Chapter 80

THE CORAL, SOLOMON AND BISMARCK SEAS REGION

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The Coral, Solomon, and Bismarck Seas lie in the western equatorial Pacific, bounded by Australia, New Caledonia, Vanuatu, the Solomon Islands and Papua New Guinea (PNG). PNG and the Solomon Islands are the coastal countries discussed.

North–south migration of the Inter-Tropical Convergence Zone brings about alternating Trade Wind and monsoon conditions. The South Equatorial Current (SEC) drives the major ocean circulation. The region's major land mass is mainland Papua New Guinea (PNG). All remaining land is grouped into archipelagos. Major coastal ecosystems are coral reefs, mangroves, seagrass beds, soft estuary and lagoon bottoms, inland saltwater lagoons, and freshwater coastal wetlands. The biodiversity of these coastal ecosystems is of global significance in extent and diversity and, overall, their condition is generally good. Little of the baseline knowledge needed to monitor trends and to assess environmental change is available, and the level of research and survey is very low.

Though the open seas of the region are characterised by low primary production, it is likely that upwelling and turbulent mixing around reefs and islands results in localised areas of high primary productivity. The region's large pelagic tuna resource is being exploited by both PNG and the Solomon Islands. Both receive support in this from the South Pacific Forum Fisheries Agency (FFA).

The majority of the population of the countries of the region (about 1.4 million) lives along the 22,400 km coastline. Port Moresby is the largest urban population (250,000). Urban centres are characterised by inadequate provision for treatment and disposal of human and industrial wastes, localised overfishing, coastline disturbances arising from land sediment discharge, and from poorly designed and positioned engineering structures, and chronic low-level pollution.

Outside urban areas the level of material development is very low and most people live a mixed subsistence and artisanal lifestyle. While traditional agriculture is the main source of food and livelihood there is a high degree of dependence upon coastal fisheries for both subsistence and income. Few coastal villagers are solely farmer or fisher.

Local fisheries are diverse and, apart from the wide range of finfish and invertebrates taken for food, there is an export trade in sea cucumbers (to produce bêche-de-mer), molluscs (for mother-of-pearl), and a few high-value food species. Not only are these stocks inherently difficult to manage but coastal fisheries management capacity in the countries of the region is very low. Over-exploitation is common. Recently, a trade in live reef food fish for export has emerged. Characterised by a quick depletion of stocks, and the use of toxic substances for stunning fish, it is considered to be a significant threat to the sustainability of coastal marine resources and to coral reef ecosystems.

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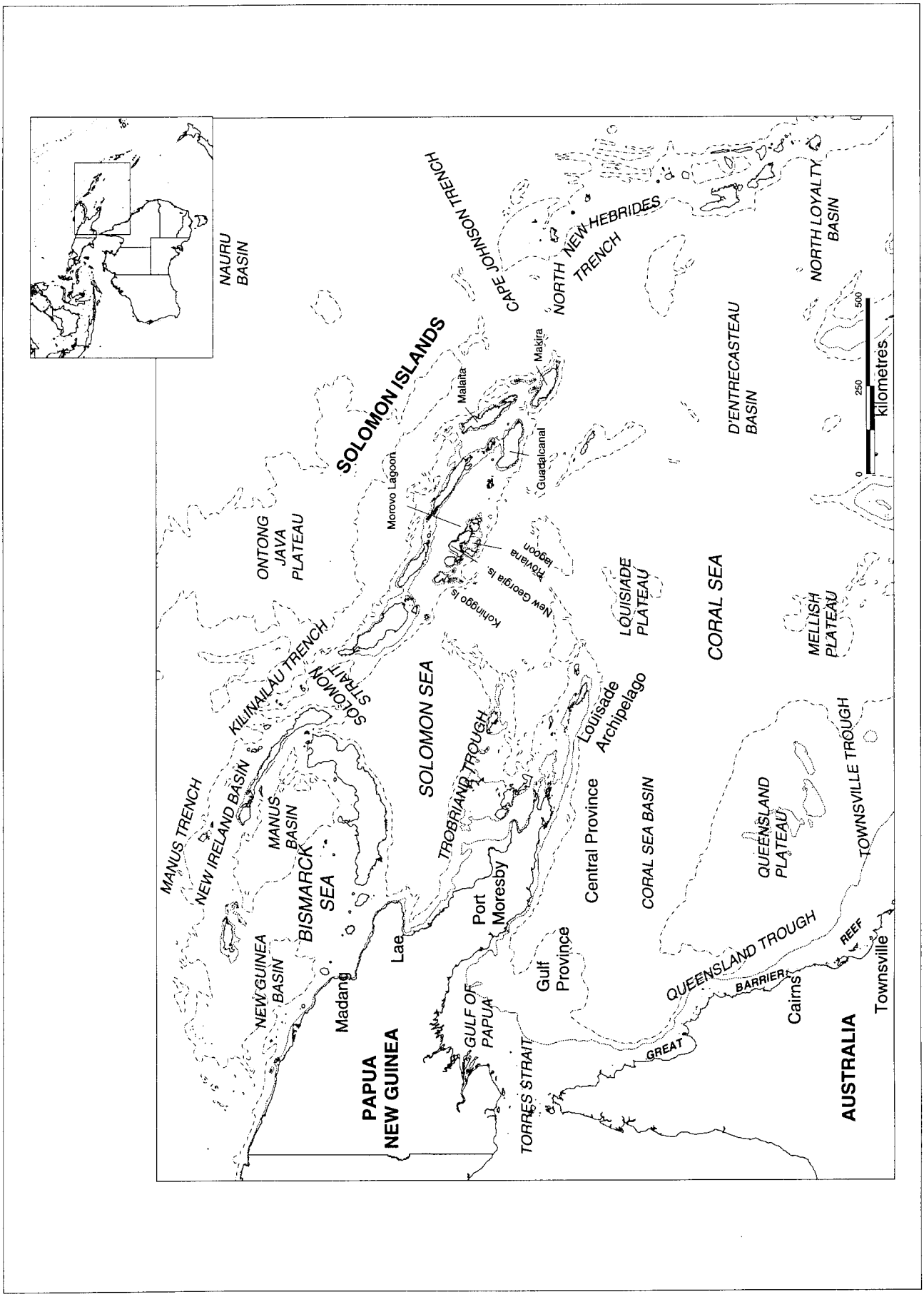

Fig. 1. Map of the defined area (from Williams, 1994).

Land-slips and their sediment plumes in nearby coastal waters are a natural feature of the dynamic landscape. Where land is disturbed by logging and agriculture, additional sediment stress on aquatic ecosystems is superimposed on this natural background stress.

Poor logging practices are effecting major changes in the nature of the land and the ecosystems from which freshwater enters the sea. Sediment loads are increased, stressing coral reefs and seagrass beds. This is accompanied by increases in the amount of freshwater runoff, adding further stress.

Domestic sewage is the most important source of point-source pollution, not only in urban areas but sometimes in rural lagoons. The low level of industrial development has precluded widespread industrial pollution but localised pollution from mines, breweries, food and agricultural processing plants, and probably other industries has occurred. There is no systematic water quality, biological, or public health monitoring of coastal waters.

Though both countries in the region have a legislative and administrative base for environmental and resource management, effective implementation is compromised by a lack of political will and weak—and declining—capacity in the management agencies. Increased attention is being paid to the promotion and support of community-based approaches that incorporate elements of traditional land and sea tenure systems and management practices.

THE CORAL, SOLOMON, AND BISMARCK SEAS REGION

At a broad scale the region's seas can be considered as three partially enclosed, deep basins at the western extreme of the southern equatorial Pacific (Fig. 1). They are bounded by Papua New Guinea (PNG), which consists of the main island of New Guinea and several hundred smaller islands, and the Solomon Islands, another archipelagic nation (Table 1). The Coral Sea is also bounded by Vanuatu (discussed by Vuki, this volume) and New Caledonia (discussed by Labrosse et al., this volume) to the east and south, the Great Barrier Reef (GBR) to the west (discussed by Zann, this volume), and Torres Strait and the Gulf of Papua (including the Western and Gulf Provinces of PNG) to the northwest (discussed by Huber, this volume). Although only the southern coasts of the Solomon Islands and Bismarck Archipelago border directly on the Bismarck and Solomon Seas, the entire coastal area of these island groups is included in the discussion.

Table 1

Physical characteristics of Papua New Guinea and Solomon Islands (sources: Davis and Huber, 1995; Wright, 1993)

	Papua New Guinea	Solomon Islands
Land area (km^2)	462,243	27,556
EEZ area (km^2)	3,120,000	1,340,000
Length of coastline	17,100	5,300
No. of high islands	83	37
No. of low islands	>350	65
No. of atoll islands and cays*	47	2

*These are probably underestimates.

The region's seas are of a general depth of the order of 4000–4500 m in the Coral Sea Basin, reducing to 2000 m above plateaus, and these depths extend eastward to New Caledonia and Vanuatu. In the vicinity of the Solomon Islands, and north of Papua New Guinea in the Bismarck Sea, depths are much less; typically of the order of 1000–1500 m. However, a marked seabed feature of the latter area is the New Britain Trench, whose bottom approaches 8000 m. The island of Guadalcanal (Solomon Islands) is the first of a long line of islands, extending east and south, and eventually along the full length of Vanuatu, which emerge from a ridge adjacent to a series of narrow ocean trenches which are mostly 5000 m in depth. The area lies at the convergent boundary of the Pacific and Australian lithospheric plates and is geologically complex (Pandolfi, 1992; Vedder and Coulson, 1986). The New Britain Trench delineates the small Bismarck lithospheric plate. The San Cristobal Trench marks the eastern edge of the small Solomon Plate.

The southern, or Papuan, coast of mainland PNG is largely of sedimentary origin overlying continental material. The northern coast was formed by the accretion of material as New Guinea collided with a Pacific Island arc commencing in the late Oligocene (Pigram and Davies, 1987). The islands north and east of the eastern tip of the island of New Guinea are of continental and raised-reef origin, while most of the northern islands of PNG, and of the Solomon Islands, are primarily volcanic, often with thick overlying raised reef deposits.

