Conservation and management of mangroves in Australasia

Norman C Duke
Centre for Marine Studies
The University of Queensland
Brisbane QLD 4072 AUSTRALIA
Email: n.duke@uq.edu.au

Abstract. Mangroves occur in most countries across the Australasian region extending from the larger islands of Australia and New Guinea to those in north and south areas of the western Pacific Ocean. The mangroves are known for their high diversity with 53 plant species, being ~75% of the world's, from 22 genera and 20 plant families, while the total area equals around 10% of the worlds, with more than 18,000 km^2. Most occur along the Australian and New Guinea coastlines which also include most species. Mangroves are managed differently across the region. Based on Australian examples chiefly, this article briefly reviews chief threats and pressures, identifies policy issues and presents recommendations for the future.

Mangroves in Australasia

The Australasian region includes the islands of: Australia, New Guinea, New Zealand and the western Pacific Ocean (Fig. 1). Mangroves occur along most coastal areas extending to temperate latitudes around the North Island of New Zealand and southern Australia. There are no obvious barriers to dispersal of mangroves through the region. However, there are notable patterns in species numbers that show significant diversity gradients reflecting distinct dispersal limitations. The number of mangrove plant species in Australasia is maximal in the Indonesian-New Guinea archipelago extending to north eastern Australia. Beyond this, the numbers drop-off in two distinct directions: 1) towards the north and south, numbers decline toward higher latitudes reflecting a temperature gradient where species have limiting lower temperature tolerances; and, 2) towards the east, declining species numbers reflect possible differences in species dispersal ranges, establishment success and niche availability.

The total area of mangroves in the Australasian region exceeds 18,000 km^2. , representing around 10% of the world's mangrove forests. Australasian mangroves are also very rich in species and variants with 53 plant taxa recorded across the region (see Table 1). This is around 75% of those in the world. Two Indo-Malesian genera, *Aglaia* (Roxb.) Pellegrin and *Kandelia* Wight & Arnold, are absent but another, *Diospyros* L. (Duke *et al.* 1981), is apparently unique to the IWP region. There are seven endemic

taxa (including six species and one putative hybrid) in Australasia, compared with eleven in Indo Malesia.

To look more closely at Australasian mangroves, the region can be conveniently considered in three parts: 1) the coastlines that predominately face the Indian Ocean including West Irian, Western Australia and the Northern Territory; 2) the south western Pacific Islands extending east from the east coast of Australia, Papua New Guinea, the Solomon Islands, Vanuatu, New Caledonia, Fiji, Tonga, Nauru, Kiribati, Tuvalu, Samoa & American Samoa, Niue, French Polynesia and New Zealand; and 3) the north western Pacific Islands extending east from Palau, Yap (FSM), Guam, Pohnpei and the rest of FSM, Northern Marianas, the Marshall Islands to Hawaii. Note that all mangrove species in Hawaii and French Polynesia were introduced so these sites represent unnatural occurrences of mangroves. Declines in species numbers from west to east can be readily seen in Table 1. There is a corresponding decline in mangrove area largely correlated with island size. Hence smaller islands generally have lower species diversity through the region. The resulting plot of logarithm conversions of both axes (Fig. 2) is evidence that mangroves in Australiasia conform with the classic species-area relationship (MacArthur and Wilson 1967) where factors limiting species diversity relate to size of mangrove areas rather than other factors, like dispersal and establishment ability.

A further notable feature and curiosity of this region is the natural co-occurrence of an AEP species alongside IWP species. In the south western Pacific Islands of New Caledonia, Fiji, Tonga and Samoa, the American *Rhizophora*, *R. samoensis* occurs among trees of of the Australasian *R. stylosa*. The association is also clearly been long term because mature hybrids, called *R.* X *selala*, abound in most locations where parental taxa co-exist. This occurrence is particularly unusual since no other species have similarly disjunct distributions, and it is of great interest that *R. samoensis* is closely related to *R. mangle* which is widespread in the AEP. The common trend otherwise is for species of the IWP flora to range eastward by varying degrees with a notable decline in species numbers across the Western Pacific.

