Chapter 13

Dynamics of the Coastal Zone in the High Islands of Oceania: Management Implications and Options

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Introduction

The years 1991 and 1992 saw the emergence of a worldwide preoccupation with the themes of environment and sustainable development as humanity prepared for the Earth Summit, which took place in June 1992 in Rio de Janeiro within the framework of the United Nations Conference on Environment and Development (UNCED) (Strong, 1992). Within the island Pacific, 13 states and territories[1] became deeply involved with this subject, first at the national scale--each nation preparing a detailed state-of-the-environment report--then at the regional scale through two workshops sponsored by the South Pacific Regional Environment Programme (SPREP).

The result of these reflections, presented as a synoptic document entitled "Environment and Development: a Pacific Island Perspective" and representing the island Pacific's contribution to the Earth Summit, underlines not only the fundamental importance of the coastal zone in the island environment and its potential for sustainable development, but also its vulnerability and the changes which it is currently undergoing. It is encouraging to note the concern with which the island nations view their foreshore zones. This concern stems, to a great extent, from the facts that the majority of the people of Oceania live in coastal areas and that they are aware of the dangers presented by global warming and the resulting risk of sea-level rise.

This emerging concern for the welfare of the foreshore is clearly demonstrated by the direction taken by the South Pacific Applied Geoscience Commission (SOPAC) over the last few years, where research into coastal and nearshore environments has gradually gained importance at the expense of deep-water research, the original raison d'être of the organization. It is also evident in the importance given by SPREP to coastal areas in its

1991-1995 Action Plan (SPREP, 1991). This organization is making a particular effort to generate and encourage an awareness of integrated coastal zone management among Pacific Islands governments (Holthus, 1992).

This article focuses on the relationships between the human and the physical parameters of the coastal zone. The first part is concerned with defining the boundaries, terrestrial and maritime, of the coastal zone. The second part deals with its dynamics. It first discusses the overall dynamics of the relationships between the foreshore and both the land and marine environments adjacent to it. It then proceeds to explain the internal dynamics of the coastal environment itself, distinguishing between the land component, the marine component, and the interface between the two. The third and final part concerns the preservation of the coastal zone and its place in the sustainable development of high islands. Following a brief overview of the dangers that threaten this fragile environment, it stresses its economic and human potential, and discusses problems raised by the pricing of the coastal zone.

The Boundaries of the Coastal Zone

Definitions

It is essential, but not easy, to begin by defining the boundaries of what we mean by 'coastal zone'. As Coutts (1989: 320) points out: "the coastal zone does not exist as a measurable or even clearly definable entity but as an idea, a concept of an area where land and sea meet and merge." Any setting of boundaries for a phenomenon is closely linked to the definition that we accept for the phenomenon. Unfortunately, the various definitions of the coastal zone are far from consistent.

For marine ecologists, the coastal zone includes the whole of the sea bed (the benthic region) of the continental shelf, from the highest level where will be found species of marine life that can survive on sea-spray and very occasional immersion, to depths beyond which even the most resistant multicellular algae cannot survive for lack of sunlight (Péres, 1990: 918).

For marine geomorphologists, the coastline is the interface of sea, land and air, and it includes the whole area where "morphogenetic processes are substantially altered by the proximity of the convergence of interfaces" (Pinot, 1990: 667). Thus, the coastal zone is defined as "between that part of the sea bed which is not subject to the direct action of the land and that part of the land which is not subject to the direct action of the sea" (Coutts, 1989: 320).

Although precise, all definitions formulated by naturalists overlook the human aspect of coastal zones. People make use of the coastal zone, manage it, develop it, and sometimes change it irreversibly. One of the few definitions that takes this essential aspect into account is that of Cornforth (1984), for whom the coastal zone is an interface of land, sea, air, wind, tides and administrative authorities. Yet this definition is also unsatisfactory.

This definition lumps together two very different kinds of factors: on one hand, four parameters whose boundaries are clearly defined and constant, namely air, land, ocean and administrative jurisdiction (this latter made up mostly of the Exclusive Economic Zone and territorial waters, to which are added some administered zones subject to specific fishing, navigation, underwater quarrying and aquaculture regulations); on the other hand, two parameters with highly changeable profiles, namely winds and tides, whose spatial impact varies in time.

Furthermore, this definition acknowledges the human factor only through the presence of authority, ignoring the users of the coastal zone and more particularly those inhabitants who, because of their occupation and their culture, are true creators of space. Through their physical activity, they affect the coastal biological habitats around them and the species which inhabit them. Through their culture, people have made the space their own, they have defined it, fixed its boundaries with their own particular geosymbols[2] and lore. Thus, having made it their territory, they imbue the coastal zone with a cultural dimension.

Thus, we arrive at another definition of the coastal zone: the interface of five kinds of space with fixed boundaries--air, ocean, land, administrative jurisdiction, cultural space of the foreshore dwellers--and of three kinds of energy flow, two of natural origin with fluctuating space/time boundaries--winds and tides--and one of human origin. Although more comprehensive than the previous ones, this definition is still insufficient to allow us to pinpoint the boundaries of the coastal zone. The difficulty lies in the fact that this zone does not correspond to any one specific ecosystem; rather it is at the interface of several different systems, each with its own spatial dimensions. It is therefore necessary to define these boundaries, to seaward and to landward, in the specific case of the high islands of Oceania.

Seaward boundaries

Geomorphologists agree that the deposition of terrigenous sediments differentiates the coastal zone from the adjacent marine environment (Pinot, 1990). This parameter can be very different along the coastline, with sedimentation off beaches or mangroves being totally unlike that off rocky or reef-fringed shores. This is difficult to assess unless one can combine it with a bathymetric criterion, as has been done in New Zealand where the 15-metre (m) depth contour, which includes all embayments in the shoreline, was chosen as the boundary of the coastal zone (Healy, 1980).

The sedimentological parameter is poorly adapted to coral waters where biotic factors play an essential role in zone differentiation (Guilcher, 1987). Battistini et al. (1975) differentiate coral coasts into five categories that are consistent from the point of view of morphology, bionomy, hydrodynamics and sedimentology. In order of increasing depth, they are:

- the foreshore made up of the non-reefal shoreline, particularly sedimentary deposits like beaches and beachrock;
- the intra-reef system made up of the boat channels separating a fringing reef from the foreshore or of the lagoon within a barrier reef;
- the reef flat of both fringing and barrier reefs;
- the frontal reef which includes the spurs and grooves of the outer reef slope in its upper part, and the fore-reef slope in its lower part;
- the extra-reef system, the non-reef covered slopes of the continental or insular shelf (Figure 13.1).