Most coastal areas of mainland PNG and the high islands are backed by mountains, and the coastline is often steep with a narrow, even non-existent, continental shelf. Important exceptions are the broad coastal plain of the Sepik River, the world's 18th largest in terms of water discharge (Alongi, 1990) and an extensive shelf area in Milne Bay Province. Most coastal watersheds are forested,

although there are some areas of apparently human-induced grasslands in areas with a pronounced dry season (Leary, 1993a; Paijmans, 1982).

It is doubtful that the Large Marine Ecosystem (LME) concept fits this seas region. Environmental variability is driven largely by global-scale oceanographic and climatic systems. The area can be considered as having several distinct ecosystems that probably have stronger interactions with adjoining systems outside the region than with each other. The Papuan Barrier Reef on the south coast of PNG, for example, has greater geological and biogeographic affinities with the GBR to the south than with the north coast of PNG (e.g., Hoeksma, 1992).

A DYNAMIC TROPICAL ENVIRONMENT: SEASONS, CURRENTS, SEISMICITY, VOLCANICITY AND CYCLONIC STORMS

Climate and Currents

The overall regional climate is "wet tropical", with average minimum and maximum temperatures of around 22° and 32°C, respectively, and relatively little annual variation (McAlpine et al., 1983; Spenceley, 1982). Annual rainfall generally ranges between 2500 mm and 5000 mm and, though there is seasonal variation, (see below), there is considerable rainfall throughout the year in most areas. Significant exceptions are "rain shadow" areas such as the central Papuan coast (which receives less than 1500 mm per year with almost no rain during the pronounced dry season of May to December) and north Guadalcanal in the Solomon Islands.

From May or June to October or November, depending on the location, the weather is dominated by southeasterly Trade Winds that blow steadily at average speeds of 10–15 knots, somewhat higher in the western Coral Sea (Fig. 2). Over most of the region this represents a dry season of varying degree; although the southeastern, windward, coasts of the islands of Guadalcanal, Malaita, and Makira experience rainfall maxima during the Trades. From December or January to March or April monsoonal conditions prevail as the Inter-Tropical Convergence Zone migrates southward over the area. It is the monsoons which bring most areas their rainfall maxima and the winds, lighter and more variable than the Trade Winds, are predominantly from the northwest. The effects of the northwesterly monsoon decrease progressively from north to south. The doldrums between the Trade and monsoon wind periods are characterised by light, variable winds and relatively frequent calms.

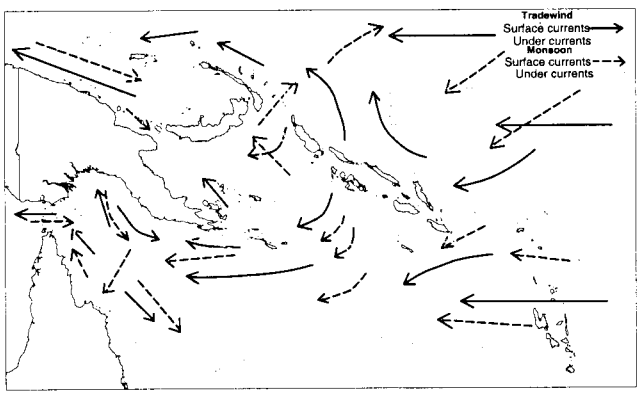

Fig. 2. Winds and current patterns during Trade Wind and monsoon conditions (from Williams, 1994).

Ocean circulation is driven by the South Equatorial Current (SEC), the westward path of which is blocked by the islands of New Guinea and Australia (Williams, 1994). The southernmost component of the SEC bifurcates in the southwestern Coral Sea, off the coast of Australia. The northern branch of this bifurcation moves northwesterly in the Coral Sea as the Coral Sea Coastal Current before turning into the Solomon Sea as the New Guinea Coastal Undercurrent. This pattern constitutes a true western boundary current (Burrage et al., 1995). In the Solomon Sea a small countercurrent flows southeasterly along the southern coast of the Solomon Islands. This general circulation pattern is substantially modified by seasonal shifts in wind patterns and by north–south movement of the Equatorial Countercurrent system in relation to bathymetry and land masses (Fig. 2). During the monsoon the SEC moves southward, bringing the Bismarck and Solomon Seas under the influence of the North Equatorial Counter Current flowing from the northwest and causing seasonal reversal of flows around the periphery of the Bismarck Sea. Surface currents in the Bismarck and Solomon Seas are also strongly influenced by seasonal wind patterns, those in the Coral Sea less so.

The oceanography of the region is of some global significance. Its waters are one of the sources of the Indonesian Throughflow from the Pacific to the Indian Ocean, aided by the SEC. Also, the Bismarck and northern Solomon Seas lie within a large, semipermanent pool of warm surface water believed to have a critical role in global climate regulation. A further point of interest is the suggestion that tectonic processes in this region may have played a significant role in enhancing primary productivity in the iron-limited eastern Pacific by injecting iron into the source waters of the Equatorial Undercurrent (Wells et al., 1999).

El Niño

El Niño events typically bring drought to the region. At the ocean basin scale El Niño is associated with lower sea-surface temperatures as the western Pacific pool of warm surface water moves eastward in response to reduced trade winds. At local scales, however, there may be surface warming. Elevated surface temperatures, for example, were observed on reefs in New Britain during the 1997–98

El Niño and coincided with mass coral bleaching and mortality (Wilkinson, 1998). Bleaching events, however, are not necessarily associated with unusually high water temperatures. For example, bleaching was reported from Milne Bay during 1997–98 in the absence of abnormally high water temperatures. Neither does bleaching occur only during El Niño events. The first published report of mass bleaching in the region, again from Milne Bay, was from early 1996 when El Niño was not underway (Davies et al., 1997).

Earthquakes, Volcanoes, and Cyclones

The area is tectonically active and experiences occasional volcanic eruptions, and numerous earthquakes. Recent dramatic events include a major volcanic eruption which obliterated much of the town of Rabaul in 1994 and, in 1998, a seismic sea wave generated by a submarine earthquake in the floor of the Bismarck Sea which killed at least 2200 coastal villagers. Wells and Jenkins (1988) have noted tectonic activity as a significant natural disturbance to the region's coastal ecosystems. This point is well taken. Over the period 1960–80, for instance, the island of Guadalcanal (Solomon Islands) experienced 34 strong earthquakes (Richter magnitude 5.5 and greater) and some of these produced mild tsunamis and localised coastline change. Perhaps of greater significance for coastal shallow water ecosystems were the land-slips triggered by these events. For instance, those from a series of four 1977 earthquakes on Guadalcanal dramatically increased stream bedloads and steepened stream gradients. Offshore sediment plumes from these streams persisted for many years (Baines, pers. obs.). There have presumably been significant ecological changes resulting from such long-term sediment impacts. Coral community structure, for example, has been shown elsewhere to be affected by elevated sediment loads (Hodgson, 1994). It is important to note that, while some of these land-slips were associated with subsistence food gardens on steep slopes, many occurred where there had been no human disturbance. A general point to be drawn is that these land-slips and their sediment plumes in nearby coastal waters are a natural feature of a dynamic landscape (Baines and Morrison, 1990).

Elsewhere in the Solomon Islands one of us (Baines) has examined cracking, subsidence, and the breaking off of reef edges on narrow fringing reefs alongside the islands of Vella Lavella and Santa Ysabel arising from earthquake events. Though some short-term effects arise from differential coral species damage, the physical changes have given rise to a diversification of physical habitat which can be expected to contribute positively to species diversity. On a larger scale, at the time of a severe Guadalcanal earthquake in 1977 a reef said to have been at a depth of 10 m was forced upwards to the sea surface. As sand deposits formed on it and built up into cays, it was claimed as new land under local customary law.

Tropical cyclones form in the Coral Sea or in the southwestern Pacific east or northeast of the Solomons (McAlpine et al., 1983). Their path after formation is unpredictable, but generally includes a southwesterly component, so that most cyclones originating in the Coral Sea move away from PNG, although they regularly impact remote reefs in the Coral Sea and occasionally move northward to affect the Papuan coast. The only part of PNG subject to major cyclonic events is its southeastern tip, including the Milne Bay area and the archipelagoes to the east. In the Solomon Islands, too, most cyclones do not cross over the country's major islands although the country still experiences an average of 1.2 cyclones a year (Leary, 1993a). Cyclone impacts on coastal shallow water ecosystems are primarily episodic sediment and freshwater fluxes resulting from high-intensity rainfall and subsequent soil erosion. No cyclone-induced wave impacts on coral communities have been studied, though it is reasonable to expect these to be a natural source of disturbance.

SHALLOW WATER MARINE AND COASTAL HABITATS

The region's major shallow-water coastal biomes are coral reefs, mangrove forests, and seagrass beds. Other important habitats are soft estuary and lagoon bottoms. These biomes and the habitats which they provide are ecologically linked at a number of locations with coastal swamps and floodplains.

Reef–Mangrove–Seagrass Complex

Most of the coastline of PNG has associated reefs, though there are extensive stretches of shoreline which are devoid of significant fringing reef development where natural freshwater and sediment levels are high, as along the Gulf of Papua (see Huber, this volume). A standard, but probably high, estimate is that there are 40,000 km^2 of coral reef and associated shallow habitats to a depth of 30 m (Dalzell and Wright, 1986). A more recent estimate of 12,000 km^2 (Bryant et al., 1998) is probably an underestimate: a map based on the same database fails to indicate the presence of reefs in many areas (e.g., most of the north coast) where in fact they occur. Even this low estimate represents nearly 5% of the world's coral reef area, and the fourth highest of any country (Bryant et al., 1998). About a third of PNG's reef area occurs around its southeast tip, in Milne Bay Province. Though coral reefs occur in all coastal provinces, their development is restricted along the northwestern mainland coast due to the influence of the Sepik and Ramu rivers.

Reef development in the Solomon Islands is less extensive. Bryant et al. (1998) estimate that there are 6000 km^2 of coral reef in the Solomon Islands. Stoddart (1969a) believed

the paucity of living coral on reef flats could be the result of tectonic upheaval of reefs, a small eustatic fall in sea level, or seasonal fluctuations. Since this condition persists, the latter possibility can probably be ruled out. Wells and Jenkins (1988) suggest that scarcity of suitable substrate on the steep coastline, or the effects of storms, tectonic activity, and/or the depression of sea level during extreme ENSO events may be responsible.