The distributional gradient eastward across the South-Western Pacific dominates the region (Fig. 1). In the west, New Guinea has the greatest diversity of mangroves in the world, owing to its location bordering Indo-Malesian and Australasian centres of diversity (Duke 1992). There are 47 mangrove species in New Guinea and 41 in northern Australia. Immediately east, in the Solomon Islands there are 22, while in Vanuatu and New Caledonia there are 16 species. The Federated States of Micronesia have 17 species. Nauru has only one species. Kiribati has 4 species. The Marshall Islands have 6 species. Tuvalu has 2 species. Fiji and Tonga have 9 species each, and Samoa has 3. The most widely-distributed mangrove species in the Pacific is *Bruguiera gymnorhiza*, occurring in all Pacific island mangrove communities except for the northern Ryukyus (Japan) and the southern limit of New Zealand. *Lumnitzera littorea* (Jack) Voigt. has the second largest range, not occurring in the Samoan group, or the southern Gilbert Islands

of Kiribati (Fosberg 1975). *Rhizophora stylosa* Griff. occurs throughout Micronesia and Guam and extends south of the equator to Tuvalu and Tonga but not to Samoa.

At the eastern limit of mangroves in Polynesia, the low diversity of mangrove species equates to some notable changes in community structure and microhabitat. In the absence of higher intertidal specialists, such as *Ceriops* Arnold., *Excoecaria agallocha* becomes more common in mangrove communities of Polynesia, forming unusual, extensive monospecific stands. In Tonga, *Excoecaria* L. forests dominate the mangrove area. In Samoa, *Bruguiera gymnorhiza* occupies most of the mangrove area, and the lack of available high intertidal plants may also explain the rare occurrence of tropical estuarine marshes (Whistler 1976). These observations imply that habitat availability is not a limitation on these islands.

Mangroves have been introduced in several Pacific islands to the east and north of the present natural limit. *Rhizophora mangle* was introduced to Enewetak in 1954 (St. John 1960). In Hawaii, *Rhizophora mangle* was introduced in 1902 to Molokai and Oahu, and *Bruguiera gymnorhiza* was introduced in 1922 to Oahu. Both are well established today (Wester 1982). Other species were introduced in 1922 but did not become established, including: *Rhizophora mucronata* last recorded in 1928; *Bruguiera parviflora* last recorded in 1948; and *Ceriops tagal* (Perr.) C.B. Robinson not after 1922. In French Polynesia, there are small areas of *Rhizophora stylosa* on Moorea and Bora Bora. It is not certain whether this was introduced or whether it is native (Ellison 1995).

Australian mangroves

The largest island in Australasia is Australia. It has the largest mangrove area of the region. However, the coastline borders higher latitudes where mangrove distributions are notably limited by temperature. Australia also has a dry climate. These key climatic factors have an important influence on the composition and extent of mangroves around the country (Duke 2006).

Australia, the island continent, is surrounded by approximately 11,000 km of mangrove-lined coast, being around 18% of the total coastline. Mangroves are uniquely adapted trees and larger shrubs that inhabit the tidal sea edge. The habitat they form is rich in plant diversity and structural complexity, but this varies from place to place. For example, in southern Australia, forests of *Avicennia marina* often form open, accessible parkland stands. By contrast, along the northern coast, *Rhizophora* species dominate as almost impenetrable thickets of arching stilt roots, especially in more arid regions.

Australia has the third largest area of mangroves in the world after Indonesia and Brazil, totalling around 11,500 km^2 representing approximately 6.4% of the world's total mangrove area. The larger forested areas of Australia's mangroves, approximately 75%, occur in the humid tropics to the north where human population densities are low. However, there are notable areas of mangroves in temperate regions as far south as Corner Inlet in Victoria around 38° S. This is the most southerly and highest latitude site

of mangroves in the world. These southern stands consist entirely of one species, *Avicennia marina*, a member of the plant family Avicenniaceae. Another mangrove family, the Rhizophoraceae, dominates the vast northern coastline. Australia is one of the world's largest countries, with a land area of over 7.7 million km^2. The country spans 33° latitudinal range between tropic and temperate zones from Cape York, around 10° S, to just south of Hobart, around 43° S. By longitude, the country spans 41°, more than 5000 km. Australia is also the world's driest inhabited continent. Bordering the coast of this vast dry land, mangroves exist as a relatively thin line hugging sheltered areas, including numerous islands and mainland enclaves. Around 70% of Australia's mangroves occur within the reported 974 catchment estuaries (Ozestuaries 2006).

Australia's mangrove flora is uniquely rich, especially along the north coast. This is partly due to Australia's proximity to species rich regions to the north. But, it also reflects regional influences of past changes over millions of years where massive continental fragments divided and rejoined mangrove communities. In the aftermath of such dramatic influences, mangroves flourish in Australia today because it is a large country affected by a range of climates with diverse temperature and rainfall conditions.

