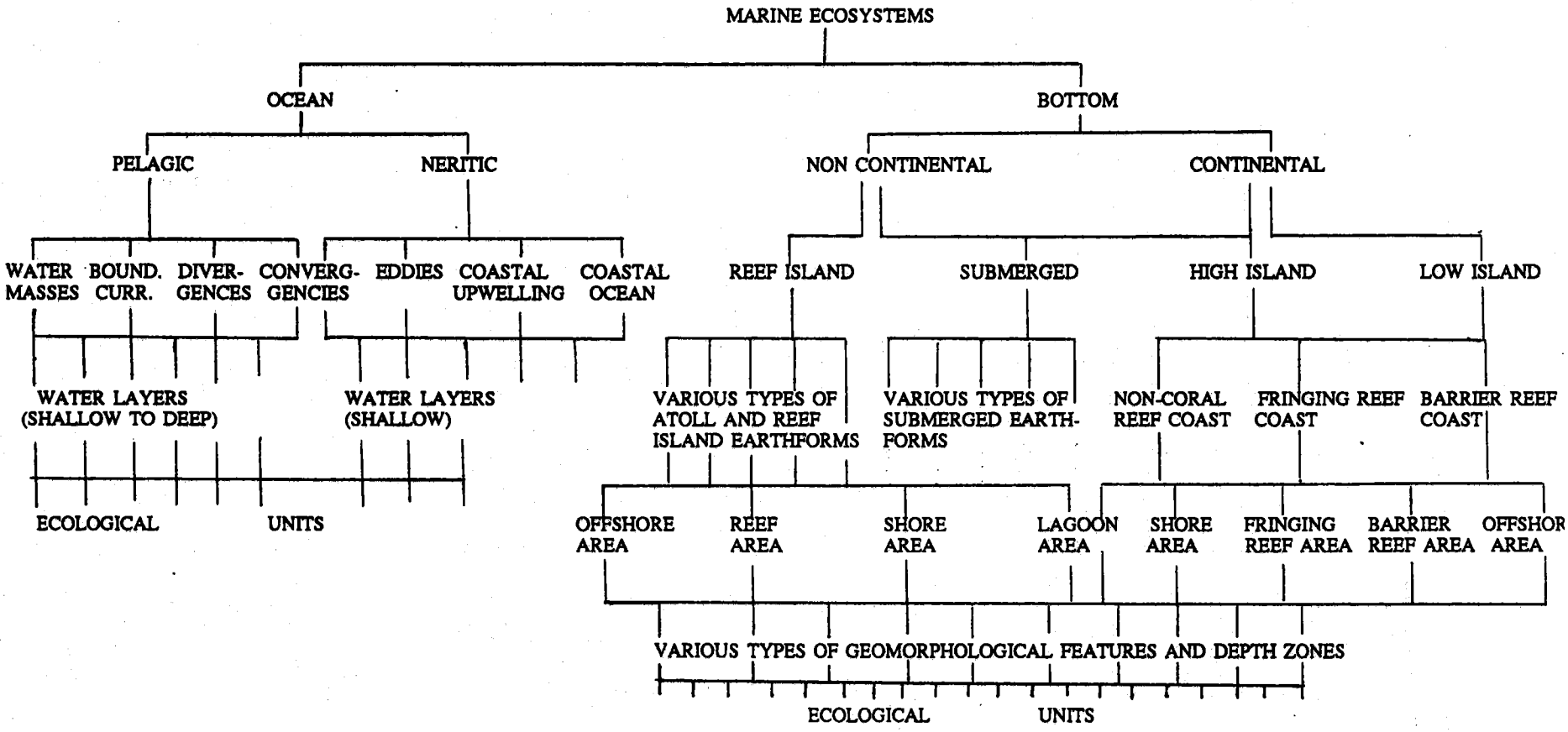
Although there have been numerous efforts over the last 150 years to develop global classification systems for vegetation and terrestrial ecosystems, serious synthesis work on marine ecosystems did not begin until the past half century. Before the advent of submersibles, snorkeling gear, and SCUBA, most early marine observations were conducted above water or along the water's edge at low tide in temperate regions. Furthermore the remote islands and reefs of the tropical Pacific were not readily accessible until after World War II and the recent expansion of air travel to the region. Even today, the great majority of marine environments and islands in the tropical Pacific have not been observed or visited by marine scientists.

The task of inventorying and assessing marine conservation needs will be formidable, requiring systematic planning and organization. An early step in this process is to define the geographic boundaries and characteristics and organize the principal marine ecosystems of the region. As the marine environment is much more a three-dimensional system compared with the terrestrial environment, its classification will require some departure from the approaches used for terrestrial ecosystems.

PURPOSE AND GOALS

This paper reviews background material of potential value in devising a marine classification system for the tropical Pacific and presents a classification system developed as a result of the workshops and other input.

FIGURE 1. The basic framework for the proposed marine ecosystem classification to be used for conservation management in the insular tropical Pacific.



The following goals are to be pursued with respect to the development and use of the marine classification system:

a) define the boundaries of the region to be covered,
b) define the dimensions and divisions to be included in the classification,
c) define the format for the classification,
d) identify all the elements and assemble a preferred classification system,
e) define the terminology and include "diagnostic" definitions for each selected term,
f) prepare or assemble visual aids (graphs, diagrams, photographs, etc.) to illustrate the various categories and educate others who will use the system,
g) compile a thorough bibliography of past attempts at classifying tropical marine environments, and
h) test the new system during a mock inventory of the marine environment in a Pacific region to be selected.

A workshop was held at the East-West Center in March 1991 to review the background papers and devise a proposed classification. Late in May 1991, the Pacific Science Congress held in Honolulu provided the opportunity for many others to review and comment on the classification. After the Congress, the classification was revised and sent out for further scientific review. At a South Pacific Regional Environment Programme Workshop in Port Vila, Vanuatu, in October 1991, the classification was subject to wider review. Since then the marine component has been further modified for presentation here.

The marine working group has tried to devise an uncomplicated and sensible classification to be used by a variety of workers in different regions which leads to consistent, replicable results. Thus, the challenge was to devise a classification that covers all the "important" categories but will still be as simple as possible. The classification also needs to be rigorous, avoiding duplication, but eliminating potential gaps in ecosystem coverage, and must be "user friendly". It must be presented and described in such a way as to be embraced by the much larger audience of scientists, educators, and resource managers who will eventually use it.

A key strategy of the selected system will be to help guide future inventory and conservation goals for natural resources including the identification, description, mapping, designation, and management of protected areas. In other circumstances a proper classification could lead to the inventory of valuable areas that should be identified, assessed, and protected during the conduct of environmental impact assessments for proposed development projects. Hence, the classification could indirectly assist decision makers in assigning priorities for future assessment and conservation work.

The marine classification will also need to be flexible in accepting additional categories of ecosystems, communities or features yet to be considered. The system must also rely on or accept a variety of data inputs. The categories in the system need to be arranged in a way to facilitate the inventory of marine ecosystems relying on the classification scheme. These include

underwater observations, ground level surveys, aerial surveys, and interpretation of aerial photos, maps, and satellite imagery.

BIOLOGICAL AND NATURAL DIVERSITY

Many marine ecosystems in the tropical Pacific have important geophysical attributes linked to biological or ecological processes. For example, atoll and barrier reefs, including depositional environments, water circulation patterns, and the size and location of islands and cays are closely associated with the growth, abundance and zonation of reef building organisms. The considerable organized variety among atolls, barrier reefs, and other coral reef systems should be clearly reflected in the classification system, and inventory and conservation strategies must be designed to treat these as largely integrated self contained biogeophysical entities.

LITERATURE REVIEW: BIOGEOGRAPHY

The earliest work on marine biogeography was accomplished by naturalists who accompanied exploration voyages during the early half of the last century. Darwin (1842) visited a number of tropical Pacific islands and reefs in the South Pacific, making observations that led him to develop his theory on coral reef evolution and to classify reefs into different stages: fringing, barrier, and atoll reefs (Darwin 1837). His extensive observations attracted the attention of many others, who later described the geomorphology and development of reefs in the broader Pacific.

James Dwight Dana, the naturalist aboard the U.S. Exploring Expedition, visited and described many reefs in the tropical Pacific. On the basis of his wide ranging observations he was able to correlate coral reef development to average sea water temperatures. He plotted the distribution of reefs using isotherms, separating the better developed reefs in the "torrid" zone from those of higher latitude (Dana 1853). Other important biogeographic work in the Pacific was accomplished by Woodward (1856) for marine mollusks, and Forbes (1856) whose publication included a map showing the global distribution of marine life. The first attempt to synthesize information from a variety of sources was accomplished by Wallace (1876, 1894) and Ortmann (1896) but the data available to them left large gaps and many poorly characterized geographic areas.

The first comprehensive global marine synthesis could not be accomplished until Ekman (1935) [later additions of his work (1953, 1967) were not significantly updated]. Ekman divided the world's oceans into several biogeographical regions, one of which included the Indo-West Pacific (Table 1A). This region is still recognized today as the world's largest tropical and marine region and the one which includes the tropical Pacific. Ekman further divided the Indo-West Pacific into several provinces (Table 1A) including southern Japan, tropical and subtropical Australia, and Hawaii in the Pacific Ocean. Other important marine biogeographical work during this time included Hedgpeth (1957a) and Thorsen (1957), the latter who described and mapped the global distribution of marine intertidal invertebrates. The first

Pacific biogeography syntheses were accomplished by Gressitt (1956), Usinger (1963), and Thorne (1963). A good historical summary of previous work on Pacific biogeography is found in Kay (1980).

Based on synthesis of considerably more information, Briggs (1974) later revised and refined the biogeography of the Indo-West Pacific (Table 1B). Among the important changes was the placement of the Eastern Pacific region in a separate region (outside of the Atlantic as proposed by Ekman). Although the overall boundaries of the Indo-West Pacific region did not change from Ekman (1935), Briggs defined a new set of provinces within the region including separate provinces for the Marquesas and Lord Howe - Norfolk Islands but deleting the province for southern Japan (without explanation). Briggs also included division in his classification scheme for ocean water masses and deep benthic areas (Table 1B).

Ray and coworkers essentially adopted the earlier zoogeographic determinations of Ekman (1967) and Briggs (1974) and developed comprehensive global marine classification systems (Ray 1975; Ray *et al.* 1984; and Hayden *et al.* 1984) (see Table 2-4). Other global systems include Pielou (1979) and Ketchum (1972). These systems included components on marine biogeography, water masses, and bottom features (Table 3). Later iterations included expanded classification of marine coastal water masses and published maps of various ocean realms and provinces (Ray *et al.* 1984; Hayden *et al.* 1984). The global ocean environment was divided into ocean realms, coastal-margin realms, marginal seas, and marginal archipelagos. The shallow water biota (less than 200 m) of the central or oceanic portions of the seas where not separated but considered evolutionary extensions of the continental shelf biota.

Dahl (1976) largely relied on Ray's (1975) global classification system for ocean features (Table 4) but subdivided a portion of the tropical Pacific region (serviced by the South Pacific Commission) into 20 archipelagic "provinces" (Table 5). Dahl's system unfortunately excluded other important tropical areas of the Pacific because they fell outside of SPC jurisdiction: southern Japan, northeastern Australia, and the tropical U.S. (Hawaii, Wake, Johnston, Palmyra, Kingman, Jarvis, Howland, Baker, *etc.*). Dahl (1976) also developed a comprehensive classification system for islands, marine biomes and other features (Tables 6 and 7). Dahl's system which included both terrestrial and marine ecosystems, was later modified by the IUCN protected areas review of the South Pacific region (IUCN 1986) (Table 8). This report includes considerably more detail on terrestrial ecosystems compared to the more expansive marine ecosystems of the region.

The recent Coral Reefs of the World publication (IUCN and UNEP 1988) also includes considerable information about the marine habitats of the region but avoided much discussion of biogeography and categorization of coral reef features. Recently Stoddart (in press) as part of the ecosystem classification working group, has devised and published a new biogeography of the insular Pacific. His system divides the tropical Pacific into two broad regions, continental and oceanic with further subdivisions for the centers of endemism (Hawaii, Marquesas, Southern Japan, Norfolk-Lord Howe Islands, *etc*).

MORPHOLOGICAL AND PHYSICAL CLASSIFICATION SYSTEMS

Parallel efforts over the past half century have been directed towards developing classification systems with respect to substratum morphology and composition, ecological habitat, tidal interactions, salinity, and depth. The synthesis by Hedgpeth (1957b) covers much of the previous work to that time (see Table 9). Without the benefit of deep sea observations until well into the twentieth century, most early researchers focused on classifying coastal and littoral environments. Hedgpeth's (1957b) review included a classification of pelagic and benthic habitats with respect to depth, from the littoral zone to the deepest trenches (Table 9). Later Ray (1975) and Briggs (1974) expanded upon and modified the depth oriented classification systems. Dahl (1976) added a section deep offshore environments to his Pacific ecosystem classification (Table 7)

Important reef geomorphological investigation and classification work in the tropical Pacific began with scientists of the U.S. Pacific Science Board working in the Marshall Islands, following World War II (Emery *et al.* 1954; Wells 1954, 1957). Based mostly on work at Arno and Bikini Atolls, the major oceanographic, physiographic and sedimentological characteristics of these large deep oceanic atolls were described. Wiens (1962) later summarizes much of this earlier work. Because the classification system was based on observation at only a few atolls in two archipelagos, it could not be widely applied to reef systems elsewhere. Later, Georg Scheer (1959) developed an English-German reef terminology, recognizing the necessity for a clearly defined nomenclature.

More recently, French scientists working in many areas of the Indian and Pacific Ocean have conducted extensive geomorphological analyses of fringing, barrier, and atoll reefs, especially in the Indian Ocean, French Polynesia and New Caledonia. The first major publication from this group (Battistini *et al.* 1975) included an illustrated review of many geomorphological terms used on coral reefs (Table 10), introducing many as new terms in French with English equivalents. No specific classification system was proposed. Other scientists have applied this terminology to reefs in the Indian and Pacific Oceans (Chevalier and Salvat 1976; Montaggioni and Faure 1980) and expanded the classification of atoll reefs in French Polynesia (Gabrie and Salvat 1985) (Table 11). Finally Guilcher (1987) has attempted to synthesize much of the earlier French work and published a comprehensive treatise on coral reef geomorphology which includes a classification system (Table 12). This latter system is the most comprehensive to date to apply to coral reef environments. Although many other reef scientists question some of the terminology (see Stoddart, 1978), the extensive use of block diagrams, underwater photographs, and aerial photographs of reef features, especially those introduced in Battistini *et al.* (1975) greatly assists in the understanding of reef geomorphology and terminology.

Scientists in Hawaii have also developed classification systems that apply to marine ecosystems and associated water quality regimes in the Hawaiian Islands. The first of these (Maragos, *et al.* 1975) was geared towards defining the ecosystems in the coastal zone which should be subject to areawide management (Table 13). A different classification system was developed for State of Hawaii "waters" to improve management and monitoring of water quality

(Technical Committee of Water Quality Standards, 1977; see Table 14). Later a classification system for nearshore ecosystems in Hawaii was developed as a prelude to a comprehensive statewide inventory of coral reef and related coastal ecosystems (Aecos, 1978), (Table 15). Over the years this last system has been expanded and modified to take advantage of using aerial photographs to interpret and classify reef features and bottom types (Eric Guinther, unpbl; Maragos and Elliott 1985). The variety among these several schemes can be best explained by the variety of purposes for which the systems were intended.

Australian scientists have also analyzed and classified features on the Great Barrier Reef (Yonge 1951; Maxwell 1968; Hopley 1978, 1982; Kuchler 1986a;) (Table 16). Hopley (1978) reviewed the reef features that can be interpreted from aerial photogrpahs (Table 18). Recent work relied heavily upon the interpretation of aerial photographs and satellite imageries (Hopley 1978, 1982; Kuchler 1986 a, b, c). Kuchler's detailed reef cover and zonation system (Table 17) included five levels and was designed for automatic data processing (Kuchler 1986c). The distinction between some of the levels ("zones" and "features") is not clear, but the concept of designing a classification system tailored to remote sensing data is worthy of serious consideration.

