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ORIGINAL PAPER

# Wetlands of the Pacific Island region

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**Abstract** The wetlands of 21 countries and territories of the Pacific Islands region are reviewed: American Samoa, Cook Islands, Federated States of Micronesia, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Nauru, New Caledonia, Niue, Northern Mariana Islands, Palau, Papua New Guinea, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu, and Wallis and Futuna. The regions' wetlands are classified into seven systems: coral reefs, seagrass beds, mangrove swamps, riverine, lacustrine, freshwater swamp forests and marshes. The diversity of species in each of these groups is at near global maxima at the west of the region, with decline towards the east with increasing isolation, and decreasing island size and age. The community structure is unique in each country, and many have endemic species with the habitat isolation that epitomises this island region. There remain, however, some serious gaps in basic inventory, particularly in freshwater biodiversity. Threats to wetlands include introduced freshwater species, loss of wetlands adjacent to urban growth, downstream effects of mining and land clearance, and over-use of mangrove, seagrass and coral reef resources by predominant subsistence economies that remain in this region. Only five countries are signatories to the Ramsar convention on wetlands, and this only recently with seven sites. Wetland managers have identified the need for community education, baseline surveys and monitoring, better legislation and policy for wetland management, and improved capacity of local communities to allow the wise use of their wetlands.

**Keywords** Oceania · Wetland · Pacific Islands · Seagrass · Mangrove · Coral reef · River · Lake · Freshwater swamp · Marsh

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## Introduction

The Pacific Islands region (Fig. 1) while comprising almost 38.5 million km$^2$, supports less than 0.6 million km$^2$ of land. In contrast to the small land area the maritime area under national jurisdictions is vast, estimated at 30.6 million km$^2$, equivalent to 30% of the world's declared exclusive economic zones (Wright et al. 2006). Of the land, 83% is in Papua New Guinea (PNG), and most of the rest is in the other larger Melanesian Islands, with islands generally declining in size from west to east across the region. There are approximately 200 high islands (volcanic, some also with raised limestone) and 2,500 low islands and atolls (low limestone or organic origin), harbouring a diverse range of freshwater, coastal and marine wetlands.

The wetlands of the Pacific Island region have not been reviewed before. In the first Wetlands of the World series, Osborne (1993) described the environmental settings and status of wetlands in Papua New Guinea, and a regional inventory was compiled by Scott (1993). This review brings together an analysis of regional trends in wetland settings, biodiversity, ecology and management. Of the Pacific Islands countries and territories (Fig. 1, Table 1), all are members of the Secretariat of the Pacific Regional Environment Programme (SPREP) apart from Pitcairn, a dependency of the UK.

In this review, wetlands are defined by the Ramsar Convention on Wetlands as “areas of marsh, fen, peatland or water, whether natural or artificial, permanent of temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres” (Article 1.1 of the Convention text; Davis 1994). Shallow marine wetlands tend to fall into biome groupings such as coral reefs, mangroves, seagrasses, while the primary classification of inland wetland types is by geomorphic setting and hydro-period (Semeniuk and Semeniuk 1997). The region is microtidal, so coastal wetland depths extend to around 7 m below MSL.

Under the regionalisation scheme of the Ramsar convention, eight terrestrial biogeographic realms of the world are recognised in many biogeogeographic studies (Millennium Ecosystem Assessment 2005). The Oceania region includes the Pacific Island region of this review, as well as West Papua and New Zealand, but excludes Australia. This review focuses on the SPREP region members while excluding the biogeographically associated Hawaii and New Zealand wetlands. This is because those are developed countries with resources dedicated to wetland research and management that would eclipse the 21 SPREP countries and territories, and the purpose of this review is to synthesise available information for the benefit of wetland research and management in this under developed region.

## Geographical setting

The divergent plate boundary of the East Pacific Rise lies to the east of the SPREP region and is the

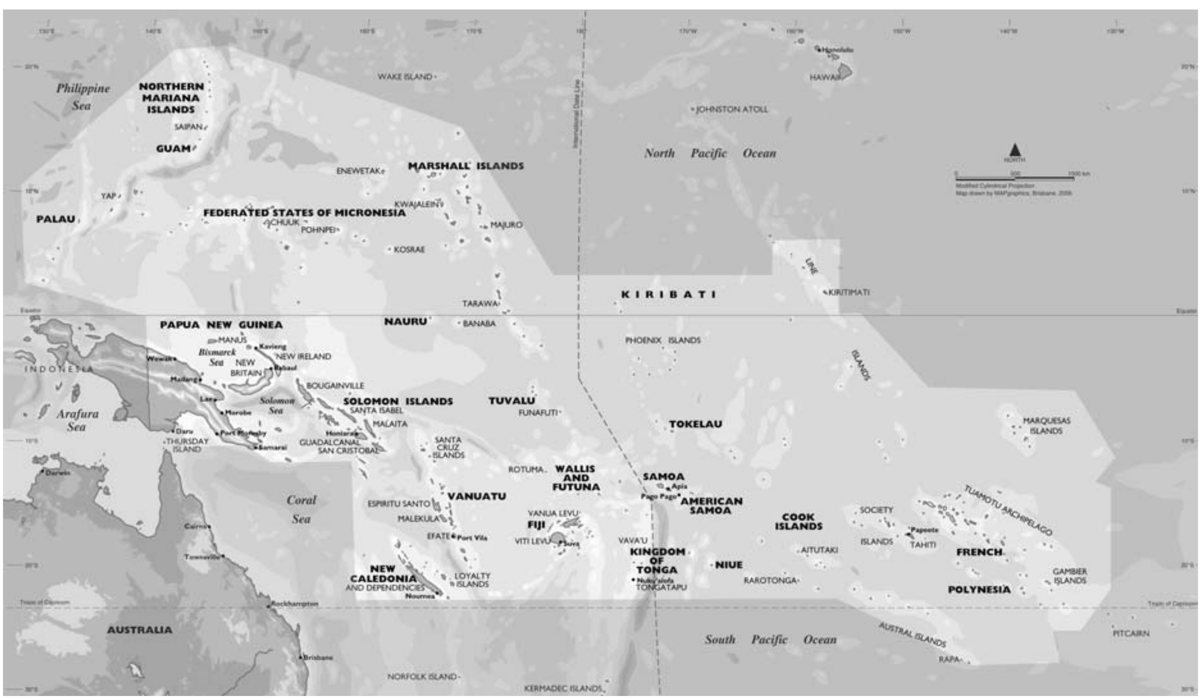


Fig. 1 Map of the SPREP region (adapted a MAPgraphics map drawn for SPREP)

**Table 1** Countries and territories of the SPREP region, ordered by longitude

| Country | EEZ area ($km^2$) | Land area ($km^2$) | Islands | Island type | Population (2005–2006) | Government |
|---|---|---|---|---|---|---|
| Palau | 600,300 | 488 | >300 | High + limestone | 20,600 | Independent; in free association with the US |
| Papua New Guinea | 3,120,000 | 462,243 | | High | 5,620,000 | Independent; member of UK Commonwealth |
| Northern Mariana Islands | 777,000 | 471 | 14 | High | 84,487 | Commonwealth in political union with the US |
| Guam | 218,000 | 541 | 1 | Uplifted ophiolite | 167,371 | Unincorporated territory of the US |
| Federated States of Micronesia | 2,980,000 | 701 | 607 | High + limestone + atolls | 110,218 | Independent; in free association with the US |
| Solomon Islands | 1,630,000 | 28,300 | 347 | High | 487,237 | Independent; member of UK Commonwealth |
| New Caledonia | 1,740,000 | 18,576 | | High | 238,035 | Territory of France |
| Vanuatu | 680,000 | 12,189 | 84 | High | 221,417 | Republic; member of UK Commonwealth |
| Nauru | 436,490 | 21.2 | 1 | Limestone | 10,131 | Independent |
| Marshall Islands | 2,131,000 | 181 | 607 | Atolls | 56,242 | Constitutional government in free association with the US |
| Tuvalu | 757,000 | 25.9 | 9 | Atoll | 9,652 | Independent |
| Fiji | 1,260,000 | 18,333 | 607 | High | 110,218 | Independent republic |
| Wallis and Futuna | 300,000 | 255 | 23 | High | 15,260 | Territory of France |
| Tonga | 700,000 | 649 | 171 | Limestone + high | 99,298 | Independent |
| Kiribati | 3,600,000 | 811 | 33 | Atolls | 93,706 | Republic |
| Tokelau | 290,000 | 12.1 | 3 atolls | Atolls | 1,152 | Territory of New Zealand |
| Samoa | 120,000 | 2,935 | 10 | High | 185,000 | Independent |
| American Samoa | 390,000 | 199 | 7 | High | 66,000 | US territory |
| Niue | 390,000 | 259 | 1 | Limestone | 1,679 | Self-governing; in free assoc. with NZ |
| Cook Islands | 1,830,000 | 237 | 15 | High + atolls | 20,200 | Self-governing; in free assoc. with NZ |
| French Polynesia | 5,030,000 | 3,521 | >118 | High | 258,709 | Territory of France |

High islands are volcanic or eroding volcanic/raised limestone assemblages

*Sources*: Falkland (2002), Wright et al. (2006), Pacific Magazine (2007)

formative source of the Pacific tectonic plate. Moving to the west-north-west, the plate passes over a number of hot spots causing the eastern Pacific volcanic island chains of Hawaii, Pitcairn, French Polynesia, and the Cook Islands, and island chains further to the west such as the Samoas are also volcanic hotspot remnants.

The Pacific plate meets and mostly subducts beneath the Australian plate to the east of the main islands of Tonga, Fiji and Vanuatu and north of the Solomons and Papua New Guinea. This margin is important in biogeography as to the east all islands are arisen through the ocean, where as to the west some larger islands are migrated Gondwanan fragments. This has a great influence on species biodiversity, with true islands being low in species, with those there are adapted to long distance oceanic migration.

New Guinea was joined to Australia during the sea-level lowstand until 12,000 years ago, while the rest of the islands in the region have been separate for much longer periods. The three geologically old, large islands of New Guinea, New Caledonia and Viti Levu form three generally accepted biogeographic sub regions in the Pacific Islands, from which species migrated to other islands (Thorne 1963). Southern New Guinea and New Caledonia are Gondwanan fragments, while the larger Fijian Islands were formed from uplifted crust over 40 million years ago. However, many islands to the west of the plate margin are also oceanic, particularly volcanic high islands and those formed by uplifting. The latter tend to be more flat-topped, favouring wetland development.

While volcanic islands can host crater lakes and river catchments, as they start to erode and submerge, then coastal plains, mangroves and freshwater swamps are likely to develop. Fringing reefs become barrier reefs with further island submergence, increasing habitat variety in reef environments and introducing lagoons and seagrass habitats. Further subsidence leads to atoll development, losing all freshwater wetlands but increasing reef and lagoon wetlands. Island types, geological ages and presence or absence of running water for many Pacific Islands are summarised by Resh and De Szalay (1995) and Craig et al. (2001).

The patterns of biological diversity of corals, mangroves, reef fish and seagrasses of the Pacific region result from their biogeographic history (Hadac 1976; Springer 1982; Kohn 1982). The Indo-Malayan archipelago to the west of the region is the centre of greatest species diversity for all four groups, where they first appeared in the Tethys Sea at equatorial latitudes. Species richness declines from this centre towards the east.

The climate instrumental record for the Pacific Island region is notable for its relative shortness and poor geographical coverage (Hay 2000). Improved climate data gathering in the region is the intention of the Pacific Islands Global Climate Observing System (PI-GCOS), involving the US, Australia, New Zealand and the Pacific Island countries (World Meteorological Organization 2000).

The El Nino Southern Oscillation (ENSO) is one of the major sources of climate variability on the 2–5 year timescale, particularly affecting winds and precipitation. During ENSOs the central and eastern Pacific Island region tends to experience increased rainfall, while the western area receives reduced rainfall. As most Pacific Islands are to the west, ENSOs cause droughts with a virtual absence of precipitation for periods of several months to a year (Meehl 1996; Rasbury and Aharon 2006). For example during the 1997–1998 ENSO, water levels in a Micronesian freshwater wetland dropped up to 0.5 m for 6 months (Drexler and Ewel 2001). Flowering and propagule setting of Rhizophoraceae was significantly reduced in Fiji in the drought year of 1998 relative to the non-drought year of 1997 (Tyagi 2004).

Climate patterns across the region are demonstrated in Fig. 2. The region is tropical, and islands within 10° of the equator experience mean annual temperatures of 27–30°C. Wetlands are most extensively developed in the western Pacific (i.e. PNG/Solomons/southern Micronesia) with annual rainfall of 2,000–4,000 mm and no dry season. In the eastern Pacific (i.e. Marquesas), the annual rainfall is below 2,000 mm. In the North Pacific, Yap and islands further north (Guam, Marianas and the Northern Marshalls) each have lower rainfall with a distinct winter dry season. South of 10°C latitude, islands are influenced mainly by the SE Trades, showing a distinct summer wet season, and strong orographic influences on rainfall distributions across higher islands. With increasing latitude towards the Tropic of Capricorn there is a distinct cooler season, pulling mean annual temperatures down to c. 23°C in New Caledonia, Southern Tonga, the Southern Cook Islands and the Tuamotus. At these locations a summer rainy season is also the pattern, with mean annual rainfalls generally of 1,000–2,000 mm. Tropical cyclones/typhoons/hurricanes occur in the subequatorial tropics between 10° and 25° latitude, when ocean surface temperatures are warm. They can cause catastrophic structural damage to wetlands, combined with flooding.

Indigenous people arrived in the Pacific Island region from the west, with New Guinea settled significantly earlier than the rest of the region at least 60,000 years before present (BP). Expansion to the northern islands of PNG and the Solomons occurred during the last glacial sea-level lowstand 29–33,000 years BP (Steadman 2006). The rest of the region was settled as a result of the expansion of the Lapita Cultural Complex from island SE Asia (Taiwan, Philippines, and Greater Sundas through the Moluccas) from 3,500 years BP, reaching Vanuatu, New Caledonia, Fiji, and Samoa 3,000–2,800 years BP (White and Allen 1980; Kirch 1997). The northern island groups of the region were settled at about the same time (Steadman 2006), and the eastern groups such as the Cook Islands shortly afterwards (Ellison 1994a).