Australia's mangroves have the fourth highest species diversity of any country, after the Philippines, Indonesia and Papua New Guinea. Most species in Australia occur widely throughout the Indo-West Pacific region. However, one species, *Avicennia integra*, is found only in Australia. Furthermore, a number of additional mangrove species and hybrids are more common in Australia than elsewhere in the world. Such notable biodiversity features help define the special characteristics that make Australia's mangroves unique.

Australia's mangroves occur in all mainland States and Territories that have coastal boundaries, including Western Australia, the Northern Territory, Queensland, New South Wales, Jervis Bay Territory, Victoria, and South Australia. Most species occur along the northern coast but they have differing ranges west and east. Some distributions are continuous and some are widespread, but others are restricted to particular local areas. The distribution of Australia's mangroves is summarised in Figure 3 showing the different levels of diversity around the country. Notice that the number of species along the southern cooler coast is low while maximal numbers are found along the wetter parts of the warmer northern coast.

Mangrove status & quality of existing mangroves in Australia

The Australian coastline although relatively lightly populated, compared with other large countries with mangroves, has over 85% of its population living within 50 km of the coast. This reflects the coastal lifestyle that is an integral part of the Australian identity. It also reflects the location of the most hospitable areas for communities to develop in a

country that is largely arid. Furthermore, the trend to move to the coast continues, with all States and Territories reporting their highest population growth rates within 3 km of the coast. Therefore, one of the emerging great challenges of the 21st century is the need to mitigate current environmental damage and disturbance, while addressing the growing threats to diminishing natural habitat.

Changing use

Prior to the arrival of Europeans in Australia, just over 200 years ago, Aboriginal and Torres Strait Islander communities of coastal areas managed mangrove areas. Many natural resource products were gathered from coastal areas and used by Indigenous peoples in a sustainable way for more than 40,000 years. Over this time, Indigenous people had little, or no, negative impact on these ecosystems. Mangroves continue to have high cultural significance to Aboriginal communities. Many Indigenous foods continue to be obtained from mangrove environments, including boring bivalves, clams, mud crabs, mangrove worms, and the fish, Barramundi and Mangrove Jack. Certain mangrove plants are also used as food, like *Avicennia marina* fruit. Mangrove plants are also a source of medicines. For instance, the ashes from burnt *Ceriops australis* and *Camptostemon schultzii* wood is used to heal sores and infections, while the bark of *Avicennia marina* is used to treat stingray stings. Mangrove timber has been used to construct canoes, paddles, spears and boomerangs. The list of such uses is long and diverse.

Current values

Australia's mangroves suffer unfairly from a bad image. This is compounded by the often destructive practices associated with unlawful access, the refuse dumped on them, and damaging alterations to hydrology and drainage. Mangroves and tidal wetlands have often been viewed as wastelands, as breeding grounds for mosquitos, as smelly and distasteful places, and as landfill sites for the creation of desirable land for coastal services and urban living. Notwithstanding such views, however, there are many who are beginning to appreciate the numerous benefits provided by mangroves.

Use and benefits

Australia's mangroves have a broad range of benefits based on their primary and secondary production, as well as their woody biomass and forested structure. The benefits of mangroves in Australia include:- fishery products of both estuarine and coastal fishes, crustaceans and molluscs; shoreline protection based on mangrove tree and root structures in reducing erosion, and providing stand protection from waves and water movement; nutrient uptake, fixation, trapping and turnover; carbon sink and sequestration; secondary production via grazing and decomposition of mangrove plants plus associated microbial and faunal production; sediment trapping based on mangroves being a depositional site for both water and airborne sediments that help reduce turbidity of coastal waters; a habitat for specialised fauna; a nursery habitat; food resources for animals such as migratory birds and fish; occasional forest products like timber and

firewood; and, visual amenity where selected mangrove trees provide shoreline beautification.

Threats, issues & problems in Australasia

Mangroves are readily valued for some benefits, such as their importance for fish biomass and diversity plus coastal protection. However, mangrove areas have been steadily removed from the more populated estuaries, particularly in Australia over the last 150 years. These practices indicate how mangroves and tidal wetlands have been valued more for their conversion to other land-uses than for their collective benefits as healthy natural habitat.