OTHER CLASSIFICATION SYSTEMS

The U.S. Fish and Wildlife Service developed a comprehensive wetland and deep water habitat classification system primarily for the continental United States (Cowardin *et al.* 1979) (also reviewed in Fosberg and Pearsall 1991). This system divides water bodies on the basis of salinity with further divisions based upon substratum composition, and geochemical and biological characteristics (e.g. "modifiers") (Table 19). This system is flexible in allowing additional subcategories, but use of this system requires in some cases detailed water quality and geochemical sampling. This system could be easily expanded for "global" application but adapting it to serve tropical marine ecosystems in the south Pacific may require restructuring. For one, the marine category is one of five systems in the classification system, but in the tropical Pacific marine water bodies overwhelmingly dominate aquatic environments. This system might be useful if brackish and fresh water ecosystems were grouped under the terrestrial classification division. It also includes vegetated categories and might also be adapted for use in terrestrial ecosystem classification (see Fosberg and Pearsall 1991). Most recently Crawford and Grossman (pers. comm.) have reviewed marine classification systems as part of their interest to develop a global marine classification system. A summary of the systems they reviewed and compared is found in Table 20.

A biographic classification system based upon plate tectonics was proposed by Springer (1982). This system also incorporates large scale geomorphological and geophysical characteristics of the Pacific Ocean crust (see Table 21) and is broadly analogous to the system now proposed by Stoddart (in press).

DISCUSSION

Previous marine classification systems reviewed in this paper have been based primarily on biogeographical, morphological and geophysical characteristics of marine ecosystems and

environments. It would seem that a combination of the above three "dimensions" would be important components for a marine classification system for the tropical Pacific.

Data requirements to use the above systems for marine resource inventories vary considerably. For some water chemistry, salinity, temperature and current measurements may be needed especially to classify ocean water masses and water bodies on land or near the shoreline. For others, some understanding of the evolution and geomorphology of reef systems is required for inventorying submarine and reef features. Experience and ability to interpret aerial photographs and satellite imagery would be needed for remote sensing-based classification systems. The biological significance of some areas in terms of endemism or the presence of rare, threatened, or endangered species would require the expertise of various biologists either to review available literature or conduct field surveys. These are all important considerations in attempting to develop a marine classification system that would be accepted and used by a large number of workers.

It seems possible that the complexity of data or information requirements to apply a classification system to site-specific inventories can be reduced considerably by focusing on the goal of identification of natural diversity worthy of recognition, assessment, or protection. The great variety among the reviewed classification systems is mostly explained by the great variety in purposes and uses for the systems. Many of these systems, although useful in their own regard, may not apply to our present needs. Thus, a useful goal may be to extract relevant components from a variety of existing systems to develop a composite classification system tailored to the needs of conserving marine natural diversity. With the above understandings in mind it may be useful to discuss the essential characteristics of a conservation-oriented marine-classification system.

Regional biodiversity

Previous studies of marine biogeography for the Indo-West Pacific indicate considerable variability within the region in terms of species richness and endemism. Relying on the "provinces" of Briggs (1974) is one way to accommodate centers of endemism, although more recent literature indicates the possible need to expand or reduce his list of provinces. For example recent unpublished work by Veron (pers. comm.) indicate that southern Japan has high species richness and endemism among stony corals, and in fact, the Japan totals for both exceed those of the Great Barrier Reef. On this basis alone it may be valid to resurrect a separate subdivision for southern Japan. Similarly other Pacific regions may need to be revisited for establishment of additional provinces or otherwise recognizing possible high levels of endemism. At the other extreme the biogeography of the tropical Pacific proposed by Stoddart (in press) includes only 2 major divisions and subsets identifying specific centers of endemism.

Natural diversity among archipelagos

Except for the continent of Australia, the entire tropical Pacific is largely an island region dominated by groups or archipelagos of volcanic and coral islands. As Dahl (1976) pointed out, the natural diversity of this region varies considerably between one island group

and another. Thus, there is some justification to retain the archipelagic provinces of Dahl (1976) and in fact expand them to include adjacent coral reef areas outside the SPC-SPREP umbrella: southern Japan, northeastern Australia, and Hawaii. In addition the other isolated U.S. affiliated islands could be included within their respective natural archipelagos. For example, Wake Atoll (Enen Kio) would be grouped with the Marshalls, Johnston would be grouped with Hawaii, and Palmyra and Kingman, Jarvis, Howland and Baker would be lumped within the Line Islands archipelago. In addition, the Phoenix Islands could also be separated from the Line Islands since the former group displays much higher biodiversity of corals; for example, compare Maragos and Jokiel (1978) with Maragos (1974). Thus the wide ranging Republic of Kiribati could have 3 archipelagic divisions: the Gilbert, Phoenix and Line Islands. Finally the political realities of the region indicate that each (national or territorial) government entity may need to constitute a separate "subdivision" to help facilitate programs for conservation of natural diversity best handled at the national government level.

Biosphere

Excluding the atmosphere, the biosphere is composed of 3 major divisions: the continents, oceans, and ocean crust (basalt). The Indo-West Pacific region is a cross-section of all three with ocean occurring throughout, basalt rock crust and islands occurring in the east and central Pacific, and islands and shelves of continental rock occurring to the west of the trenches. Marine ecosystems also vary considerably among these categories. Plankton, neuston and nekton dominate the oceanic water masses. Shallow water plants and animals dominate the benthos of continental shelves and islands. Both shallow and deep benthos dominates the deep sea, and reef dominated systems are also different on the oceanic islands compared to the shelf islands and continents. Hence there seems to be a good basis for retaining these major distinctions as proposed by Ray (1975) and Stoddart (in press).

Substrate and geomorphology

Aside from considerable differences between continental and oceanic marine geology and biology, there are considerable differences in island and reef morphology between the two. There is a much better understanding now of the interactions of the oceans reefs and islands, and considerable work has been accomplished to describe these features. Thus, it seems feasible and useful to develop a hierarchy of submarine and reef features to be included in the overall marine classification system. Three characteristics: substrate composition, substrate texture (*e.g.*, sediment characteristics) and substrate form (geomorphology) could be emphasized in the classification.

Depth

It is clear from the information available to date that the composition of the biota above a depth of 200 m differs substantially from that at below 200 m. Thus it seems logical that hierarchies be established for both the benthic and pelagic components of these two divisions of the ocean.

Salinity

On continents and large islands, salinity exerts great control over the composition of biota within enclosed or semi-enclosed water bodies. The same applies to raised or closed atolls with isolated lagoons and lakes where salinities can range from nearly fresh (such as in Teraina Atoll's lagoon) to hypersaline (such as in the lagoon of Kiritimati Atoll some 300 miles to the southwest). If raised lagoons and other semi-enclosed water bodies are to be included in the marine classification system, then salinity should be included as a principal parameter to differentiate the various categories (refer to Cowardin *et al.* 1979 for a possible salinity-based classification component). (Table 19).

Temperature, density and water movement

Hedgpeth (1957), Ray (1975), and Briggs (1974) recognized the need to differentiate pelagic and benthic-based marine ecosystems. The latter two proposed classifying the oceans into various water masses in recognition of their biological and physical differences. Oceanic currents often occur within the centers or boundaries of the predominant shallow water masses and it might be possible to expand upon the earlier classifications by labeling and describing these water current systems as part of the ocean water mass division of the classification system.

Dominant benthic organisms

A marine classification system could also include, perhaps at the lowest level of any hierarchy, characterization of bottom habitats dominated by benthic animals and plants (see Cowardin *et al.* 1979).

Boundary between land and sea

The boundary between land and sea is often not distinct, and it is important to draw the lines so that there is no overlap or inconsistencies between the two systems. This is largely an arbitrary exercise but an important one. The working groups agreed that the following components be included in the terrestrial classification system: 1) all freshwater bodies and moving waters except raised atoll lakes; 2) all freshwater and coastal wetlands including the vegetation components of mangroves; 3) all non-marine vegetation; and 4) beach systems above the high water mark. By inference the marine classification system would include the remainder of the mangroves, all atoll lakes, estuaries, and other marine plants (seagrasses), and beach systems below the high water mark.

Responsiveness to mapped and remotely sensed data

The classification-system categories should be divided in a way to facilitate their being mapped through interpretation of detailed maps, aerial photographs, and high resolution satellite imagery. For many island groups in the tropical Pacific, these forms of data may be the only information available upon which to base a preliminary inventory. Thus the definitions for each category should be defined or illustrated in a manner conducive to being

used later for mapping features based only on remotely sensed information and good quality maps.

Other aids

Aside from including aerial photographs, the inclusion of diagrams (see Battistini *et al.* 1975) and other illustrations and photographs to describe various features may be very important.

Consistency with worldwide marine classification system(s)

As of this date the author is not aware of an established or accepted global classification system for marine ecosystems, other than Ray (1975). However any established global marine system may need to accommodate the "national" and archipelagic characteristics unique to the tropical Pacific region.

Terminology

Stoddart (1978) points out the need to maintain clarity and consistency when using or coining new terms to describe coral reef features. Each category or element in the marine classification system will need to be defined clearly preferably using a combination of words and illustrations. Each category will need to be mutually exclusive and described in a way to avoid confusion or redundancy with other categories. Comparative terminology and definitions in French and German are also advised for a South Pacific ecosystem classification.

Criteria of importance for conservation

As part of assembling a marine classification system it will be important to draw attention to those elements or units warranting greater attention during subsequent inventories of marine ecosystems within specific regions. This may be best accomplished by assigning generic "importance" criteria to each category or element in the system. For example, importance criteria for a sandy beach near seagrass areas may be: (i) high possibility for sea turtle feeding, (ii) possibility for sea turtle nesting, (iii) probability for seasonal nesting activity, etc. Another example for a coral rich area lining the slopes of a reef hole might be (i) high possibility of reef fish spawning area, (ii) important coral spawning site, (iii) potential natural mariculture site, (iv) possible pearl oyster habitat on the adjacent sand floor, *etc.*

A list of these criteria for each category may help scientists and resource managers to make hard choices on where limited inventory, assessment, and management efforts need to be expended. The ecosystem classification working groups also developed criteria for conservation that addresses these needs, and a separate report is presently in preparation.

Use of the term "ecosystem"

In an unpublished paper, Fosberg and Pearsall (1991) do an excellent job in tracing the ecosystem concept during the evolution of various terrestrial based classification schemes. There appears to be no practical working definition of ecosystem that could have prevented the various historical and often conflicting interpretations of the concept. It is certainly appropriate to characterize the purpose of the classification system: to characterize and organize the various ecosystems in the marine environment in order to further the efforts of conserving natural diversity. However ecosystems have been defined to be synonymous with very small "communities" at one extreme to large regional "biomes" at the other extreme. This lack of consistent scale has led to confusion and disputes over the concept. Thus it may be best to exclude use of term "ecosystem" within the terminology of the classification system itself. Rather it may be best to refer to ecosystems as the "glue" that holds the classification system together.

The review of a variety of previous marine classification systems has revealed many components and concepts appropriate for the tropical Pacific. Other components and concepts seemed less appropriate for the purposes of our classification initiative to lead to systematic inventories of specific areas for the purpose of conserving natural or biological diversity. It seems possible to develop a composite system which essentially scavenges useful parts from previous "models" to design and operate a new and better model for the tropical Pacific. After the system is constructed, then an "operator's manual" is needed, which defines each of the parts and explains how to differentiate them in the field or through interpretation of remotely sensed data. Importance criteria also need to be listed to insure that sufficient attention is paid to the more valuable parts of the system.

Since the marine environment is three dimensional and dominated by two completely different media - oceanic and geological, it makes sense that some early or higher levels of the classification system lead to separate divisions, one focusing on benthic or bottom features, and the other focusing on pelagic or water-column features.

CONCLUSIONS

On the basis of reviewing the literature on previous marine classification schemes at the March 1991 workshop, the marine working group developed a draft marine ecosystem classification for the south Pacific. Based upon review comments from the Pacific Science Congress at which the proposed system was presented, and additional review comments at the October 1991 SPREP meeting in Vanuatu, the classification was further revised to its present form (Table 22). This system was tested at the last meeting by using maps to identify and classify field survey and other sites marked on the maps. Field use of the marine classification has not yet been used, and further refinements are expected after additional testing and interpretation.

The system is intended to cover the tropical Pacific excluding the continents of the Americas and Australia. The classification is intended to cover the southern Ryukyu Islands

at its northernmost limit but excludes the remainder of Japan. At its easternmost extreme, the classification covers all of the Polynesian Islands but excludes the Galapagos and other continental islands off the west coast of the Americas. At its southern limit the classification covers all of the Melanesian islands, Norfolk and Lord Howe Islands but excludes New Zealand. At its western limit the classification includes the Great Barrier Reef and Torres Strait regions up through Papua New Guinea and northward to include all of Micronesia, and the Philippines but excludes the rest of Southeast Asia.

The adopted classification has a simplified biogeographic component, following Stoddart (in press), in having only continental and non-continental or oceanic subdivisions. Although there are several centers of endemism within this region, the working groups felt that endemism should be treated as a criterion to establish conservation priorities rather than to constitute a specific element of the ecosystem classification.

The marine ecosystem classification is hierarchial with lower levels in the system being complete subsets of higher levels. The size scale of the elements within any one level increases when moving up through the hierarchy. All but the lower levels in the classification are capable of being mapped using aerial photographs, satellite imagery, or existing base maps.

The lowest levels in the classification are not shown but are termed ecological units which constitute coherent ecological communities characterized by prevalent or dominant organisms associated with specific water column or substrate characteristics. None of the specific ecological units are listed in the classification (Table 22), but the position of the ecological units is shown in figure one. A partial listing of specific ecological units and their association with water column or substrate features is given in Table 23. With time and experience, additional ecological units can be added to the list. Ground level or underwater observations are generally required to identify the dominant organisms and to list the genus and species name of each.

A glossary of terms has also been prepared for use with the classification, but it is too long to present here. Interested parties can contact the author to obtain a copy of the glossary. Every term in the marine ecosystem classification is defined in the glossary.

Future improvements to the marine ecosystem classification include the additions of sketch drawings and diagrams to illustrate the characteristics of each element, the inclusion of photographs to illustrate ecological units, and complete multi-language glossaries of all terms (English, French and German). These improvements should allow a greater number of workers to use and understand the classification. The updating and revision of the marine ecosystem classification is an ongoing process, and the system itself will benefit from "revisions" based upon additional experience in using it. Suggestions and comments are welcome at any time, and descriptions, photographs, or illustrations of elements and ecological units would be most appreciated.

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Table 1. Classification of the principal zoogeographic regions of the Indo-West Pacific

A. System developed by Ekman (1935, 1953, 1967)

INDO-WEST PACIFIC
- Indo-Malayan Region
- Central Pacific Islands
- Hawaii
- Subtropical Japan
- Tropical and Subtropical Australia
- Indian Ocean

B. Later system developed by Briggs (1974), including the provinces within the Indo-West Pacific

CONTINENTAL SHELVES REALM

The Tropical Ocean
- Indo-West Pacific Region
  - Western Indian Ocean Province
  - Red Sea Province
  - Indo-Polynesian Province
  - Northwest Australian Province
  - Lord Howe - Norfolk Province
  - Hawaiian Province
  - Easter Island Province
  - Marquesan Province
  - Other isolated areas
- 5 other regions

Southern Ocean
- 2 regions

Northern Ocean
- 2 regions

PELAGIC REALM

(vertical)
- Epipelagic (Sunlit) Zone
- Mesopelagic (Twilight) Zone
- Bathypelagic (Sunless) Zone
- Hadopelagic (Trench) Zone

(geographical)
- Tropical Seas
- Indo-Pacific Region {Indo-West Pacific Province / Atlantic Region
- 2 other Oceans

DEEP BENTHIC REALM
- Indo-West Pacific Region
- 2 other regions

Table 2. Classification of Marine Habitats as Proposed by Ray (1975) for Coastal and Coastal Associated Environments

A. Coastal Environments

1. Exposed
   - (a) with rocky substrate
     - (i) highly calcareous
     - (ii) weakly or non calcareous
   - (b) with unconsolidated substrate
     - (i) with low organic content
       1) gravels
       2) sands
       3) silts
       4) clays
     - (ii) with high organic content

2. Protected
   - (a) with rocky substrate
     - (i) highly calcareous
     - (ii) weakly or non calcareous
   - (b) with unconsolidated substrate
     - (i) with low organic content
       1) gravels
       2) sands
       3) silts
       4) clays
     - (ii) with high organic content

3. Deltas

B. Coast Associated Environments

1. Submarine vegetation beds
   - (a) dominated by algae
   - (b) dominated by vascular plants

2. Estuaries
   - (a) mixoeuhaline (30-35°/$_{oo}$ salinity)
   - (b) polyhaline (18-30°/$_{oo}$)
   - (c) mesohaline (5-18°/$_{oo}$)
   - (d) oligohaline (0.5-5°/$_{oo}$)

3. Lagoons
   - (a) hyperhaline (over 40°/$_{oo}$)
   - (b) euhaline (30-40°/$_{oo}$)
   - (c) mixoeuhaline (30-35°/$_{oo}$)
   - (d) polyhaline (18-30°/$_{oo}$)
   - (e) mesolhaline (5-18°/$_{oo}$)
   - (f) oligohaline (0.5-5°/$_{oo}$)

4. Tidal salt

5. Nontidal salt marshes and flats

6. Mangrove swamps

7. Drainage basins
   - (a) extent (size)
   - (b) type (agriculture, industrial)

Table 3. Classification of Ocean Realms, with emphasis on water mass and surface current characteristics, developed by Ray and co-workers.