According to this classification, the boundary of the coastal zone falls at the limit between the foreshore and extra-reef systems.

The growth of coral reefs is the result of a symbiosis between coral polyps and endozoic algae which live within the coral's calcareous skeleton. Thus, the availability of sunlight determines the difference between the frontal reef and the extra-reef systems, and so the extent of the coastal zone. This boundary definition does not consider the human factor; as such it is unsatisfactory. It is preferable to consider a shallower boundary, that of the limit between the outer slope spurs and grooves and the fore-reef slope, or, in the case of a deep lagoon, the limit between the inner edge of the spur-and-groove system and the lagoon floor.

Setting the boundary in this way has the merit of introducing a human factor: in many parts of the Pacific, this corresponds to the seaward boundary of fishing territories (Ruddle, 1989). Fishermen recognize the boundary between the fishing grounds, areas of sea bed with which they are familiar, and the open ocean, which may be fished occasionally but is not part of

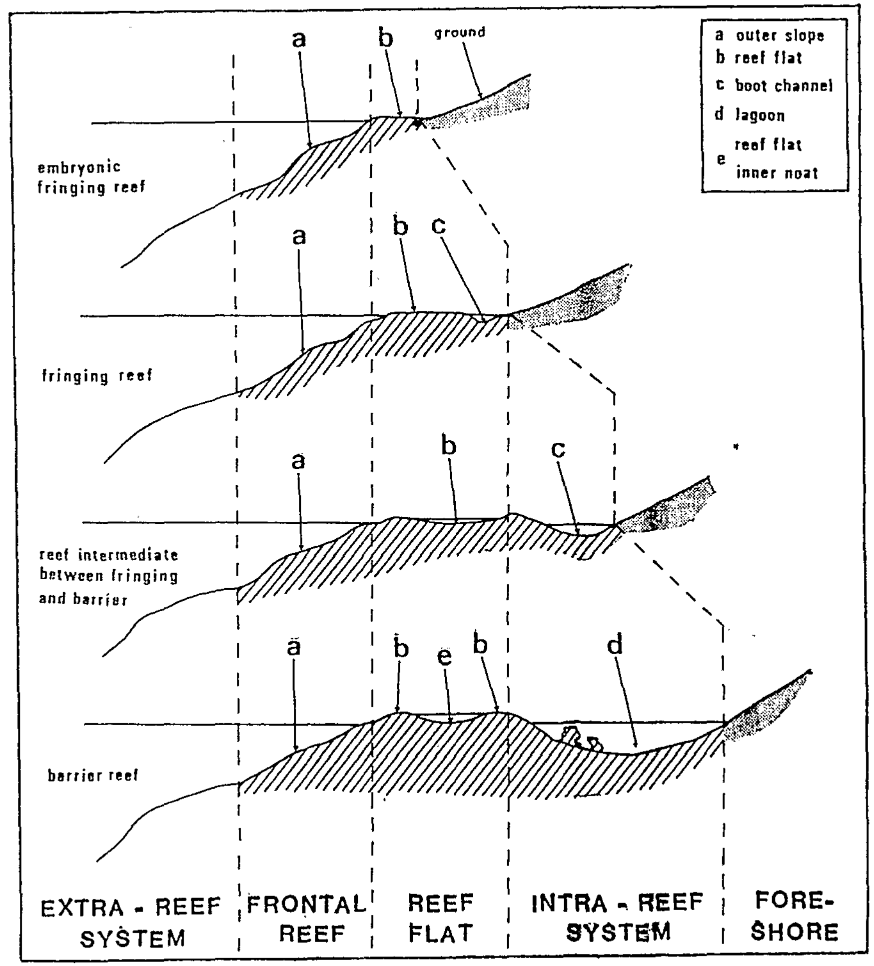

Figure 13.1. Zonation of Pacific Island reefs (after Battistini et al., 1975).

their traditional fishing area. Thus, Ni-Vanuatu have a rich and complex taxonomy concerning shallow-water fish but a considerably poorer one for deep-sea species.[3]

This delimitation of fishing areas can take several forms. It can materialize or be explained by:

- a change of place name between one zone and another, without any explicit reason for the change. Many examples of this are given by Sudo (1984) for Micronesia; Carrier (1981) mentions similar situations in Manus Province, Papua New Guinea;
- visual criteria, such as bottom visibility, as noted by Baines (1989) in the case of Solomon Islands;
- criteria based on fishing techniques; the maximum distance from the outer edge of the reef flats where the most usual fishing implements can be used;
- ichthyological criteria, where the change in the nature of the catch occurs between reef species and deep-sea species, as noted by Akimichi (1986) in the central Caroline Islands; or
- a combination of depth parameters and ichthyological criteria, as is the case in Vanuatu (Taurakoto, 1984) where the boundary is defined by the maximum depth that divers can reach in search of their target species, particularly trochus *(Trochus niloticus)*, greensnail (*Turbo marmoratus*) and lobster.

Landward boundaries

Ecologists and geographers limit the coastal zone to the area under the influence of the sea, whether through occasional dousing of the vegetation by sea spray, or through the distance which beach material can be moved inland during storms (Péres, 1990; Pinot, 1990). Botanists take a less restricted view, but generally do not agree with each other as to the location of the boundary. Some consider that the coastal zone includes all those areas where coastal forest species are found, a strip a few hundred metres wide where *Intsia, Calophyllum, Terminalia, Barringtonia, Casuarina, Ochrosia, Hernandia, Acasia and Pandanus* predominate (Schmid, 1979). This type of forest thrives on low-lying raised coral platforms where it enjoys particular drainage and soil conditions (rapid rain-water infiltration, poor soils). Thus, most botanists define 'coastal' through two ecological factors

and through flora. The coastal forest is distinct from that of the adjacent alluvial terraces and swamps which are environments characterized by greater soil water retention and greater fertility owing to ground-water inputs. Other botanists consider that topography, particularly elevation, and proximity to the sea, give the whole coastal plain and lower reaches of the valleys a geographical unity, making it distinct from the foothills (Marten, 1985).