Fringing and patch reefs are most common, but the full spectrum of reef types occurs, including barrier reefs, atolls, and coral pinnacles in both countries. The Papuan Barrier Reef extends from Yule Island for some 900 km along the south coast of PNG to merge with the extensive reef systems of Milne Bay. Geologically and biogeographically it is essentially an extension of the GBR. Another large barrier reef is found off Madang, on the north coast. Some of the many islands of the Solomon Islands have associated barrier reefs. Those at Marovo Lagoon on New Georgia Island and at Kohinggo Island along Blackett Strait are of particular interest because they are considered to be among the best-defined double barrier reefs in the world. The barrier reef at Marovo Lagoon, in fact, is in part a triple barrier (Stoddart, 1969 a,b). There are many smaller barrier reefs. More detail on the coral reefs of PNG and the Solomon Islands is provided by Wells and Jenkins (1988).

Mangroves are found on most coasts where there is some protection from wave exposure and the shoreline is of sufficiently low gradient to allow accumulation of suitable sedimentary substrate. They are best developed in bays, lagoons, and estuaries, where there is more fresh water input, soft substrate, and protection from waves. Mangroves cover more than 4100 km^2 in PNG and 640 km^2 in the Solomon Islands (Saenger et al., 1983). Most of PNG's mangroves are found in Western and Gulf provinces (see Huber, this volume), but there are also significant areas of mangrove in other parts of the country. Central Province, for example, has nearly 600 km^2 of mangroves (Osborne, 1993). Other large areas of mangrove in PNG include the mouth of the Sepik–Ramu river system, Madang lagoon, the mouth of the Markham River at Lae, and the Orangerie Bay/Mullins Harbour area of Milne Bay Province (Percival and Womersley, 1975; Huber, pers. obs.) The largest mangrove areas in Solomon Islands are at Santa Isabel, New Georgia, Choiseul and South Malaita (Maramasike Passage; Hansell and Wall, 1976).

In PNG, the genera *Rhizophora, Bruguiera, Sonneratia,* and *Avicennia* typically dominate the seaward parts of mangrove forests, while common genera to landward include *Ceriops, Osbornia, Lumnitzera,* and *Sonneratia* (Cragg, 1987; Johnstone and Frodin, 1982; Percival and Womersley, 1975). Well-developed estuaries with enough freshwater input to produce very low (<1 ppt) salinities usually have stands of the nypa palm (*Nypa fruticans*). There are extensive stands on the Sepik floodplain. *Rhizophora, Bruguiera,* and to a lesser extent *Avicennia* are the dominant genera of the Solomon Islands (G. Pillai, pers comm; Leary, 1993a).

Seagrasses are widespread on reef flats and shallow areas of lagoon floors in the Coral, Solomon, and Bismarck Seas. Coastlines that slope steeply into deep water have relatively little seagrass. Seagrass beds support a diverse and productive flora and fauna, are breeding and nursery grounds, and are feeding grounds for dugong (*Dugong dugon*) and the green turtle (*Chelonia mydas*). The distribution of seagrass beds in the region has not been mapped, and no quantitative estimates of the area of seagrass coverage are available. There have been some geographic surveys of seagrass PNG (Balat, 1993; Heijs and Brouns, 1986; Johnstone, 1982), and detailed studies of the associated flora and fauna, trophic relationships, and community structure of seagrass beds near Port Moresby (Brouns and Heijs, 1991; Hattori, 1987; and references therein). Seagrass beds occur in the Solomon Islands, but have not been the subject of scientific investigation.

The coral reefs, mangroves, and seagrass beds rarely exist as isolated ecological units. Usually they function as interacting components of an integrated coastal ecosystem. In a typical barrier reef–lagoon–estuary system, for example, the barrier reef and associated sand cays enclose a lagoon with extensive development of patch reefs. A fringing reef along the shoreline is backed by mangroves, and seagrass beds are on parts of the reef flats and shallow (typically 30–50 m) lagoon floor. Prominent examples of this type of coastal complex include Marovo and Roviana Lagoons in the Solomons, which are among the world's largest, and the Papuan and Madang Lagoons in PNG. Wells and Jenkins (1988) provide some detail of Marovo Lagoon's coral reefs, while Osborne (1993) details the coastal swamp forests through which freshwater feeds into the lagoon. Extensive soft-bottom areas are also associated with these systems, but the soft-bottom communities here, and elsewhere in the region have been poorly studied.

Coastal Swamps

A number of enclosed coastal saltwater lagoons are of interest. The largest, the Murik Lakes at the mouth of the Sepik, cover about 90 km^2 with 185 km^2 of associated mangroves (Dalzell et al., 1996). Similar but smaller lagoons include Sissano Lagoon to the west of the Murik Lakes and, in the Solomon Islands, Lauvi Lagoon on the south coast of Guadalcanal.

In many parts of the region there are lowland freshwater swamps that are important sources of nutrients and organic matter to coastal marine waters. Most notable, because of the large area involved, is the Sepik–Ramu river system. These rivers meander through a swampy coastal floodplain with more than 1500 oxbow and other lakes (Osborne, 1993), and the above-mentioned extensive nypa thickets. Also important are smaller areas of "big tree" swamp forests dominated by *Terminalia* and *Campnosperma,* and swamps dominated by sago palm (*Metroxylon sagu*) or *Pandanus* spp.

Detail on these swamps is given by Osborne (1993). Similarly constituted swamp forests occur in the Solomon Islands.

Because of the high freshwater outflow from the Sepik (75 km^3/yr; Alongi, 1990) there is little estuarine development upstream of the Murik Lakes. Even so, a number of marine fish species occur several hundred kilometres upstream. The depauperate, highly endemic native fish fauna is largely unsuitable to support fisheries. Some two-thirds of Sepik–Ramu fisheries production is based on tilapia (*Oreochromis mossambica*) and carp (*Cyprinus carpio*), which were initially introduced to PNG for pond culture and subsequently escaped or were released into rivers (Kailola, 1995). Several other species have been deliberately introduced to further enhance fisheries despite environmental concerns about their possible suppression of indigenous species (Coates, 1993; Allen, 1991).

Biodiversity

The Coral, Solomon, and Bismarck Seas region lies within or immediately adjacent to the global centres of diversity of corals, mangroves, and seagrasses. Shallow-water biological diversity here is among the highest in the world. In general, the diversity is highest in PNG, Indonesia and the Philippines, and decreases moving eastward across the Pacific as well as to the north and south (McCoy and Heck, 1976; Mukai, 1993; Veron, 1993; Woodroffe, 1987). Though the current estimates of species diversity, below, are high, these should be regarded as conservative because of very low sampling effort.

More than 70 coral genera have been recorded from PNG's reefs (Veron, 1993) which are as, or more, diverse than any in the world. Coral diversity on the Papuan Barrier Reef is higher than on the well-studied Great Barrier Reef to the south (Veron and Kelley, 1988). With more than 60 coral genera, Solomon Islands' reefs are also very diverse by global standards. The species diversities of reef-associated fishes and invertebrates are also among the world's highest (e.g., Allen and Swainston, 1993; Ghiselin, 1992; Gosliner, 1992; Wells, 1990).

While in nearby coral species-rich Indonesia and the Philippines a high proportion of reefs is threatened by human activities (Bryant et al., 1998; Chou et al., 1994) the reefs of PNG and the Solomon Islands are still in relatively good condition (Huber, 1994; Maragos, 1998) and so are of great significance for the conservation of global biodiversity.

There are more than 30 recorded species of mangroves in PNG (Percival and Womersley, 1975; Woodroffe, 1987), while in the Solomons 27 have been identified (G. Pillai, pers comm). As with coral reefs, the mangrove forests support a diverse associated biota. A total of more than 130 species of fishes, for example, has been recorded from the mangrove habitat of PNG and the Solomon Islands; at any one site, from 20 to more than 50 species have been found (Blaber and Milton, 1990; Collette, 1983).

Seagrass species diversity reaches a maximum in western PNG and the Torres Strait, where 13 species have been identified (Huber, this volume). Elsewhere on the PNG coast there are 9–11 seagrass species (Johnstone, 1982; Mukai, 1993). The diversity of seagrasses, like that of other shallow tropical communities, declines moving eastward across the Pacific (McCoy and Heck, 1976; Mukai, 1993). Accordingly, the Solomon Islands probably has fewer species, but there have been no studies of seagrasses there.

Six of the world total of eight species of marine turtle are found in PNG seas, and five of these have been recorded in the Solomon Islands. The estuarine crocodile (*Crocodylus porosus*) population of the Solomons has been severely depleted by hunting (Messell and King, 1989). A ten-year ban on export of crocodile skins, implemented in 1989, appears to have been followed by some recovery (M. Lam, pers. comm.) The largest population now is at Lauvi Lagoon. Though substantially reduced in PNG, management measures introduced for this species (including farming) have had some success in maintaining population levels while also catering for a village-based industry in skins. Dugong populations in both countries have been much reduced by hunting.

Several coastal endemic animals are known from the region. An anemone fish (*Amphiprion leucokranos*) is known only from northern PNG and the Solomon Islands (Fautin and Allen, 1992). An endemic subspecies of the mangrove monitor lizard, *Varanus indicus spinulosus,* has been found only in the small area of San Jorge and Thousand Ships Bay, at the southern end of Santa Isabel. For another rare species, an endemic giant rat, *Uromys ponceleti,* the preferred habitat is believed to be *Terminalia brassii* coastal swamp forest (Leary, 1993b). In Lake Tenggano, on the small Solomons island of Rennell, there is an endemic sea krait *Laticauda crockeri* (McCoy, 1980). Undoubtedly there are more discoveries to be made of interesting endemics. A comprehensive account of coastal biodiversity in PNG is to be found in Sekhran and Miller (1994). The biodiversity of coastal ecosystems in the Solomon Islands has been less studied.

OFFSHORE SYSTEMS

The Environment

The Coral, Solomon, and Bismarck Seas are oligotrophic. At oceanic stations in the Coral and southern Solomon Seas, Furnas and Mitchell (1996) found deep (generally >60 m) surface mixed layers with low surface nutrient concentrations. They estimated primary production in the oceanic Coral Sea, which was dominated by picoplankton, to be 9–180 gC/m^2/yr.