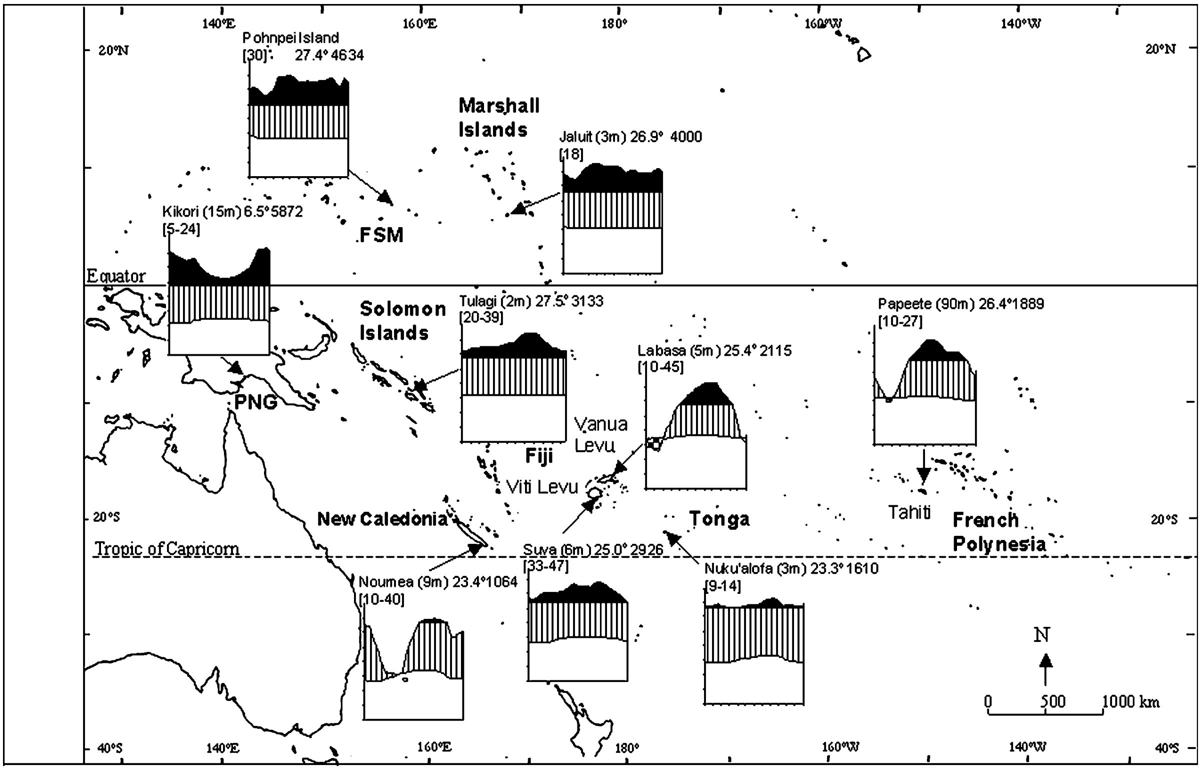


**Fig. 2** Representative climate diagrams from the Pacific region (using data from Walter et al. 1975). Each diagram is labelled with its location, elevation above sea level (m), number of years from which the data is derived (in square brackets, if two numbers then the first is for temperature and the second for rainfall); mean annual temperature (°C) and mean annual rainfall (mm). The x-axis is month where north of the equator (Pohnpei and Jaluit) these start with January while south of the equator these start with July, for easy comparison of the seasonal trends. Plots simultaneously illustrate mean monthly temperature (tick intervals = 10°C) and rainfall (tick intervals = 200 mm). Dotted fields indicate periods of relative drought (ratio of temperature to precipitation >1:2), which only significantly occur in this region at leeward stations on high islands such as Labasa

## Wetland inventory

The status of wetland inventories in the Oceania region was assessed by Watkins (1999), focussing on their capability to provide baseline information for consideration of wetland conservation or loss. The Pacific Island region overall is lacking in information and baseline assessment.

The Directory of Wetlands in Oceania (Scott 1993) was not designed to yield information on the extent and distribution of wetland types, rather focussed on the larger wetlands and reviewing the fragmentary knowledge available (Watkins 1999). The Directory has been recognised as needing revision (Watkins 1999; SPREP 2005) and this is currently underway, with an initial focus on Fiji, the Marshall Islands, New Caledonia and Samoa.

While adoption of the Ramsar Convention has been limited in the Pacific Island region relative to elsewhere in the world, this review follows Ellison (2004) in using the Ramsar classification of wetlands to include in this region shallow marine, inter-tidal, riverine, lacustrine and palustrine wetland systems.

## Wetland types and species distributions

### Coral reefs

Coral reefs are the most extensive wetland type in the Pacific Island region, occurring offshore of nearly all coastlines that lack significant river discharge. New Caledonia has coral reefs of around 24,000 km$^2$, including the second largest barrier reef in the world surrounding the main island, and enclosing a lagoon of 16,000 $km^2$ (Zann and Vuki 2000). PNG has 40,000 $km^2$ of coral reef, and some countries in Micronesia and Polynesia are almost entirely composed of coral atolls. There are 13,000 $km^2$ coral reefs in just the countries east of Samoa (Vieux et al. 2004), compared with 6,000 $km^2$ of land. Coral reef locations and relationships with other wetlands on high islands and coral atolls are shown in Figs. 3 and 4. Coral reefs in some countries are limited because there are only fringing reefs close to shore, such as Samoa, American Samoa and Nauru.

The diversity of reef—building coral genera in the equatorial western Pacific is close to the highest in the world. Diversity declines to the north and the south with cooler temperatures, and declines from west to east across the Pacific with increasing distance from this centre of coral reef evolution (Veron 1995; Table 2).

The status of coral reefs in the Pacific Island Region is reviewed in Wilkinson (2004), and an expanded revision is near completion by the University of the South Pacific Institute of Marine Studies (C. Whippy-Morris, pers. comm.). American Samoan reefs are well studied and a detailed inventory available (US Army Corps of Engineers 1980). By contrast, Niue is situated on a relatively barren seamount, with a rugged shoreline, though with three distant reef systems which are little studied: Antiope, Harran's and Beveridge reefs (Lane 1994).

There are 179 families of shallow water fin-fish of the Indo-Pacific, which also decline in diversity from west to east (Springer 1982; Table 2). High diversity occurs in PNG with 149 families, declining to 125 in New Caledonia, 116 in Fiji, and 111 in total for islands on the Pacific Plate. Of these families, which include 461 genera and approximately 1,312 species, diversity continues to decline from west to east. There are 102 in the Samoas, 83 in the Cook Islands and 47 in French Polynesia. The nearshore shallow water gastropod genus (conch) has a similar decline in species numbers from west to east (Abbott 1960; Springer 1982; Table 2).

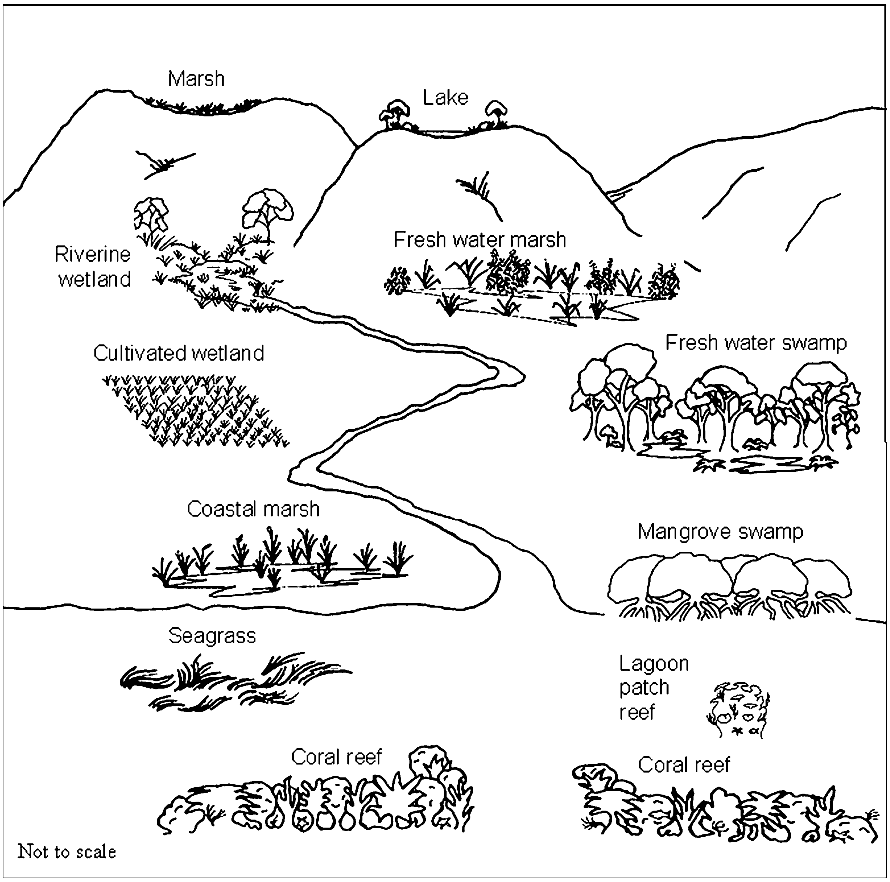


**Fig. 3** High island wetland settings of the Pacific Islands

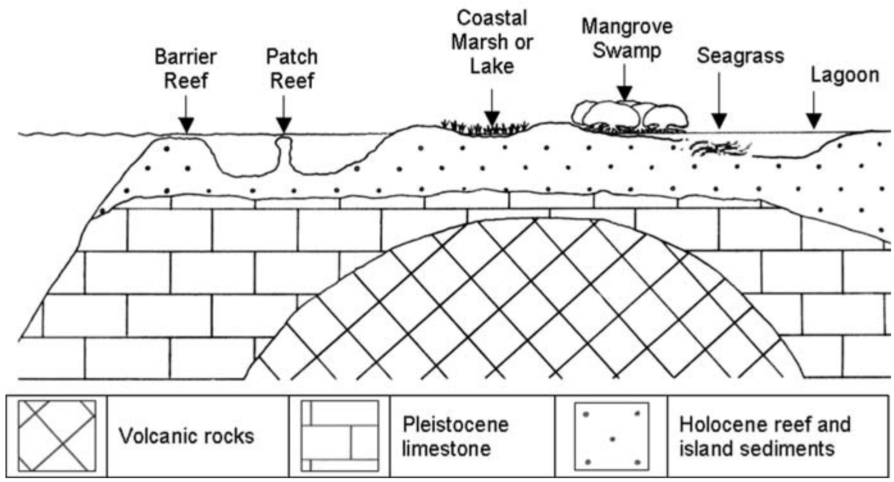


**Fig. 4** Low island wetland settings of the Pacific Islands

## Seagrass beds

Seagrasses occur mostly in shallow lagoons between coral reefs and shoreline mangroves in the Pacific Region (Figs. 3 and 4), with a close proximity and connectivity of all three wetland types typical of island shorelines. Seagrasses evolved from terrestrial grass species in the Cretaceous Tethys and spread into the Pacific and Atlantic, and today there are common genera in both. The centre of biodiversity for seagrass is Indonesia/New Guinea with up to 13 species (Mukai 1993), and Coles and Kuo (1995) identified 12 species of seagrass from the Pacific Islands. East from PNG two families and seven genera extend into the region, declining in diversity with distance (Mukai 1993).

Known distribution of seagrass species in the Pacific Islands are shown in Table 3. All the species have an Indo-Pacific distribution, except *H. ovalis ssp. bullosa* which is endemic to Fiji, Tonga and Samoa. Records of *Thalassia hemprichii*, *Cymodocea serrulata*, *Halophila minor*, and *Halophila ovata* previously credited to Fiji and Samoa are either erroneous or remain to be verified (Skelton and South 2006).

In the eastern Pacific, seagrass is absent from the Cook Islands and only one species is recorded from Moorea in French Polynesia (Mukai 1993). The fruits of most seagrass species are not buoyant, hence reducing their ability to disperse over long distances (Fortes 1988).

## Mangrove swamps

Mangroves occur on intertidal elevations of sheltered shorelines (Figs. 3 and 4), which are most extensive at sedimentary estuaries. In the Pacific Islands region the total mangrove area is about 5,975 km$^2$ (Table 2), with the largest areas in Papua New Guinea, Solomon Islands, Fiji and New Caledonia. The species mixture is unique in each country (Table 4), and the mangroves provide useful ecosystem services.

There are 31 species of mangroves and 5 hybrids in the region (Table 4). These are of the Indo-Malayan assemblage (with one exception) with highest global biodiversity in southern PNG, and decline in diversity from west to east across the Pacific, reaching a present limit at the Marshall Islands in the north and Samoa in the south, with an outlier in French Polynesia.

In New Caledonia, Fiji, Tonga and Samoa *Rhizophora samoensis* occurs, thought by some to be the same species as *R. mangle*, disjunct from its extensive ranges in America (Ellison 1991). This is the only mangrove species present in both the Indo-Malayan and American mangrove assemblages (Chapman 1975; Tomlinson 1986). In Fiji and New Caledonia *Rhizophora x selala* occurs, a hybrid between *R. samoensis* and *R. stylosa* (Tomlinson 1978). Why this does not also occur in Tonga and Samoa is unknown, possibly due to lack of appropriate estuarine habitats.