A. Ocean Realms as defined by Ray *et al* (1984)

REALMS OF THE WESTERN AND EASTERN CONTINENTAL MARGINS
- Intertropical realms - seasonally within the trade winds of both hemispheres
- Tropical Realms - persistently within the trades of one hemisphere
- Subtropical Realms - Seasonally within the polewind extensions of the trade winds and within continental air streams
- Monsoon Realms - with seasonal and interhemispheric wind reversals
- Temperate Realms - within the westerly atmospheric and oceanic drifts of the mid latitudes
- Subpolar Realms - within the circulation domains of the subpolar cyclones

CIRCUMPOLAR REALMS
- Arctic Realms - along the Arctic Ocean Coast
- Antarctic Realm - along the Antarctic Continent only

MARGINAL SEAS OF COASTAL REALMS
(not described for insular tropical Pacific)

B. As defined by current direction in Hayden *et al* (1984) following Dietrich's (1963) classification
- I. Variable eastward currents
- II. Weak and variable currents
- III. Trade-wind currents
  - Strong equatorial currents
  - Westward currents
  - Strong poleward currents
- IV. Strong westward and equatorward currents
- V. Monsoon currents (seasonal reversals)

C. Coastal Margin Realms as related to currents and windstreams (after Hayden *et al*, 1984)

Coastal Realm	Dominant Directions	
	Currents	Windstream
Arctic (M)	ice margin coast	W
Antarctic (L)	W-ice margin coast	W
Subpolar (A)	W	W
Eastern Side of Ocean		
temperate (B)	poleward	E
monsoon (J)	equatorward-poleward	onshore-offshore
subtropical (C)	poleward	poleward
tropical (D)	W	W
intertropical (E)	W	W
Western Side of Ocean		
temperate (F)	poleward	poleward-equator
monsoon (K)	poleward-equatorward	onshore-offshore
subtropical (G)	equatorward	equatorward
tropical (H)	equatorward	W-equatorward
intertropical (I)	E-equatorward	equatorward

Table 4. Classification of Marine Habitats as proposed by Ray (1975) for offshore, man-made, special interest and water circulation environments

Offshore Environments

1. Kelp beds
2. Coral reefs (active) bordering continents
   (a) algal
   (b) coral
3. Coral reefs bordering oceanic islands and atolls
   (a) algal
   (b) coral
4. Drowned reefs (on subsiding shorelines)
5. Insular environments
6. Continental shelf areas
7. Submarine canyons
8. Ice
   (a) shore fast
   (b) pack
   (c) shelf
   (d) glacial and berg
9. Continental slope environments
10. Offslope environments
    (a) abyssal plains
    (b) submarine trenches
    (c) seamounts
    (d) submarine ridges

Man-made environments

1. Spoil
2. Reefs
3. Mariculture

Special Interest

1. Sea bird rookeries and waterfowl moulting sites
2. Sea turtle rookeries
3. Sea mammal rookeries
4. Seasonal fish concentrations

Water Circulation Bodies

1. Inshore circulation cells
2. Larger scale circulation cells
3. Upwelling systems

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V. Marine Ecosystem Classification

A MARINE ECOSYSTEM CLASSIFICATION FOR THE SOUTH PACIFIC REGION

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ABSTRACT

In 1991, the South Pacific Regional Environment Programme (SPREP), the U.S. Agency for International Development, The World Wildlife Fund, The Nature Conservancy, the East-West Center, and the U.S. Fish and Wildlife Service all collaborated and sponsored a program to develop an ecosystem classification of the insular tropical Pacific that would be useful in furthering resource inventories and conservation efforts in the region. The steps followed in developing the classification included: 1) preparation and distribution of review papers (in February 1991) summarizing past efforts at classifying ecosystems, especially those applicable to the South Pacific, 2) sponsoring workshops at the East-West Center in Honolulu (in March 1991) to assemble scientific experts to review past efforts and develop an ecosystem classification applicable the South Pacific, 3) presentation of the draft ecosystem classification before a broader scientific audience at the Seventeenth Pacific Science Congress in Honolulu (in May 1991) in order to solicit suggestions and revisions, 4) preparation of a revised classification for formal scientific review (in September 1991), 5) sponsoring another workshop in Vanuatu (held in October 1991) to solicit feedback from the 22 member countries of SPREP and to "test" the ecosystem classification, and 6) to finalize the ecosystem classification (in December 1991) so that it can be used for field inventories and other conservation efforts that are now being planned throughout the region. This report covers progress to date on the marine component of the ecosystem classification. A second component covering inland waters is being published separately by Polhemus *et al.*, and a third component (terrestrial ecosystems) is still undergoing revision while this report is being prepared. Collectively these three components (marine, terrestrial and inland) constitute the entire ecosystem classification developed for the South Pacific, and the classification has been structured to allow it to be incorporated into a larger global ecosystem classification if or when one is eventually adopted.

Considerable effort is being placed on establishing the ecosystem classification to ensure that future field work can follow standardized guidance and a more widely accepted system. In addition the classification is intended to ensure a more systematic evaluation of biodiversity in the tropical Pacific and to establish priorities for future conservation efforts including planning, inventories, on-site protection, monitoring and educational efforts. Figure 1 presents the basic structure of the proposed marine ecosystem classification; the fully developed classification is included at the end of the text as Table 22. There is widespread recognition that the ecosystem classification will require periodic revision and updating as investigators begin to use it.

INTRODUCTION

> Since biosphere preserves are to include representative and unique areas of the world's biomes and their subdivisions, it is essential that their establishment be based on a knowledge of the nature and extent of the important biotic communities of the biosphere. This involves international and national support for development of mutually acceptable classifications of the world's biomes and for the required surveys and inventories of biotic communities to determine their nature and extent. (Man and Biosphere Programme, UNESCO, 1974)

> A classification is at the heart of the work of marine conservation, research, and monitoring. It is to be highly recommended that a workshop be convened in the very near future for the purpose of refining this scheme or replacing it with another which is more reflective of marine ecosystems. (Ray 1975)

The foregoing quotes succinctly and accurately reflect the value of both a marine classification system and the need for a proper forum to help devise it for the purpose of inventory and conservation of biological and related natural diversity. The present effort will focus on a marine classification system for the tropical Pacific that was developed as a result of the cooperative efforts of a working group of marine scientists (refer to the acknowledgements for a listing of the participants) and three workshops held in 1991.

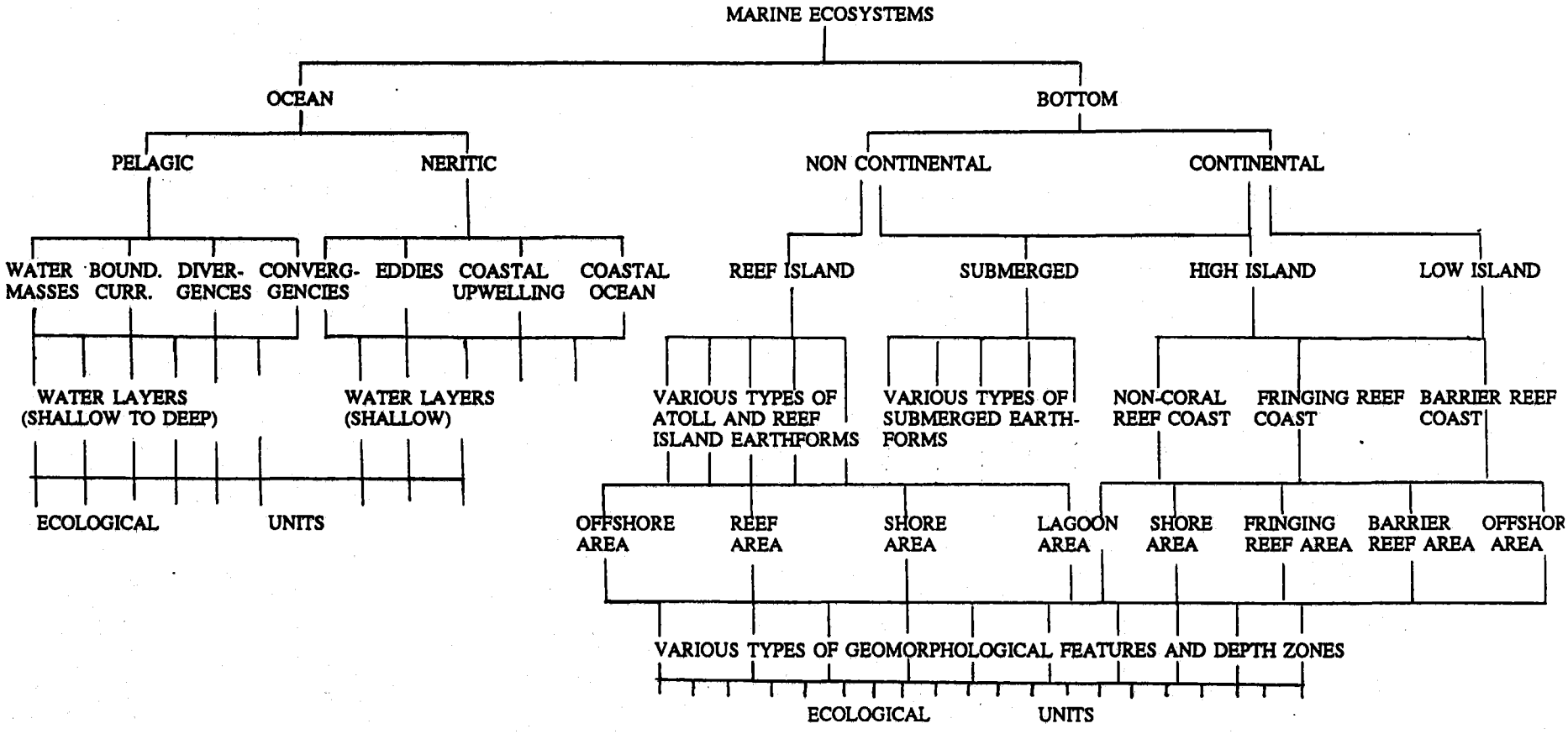
Although there have been numerous efforts over the last 150 years to develop global classification systems for vegetation and terrestrial ecosystems, serious synthesis work on marine ecosystems did not begin until the past half century. Before the advent of submersibles, snorkeling gear, and SCUBA, most early marine observations were conducted above water or along the water's edge at low tide in temperate regions. Furthermore the remote islands and reefs of the tropical Pacific were not readily accessible until after World War II and the recent expansion of air travel to the region. Even today, the great majority of marine environments and islands in the tropical Pacific have not been observed or visited by marine scientists.

The task of inventorying and assessing marine conservation needs will be formidable, requiring systematic planning and organization. An early step in this process is to define the geographic boundaries and characteristics and organize the principal marine ecosystems of the region. As the marine environment is much more a three-dimensional system compared with the terrestrial environment, its classification will require some departure from the approaches used for terrestrial ecosystems.

PURPOSE AND GOALS

This paper reviews background material of potential value in devising a marine classification system for the tropical Pacific and presents a classification system developed as a result of the workshops and other input.

FIGURE 1. The basic framework for the proposed marine ecosystem classification to be used for conservation management in the insular tropical Pacific.



The following goals are to be pursued with respect to the development and use of the marine classification system:

a) define the boundaries of the region to be covered,
b) define the dimensions and divisions to be included in the classification,
c) define the format for the classification,
d) identify all the elements and assemble a preferred classification system,
e) define the terminology and include "diagnostic" definitions for each selected term,
f) prepare or assemble visual aids (graphs, diagrams, photographs, etc.) to illustrate the various categories and educate others who will use the system,
g) compile a thorough bibliography of past attempts at classifying tropical marine environments, and
h) test the new system during a mock inventory of the marine environment in a Pacific region to be selected.

A workshop was held at the East-West Center in March 1991 to review the background papers and devise a proposed classification. Late in May 1991, the Pacific Science Congress held in Honolulu provided the opportunity for many others to review and comment on the classification. After the Congress, the classification was revised and sent out for further scientific review. At a South Pacific Regional Environment Programme Workshop in Port Vila, Vanuatu, in October 1991, the classification was subject to wider review. Since then the marine component has been further modified for presentation here.

The marine working group has tried to devise an uncomplicated and sensible classification to be used by a variety of workers in different regions which leads to consistent, replicable results. Thus, the challenge was to devise a classification that covers all the "important" categories but will still be as simple as possible. The classification also needs to be rigorous, avoiding duplication, but eliminating potential gaps in ecosystem coverage, and must be "user friendly". It must be presented and described in such a way as to be embraced by the much larger audience of scientists, educators, and resource managers who will eventually use it.

A key strategy of the selected system will be to help guide future inventory and conservation goals for natural resources including the identification, description, mapping, designation, and management of protected areas. In other circumstances a proper classification could lead to the inventory of valuable areas that should be identified, assessed, and protected during the conduct of environmental impact assessments for proposed development projects. Hence, the classification could indirectly assist decision makers in assigning priorities for future assessment and conservation work.

The marine classification will also need to be flexible in accepting additional categories of ecosystems, communities or features yet to be considered. The system must also rely on or accept a variety of data inputs. The categories in the system need to be arranged in a way to facilitate the inventory of marine ecosystems relying on the classification scheme. These include

underwater observations, ground level surveys, aerial surveys, and interpretation of aerial photos, maps, and satellite imagery.

BIOLOGICAL AND NATURAL DIVERSITY

Many marine ecosystems in the tropical Pacific have important geophysical attributes linked to biological or ecological processes. For example, atoll and barrier reefs, including depositional environments, water circulation patterns, and the size and location of islands and cays are closely associated with the growth, abundance and zonation of reef building organisms. The considerable organized variety among atolls, barrier reefs, and other coral reef systems should be clearly reflected in the classification system, and inventory and conservation strategies must be designed to treat these as largely integrated self contained biogeophysical entities.

LITERATURE REVIEW: BIOGEOGRAPHY

The earliest work on marine biogeography was accomplished by naturalists who accompanied exploration voyages during the early half of the last century. Darwin (1842) visited a number of tropical Pacific islands and reefs in the South Pacific, making observations that led him to develop his theory on coral reef evolution and to classify reefs into different stages: fringing, barrier, and atoll reefs (Darwin 1837). His extensive observations attracted the attention of many others, who later described the geomorphology and development of reefs in the broader Pacific.

James Dwight Dana, the naturalist aboard the U.S. Exploring Expedition, visited and described many reefs in the tropical Pacific. On the basis of his wide ranging observations he was able to correlate coral reef development to average sea water temperatures. He plotted the distribution of reefs using isotherms, separating the better developed reefs in the "torrid" zone from those of higher latitude (Dana 1853). Other important biogeographic work in the Pacific was accomplished by Woodward (1856) for marine mollusks, and Forbes (1856) whose publication included a map showing the global distribution of marine life. The first attempt to synthesize information from a variety of sources was accomplished by Wallace (1876, 1894) and Ortmann (1896) but the data available to them left large gaps and many poorly characterized geographic areas.