Upwelling and turbulent mixing around reef and archipelagic systems, however, may result in much higher primary production in coastal areas. For instance, Furnas

and Mitchell (1996) measured daily production rates of 1–3 g/C/m^2/day at sites adjacent to the Papuan Barrier Reef and in the Louisiade Archipelago. This, coupled with the area's complex bathymetry and circulation patterns, probably gives rise to high spatial and temporal variability in productivity. Very little is known, however, about such variability, or its relationship to climatic and oceanographic forcing functions. Furnas and Mitchell (1996) found high variability in productivity estimates derived from two cruises undertaken in 1985 and 1988. They were unable to determine whether this reflected natural variability or whether it was a methodological artefact. High cloud cover and inadequate ground truthing limit the utility of satellite observations in oceanographic studies of the region (e.g., Furnas and Mitchell, 1996).

Tuna Fisheries

Pelagic tunas are by far the largest fisheries resource for both PNG and the Solomon Islands. In 1995 the combined catch of over 340,000 mt (Table 2) in these countries' EEZs accounted for about 11% of the global catch of tuna (Gillett, 1997). About 40% of this catch, which is dominated by skipjack and yellowfin tuna, comes from the Coral, Solomon, and Bismarck Seas (Fig. 3). (The catch from these seas within the EEZs of PNG and the Solomons cannot be calculated precisely; statistics provided by the South Pacific Commission are tabulated on the basis of grids of five degrees of latitude and longitude. The data for the Coral Sea in Fig. 3 include a small catch from the EEZs of Australia, Vanuatu, and New Caledonia.) Catches are well below the estimated maximum sustainable yield for all species, a situation rare among the world's fisheries.

The Solomon Islands tuna fishery was established in 1971 with a catch of 4666 tonnes by a small pole-and-line fleet. The tuna fishing fleet has since expanded and now includes purse seiners and long liners. The annual domestic catch, 1990–96, averaged over 48,000 tonnes. Continued development of the industry led to a 1998 domestic fleet catch of 116,438 tonnes (S.I. Fisheries Department files). The economic returns from the tuna fishery, including royalties earned from distant water fishing vessels that do not land their catch in the Solomon Islands, make it a key industry for the country. The domestic fleet takes 65–95% of the total tuna catch of the Solomon Islands' EEZ, and around half the catch is consumed locally or processed prior to export (Gillett, 1997; FAO, 1998; Solomon Islands, 1992). Tuna fishing and processing account for over 8% of the country's formal employment (and a higher proportion of private sector employment) and a third of export revenue; foreign access fees provide 5% of government revenue (Gillett 1997; Leary, 1993a). In the face of opposition from some distant water fishing nations, the Solomon Islands has taken the initiative to introduce a far sighted "Tuna 2000" policy as a basis for sustainable management of the nation's tuna resources. Under this regime, the nation is to receive fairer economic returns.

In PNG the situation is different. Since a pole-and-line fleet based in New Ireland ceased operations in 198 (Doulman and Wright, 1983, describe the domestic tuna fishery at that time), tuna fisheries in PNG have been exploited almost entirely by distant water fishing fleets from other countries. Other than access fees of about US$2 million annually, or about 2% of government revenue (Gillett, 1997; Gumoi and Sekhran, 1994), tuna fisheries provided almost no domestic benefit during most of the 1980 and 1990s. Tuna vessels did not call or land product at PNG ports and, in 1995, tuna fisheries, with a catch approaching US$500 million in value, provided only an estimated 12 jobs in PNG (Gillett, 1997).

Recent government policy has given high priority to the development of domestic participation in tuna fishing and processing, as well as to support services for domestic and foreign vessels. In 1995 the long-line industry was reserved exclusively for domestic vessels, and small longline and purse seine fleets have since developed. A cannery opened in Madang in 1997. Despite such initiatives, domestic benefits from the large tuna resource remain largely unrealised. Tuna exports during the first half of 1998 amounted to less than 9400 mt with a value of about US$12.5 million; 70% of the exports were unprocessed frozen fish (NFA, 1998). There are plans to continue to develop the embryonic domestic industry, but previous efforts have often failed to materialise and it remains to be seen whether the potential of PNG's tuna stocks can be managed so as to make a significant contribution to its economy.

The resources of the region's seas are important for the nations who control them, and not least because of their very long coastal fishing tradition. Inshore tuna schools have always been an integral part of this tradition, and for many coastal communities the skipjack tuna (*Katsuwonus pelamis*, locally called "bonito") had special status, symbolised in cultural practice through art, song and dance.

Table 2

Nominal tuna catches in the EEZs of Papua New Guinea and Solomon Islands in 1995 by gear type (from Gillett, 1997)

Gear Type	Papua New Guinea	Solomon Islands
Longline[1]	406	8,248
Pole and line	66	31,943
Purse seine	264,531	37,053
Total catch	265,003	77,244
Estimated value (US$ million)[2]	452.3	131.8

1. Gillett (1997) suggests that longline catches should be adjusted upward by a factor of 1.7 to allow for under-reporting.
2. Calculated from an average value of US$1707/mt for tuna catches in the South Pacific Commission statistical area (Gillet, 1997).

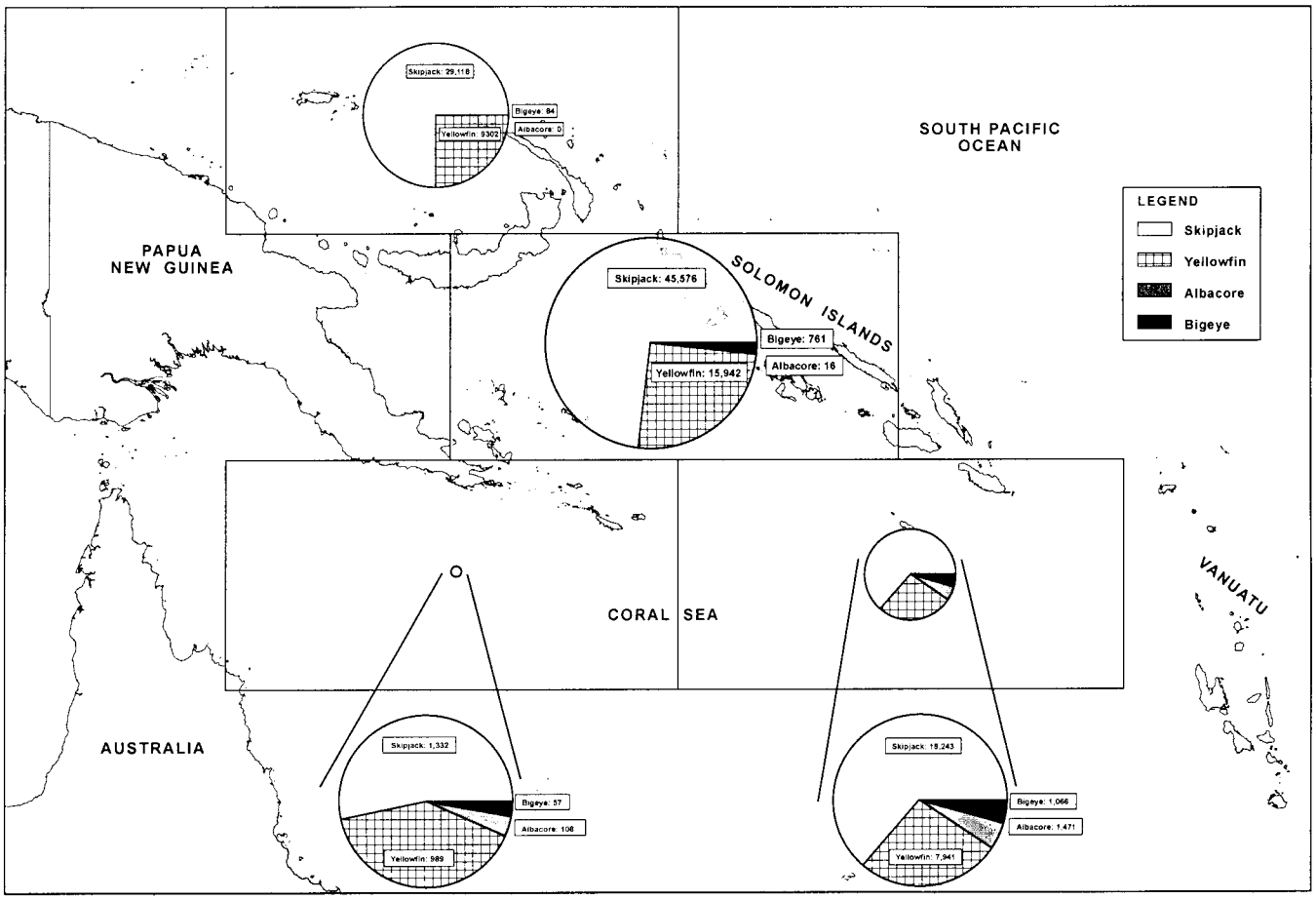

Fig. 3. Tuna catch and catch composition in the Coral, Solomon, and Bismark Sea region. Size of circles inside the 5° latitude and longitude grids is proportional to total catch (source: SPC database).

PEOPLE, DEVELOPMENT AND CHANGE

Population and Demography

Population data for PNG and the Solomon Islands are shown in Table 3. These are presented as national aggregates, since data specific to the coastal population are not available. A large component of the PNG population lives inland. The five highlands provinces isolated from the coast account for 38% of the national population. Furthermore, most of the "coastal" provinces, i.e. those that have some coastline, also contain significant inland populations. On the basis of 1980 census data, Frielink (1983) estimated that the rural coastal population of PNG was 23.1% of the national total, which if unchanged would currently represent some 1 million people. For PNG as a whole only 16% of the population lives in urban areas (UNDP, 1994). The 1980 census revealed that about 44% of the coastal population lived in urban areas (Frielink, 1983). The country's largest two cities, Port Moresby (195,000; 1990 census) and Lae (88,000), account for a great part of the coastal urban population and are undergoing rapid growth as a result of in-migration from rural areas. Recent population estimates are about 250,000 for Port Moresby and 140,000 for Lae. Other important coastal towns, most of which are growing much less rapidly, include Madang (27,000; 1990 census), Wewak (23,000) Rabaul (17,000), Kimbe/Hoskins (9000), Vanimo (7800), Kavieng (6800), Alotau (6400), and Lorengau/Lombrum (5800). The Kieta/Arawa/Panguna urban area on Bouganville island had an estimated 18,000 people in 1980 but the population has declined dramatically as a result of civil unrest.