Here we shall use the limit, indicated by a change in gradient, between the coastal plain and the foothills as the landward boundary of the coastal zone.[4] Although seemingly purely physical in nature, this definition has human significance: villages which fish regularly are usually located within the coastal plain or at the lower end of valleys. At the same time, and because of lack of space, their food gardens and fallow fields frequently extend upslope.

Dynamics of the Coastal Zone

The coastal zone can be seen as a 'black box' containing the relationships between it and its land and marine peripheries.

System dynamics

The coastal zone is constantly subjected to the effects of energy flows and receives inputs of organic and mineral matter issued from the land and marine ecosystems around it. Through streams and rain-water runoff, terrestrial ecosystems export various materials resulting from the soil erosion to the coastal zone through the river system, organic matter, both living (adult and juvenile fish, larvae) and dead (particulate matter, plant detritus) finds its way there. For its part, the ocean contributes mineral salts and planktonic material.

Five types of energy flow affect the coastal zone: tides, waves and swells, wind, solar radiation and rivers. Of these, the first two come from the ocean, the last from the land; as for the wind and solar radiation, their origin is atmospheric, one acting parallel to the surface, the other perpendicular to it. The diversity of these energy flows, and of the area of the affected surface, is what makes the coastal zone the richest environment for bio-energetic exchanges within the biosphere, and accounts for the fact that it is one of the most biologically productive. Odum (1971) estimates the gross primary productivity of reef/estuarine systems at 20,000 kilocalories per square metre per year (kcal/m^2/year), which is similar to the productivity of broad-leafed evergreen forests, and is well in excess of that of contemporary agricultural land (12,000 kcal/m^2/year) in spite of the latter's heavy reliance on artificially-added nutrients. Thus, the coastal zone may be considered as a bio-energetically open system, constantly exchanging energy and nutrients with the ocean, land and atmosphere.

This representation of the inter–relationships between the coastal zone and its adjacent land and marine environments is incomplete without the human factor. Indeed, people are the major influence in the dynamics of the coastal zone today, through the information and energy flows that they generate through work and population pressure. From the human point of view, the place that the coastal zone occupies in the islands has evolved considerably over the last two centuries--marginal, especially in Melanesia before the coming of the Europeans, it has now become essential to human well-being.

Compared to the land, the ocean played a very minor role in the traditional societies of the high islands of Melanesia. Wherever ecological conditions allowed,[5] the interior of these islands was settled, the population density being higher than that of the coast. In the whole of Melanesia (Bonnemaison, 1986a) and in some of the high islands of Polynesia, such as Wallis and Futuna (Di Piazza, 1993), we observe a cultural, agricultural and territorial split between the people of the coast and the people of the interior. The former catch fish, grow yams and coconuts, and raise pigs which feed on coconut; the latter grow taro, sometimes kava, and raise pigs with difficulty because coconuts are scarce and they must feed on surplus root-crops. Where interior people lack a traditional ('custom') means of access to the foreshore, they have created for themselves a mental island-space which is limited to their highlands. There exists a system of exchange for taro, kava, pigs, yams and products of marine origin, but this barter is seldom direct; rather, it relies on networks of alliances. Bonnemaison (1987) gives a good example of this in the sharing cycle of turtles on the island of Tanna in Vanuatu.

The arrival of Europeans considerably upset the ancestral balance between coastal and inland dwellers. Coastal populations, psychologically vulnerable and defenceless against viral and sexually transmitted European-borne diseases, first targets of the blackbirders, paid the heaviest toll. In places coastline that was practically depopulated was left open for settlement by missionaries and other colonists. A new kind of authority ruled over the coastal areas, that of the church and of the trading post. This would eventually shift to the governments of the emerging colonial nations. The new masters could rely on a solid, Pacific-wide, economic and political

support network, and they were determined to extend their authority over the whole native population. To this end, the easiest and cheapest way was to lure or force the inhabitants of the interior to the coast. This was undertaken on a grand scale through the second half of the last century and the first half of the present one, with each mission (invariably established near the coast) as the focus of a new Christian settlement. There, apart from religious indoctrination, the new convert discovered education, health care, and the novel joys of a consumer society. European settlement of the coastal zone of the islands turned it into a centre of outward-oriented economy, linked to the international marketplace through the sale of copra, sugarcane, coffee, and occasionally cocoa (Panoff, 1986).

Within this framework the coastal zone received inputs of population from the interior, which constituted a future workforce and a receptacle for the information flow delivered by the missionaries, at the same time receiving from seaward a flow of goods, money, and information, plus a trickle of population input in the form of clergy and native lay preachers (Doumenge, 1966).

The increasing involvement of the island nations within the world system has contributed powerfully to the alienation of the hinterland in favour of the coastal areas.[6] This has also brought about the appearance of a new phenomenon, this time within the coastal human environment itself, involving the alienation of the rural areas in favour of urban and suburban centres. This observation leads us now to consider the internal dynamics of the coastal zone itself.

Internal Dynamics of the Coastal Zone

The coastal zone can be seen as an 'open system'. Similarly, we can picture it as a system of nested sub-systems that are open, made of adjoining spaces, each one affected by the passage of energy flows, of flows of organic and/or inorganic matter, of information flows, and each one affecting the direction, velocity and amplitude of these flows. Some of these sub-systems can themselves be the origin or the final destination of the flows (Figures 13.2 and 13.3).

Schematically, the coastal zone is made of three parts: a marine component, a land component, and an interface component between land, salt water, fresh water, and the atmosphere. The whole takes the shape of three parallel bands, each containing several types of space, themselves arranged in either parallel bands or mosaics.