The first comprehensive global marine synthesis could not be accomplished until Ekman (1935) [later additions of his work (1953, 1967) were not significantly updated]. Ekman divided the world's oceans into several biogeographical regions, one of which included the Indo-West Pacific (Table 1A). This region is still recognized today as the world's largest tropical and marine region and the one which includes the tropical Pacific. Ekman further divided the Indo-West Pacific into several provinces (Table 1A) including southern Japan, tropical and subtropical Australia, and Hawaii in the Pacific Ocean. Other important marine biogeographical work during this time included Hedgpeth (1957a) and Thorsen (1957), the latter who described and mapped the global distribution of marine intertidal invertebrates. The first

Pacific biogeography syntheses were accomplished by Gressitt (1956), Usinger (1963), and Thorne (1963). A good historical summary of previous work on Pacific biogeography is found in Kay (1980).

Based on synthesis of considerably more information, Briggs (1974) later revised and refined the biogeography of the Indo-West Pacific (Table 1B). Among the important changes was the placement of the Eastern Pacific region in a separate region (outside of the Atlantic as proposed by Ekman). Although the overall boundaries of the Indo-West Pacific region did not change from Ekman (1935), Briggs defined a new set of provinces within the region including separate provinces for the Marquesas and Lord Howe - Norfolk Islands but deleting the province for southern Japan (without explanation). Briggs also included division in his classification scheme for ocean water masses and deep benthic areas (Table 1B).

Ray and coworkers essentially adopted the earlier zoogeographic determinations of Ekman (1967) and Briggs (1974) and developed comprehensive global marine classification systems (Ray 1975; Ray *et al.* 1984; and Hayden *et al.* 1984) (see Table 2-4). Other global systems include Pielou (1979) and Ketchum (1972). These systems included components on marine biogeography, water masses, and bottom features (Table 3). Later iterations included expanded classification of marine coastal water masses and published maps of various ocean realms and provinces (Ray *et al.* 1984; Hayden *et al.* 1984). The global ocean environment was divided into ocean realms, coastal-margin realms, marginal seas, and marginal archipelagos. The shallow water biota (less than 200 m) of the central or oceanic portions of the seas where not separated but considered evolutionary extensions of the continental shelf biota.

Dahl (1976) largely relied on Ray's (1975) global classification system for ocean features (Table 4) but subdivided a portion of the tropical Pacific region (serviced by the South Pacific Commission) into 20 archipelagic "provinces" (Table 5). Dahl's system unfortunately excluded other important tropical areas of the Pacific because they fell outside of SPC jurisdiction: southern Japan, northeastern Australia, and the tropical U.S. (Hawaii, Wake, Johnston, Palmyra, Kingman, Jarvis, Howland, Baker, *etc.*). Dahl (1976) also developed a comprehensive classification system for islands, marine biomes and other features (Tables 6 and 7). Dahl's system which included both terrestrial and marine ecosystems, was later modified by the IUCN protected areas review of the South Pacific region (IUCN 1986) (Table 8). This report includes considerably more detail on terrestrial ecosystems compared to the more expansive marine ecosystems of the region.

The recent Coral Reefs of the World publication (IUCN and UNEP 1988) also includes considerable information about the marine habitats of the region but avoided much discussion of biogeography and categorization of coral reef features. Recently Stoddart (in press) as part of the ecosystem classification working group, has devised and published a new biogeography of the insular Pacific. His system divides the tropical Pacific into two broad regions, continental and oceanic with further subdivisions for the centers of endemism (Hawaii, Marquesas, Southern Japan, Norfolk-Lord Howe Islands, *etc*).

MORPHOLOGICAL AND PHYSICAL CLASSIFICATION SYSTEMS

Parallel efforts over the past half century have been directed towards developing classification systems with respect to substratum morphology and composition, ecological habitat, tidal interactions, salinity, and depth. The synthesis by Hedgpeth (1957b) covers much of the previous work to that time (see Table 9). Without the benefit of deep sea observations until well into the twentieth century, most early researchers focused on classifying coastal and littoral environments. Hedgpeth's (1957b) review included a classification of pelagic and benthic habitats with respect to depth, from the littoral zone to the deepest trenches (Table 9). Later Ray (1975) and Briggs (1974) expanded upon and modified the depth oriented classification systems. Dahl (1976) added a section deep offshore environments to his Pacific ecosystem classification (Table 7)

Important reef geomorphological investigation and classification work in the tropical Pacific began with scientists of the U.S. Pacific Science Board working in the Marshall Islands, following World War II (Emery *et al.* 1954; Wells 1954, 1957). Based mostly on work at Arno and Bikini Atolls, the major oceanographic, physiographic and sedimentological characteristics of these large deep oceanic atolls were described. Wiens (1962) later summarizes much of this earlier work. Because the classification system was based on observation at only a few atolls in two archipelagos, it could not be widely applied to reef systems elsewhere. Later, Georg Scheer (1959) developed an English-German reef terminology, recognizing the necessity for a clearly defined nomenclature.

More recently, French scientists working in many areas of the Indian and Pacific Ocean have conducted extensive geomorphological analyses of fringing, barrier, and atoll reefs, especially in the Indian Ocean, French Polynesia and New Caledonia. The first major publication from this group (Battistini *et al.* 1975) included an illustrated review of many geomorphological terms used on coral reefs (Table 10), introducing many as new terms in French with English equivalents. No specific classification system was proposed. Other scientists have applied this terminology to reefs in the Indian and Pacific Oceans (Chevalier and Salvat 1976; Montaggioni and Faure 1980) and expanded the classification of atoll reefs in French Polynesia (Gabrie and Salvat 1985) (Table 11). Finally Guilcher (1987) has attempted to synthesize much of the earlier French work and published a comprehensive treatise on coral reef geomorphology which includes a classification system (Table 12). This latter system is the most comprehensive to date to apply to coral reef environments. Although many other reef scientists question some of the terminology (see Stoddart, 1978), the extensive use of block diagrams, underwater photographs, and aerial photographs of reef features, especially those introduced in Battistini *et al.* (1975) greatly assists in the understanding of reef geomorphology and terminology.

Scientists in Hawaii have also developed classification systems that apply to marine ecosystems and associated water quality regimes in the Hawaiian Islands. The first of these (Maragos, *et al.* 1975) was geared towards defining the ecosystems in the coastal zone which should be subject to areawide management (Table 13). A different classification system was developed for State of Hawaii "waters" to improve management and monitoring of water quality

(Technical Committee of Water Quality Standards, 1977; see Table 14). Later a classification system for nearshore ecosystems in Hawaii was developed as a prelude to a comprehensive statewide inventory of coral reef and related coastal ecosystems (Aecos, 1978), (Table 15). Over the years this last system has been expanded and modified to take advantage of using aerial photographs to interpret and classify reef features and bottom types (Eric Guinther, unpbl; Maragos and Elliott 1985). The variety among these several schemes can be best explained by the variety of purposes for which the systems were intended.

Australian scientists have also analyzed and classified features on the Great Barrier Reef (Yonge 1951; Maxwell 1968; Hopley 1978, 1982; Kuchler 1986a;) (Table 16). Hopley (1978) reviewed the reef features that can be interpreted from aerial photogrpahs (Table 18). Recent work relied heavily upon the interpretation of aerial photographs and satellite imageries (Hopley 1978, 1982; Kuchler 1986 a, b, c). Kuchler's detailed reef cover and zonation system (Table 17) included five levels and was designed for automatic data processing (Kuchler 1986c). The distinction between some of the levels ("zones" and "features") is not clear, but the concept of designing a classification system tailored to remote sensing data is worthy of serious consideration.

OTHER CLASSIFICATION SYSTEMS

The U.S. Fish and Wildlife Service developed a comprehensive wetland and deep water habitat classification system primarily for the continental United States (Cowardin *et al.* 1979) (also reviewed in Fosberg and Pearsall 1991). This system divides water bodies on the basis of salinity with further divisions based upon substratum composition, and geochemical and biological characteristics (e.g. "modifiers") (Table 19). This system is flexible in allowing additional subcategories, but use of this system requires in some cases detailed water quality and geochemical sampling. This system could be easily expanded for "global" application but adapting it to serve tropical marine ecosystems in the south Pacific may require restructuring. For one, the marine category is one of five systems in the classification system, but in the tropical Pacific marine water bodies overwhelmingly dominate aquatic environments. This system might be useful if brackish and fresh water ecosystems were grouped under the terrestrial classification division. It also includes vegetated categories and might also be adapted for use in terrestrial ecosystem classification (see Fosberg and Pearsall 1991). Most recently Crawford and Grossman (pers. comm.) have reviewed marine classification systems as part of their interest to develop a global marine classification system. A summary of the systems they reviewed and compared is found in Table 20.

A biographic classification system based upon plate tectonics was proposed by Springer (1982). This system also incorporates large scale geomorphological and geophysical characteristics of the Pacific Ocean crust (see Table 21) and is broadly analogous to the system now proposed by Stoddart (in press).

DISCUSSION

Previous marine classification systems reviewed in this paper have been based primarily on biogeographical, morphological and geophysical characteristics of marine ecosystems and

environments. It would seem that a combination of the above three "dimensions" would be important components for a marine classification system for the tropical Pacific.

Data requirements to use the above systems for marine resource inventories vary considerably. For some water chemistry, salinity, temperature and current measurements may be needed especially to classify ocean water masses and water bodies on land or near the shoreline. For others, some understanding of the evolution and geomorphology of reef systems is required for inventorying submarine and reef features. Experience and ability to interpret aerial photographs and satellite imagery would be needed for remote sensing-based classification systems. The biological significance of some areas in terms of endemism or the presence of rare, threatened, or endangered species would require the expertise of various biologists either to review available literature or conduct field surveys. These are all important considerations in attempting to develop a marine classification system that would be accepted and used by a large number of workers.

It seems possible that the complexity of data or information requirements to apply a classification system to site-specific inventories can be reduced considerably by focusing on the goal of identification of natural diversity worthy of recognition, assessment, or protection. The great variety among the reviewed classification systems is mostly explained by the great variety in purposes and uses for the systems. Many of these systems, although useful in their own regard, may not apply to our present needs. Thus, a useful goal may be to extract relevant components from a variety of existing systems to develop a composite classification system tailored to the needs of conserving marine natural diversity. With the above understandings in mind it may be useful to discuss the essential characteristics of a conservation-oriented marine-classification system.

Regional biodiversity

Previous studies of marine biogeography for the Indo-West Pacific indicate considerable variability within the region in terms of species richness and endemism. Relying on the "provinces" of Briggs (1974) is one way to accommodate centers of endemism, although more recent literature indicates the possible need to expand or reduce his list of provinces. For example recent unpublished work by Veron (pers. comm.) indicate that southern Japan has high species richness and endemism among stony corals, and in fact, the Japan totals for both exceed those of the Great Barrier Reef. On this basis alone it may be valid to resurrect a separate subdivision for southern Japan. Similarly other Pacific regions may need to be revisited for establishment of additional provinces or otherwise recognizing possible high levels of endemism. At the other extreme the biogeography of the tropical Pacific proposed by Stoddart (in press) includes only 2 major divisions and subsets identifying specific centers of endemism.

Natural diversity among archipelagos

Except for the continent of Australia, the entire tropical Pacific is largely an island region dominated by groups or archipelagos of volcanic and coral islands. As Dahl (1976) pointed out, the natural diversity of this region varies considerably between one island group

and another. Thus, there is some justification to retain the archipelagic provinces of Dahl (1976) and in fact expand them to include adjacent coral reef areas outside the SPC-SPREP umbrella: southern Japan, northeastern Australia, and Hawaii. In addition the other isolated U.S. affiliated islands could be included within their respective natural archipelagos. For example, Wake Atoll (Enen Kio) would be grouped with the Marshalls, Johnston would be grouped with Hawaii, and Palmyra and Kingman, Jarvis, Howland and Baker would be lumped within the Line Islands archipelago. In addition, the Phoenix Islands could also be separated from the Line Islands since the former group displays much higher biodiversity of corals; for example, compare Maragos and Jokiel (1978) with Maragos (1974). Thus the wide ranging Republic of Kiribati could have 3 archipelagic divisions: the Gilbert, Phoenix and Line Islands. Finally the political realities of the region indicate that each (national or territorial) government entity may need to constitute a separate "subdivision" to help facilitate programs for conservation of natural diversity best handled at the national government level.

Biosphere

Excluding the atmosphere, the biosphere is composed of 3 major divisions: the continents, oceans, and ocean crust (basalt). The Indo-West Pacific region is a cross-section of all three with ocean occurring throughout, basalt rock crust and islands occurring in the east and central Pacific, and islands and shelves of continental rock occurring to the west of the trenches. Marine ecosystems also vary considerably among these categories. Plankton, neuston and nekton dominate the oceanic water masses. Shallow water plants and animals dominate the benthos of continental shelves and islands. Both shallow and deep benthos dominates the deep sea, and reef dominated systems are also different on the oceanic islands compared to the shelf islands and continents. Hence there seems to be a good basis for retaining these major distinctions as proposed by Ray (1975) and Stoddart (in press).

Substrate and geomorphology

Aside from considerable differences between continental and oceanic marine geology and biology, there are considerable differences in island and reef morphology between the two. There is a much better understanding now of the interactions of the oceans reefs and islands, and considerable work has been accomplished to describe these features. Thus, it seems feasible and useful to develop a hierarchy of submarine and reef features to be included in the overall marine classification system. Three characteristics: substrate composition, substrate texture (*e.g.*, sediment characteristics) and substrate form (geomorphology) could be emphasized in the classification.

Depth

It is clear from the information available to date that the composition of the biota above a depth of 200 m differs substantially from that at below 200 m. Thus it seems logical that hierarchies be established for both the benthic and pelagic components of these two divisions of the ocean.

Salinity

On continents and large islands, salinity exerts great control over the composition of biota within enclosed or semi-enclosed water bodies. The same applies to raised or closed atolls with isolated lagoons and lakes where salinities can range from nearly fresh (such as in Teraina Atoll's lagoon) to hypersaline (such as in the lagoon of Kiritimati Atoll some 300 miles to the southwest). If raised lagoons and other semi-enclosed water bodies are to be included in the marine classification system, then salinity should be included as a principal parameter to differentiate the various categories (refer to Cowardin *et al.* 1979 for a possible salinity-based classification component). (Table 19).

Temperature, density and water movement

Hedgpeth (1957), Ray (1975), and Briggs (1974) recognized the need to differentiate pelagic and benthic-based marine ecosystems. The latter two proposed classifying the oceans into various water masses in recognition of their biological and physical differences. Oceanic currents often occur within the centers or boundaries of the predominant shallow water masses and it might be possible to expand upon the earlier classifications by labeling and describing these water current systems as part of the ocean water mass division of the classification system.

Dominant benthic organisms

A marine classification system could also include, perhaps at the lowest level of any hierarchy, characterization of bottom habitats dominated by benthic animals and plants (see Cowardin *et al.* 1979).

Boundary between land and sea

The boundary between land and sea is often not distinct, and it is important to draw the lines so that there is no overlap or inconsistencies between the two systems. This is largely an arbitrary exercise but an important one. The working groups agreed that the following components be included in the terrestrial classification system: 1) all freshwater bodies and moving waters except raised atoll lakes; 2) all freshwater and coastal wetlands including the vegetation components of mangroves; 3) all non-marine vegetation; and 4) beach systems above the high water mark. By inference the marine classification system would include the remainder of the mangroves, all atoll lakes, estuaries, and other marine plants (seagrasses), and beach systems below the high water mark.

Responsiveness to mapped and remotely sensed data

The classification-system categories should be divided in a way to facilitate their being mapped through interpretation of detailed maps, aerial photographs, and high resolution satellite imagery. For many island groups in the tropical Pacific, these forms of data may be the only information available upon which to base a preliminary inventory. Thus the definitions for each category should be defined or illustrated in a manner conducive to being

used later for mapping features based only on remotely sensed information and good quality maps.

Other aids

Aside from including aerial photographs, the inclusion of diagrams (see Battistini *et al.* 1975) and other illustrations and photographs to describe various features may be very important.