Past distributions of mangroves in the east Pacific have been shown to be far more extensive than at

**Table 2** Summary of the number of wetland species in the Pacific Islands (ordered by longitude), along with mangrove areas (ha) and coastal subsistence fisheries catch (t)

| | Coral genera | Shorefish families | Strombus species (conch) | Seagrasses species | Mangroves species (hybrids) | Mangrove area (ha) | Freshwater fish | Freshwater snail species | Amphibians and reptiles (incl terrestrial) | Annual coastal subsistence fisheries catch (t) |
|---|---|---|---|---|---|---|---|---|---|---|
| *North Pacific* | | | | | | | | | | |
| Palau | 70 | 158 | 14 | 8 | 14 (1) | 4,708 | 40 | | | 750 |
| Guam | 40 | 102 | 12 | 5 | 12 | 70 | | | | 472 |
| N Marianas | 40 | 102 | 12 | 5 | 3 | 7 | | | | 2,825 |
| FSM | 60 | 102 | 13 | 11 | 15 (1) | 8,564 | | 20 | | 6,243 |
| Marshall Is | 50 | 91 | 12 | 1 | 5 | 3? | | | | |
| *South Pacific* | | | | | | | | | | |
| PNG | 70 | 149 | 22 | 12 | 31 (2) | 464,000 | | | 472 | 20,588 |
| Solomon Is | 60 | | 20 | 9 | 17 (2) | 52,500 | 52 | 39 | | 10,000 |
| New Caledonia | 60 | 125 | 20 | 11 | 15 (3) | 20,250 | 85 | 39 | | 2,500 |
| Vanuatu | 60 | | | 12 | 14 (3) | 2,519 | 52 | 43 | 49 | 2,045 |
| Nauru | | | | | 2 | 1 | | | | 98 |
| Fiji | 60 | 116 | 14 | 6 | 7 (1) | 42,464 | 80 | 42 | 29 | 16,600 |
| Tonga | 40 | | | 4 | 7 | 1,305 | | | 20 | 933 |
| Samoa | 50 | 102 | 9 | 4 | 3 | 752 | 49 | 28 | 15 | 3,281 |
| American Samoa | 50 | 102 | 9 | 4 | 3 | 52 | 49 | 28 | 15 | 215 |
| Niue | | | | | 1 | 0 | | | | 2,000 |
| Wallis and Futuna | | | | | 0 | 0 | | | | 621 |
| Tuvalu | | | | 1 | 2 | 40 | | | | 807 |
| Kiribati | | | | 1 | 4 | 258 | | | | 9,084 |
| Cook Islands | 30 | 83 | | 0 | 0 | 0 | 10 | | | 858 |
| Tahiti/Moorea | 30 | 47 | 7 | 1 | 1 | ? | | 12 | | 3,691 |
| Marquesas | 10 | | 1 | 0 | 0 | 0 | | | | |

*Sources*: Abbott (1960), Springer (1982), Veron (1986, 1995), Ryan (1991), Dalzell et al. (1996), Coles and Kuo (1995), Allison (1996), Ellison (1999), Haynes (2001), and FAO (2003)

? means uncertain data

**Table 3** Distribution of seagrass species in the Pacific Islands (ordered by hemisphere, then longitude)

| **North Pacific** | *Enhalus acoroides* | *Thalassia hemprichii* | *Halophila decipiens* | *Halophila hawaiiana* | *Halophila minor* | *Halophila ovalis* | *Halophila ovalis ssp. bullosa* | *Halophila ovata* | *Halodule uninervis* | *Halodule pinifolia* | *Cymodocea serrulata* | *Cymodocea rotundata* | *Zostera capricorni* | *Syringodium isoetifolium* | *Thalassodendron ciliatum* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Palau | ■ | ■ | | | ■ | ■ | | | ■ | ■ | ■ | ■ | | ■ | ■ |
| Guam | ? | | | | | | | | ■ | | | | | | |
| N Marianas | ■ | | | | ■ | ■ | | | ■ | ■ | | | | | |
| FSM | ■ | ■ | | | ■ | ■ | | | ■ | ■ | ■ | ■ | | ■ | ■ |
| Marshalls | | ■ | | | | | | | | | | ■ | | | |
| **South Pacific** | | | | | | | | | | | | | | | |
| PNG | ■ | ■ | ■ | | ■ | ■ | | ■ | ■ | ■ | ■ | ■ | | ■ | ■ |
| Solomons | | ■ | ■ | | | | | | | | | | | ■ | ■ |
| New Caledonia | ■ | ■ | ■ | | ■ | ■ | | | ■ | ■ | ■ | ■ | | ■ | |
| Vanuatu | ■ | ■ | ■ | | ■ | ■ | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Nauru | ? | | | | | | | | | | | | | | |
| Fiji | | | ■ | | | ■ | ■ | | ■ | ■ | | | | ■ | |
| Tonga | | | | | | ■ | ■ | | ■ | | | | | ■ | |
| Samoa | | | | | | ■ | ■ | ■ | | | ■ | | | ■ | |
| Am Samoa | | | | | | ■ | ■ | | | | | | | ■ | |
| Niue | ? | | | | | | | | | | | | | | |
| Tuvalu | | ■ | | | | | | | | | | | | | |
| Kiribati | | ■ | | | | | | | | | | | | | |
| Cook Is | | | | | | | | | | | | | | | |
| French Polyn. | | | ■ | | | | | | | | | | | | |

? in the second column are countries/territories which lack seagrass records

*Sources*: Coles and Kuo (1995), Green and Short (2003), Walcott et al. (2004), and Skelton and South (2006)

present, Leopold (1969) recording *Rhizophora, Sonneratia, Avicennia* and *Scyiphora* pollen from the Miocene of Enewetok Atoll, Marshall Islands. All of these species have more restricted distributions today. In Miocene peat sediments on Viti Levu, Fiji, Ladd (1965) found pollen of *Sonneratia*, which today extends only east as far as Vanuatu. Leopold suggested that, at times, post-Miocene Enewetok was completely submerged, necessitating later recolonization by plants, which may explain the local extinction of *Rhizophora*.

Further evidence of more recent increased ranges of mangroves comes from Mangaia in the Cook Islands, where Ellison (1994a) found *Rhizophora* pollen (probably *R. stylosa*) for periods during the Holocene. These reached concentrations of 2,691 grains/cm$^3$ and occurred around 7,250, 5,000 and 2,000 years BP, while man did not arrive until 2,500 years BP. *Rhizophora* was not previously believed to be indigenous east of Samoa (Ellison 1991), and seems to have colonised the inner swamps of Mangaia through conduit caves. The loss of

**Table 4** Distribution of mangrove species in the Pacific Islands (ordered by hemisphere, then longitude)

| N. Pacific | *Herieira littoralis* | *Aegiceras corniculatum* | *Sonneratia alba* | *Sonneratia caseolaris* | *Sonneratia x gulngai* | *Osbornia octodonta* | *Lumnitzera littorea* | *Lumnitzera racemosa* | *Lumnitzera x rosea* | *Rhizophora apiculata* | *Rhizophora stylosa* | *Rhizophora x lamarkii* | *Rhizophora x neocaledonica* | *Rhizophora mucronata* | *Rhizophora samoensis* | *Rhizophora x selala* | *Bruguiera gymnorhiza* | *Bruguera parviflora* | *Bruguiera cylindrica* | *Ceriops tagal* | *Excoecaria agallocha* | *Xylocarpus granatum* | *Avicennia alba* | *Avicennia marina* | *Scyphiphora hyrophyllacea* | *Nypa fruticans* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Palau | ■ | | ■ | | | | ■ | | ■ | ■ | ■ | ■ | | ■ | | | ■ | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Guam | ■ | | | | | | ■ | ■ | ■ | ■ | ■ | | | | | | ■ | | | | ■ | ■ | | ■ | | ■ |
| N Marianas | | | | | | | | | | | ■ | | | | | | ■ | | | | ■ | | | | | |
| FSM | ■ | | ■ | | | | ■ | | ■ | ■ | ■ | ■ | | ■ | | | ■ | | | ■ | ■ | ■ | | ■ | ■ | ■ |
| Marshalls | | | ■ | | | | ■ | | | | ■ | | | | | | ■ | | | | | ■ | | | | |
| **South Pacific** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PNG* | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Solomons | ■ | ■ | ■ | ■ | ■ | ? | ■ | | | ■ | ■ | ■ | | ■ | | | ■ | ? | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| NCaledonia | ■ | | ■ | ■ | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | ■ | | | ■ | ■ | ■ | | ■ | ■ | |
| Vanuatu | ■ | | ■ | ■ | ■ | | ■ | | ■ | ■ | ■ | ■ | | ■ | | | ■ | ■ | | ■ | ■ | ■ | | ■ | | |
| Nauru | | | | | | | | | | | ■ | | | | | | ■ | | | | | | | | | |
| Fiji | ■ | | | | | | ■ | | | | ■ | | | | ■ | ■ | ■ | | | | ■ | ■ | | | | |
| Tonga | ■ | | | | | | ■ | | | | ■ | | | | ■ | | ■ | | | | ■ | ■ | | | | |
| Samoa | | | | | | | | | | | | | | | ■ | | ■ | | | | | ■ | | | | |
| Am Samoa | | | | | | | | | | | | | | | ■ | | ■ | | | | | ■ | | | | |
| Niue | | | | | | | | | | | | | | | | | | | | | ■ | | | | | |
| Tuvalu | | | | | | | ■ | | | | ■ | | | | | | | | | | | | | | | |
| Kiribati | | | ■ | | | | ■ | | | | ■ | | | | | | ■ | | | | | | | | | |
| Cook Is | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fr. Polyn | | | | | | | | | | | ■ | | | | | | | | | | | | | | | |

Older records that need confirmation are shown by ?. *PNG also has several species not found elsewhere in the Pacific Islands: *Aegialitis annulata, Camptostemon schultzii, Sonneratia ovata, Sonneratia lanceolata, Bruguiera exaristata, Bruguiera hainesii, Ceriops decandra, Avicennia officinalis, Avicennia rumphiana* and *Xylocarpus moluccensis*

*Sources*: Ellison (1995), Vander Velde and Vender Velde (2005), Duke (2006) and N. Duke pers. comm.

*Rhizophora* from Mangaia could have been caused by decreasing salinity of the inner swamps with later sea-level fall, and closure of the conduit caves by sedimentation. It seems that Pacific mangrove ranges are more controlled by availability of habitats and less by dispersal capability than was previously thought (Mepham 1983). This record lends support to Taylor's (1979) view that *R. stylosa* in Moorea and Bora Bora is not introduced. I talked with the eminent Pacific botanist F. Raymond Fosberg about *Rhizophora* in Tahiti a few months before his passing away in 1993. Fosberg had been tracking down the dispersed collection of Forster, who apparently collected *Rhizophora* in French Polynesia in the 1770's, and told me that he was becoming convinced by the argument that it was indigenous.

Mangrove area estimates available for the Pacific Island countries are mostly from dated sources. Spalding et al. (1997) concentrated on the main islands of a few countries. A second edition of the World Mangrove Atlas is in preparation. Kiribati has had a baseline survey completed (Metz 1997), and there have some other corrections. Niue has one true mangrove species *Excoecaria agallocha* but this occurs in littoral forest not mangrove wetland (Yuncker 1943), and the FAO (2003) mangrove area of 3,000 ha is incorrect. There are improved estimates for Samoa, where Pearsall and Whistler (1991) recorded a mangrove area of 700 ha while FAO (2003) records 752 ha. Similarly Tonga, where Saenger et al. (1983) recorded 1,000 ha while FAO (2003) records 1,305 ha. These reflect better estimates rather than mangrove area increase. In Samoa however, there have been some very serious losses of wetlands, particularly in the lowlands, and only a few intact areas of each type remain (Schuster and Butler 2001).

### Riverine wetlands

Only the larger islands of the region have rivers of substantial length and discharge, though the largest PNG rivers have among the world's highest river discharges per catchment area (Milliman et al. 1995). Given the high rainfall (2,500–4,000 mm) and generally rugged topography, PNG rivers are generally fast-flowing, with high discharges and high sediment loads (Osborne 1988). The Sepik has a catchment area of 78,000 $km^2$ and discharge of 120 $km^3$ $year^{-1}$ (Milliman et al. 1995) with a floodplain of up to 70 km wide with wetlands of some 7,800 $km^2$, though the estuary is limited. The Fly River has a catchment of 76,000 $km^2$ with discharge of 77 $km^3$ $year^{-1}$, and like some other south coast rivers enters a vast delta and estuarine zones. Both have total suspended solids among the highest of the world's rivers, of $100 \times 10^6$ t $year^{-1}$ (Milliman et al. 1995).

The Fly River floodplain is the largest wetland in PNG and the whole Pacific Island region occupying an area of 4.5 million hectares. This vast low elevation floodplain has numerous oxbow lakes, and lateral lakes caused by tributaries being blocked by lateral accretion of the main channel (Jaensch 1994). Pure stands of *Melalueca* occur in seasonally dry swamps which can flood to a depth of about 1 m (Paijmans, 1990), while lower floodplains are dominated by herbaceous swamps commonly comprising the reeds *Phragmites karka* and *Saccharum* sp. (Jaensch 1994).

Rivers elsewhere in the region tend to have small drainage areas with a mostly variable discharge, bedrock confined, featuring water quality of low mineral/ionic content as well as high organic solutes and particulate matter (Maciolek and Ford 1987; Resh and De Szalay 1995). On Pohnpei, the largest and highest island of the Federates States of Micronesia (FSM), headwater streams are well formed due to 4,000 mm of rainfall per year and no dry season, and have important biodiversity values with a number of endemic species (Merlin and Raynor 2005). On Tutuila, American Samoa (Whistler 1978) describes an endemic Urticaceae herb found rarely in streambeds, *Elatostema tutuilense*.

Some rivers have been dammed to provide water supply and electricity. Pacific countries comprising mainly atolls or limestone islands (such as the Marshall Islands, Tuvalu, Nauru and Kiribati) have no rivers and consequently have limited water supplies. Threats to rivers include river pollution from untreated domestic discharges and mine waste (SPREP 1999).

### Lacustrine wetlands

Types of lakes that occur the Pacific Island countries include crater lakes, lakes in highland valleys or basins, freshwater lakes in the coastal zone of high islands, and coastal lakes, either freshwater or saline, on coralline limestone islands (Figs. 3 and 4). Large river floodplain lakes occur in PNG as reviewed above. Chambers (1987) estimated that there were 5,383 lakes in PNG, of which 22 have an area greater than 1,000 ha. The freshwater ecology of PNG is relatively well studied compared with other Pacific Island countries (Osborne 1988; Kailola 2003), however given the scale and complexity of these habitats there remains a great deal to learn about species diversity and ecology (Polhemus et al. 2004). The largest lake (647 $km^2$) in PNG is Lake Murray, which is a lateral lake formed at the junction of the Strickland and Fly Rivers. The second largest is Lake Chambri in the Sepik floodplain (Nicholls 2004), which can extend up to 250 $km^2$ during floods. Both these lakes are shallow, with maximum depths of 4–6 m. The floodplain lakes of PNG support large populations of waterbirds and fishes and are essential to the subsistence and commercial livelihoods of local communities.

Many highland lakes have suites of endemic fish species or have been stocked with exotic fishes that sustain subsistence fisheries, such as Lake Kutubu, PNG (4,924 ha). Polhemus et al. (2004) list 12 pages of species endemic to single lakes or lake groups in New Guinea. Some coastal lakes of high islands have the potential function of water supply for growing urban centres, although ecological roles such as support for threatened fauna (e.g. crocodiles, endemic taxa) may be at risk. Most lakes in the region, especially those on limestone islands, have high aesthetic values and thus offer potential eco-tourism opportunities. Examples include Lake Ngardok, Palau (~12 ha) and Lake Te-Nggano, Solomon Is (15,500 ha).

Some of the PNG lakes are crater lakes, such as Lake Kutubu at 800 m altitude which has a well developed aquatic flora (Conn 1979), and Lake Dakataua at low altitude but of 111 m depth, with shallow water areas supporting dense beds of mixed aquatic plants (*Najas tenuifolia* and *Chara* sp.; Ball and Glucksman 1980). Most crater lakes in the region do not support rich biodiversity and some lack any native fish species, essentially due to their isolation and relatively recent formation, though some support distinctive wetland floras.

Fiji has few freshwater lakes, the largest is Tagimaucia crater lake (16 ha) at 820 m on Taveuni, adjacent to a 197 ha sedge peat swamp which is gradually infilling the lake (Southern et al. 1986; Scott 1993). On the windward side of Taveuni, the site receives an average rainfall of over 6,800 mm. Swamp vegetation of *Lepironia articulata* with a jelly-like surface of cyanophyta and algae fringes the lake and extends as floating peat mat of 2–3 m thickness, including floating islands. Faunal diversity is very low with the lake draining via a precipitous creek (Southern et al. 1986).