In the Solomon Islands, where there are no large land masses and no place as much as 20 km from the coast, virtually everyone is a coastal dweller. Except for a couple of urban areas, virtually every family harvests coastal resources. Thus, the data in Table 3 do reflect the coastal population of the Solomon Islands. Most of the urban population lives in Honiara, with an estimated 1997 population of 65,000 growing at about 10% annually (Commonwealth, 1998). Gizo (2331; 1986 census) and Auki (948; 1986 census) are the other towns of significance.

In both countries, although the crude population density (number of people per unit land area) is low on average, the population per unit of arable land is considerably higher, especially on smaller islands. There are also

Table 3

Selected Social Indicators for Papua New Guinea and Solomon Islands (sources: AusAID, 1997; Leary, 1993; SPC, 1998; UNDP, 1989, 1994, 1998)

	Papua New Guinea[1]	Solomon Islands
Estimated population in 1998	4,412,400	417,800
Annual population growth rate (%)	2.3[2]	3.4
Population density (persons/km^2)	10	15
Fertility (no. children per woman)	4.7	5.8
Population under 15 (%)	42	47
Dependency ratio[3]	85	109
Life expectancy	54	65
School attendance by school-age children (%)	28	35
Adult literacy (%)	28	30
GDP per capita (US$)	1196	926
Participation in cash economy (males/females; % of population aged 15–64[4])	54/37	36/13
Formal employment (% of workforce)	10	15
Public sector employment (% of formal employment)	27	36
% Urban population	15	13
% Population in main centre	5	11
UNDP Human Development Index	0.341	0.371

1. Excludes North Solomons Province.
2. Unisearch (1991) suggest that this is an underestimate
3. Dependency ratio = (population under 15 + population over 60)/(population 15–60).
4. For Solomon Islands females, aged 14 and over.

wide differences in crude population density among islands. High fertility in both countries has produced a youthful population structure and high population growth rates.

The Nature of Development

The level of social and economic development is very low. Indeed, PNG and the Solomon Islands have the lowest "human development indices" (an index calculated by UNDP for all countries, from a range of social and economic parameters) of Pacific Islands nations, by a considerable margin (UNDP, 1998). There has been little progress during the 1990s. The national aggregate statistics presented in Table 3 mask wide disparities in development among provinces, and between urban and rural areas. For the most part the rural majority lives an essentially traditional lifestyle in small villages constructed in large part of locally available "bush materials". They often have little access to education, health care, safe water, and other basic services. Electricity supplies are restricted to urban centres, except in a few rural communities where a nearby industrial-scale development provides limited access. The level of formal employment is low and is dominated by the public sector. Over 80% of the workforce is engaged in agriculture, primarily in traditional subsistence and market gardening. The commercial sector is dominated by extractive primary resource industries—mining, logging, agriculture, and fisheries.

Use of the Sea and its Resources

In PNG and the Solomon Islands the main use of coastal marine resources is subsistence and artisanal fishing. There is a high degree of rural reliance upon seafood and other marine resources (see below). Marine resources were first exploited at a commercial level early in the 19th century when American whalers began to take humpback whales. An export trade in "tortoiseshell" (the carapace of the hawksbill turtle, *Eretmochelys imbricata*) then developed. In the Solomon Islands tortoiseshell was exchanged with visiting Europeans for firearms and ammunition. This trade enabled communities with access to good stocks of hawksbill turtle to gain superiority in the inter-island warfare endemic at the time (McKinnon, 1975). In the western Solomons these gains are still reflected today in the distribution of people and the rights of communities to access land and sea resources. Foreign interest in marine resources subsequently extended into mother-of-pearl and bêche-de-mer. A similar sequence of commercial trade developed over this period in PNG. As described below, present-day commercial trade in coastal marine resources is dominated by bêche-de-mer and mother-of-pearl.

Though in PNG and the Solomon Islands the State has ultimate jurisdiction over coastal sea areas, most of these are subject to a long tradition of customary ownership and resource allocation. A typical traditional coastal resource management system is a community-based, participatory system for the integrated management of both land and sea. It is not a management system specifically for fisheries. It is based on social relationships among people, and is expressed as rights to exploit resources (Baines, 1985; Hviding, 1996). Rights to access marine resources are mediated through a system of customary marine tenure (CMT). These rights may apply not only to specific places such as reefs, spawning grounds, or fish migration routes, but also to particular species or fishing methods. Though CMT is widespread, and profoundly affects marine resource use, only limited information about it has been documented (see Baines, 1985; Carrier and Carrier, 1989; Hviding, 1996; Polunin, 1984, Wright, 1985 and references therein).

The Information Baseline

Fisheries agencies in both PNG and the Solomons have generated considerable information on coastal fisheries stocks (see Dalzell et al., 1996; Kailola, 1995; Skewes, 1990), though there are important gaps, questions about reliability, and often a lack of continuity through time. The information is largely limited to stock assessments and production figures for export products. There are few catch

data for subsistence and non-export artisanal fisheries, and catch-effort data in all coastal fisheries is very limited.

Aside from fisheries, there is inadequate information on the marine environment to establish any form of baseline against which trends might be identified as a basis for management. The situation in PNG is somewhat better than in the Solomon Islands. Some of the earliest work on shallow water ecosystems in PNG was undertaken from the Kanudi Research Station near Port Moresby in support of fisheries development. Coastal research by staff at the University of Papua New Guinea commenced in the early 1970s. Around the same time the University established a research station on Motupore Island, near Port Moresby, and the Royal Belgian Institute of Natural Sciences established another at Laing Island on the north coast; the latter has recently closed. The Christensen Research Institute operated a research station at Madang from the mid-1980s until 1998. Another small research facility opened at Kimbe on the north coast of the island of New Britain in the late 1990s. These and other efforts have provided considerably more information about the coastal biota of PNG than is available for the Solomon Islands, but it is still very limited, geographically and taxonomically. Large areas of the country, and major ecotypes such as soft-bottom communities, remain essentially unknown. Nearly all work has consisted of "one off" studies at one or a very few sites, and there is no information about spatial and temporal variability.

Reports arising from a 1965 Royal Society Expedition (Stoddart, 1969a,b), remain the primary source of published information about Solomon Islands reefs. A coordinated range of ecological, resource and anthropological studies has been made, in support of a community resource management initiative, in the Marovo Lagoon (Baines, 1985; Hviding, 1996). Increased knowledge is emerging from local research on giant clam (*Tridacna* spp.), pearl oysters and bêche-de-mer (various holothurians) at an International Centre for Living Aquatic Resource Management coastal aquaculture centre (ICLARM-CAC) at Aruligo, Guadalcanal. Elsewhere, research is underway on trochus and green snail. A research centre of the University of the South Pacific's Institute of Marine Resources is under establishment.

In PNG, water quality, habitat, and related environmental surveys and monitoring have been undertaken in connection with large mining projects that impact on coastal waters. A few monitoring sites have been established as part of the Global Coral Reef Monitoring Network established in the late 1990s but the viability of this effort is questionable.

A considerable source of knowledge is yet to be accessed and presented in a form that makes it useful for advancing scientific understanding. This is local traditional knowledge of coastal marine systems and resources, which underpins traditional coastal resource use systems. Such knowledge may not be overtly linked with conservation objectives, but its application often serves to conserve resources. Nor is this knowledge "complete" in an ecological sense. Knowledge of the behaviour of target species, for instance, is extensive—of other species, very limited. Further, it appears that an appreciation of ecological processes is only now developing as information from scientific studies is made available to traditional fishers. Nonetheless, the body of traditional knowledge represents an important store of scientifically useful information. Johannes (1988), for example, made use of traditional knowledge in a study of spawning behaviour of coral trout, *Plectropomus leopardus*.

LAND AND SEA USE FACTORS IMPACTING ON COASTAL WATERS

Land Use

Food gardens for subsistence, and for limited marketing, are widespread in coastal PNG and the Solomon Islands. Some of this cropping is undertaken as shifting cultivation, which is a source of forest disturbance (Leary, 1993a; Levett and Bala, 1994; Louman and Nicholls, 1994). It can also give rise to increased soil erosion. Large-scale agriculture is conducted mostly as plantations of export tree crops, mainly coconuts, oil palm, and cocoa. Rubber, and coffee, and sugar, are also grown in parts of PNG, primarily inland but in some cases also in coastal areas. Much of the coastal tree cropping is on flat or gently sloping land and, since ground cover is maintained in these plantations, soil losses to coastal waters may not be significant.

A desk study of fertiliser and pesticide loading of the coastal environment suggests that this is relatively low by world standards, though the Solomon Islands is estimated to have among the highest in the Pacific (Convard, 1993; Table 4). A more significant problem for coastal waters arises from organic processing wastes (see below).

A crude form of rainforest logging, using heavy machinery and with little effort to minimise collateral damage, has been an economic mainstay which in recent years has outstripped fisheries as the leading source of export earnings in the Solomon Islands. In PNG, logging revenues are second only to those of mining. Nearly all production is exported as unprocessed round logs. The extraction of logs has greatly exceeded sustainable rates, and environmental practice has been poor (Hughes and Sullivan, 1989; Louman and Nichols, 1994; Leary, 1993a; Marshall, 1990; Nadarajah,

Table 4

Estimated total loadings of fertilisers and pesticides from agricultural runoff per kilometre of coastline (calculated from data in Convard 1993 and Table 1)

	Papua New Guinea	Solomon Islands
Fertilisers (kg/km/yr)	0.1	22.6
Pesticides (kg/km/yr)	1.8	4.7

1993; Solomon Islands, 1992; UNDP, 1994). Increased sedimentation arising from forest canopy removal and soil disturbance by logging is widely regarded as a major threat to coral reefs and other coastal ecosystems in the area (Asquith et al., 1994; Huber, 1994; Leary, 1993a; Maragos, 1998). However, there are inadequate data with which to assess the problem. Baines and Morrison (1990) reported that, for the logged island of Kolombangara in the Solomons, "Within a few years of the cessation of logging, except following heavy rain, these streams were flowing clear, into coastal seas where no polluting suspended sediment was apparent.". This does not rule out the possibility that damage was inflicted while logging was in progress, or that accumulated sediment on the reef may have had subsequent effects. It has been suggested (e.g., Asquith, 1994) that the generally narrow continental shelf, which may reduce sediment retention in the coastal zone, and high rainfall and steep slopes, which are likely to produce high natural sediment fluxes, might enhance ecosystem resilience, but to what extent, if any, is not known. Neither is there information on possible interactions between sedimentation and other chronic stresses and ecosystem capacity to recover from natural disturbances such as storm damage and mass bleaching events.