Consistency with worldwide marine classification system(s)

As of this date the author is not aware of an established or accepted global classification system for marine ecosystems, other than Ray (1975). However any established global marine system may need to accommodate the "national" and archipelagic characteristics unique to the tropical Pacific region.

Terminology

Stoddart (1978) points out the need to maintain clarity and consistency when using or coining new terms to describe coral reef features. Each category or element in the marine classification system will need to be defined clearly preferably using a combination of words and illustrations. Each category will need to be mutually exclusive and described in a way to avoid confusion or redundancy with other categories. Comparative terminology and definitions in French and German are also advised for a South Pacific ecosystem classification.

Criteria of importance for conservation

As part of assembling a marine classification system it will be important to draw attention to those elements or units warranting greater attention during subsequent inventories of marine ecosystems within specific regions. This may be best accomplished by assigning generic "importance" criteria to each category or element in the system. For example, importance criteria for a sandy beach near seagrass areas may be: (i) high possibility for sea turtle feeding, (ii) possibility for sea turtle nesting, (iii) probability for seasonal nesting activity, etc. Another example for a coral rich area lining the slopes of a reef hole might be (i) high possibility of reef fish spawning area, (ii) important coral spawning site, (iii) potential natural mariculture site, (iv) possible pearl oyster habitat on the adjacent sand floor, *etc.*

A list of these criteria for each category may help scientists and resource managers to make hard choices on where limited inventory, assessment, and management efforts need to be expended. The ecosystem classification working groups also developed criteria for conservation that addresses these needs, and a separate report is presently in preparation.

Use of the term "ecosystem"

In an unpublished paper, Fosberg and Pearsall (1991) do an excellent job in tracing the ecosystem concept during the evolution of various terrestrial based classification schemes. There appears to be no practical working definition of ecosystem that could have prevented the various historical and often conflicting interpretations of the concept. It is certainly appropriate to characterize the purpose of the classification system: to characterize and organize the various ecosystems in the marine environment in order to further the efforts of conserving natural diversity. However ecosystems have been defined to be synonymous with very small "communities" at one extreme to large regional "biomes" at the other extreme. This lack of consistent scale has led to confusion and disputes over the concept. Thus it may be best to exclude use of term "ecosystem" within the terminology of the classification system itself. Rather it may be best to refer to ecosystems as the "glue" that holds the classification system together.

The review of a variety of previous marine classification systems has revealed many components and concepts appropriate for the tropical Pacific. Other components and concepts seemed less appropriate for the purposes of our classification initiative to lead to systematic inventories of specific areas for the purpose of conserving natural or biological diversity. It seems possible to develop a composite system which essentially scavenges useful parts from previous "models" to design and operate a new and better model for the tropical Pacific. After the system is constructed, then an "operator's manual" is needed, which defines each of the parts and explains how to differentiate them in the field or through interpretation of remotely sensed data. Importance criteria also need to be listed to insure that sufficient attention is paid to the more valuable parts of the system.

Since the marine environment is three dimensional and dominated by two completely different media - oceanic and geological, it makes sense that some early or higher levels of the classification system lead to separate divisions, one focusing on benthic or bottom features, and the other focusing on pelagic or water-column features.

CONCLUSIONS

On the basis of reviewing the literature on previous marine classification schemes at the March 1991 workshop, the marine working group developed a draft marine ecosystem classification for the south Pacific. Based upon review comments from the Pacific Science Congress at which the proposed system was presented, and additional review comments at the October 1991 SPREP meeting in Vanuatu, the classification was further revised to its present form (Table 22). This system was tested at the last meeting by using maps to identify and classify field survey and other sites marked on the maps. Field use of the marine classification has not yet been used, and further refinements are expected after additional testing and interpretation.

The system is intended to cover the tropical Pacific excluding the continents of the Americas and Australia. The classification is intended to cover the southern Ryukyu Islands

at its northernmost limit but excludes the remainder of Japan. At its easternmost extreme, the classification covers all of the Polynesian Islands but excludes the Galapagos and other continental islands off the west coast of the Americas. At its southern limit the classification covers all of the Melanesian islands, Norfolk and Lord Howe Islands but excludes New Zealand. At its western limit the classification includes the Great Barrier Reef and Torres Strait regions up through Papua New Guinea and northward to include all of Micronesia, and the Philippines but excludes the rest of Southeast Asia.

The adopted classification has a simplified biogeographic component, following Stoddart (in press), in having only continental and non-continental or oceanic subdivisions. Although there are several centers of endemism within this region, the working groups felt that endemism should be treated as a criterion to establish conservation priorities rather than to constitute a specific element of the ecosystem classification.

The marine ecosystem classification is hierarchial with lower levels in the system being complete subsets of higher levels. The size scale of the elements within any one level increases when moving up through the hierarchy. All but the lower levels in the classification are capable of being mapped using aerial photographs, satellite imagery, or existing base maps.

The lowest levels in the classification are not shown but are termed ecological units which constitute coherent ecological communities characterized by prevalent or dominant organisms associated with specific water column or substrate characteristics. None of the specific ecological units are listed in the classification (Table 22), but the position of the ecological units is shown in figure one. A partial listing of specific ecological units and their association with water column or substrate features is given in Table 23. With time and experience, additional ecological units can be added to the list. Ground level or underwater observations are generally required to identify the dominant organisms and to list the genus and species name of each.

A glossary of terms has also been prepared for use with the classification, but it is too long to present here. Interested parties can contact the author to obtain a copy of the glossary. Every term in the marine ecosystem classification is defined in the glossary.

Future improvements to the marine ecosystem classification include the additions of sketch drawings and diagrams to illustrate the characteristics of each element, the inclusion of photographs to illustrate ecological units, and complete multi-language glossaries of all terms (English, French and German). These improvements should allow a greater number of workers to use and understand the classification. The updating and revision of the marine ecosystem classification is an ongoing process, and the system itself will benefit from "revisions" based upon additional experience in using it. Suggestions and comments are welcome at any time, and descriptions, photographs, or illustrations of elements and ecological units would be most appreciated.

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Table 1. Classification of the principal zoogeographic regions of the Indo-West Pacific

A. System developed by Ekman (1935, 1953, 1967)

INDO-WEST PACIFIC
- Indo-Malayan Region
- Central Pacific Islands
- Hawaii
- Subtropical Japan
- Tropical and Subtropical Australia
- Indian Ocean

B. Later system developed by Briggs (1974), including the provinces within the Indo-West Pacific

CONTINENTAL SHELVES REALM

The Tropical Ocean
- Indo-West Pacific Region
  - Western Indian Ocean Province
  - Red Sea Province
  - Indo-Polynesian Province
  - Northwest Australian Province
  - Lord Howe - Norfolk Province
  - Hawaiian Province
  - Easter Island Province
  - Marquesan Province
  - Other isolated areas
- 5 other regions

Southern Ocean
- 2 regions

Northern Ocean
- 2 regions

PELAGIC REALM

(vertical)
- Epipelagic (Sunlit) Zone
- Mesopelagic (Twilight) Zone
- Bathypelagic (Sunless) Zone
- Hadopelagic (Trench) Zone

(geographical)
- Tropical Seas
- Indo-Pacific Region {Indo-West Pacific Province / Atlantic Region
- 2 other Oceans

DEEP BENTHIC REALM
- Indo-West Pacific Region
- 2 other regions

Table 2. Classification of Marine Habitats as Proposed by Ray (1975) for Coastal and Coastal Associated Environments

A. Coastal Environments

1. Exposed
   (a) with rocky substrate
      (i) highly calcareous
      (ii) weakly or non calcareous
   (b) with unconsolidated substrate
      (i) with low organic content
         1) gravels
         2) sands
         3) silts
         4) clays
      (ii) with high organic content

2. Protected
   (a) with rocky substrate
      (i) highly calcareous
      (ii) weakly or non calcareous
   (b) with unconsolidated substrate
      (i) with low organic content
         1) gravels
         2) sands
         3) silts
         4) clays
      (ii) with high organic content

3. Deltas

B. Coast Associated Environments

1. Submarine vegetation beds
   (a) dominated by algae
   (b) dominated by vascular plants

2. Estuaries
   (a) mixoeuhaline (30-35‰ salinity)
   (b) polyhaline (18-30‰)
   (c) mesohaline (5-18‰)
   (d) oligohaline (0.5-5‰)

3. Lagoons
   (a) hyperhaline (over 40‰)
   (b) euhaline (30-40‰)
   (c) mixoeuhaline (30-35‰)
   (d) polyhaline (18-30‰)
   (e) mesolhaline (5-18‰)
   (f) oligohaline (0.5-5‰)

4. Tidal salt

5. Nontidal salt marshes and flats

6. Mangrove swamps

7. Drainage basins
   (a) extent (size)
   (b) type (agriculture, industrial)

Table 3. Classification of Ocean Realms, with emphasis on water mass and surface current characteristics, developed by Ray and co-workers.

A. Ocean Realms as defined by Ray *et al* (1984)

REALMS OF THE WESTERN AND EASTERN CONTINENTAL MARGINS
- Intertropical realms - seasonally within the trade winds of both hemispheres
- Tropical Realms - persistently within the trades of one hemisphere
- Subtropical Realms - Seasonally within the polewind extensions of the trade winds and within continental air streams
- Monsoon Realms - with seasonal and interhemispheric wind reversals
- Temperate Realms - within the westerly atmospheric and oceanic drifts of the mid latitudes
- Subpolar Realms - within the circulation domains of the subpolar cyclones

CIRCUMPOLAR REALMS
- Arctic Realms - along the Arctic Ocean Coast
- Antarctic Realm - along the Antarctic Continent only

MARGINAL SEAS OF COASTAL REALMS
(not described for insular tropical Pacific)

B. As defined by current direction in Hayden *et al* (1984) following Dietrich's (1963) classification

I. Variable eastward currents
II. Weak and variable currents
III. Trade-wind currents
Strong equatorial currents
Westward currents
Strong poleward currents
IV. Strong westward and equatorward currents
V. Monsoon currents (seasonal reversals)

C. Coastal Margin Realms as related to currents and windstreams (after Hayden *et al*, 1984)

Coastal Realm	Dominant Directions	
	Currents	Windstream
Arctic (M)	ice margin coast	W
Antarctic (L)	W-ice margin coast	W
Subpolar (A)	W	W
Eastern Side of Ocean		
temperate (B)	poleward	E
monsoon (J)	equatorward-poleward	onshore-offshore
subtropical (C)	poleward	poleward
tropical (D)	W	W
intertropical (E)	W	W
Western Side of Ocean		
temperate (F)	poleward	poleward-equator
monsoon (K)	poleward-equatorward	onshore-offshore
subtropical (G)	equatorward	equatorward
tropical (H)	equatorward	W-equatorward
intertropical (I)	E-equatorward	equatorward

Table 4. Classification of Marine Habitats as proposed by Ray (1975) for offshore, man-made, special interest and water circulation environments

Offshore Environments
1. Kelp beds
2. Coral reefs (active) bordering continents
   (a) algal
   (b) coral
3. Coral reefs bordering oceanic islands and atolls
   (a) algal
   (b) coral
4. Drowned reefs (on subsiding shorelines)
5. Insular environments
6. Continental shelf areas
7. Submarine canyons
8. Ice
   (a) shore fast
   (b) pack
   (c) shelf
   (d) glacial and berg
9. Continental slope environments
10. Offslope environments
   (a) abyssal plains
   (b) submarine trenches
   (c) seamounts
   (d) submarine ridges

Man-made environments
1. Spoil
2. Reefs
3. Mariculture

Special Interest
1. Sea bird rookeries and waterfowl moulting sites
2. Sea turtle rookeries
3. Sea mammal rookeries
4. Seasonal fish concentrations

Water Circulation Bodies
1. Inshore circulation cells
2. Larger scale circulation cells
3. Upwelling systems

Table 5. Biogeorgraphic Provinces of the South Pacific (adapted from Dahl 1976)

PROVINCE	LOCALITY
I	New Guinea
II	Outer Papua New Guinea
III	Solomons
IV	New Caledonia and Dependencies
V	Vanuatu
VI	Norfolk (Lord Howe, Kermadec)
VII	Fiji (including Rotuma)
VIII	Niue and Tonga
IX	Wallis and Futuna and Samoa
X	Tokelau and Tuvalu
XI	Gilberts, Nauru and Ocean Island
XII	Marianas (including Guam)
XIII	Carolines
XIV	Marshalls (plus Enenkio [Wake Atoll])
IV	Line and Phoenix Islands
XVI	Cook and Austral Islands
XVII	Society Islands
XVIII	Tuamotus
XIX	Marquesas
XX	Gambier, Rapa and Pitcairn

Table 6. Elements of a Classification of Ecosystems for the South Pacific (adapted from A. Dahl, 1976)

Ecosystem classification
- biogeographical dimension: biotic provinces (see table 5)
- climate
- island (physical) structure (described below)
- biomes (largest scale at functional biological unit) (see table 7)

Structural types of islands
- low
- volcanic
- elevated reef
- continental island

Structural types for the marine environment
- rocky substrate
  - calcareous
  - non-calcareous
- sedimentary substrate (unconsolidated)
  - gravels
  - sands
  - silts
  - clays
  - high organic content

Climatic and tectonic dimensions
- tectonic
  - submerging
  - emerging
  - apparently stationary
- climatic
  - exposed

Table 7. Marine and Related Coastal Biomes for the South Pacific Region (adapted from Dahl, 1976)

A. SHALLOW COASTAL ENVIRONMENTS ENVIRONMENTS

Submarine vegetation bed
- algal bed
- seagrass bed (principally vascular plants)

Animal dominated sedimentary bottom
- coral reef
  - algae dominated (coralline algae)
  - coral dominated
- animals in sediments

Note: (reefs may also be subdivided by situation and form)
- atoll reef
  - windward
  - leeward
- barrier reef
- fringing reef
- lagoon or patch reef
- "dead" reef
- drowned reef
- rocky coastline
- beach
- lagoon
  - saline (salinity greater than seawater)
  - open
  - closed
  - dilute
  - brackish
  - freshwater

Estuaries
- closed to seawater
- dilute seawater
- brackish water
- nearly freshwater

Marine lake

Marine cave

Man-made environments
- spoil (dredged spoil or other dumped sedimentary materials)
- reef (artificial structures made of stable materials)
- maricultural (enclosures or structures for cultivation)

B. DEEP OFFSHORE

Offshore terrace
Offshore slope
Continetal shelf
Submarine canyon
Offshore environments
- abyssal plain
- submarine trench
- submarine ridge
- seamount

C. WATER CIRCULATION BODIES

Inshore circulation cell
Larger scale circulation cell
Upwelling system

Table 8. Classification Scheme for Ecosystem Conservation Strategies for the South Pacific (from IUCN, 1986)

lowland rainforests
limestone forests
montane and sub-montane rainforests
cloud forest
special forests
    riverine
    bog
    swamp
    bamboo
    seasonal
    semi-deciduous
atoll beach strand forest
mangrove forest
scrub vegetation
grasslands and savannas
freshwater marshes, swamps, bogs
streams, rivers, lakes
desert
caves
seagrass beds
coral reefs
beaches and sandy or sedimentary bottoms
rocky shorelines
lagoons
marine lakes

Classification for islands of conservation significance
    continental islands
    volcanic islands
    atolls
    low islands
    raised coral limestone

Table 9. Major Classification of Marine Environments Based Upon "Vertical Factors (After Hedgpeth, 1957)

SUBSTRATE	WATER COLUMN
supralittoral	high water
littoral (intertidal)	low water
sublittoral	pelagic
inner	neritic
outer	oceanic
	epipelagic (photic)
	mesopelagic (aphotic)
bathyal	bathypelagic (aphotic)
	abyssopelagic (aphotic)
abyssal	
hadal	

Marine Classification Based Upon Salinity Regimes (After Hedgpeth, 1957a, adapted from other sources)

SALINITY REGIME	REFERENCES	
	(Redeke 1922,1933)	(Valikangas,1933)
freshwater(infrahaline)	less than 0.1‰	less than 0.2-0.5‰
brackish water		
oligohaline	0.1-1.0‰	(0.2) 0.5-(2.0)3.0‰
mesohaline		
meiomesohaline	1.0-5.5‰	2.0 (3.0)-8.0 (10)‰
pleiomesohaline	5.5-10.0‰	8.0 (10.0)-16.5‰
polyhaline	10.0-17.0‰	16.5-30.0‰
marine water		
ultrahaline	more than 17.0‰	more than 30.0‰