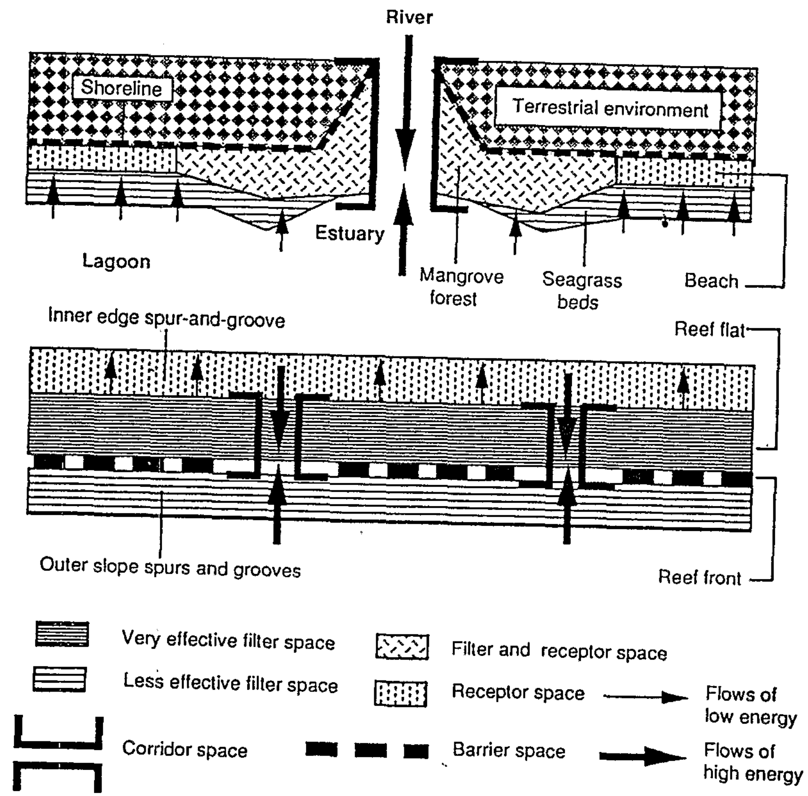

Figure 13.2. Structure and functions of the coast in terms of energy flows.

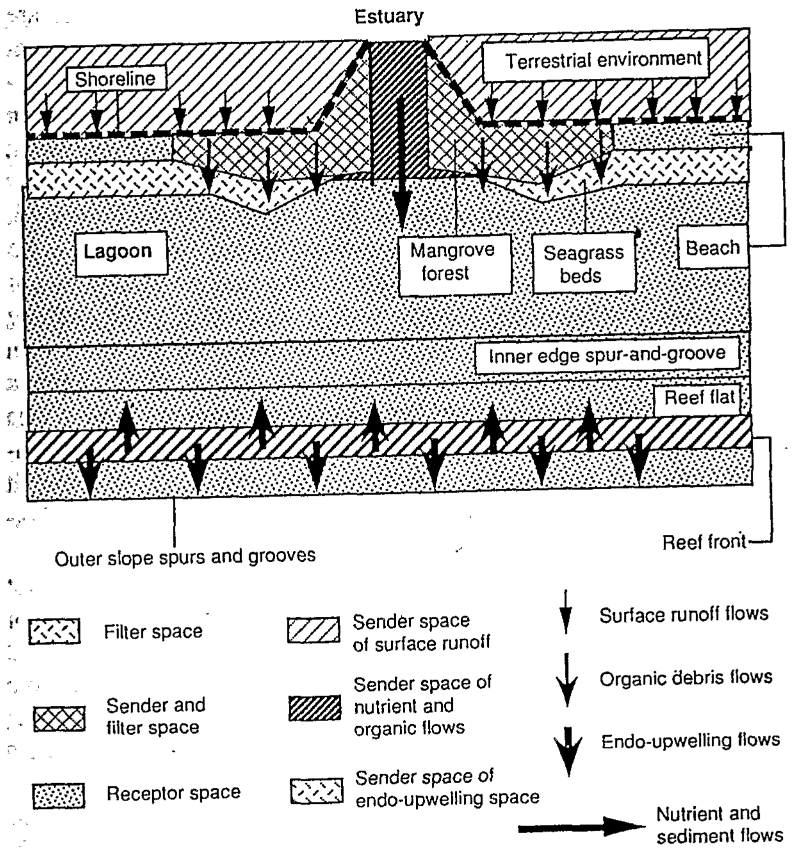

Figure 13.3. Structure and functions of the coast in terms of nutrient and sediment flows.

The marine component of the coastal zone is made of three major types of space: the outer reef slope spurs and grooves, the inner edge spurs and grooves, and the passes. The first two areas are parallel to the shoreline, the third is perpendicular to it, so lies across the first two and connects them. Thus, the pass may be seen as a 'corridor' space, allowing exchanges through the flow of the tides between a 'sender' space and a 'receptor' space. This relationship of sender and receiver will reverse according to the direction of the tidal flow.

From the point of view of fishing potential, the passes constitute a privileged space where fish, going from ocean to lagoon and vice versa are concentrated. The most effective way to catch them is to set fish traps at the lagoon end of the pass. These are commonly made of a few dozen metres of wire mesh (chicken wire) stretched on timber or metal uprights driven into the coral. This technique is particularly popular in French Polynesia (Blanchet et al., 1985) where fish traps of this type are even set in the upper portion of the spur-and-groove zone of the inner reef slope (Echinard, 1972). The boisterousness of the wave action on the outer reef slope is too great for this kind of device; fishing is usually done here with hand lines or by diving. This latter technique is particularly well adapted to the catching of lobsters and pearl-shell species, such as trochus and greensnail, the main economic resource of this particular part of the reef (Bour, 1990). From a purely hydrodynamic point of view, the outer slope spur-and-groove area may be considered as a 'damper' space because it represents the first contact between the reef and the ocean swells, a small part of whose energy it tends to dissipate by slowing their progress as soon as the depth of the bottom becomes equal to or less than half of its wavelength (Figure 13.2).

The land component of the coastal zone is the one which has the greatest importance for coastal dwellers because it provides them with space for their habitat and their agriculture and offers them a vast array of useful natural products, such as medicinal plants; firewood; building timber (both for houses and canoes); decorative and aromatic plants; fibres for cordage; handicrafts and clothing; poisons used in fishing, dyes and tannin; and a host of edible plants (Thaman, 1992a).

The land component of the coastal zone can be subdivided into nine major types of space. Seven are disposed as a mosaic, namely forests, scrubland and fallows, grasslands, commercial fields and plantations, villages and urban centres, subsistence farming gardens, and fresh water swamps and wetlands. An eighth type of space lies parallel to the shoreline, consisting of the upper portion of beaches or of rocky or coral coastlines beyond the intertidal zone. The ninth type of space consists of the lower reaches of rivers and is usually roughly perpendicular to the shore.