The arrival of Europeans to Australia in the late eighteenth and nineteenth centuries saw the significant alteration of estuaries along southern and eastern coasts as they became the major centres of human settlement and development in the country. As population growth increased along Australia's coastline there was a corresponding increase in recreational use and urban development. Coastal natural resources including mangroves came under increased risk, particularly near the large urban centres. Degradation of mangrove habitat by the direct loss and alteration of trees reduced their capacity to function effectively as a viable ecosystem. This in turn has endangered the species that depend upon these ecosystems.

Threatened species

While it is currently believed that none of Australia's mangrove species are at risk, the coastal zone they occupy has the greatest number of threatened animal species. One example is the rare and endangered Rusty Monitor, *Varanus semiremex* - a small crab-eating goanna restricted to tree hollows in mangroves of north eastern Queensland. One of the few mangrove tree species to form suitable hollows for this monitor, is *Avicennia marina*. This tree species is also the one threatened most by chemicals in agricultural runoff. The chief threats to mangrove habitat come from: conversion and landuse change and the indirect effects of sediments and chemicals in runoff from catchments degraded by clearing of upland vegetation and intensive agriculture.

Chemicals in runoff from agricultural lands

Agricultural chemicals in runoff are apparently affecting mangrove health. In five adjacent estuaries in the Mackay region of Central Queensland, more than 30 km^2 of mangroves have been affected by severe dieback of *Avicennia marina* (Duke et al. 2005). Twenty other species appear unaffected, but as *A. marina* occupied about 50% of the total mangrove area the threat to habitat stability is serious. Correlative evidence has implicated herbicides used in sugar cane production as the most likely cause of this dieback. Key indicators of mangrove plant health were positively correlated with diuron concentrations in sediments. Planthouse trials further demonstrated that salt-excreting

mangroves like *A. marina* were more affected by herbicides than the more salt-excluding species.

Landfill conversion and landuse change

Around 17% of Australia's mangroves have been destroyed since European settlement. Mangroves near developing centres have been systematically destroyed and damaged. Moreton Bay, for example, is situated near the city of Brisbane where an estimated 20% of the pre-European mangrove area has been subject to reclamation landfill (Duke et al. 2003). Compared with other countries, however, these impacts are relatively low. This is largely because most of Australia's mangroves are located in the more sparsely populated northern regions of the country, like north Queensland, the Northern Territory and northern Western Australia. Mangrove forests in these regions have largely remained pristine, or in near pristine condition. But, where development has taken place, then the effects on mangroves is usually severe. For example, the development associated with the expansion of the Northern Territory's major population centre of Darwin has resulted in the recent clearing of 2% of the pre-European area of mangroves in the harbour area.

Sediments in catchment runoff

Increased sediment loads in catchment runoff are affecting mangrove distributions within estuaries. In recent decades, there have been unprecedented gains in mangrove areas at the mouths of at least four Queensland river estuaries, including Trinity Inlet, Pioneer River, Johnstone River, and Fitzroy River (Duke 1997). It is expected that the pattern is similar in other states. The increase in such mud banks is indicative of increased clearing of catchment vegetation, and the construction of barrages and dams.

In New Zealand, mangroves are also threatened with eradication programs to control their expansion across accreting depositional banks along coastal margins. Mangroves in New Zealand also appear to be spreading south. While locals acknowledge the causal relationship with global warming and increased sediment erosion from clearing of catchment vegetation, they appear committed to focusing management responses toward controlling the symptom of mangrove expansion rather than the cause.

Invasive species and introductions

A recently introduced pest species from Central America, *Annona glabra*, known as Pond Apple, has invaded mangroves and tidal wetland habitat in north eastern Queensland. It is listed in the top 20 Weeds of National Significance in Australia. Since its introduction as graft stock for custard apples, this species has spread aggressively into upstream estuarine areas like the Daintree River Wet Tropics Area. Its' dispersal appears to have been widened by Cassowaries who like its fruit, and the ready dispersal of its buoyant fruits. An eradication program for Pond Apple is currently being undertaken in affected Queensland estuaries by the Queensland Department of Natural Resources.

In Australasia, introduced mangrove species have also become pest species. The key example is *Rhizophora mangle* introduced to Hawaii in 1927 by sugar cane farmers to

control sediment loss in coastal areas. Since its introduction the species has spread widely, easily spreading to neighbouring islands in the group. Coastal foreshore habitats have been seriously altered by the presence of mangroves causing the loss of many Hawaiian shoreline marine and intertidal animal species (Allen 1998). In Australia, the *R. mangle* is listed as an invasive species and a small population in the Townsville area of North Queensland was eradicated to remove the threat that it might spread. There is the threat of genetic contamination with native populations, even though they might be different species. This was demonstrated in the south-western Pacific by the cross between *R. samoensis* (being very similar to *R. mangle*) and the IWP *R. stylosa* to form the hybrid, *R*. X *selala*. This shows that even the most distant *Rhizophora* species are genetically compatible and can share genes.