Table 10. Geomorphological Features of Coral Reefs (After Battistini *et al*, 1975)

1. organic build up
2. reef formation
3. bafflestone
4. bindstones
5. framestones
6. boundstones
7. organic reef
8. coral reef
9. fringing reef
10. apron reef
11. boat channel
13. barrier reef
13. double or multiple barrier reef
14. sand cay reef
15. coral bank
16. coral head
17. atoll
18. almost atoll
19. faro
20. emerged or elevated reef
21. drowned reef
22. lagoon
23. coral reef complex
24. outer slope
25. terrace
26. outer slope spurs and grooves
27. buttresses and valleys
28. reef tunnel
29. reef gallery
30. furrowed platform
31. outer reef slope furrows
32. subspur or subbuttress depression
33. transversal spur-building lack
34. lower sloping platform
35. groove riegel
36. outer slope hillock-form building
37. coral ridge
38. outer sandy spread
39. precipitous slope
40. reef flat
41. atoll rim
42. reef front
43. outer reef flat
44. spur upper platform
45. outer biogenic ridge
46. algal ridge
47. surge channel
48. room-and-pillar structure
49. outer creek
50. surge openings, blow holes, surge clefts
51. outer reef flat furrow
52. feeding groove
53. residual basin
54. obturation basin
55. residual pool (vasque temoin)
56. old reef spit (feo)
57. outer reef flat flagstone
58. outer moat
59. upper reef glacis
60. residual coral bench
61. erosion pot hole
62. negro head, megablock

Table 10. (con't)

63. outer detrial ridge
64. crag
65. gravel tail
66. tidal couloir
67. filtering dike
68. residual pool (mare residuelle)
69. boulder bank outfall
70. boulder rampart
71. gravel sheet
72. residual puddle
73. shingle spread
74. cay
75. motu (on atoll)
76. beach rock
77. coral reef conglomerate
78. cay sandstone
79. inner reef flat
80. reef flat moat, inner moat
81. sandy accumulation (of reef flat)
82. compact reef flat
83. reef flat with transverse stripes
84. reef flat with irregular coral growths
85. stopping-up and filling-up reef flat
86. branching coral reef flat
87. branching coral field
88. branching coral rim
89. reef flat with scattered coral growths
90. reef flat with microatolls
91. microatoll
92. reef flat with sandbanks without seagrass bed
93. seagrass reef flat
94. rubble reef flat
95. dying reef flat
96. reef flat spillway (hoa)
97. residual pool of emerged hoa
98. seagrass bed hollow
99. seagrass bed basin
100. seagrass bed channel
101. reef flat hydraulic bank
102. retention bench
103. mount-and-funnel reef flat field
104. pass
105. blind passage
106. enclosed lagoon
107. inner slope
108. inner edge spur-and-groove, buttress and valley system
109. lagoonal border spit
110. littoral spit
111. lagoonal tongue
112. closing spit of hoa
113. inner fan
114. inner slope talus
115. inner slope hydraulic sandbank
116. lagoonal bottom
117. lagoonal coral patch, knolls
118. lagoon reef
119. pinnacle
120. lagoon pattern reef
121. herring-bone reef (kaoa)
122. cuspate reef, open ring reef, annular reef
123. organogenous covering course
124. coral head field

Table 11. Atoll Classification (After Gabrié and Salvat, 1985)

1. Submerged Atoll

2. Open atoll
   A. with 3 passes
   B with 2 passes
   C. with one (wide and deep) pass, bordered by flagstone
   D. with one narrow pass

3. Closed atoll with large part of rim submerged at water surface (at high tide)

4. Closed atoll
   A. with numerous hoa (shallow channels or reef flats submerged at high tide)
   B. with some hoa and near continuous coconut groves (permanent islands)

5. Completely closed atoll with water entering only during bad weather or tsunamis

6. Nearly filled atoll

7. Raised atoll

Table 12. Geomorphological Classification of Coral Reefs (adapted from Guilcher, 1987)

1. FRINGING REEFS
   - 1.1 without boat channel
   - 1.2 with incipient boat channel
   - 1.3 with well-developed boat channel
   - 1.4 with multiple landlocked mini-lagoons
   - 1.5 intermediate with barrier reefs
   - 1.6 asymmetrical

2. BANK REEFS
   - 2.1 patch reefs
   - 2.2 with sand cays
   - 2.3 bank reef
   - 2.4 table reefs

3. BARRIER REEFS
   - 3.1 continuous
   - 3.2 segmented
     - arcuate
     - ribbon
     - coral knolls
   - 3.3 with secondary lagoons
   - 3.4 drowned
   - 3.5 almost-atoll
   - 3.6 double barrier
   - 3.7 multiple barrier
   - 3.8 with sand cay reefs and low isles in lagoons

4. ATOLLS
   - 4.1 with mangroves
   - 4.2 with pinnacles or knolls in lagoon
   - 4.3 with ava, hoa, tairua, overflow or temporarily ponded (closed)
   - 4.4 with motus
   - 4.5 with reticulated lagoon reefs
   - 4.6 drowned
   - 4.7 double and triple-ring atolls
   - 4.8 giant atolls
   - 4.9 faros
   - 5.0 elevated atolls

5. RIDGE REEFS
   - 5.1 Horst and graben reefs
     - Farsan Bank (Red Sea)
     - Sinai Penninsula
   - 5.2 Ridge atoll
   - 5.3 Ridge reef

6. SPECIAL REEFS
   - 6.1 Bahaman Bank reefs
   - 6.2 Houtman's Abrolhos
   - 6.3 Brazilian arrecifes (Abrolhos and Paredes Reefs)

Table 13. Classification of Hawaiian coastal water ecosystems based upon the physiography of bottom living organisms and certain fish assemblages (After Maragos *et al*, 1975)

I. Inland
Coastal wetlands
1. permanent ponds and marshes
2. seasonal ponds and marshes
3. anchialine pools
Perennial streams
4. interrupted
5. continuous

II. Shoreline
Estuaries
6. embayments
7. stream mouths
Rocky marine beaches
8. vertical basalt faces
A. supra-spray zone
B. spray or splash zone
9. horizontal basalt faces
10. boulder habitats
11. tide pools
12. limestone solution benches
Sediment beaches (or depositional shorelines)
13. sandy beaches
A. upper beach (including vegetation line)
B middle beach
C. lower beach
14. mud flats
15. mangroves

III. Offshore
16. coral reef flats
A. apron reef flats
B. fringing reef flats
C. barrier reef flats
D. patch reef flats
E. atoll reef flats
17. shallow wave surge habitats
A. basalt slopes
B. coral reef slopes
18. rocky steep slope habitats
19. protected or calm water coral communities
A. leeward coasts
B. coral lagoons
20. sand deposits and channels
21. deep water terraces and slopes
A. sea fans and black coral habitats
B. gold, pink, bamboo and other coral habitats

Table 14. Summary Classification of State waters (Hawaii) (after State of Hawaii Technical Committee on Water Quality Standards, 1977)

Inland Waters

Water Types	Ecological Subtypes
A. Freshwater	1. Streams
	2. Ditches and flumes
	3. Springs and seeps
	4. Natural lakes
	5. Reservoirs
	6. Elevated wetlands
	7. Low wetlands
B. Mixohaline and Saline	8. Coastal wetlands
	9. Estuaries
	10. Anchialine pools

Marine Waters

Water Types	Bottom Subtypes
C. Embayments	11. Lava rock shorelines
1. Wet	12. Sand beaches
2. Dry	13. Solution benches
3. Seasonally wet	14. Marine pools and protected coves
	15. Artificial basins
	16. Nearshore reef flats
D. Open Coast	17. Offshore reef flats
1. Wet	18. Wave-exposed reef communities
2. Dry	19. Protected coral communities
3. Seasonally wet	20. Soft bottom communities
E. Transition	
	21. Deep Benthos
F. Open Ocean	

Table 15. Key to Classification of Aquatic Environments in Hawaii (after Aecos, Inc. 1978)

1A. Marine environments
1B. Inland, fresh or brackish water environments
[1st ORDER - GENERAL EXPOSURE]
2A. Open coast or bight
2B. Embayment
[2nd ORDER - PHYSIOGRAPHY]
3A. No reef structure
3B. Shallow reef structure habitat
4A. Habitat at shoreline and eulittoral
4B. Habitat sublittoral
5A. True, shoaling reef structure
5B. No reef structure
6A. Front of reef slope or surge channels through reef front
6B. Reef margin, reef flat, reef hole, or back reef channel
7A. Reef flat continuous from shoreline
7B. Reef separated from shoreline by intervening channel or lagoon
8A. Reef "margin" submerged
8B. Reef margin defined at less that 2m in depth
9A. Barrier or atoll (ribbon) reef
9B. Patch, line, or table reef
[3rd ORDER - ZONES]
10A. Outer reef zone
10B. Reef flat, reef holes, dredged channels behind reef margin
11A. Middle reef zone
11B. Inner reef zone
11C. Reef holes, lagoons or dredged channels behind reefs
12A. Depth 0 to approximately 10m (high surge)
12B. Depth below zone of high surge but within photic zone
12C. Depth below penetration of light (aphotic zone)
[4th ORDER - SUBSTRATUM TYPE]
13A. Substratum solid or consolidated
13B. Substratum loose material
14A. Substratum consolidated limestone
14B. Substratum volcanic
14C. Substratum artificial
15A. Substratum basalt rubble
15B. Substratum limestone rubble
15C. Substratum sand
15D. Substratum mud or muddy sand

Table 16. Listing of Reef Cover and Zonation Classifications (after Kuchler, 1986a)

LEVEL 1 CLASSIFICATION ACCORDING TO ZONES	LEVEL II CLASSIFICATION ACCORDING TO REEF FEATURES	LEVEL III CLASSIFICATION ACCORDING TO COMPOSITION AND POSITION	LEVEL IV CLASSIFICATION ACCORDING TO CONDITION, PATTERN AND MORPHOLOGY	LEVEL V CLASSIFICATION ACCORDING TO PRESENCE
5 Ocean	5 Slope	5 Upper	5 Steep	5 0-10%
6 Off-Reef-Floor	6 Moat	6 Middle	6 Gentle	6 10-20%
7 Reefal Shoal	7 Submarine Moat	7 Lower	7 Live State	7 20-30%
8 Reef Flank	8 Patch Reef	8 North	8 Dead State	8 30-40%
9 Multiple Reef Front	9 Coral Head	9 South	9 Mixed (live/dead) State	9 40-50%
10 Spur and Groove	10 Coral Pool	10 East	10 Aligned Pattern	10 50-60%
11 Reef Slope	11 Microatoll	11 West	11 Truncated Pattern	11 60-70%
12 Reef Rock Slope	12 Pool	12 Windward	12 Patched Pattern	12 70-80%
13 Back-Reef Zone	13 Rock	13 Leeward	13 Reticulate Pattern	13 80-90%
14 Patch Reef Zone	14 Ridge	14 Phosphate	14 Dispersed Pattern	14 90-100%
15 Reef Rim	15 Rim	15 Reef	15 Remnant Pattern	15 <.5m Water
16 Algal Reef Rim	16 Rampart	16 Rampart	16 Deltaic Pattern	16 .5-1m
17 Reef Top	17 Bassett Edge	17 Beach	17 Sheet Pattern	17 1-2m
18 Reef Flat	18 Bank	18 Boulder	18 Circular	18 2-3m
19 Outer Reef Flat	19 Tongue	19 Algal Coating	19 Oval	19 3-4m
20 Inner Reef Flat	20 Platform	20 Algae (macro)	20 Continuous	20 4-5m
21 Living Coral Zone	21 Boulder Tract	21 Algal Encrustation	21 Intermittant	21 5-6m
22 Dead Coral Zone	22 Wedge	22 Seagrass	22 Isolated	22 6-8m
23 Aligned Coral Zone	23 Terrace	23 Coral	23 Turbid State	23 8-10m
24 Rubble Zone	24 Shoal	24 Rubble	24 Moderate State	24 10-15m
25 Sand Zone	25 Chute	25 Shingle	25 Calm State	25 15-30m
26 Seagrass Zone	26 Sand Patch	26 Sand	26 Coarse Grained	26 30-35m
27 Lagoon	27 Reef Rim Lagoon	27 Sediment	27 Medium Grained	27 >30m
28 Shallow Lagoon	28 Lagoon Wall	28 Conglomerate	28 Fine Grained	28 Variable Water Depth
29 Medium Lagoon Covering	29 Lagoon Floor	29 Living Margin	29 Supra-tidal	29 Light
30 Deep Lagoon Covering	30 Beach	30 Dead Surface	30 Inter-tidal	30 Medium
31 Blue Hole Covering	31 Dune	31 Breaking Waves	31 Sub-tidal	31 Heavy
32 Cay	32 Spit	32 Partially Vegetated	32 Single Level	? Field Data Req.
33 Island	33 Spur	33 Cleared Vegetation	33 Multiple Levels	N Level V not used
34 Cloud	34 Groove	34 Dune Vegetation	34 Enclosed	
35 Shadow	35 Perimeter	35 Mangrove	35 Partially Open	
X Data Anomaly	36 Vegetated	36 Mangrove Swamp	36 Fully Open	
? Field Data Required	37 Unvegetated	37 Ponded Water	37 Narrow Gutter	
N Level 1 Not Used	38 Channel Between Reefs	38 Boat	38 Shallow Wide Depression	
	39 Channel in Reef Top	39 Wharf	39 Permanent Feature	
	40 Channel in Deltaic Pattern	40 Building	40 Temporary Feature	
	? Field Data Required	41 Walking Track	? Field Data Required	
	N Level 11 Not Used	42 Engineering Construction	N Level IV Not Used	

Table 17. Reef cover and zonation classification system for use with remotely sensed Great Barrier Reef data (after Kuchler, 1986b)

Level I:
CLASSIFICATION ACCORDING TO ZONES
Ocean
Off-reef Floor
Reefal Shoal
Reef Flank
Multiple Reef Front
(Double Reef Front)
Spur and Groove
Reef Slope
Reef Rock Slope
Back-Reef Zone
Patch Reef Zone
Reef Rim
Algal Reef Rim
Reef Top
Reef Flat
Outer Reef Flat
Inner Reef Flat
Living Coral Zone
Dead Coral Zone
Aligned Coral Zone
Rubble Zone
Sand Zone
Seagrass Zone
Lagoon
Shallow Lagoon
Medium Lagoon
Deep Lagoon
Blue Hole
Cay
Island
Cloud
Shadow
Data Anomaly
Field Data Required
Level I Not Used

LEVEL II - ACCORDING TO REEF FEATURES
Slope
Moat
Patch Reef
Coral Head
Coral Pool
Microatoll
Pool
Rock
Ridge
Rim
Rampart
Bassett Edge
Bank
Tongue
Platform
Boulder Tract
Wedge
Shoal
Chute
Sand Patch
Reef Rim Lagoon
Lagoon Wall
Lagoon Floor
Beach
Dune
Spit
Spur
Groove
Perimeter
Vegetated
Unvegetated
Channel Between Reefs
Channel in Reef Top
Channel in Deltaic Pattern
Field Data Required
Level II Not Used

LEVEL III - CLASSIFICATION ACCORDING TO COMPOSTION AND POSITION
Windward
Leeward
Phosphate
Reef
Rampart
Beach
Boulder
Algal Coating
Algae (Macroscopic)
Algal Encrustation
Seagrass
Conglomerate
Living Margin
Breaking Waves
Partially Vegetated
Cleared Vegetation
Dune Vegetation
Mangrove
Boat
Wharf
Building
Walking Track
Engineering Construction
Wreckage
Field Data Required
Level III Not Used

LEVEL IV - CLASSIFICATION ACCORDING TO CONDITION, PATTERN AND MORPHOLOGY
Aligned Pattern
Reticulate
Dispersal Pattern
Remnant Pattern
Deltaic Pattern

LEVEL V - CLASSIFICATION ACCORDING TO PRESENCE
entries in Level V are self defined in the Classification System (depending upon what is selected)