To a varying degree, these spaces have been – and frequently still are – subject to traditional management or development by humans. This is most obvious in the case of cultivated gardens, habitat and grasslands, usually cleared by the use of fire, but less so in the case of natural – or seemingly natural – environments, such as forests, thickets, upper reaches of beaches, swamps and rivers. Although subtle, human management of such areas is nonetheless real and is based on an in-depth understanding of coastal flora and fauna. As pointed out by Walter (forthcoming), in the case of forests and thickets, it can be considered as a very scattered type of gardening, characterized by the small number of work hours per unit area. It can take the form of a crude weeding of wooded areas aimed at encouraging the growth of certain desirable species, to which might be added the occasional transplanting of young shoots or, more rarely, the topping of young trees in order to slow down their growth and make the gathering of their fruit or nuts easier. In the case of swamps and marshes, human activity is more in the nature of land development than of plant management: it typically consists of the creation of small artificial islands on which taro is grown. The area where the material making up the island is taken from becomes its drainage ditch. Such artificial ecosystems are often far more productive than the natural environment.

A similar approach is seen in the construction of earth mounds for the planting of yams in New Caledonia's flood-plains (Doumenge, 1984) or the creation of irrigated taro gardens in the low-lying areas of the coastal plain on Futuna (Di Piazza, 1993). Such approaches aim at limiting the natural constraints and the hazards imposed on cultivation by the environment while keeping the energy output (i.e., the number of work hours required) to a minimum. The concern with minimizing the risks to the crops stems from a general philosophy of trying to improve the chances of survival of the village community, which has led the people of Oceania to seek the greatest possible diversity in their agriculture, in terms of the number of cultivated species and of the number of varieties within each species. So we see root-crops, vegetables and fruit systematically cultivated side by side, selected because they mature in different seasons.

The respective dimensions of the nine spaces are unchangeable. The population dynamics of the coastal people of the high islands of Oceania also cause change. Everywhere forests, thickets and wooded fallow areas are being replaced by cultivated fields. In certain districts, the forest is cleared for the creation of grasslands, but there the motive for extension is quite different: the primary cause is not demographic pressure, but the economics of land speculation. As Ward (1993: 14) points out under customary practices in many areas, if one clears land from forest it remains under one's control as long as it continues to be used. If abandoned to fallow, it would gradually revert to the common pool, perhaps to be reused by the same kin group in the future--or perhaps by another group. In the new context, simply by keeping the land in use, for example by fencing it for extensive grazing, one could retain authority over it, and have what might be almost permanent tenure. Traditional mechanisms were being used for non–traditional purposes.Thus in Western Samoa 7% of the whole country has been cleared from forest within the last three years, and 20% since the end of 1950 (WSDEC, 1991).

Generally speaking, spaces used by people tend gradually to encroach on natural spaces, even taking them over completely as is the case in the vicinity of urban centres. These urban spaces are the most dynamic of the nine types of space defined for the land component of the coastal zone. They generate population flows, both by natural increase and by being the final receptor space for the migration from the rural areas.[7] Just as we can establish a progression in dynamics from habitat in general to urban centres, a similar progression can be observed from urban centres in general to capital cities. In a region where international aid per capita reaches a level unparalleled anywhere else in the world (Antheaume & Bonnemaison, 1988; Gibson, this volume), the bulk of this aid ends up concentrated in the capital cities, little of it finding its way to rural areas. The capital city is frequently the only port of sufficient size to allow unloading of container and roll-on-roll-off ships, thus tending to monopolize most of the industrial, service, and even agricultural drive of the island nation.

As noted by Bayliss-Smith et al. (1988) and Ward (1993: 5), "despite government subsidies for freight services, a copra producer on an outer island in Fiji must produce 50 percent more copra than one located on the main island in order to buy the same basket of goods". The same comments can be applied to artisanal fishing in Vanuatu (David, 1991), where commercial fishing is economically viable only on the islands of Efate and Espiritu Santo, where the country's two main urban centres are located. This process of concentration of island nations' economies around their capital

cities/major ports can only lead to depopulation of outlying islands, as their inhabitants tend to migrate toward the city, the only place where paid employment may be found.

The area of interfaces supports the bioenergetic system of the coastal zone and is responsible for both its high level of biological productivity and its fisheries-based economy. Acting as a buffer between land and ocean, it protects the former from the energy flows of the latter, while protecting the ocean from the flow of land matter and from the pressure of overfishing by redirecting this pressure onto its own space (Figures 13.2 and 13.3).

A total of six main types of space can be identified within this area: the reef front (formed of an algal ridge or an outer biogenic ridge), the reef flat, the beaches, the seagrass beds, the mangrove swamps and the estuaries. The first five are included in the intertidal zone and constitute an interface between sea, land and atmosphere, and their location varies to some extent with the rhythm of the tides. The estuaries, on the other hand, represent a complex interface that can be broken down into two elements existing side by side:

- a main interface bringing into contact fresh water and sea water and
- a secondary interface, part of the intertidal zone, which at low tide brings into contact the shallowest parts of the bottom of the estuary with the atmosphere.

The reef front plays an essential role in dissipating wave energy, so in protecting the shoreline from erosion, particularly when this shoreline is of a sedimentary nature. Thus, the reef front can be seen as a 'barrier' space. It is also extremely biologically rich on account of the intensity of the energy exchanges that take place, both through the breaking of the waves and the diffusion of endo-upwelled water. This upwelled water originates in the deeper layers of the ocean – it is in fact Antarctic water – and is extremely rich in nutrient salts, such as phosphates, nitrates and silicates. Once it penetrates the porous lower portion of the reef base or the permeable underlying volcanic formations, it is raised by thermal convection to the upper layers of the reef. This interstitial reef water then drains toward the ocean at the level of the reef front, where zooxanthellae living in the coral and the algae of the algal ridge consume its nutrients. As pointed out by Rougerie and Wauthy (1993), this dynamic process induces a permanent release of blooming zooxanthellae from coral and can be viewed as a starting point of the specific reef food chain.