Subsistence and Artisanal Fisheries

There are few full-time fishers and, where land is available, agriculture is the more important subsistence activity. Nevertheless, subsistence and artisanal fisheries are by far the most important use of coastal marine resources in the region. Seafood consumption is very high in the Solomon Islands (Richards et al., 1994), and Pernetta and Hill (1981) have pointed out the importance of seafood as a source of protein in PNG. In both production and value the subsistence catch in both countries greatly exceeds the commercial (mostly artisanal) catch (Table 5).

Subsistence fishers typically use the full range of available resources, directing effort to estuarine, mangrove, lagoon, reef, and/or nearshore pelagic species according to season or weather conditions, resource availability, and social factors such as customary access rights. Their methods vary widely with location, target species, season, and the age and sex of the fisher. They include drive nets, gill nets, beach seines, droplines, handlines, troll lines, spears (used both from the surface and while underwater), bow and arrow, hand traps, stone traps and weirs, hand gathering (both by gleaning shallow flats and by diving), derris root and other natural poisons, and explosives. Hviding (1996) provides a comprehensive account for Marovo Lagoon. Turtles, dugong, and porpoises are sometimes herded with boats to facilitate their capture with spears or nets. There are also some unusual traditional methods such as "calling" sharks with coconut shell rattles and then lassoing them, and catching "garfish" (Hemirhamphidae) by entangling their teeth in lures of spiders' web suspended from kites.

Subsistence fishing is often defined as fishing for the direct consumption of fishers and their families and artisanal fishing as fishing for products that will be sold or traded. In practice it may be difficult to distinguish between subsistence and artisanal catches. The exchange of fisheries products in the area is part of a complex system of social exchange and obligation, and a distinction between consumption by a fisher's family and consumption by others in the community is artificial. It is also common for fishers who lack access to agricultural land to trade part of their catch for plant foods; in the case of Western and Gulf provinces of PNG, sago. Subsistence catches have been estimated from seafood consumption rates (e.g. Dalzell et al., 1996), in which case locally-traded catches, even if bought and sold in markets, are included in subsistence catch estimates. The basis of reporting of "subsistence" and. "artisanal" catch categories in statistics is often poorly defined. In this chapter "artisanal" catches are primarily those of products that are exported beyond the local area in exchange for cash. "Subsistence" catches refer in general to those that are consumed locally. This distinction is, however, neither precise nor necessarily consistent.

Table 5
Estimated mean annual coastal fisheries production, 1989–1992 (from Dalzell et al., 1996)

	Papua New Guinea		Solomon Islands	
	Production (t)	Value (US $)	Production (t)	Value (US $)
Subsistence fisheries	21,014	42,028,000	10,000	8,405,660
Commercial fisheries	4,966	22,096,078	1,150	4,343,811

Catches are highly diverse. Several hundred species of fishes may be involved, of more than 20 families (Dalzell et al., 1996; Lock, 1986a; Richards et al., 1994; Wright and Richards, 1985). A variety of molluscs, crustaceans, echinoids, and other invertebrates is also taken, as well as sea turtles, dugong, crocodiles, and porpoises. A number of other marine products are harvested for traditional purposes. Though a trade in sea salt with inland communities is no longer of importance in PNG, certain shells are still traded between communities as a form of currency and as a demonstration of cultural links. Demand for one of the species involved (*Nassarius camelus*) is so great that some supplies are imported from the Solomon Islands, where this species does not have the same cultural significance. In 1990, over 12 tonnes of this tiny shell were subject to this international trade (SI Fisheries Department data). There are other mollusc species harvested for cultural purposes by both PNG and Solomon Islander communities, often physically processed into small discs from which "shell money" strings are made. This product is of vital social importance for some

communities, for example on Malaita, Solomon Islands and the Trobriand Islands, PNG. Other marine products collected include *Acropora* coral, which is burned to produce lime to be chewed with betel nut.

Commercial activity in inshore fisheries is dominated by artisanal fisheries, which are an important source of village incomes. Export fisheries for bêche-de-mer, the dried product of various holothurians, and shells used to produce mother-of-pearl, most importantly trochus (*Trochus niloticus*), black- and gold-lipped pearl oyster (*Pinctada margaritifera* and *P. maxima* respectively), and green snail (*Turbo marmoratus*), dominate inshore fisheries in both volume and value. These products are a major source of cash income for many coastal communities but, being poorly managed, stocks are rapidly depleted.

Other targets of artisanal fisheries include sharks, spiny lobsters (*Panulirus* spp.), mangrove crab (*Scylla serrata*), and snappers taken by deeplining along reef fronts (including high priced market favourites such as *Pristipomoides*). Corals, shells, and reef fish are collected, the former for processing into decorative products for sale to tourists, and the latter for an export aquarium trade. Fisheries for giant clams (*Tridacna*), hawksbill turtle shell (*Eretmochelys imbricata*), and the estuarine crocodile (*Crocodylus porosus*) have been curtailed by local regulation both in response to the listing of these species in the CITES Convention (Convention on International Trade in Endangered Species) because of their endangered status, and through local recognition of population declines (Hair, 1994; Kailola, 1995; Richards et al., 1994). The effectiveness of controls is uncertain, however.

Threats to Sustainability

Overfishing is a primary concern in coastal fisheries of the Coral, Solomon, and Bismarck Seas. While, overall, coastal living marine resources are regarded as under-utilised, this results from a lack of markets rather than from effective management. Wherever there has been access to receptive markets, over-exploitation has inevitably followed. Export coastal fisheries typically expand until the resource is depleted, or a drop in the market price provides a disincentive to harvest. Fisheries for bêche-de-mer, mother-of-pearl, giant clams, and other sedentary species typically undergo "boom-and-bust" cycles; these resources appear to be inherently difficult to manage and susceptible to over-exploitation (see chapters in Wright, 1993).

Data presented in Table 6 demonstrate this. Through the 1980s, the primary sources of cash income for coastal villagers in the Solomon Islands were trochus shell and copra (dried coconut flesh). Copra prices, however, were depressed and, where the alternative of fishing for trochus was available, a typical villager response was to concentrate on that. The resultant over-harvesting is evident in the subsequent rapid decline in exports after 1990. A renewed interest in bêche-de-mer emerged in 1991. Not only was this a convenient alternative source of income, but there had been a surge in prices offered for this product. Again, a steady production decline followed, culminating in a collapse of interest as stocks became depleted. A similar sequence is evident in the export tonnage of pearl shell. For pearlshell, the "nil" entries beginning in 1995 mark the introduction of an export ban. This pattern of "boom, bust and ban" reflects an inability to manage stocks for sustainability. PNG fisheries for sedentary marine resources have followed a similar pattern.

In the Solomon Islands hunting for skins and shells for export quickly drove crocodiles to near extinction and severely reduced breeding populations of hawksbill turtle (*Eretmochelys imbricata*; Richards et al., 1994).

The complex social and political difficulties faced by Solomon Islands and PNG fisheries authorities in effecting sustainable management of coastal resources can to some extent be avoided through export bans on commodities for which there is no local market. However, bans cannot be applied to resources such as shellfish and most fishes other than tunas, for which the primary market is domestic. This is troubling, particularly as artisanal fisheries near urban centres are expanding to meet local demand. Overfishing of finfish and other food species has also occurred near urban areas (Solomon Islands, 1992; Lock, 1986b). In at least some subsistence and rural artisanal fisheries of PNG, human population growth has been identified as a major factor in overfishing (Apinia, 1986; Swadling, 1982).

Habitat degradation from subsistence and artisanal fishing is not widespread, but there are some localised

Table 6

Exports (tonnes), of selected non-fish marine products arising from artisanal fisheries in the Solomon Islands, 1990–1997 (source: Solomon Islands Fisheries Department files)

Product	1990	1991	1992	1993	1994	1995	1996	1997
Trochus shell (*Trochus niloticus*)	307	87	51	24	67	nil	nil	113
Bêche-de-mer (various holothuria)	119	622	715	316	285	219	nil	nil
Green snail shell (*Turbo marmoratus*)	3.6	3.3	2.0	0.6	0.9	nil	nil	nil
Black lip pearl shell (*Pinctada margaritifera*)	31.4	43.7	27.9	26.0	0.3	nil	nil	nil
Gold lip pearl shell (*P. maxima*)	25.7	13.9	4.8	1.2	nil	nil	nil	nil

concerns. One of these is blast fishing, involving explosives diverted from construction and mining projects, or from World War II munitions caches still found in many remote areas. Though illegal, enforcement capacity is minimal. Blast fishing breaks up corals, so damaging habitat, and brings about collateral damage to non-target species. The use of poisons to stun fish is an occasional but not widespread problem (Veitayaki et al., 1995). Substances used include cyanide, some pesticides, and timber preservative chemicals. The use of cyanide in the live reef-fish trade is a particular concern (see below). Though not yet widespread there is a possibility that the practice, once introduced, could spread to other fisheries and involve other poisons. This dangerous practice may be more readily accepted at a community level in the light of the long-established traditional use of *Derris* and other plant poisons. Traditional poisons are typically used on a small scale, and on special occasions, and it has not been established that they cause significant damage. There are anecdotal reports of localised pollution from bêche-de-mer processing, which produces organic matter and in some cases natural toxins.

Some forms of netting and gathering cause physical disturbance to reefs and seagrass beds. The collection of corals to produce lime also causes physical disruption. Leary (1993a) believes that the collection of corals for the aquarium and shell trade has contributed to reef degradation in some areas in the Solomon Islands. While no evidence of serious widespread impact has been sighted, these practices are expanding to an extent that makes them a concern.