Crater lakes also include Lake Letas, Vanuatu (1,900 ha), seven volcanic lakes on Uvea in Wallis and Futuna the largest of which is Kikila (17.9 ha; Scott 1993), also Tofua and Kao in the Tongan Ha'apai group. These are young islands, with active volcanoes and some endemicity. Tofua has an explosion crater that is as large an area as the surrounding island, featuring precipitous cliffs.

While Oceania has the fewest registered large dams/reservoirs of all regions, with only 685 (2.7%; Finlayson and Nicholson 1999), river modification remains a problem for wetland management (SPREP 1999). In French Polynesia the only freshwater lake Lac Vaihiria at 473 m on Tahiti is used for generation of hydro-electricity and has a number of introduced/invasive species (Scott 1993). In Viti Levu, Fiji the Monasavu Lake and dam were established in 1982, with the lake covering 670 ha (Tuiwawa 2005). The introduced fish species *Tilapia* and *Ctenopharyngodon idella* are plentiful in the lake. In a side valley is the peat bog of Nadrau Swamp, with herbaceous vegetation dominated by *Eleocharis* and *Coix lacryma-jobi*. This vicinity is also the only known record in Fiji of the subaphyllous perennial *Lepironia articulate* (Smith 1979). There are increased invasive species in the area since dam development, and free ranging horses and cattle frequent areas adjacent to the Nadrau Swamp.

The freshwater resources of Kiribati are by contrast extremely limited, confined to a single fresh-water lake on Terina in the Line Islands (Wilson 1994). This is a series of peat bogs composed of the sedge *Scirpus riparius*. Otherwise, there are small ephemeral wetlands on islands including Abaiang. The largest perennial freshwater body in Palau is Lake Ngardok, a 493 ha Ramsar site with significant fish and avian fauna, though there seems to be little published on it in the scientific literature.

Threats to lakes in the region include introduced species (fish, weeds; Eldredge 2000), exploitation and pollution resulting from adjacent urban growth (coastal lakes) and poorly planned eco-tourism, and downstream effects of changes to catchments (mining, agriculture, logging; SPREP 1999).

## Freshwater swamp forests

Only a few of the Pacific Island countries have freshwater swamp forest: PNG, the Solomons, FSM, Palau, Fiji and limited areas in Vanuatu and New Caledonia (Scott 1993). Wooded swamps in New Guinea were reviewed by Paijmans (1990). Smaller countries particularly to the east of the region lack this wetland type, including Kiribati, the Marshalls, Northern Marianas, American Samoa, Tokelau, Tonga, Tuvalu and Wallis and Futuna.

The most extensive areas of freshwater swamp forest in the region occur in PNG, with an estimate of 500,000–2,890,000 ha (Watkins 1999). This wide range of estimate is because of the differing definitions and the difficulty of interpretation of remotely sensed data (Rieley et al. 1996). Forest trees are diverse, tending to be generalist in habitat (Mueller-Dombois and Fosberg 1998), with canopies of 30–35 m, trees with well developed buttresses, and an abundance of woody climbers (Paijmans 1990). Pure stands of *Campnosperma* of up to 30 m height occur in stagnant permanent waters of river plains and basins. Fiji has 4,000 ha of swamp forest mainly on the windward side of Viti Levu (Watkins 1999), New Caledonia has limited areas of *Melaleuca quinquenervia* swamp forest (Mueller-Dombois and Fosberg 1998), and Palau has 11 disturbed swamp forest areas primarily of *Hibiscus tiliaceus* adjacent to mangroves (Scott 1993).

Freshwater forested wetlands are found on many of the high islands of Micronesia, with closed canopies of 25 m in height of *Campnosperma*, *Calophyllum*, *Terminalia* or *Metroxylona* (Allen et al. 2005). Facilitated by high annual rainfall (c. 5,000 mm) these wetlands are located on the lower reaches of rivers between uplands and mangrove forests (Fig. 3) and have a number of natural and socio-economic values (Drew et al. 2005). However, some areas have been converted to agroforestry. Kosrae has about 300 ha of freshwater forested wetlands, including large areas of peatland (Chimner and Ewel 2004). These are located in the lower catchments adjacent to mangrove forests, and are dominated by the endemic *Terminalia carolinensis*, which is a large tree up to 35 m tall, with a distinctive pagoda-shaped crown and large root buttresses.

In the Solomons, there is a total of 108,800 ha of freshwater swamp forest (Scott 1993), comprising 4.1% of the land area (Hancock and Henderson 1988), of four types: mixed herbaceous, palm, pandanus and swamp forest. Swamp forest occurs on most of the islands in waterlogged locations, with *Inocarpus fagiferus* and *Eugenia tierneyana* commonly found in association with other tree species such as *Barringtonia* spp., *Calophyllum vexans* and *Pterocarpus indicus*, with common climbers and epiphytes. Some swamp forests are dominated by a single species, the most unusual of which are the *Campnosperma breviipetiolatum*, *Casuarina papuana* and *Termnalia brassii* swamp forests.

The largest lowland swamp forest in Vanuatu is at Jordan River Floodplains ($\sim$1,000 ha) dominated by species of *Erythrina* and *Hibiscus*. This is part of the Vatthe Conservation Area that was a recent World Heritage Site nomination. Samoa has one 520 ha freshwater swamp forest at the highland Vaipu Swamp Forest (240 m) elevation (Scott 1993). This is in a waterlogged basin with a diverse mixture of canopy trees such as *Barringtonia samoensis*.

### Marshes

The region has examples of freshwater palustrine marshes dominated by grasses, reeds and/or herbs (usually in lowlands such as large areas of PNG floodplains) and marshes on peaty substrate (usually in highlands). Figures 3 and 4 illustrate the various settings of marshes on high and low islands. The PNG floodplain marshes with herbaceous communities of sedges, herbs, and ferns are characteristic of stagnant, permanent, relatively deep swamps (Osborne 1993).

Significant lowland and upland peat swamps in Fiji are Bonatoa peat bog (890 ha) at Rewa delta, Melimeli (507 ha) on Navua delta margins, Vunimoli (262 ha) behind beach ridges at Vatuloa and the Navua river mouth and coastal valley wetlands (Ash and Ash 1984). The largest, Bonatoa, in poorly drained conditions peat has accumulated up to 3 m deep under sedge dominated flora. Occasional floods wash alluvial horizons into the peat, and better drained alluvial soils adjacent support grasses, herbs and sedges. An example of a highland marsh at 1,500 m in Samoa is Mount Silisili Bog, dominated by *Carex*. Surrounded by cloud forest, this is an important bird habitat.

The main conservation value of the smaller, isolated marshes is for the diversity of aquatic plants, some of which are endemic. However, small coastal marshes on small islands are often converted to taro cultivation. Coastal freshwater marshes formed from organic residues are highly distinctive environments in the Samoan Islands, and are habitats for water birds such as the grey duck (*Anas superciliosa*). In Samoa (Wright 1963) identified two small localities of organic residues, one at Cape Mulinu'u on Savai'i and the other in a similar westernmost point on 'Upolu at Apolimafou (Park et al. 1992). There is a coastal marsh on Aunu'u off the main island of American Samoa, with a substrate of loose red organic mud that is devoid of vegetation but surrounded by inland *Bruguiera* (Whistler 1976).

Threats to these wetlands include over-exploitation for cultivation, destruction or pollution due to urban landfill, and (especially for floodplains) downstream effects of changes to catchments (mining, agriculture, logging; SPREP 1999).

## Wetland soils

There has been very little quantitative research on the soils of wetlands in the Pacific Island region, though several countries have had soil mapping carried out. For example, Leslie (1997) described 45 soil types in Fiji, including Dreketi, a saline soil of marine marsh; Melimeli, a very poorly drained and poorly decomposed rushes/fern fibrous peat; Narewa, a poorly drained valley floors soil; Soso, a very poorly drained humus rich peaty silty clay, saline soil of marine marsh; Togoru, a very poorly drained sandy gley of low lying land inland of coastal sands and saline areas; and Tokotoko, a very poorly drained gley of low lying surfaces on major flood plains.

Ash and Ash (1984) located wetlands in Fiji using earlier soil maps (Twyford and Wright 1965), looking for poorly drained gley soils and three types of peats. Wetlands of Viti Levu are largely restricted to higher rainfall areas (>2,500 mm year$^{-1}$) in the SE, in areas of recent alluvial and recent coastal sediments, where soils present are peats and gleys.

*Terminalia* freshwater swamp forest of Micronesia is found on three soil types, which all have similar parent materials and soil texture but vary in depth of water table and flood frequency (Laird 1983; Allen et al. 2005). The Inkosr types are deep and extremely wet, with higher sodium concentrations possibly caused by lower elevations and proximity to mangroves. Forest here is of lower diversity and slower growth rates. Nansepsep types have a lower water table and are more susceptible to agroforestry conversion or tree harvesting. The Sonahnpil types include some cobbles and larger stones with higher pH possibly caused by having the better drainage of the three soil types (Allen et al. 2005).

Plant production at two tropical freshwater forest sites on Kosrae was found to be 1.12 kg Cm$^2$ year$^{-1}$ and estimated peat accumulation of 300 g Cm$^2$ year$^{-1}$ (Chimner and Ewel 2005). This high peat accumulation was due to slow decomposition rates with the anaerobic conditions of high water tables and low drainage. This indicates susceptibility to changes in hydrology, be this human modification or ENSO related droughts. Such tropical peatlands account for 10% of the world's peatlands, and those of Micronesia accumulate peat primarily due to slow decomposition of organic matter under anaerobic conditions that result from nearly constant high water levels (Chimner and Ewel 2005).

On Mangaia, the second largest island of the Cook Islands Ellison (1994a) cored the seven major freshwater wetlands inside the coastal raised limestone makatea rim. This showed sediment depths of up to 12 m dating back to the mid Holocene, when five of the wetlands were lakes. In the later Holocene, organic lake gyttja was replaced by clay inwash associated with the arrival of man and catchment disturbance from 2,500 years BP. Four of the lakes infilled completely to become reed swamps, with only Lake Tiriara remaining today (Fig. 5). These modern reed swamp soils are mostly allochthonous clay from erosion off the volcanic core of the island, and some organic content.

Catchment erosion, and sediment accretion in a lower floodplain has been demonstrated in the Rewa catchment of Fiji by Terry et al. (2002). $^{137}$Cs was used to date accretion rates in an upper catchment floodplain of 3.2 cm year$^{-1}$ over the last 45 years, a record that exceeds rates recorded elsewhere. Greater

**Fig. 5** Lake Tiriara, Mangaia, Cook Islands, showing the subdued volcanic island core in the foreground, and raised limestone rim behind the lake

cyclone intensities with future climate change are expected to increase floods in the Rewa catchment, and increase rates of floodplain sedimentation.

The predominant soil type in American Samoa mangroves is Ngerungor Variant organic peat, a mixture of peat and basaltic and calcareous sand, comprised of 10–30% organic matter (US Soil Conservation Service 1984; Ellison 2001). The color for moist soil from 0–10 cm is a very dark grayish brown (10YR 3/2) organic peat. The color for moist soil from 10–52.5 cm is a very dark brown (10YR2/2) peat (US Soil Conservation Service 1984). In Kosrae, Federated States of Micronesia, Ward (1988) cored stratigraphy under all major coastal mangroves. This found up to 6 m depth of sediment with basal dates only of between 1,200 and 4,000 years before present, with sediment varying between mangrove peat and gray clay inwash which in some swamps was prolific.

In Tongatapu, Ellison (1989) cored the largest mangrove swamp at Nukuhetulu to find a buried mangrove peat from a large forest which existed 7000–5500 years BP, which is the earliest known Holocene mangrove refuge in the Pacific Island region. This died off with later sea level rise, and re-established with more recent sea-level stability. Surface mangrove soils were shallow above lagoon sediment indicating recent colonisation, and were dark greyish brown organic silt (10YR 3/2) with percent organic of 52% (range 33–69%).

## Fauna

### Mammals

The tropical Pacific terrestrial mammal fauna is immensely depauperate compared with other regions, due to island isolation and lack of geological landbridges, and dominated by bats derived from the western regions. No mammals at all are present in French Polynesia, Tuvalu, Kiribati, the Marshalls, and Tokelau (Carvajal and Adler 2005), and one bat species is the only native mammal species present in the Cook Islands and Niue. This most widespread species is the Pacific flying fox *Pteropus tonganus*, which roosts in tall coastal trees, while in the North Pacific *Pteropus mariannus* occurs in FSM and the Marianas.

There are two marine mammals that are known to inhabit Pacific Island shallow coastal waters included as wetlands in this review, one Odontocete cetacean, and one Sirenian. The Irrawaddy dolphin *Orcaella brevirostris* extends from its ranges in SE Asia into southern PNG and possibly the Solomons. It inhabits turbid rivers, estuaries and coastal waters, and in PNG can be found up to 16 km from the sea (Reeves et al. 1999). The dugong *Dugong dugon* formerly extended from its ranges to the west to be widespread in Palau, Melanesia and to the western FSM, but has become extirpated or depleted in many areas. Only small numbers have recently been recorded in New Caledonia and Vanuatu (Reeves et al. 1999). Their reliance on relatively shallow seagrass beds for food limits the abilities of dugong to travel between islands, causing populations in the Pacific Island region to be isolated and especially vulnerable for extinction. The dugong is currently vulnerable in the Pacific Island region (IUCN 2006).

### Birds

The archipelagos of the Solomons and the Bismark Archipelago of northeastern PNG have the most diverse bird faunas of the Pacific Island region (Mayr and Diamond 2001). These avifaunas are derived from the populations of the adjacent larger continents of New Guinea and Australia.

In review of Pacific Island birds (including Hawaii), Adler (1992) found 485 species from 48 families, of which 292 species are endemic to a single island group. Of these are some which are either obligate to or prefer wetland habitats, including 9 species of herons, 11 ducks, 15 kingfishers and 15 seabirds. The herons and ducks are notable for their wide distribution and low rates of endemism. Endemism is enhanced by isolation from other landmasses.

Pacific Island birds had late contact with humans with the arrival of Polynesians only in the last one or two millenia (Steadman and Martin 2003), when many flightless or ground nesting species then became extinct before European sailors arrived (Steadman 2006). Each Polynesian Island investigated has yielded the remains of two or three endemic species of flightless rails, perhaps 2,000 species across the whole region (Steadman 1991). Other heavy losses have been the petrels, shearwaters, terns and kingfishers, and other recent wetland examples include the Marianas Mallard and the Guam Broadbill which have not been seen for some decades now due to hunting, habitat loss and predator introduction (United States Government 2004). The Micronesian megapode (*Megapodius laperouse*) for similar reasons was thought to be extinct until one was recently observed on Tinian (O'Daniel and Krueger 1999).