So, the reef front is a barrier space which provides protection, nutrition and fertilization, functions which give it a major role in the economy of the coastal zone, particularly as it also provides a spatially limited but important environment for fishing activities. The reef front is used by line fishermen as a platform, and it serves as anchoring point for gill nets during low-tide calm-weather fishing operations on the reef slope.

The reef flat, although far larger than the reef front, is considerably poorer from the biological point of view. Large portions of it consist of dead coral, and life only really abounds in the pools and hollows. From the energy point of view, the reef flats impede the propagation of the wavelets resulting from the breaking of the ocean waves against the reef front and dissipate their energy. The reef flats can thus be described as a 'filter' space. Yet, from the point of view of fishing, the reef flats are essential. It is the space most frequented by the coastal inhabitants for this purpose. A wide range of fishing devices and techniques are used there: hand lines, gill nets, casting nets, hand spears, spear guns, bows and arrows, bush knives, holding pens, fish traps and vegetable poisons, among others. (David, forthcoming). The whole coastal population, including women and children, fish here, the latter concentrating on collecting shells, crustaceans and octopus.

Mangrove swamps, located along the line of contact of land and sea, are the only example of a marine forest on the planet. Providing the triple function of protection, nutrition and fertilization for the coastal environment, mangrove swamps are as economically important as the reef front for the high islands of Oceania.

Placed as a buffer between the destructive force of the ocean that of the land and the threatened coastal space, mangrove swamps act as a filter and reduce the potential for harm. This filter space is made of two superimposed sub-spaces: one aerial, the crowns of the trees, and the other semi-aquatic, the part of the their aerial root system that is submerged at high tide, made of both buttress roots and pneumatophores. The main effect of this aerial root system is to protect the sedimentary base on which it grows from erosion by wave action. In estuaries, by encouraging settling of suspended sediment, mangroves also contribute to reducing muddiness of the water, which otherwise would be destructive for coral growing near the river mouths. The aerial root system of the mangroves also creates a sanctuary where herbivorous fish such as *Clupeidae* and juveniles of other species may take refuge from the predators of both ocean and river mouth. The tree crowns act purely as filter: if the mangrove swamp is sufficiently large, it will absorb some of the force of ocean-born onshore storm winds, thus protecting dwellings and gardens lying inland.

Generally speaking, mangrove swamps are environments which are rich in nutrients for the species that shelter there. Decaying organic matter is abundant, and the part of the aerial root system submerged at high tide supports a number of small and microscopic marine algae. For this reason, a large population of coprophagous species, macrophagous herbivores, and species which feed on matter in suspension is found in mangrove swamps. In turn, the presence of these organisms attracts numerous predators. Thus, the mangrove swamps act as an 'biological magnet' for marine species particularly the following:

- shells and crustaceans which spend their entire existence there;
- species which come there to feed at each rising tide;
- species that feed there occasionally;
- fish species whose presence in the mangrove is linked to their reproductive cycle; and
- species that are born and live in deep water and migrate to the shore only for the duration of their juvenile stage; mangrove swamps provide them with optimum conditions for growth and survival.

The influence of mangrove swamps on the marine environment extends well beyond the adjacent waters. Exportations of leaf material can be assessed at an average value of eight to ten tonnes (t) per hectare (Lugo & Snedaker, 1974), and productivity, defined as the amount of biomass produced during a set time over a set area, has been estimated at approximately 30t per hectare per year where the mangrove trees are 15-20m tall (Chapman, 1977). The decay of this material provides a large quantity of nutrients to the marine environment and constitutes the basis of the food chain of the detritus consumer species which recycle organic matter directly without going through phases of mineralization and primary production (David, 1985).

Beaches constitute a final 'receptor' space where the energy flows generated by waves and tides terminate (Figure 13.2). Beaches are found mostly in bays and other locations protected from prevailing ocean swells. Surf action can nevertheless generate littoral drift which constitutes a powerful erosion factor. From the biological point of view, beaches provide a suitable environment for turtles to lay eggs.

Seagrass beds are found in a variety of locations. They occur most frequently seaward of mangrove swamps, on reef flats, and in the lower portion of well-sheltered beaches. From the energy point of view, their action is twofold: on one hand, the slowing down of the wavelets arriving at the shoreline and that of longshore currents--in this, the seagrass bed can be considered as a 'filter' space much as for the reef flats. On the other hand, they trap sediments carried by longshore drift (Figure 13.3).

Thus, seagrass beds play a substantial role in protecting the coastal zone from erosion. Their biological role is also important. Beyond the fact that they constitute the staple diet of dugongs and green turtles (*Chelonia mydas*), they fulfil a dual function of nutrition and protection for a number of invertebrate and fish species who either permanently inhabit the seagrass beds, or, more frequently, reef or mangrove species which occasionally wander there. Chambers et al. (1990: 98) note that seagrass beds provide protection and shelter to animals in a number of ways: by providing attachment surfaces for epibiota; by reducing current velocity; by reducing environmental extremes of temperature, salinity and light, particularly in intertidal and shallow water situations. For this reason seagrass beds constitute an attractive spawning zone for adults and a safe nursery for young fish. From the economic point of view, it is the bêche-de-mer found in seagrass beds that constitutes their main attraction (Conand, 1986).

The Coastal Zone and Sustainable Development

The dangers for the coastal zone

Being a buffer between ocean and land environments, the coastal zone is subject to attack by both. Although well adapted to withstand attack from natural causes, the coastal zone is particularly vulnerable to depredations caused by people. This situation is steadily worsening as island economies modernize and demographic pressures increase.

Among the factors tending to escalate the aggression on the coastal zone, the first one, which affects mostly coral reefs, is the increase in the volume of terrigenous sediment commonly attributed to intensification of human activity upstream. The quantity of this sediment has substantially increased over the last two decades owing to a shortening of the time the land is left to lie fallow (when the practice of fallow has not been altogether abandoned), the cultivation of sloping sites, the adoption of new agricultural techniques, the deforestation of steep catchment basins, and the changing climate (Nunn,

1990). This increase in soil erosion, particularly when compounded by damage to the mangrove swamps, may lead to a lasting increase in the suspended sediment content of coastal waters, severely disrupting coral ecosystems and affecting the economy of coastal village communities.