Table 18. Coral reef features that can be interpreted from aerial photographs (adapted from Hopley, 1978)

ISLAND
- Cay
- Beachrock
- Raised feef
- Mangroves

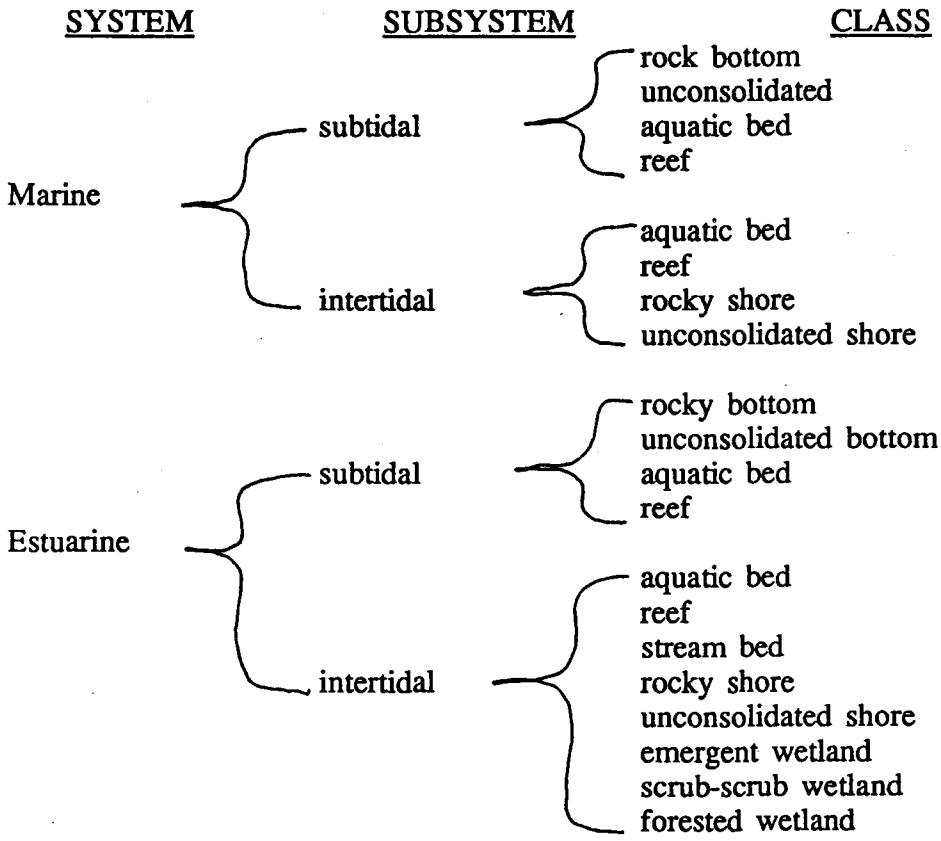
MOAT AND RAMPART
- Shingle ramparts
- Basset edges and cemented reef rubble
- Moats

REEF FLAT
- Lagoon
- Lagoon Corals
- Reef flat corals behind algal rim
- Sandy reef flat, lee side
- Seagrass bed

REEF EDGE
- Algal terrces
- Algal rim
- Sand chute
- Spurs and grooves
- Living coral

Table 19. Classification of wetland and deepwater habitats of the United States: excerpts on the estuarine and marine classification components (after Cowardin *et al* 1979).

I. MAJOR DIVISIONS



II. SALINITY MODIFIERS USED IN THE CLASSIFICATION SYSTEM

Coastal Modifiers	Inland modifiers	Salinity
Hyperhaline	Hypersaline	greater than 40‰
Euhaline	Eusaline	30-40‰
Mixohaline (brackish)	Mixosaline	0.5-30‰
Polyhaline	Polysaline	18-30‰
Mesohaline	Mesosaline	5-18‰
Oligohaline	Oligosaline	0.5-5‰
Fresh	Fresh	less than 0.5‰

III. SUBCLASSES AND EXAMPLES OF BENTHIC DOMINANCE MODIFIERS

SYSTEM, CLASS AND SUBCLASS	EXAMPLES OF DOMINANCE TYPE
Marine	
Rock bottom	American lobster (*Homarus*)
Rubble	Encrusting sponge (*Hippospongia*)
Unconsolidated bottom	
Cobble-gravel	Brittle star (*Amphipholis*)
Sand	Great Alaskan tellin (*Tellina*)
Mud	Atlantic deep sea scallop (*Placopecten*)
Organic	Clam worm (*Nereis*)
Aquatic bed	
Rooted vascular	Turtle grass (*Thalassia*)
Algal	Kelp (*Macrocystis*)
Reef	
Coral	Coral (*Porites*)
Worm	Reef worm (*Sabellaria*)
Rocky Shore	
Bedrock	Gooseneck barnacle (*Pollicipes*)
Rubble	California mussel (*Mytilus*)
Unconsolidated shore	
Cobble-gravel	Acorn barnacle (*Balanus*)
Sand	Pismo clam (*Tivela*)
Mud	Boring clam (*Platyodon*)
Organic	False angel wing (*Petricola*)
Estuarine ...etc.	

Table 20 Comparison of global marine classification systems (adapted from Crawford and Grossman, 1990)

AUTHOR	LEVEL	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	COMMENTS
Pielou (1979)	5	Realms (Biosphere): shelf deep ocean	Habitat: pelagic benthic	Life Mode: nekton nueston plankton epifauna infauna	Benthic depth zones and pelagic water mass zones	Subzones, based on light penetration and temperature range	Neritic realm unclassified, continental sheves are extensions of adjoining terrestrial realms
Ray (1975) Hayden *et al* (1984)	5	Biomes (geographical): open ocean coastal margin marginal sea marginal archipelago	Realms: 10 units based upon surface currents and related atmospheric winds	Provinces 40 units based upon coastal associations	Habitat (benthic) 30 units based upon dominance of substrate, flora, or fauna	Habitat modifiers greater specificity on dominant life forms, sediment size, etc.	classification based on relationship of physical environment to marine biotic provinces no ocean provinces defined emphasis on temperature and boreal biota
Ketchum (1972)	1	Regions 12 units based upon seasonal variation, circulation patterns and key species, e.g., insular, precipitous mountains, heavy wave action, tropical & subtropical endemsim.					limited to neritic zone of North America based on zoogeography physionomy currents, and climate
Cowardin *et al* (1979)	5	System "complex": marine lacustrine estuarine riverine palustrine	Subsystem: marine intertidal marine subtidal estuarine intertidal estuarine subtidal riverine tidal riverine lower perennial riverine upper perennial riverine intermittant lacustrine limnetic lacustrine littoral	Class: general appearance of habitat based on dominant life form or substrate composition/ physiography (visible from remote imagery)	Subclass - finer scale description of dominant life form or substrates, e.g., coral mollusk worm bedrock rubble algal mat, etc.	Dominance type taxonomic name of dominant life forms, plant, animal or both	System is open ended below the class level heavily oriented towards continental systems Crawford & Grossman suggest including geological terms in substrate dominated community name
Briggs (1974)	4	Geographic Divisions: continental shelf open sea deep sea	Oceans: Tropical Southern Northern	Regions (9 total): For TROPICAL OCEAN these are Indo-West Pacific Eastern Pacific Western Atlantic Eastern Atlantic	provinces (30 total) based upon prevailing wind and current patterns and reflected in recruitment patterns of key species		Crawford & Grossman believe system is impossible to adapt to marine classification scheme useful to conservation, but considerable useful information

Table 21. Island groups overlying the tectonic plates of the tropical Pacific (after Springer, 1982). Island groups with asterisks occur eastward of the Indian-Australian Continental plate but are westward of the Andesite Line. Cross indicates islands outside of the tropics.

NASCA PLATE
- Easter Is. - Sala y Gomez
- Galapagos Is. +
- San Felix - San Ambrosio
- Juan Fernandez Is. +

PACIFIC PLATE
- Vanuatu *
- N. Irian Jaya & Papua New Guinea (Bismarks) *
- Solomons *
- Eastern Carolines (Chuuk, Pohnpei, Kosrae)
- Marcus Is.
- Marshalls & Wake
- Hawaii & Johnston
- Line Is.
- Phoenix Is.
- Gilbert, Nauru & Ocean Is.
- Tuvalu
- Tokelau
- Samoa
- Cooks
- Societies
- Tuamotus
- Marquesas
- Pticairn & Duce
- Australs
- Rapa
- Guadalupe
- Clipperton
- Revillagigedos Is.

INDIAN-AUSTRALIAN PLATE
- S. Papua New Guinea & Irian Jaya
- New Caledonia
- Fiji, Lau & Rotuma
- Tonga
- Norfolk - Lord Howe
- Kermadecs
- New Zealand +
- Chatham Is. +
- Timor & Sulu Sea islands of Indonesia

PHILIPPINE PLATE
- Southern Ryukyus
- Bonin Is.
- Taiwan
- Marianas
- Western Carolines (Yap, Palau)
- N. Philippines

EURASIAN PLATE
- Northern Ryukyus
- Remainder of Malay archipelago

COCOS PLATE
- none

TABLE 22. PROPOSED MARINE ECOSYSTEM CLASSIFICATION

OCEAN

I. OPEN OCEAN (PELAGIC)

1. Divergences (upwelling zone)
   - 1.1. Surface microlayer
   - 1.2. Epipelagic (0-200m)
     - 1.2.1. Shallow
       - 1.2.1.1. Surface waters
       - 1.2.1.2. Mixed waters
       - 1.2.1.3. Thermocline waters
     - 1.2.2. Deep

     Modifiers
     a. Photic
     b. Aphotic

   - 1.3. Mesopelagic (200-1000m)
   - 1.4. Bathypelagic (1000-4000m)
   - 1.5. Abyssopelagic (4000m-7000m)
   - 1.6. Hadalpelagic (greater than 7000m)

2. Convergences (downwelling zone)
   (as in 1.)

3. Boundary Currents
   (as in 1.)
4. Water Masses
   (as in 1.)

II. NEARSHORE OCEAN (NERITIC)

1. Eddies
   - 1.1. Surface microlayer
   - 1.2. Epipelagic (0-200m)
     (as in 1.2.)

2. Coastal Upwelling Zone
   - 2.1. Surface microlayer
   - 2.2. Epipelagic (0-200m)
     (as in 1.2.)

3. Coastal Ocean
   - 3.1. Surface microlayer
   - 3.2. Epipelagic (0-200m)
     (as in 1.2.)

4. Convergences
   2.1. Surface microlayer
   2.2. Epipelagic (0-200m)
   (as in 1.2)

BOTTOM (BENTHIC)

I. CONTINENTAL SHELF (Non-Oceanic)

1. High Island Earthform (Height greater than 10m)
   1.1. Non-coral reef coast
      1.1.1. Shore area
         1.1.1.1. Undifferentiated coast
            1. Boulder/cobble beach (sediment slope shore)
            2. Sand/gravel beach
            3. Silt/clay sediment shore
            4. Flat shore - boulder/cobble
            5. Sand flat
            6. Mudflat
            7. Ramp (solid slope shore)
            8. Marine bench
            9. High cliff (greater than 10m)
            10. Medium cliff (2-10m height)
            11. Low cliff (less than 2m)
            12. Marine cave
            13. Talus slope
            14. Beachrock
            15. Artificial shore
            16. Fishpond

            Descriptive Modifiers
               A) Tidal Position
                  a. Supratidal
                  b. Intertidal
                  c. Subtidal
               B) Height
               C) Steepness

         1.1.1.2. Dry bay
            (as in 1.1.1.1.)
         1.1.1.3. Wet bay
            (as in 1.1.1.1.)
         1.1.1.4 . Estuary
            (as in 1.1.1.1.)
         1.1.1.5. Coastal lagoon
            (as in 1.1.1.1.)
         1.1.1.6. Open marine pond/lake
            (as in 1.1.1.1.)
         1.1.1.7. Anchialine pond/lake
            (as in 1.1.1.1.)

1.1.1.8. Sealed marine pond/lake
(as in 1.1.1.1.)
1.1.2. Nearshore bottom area

1.2. Fringing reef coast
1.2.1. Shore area
(as in 1.1.1.)
1.2.2. Fringing reef area
1.2.2.1. Reef top
1. Reef flat
2. Algal ridge
3. Surge channel
4. Hoa
5. Moat and depression
6. Rubble platform
7. Beachrock
8. Reef conglomerate
9. Aeolianite
10. Coral/algal dam and spillway
11. Storm blocks
12. Boulder ramparts
13. Sand and gravel sheets on reef flat
14. Gravel ridge
15. Sand cay
16. Motu (low islet; height 10m or less)
17. High islet (height greater than 10m)
18. Lagoon sand bar and spit
19. Reef pool (depth 5m or less)
20. Reef hole (greater than 5m)
21. Artificial structure
22. Channel (dead end pass)

1.2.2.2. Outer slope
1. Terrace
2. Groove and spur
3. Buttress and valley
4. Tunnel (room and pillar)
5. Furrowed platform
6. Vertical cliff
7. Notch/cave
8. Detrital boulders on slope and terrace

1.3. Barrier reef coast
1.3.1. Shore area
(as in 1.1.1.)
1.3.2. Lagoon fringing reef area
(as in 1.2.2.)
1.3.3. Lagoon area
1.3.3.1. Lagoon patch reef or pinnacle
1.3.3.2. Lagoon reticulate reef
1.3.3.3. Reef hole (depth greater than 5m)
1.3.3.4. Lagoon floor

1.3.3.5. Algal (Halimeda) mound
1.3.3.6. Deep lagoon floor sediment sink
1.3.4. Barrier reef area
1.3.4.1. Reef top
(as in 1.2.2.1.)
23. Shallow pass (depth 5m or less)
24. Deep pass (depth greater than 5m)
1.3.4.2. Outer slope
(as in 1.2.2.2.)
1.3.4.3. Lagoon slope

2. Low Island Earthform (height 10m or less)
2.1. Non-coral reef coast
2.1.1. Shore area
(as in 1.1.1.)
2.1.2. Nearshore bottom area
2.2. Fringing reef coast
2.2.1. Shore area
(as in 1.1.1.)
2.2.2. Fringing reef area
(as in 1.2.1.)
2.3. Barrier reef coast
2.3.1. Shore area
(as in 1.1.1.)
2.3.2. Fringing reef area
(as in 1.2.1.)
2.3.3. Lagoon area
(as in 1.3.3.)
2.3.4. Barrier reef area
(as in 1.3.4.)

3. Submerged Earthform (non-land associated and below sea level)
3.1. Nearshore reef/shoal (incl. fringing reef)
3.2. Mid-shelf reef/shoal/bank
3.3. Outer shelf reef/shoal/bank (incl. outer barrier reef)
3.4. Nearshore plain
3.5. Offshore plain
3.6. Canyon
3.7. Continental slope

II. NON CONTINENTAL (Oceanic)

1. High Island Earthform
1.1. Non-coral reef coast
1.1.1. Shore area
(as in 1.1.1.)
1.1.2. Nearshore bottom area
1.1.3. Deep bottom area
1.1.3.1. Bathyal (200-4000m)
1.1.3.2. Abyssal (4000-7000m)
1.1.3.3. Hadal (greater than 7000m)

1.2. Fringing reef coast
    1.2.1. Shore area
        (as in 1.1.1.)
    1.2.2. Fringing reef area
        (as in 1.2.2.)
    1.2.3. Deep bottom area
        (as in 1.1.3.)
1.3. Barrier reef coast
    1.3.1. Shore area
        (as in 1.1.1.)
    1.3.2. Fringing reef area
        (as in 1.2.2.)
    1.3.3. Lagoon area
        (as in 1.3.3.)
    1.3.4. Barrier reef area
        (as in 1.3.4.)
    1.3.5. Deep bottom area
        (as in 1.1.3)

2. Reef Island Earthform
    2.1. Atoll with many deep passes/partially enclosed
        2.1.1. Shore area
            2.1.1.1. Undifferentiated coast - outer/ocean
                1. Boulder/cobble beach (sediment slope shore)
                2. Sand/gravel beach
                3. Boulder/cobble field
                4. Sand flat
                5. Ramp (solid slope shore)
                6. Marine bench
                7. Low cliff
                8. Beachrock
                9. Artificial shore
            2.1.1.2. Undifferentiated coast - inner/lagoon
                1. Boulder/cobble beach (sediment slope shore)
                2. Sand/gravel beach
                3. Boulder/cobble field
                4. Sand flat
                5. Ramp (solid slope shore)
                6. Marine bench
                7. Low cliff
                8. Beachrock
                9. Artificial shore
                10. Mud flat
                11. Silt/clay sediment shore
            2.1.1.3. Undifferentiated coast - inter-islet
                (as in 2.1.1.2.)
            2.1.1.4. Cove
                (as in 2.1.1.2.)
            2.1.1.5. Inlet (Barachois)
                (as in 2.1.1.2.)
            2.1.1.6. Coastal Lagoon
                (as in 2.1.1.2.)