On isolated islands with reduced human pressure bird populations remain important. The near threatened Micronesian pigeon (*Ducula oceania*) fares better on Kosrae with a lower human population than on Pohnpei. More than 100,000 sooty terns (*Sterna juscata*) have been recorded as breeding on the volcanic crater on Fonualei Island in the Tongan Vava'u Group (Jenkins 1980). On uninhabited and rat-free islands large seabird colonies occur, including particularly large numbers of brown noddy (*Anous stolidus*). Endemic to the volcanic island of Niuafo'ou is the endangered Niuafo'ou megapode (*Megapodius pritchardii*) which incubates its eggs by burying them in warm sands near volcanic ducts (Rinke 1986). Recently chicks and eggs have been released on the predator-free Tongan Islands of Late and Fonualei (Bird life International 2003).

## Reptiles and amphibians

Distributions of the 672 valid species of freshwater and terrestrial Pacific Island amphibians and reptiles were reviewed by Allison (1996), finding the greatest total of 472 in New Guinea. This includes seven species of the freshwater turtle family Chelidae of Gondwanan origin. The shoftshell turtle *Pelochelys bibroni* is in PNG at the southern limit of a range through China and SE Asia. *Carettochelys insculpta* is also a softshell species the last remaining of a family with a rich fossil record indicating it was once widespread in Europe and Asia.

The southern lowlands of Papua New Guinea have the highest diversity of freshwater turtles in the Australasian region with 10 species, 7 of which are endemic (Georges et al. 2006). In the Western Province these inhabit rivers, permanent lakes and riverine lagoons, freshwater swamps, with habitat preferences between species. This is an area of low human population with poor access, but there has been increased exploitation of turtles in recent years to service the Asian live turtle market.

The numbers of amphibian and reptile species decreases rapidly with distance to the east of New Guinea, due to decrease in island size, proximity of other islands and island age. Amphibians are intolerant of salt water and therefore have difficulty migrating in this region. Both snake and lizard species reduce rapidly in numbers to the east of New Guinea (Allison 1996), though the monitor lizard occurs on many Pacific Islands, where it may have been introduced by man as a food source.

Six of the seven marine turtles are found in the Pacific Island Region, the three more common are the green turtle *Chelonia mydas*, hawksbill *Eretmochelys imbricata* and leatherback *Dermochelys coriacea* (Bleakley 2004). Of these the hawksbill is critically endangered, and the green and leatherback endangered (IUCN 2006). Less common are the loggerhead *Caretta caretta*, flatback *Natator depressus* and olive Ridley *Dermochelys coriacea*, of which the olive Ridley is endangered, and the loggerhead and flatback turtle vulnerable (IUCN 2006).

Marine turtles are slow to reach maturity, and migrate long distances between nesting and feeding areas. Individuals tracked nest at Rose Atoll, American Samoa then moved to the rich seagrass and algae beds of Fiji, spending 90% of their time there. Impacts to turtles include by catch from long line fisheries, over-exploitation by local communities, and vulnerability to human hunting when nesting on beaches. Numbers present of green and hawksbill turtles are depleted in locations with no restriction on human take (Buden 2000).

In response, in 2006 the Turtle Research Database System was established at SPREP, providing co-ordination of turtle database services including envelopment of previous databases from Queensland and the Pacific, tagging programmes, information exchange, regional and international co-operation, and training opportunities. Also, March 2006 to March 2007 was the Pacific Year of the Sea Turtle, a campaign run from SPREP to promote a regional partnership to increase turtle conservation, with communities, governments and industry working together.

The estuarine crocodile *Crocodylus porosus* occurs in the Pacific, fairly common in PNG and extending to Palau, Solomon Islands and Vanuatu which is the limit of its range (Chambers and Esrom 1994). The Solomon Islands once had substantial populations, but these are now decimated. Extensive surveys by Messel and King (1991) in Palau sighted only 17, mostly at Belilou Island, with three seen at Babeldaob and one seen at Kedebel River. In Vanuatu it occurred up until to 1980's at a few locations, with one breeding population on the island of Vanua Leva which was of 200 individuals before devastation in Cyclone Wendy in 1972, reducing to 50 by the early 1980's, and only very few by 1989. The crocodile is currently vulnerable in the Pacific Island region (IUCN 2006), there has not yet been a Year of the Crocodile however. Records of an extinct species of crocodile was found in Vanuatu (Mead et al. 2002), similar to another in New Caledonia and Fiji, all of which were most likely extirpated with the arrival of man.

### Fish

Freshwater fish communities of Australia and the Pacific Island region are relatively depauperate, due to the absence of the Ostariophysi, which account for almost 88% of the world's primary freshwater fish (Powell and Powell 1999; Cook 2004). Island age, area and isolation are all influences on the freshwater biodiversity of islands (Drake et al. 2002).

Systematic surveys of freshwater fishes and invertebrates on New Guinea and nearby islands, revealed previously unsuspected levels of species richness and endemism (Polhemus et al. 2004). The numbers of new species identified in this survey highlights the knowledge gaps and potentially similar levels of undocumented freshwater biodiversity in other islands of Melanesia, particularly the large islands. They found few impacts at the time of survey but identified invasive aquatic species as a threat to future biodiversity.

The high islands of the tropical Pacific possess a sparse native fish fauna dominated by the family Gobiidae (Ryan 1991). The evolution of streams in the high islands of the tropical Pacific is relatively recent, thus there has been little time for colonisation to occur. Furthermore, estuaries in some islands are poorly developed, thereby placing euryhaline estuarine species at a competitive disadvantage. Factors favouring the Gobiidae include a marine larval stage, euryhalinity, small size, an excellent climbing ability, a range of trophic level from carnivory through omnivory to herbivory, frequent lack of a gas bladder, and an associated bottom-living life style (Ryan 1991).

The Conservation International Melanesian hotspot of Vanuatu, the Solomons and the northern islands of PNG has approximately 52 species of freshwater fish, of which three are endemics (Beehler et al. 2005). These islands are true islands with no previous connection with New Guinea, so fishes are of marine origin adapted to freshwater conditions, tending to be migratory with varied tolerances of salinity. Hence diversity decreases with distance from the ocean, and the Gobiidae are the only native taxonomic group to be observed above a precipitous obstruction. These factors have caused a distinct fish faunal assemblage that has not been fully documented.

New Caledonia has an inland fish fauna of 85 species in 49 genera, of which 9 are endemic (Lowry et al. 2005). This includes an endemic galaxiid *Galaxias neocaledonicus*, the northernmost representative of a group that is only found in the other southern Gondwanan relics. Two new records of Gobiidae species in New Caledonia and Vanuatu were described by Keith et al. (2000), extending south the previous Pacific Island ranges of these. On the small high island of Tau, American Samoa, Cook (2004) found six native fish species from the families Gobiidae, Eleotridae and Anguillidae, including *Anguilla megastoma* which has limited distribution on Tutuila. In rivers of Pohnpei, FSM there are a number of endemic species including six Gobiidae, and one freshwater eel (Merlin and Raynor 2005).

A recent contribution to the knowledge on freshwater fish species on the large islands in Fiji is Boseto (2006), finding 89 freshwater species from 26 families, and 72 estuarine fishes from 31 families, to give a total of 161 fish from 45 families in Fiji. Boseto found new species: *Glossogobius* sp., *Redigobius* sp., *Sicyopus* sp. *Stenogobius* sp., *Stiphodon* sp., *Stiphodon* sp., and *Scicydiinae*: new genera. One new species has been described by Jenkins and Boseto (2005) as *Schismatogobius vitiensis*. The most common species collected was *Anguilla marmorata* (Anguillidae). The study shows species richness depends on physical habitat factors, mainly water temperature and river depth. In Samoa there has not been a detailed study of native freshwater fish fauna (Schuster and Butler 2001).

### Invertebrates

Coral reefs and freshwater molluscs are the best studied wetland invertebrate groups in the Pacific

Island region, work on other groups has pointed out even more the need for baseline surveys and inventories. Some of the better distributional records of groups are summarised in Table 2.

Mollusca have a single shell of three main classes, Gastropoda, Bivalvia and Cephalopoda (squid, octopus, cuttlefish). Freshwater neritids and thiarid gastropods dispersed into the Pacific Island region from New Guinea, through the Solomons and Vanuatu and from there to both New Caledonia and Fiji (Haynes 2001). Haynes (2001) tabulates known records of 87 species in the Pacific Island region, from 11 families and 25 genera (Table 2). Distributions may be wider than these records.

Freshwater gastropods are often abundant in the streams and rivers of high volcanic Pacific Islands such as *Clithon* and *Thiara*, and *Neritina* in brackish areas. The species most common in the region is the parthenogenetic thiarid *Melanoides tuberculata* (Haynes 1990). This can easily spread on plant material, and can survive on islands which have no running water.

Pacific Island Neritidae and Thiaridae species also occur in the Philippines, Indonesia and PNG, indicating that these groups reached the Pacific Islands from SE Asia. In Vanuatu, Haynes (2000) found 23 neritid species, while Fiji has 24 neritid species, Samoa 16 and French Polynesia 9 (Haynes 2001). Endemics have evolved at the extremes of these ranges. Samoa has two endemic thiarid species, *Melanoides laxa* and *Melanoides peregrine* both found on Upolu (Haynes 1990). Fiji has *Fijidoma maculata* and New Caledonia has *Melanoides lamberti*. French Polynesia has two endemic *Septaria* species, *Septaria apiata* and *Septaria taitana*, while *Septaria macrocephala* is only found in Fiji and New Caledonia, and *Septaria bougainvillea* is found only in Fiji, New Caledonia and the southern Vanuatu Island of Tanna. In the neritids, Acochlidiacea have only been found on the islands of Viti Levu and Vanua Levu, Guadalcanal, Efate (Vanuatu) as well in Palau and locations in Indonesia.

The small Hydrobiidae species that inhabit the Pacific Islands have near relatives in Australia and New Zealand and are not found further north than Vanuatu. The family has undergone extensive speciation in New Caledonia where over 50 species have been described, especially from the genus *Fluviopupa*. Similarly the planorbid genus *Physastra* appears to have an origin in Australia and New Zealand, and spread into the Pacific through New Guinea (Haynes 1990). All Neritidae species found in the North Pacific also are found in the South Pacific.

Some spread may be by man on taro leaves, particularly *Melanoides tuberculata* and *Physastra nasuta* (Haynes 1990), it is unlikely that man has dispersed other species as these do not live on vegetation, more in mud or under river stones. There are also accidental or careless introductions, the East African *Melanoides tuberculata* occurs in ditches and ponds on Tongatapu and Rotuma. Species of *Lymnaea* and *Physa* have been introduced to ponds. *Viviparus japonicus* was introduced to Viti Levu from Japan in a prawn aquaculture attempt.

Reef and shore molluscs also decline in diversity from west to east across the region. Kay (1995) lists 1,139 species in Guam, 1021 in the northern Marshalls and 959 in French Polynesia. Species present are however dependent on habitat types, there being different molluscan assemblages of reef slopes, outer lagoons and inner lagoons for example. Coastal sponges, polychaetes and crustaceans also generally decline in diversity from west to east, however records are patchy (Kelly-Borges and Valentine 1995; Bailey-Brock 1995; Eldredge 1995).

Freshwater crustaceans of the Pacific Islands have not been comprehensively investigated (Eldredge 2000). In headwater streams of Pohnpei, Buden et al. (2001) collected 986 decapod crustaceans (freshwater shrimps) of which all are indigenous though none endemic, and all occur widely in the region. Slope clearance may alter stream conditions deleteriously. In Samoa there has not been a detailed study of native invertebrates (Schuster and Butler 2001). Two freshwater prawn species are used for food throughout Samoa, *Macrobranchium lar* and *Palaemom* sp.

On the small high island of Tau, American Samoa, Cook (2004) found a diverse and abundant riverine shrimp community dominated by *Macrobranchium latimanus* which is not widespread or abundant on the larger island of Tutuila. Atyid shrimps are common in the freshwater habitats of oceanic islands (Leberer and Nelson 2001). Seven species are recorded in Guam, where distributions are controlled by habitat types, particularly habitat factors such as *Atoida* mostly occurring in riffles, *Caridina* mostly in runs and pools. In rivers of Pohnpei, FSM there are a number of endemic species including one freshwater shrimp and nine species of dragonflies and damselflies (Merlin and Raynor 2005). Fossati et al. (1992) sampled streams of Nuku-Hiva Island in the Marquesas, finding low diversity due to isolation, with six species of Gastropoda and four species of *Macrobranchium* in Decapoda.

There is poor knowledge of systematics and biogeography of Pacific Island insects (Miller 1996), though there have been recent improvements. The Pacific blackfly subgenus *Inseliellum* has been found to be limited to islands with a geological history of running water habitats (Craig et al. 2001). In French Polynesia Polhemus et al. (2000) collected aquatic insects and other macro invertebrates from streams and wetlands of the four main high islands of the Marquesas (also briefly in the Society Islands), and found a rich variety of undescribed species in the family Dolichopodidae. Two new species of water skating *Campsicnemus* flies, were collected from stream pool habitats on Ua Hiva and Hiva Oa. These are the only known populations of this genus in the southern hemisphere. In the Heteroptera, they found different sets of endemic species of the family Saldidae present in northern and southern sections of the Marquesan archipelago. They also found that the family Hydrometridae has undergone a radiation, with two endemic and monotypic genera already known from the group, and a third undescribed endemic genus on Hiva Oa. The brevity of this reported survey means that other previously undescribed species must be present.

Surveys found intact aquatic ecosystems throughout the four islands with no introduced fish species, which was thought to be the most conservation-related finding of the study. There was also a lack of introduced and pernicious species of aquatic vegetation which occur in Tahiti and/or Hawaii. The adverse impacts of such introduced species to aquatic habitats are well documented particularly in Hawaii (Englund 1999; Eldredge 2000). The Marquesas have so far escaped such disturbance.

## Ecological characteristics, populations, communities

The mangroves and the freshwater forested wetlands of the Federated States of Micronesia have benefited from a wealth of ecological studies by the USDA Forest Service over the last 15 years. This started with baseline assessment of the forest resource (Petteys et al. 1993) and assessment of values and recommendations for creation of forest reserves (Devoe 1993). Subsequent research has included community structure (Cole et al. 1999; Allen et al. 2003; Ewel et al. 2003; Krauss and Allen 2003; March et al. 2003), productivity and growth (Ewel et al. 1998a; Devoe and Cole 1998; Allen et al. 2000; Pinzón et al. 2003; Allen et al. 2005; Krauss et al. 2006), carbon fluxes (Gleason and Ewel 2002; Chimner and Ewel 2004, 2005), organic matter dynamics (Gleason et al. 2003), sedimentation (Krauss et al. 2003), disturbance (Ewel et al. 1998b; Allen et al. 2001; Hauff et al. 2006) and wetland valuation (Naylor and Drew 1998; Naylor et al. 2002; Drew et al. 2005). Other countries in the region are very depauperate of such detailed and interconnected scientific ecological work, and in many none has occurred at all.