Another factor contributing to increased the pressure on the coastal zone is the discharge of waste products resulting from human activities. This can be domestic sewage, linked to increasing urbanization, soil and heavy-metal contaminated tailings entering the river system as a result of mining activity, pesticides from agricultural activity, and accidental spilling of petroleum products or industrial chemicals. All this contamination is particularly hard on mangrove swamps and coral reefs and can lead to their complete destruction (see McShane, this volume).

A third type of attack on the coastal environment is the destruction of natural spaces to make way for human activity. Here again, mangrove swamps and reefs are prime targets. In island nations where, on account of increasing demographic pressure, residential and public works projects are multiplying, the coastal zone often represents the only source of building materials. Reefs and underwater sand deposits are intensively dredged, often without any prior assessment of the possible sedimentological and biological repercussions of this disruption (Salvat, 1987). As for mangrove swamps, when they are not used for rubbish disposal, they are often filled to create new land for residential development or roads. In rural districts, mangrove swamps are also sometimes turned over to aquaculture projects[8] or simply to agricultural land.

Over-harvesting of resources also affects the coastal zone. Over-harvesting is commonly a function of population growth and the resulting increased demand for fisheries products. It can also be attributed to the introduction and spreading of more effective fishing devices, such as nets and spear guns. Yet, provided seriously damaging techniques, such as the use of dynamite, are avoided, this type of aggression on the coastal environment is less dangerous than the previous three. Indeed, while it endangers the sustainability of fishing activities, it does not seriously threaten the survival of most marine species; reef fish populations have demonstrated a great ability to recover their densities once fishing has significantly decreased, either through internal demographic dynamics or through migration from adjacent reef habitats. On the other hand, destruction of live coral on the reef flats by trampling and damage to submerged coral heads by boat chains and anchors in areas heavily frequented by pleasure boaters, constitute a far more serious danger. There, the very habitat of the marine species is threatened, and this is much slower to recover from damage than the species themselves.

Social and Economic Value of the Coastal Zone: the Example of Urban and Suburban Areas

Under attack from the four types of human aggression described above, the shorelines of urban and suburban areas are today the most threatened coastal zones in the high islands of Oceania. This is undesirable for ecological reasons and for social and economic reasons, which are seldom taken into account by the authorities. For Islanders living in towns and cities, the waterfront represents an important source of foodstuffs and a place for recreation. Mangrove swamps and reefs provide ways of varying the daily fare without financial outlay and offer the townfolk, who are often former country dwellers, a break from urban routine and the opportunity to spend a healthy day outdoors. For many of these people, urban living is often difficult from a material point of view, and culturally upsetting; fishing outings offer an ecological and cultural link with their former way of life. The more underprivileged these populations are, the more the role played by the waterfront in their perception of the world becomes important. These aspects have been but little discussed in the literature.

The majority of Pacific Islanders living in towns and cities were not born there. They are rural people who were lured to urban spaces in search of employment and a more modern life-style. Even though the rural migrant arriving in the city is often received by relatives or friends which helps lessen the shock of uprooting, the shift can nevertheless still be socially and culturally traumatic. The new migrant is confronted with an alien landscape and has to learn the ways of a new type of space.

The urban life-style, made of wage earning and a market economy, requires new habits and new rules of conduct. The migrant will have to become integrated into a new territory, a portion of which he will possibly have to claim as his own. Unlike his original territory, this new space is bare and devoid of familiar geosymbols, except for the site of his dwelling where he can bask in the warmth of his family, a small island of identity in the emotional vacuum that is the city. To fill this vacuum is no easy matter. Although in the rural setting every child is taught the ways of the village territory by the community, making the urban territory one's own can be achieved only by individual effort.

The kind of 5- to 10-storey residential buildings that are common in certain 'Islander' districts of Noumea and where hundreds of families live cheek by jowl in the heat and the din cannot possibly offer any shelter or protection against culture shock to the new rural migrants. Such an urban environment can only be culturally devastating for its inhabitants if they do not have the possibility occasionally to 'return to the source' through access to the reef flats and mangroves which have so far been spared by urbanization and which frequently constitute for them the last ecological and cultural link with their rural past.

Destruction of the foreshore means the loss of this last link leading, for the whole population, to a destructuring of perceived space,[9] a general feeling of dissatisfaction, and, for the youth, an escalation of a potentially dangerous kind of idleness which fishing activities could otherwise alleviate. Here, we uncover an essential aspect of the management of the coastal zone: the value that we can place on it.

Economic Planning and the Price of Nature

Far from being simply a physical space whose only economic interest resides in the part of its area that has potential for development, the coastal zone's real economic value derives from its ability to provide protection, nutrition and fertilization to marine animal communities used by people. The coastal zone can thus be considered as a piece of capital that returns a dividend every year, the amount of this corresponding to what the services it has performed are worth. By looking at it this way, once we have assessed the value of the dividend, we should be able to estimate the value of the entire capital.

Unlike human constructions, biological capital does not depreciate with time, provided it is managed in a rational manner and following the principles of maximum sustainable yield. The span of a generation (25-30 years) would seem to me sufficiently long to correspond to the resource management objective of maintaining a balance, which is the basis of sustainable development. It also corresponds to the most usual time frame chosen by the authorities for the granting of leases for harvesting of marine resources (Munro-Faure, 1992). Based on this assumption, the price of a mangrove swamp or a coral reef would correspond to the accrued interest generated by these assets over 25-30 years.

Another method for calculating the value of the coastal zone consists of calculating the cost of the technological equipment and constructions required to carry out the same functions as the natural heritage in the event of the latter being destroyed. In the case of mangrove swamps, two types of installations would have to be considered: first, the building of erosion protection installations in order to take over the function of protection of the land component of the coastal zone normally provided by mangrove swamps and, second, the creation of aquaculture ponds able to produce yearly a quantity of fish equivalent to that which would be lost, in their juvenile or adult stages, for lack of the protection and the feeding and spawning grounds afforded by the mangrove swamp.

Both of the above replacement measures require as precise knowledge as possible of the actual productivity of the threatened environment. This can be acquired by carrying out an extensive ecological inventory, which, because of the need for a large staff and for specialized craft, would be quite expensive. The high cost of such a survey can be considerably lowered by the use of high-resolution satellite remote sensing systems.