COASTLINE CHANGE

In a region of high levels of tectonic activity and of geological complexity, it is not surprising that different sections of the coastline of a single island may be subject to both long-term subsidence, and uplift at the same time. Superimposed on these long-term adjustments are the short-term shifts brought about by earthquakes. An example of reef uplift is described earlier for Guadalcanal. Both earthquakes (by inducing land-slips), and periods of unusually intense rainfall attendant on tropical cyclones, result in peaks of sediment transfer to coastal waters. As these sediments are reworked by waves and currents, they can bring about large short-term changes in coastline.

Sea transport is of such importance for the coastal population centres of PNG and the Solomon Islands that there are many examples of small-scale, sometimes improvised, coastal infrastructure development. Local coastal dynamics often are not closely studied, nor is local knowledge used in siting decisions or infrastructure design. In some cases the result is that a port structure is damaged by wave action or scouring, or its function impaired by sediment accumulation.

Most urban ports have undergone significant development involving foreshore reclamation, and channel dredging. Many PNG coastal villages have landing facilities for small, drop-front freighters (landing craft). A small area of reclamation may be involved, though more commonly the freighter offloads directly on to the foreshore. Larger reclamation projects for log and agricultural produce loading facilities are also widespread. These rural "port facilities" are usually very basic. At a few locations modern loading facilities have been developed for mines. With the exception of the mine project ports, there is minimal environmental management of this port development, but it affects only a small fraction of the coastline.

HUMAN IMPACTS ON COASTAL SEAS

Village-level Impacts

Corals and beach sand are widely used as building materials in the Polynesian Pacific Island nations, but this practice is not widespread in PNG and the Solomons. More common is the use of mangroves for building materials and firewood, and the clearing of mangroves for housing sites. Considerable areas of mangrove have been deforested in this way near urban areas, but the greater impact on mangrove habitat has been from clearance alongside coconut plantations in the mistaken belief that this is necessary for the health of coconuts (Baines, pers. obs). Mangrove deforestation has also occurred where mangrove fuel is used for drying bêche-de-mer or copra (Huber, Baines, pers. obs.; Leary, 1993a). Removal of mangroves has led to coastal erosion (e.g., Hughes et al., 1986) and to loss of important fisheries habitat which mangroves provide.

Though the ecological conditions required for small-scale aquaculture are present, the social requirement for sustained effort is not. A generally satisfactory supply of wild stock removes much of the incentive for aquaculture for subsistence or small-scale commerce. Small-scale aquaculture has been conducted on a trial basis in north Guadalcanal. Here, villagers grow out giant clams for the aquarium trade from spat produced at the nearby ICLARM coastal aquaculture facility, which is also investigating the suitability of pearl oysters, sea cucumbers, and other species for village-level aquaculture enterprises. Various industrial-scale aquaculture enterprises have been established but some have been short-lived. Those currently operating include two small penaeid prawn farms. Prospects for aquaculture remain promising, and a recent boost for this in the Solomon Islands has been a 1999 crop of high quality pearls harvested from a culture trial at Gizo.

In the Solomon Islands there are concerns about pesticide pollution in rural areas from spraying for malaria control (Convard, 1993; Leary, 1993a; Solomon Islands, 1992). The ecologically notorious chemical used (DDT) was introduced regularly into the coastal village environment over a forty year period in line with World Health Organization advice to the Solomon Islands Department of Health.

Industrial-scale Impacts

Mining in PNG is easily the largest industry in the area. The massive excavation of surface and/or subsurface material that accompanies mineral development poses a pollution threat to coastal waters. Baines and Morrison (1990) provide a dramatic example of this—the Bougainville copper mine. Until its closure in 1989 by the actions of militant customary landowners, for 18 years the mine discharged 150,000 tonnes of tailings a day into the Jaba River, and from there into Empress Augusta Bay. In the Jaba River valley, the sediments built up to a depth of 27 m, spread out across the valley floor. These sediments are reported by Brodie et al. (1990) to have created a 7 km^2 delta and affected more than 100 km^2 of sea floor. An open cut gold mine on the island of Misima for 20 years has discharged tailings directly into the sea at a depth of 75–100 m on the outer edge of a fringing coral reef. In addition, some 20,000 tonnes of soft waste rock have been tipped daily into the sea. This ocean outfall was positioned below the thermocline, the objective being to minimise chances of sediment-laden water rising to the surface, where its ecological effects would have been more damaging. An ocean outfall of similar design is in use at another island mine developed later at Lihir. Both mines were subject to environmental assessment prior to mining. Following on the disastrous Bougainville example, mining industry interest in establishing acceptable environmental practice has resulted in assessments which are among the best undertaken in the Pacific island region, with most impacts being predicted, and addressed. Environmental monitoring has been conducted at both mines. An independent assessment of the impacts of these discharges would be valuable as more coastal mines are expected to open.

Environmental aspects of the one and only mine in the Solomon Islands—at Gold Ridge, Guadalcanal, have been independently assessed. Its waste is contained in storage areas which in 1999 attracted an Australian mining industry award for excellence in tailings dam design. This mine has been described as "a model for future development of a responsible mining industry in the South Pacific region." (Islands Business 25 (7), 18. July 1999).

In both PNG and the Solomon Islands the manufacturing base is small. Convard (1993) estimated marine contaminant loadings from major agricultural and food processing industries including palm and coconut oil milling, sugar refining, brewing, soft drink manufacture, and meat and fish processing (Table 7). Other small industries, such as paint manufacturing, metal plating and fabrication, and vehicle and ship repair, also generate marine contamination of unknown quality and quantity (Convard, 1993). Various proposals for new canneries, oil and mineral refineries, and other coastal industrial infrastructure have been prepared. Only a few of these are expected to materialise. The contaminant loads in Table 7 are low in terms of average coastal loadings, especially in PNG, but of course are concentrated near discharges. There have been cases of serious localised pollution from fish canneries, oil palm mills, and other industries, especially when discharges are located in waters with restricted circulation (Convard, 1993; Huber, 1994; Solomon Islands, 1992). There is no routine water quality or other pollution monitoring, however, and the status of the problem is not known.

There is no mass tourism. Both countries have a small tourism industry and there is some focus on marine tourism—small island and beach resorts and guest houses, and live-aboard dive vessels. A few cruise ships also visit. At present levels tourism does not appear to have major environmental impacts. There is considerable potential for expansion of tourism, and this prospect has given rise to concerns that adverse impacts on coastal ecosystems may result. At the same time, there is hope that tourism-focused attention to natural attractions may help deflect coastal developments that would otherwise damage the coastal environment and its resources.

The Impacts of Large Urban Areas

Rapid population growth and poor urban planning, especially in Port Moresby, Lae, and Honiara, have clearly had significant adverse impacts on the surrounding coastal areas. These include overfishing, soil erosion and other

Table 7

Estimated waste loads (mt/yr) on the marine environment in Papua New Guinea (PNG) and Solomon Islands (SI) (from Convard, 1993)

Source	Country	BOD	SS	Oil and grease*	N	P
Domestic wastewater	PNG	5666	2425	-	3107	374
	SI	2137	1763	-	979	139
Industrial wastewater (selected industries	PNG	509	1083	765	0	0
	SI	513.6	494.8	560.8	18.7	0.1

*Loads of oil and grease from domestic wastewater not available.

consequences of intensified agriculture, and deforestation. Part of the problem arises from the fact that many urban dwellers live in unserviced squatter settlements. They retain aspects of the rural lifestyle that do not suit urban areas, such as partial dependence on subsistence and market gardening, the use of wood as a cooking fuel, and direct disposal of human wastes to the sea.

Domestic sewage is the largest urban source of marine contamination. The population is not well served with sanitary services (Table 7). Convard's (1993) data for PNG contain obvious errors (e.g., the population of Lae is reported as only 33,000, entirely served by sewerage, while Madang's population is reported at over 90,000) and overestimate the provision of sanitary services. Simple bush or over-the-water latrines are not uncommon in urban areas of PNG, and in rural areas are the norm. Even where septic or reticulated sewerage systems are available, they are often poorly designed, maintained, and operated. Except in Port Moresby, where much of the sewage is treated by settlement in a natural swamp, primary treatment, where it exists, usually consists only of screening. Secondary treatment is confined to oxidation ponds serving some of the populations of Lae, Popondetta, and a few hospital and other facilities (Waterboard of PNG files). A few other hospitals have packaged secondary treatment plants. There is no systematic monitoring of water quality, much less environmental or human health impacts, but microbiological contamination and other evidence of sewage pollution has been reported in both urban and rural areas (Moore, 1982; Naidu et al., 1991; Waterboard of PNG, 1987).

Solid waste disposal is a persistent problem. In both urban and rural areas household waste may be dumped directly into watercourses or the sea, and rubbish dumps are often located in mangrove or other foreshore areas, or near watercourses. There are no waste management provisions to prevent leaching. While this problem has not been assessed in PNG or the Solomon Islands, coastal heavy metal and other pollution has been observed near waste dumps in other Pacific island countries (Naidu et al., 1991).

Fisheries

There are few industrial fisheries in coastal areas. A small trawl fishery in Orangerie Bay, Milne Bay Province, produces around 20 mt/yr of prawns, mostly banana prawn (*Penaeus merguiensis*). The fishery is considered fully exploited and access is limited to two small (15 m) vessels. Other PNG industrial fisheries, in the Gulf of Papua and in Torres Strait, are discussed by Huber (this volume).

The main inshore industrial fishery in the Solomon Islands is a bait fishery conducted at several locations by the pole-and-line tuna fleet, harvesting some 2000 mt annually, mostly of anchovies (*Stolephorus*) and sprats (*Spratelloides*). Based on limited data this appears to be around the maximum sustainable yield. Fishing grounds are rotated as catches decline (Tiroba, 1993). Concerns have been expressed about possible adverse trophic and by-catch effects of the bait fishery on subsistence fisheries. Blaber et al. (1990) concluded that the species most likely to be affected are nearshore pelagics caught primarily by trolling. Trolling is a relatively minor method in the subsistence fishery (Blaber et al., 1990; Leqata et al., 1990). So long as this remains the case baitfish harvests are not expected to adversely affect local catches. However, should increasing wealth in local communities bring about an increase in the use of fishing techniques targeting nearshore pelagic species, there is a possibility that a classic industrial–subsistence fisheries clash could develop.

There is potential for small-scale industrial development of a few other coastal wild fisheries, but little development activity. Studies and pilot projects are underway regarding the culture of pearl oysters, bêche-de-mer, and tridacnid clams.