Ecological research in the region has demonstrated species zonation within wetland types, though the complement present varies between island groups. At the global centre of mangrove biodiversity, the Fly River delta has 87,000 ha of mangroves with distributions of controlled by salinity gradients (Robertson et al. 1991). *Nypa fruticans* covers 44% of the mangrove area, in high tide salinities of 1–10 parts per thousand (‰). *Rhizophora apiculata–Bruguiera parviflora* forest covers 36% in sections where water salinities are >10‰. *Sonneratia lanceolata* occurs on accreting banks in low salinity areas, and *Avicennia marina* on accreting banks in higher water salinities of >15‰. Figure 6 shows this zonation typical of PNG. Owing to high river high discharge through restricted channels and overall consequent low salinity, the Purari delta has different mangrove distributions. Extensive mangrove stands are dominated by *Bruguiera* species with some *Rhizophora apiculata* in salinities of >10 (‰), and *Nypa fruticans* in salinities of <10‰ (Cragg 1983).

Mangrove zonation in the Solomons is simpler, with *Rhizophora apiculata* and *R. stylosa* in seaward exposed locations (Hancock and Henderson 1988). More inland, *Brugueira gymnorhiza* dominates, and *Lumnitzera littorea* further inland. *Avicennia* only occurs locally. In FSM mangroves usually have fringe, riverine and interior zones reflecting their different hydrogeomorphic settings (Ewel et al. 1998a, 2003; Krauss et al. 2006). Large *Xylocarpus granatum* trees are common in the upper reaches of the intertidal zone, but mature trees are occasionally found at lower elevations. This has been shown to be caused more

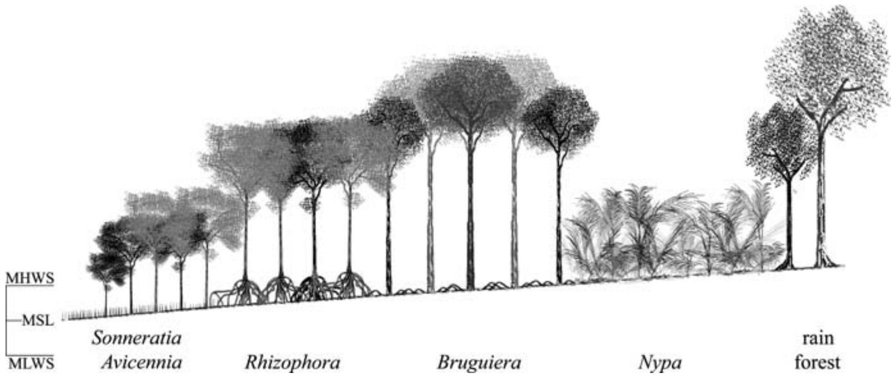


**Fig. 6** Mangrove zonation typical of Papua New Guinea

likely by seedling tolerance of flooding or salinity, rather than seed predation (Allen et al. 2003).

At the eastern limit of mangroves in Polynesia, low diversity of mangroves causes changes in community structure and microhabitat. In the absence of landward zone species, such as *Lumnitzera* and *Ceriops*, *E. agallocha* becomes more common in mangrove communities of Polynesia, forming extensive monospecific stands (Fig. 7). In Tonga, *Excoecaria* forest dominates the mangrove area. In Samoa with *Excoecaria* absent, *Bruguiera* occupies most of the mangrove area with no landward mangrove species present, also possibly allowing the existence of coastal marshes described by Whistler (1976). In Fiji extensive salt flats occur on the landward margin of mangroves on the leeward shore of Viti Levu, rare elsewhere in the region.

Bridges and McMillan (1986) investigated zonation of seagrass species in shallow tidal conditions at Yap, FSM. They found that *Cymodocea rotundata*, *T. hemprichii* and *Enhalus acoroides* extend to shallow sites nearshore, where they can tolerate the extreme conditions of over 40°C water temperature, and river diluted salinity to as low as 2‰. *Cymodocea serrulata* and *Syringodium isoetifolium* did not extend into low tide conditions, preferring less extreme environments further offshore. Seagrasses in the region are often closely linked with complex interactions to mangrove communities and coral reef systems. Dense seagrass communities of *Enhalus* and *Cymodocea* are often present on intertidal banks adjacent to mangroves and fringing reefs (Coles et al. 2003).

Freshwater gastropods in the region show zonation by elevation and habitat (Resh and Szalay 1995). On the main island of New Caledonia Starmuhler (1979) found *Melanopsis frustulum f. maculatus* only in headwaters. This species also occurred in moderate currents at elevations of 500–100 m along with *Fluviopupa* sp., while at 100–10 m was *Septaria porcella depressa*, with *Neritina pulligera* and *Melanopsis frustulum f. multistriatus*. The latter

**Fig. 7** *Excoecaria* mangrove forest, Tongatapu. The cable roots are preferentially seeking out a raised pathway built centuries ago

occurred in lower elevations at 10–1 m along with *Clithon nucleolus* and *Neritina variegata*. River floods can however devastate freshwater snail populations, for example from 1,475 individuals per $m^2$ in the Wainibuka River, Viti Levu before a cyclone, to 250 post cyclone, with slow recovery (Haynes 1990).

There is little monitoring in the region apart from in coral reefs. In New Caledonia monitoring commenced in 1997 and expanded in 2003 (Lovell et al. 2004) with the French Initiative for Coral Reefs funding a new phase. Censuses were carried out at 31 stations over 11 sites. The overall status of the sampled sites was satisfactory in 2003, with the exception of three sites that demonstrated hyper-sedimentation from estuaries, or over-fishing. Outside marine protected areas invertebrates and fish diversity and abundance were generally poorer, and individuals smaller.

Fiji's reefs are a significant proportion of the world's coral reefs, and are recognized as being of high ecological significance from a biodiversity standpoint (Whippy-Morris and Pratt 1998; Obura and Mangubhai 2001). However, Fiji's coral reef biodiversity is not well known (Vuki et al. 2000). The Great Astrolabe Reef on Kadavu is the best studied, including coral distributions and ecology, water quality, and fisheries (Schlacher et al. 1998; Morrison and Naqasima 1999; Obura and Mangubhai 2001).

Fiji's marine environment has been better studied than most other Pacific Island countries, though generally in an ad hoc manner (Zann and Vuki 2000). Marine studies in Fiji are facilitated by a good marine research and training capability at USP (Veitayaki and South 2001), though people in government with training in reef monitoring tend to move to other positions and do not utilise these skills (Sulu et al. 2002). There have been very few long term ecological studies on the reefs of Fiji (Vuki et al. 2000).

In 2000, Fiji's reefs suffered an extensive mass bleaching event, causing loss of 40–80% of stony corals across the country (Cumming et al. 2002). At this time, the Global Coral Reef Monitoring Network Fiji (GCRMN) node was formed to monitor current reef health from around the region. The value of monitoring networks has been made apparent through this GCRMN Fiji node, the Reef Check program (Cumming et al. 2002) and the Fiji Local network. Monitoring efforts have become more coordinated, which has been more recently improved with the Coral Reef Initiative for the South Pacific (CRISP). In some coastal areas, poor inshore water quality with nutrients, suspended sediment and trace metals affect inshore reefs (Vuki et al. 2000).

CRISP initiated in 2002 with 15 projects in at least 15 countries and territories of the SPREP region (Kaur and Emmanuelli 2006). With E12 million from the French Development Agency and further funding from the French Pacific Fund and WWF (World Wide Fund for Nature) its objectives are to gain a better understanding of coral reef biodiversity, protect and manage reefs, promote economic gains from reef use, and build information capacity and networks in the region.

The reefs of Tonga and Vanuatu are little studied compared with New Caledonia or Fiji. In Palau the vulnerable humphead wrasse *Cheilinus undulatus* uses lagoon branching coral mixed with bushy macroalgae as nursery sites, while the squaretail coralgrouper *Plectropomus areolatus* almost exclusively uses coral rubble habitats between 5 and 7 m in depth (Tupper 2007).

## Wetland use and environmental impacts

Pacific Island peoples through their Lapita origins have a long history of use of wetland coastal resources, including the development of traditional management strategies (Matthews 2004). With limited resources and growing populations, the alteration of wetland resources under unsustainable use has however become recently intense in some locations. Within a country, there tends to be internal migration to the capital island, where opportunities are the highest. This also leads to intense pressure on the natural resources of the capital island and associated environmental pressures and degradation. However, some of the outlying islands in the Pacific Island countries and territories remain among the most pristine in the world.

Estimated subsistence fisheries production in the Pacific Island countries is shown in Table 2, with every coastal village in the region involved in these activities (Dalzell et al. 1996). There has however been recent large declines in consumption of lagoon fish in Rarotonga (Cook Is) owing to the prevalence of fish poisoning that probably results from watershed pollution (Hajkowicz 2006). Commercial fisheries are largest in Fiji, Kiribati and PNG. The majority of annual catch comes from shallow reefs and inshore lagoons. Inshore fishing in Samoa is essential to the subsistence economy, with 55% of families fishing for subsistence each week. In all countries fisheries have declined in recent years due to over exploitation, along with clams and turtles (Zann and Vuki 2000).

However, coastal construction is responsible for degradation of inshore coral reefs and erosion of coastal areas in many countries. Inshore reefs also tend to be under heavier pressure from commercial coral collection (Lovell 2000), Fiji is the major exporter of live coral in the Pacific Islands, along with exploitation of reef products for a range of other purposes. Dynamiting of coral reefs is common in western Viti Levu, and the use of poison (such as *Derris*) are relatively prevalent in most areas of Fiji (Vuki et al. 2000).

Over-fishing in Fiji is well documented over several decades, with consequent decline in mullet numbers, stout chub mackerel and trevally (Lal et al. 1983; Fong 1994; Jennings and Polunin 1996; Vuki et al. 2000). There is no systematic monitoring to detect over-fishing (Vuki et al. 2000), and better management of inshore fisheries needs additional resources (Hunt 1999). Over-exploitation has resulted in the recent extinction in Fiji of the giant clams, *Hippopus hippopus* and *Tridacna gigans*. Fijian breeding populations of green turtles (*Chelonia mydas*) and hawksbill turtles (*Eretmocheleys imbricata*) are very seriously endangered and will become extinct unless urgent action is taken (Vuki et al. 2000).

Mangrove forests provide Kosreans with the equivalent of nearly \$1 million year$^{-1}$ or approximately 14% of median annual household income from the harvest of fish, fuel wood and crabs (Naylor and Drew 1998; Ewel 2008). Combined with freshwater *Terminalia* forests, these wetlands provide \$4 million annually (equivalent to 60% of median annual household income; Drew et al. 2005). Uses of mangroves in the region are reviewed by Ellison (1997, 2002), with widespread fishing, gathering of clams and crabs, wood for construction and handicrafts, and fuel wood sources.

Seagrasses are used by Pacific islanders as a food, also for the manufacture of baskets, burning for salt, bedding, roof thatch, upholstery or packing material, fertiliser, insulation, cigars and children's toys (Coles et al. 2003). Seagrass beds are also an important food source for subsistence and commercial fisheries, and provide a sediment sink for the benefit of coral reefs. Coastal developments usually proceed without assessment of impacts on seagrass meadows, such as the building of causeways without consideration of the need to maintain water flow, and direct reclamation (Coles et al. 2003).

Deforestation of catchments in volcanically young and rugged high islands particularly has led to massive soil erosion and impacts upon wetlands. Since human arrival on Mangaia, Cook Islands soil erosion has caused the infill of four out of five coastal lakes (Ellison 1994a). On the wet side of Viti Levu in the Waibau area including the Rewa river basin Nunn (1990) estimated soil losses of 35 tonnes ha$^{-1}$ year$^{-1}$. Land degradation included aerial evidence of 620 landslides in the catchment with 570,000 m$^3$ of eroded material associated with a major storm and land disturbance.

Some freshwater forested wetlands, such as the *Terminalia* swamp forests of the Solomon Islands, are managed for commercial logging. Others, such as the sago palm *Metroxylon sagu* wooded swamps of PNG, are important for subsistence livelihoods. Surveys on usage of *Terminalia* forest wetlands in Kosrae, FSM found provision of goods worth \$2,505 ha$^{-1}$ year$^{-1}$, including agricultural products of \$1,946 ha$^{-1}$ year$^{-1}$ (Drew et al. 2005). Threats to swamp forests include unsustainable logging and excessive burning.

Wetlands play a significant role in the livelihood of Fiji's population (Lal et al. 2004), producing resources that are consumed in rural areas and also provide much of those that are sold to urban markets and outlets. Despite their importance, wetlands are becoming a vulnerable eco-system from both natural and human-induced impacts. Natural disasters such as cyclones and storm waves have caused extensive damage to coral reefs and at many places initiating coastal erosion. But the less dramatic, day to day impacts of human activities have far reaching consequences. This includes logging of mangroves, foreshore reclamation and developments, impacts of inland activities and land-use to the coastal zone, unsustainable commercial fisheries, poor water quality and conversion of inland wetlands to taro cultivation. Davis and Quinn (2004) found high intensity of damage from the bark stripping of *Bruguiera* in areas adjacent to a residential area, with mangrove decline around Suva due to expanding land use and increased resource utilisation.

Pacific Island countries are particularly vulnerable to the effects of invasive species, resulting in higher rates of extinction than anywhere in the world (Sherley 2000). Two widespread invasive exotic pest species, *Salvinia molesta* and *Eichornia crassipes* (water hyacinth) are now widespread in many of the lowland wetlands of PNG (Nicholls 2004). Fundamental to these problems is shortage and inaccessibility of scientific information on basic biology for management of pests, lack of awareness on impacts, insufficient networking systems of information exchange, and little coordination within the region. Existing legislation, regulations and cross-sectoral policies in Pacific Island countries do not fully address the impact of invasive species on biodiversity, and there is a shortage of technically trained personnel.

## Wetland conservation and management

### Ramsar

Uptake of the Convention on Wetlands of International Importance (Ramsar Convention) has been slow in the Pacific Island region relative to other areas of the world. PNG was the only signatory until the last few years, and now there are a total of five countries with Samoa, Palau, the Marshall Islands and Fiji joining. Kiribati is likely to join in 2007 with a Ramsar small grant to develop an information sheet, and the Cook Islands, Tonga and Nauru are considering joining (V. Jungblut, pers. comm.). The Ramsar sites (Table 5) represent the range of wetlands found in the region, from highland lakes and swamps, to coastal freshwater floodplains, and atoll and lagoon systems.

There are currently six Ramsar sites in the region, two in PNG and one each in the other signatory nations (Table 5). A further three are in the process of being nominated in each of Samoa, the Marshall Islands and Fiji. A member since 1993, PNG hosted the 1994 regional wetland workshop (Jaensch 1996), then funds were secured from Australia by the Asian Wetland Bureau to continue Ramsar promotion and support in the region 1995–8. In 1999 a package of World Conservation Foundation funds was awarded to five countries to prepare for Ramsar accession. In 2002 SPREP and the Ramsar Convention signed a Memorandum of Understanding and developed a Joint Work Plan to further sustainable use of wetlands in the region. In 2004 a new out-posted office of the Ramsar Convention was created for the Pacific Region, based at SPREP to further conservation and management of wetlands, with the appointment of a Ramsar Officer. This followed the loss of a Wetland Officer position from SPREP, and the Ramsar Officer by default took over responsibility for implementation of the Regional Wetland Action Plan (SPREP 1999).