Given the difficulty of distinguishing sea-bed features below a depth of 5m, inventories can be taken only for species living in shallow waters. In places where the fringing reef is very narrow, the ground resolution of satellites is often inadequate to properly identify the sea-bed features (David, 1989). The solution is to use satellite data and aerial photographs in conjunction with each other, these latter having first been digitized and geometrically normalized prior to image processing analysis.

The ability to attribute a price to the coastal zone constitutes a valuable tool for decision makers (INSEE, 1986). So often in the past, coastal environments, such as mangroves or coral reefs, were sacrificed for the purpose of urban development and expansion of agricultural projects. The lack of pricing used to be associated with a lack of inherent value, whereby natural resources could not be expressed in monetary terms. The public authorities did not hesitate to replace natural space that they deemed of no value with an anthropic space that cost money to set up and was intended to be a source of eventual profits.

From now on, through a simple cost-benefit analysis, the planner and the politician will be able to assess the respective advantages of preserving the natural environment versus replacing it with an artificial environment. This should greatly facilitate the task of managing the coastal zone.

Conclusion

In view of the increasing concentration of population and economic activities around coastal cities prevalent in island nations, there can be no

doubt that management of the coastal zone, still seen by most island governments as an esoteric discipline, will become central to planning.

Four objectives are as follows:

1. to make use of the potential of the natural environment with care to preserve the ecological balance;
2. to fulfil the current requirements of village communities and plan for their future needs;
3. to fulfil the requirements of the public authorities and of the developers; and
4. to minimize conflicts between the needs of the various current or potential users of the space.

It is essential to respect this last objective in order to avoid contradictions in the application of objectives 2 and 3, and the risks that this could mean for objective 1. The diversity of the interfaces found in the coastal zone and the diversity of the associated flows of energy and matter give the coastal zone potential for productivity of which human communities must be able to take full advantage. The long-term preservation of this productivity at its highest possible level for the least possible cost must be the golden rule on which to base any future management policy for the coastal zone. This rule will be adhered to only if development planners and public leaders, in whose power rests the decision to either destroy or preserve this unique environment, are fully aware of its value to the community.

The ability to assess the price of the various components of the coastal zone is invaluable in developing this awareness. In urban areas, because of their population density, their limited area, and the intensity of the use to which they are put, the coastal zone is the most threatened. The preparation of integrated coastal zone management plans for these urban areas should be one of the first priorities in the formulation of any coastal zone management policy. Such management plans must take into account the cultural and social role played by mangroves and reef flats in the lives of low-income urban families. The importance of the foreshore in the perceived space of these populations, therefore the consequences of its total or partial disappearance, is a subject which has not been sufficiently analysed.

In this particular field, as in the technical aspects of coastal development and management, geographers can play an essential role in the future. Geography's main concern is with the study of the interaction between the physical and human environment; it represents the meeting of physical sciences and human studies, and makes use of increasingly sophisticated tools, such as satellite high-resolution remote sensing, statistical cartography applied to data analysis, and geographical information systems.

Notes

1. Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Republic of the Marshall Islands, Niue, Papua New Guinea, Solomon Islands, Tokelau, Kingdom of Tonga, Tuvalu, Vanuatu and Western Samoa.

2. By "geosymbol" we mean a place, an itinerary or an area which, for religious, political or cultural reasons is considered by certain people or ethnic groups to possess a symbolic dimension in which they find comfort and which helps them define their own identity (Bonnemaison, 1981).

3. This was noted for the Banks Islands by Vienne (1984) and confirmed by my own observations in Pentecost and Malakula. I believe it can be extrapolated to the whole country, when one considers the fishing techniques used at village level, where 70% of fishing outings consist of either wading in shallows or underwater diving (David & Cillaurren, 1989).

4. In her study of subsistence horticulture in the islands of Wallis and Futuna, Di Piazza takes this boundary even further because she considers that "coastal vegetation occupies the coastal plains and the lower slopes of the islands between elevations 0 m and 20 m" (1993: 18).

5. Elevation is the major limitation to human settlement in high islands. Apart from Papua New Guinea, where populated areas exist even above 2000m, human settlement is usually below 800m. In large, mineral-rich islands, such as New Caledonia, soil saturation in metallic salts constitutes an important limitation to agricultural expansion, thus to human settlement. For this reason, people have never permanently occupied the interior of the extreme south of New Caledonia.

6. Today, throughout much of the island Pacific, the population shift from the interior to the foreshore can be considered as complete. Yet Bonnemaison (1986) has noted one instance, in the interior of Pentecost Island, Vanuatu, of migration in the opposite direction, where people

settled on the coast were moving back to the empty interior. Yet, in most of the larger Melanesian islands, where only a few years ago one could still find isolated pockets of highland people which had had but few contacts with the outside world, migration is proceeding apace. In western Espiritu Santo, Vanuatu, the 1979 and 1989 census showed that many hill dwellers had left their mountains to resettle on the west and south coasts of the island, in search of a more modern way of life.

7. In the case of Western Samoa, Tonga and the Cook Islands, the urban space has also become a "sender" space, origin of a migratory population flow toward foreign countries, particularly New Zealand and the United States.

8. Aquaculture in these areas does not necessarily have to mean the destruction of mangrove swamps, as evidenced in New Caledonia where salt-water prawn farms have been established in the salt-saturated mud flats lying at the back of mangroves. This example, however, represents something of an exception. Most everywhere else in the Asia-Pacific region, where salt-water pond aquaculture has become an economic priority, mangrove swamps have been destroyed. Parish (1989) estimates that 70% of all Philippines mangrove swamps have disappeared to make way for aquaculture.

9. The role played by the disappearance of the natural foreshore in the destructuring of perceived space, followed by its restructuring on a different basis offers the geographer a wide field for investigation. Logically, it would seem that two scenarios are possible. Either one places the greatest value on the nature of the landmarks which structure one's perceived space, thus one is prepared to enlarge one's familiar territory in order that it may include, for instance, a new piece of shoreline, or one prefers to place greater value on maintaining the boundaries of one's territory, thus will seek a new landmark, of a different nature, to take the place of the vanished foreshore. If such a landmark does not exist, one will demand one of the authorities, such as a community recreation centre, a stadium, etc.

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"... all experience is an arch wherethro'
Gleams that untravell'd world whose margin fades
For ever and for ever when I move."

Alfred Tennyson (*Ulysses*)