2.1.1.7. Open Marine pond/lake
(as in 2.1.1.2.)
2.1.1.8. Anchialine pond/lake
(as in 2.1.1.2.)
2.1.1.9. Sealed marine pond/lake
(as in 2.1.1.2.)

2.1.2. Reef area
(as in 1.2.2.)
2.1.3. Lagoon area
(as in 1.3.3.)
2.1.4. Deep bottom area
(as in 1.1.3.)

2.2. Atoll with few/one deep pass(es), (depth greater than 5m)
2.2.1. Shore area
(as in 1.1.1.)
2.2.2. Reef area
(as in 1.2.2.)
2.2.3. Lagoon area
(as in 1.3.3.)
2.2.4. Deep bottom area
(as in 1.1.3.)

2.3. Atoll with no deep pass
2.3.1. Shore area
(as in 1.1.1.)
2.3.2. Reef area
(as in 1.2.2.)
2.3.3. Lagoon area
(as in 1.3.3.)
2.3.4. Deep bottom area
(as in 1.1.3.)

2.4. Atoll completely land ringed
2.4.1. Shore area
(as in 1.1.1.)
2.4.2. Reef area
(as in 1.2.2.)
2.4.3. Lagoon area
(as in 1.3.3.)
2.4.4. Deep bottom area
(as in 1.1.3.)

2.5. Reef island with water body
2.5.1. Shore area
(as in 1.1.1.)
2.5.2. Reef area
(as in 1.2.2.)
2.5.3. Lagoon area
(as in 1.3.3.)
2.5.4. Deep bottom area
(as in 1.1.3.)

2.6. Reef island without water body
    2.6.1. Shore area
        (as in 1.1.1.)
    2.6.2. Reef area
        (as in 1.2.2.)
    2.6.3. Deep bottom area
        (as in 1.1.3.)

3. Submerged Earthform
    3.1. Atoll-reef (crest at depth less than 20m)
        3.1.1. Near surface (less than 200m)
        3.1.2. Bathyal (200-4000m)
        3.1.3. Abyssal (4000-7000m)
        3.1.4. Hadal (greater than 7000m)
    3.2. Table reef (at depth less than 20m)
    3.3. Shoal (at depth less than 20m)
    3.4. Bank (at depth between 20-200m)
    3.5. Seamount (at depth greater than 200m)
    3.6. Guyot (at depth greater than 200m)
    3.7. Ridge
    3.8. Plain
    3.9. Trench
    3.10. Fracture
    3.11. Submarine volcano
    3.12 Geothermal vent

TABLE 23. Examples of ecological units associated with the marine ecosystem classification for the tropical Pacific

CLASSIFICATION ELEMENT	ELEMENT NUMBER	ECOLOGICAL UNIT	DOMINANT OR CONSPICUOUS ORGANISMS
open ocean, divergence, epipelagic	1.2.1.1.	yellowfin tuna aggregations	Thunnus albacares
open ocean, boundary current, epipelagic	3.1.2.1.	albacore schools	T. alalunga
nearshore ocean, coastal ocean, epipelagic	3.3.2.1.	skipjack tuna schools	Katsuwonus pelamis
open ocean, water mass, epipelagic	1.4.2.2.	bigeye tuna aggregations	T. obesus
open ocean, coastal ocean, epipelagic	3.3.2.1.	eastern little tuna	Euthynnuis affinis
open ocean, boundary current, epipelagic	3.1.2.1.	bonito	
bottom continental, high island, sand beach	1.2.1.1.2	ghost crab community	Ocypode sp.
bottom continental, high island, boulder beach	1.1.1.1.1.	littorine snail community	Littorina sp., Nerita sp.
bottom, non-continental, marine beach	1.2.1.1.8.	boring urchin community	Echinometra mathaei
bottom, continental, lagoon fringing reef	1.3.2.1.3.	mangrove forest	Brugiera gymnorhiza
bottom, non-continental, reef area	2.1.2.1.1.	microatoll corals	Porites lutea

VI. OCA/PAC (UNEP) Inter-Regional Seas Meeting, XVII Pacific Science Congress

OCA/PAC (UNEP) INTER-REGIONAL SEAS SEMINAR HELD AT XVII PACIFIC SCIENCE CONGRESS: DISCUSSION AND RECOMMENDATIONS

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INTRODUCTION

As outlined in the Preface to this volume, the Oceans and Coastal Areas Programme Activity Centre (OCA/PAC) of UNEP has, since 1983, sponsored four inter-regional symposia or seminars to encourage interaction among the three Regional Seas programmes of the Pacific Basin (East Asian Seas, South Pacific, South-East Pacific). The fourth such meeting, which is the subject of this report, was held for half a day on 30 May 1991 in Honolulu during the XVII Pacific Science Congress. The meeting attracted the interested participation of over 50 scientists, educators, and managers, who joined in discussion with the representatives of the three Regional Seas programmes and other concerned regional organisations, such as the Association of South Pacific Educational Institutions (ASPEI).

The seminar's attention was particularly directed to the following topics:

a) Climate change and sea-level rise
b) Marine-pollution assessment and control
c) Integrated coastal zone management
d) Coastal ecosystem monitoring
e) Conservation of marine biological diversity

Programme representatives reviewed activities, issues, and problems with regard to each of these topics within their region, and discussion followed on ways to facilitate interaction and improve coordination among the programmes in the Pacific. The educational aspects of the topics were also discussed, and information provided on the proposal to organise an Indo-Pacific network of marine and environmental science institutions (see MAYNARD and HARGER, this volume).

Additionally, the seminar took advantage of the gathering of environmental experts from across the Pacific Basin to consider Pacific-wide issues to be brought to the attention of the United Nations Conference on Environment and Development (UNCED). At its conclusion, the seminar proposed and adopted recommendations for consideration by the Pacific Basin Regional Seas programmes and UNEP OCA/PAC.

DISCUSSION

Climate Change and Sea-Level Rise

The seminar was briefed on the developments and activities of the Climate Change Task Team operating in each of the Programme regions. The Chairman of the SPREP Task Team reported on the topic studies undertaken so far in the South Pacific and noted that the focus of activity is on the identification of vulnerable components and the development of mitigating strategies rather than on attempts, as through legislation, to limit the emissions of greenhouse gases. Individual country reports, as for the atoll country of Kiribati, are being produced to evaluate the potential impacts of climate change. Although problems arise in the South Pacific from the lack of continuity among skilled staff, activities are growing in the climate-change area, and outside funding has enabled SPREP to appoint a climate-change officer.

EAS representatives noted that a report was in press on the projected impacts of climate change. Concern in the EAS region is particularly focused on (1) the effects on agriculture that would result from changes in monsoon precipitation, (2) the effects of global changes on coastal ecosystems (particularly coral reefs, mangroves, seagrasses, and seaweeds) (see ATMADJA *et al.* on Indonesia, this volume), (3) the effects on major population centres in Southeast Asia, some of the largest of which are subsiding tectonically as well as being prone to damage from sea-level rise, and (4) the potential of climate change to accelerate the depletion of ground-water supplies. There is need for further research and the preparation of case studies.

The South-East Pacific Task Team representative noted the emphasis in that region on studies relating to the significance of El Niño phenomena (see ANDRADE, this volume), storm surges, and coastal erosion.

In general discussion, appreciation was given to the valuable contributions that the Task Teams and other programmes have already made. It was further noted that an important component of regional programmes investigating the effects of projected climate change is an on-going review of scientifically-based changes in the projections for global warming and sea-level rise -- that is, the programmes require an inbuilt evolutionary component responsive to the rapidly changing state of knowledge with regard to climate change so that the latest ideas and data can be entered into the programmes on an iterative basis. There is also a need to increase efforts to transmit information rapidly from scientists to authorities responsible for developing and implementing national and international responses to climate change. These issues raised general discussion on failures of cross-communication and the sociological/disciplinary barriers to the transmission of information -- problems whose solution is equal in significance to the scientific research that leads to better projections of climatic change.

The representative of UNEP Asia/Pacific highlighted the role of the UNEP Global Environment Monitoring System (GEMS) in collecting and collating information related to climate change and noted the need to address the socio-economic impacts of climate change. A GEMS project implemented in Thailand, Malaysia, and Indonesia involved decision makers in an innovative policy exercise of looking at options over a long time scale, given certain

climatic conditions. Inter-regional cooperation was pointed out as being especially useful in studies of climate-change impacts on ecosystems shared across the Pacific, notably coral reefs and mangroves.

Marine-Pollution Assessment and Control

The marine pollution programmes undertaken in the region were described. The implementation of the SPREP Marine Pollution Monitoring and Control programme (SPREP POL) has highlighted the lack of long-term data sets on marine water quality, the need for data-quality control, and the necessity to develop indigenous capabilities for pollution assessment (see MORRISON, this volume).

The present lack of an analogous programme in the EAS region results from lack of funding and a need for greater regional coordination on this problem. There are, however, a number of ASEAN and national programmes underway on pollution assessment and control, *e.g.*, on monitoring organic pollution or the Singapore programme on assessment of land-based sources of pollution, for which a good handbook has been produced.

The need to give particular attention to toxic and hazardous materials entering the marine environment was stressed and the existence of the Pacific Basin Consortium on Hazardous Waste Research was noted by a representative of the Environment and Policy Institute of the East-West Center in Honolulu. The Consortium can advise on movements of hazardous wastes and the provision of adequate controls. Long-distance movement of solid wastes in the broad offshore oceans was also noted, with the suggestion that monitoring of ocean debris deposited on isolated beaches -- as along the unpopulated coasts of southern Australia -- can provide an effective measure of solid wastes and their movements in the oceans.

Integrated Coastal Zone Management

General discussion on the need for integrated coastal zone management (CZM) to deal with issues covered by the seminar revealed that most action in developing CZM programmes and plans is carried out at the national level, with plans being pursued in various countries of the EAS region and the South-East Pacific (see RETAMAL, this volume, for an overview of the South-East Pacific), while progress in this regard is very slow in the South Pacific.

Several speakers stressed (as with the issue of climate change) that if CZM is to be successfully planned and implemented, there is a great need for effective communication and information transfer between scientists, engineers, planners, and decision-makers (at sub-national, national, and regional levels). The matter of economic valuation of coastal resources and uses was brought up as one aspect of CZM that requires more effort (see MUNRO-FAURE, this volume).

Coastal Ecosystem Monitoring

Activities related to coastal ecosystem monitoring were presented for each of the Pacific Regional Seas Programmes. The Living Coastal Resources project in Southeast Asia, with funding and co-operative scientific contributions from Australia, has reviewed the methodology of coastal monitoring and developed standardised techniques for monitoring the structure (phase I) and function (phase II) of coastal ecosystems. The second phase has determined metabolism to be a useful measure of environmental stress. The importance of obtaining comparable data through standardised research techniques was emphasised as a way to develop regional databases that could lead on to inter-regional databases and the elucidation of widespread natural patterns (see YAP, this volume).

The attempts to develop a SPREP coastal monitoring programme (PACICOMP) were described and the need for such a programme reiterated. The similar Caribbean programme (CARICOMP) was outlined. CARICOMP methodology focuses on the growth of organisms and community structure, with a firm base of data on weather and water temperature. It is a tiered programme, with all participating institutions contributing at least at a standard minimum level. The value of simple measurements and proxy measurements was pointed out -- *e.g.*, chemical measurements may not show nutrient increases in the water or there may be no instruments available to carry out measurements, but the growth of algae show a nitrogen input. The CARICOMP experience to date has highlighted the need for effective data transfer and management.

A ten-year study of coastal systems in Hawaii was described. The study is evaluating point and non-point sources of stress, habitat destruction, and over-fishing of coastal ecosystems, with comparisons with pristine sites. The representatives of several international programmes stressed the need for cooperation and coordination with regard to ecosystem monitoring programmes.

Conservation of Marine Biological Diversity

The discussion on the conservation of marine biological diversity reconfirmed disturbance, degradation, and destruction of habitat to be the major problem. The development of an ecological classification of coastal and marine habitats and ecosystems in order to clarify the presence and status of habitats at a regional, national, or local scale, such as is being done in the SPREP region, was considered an important method for determining conservation priorities (see MARAGOS, this volume).

The case of endangered marine species, especially marine turtles, dugong, and cetaceans, was discussed. It was felt that regional conservation planning and management was required for these species, with a focus on conservation of critical habitat. The conservation of globally endangered species should be supported by the international community.

Pacific-wide Issues for UNCED

Country reports on environment and development are being prepared by most nations. In addition, some regions, such as the island South Pacific, are preparing regional reports. The seminar discussed whether there were issues of importance to the Pacific Basin as a whole that may not be addressed by national or regional reports, or that should be reiterated as they are of Basin-wide significance. Two matters were emphasised. First, the shared marine environment of Pacific-Basin countries should not be treated as a dumping ground for toxic or hazardous materials or as a site for testing weapons. Second, there is a need for coordinated Basin-wide approaches to understanding large-scale climatic and oceanographic phenomena. Recommendations were formulated regarding both these issues.

CONCLUSIONS AND RECOMMENDATIONS

Climate Change

1. Mechanisms need to be developed to ensure greater and more timely transmission of climate-change information from the scientific community to climate-change programmes, such as those sponsored by UNEP and other UN agencies.

Coastal Ecosystem Monitoring

2. A programme of monitoring coastal ecosystems for short and long-term ecological changes should be developed and implemented in the South Pacific region. The programme should utilize standard methods and parameters within the region, with inter-calibration as appropriate, and be compatible with similar programmes elsewhere. Such a programme could be developed and initiated at a regional workshop.

Conservation of Marine Biological Diversity

3. Regional or inter-regional action is required for the conservation of marine mammals in the Pacific Basin. UNEP OCA/PAC and the Marine Mammals Action Plan should provide the framework and coordination for such action, through the Regional Seas Programmes.

Integrated Coastal Zone Management

4. The development of coastal zone management programmes in the Pacific Basin must take account of demographic trends, especially the linkage between population growth and resource use in the coastal zone, as is being done in the Mediterranean.

5. Methods for the economic valuation of marine resources must be further developed and applied to coastal-management planning.

UNCED Pacific Basin-Wide Issues

6. As a result of the common marine environment, which is shared by all countries of the Pacific, there are a number of issues that, although important, may not be highlighted by national or even regional input to UNCED. These include:

   6a. The Pacific Ocean should no longer be considered by the rest of the world as a place for the dumping, incineration, or importation of wastes or the testing of weapons.

   6b. The study of large-scale oceanographic and atmospheric phenomena in the Pacific Ocean (*e.g.*, El Niño), which have considerable impact on populations and resources and are linked with global environment change, must be approached and coordinated on a Basin-wide basis.

Inter-Regional Activities

7. There should be expanded, regular, and systematic interaction between the secretariats and scientists of the Regional Seas Programmes of the Pacific Basin. UNEP OCA/PAC should identify the resources to undertake such interaction if Pacific Basin-wide environmental issues are to be addressed.

8. Future Pacific Inter-Regional Seas meetings should be organised and funded well enough in advance to ensure full participation of appropriate individuals and organisations. Such meetings, which are held as part of the Pacific Science Congress, should continue to be convened in the same venue as the main Congress in order to encourage and take advantage of involvement by a wider group of participants.

9. Individuals, agencies, and organisations involved in the potential development of a Regional Seas programme in the North West Pacific should be invited by UNEP OCA/PAC to participate in the next Pacific Inter-Regional Seas meeting.