### Legislation

At the regional level there are plans, policies and partnerships that are mostly regionally accepted having been voted on by the SPREP council representing all member countries. Many countries are still in the process of getting legislation into place, or revising existing legislation to make it more usable. Fiji and the Cook Islands are the better advanced in this process, while Samoa is still in the process of revising its key 1989 Lands, Surveys and Environment Act. PNG's environmental legislation has recently undergone major revision and realignment with the enactment of the new integrated Environment Act 2000 (Nicholls 2004). This was designed to be simpler and more usable, with greater onus on the

**Table 5** Ramsar sites in the Pacific Island region

| Country | Ramsar site | Designation | Size (ha) | Wetland types |
|---|---|---|---|---|
| PNG | Tonda wildlife management area | 16-03-1993 | 590,000 | Swamp forest, mangroves |
| | Lake Kutubu | 25-09-1998 | 4,924 | Lake, reed swamps |
| Samoa | Lake Lanoto'o | 10-07-2004 | 470 | Three crater lakes, herbaceous marsh, swamp forest |
| Marshall Islands | Jaluit Atoll | 13-07-2004 | 69,000 | Reefs, lagoons, seagrass, mangroves, sand cays |
| Palau | Ngardok | 18-10-2002 | 493 | Lake, herbaceous swamp |
| Fiji | Upper Navua | 11-4-2006 | 615 | River, highland rainforest |
| Vanuatu | Uri (Narong) Marine Park | Pending | 200 | Mangrove, reefs, mudflat, seagrass, sand cays |

developer in terms of compliance with prescribed standards and approval conditions, and the responsibility in avoiding serious environmental harm. There is still a need however for environmental inspections and verification. The Department of Environment and Conservation is currently considering a number of options to provide important environmental regulations services (Nicholls 2004).

The GEF funded International Waters Project recently carried out environmental legislative reviews in 5 countries: Fiji (Evans 2006), Niue (Powell 2007a, b), Samoa (Powell 2004), Tonga (Powell 2006), Vanuatu (Tavala and Hakwa 2004). There were earlier reviews carried out as part of SPREP projects such as Pulea (1992) in Tonga, and Pulea and Farrier (1994) in Tuvalu. The environmental legislation in SPREP member countries can be viewed through the legal pages of the SPREP website (http://www.sprep.org), connecting to the Pacific Islands Legal Information Institute of the USP Law School.

Environmental law in Tonga was found to be scattered through a range of legislation on public health, land, fisheries and water (Pulea 1992). Despite the Water Board Act 2000, there remains no comprehensive law dealing with the ownership, management and protection of water resources (Powell 2006). A number of laws in Tonga make appropriate provision in relation to the protection, conservation and management of coastal waters (Powell 2004), including the Fisheries Management Act 2002 applying to the conservation of fisheries resources. Revised legislation however is needed for the protection of whales and other wildlife.

In Niue, the Environment Act 2003 is the principal environmental law, founding an Environment Department with provision to protect indigenous flora and fauna, and coastal zones, and carry out environmental monitoring (Powell 2007a). A power to make environmental impact assessments is given to Cabinet, however substantive provision for this is not made in the Act (Powell 2007b). There is also no effective provision in Niue's laws controlling the dumping of wastes on land (Powell 2007b). The Water Resources Act 1996 influences activities which may influence water quality, protecting natural sources of water, ensuring the investigation of development proposals which may impact the water resource (Powell 2007a). As Niue is a limestone island, this specifically includes cave water and groundwater.

Environmental legislation in Tuvalu is fragmentary particularly in land use planning, and with some significant overall gaps (Pulea and Farrier 1994). A broad range of responsibilities are conferred on local councils, and there are doubts about the carrying of responsibility at this level, such as in the siting of wells and toilets. Lacking in Tuvalu legislation was environmental impact, mining regulations, the water act still proposed at that time, and control of human development influences on wildlife habitat.

In Fiji, much legislation in use is old and outdated, with very little attention given to environmental issues, and little opportunity given for stakeholders to have a say (Evans 2006). In the 2005 Environmental Management Act includes an environmental impact system, and a natural resources inventory, database and management plan. However, the coastal zone definition in the Act excludes water and includes only land (Evans 2006).

In Vanuatu some laws are specific to a particular resource such as water resources (Tavala and Hakwa 2004), while others such as the Environmental Management and Conservation Act 2002 cover a whole ambit of natural resources. In Samoa there has been a remarkable level of legislative reform in recent years (Powell 2004), however it remains urgent to reform environment related laws. For example, the Lands, Surveys and Environment Act 1989 is to ensure and promote the conservation and protection of natural resources and environment. Provision is made for the protection of foreshores and coastal waters (Powell 2004). However, it is not specific enough to mangroves to ensure their protection. Despite the efforts of many in relevant departments, there has been extensive conversion of mangroves to the west of Apia in recent years. Mangroves that are in law government owned land have been reclaimed, subdivided and sold for commercial activities (Boon 2002). Overall, the degree of enforcement of environmental legislation in the Pacific Island region is generally poor, though there are exceptions particularly in the US territories with EIA procedures established.

## Community management

Wetlands in the region are under customary ownership protected by the constitutional rights of local people. Management has to work through the traditional systems, and also work in with the needs of the village to function socio-economically in a culturally acceptable manner. There are recent examples where this has been successful such as the Locally-Managed Marine Area Network (LMMA 2006). In Fiji, there are currently more than 100 Marine Protected Areas on Fiji's coastal reefs being managed by local communities, covering approximately 15% of Fiji's coastline (Tawake and Rupeni 2004). The Fiji LMMA network includes NGOs and conservation organisations, university institutes, government departments, tourism concerns and private enterprise. Pohnpei (FSM) now has 11 Marine Protected Areas designated by law.

In the last few years the number of NGO initiatives has grown particularly, particularly in PNG (Nicholls 2004) and in Fiji. Many of these programs focus on a conservation and development approach integrated into a locally-based development model. WWF has been working with communities in Tikina Wai since 2000, where three mangrove reserves are established and managed by a committee with representatives from six villages. From condition reports, the committee controls levels of use within the mangrove resource. In FSM, catch sizes of the mud crab (*Scylla serrata*) correlated with differences in harvest pressure of local villagers (Ewel 2008; Bonine et al. 2008), demonstrating that community management of this valued resource may be effective.

Trying to address needs in both regional legislation and community management has been the SPREP regional wetland action plan (RWAP).

## Regional wetland action plan

In the RWAP (SPREP 1999) endorsed by the 26 member countries, 28 actions were identified as needed in the areas of management, capacity building, research and monitoring and specific needs for freshwater wetlands. Table 6 summarises these actions, work subsequently carried out, and the current situation for each.

Since 1999 regionally coordinated, nationally executed programs have developed National Biodiversity Strategies and Action Plans (Wright et al. 2006), which include wetland ecosystems. Examples cited elsewhere are Fiji (Whippy-Morris and Pratt 1998), Niue (Richmond-Rex et al. 2001) and Samoa (Schuster and Butler 2001). Developing these plans each involved a multi-sectoral Steering Committee that assimilated material from technical steering groups and community workshops, with assessment of biodiversity and threats to these.

In 2005 a wetland workshop was organised by SPREP to assess the current status of wetland management in the region (V. Jungblut, pers. comm.). This identified four key challenges:

1. Limited awareness and support for wetland conservation and management at government and community levels.
2. Insufficient knowledge on which to base wetland conservation and management decisions, and limited access to existing knowledge.
3. Limited ability of local communities to influence and control the wise use of their wetlands.
4. Inadequate policy and institutional frameworks for biodiversity and natural resource management.

The Pacific region has a long history of project based work funded by international aid donors such as the US, Australia, NZ and France mostly in association with political affiliations (Table 1), or increasingly by NGO's. Two major projects give examples of the challenges faced by such projects and their achievements, the South Pacific Biodiversity Conservation Programme (SPBCP) and the current Conservation International (CI) Biodiversity Hotspots Program.

## South Pacific Biodiversity Conservation Programme

The SPBCP was a multi-country conservation initiative 1992–2001 primarily funded by the UNDP Global Environment Facility (Baines et al. 2002) with an initial US $10 million grant later extended, and was based at SPREP. Some consultants to the project were AusAID-funded. The project intended to improve management of the biological diversity of island countries by helping establish conservation area projects at selected sites, and there develop management and sustainable use in cooperation with local communities. The 17 Conservation Area (CA) project sites in 12 countries encompass a range of ecosystems, chosen for significant biodiversity values (Table 7). About half of these are primarily coastal wetlands (lagoon, mangroves, coral reef), while the majority of the rest are inland forest areas including

**Table 6** Wetland actions of the regional wetland action plan (SPREP 1999)

| RWAP action 1999 | What was done | Current situation |
|---|---|---|
| Establish a wetlands management officer position at SPREP to implement the RWAP | Recruited 2002–2005, then position discontinued | Ramsar Officer at SPREP has taken on the RWAP |
| Inventory and mapping as baseline for development of management plans | Some ad hoc activity in Vanuatu, FSM, Tonga and PNG | Coral reef related: NASA Millennium coral reef assessment, NOAA Benthic habitat mapping for US territories, Coral Cay Conservation, WWF/WCS Seascapes work; Update underway of the 1993 Directory of Wetlands in Oceania |
| Establishment of mangrove/wetland committees | Some established e.g. Fiji, Marshall Islands | Otherwise, existing committees taking this on as a secondary role |
| Preparation of management plans | Some activity in Samoa, Fiji, Tonga, Kiribati, Marshall Islands, Palau. Also through the SPREP SPBCP project at CA sites | Little activity—wetland management plan development training scheduled for Nov 2007 |
| Implementation of plans | Little activity | Contained in country national biodiversity strategy action plans |
| Review of management plans | Little activity | Little activity |
| Legislation and policy for protection of wetlands | International Waters Project at SPREP 04–07 did environmental legislative reviews in five countries, national biodiversity strategy action plan | Some improvements in Samoa, Vanuatu (see text) |
| Improved environmental impact procedures | As above; annual training course for countries in SEA/EIA funded by JICA | Stronger in US affiliates/territories, Biodiversity related EIA/SEA training attended by Palau and Marshall Islands |
| Linkage and coordination between wetland projects active in region | Some activity | Better with WI and IUCN new regional offices in Fiji. Coastal wetland practitioner exchanges between FSM and Am Samoa, Tuvalu and Kiribati |
| Institutional strengthening and staff training | SPREP in collaboration with USP runs a bi-annual regional Community-based conservation course since 2001; Ramsar SGF projects in Fiji, Tonga and Marshall Islands | Little regional technical expertise |
| Community education on wetland values | Booklets, education kits and posters produced in Samoa, American Samoa, Tonga. Access to Ramsar CEPA tools of Ramsar PIC parties | Public awareness has improved, annual World Wetlands Day national awareness campaigns (Feb 2) |
| Interpretive facilities for visitors | Established in Samoa, recently American Samoa, Marshall Islands, Federated States of Micronesia | Samoan boardwalk in disrepair since SPBCP finished |
| Information management | Some ad hoc progress in Samoa, PNG, Fiji, GLOMIS | Marine conservation analyst position under recruitment at SPREP, SOPAC mapservers project (EU funded) |
| Regional monitoring of mangroves | Ad hoc trials in Tonga, American Samoa, Marshalls | Draft manual produced by SPREP under review |
| Documentation of traditional knowledge | Mostly national level work in Vanuatu, Samoa, Fiji; SPC/PIFS model laws on culture and traditional knowledge related to biodiversity | Nothing coordinated |
| Ecological research on knowledge gaps | Some activity in FSM, Fiji (WWF) | Still great needs exist |

**Table 6** continued

| RWAP action 1999 | What was done | Current situation |
|---|---|---|
| Improved knowledge of endangered species | Regional turtle/dugong action plans, WCMC mapping | Conservation International work (see text) |
| Sea level rise impact work and monitoring | US EPA project in American Samoa, PI GOOS project; UNEP regional seas/WPRFMC study on Pacific Island mangroves in a changing climate and rising seas; National V& A assessments carried out under SPREP PICCAP project, CBDAMPIC project funded by Canadian government, AUSAID Sea level monitoring project | SPREP mangrove monitoring manual under review |
| Research on economic values | Some activity in Cook Is, Fiji, Samoa. Some IWP reports | Some expertise in region (Fiji, American Samoa). |
| Improved biodiversity conservation | National biodiversity strategy action plans published | Remaining BSAP's published this year (i.e. Tonga) |
| Better awareness on introduced species | Regional invasive species strategy 2000, GEF regional invasive species project proposal (pending) | Trial eradication pilot projects (FSM), Samoa currently in planning phase; Pacific Islands invasive species learning network |
| Better awareness on river modification | No progress | No progress |
| Pilot studies on sustainable fisheries | Some marine work, Little freshwater (Tilapia and freshwater shrimp trials in Samoa) | Little progress |
| Studies on appropriate lake ecotourism | No progress | No progress |
| Map and classify freshwater wetlands | No progress | No progress |
| Regional inventories of flora and fauna of freshwater wetlands | Ad hoc work—Bishop Museum etc | Some progress, reviewed in text |
| Assess threats to freshwater fauna | Ad hoc work—Bishop Museum etc | Some progress, reviewed in text |
| Research on ecology of freshwater species | Ad hoc work—PNG, Fiji, Vanuatu | Some progress, reviewed in text. Planned freshwater fauna surveys for Tonga, Solomon Islands and Samoa funded by IUCN Oceania in conjunction with the Museum of Natural History and Wetlands International Oceania (June 2008) |

(Table developed with assistance from Vainuupo Jungblut, RAMSAR Officer, SPREP)

**Table 7** Conservation area project sites of the South Pacific Biodiversity Conservation Programme

| Country | Name | Type |
|---|---|---|
| Cook Islands | Takitumu | Inland forest and fern forest |
| FSM | Utwe-Walung, Kosrae | Forest, mangroves, lagoon and reef |
| | Pohnpei Island | Upland, swamp and mangrove forest |
| Fiji | Koroyanitu | Tropical montane forest, rivers |
| Kiribati | North Tarawa | Atoll, coral reefs, lagoon, mangrove |
| | Kiritmati | Atoll, coral reefs, lagoon, island forest |
| Marshall Islands | Jaluit Atoll | Atoll, lagoon, coral reefs, mangroves |
| Niue | Huvalu Forest | Lowland inland and coastal forest |
| Palau | Rock Islands | Limestone islands, coral, lagoons |
| | Ngaremeduu | Lagoon, coral reefs, mangrove, forest |
| Samoa | Sa'anapu-Satoata | Mangrove swamp, lagoon, coral reef |
| | Uafato | Rainforest, rivers, mangroves, coral |
| Solomon Islands | Komarind | Rainforest and river catchment |
| | Arnarvon Islands | Islands, mangroves, coral reefs |
| Tonga | Ha'apai Islands | Rainforest, lagoons, coral reefs |
| Tuvalu | Funafuti | Atoll, coral reefs, lagoon, Island forest |
| Vanuatu | Vatthe | Lowland limestone alluvial forest |

wetland or riverine habitats. The smallest wetlands would be at Huvulu Forest, Niue.