In both PNG and Solomons an unsustainable form of live reef food fish trade has been introduced. This focuses on the capture of a few species of grouper, wrasse, stonefish, and spiny lobster for transport, live, to Hong Kong, China, Taiwan and other Asian markets, where they command very high prices in the restaurant trade. Overfishing, the targeting of spawning aggregations, the use of cyanide and other poisons, physical disruption of the reef matrix to extract fish, and high mortality of both target species and by-catch are typical in this trade (Aini and Hair, 1995; Johannes and Riepen, 1995; Johannes and Lam, 1999; Richards, 1993). To date, most operations have been short-lived, often because of rapid resource depletion, withdrawal of harvest approvals by customary reef owners concerned about the adverse environmental consequences, or dissatisfied with benefits they derive from the operations, or breaches of licensing conditions. With its poor environmental track record, high profitability, and the prospect of market expansion in southern Asia, this trade continues to pose a threat to the reef ecosystems of the Coral, Bismarck, and Solomon Seas. National capacity to contain and manage the threat is low.

Shipping and Offshore Accidents and Impacts

There are no port reception facilities for solid or oily wastes in either PNG (Envision, 1993) or the Solomon Islands. Ship-based sewage is, at best, discharged into municipal systems. Pollution controls are not enforced and pollution from ships in harbours and in passage is common. The extent of the problem has not been quantified.

Though reef groundings of ships are not unusual there is no systematic reporting of such accidents. Neither are there procedures for assessing or addressing threats of physical damage to habitats or pollution from this cause.

Concern has been expressed in the Solomon Islands about prodigious quantities of bunker oil which lie in the deteriorating fuel tanks of battleships, cruisers and

numerous smaller warships sunk in deep water close to the coast of Guadalcanal during World War II. While gradual seepage over the years appears not to have had significant environmental effects, this legacy of war could become a marine environmental issue for the new millennium if these corroding tanks were to rupture.

Both PNG and the Solomon Islands have addressed the need for oil spill contingency planning, and PNG has a national plan, and practical procedures, developed in close consultation with the petroleum industry. Yet very little oil spill control equipment is in place, and only limited training has been carried out. Plan implementation relies heavily on support from nearby countries, notably Australia.

PROVISIONS FOR THE MANAGEMENT AND PROTECTION OF COASTAL SEAS

National Administrative and Legal Arrangements

The relatively healthy coastal environments of PNG and the Solomon Islands reflect low development and population pressures rather than effective environmental management. When industrial and urban development has taken place, environmental problems have followed.

Environmental protection and sustainable resource use are enshrined as one of the national goals of PNG's constitution. This is supported by generally adequate environmental legislation (Hedemark and Sekhran, 1994). However, implementation of PNG's innovative environmental legislation has been very weak. The Solomon Islands has less comprehensive legislation than PNG but here, too, it is of limited effectiveness because implementation is hindered by the inadequate number and experience of enforcement officials and by a limited general awareness of the legislation and of the rationale for it.

Table 8

Participation in Selected Conventions. ✓ indicates party to the convention. (Source: CIA, 1998 and World Wide Web pages of administering agencies of some agreements.)

	Papua New Guinea	Solomon Islands
MARPOL	✓	
London Dumping	✓	✓
Civil Liability for Oil Pollution	✓	
Basel (Hazardous Wastes)	✓	
Law of the Sea	✓	✓
CITES (Trade in Endangered Species)	✓	
Ramsar (Wetlands)	✓	
Climate Change	✓	✓
Montreal Protocol (Ozone Layer)	✓	✓
Biodiversity	✓	✓
Straddling and Migratory Fish Stocks		✓
Apia (Conservation in the South Pacific)	✓	✓
SPREP (South Pacific Environment Programme)	✓	✓

PNG has at times been prominent on the international stage in advocating and making commitments to environmental management initiatives. However, in the absence of the required political support, and in the face of a heavy economic development emphasis on resource extraction with minimal control, it has not been possible to sustain these initiatives at home. Those advocating a more responsible approach to management of the coastal environment in the Solomon Islands have faced similar pressures. A useful participative multisectoral National Environmental Management Strategy (Solomon Islands, 1992, 1993) has been prepared. However, it has not been possible to translate this into effective action. As parties to relevant international conventions (Table 8) both countries have entered into important commitments to protect and manage the shared regional marine environment. Yet neither country has been able to demonstrate that its good international intentions can be translated into rigorous attention to growing marine environmental problems within national boundaries.

Protected Species, Habitats and Areas

Some marine protected areas have been formally established in this region, mostly in PNG. However, in line with the general deficiency in support for environmental management activities, few have any form of management regime. A major problem has been the approach to protected area identification and management, which has been "top-down ", driven by conservation criteria which are often not appreciated by those who have long-established customary rights to access and harvest those areas. Much of the consultation by protected area proponents with local communities has been on the basis of persuasion rather than participation, making local communities feel the protective regime is being imposed on them. Lessons have been learned. For instance, a late 1970's effort to establish a marine sanctuary focused on marine turtle habitat at the Arnarvon Islands, Santa Isabel, Solomon Islands, failed dramatically with the destruction of infrastructure and equipment by a group claiming to have customary rights to the area and resentful that they had no role in the exercise. A new project established in the 1990s after extensive consultation with all groups with a history of access and use rights, and continuing that consultation throughout, appears to have been successful. PNG legislation provides for local communities to establish and manage Wildlife Management Areas (WMAs). Some of the WMAs declared have the objective of protecting marine species such as turtles and dugong. The concept is sound. Yet most WMAs have not succeeded, because the prevailing political lack of enthusiasm for conservation means that the Department of Environment and Conservation has not been funded to support the WMA trustees with the technical and financial support they need. In late 1999 the Department of

Environment and Conservation was downgraded to the status of an "Office", with an attendant loss of Cabinet status and a dramatic reduction in already low levels of funding and staffing.

Responding to signs of depletion of coastal fisheries stocks, the two countries have introduced a range of fisheries management measures including closed areas and seasons, minimum sizes, licensing of fishers and traders, restriction of certain areas and/or stocks to domestic participants, harvest quotas and moratoria, and export bans on certain species. Though the National Fisheries Authority of PNG has developed management plans for several commercial stocks, a great deal more surveying and planning is needed.

Because of their multispecies nature, what seems to be the inherent vulnerability of some stocks (for instance, sedentary species), and a limited scientific understanding of them, tropical fisheries are notoriously difficult to manage even in developed countries. Given the limited capacities of management authorities, and the eagerness of some outside interests to exploit these limitations, prospects for sustainable coastal fisheries management in PNG and the Solomon Islands are uncertain.

Regional Cooperation

In light of the limited capacity for sustainable development and environmental management, not only in PNG and the Solomon Islands but throughout the South Pacific, several regional organisations have been established to assist with technical support, information exchange, and capacity building. These include the South Pacific Environmental Programme (SPREP), the South Pacific Community (SPC, formerly known as the South Pacific Commission), the South Pacific Forum Fisheries Agency (FFA), the South Pacific Applied Geoscience Commission (SOPAC), and the University of the South Pacific (USP), in particular its Institute of Marine Resources (IMR). A variety of international aid and non-governmental organisations have undertaken sustainable development and conservation projects in the area and some of these initiatives, too, are regional.

Community-based Management

It is no surprise that a western-style, "top-down" approach to resource management and conservation has been ineffective. Self-management of coastal marine areas has long been carried out by small kinship-based groups living in villages. The first attempt at centralised administration in PNG and the Solomon Islands was barely 100 years ago and only gradually, over decades, took hold. The concept of nation is still being developed among disparate communities who speak many languages—it is estimated that about 700 distinct languages are spoken in PNG, and 65 in the Solomon Islands. Most languages also have dialect variations. As declining funding increasingly compromises the national governments' capacity to undertake, or even to oversee, resource management in rural areas—despite the existence of provincial governments established to address local needs—so, management responsibilities revert to those who held them before. However, this is by default, not by plan, and so is not happening smoothly or efficiently.

Though Government fisheries agencies have attempted to enforce "modern" fisheries management systems, these have been largely unsuccessful. The coastal resources and ecosystems in PNG and the Solomons are dispersed over a vast, remote area with poor transportation and communication infrastructure. The financial, technical, and human resources required to centrally manage them far exceed those that could ever be made available to the relevant agencies. More importantly, government-imposed management measures have not been widely accepted among rural communities. Evidence of this emerges from the discussion, above, on artisanal fisheries. Fisheries policy makers are coming to realise that these problems are best addressed by community-based initiatives that incorporate traditional management systems. In PNG and the Solomon Islands the best approach to coastal fisheries management is for governments to provide the legal and administrative framework to support traditional management systems (Baines, 1995). Though a new Solomon Islands Fisheries Act, 1998 makes provision for this, PNG missed an opportunity to incorporate appropriate provisions in its most recent Fisheries legislation.

An examination of traditional coastal area management systems is revealing. As Johannes (1978) has pointed out, there are many parallels with modern fisheries management. Taboos that prohibit harvests in certain places, at certain times, or by certain people, are analogous to area or seasonal closures, or limited entry. Customary marine tenure has been described as a form of "limited entry". In most areas traditional systems continue to operate, though they have been weakened by the centralisation of power, which has had the effect of undermining local-level leadership. Increasing economic pressures on fishers to exploit their resources at a commercial scale, together with the pressures of rapid population growth, also threaten the integrity of traditional coastal-area management systems. Further, rural communities are profoundly disadvantaged in dealing with external pressures, as in negotiations with proponents of commercial fishing enterprises in their areas. The practicalities of one of these systems, the stresses on it, and the adaptations it has successfully made, are described for Marovo, Solomon Islands by Hviding and Baines (1994).

Traditional management systems are common and widespread in the region, though it has not been established that they are ubiquitous. Some have questioned their effectiveness (Aswani, 1998; Polunin, 1984; Swadling, 1982). They do not, in their present form, guarantee sustainable resource management in the modern context, a point made by Adams (1998), Baines (1989), Johannes (1978), and

others. Nevertheless, there is growing consensus that, since local communities organised on socially meaningful lines are "on site", have extensive knowledge of local ecology and conditions, and have a vested interest in sustainability, the best management option is government support and empowerment of communities to manage their own resources (Adams, 1998; Dalzell et al., 1996; Hviding and Baines (1994)).

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