Each site initially developed a project proposal document, and then resource condition reports. The process of reporting varied markedly between countries, some producing 150 pages and some 20 or less, I found it difficult to obtain many of these reports. The scientific detail of wetland assessment was limited, with focus more on training and community capacity building. Information on biodiversity was achieved only late with the addition of community-based biodiversity monitoring.

While coordinated at SPREP in Apia the project employed Conservation Area Support Officers in participating countries, and occurred before the advent of email communication in the region. This centralised approach was inefficient and ineffective, with difficulties of travel between countries and considerable differences in cultural aspects of tenure and resource conditions between countries. This has not been the only regional project to demonstrate that it is difficult from these to bring benefits to community levels. While all CA's were of biodiversity value, some very significant, some CA's had inherent problems that retarded their success. These included civil strife in the Solomons, raiding of biological resources by adjacent communities at North Tarawa, sharing of the CA by two villages with little history of cooperation at Sa'anapu-Sataoa, poor stakeholder involvement choices at Utwe-Walang and land ownership dispute problems at Vatthe.

However, of the 17 sites involved in the SPBCP project over the 10 year period to 2001, more than half are still operating today as a community based protected area (F. Martel, pers. comm.), while some others have been taken over by another agency, such as Jaluit Atoll is now a Ramsar site, and Vatthe was recently a world heritage site nomination. There has also been a benefit from the project in the training and mentoring of a large number of conservation practitioners across the region.

## Conservation International Programs

Techniques for choosing areas for conservation have become increasingly sophisticated, as demonstrated by the current CI projects in the region. Recent activities have prioritised areas with a high proportion of endemic taxa that have evolved in and are restricted to a particular area (Fa et al. 2004).

Commencing in 2005, the CI Pacific Islands Program comprises three main components: the Polynesia-Micronesia biodiversity hotspot (Allison and Eldredge 2005), the New Caledonia biodiversity hotspot (Lowry et al. 2005) and a Marine Conservation Initiative. There is a separate East Melanesian hotspot (Beehler et al. 2005), including Vanuatu, the Solomons and the northern islands of PNG. The New Caledonian hotspot is the smallest of the CI global biodiversity regions, but is exceptionally diverse being a Gondwanan continental fragment, with 265 species classified as globally threatened. The East Melanesian region has unique insular biodiversity under pressure from accelerating habitat loss, making this region a priority for global conservation effort.

The Polynesia-Micronesia biodiversity hotspot includes most of the central and eastern islands of the SPREP region (Fig. 1) with islands ranging from the large Fijian Islands over 40 million years old to more recent volcanic hotspot islands of the eastern Pacific. The hotspot has 536 terrestrial and marine species that are classified as globally threatened (476 are terrestrial and 60 marine). As a consequence, 161 terrestrial Key Biodiversity Areas have been identified in the Polynesia-Micronesia hotspot, including wetlands, each on the basis of presence of one or more globally threatened terrestrial species (F. Martel, pers. comm.). These are identified through similar methodology to Birdlife International's Important Bird Areas, using criteria and thresholds based on the vulnerability and irreplacability of individual sites within the broader geographic region. These sites are identified through a participatory, consultative and scientific process, with interaction with other key partners such as the Bishop Museum. Sites that are the only remaining location where a globally threatened species is found are designated as a top target, as an Alliance for Zero Extinction Site (Ricketts et al. 2005). There are 26 such sites so far identified in the Pacific Island region (Table 8), most of which have no protection.

Of these 161 Key Biodiversity Areas, there are a total of 48 in the region that are wetland locations and species (42 marine and 6 freshwater; J. Atherton, pers. comm.). These sites all have wetland obligate species from the IUCN (2006) redlist, and some marine sites have more than one threatened species.

There are many limitations to this assessment that require further work, such as the list currently excludes fish and corals, and seabirds such as the Phoenix petrel (J. Atherton, pers. comm.), and there is a great paucity of data on freshwater species and habitats in the region. This was demonstrated by Polhemus et al. (2000), Polhemus et al. (2004) and Boseto (2006) reviewed in the lacustrine, fish and invertebrate sections earlier. Also only 14 of the 20 countries in the hotspot have signed the UNEP Convention on Biological Diversity so are eligible for Critical Ecosystem Partnership Funds. Unsigned countries are not a priority in the vast CI workload.

## Discussion and recommendations

The wetlands of this region are biogeographically fragmented by physical separation of habitats within the biomes of coral reefs, mangroves, seagrasses, and even more so within the freshwater wetland types. Like the forest vegetations described by Mueller-Dombois (2002), wetlands in the Pacific Islands have many analogous environmental settings, but due to the filter effect of oceanic separation there is a unique biogeographic complexity not found in continental tropical regions. The species present in wetlands all differ between countries (Table 2). This results from two factors, first, as confirmed by this review the centre for species diversity within all groups is on the margins of the western edge of the region, and second, island size tends to decrease and island isolation increase towards the east and north of the region.

This review has found that baseline survey of wetlands in the Pacific Island region has improved since the assessment of Watkins (1999), but large gaps still require attention. There remains lack of baseline assessments, wetland inventory (Whyte 2002), and the mechanisms by which to identify management needs. Freshwater wetland mapping and classification are particularly needed, these could use the soil maps that exist in most countries (e.g. Orbell 1983).

The biotas of the Pacific Island wetlands are vulnerable to the impacts of introduced species. The greatest threat to the rich aquatic biota of New Guinea and other Melanesian Islands is in individual cases the physical destruction of habitats, but regionally the impacts of invasive species (Polhemus et al. 2004). For example, cane toads *Bufus marinus* have been introduced to Guam, Fiji, Papua New Guinea, the Solomons and American Samoa (Eldredge 2000), and ecological impacts have been disastrous. Invasive fish species have been documented to cause extinction or severe range reductions of native fish in other parts of the world, and their impacts in New Guinea are at present conjectural (Polhemus et al. 2004). The situation is

**Table 8** Alliance for zero extinction sites in the Pacific Islands (data from http://www.zeroextinction.org)

| Country | Site name | Species | Common name | Status | Area (ha) | Hotspot |
|---|---|---|---|---|---|---|
| PNG | Mt Simpson | *Stenomys vandeuseni* | Van Deusen's rat | EN | ? | E-M |
| | West Ferguson Mountains | *Dactylopsila tatei* | Tate's triok | EN | 30,000 | E-M |
| | Goodenough Mountains | *Dorcopsis atrata* | Black dorcopsis wallaby | EN | 10,000 | E-M |
| | Mount Elimbari | *Albericus siegfriedi* | | CR | ? | E-M |
| | Telefonin Valley | *Phalanger matanim* | Telefomin cuscus | EN | 10,000 | E-M |
| Solomons | Makira Mountains | *Gallinula silvestris* | Makira moorhen | CR | ? | E-M |
| | Ramos Island | *Gallicolumba salamonis* | Thick-billed ground-dove | CR | 4 | E-M |
| | Mt Makarakomburu | *Pteralopex pulchra* | Montane monkey-faced bat | CR | ? | E-M |
| N Marianas | Sabana region, Rota | *Zosterops rotensis* | Rota bridled white-eye | CR | 2,541 | P-M |
| | Saipan | *Cleptornis marchei* | Golden white-eye | CR | 12,000 | P-M |
| FSM | Mt Winipot | *Rukia ruki* | Faichuk white-eye | CR | 125 | P-M |
| | Namoi Islands | *Pteropus phaeocephalus* | Mortlock Islands flying fox | CR | 1,631 | P-M |
| | Pohnpei | *Aplonis pelzelni* | Pohnpei Mountain starling | CR | 10,371 | P-M |
| Fiji | Nausori Highlands | *Dacrydium nausoriense* | | EN | ? | P-M |
| | Yadua Tuba | *Brachylophus vitiensis* | Fiji crested iguana | CR | 70 | P-M |
| New Caledonia | Port Boisé | *Araucaria nemorosa* | | CR | 1,000 | NC |
| | Uvea | *Eunymphicus uvaeensis* | Uvea parakeet | EN | 8,240 | NC |
| Samoa | Tua sivi Ridge, Savaii | *Gallinula pacifica* | Samoan moorhen | CR | ? | P-M |
| Cook Islands | Rarotonga | *Pomarea dimidiata* | Rarotonga monarch | EN | 155 | P-M |
| French Polynesia | Maruapo Valley, Tahiti | *Pomarea nigra* | Tahiti monarch | CR | 25 | P-M |
| | Makatea, Tuamotus | *Ducula aurorae* | Polynesian imperial-pigeon | EN | 17,000 | P-M |
| | Acteon Group, Tuamotus | *Gallicolumba erythroptera* | Polynesian ground-dove | CR | 306 | P-M |
| | Ua Huku Island, Marquesas | *Vini ultramarina* | Ultramarine lorikeet | EN | 8,100 | P-M |
| | Nuku Hiva Island, Marquesas | *Ducula galeata* | Marquesan imperial-pigeon | CR | 32 | P-M |
| | Hetutaa Island, Marquesas | *Gallicolumba rubescens* | Marquesan ground-dove | EN | 1,813 | P-M |
| | Mohotani, Marquesas | *Pomarea mendozae* | Marquesan monarch | EN | 1,354 | P-M |

EN = endangered; CR = critically endangered; E-M = East Melanesian hotspot; P-M = Polynesia-Micronesia hotspot; NC = New Caledonia hotspot

? means data currently unavailable

even less clear in regard to freshwater invertebrates. Research is needed on the effects of introduced species, and how quickly they are expanding their ranges, and resultant alteration of aquatic ecology.

The biotas are also vulnerable to direct human impacts, primarily from over-use of species valued for food products. There have been heavy prehistoric losses of birds, particularly rails, petrels, shearwaters, terns and kingfishers (Steadman 1991), and the ranges and population numbers of crocodiles, dugong and turtles have all been severely reduced.

Area estimates of Pacific Island wetlands as listed for mangroves (Table 2) are possible for the region's lakes (Scott 1993), but impossible for other wetlands. This is due to lack of comprehensive surveys of seagrass, coral reefs (where available area estimates for each country are at a resolution of 1,000 $km^2$), freshwater swamp forest (with the exception of FSM), riverine wetlands and marshes in the Melanesian countries. The sources of mangrove areas are in most cases dated by several decades (Ellison 1999).

The freshwater species of the region including obligate flora cannot be listed in distributions by country in the region as I have done for seagrass, mangroves and other coastal groups (Tables 2–4), apart from gastropods (Haynes 2001) and some fish. Freshwater flora tables were produced by Stemmermann (1981) for the American affiliates of FSM, Guam and American Samoa. In PNG the freshwater flora has 130 flowering plants, 21 ferns and fern-allies and 8 Characeae species (Osborne 1993). Of the freshwater aquatic obligate flora, Stemmermann (1981) listed 25 species in the American Islands, Smith (1979) described 10 of these in Fiji and there are none in Niue (Sykes 1970). In FSM Stemmermann (1981) listed 48 freshwater marsh species, while Fiji has 27 (Smith 1979) and Niue has 6 (Sykes 1970). Due to taxonomic changes such a review needs to be taken on by a better freshwater expert than myself, and turned out to be too huge a task for this paper.

None of the Pacific Island countries have a Wetland Policy or specific legislation that can centrally address wetland issues. There are a handful of legislations relevant to various wetland issues from the perspectives of various individual government sectors. Fiji has the best wetlands working group actively involved in community awareness, which facilitated Fiji to become a party to the Ramsar Convention.

In many islands of the Pacific, water resource assessments have not been conducted or have been based on limited data only. There is a shortage of good quality meteorological, hydrological, hydrogeological and water quality data in many of the countries (UNEP 2000). There is generally insufficient baseline data on freshwater quality to evaluate the impacts of developments or land use practices, and little data available on the physical, chemical and biological processes in island watersheds, including soil erosion, loss of biodiversity and land clearance (Falkland 2002). In PNG, the primary priority environmental issue recently found from an extensive review by Nicholls (2004) was declining water quality in rivers and coastal waters. Despite these issues being raised over the last 25 years, in some islands there appears to be a decline in the quality of data collection from long-term climate stations for example. Baseline surface and groundwater monitoring programs are needed, with staff training as a component (Falkland 2002).

Most projects in the region are generally a few years length in timeframe, which is unsuited for long term monitoring of benefits. An exception is the AusAID sponsored regional tide gauge network since the early 1990's (Mitchell 2006). It is difficult or impossible to measure direct changes in ecosystems over the timeframe of most project activities (Whyte 2002).

Gaps in wetland management in the region include weak or vague legislation for the sustainable use/protection of wetlands in many countries. There is continuing need for capacity building in management agencies including the capacity to enforce legislation, and improvement of poor technical understanding by staff on wetland science and rehabilitation. There is generally lack of consideration of wetlands downstream in planning or development. Wetlands are utilised without zoning for different levels of use and protection, or monitoring of sustainable use. This best happens in community-based conservation areas, where local committees close or restrict use of areas based upon the state of resources. Coastal wetlands fare better here than freshwater wetlands.

Unsustainable use of coastal wetlands in particular tends to occur due to the needs of coastal village communities, combined perhaps with some weakened traditional control of use of community natural resources. There is consequent poor condition of many coastal wetlands, which means they are less resilient to pressures from impacts such as storms or sea-level rise. While wetland projects have been carried out in the region, these have not been coordinated leaving an ad hoc result, and there has been lack of follow-on benefits of some projects in some countries. Apart from the Fiji wetland database (Lal et al. 2004), there has been little compilation of wetland information from past projects, though improvement of this situation is an objective of a new database position being created at SPREP.

For effective wetland management in this region, there has to be adoption at the village level of sustainable practices and suitable management (Huber and McGregor 2002). Top-down declarations of protected areas have resulted in little protection, while those in community-run conservation areas are governed by local committees with wide powers through the village social system.

Pacific Island wetlands are largely vulnerable because of their relatively small size, poor state of protection or available information, and proximity to rapidly increasing human populations with heavy demands on these natural resources to support their economic development (Wright et al. 2006). Climate change, sea-level rise and cyclone damage will increase vulnerability. The key to wetland survival is engagement of local communities in their sustainable management, with accessible technical support from the scientific community particularly in baseline assessment of the resource, monitoring and rehabilitation where required.

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