Rising sea levels and climate change

Gillman et al. (2006) reported that mangroves on islands throughout the Australasian region are seriously threatened by rising sea levels. This differs for each island but some places like Fiji are expected to lose between 20-60% of mangrove area by 2100. This does not account for losses from erosion and altered coastal hydrodynamics where coastlines might be expected to incur greater sea waves and wash with elevated water levels across reef flats (Mimura 1999).

Sea level rise is one of the most certain outcomes of global warming. An average increase of 10-20 cm in sea level has been recorded over the last century, and the rate of change is predicted to increase much more (Gilman et al. 2006). The threat of sea level rise is very real and urgent for many island communities of the Pacific. Climate scenarios predict up to 14% loss of coastal lands due to sea-level rise and flooding by 2050. Furthermore, these coastal lands are the prime areas for economic activities and human settlement. In 1990-2000 alone, the Pacific region bore up to $US1 billion costs related to climate extremes. And, the costs are expected to rise further with the predicted rise in frequency and intensity of extreme events. Rates vary across the region, but increases are very high in some countries notably Fiji (Gilman et al. 2006). Unless climate change adaptation is planned and implemented at all levels of society, islands like Viti Levu in Fiji will incur costs up to 2-4% of the countries GDP (US$23-52 million) by 2050 directly because of damages associated with climate related disasters. In addition, the effects due to climate change on coastal marine ecosystems, including coral reefs and mangroves alone, have been estimated at between US$8.4-20.4 million; e.g., in Viti Levu. The recent report by Gilman et al. (2006) further emphasized the anticipated loss of significant benefits of mangrove habitat to rising seas. It appears inevitable that coastal and marine environments across the Pacific will be altered dramatically over coming decades. The absence of reliable future climate scenarios relevant to specific coastal communities, like those in Fiji, is a serious impediment to managing the expected impacts. Rural communities in coastal areas require urgent assistance to deal with this severe threat to their way of life, and their fragile livelihoods.

Key policies & management interventions/changes

Coastal management by Indigenous Australians

Today, nearly half of Australia's Aboriginal and Torres Strait Islander population live near the coast and maintain a close association with the sea boundary based on ownership, common law rights and interests, cultural and historic associations, and traditional use of resources. In the past, some communities had depended almost entirely on fish and shellfish for their subsistence. Food from the sea remains an important part of the diets of coastal communities of Indigenous people. The most prominent fish species used are mullet, catfish, sea perch/snapper, bream and barramundi; and, the most prominent non-fish species are mussels, other bivalves, prawns, oysters and mud crabs. In the Northern Territory, Aboriginal communities currently own and manage approximately 85% of coastal land in the state, containing vast tracts of mangroves. Aboriginal lands are administered by four Aboriginal Land Councils, individual communities, or through joint management agreements reached with the Northern Territory Parks and Wildlife Commission. Approximately 17 Indigenous Protected Areas covering almost 14 million hectares have been established through the National Reserve System Program in accordance with IUCN protected area management categories. These categories offer Indigenous landowners protected area status that can accommodate customary values and uses. This includes the sustainable use of mangrove ecosystems.

Management of Australia's mangroves

Australia's federal system divides power between the Commonwealth, State/Territory and local governments. All three levels of government are involved in the management of mangroves. However, there are no specific Commonwealth policies or Acts dealing exclusively with mangroves. Mangroves are managed through more general legislation relating to the environment, fisheries, coasts and wetlands. The Intergovernmental Agreement on the Environment aims to facilitate a cooperative national approach to the environment and several Ministerial Councils have been established to assist in coordinating governmental activities in the coastal zone. This is coupled with an increased recognition of the value and importance of mangroves, supported by a better understanding of their ecology and, environmental and cross-sectoral linkages. There has been a drive to incorporate this knowledge into management efforts combined with a move to establish integrated strategies to manage both the direct industry uses of coastal resources and their impact on the broader environment.

Since the Coastal Zone Inquiry in 1993, several achievements have been made towards the sustainable use and management of mangrove ecosystems. For instance, no mangrove species is currently considered threatened. And, the total mangrove area in Australia may now be increasing, although this may be largely due to the growth in areas of accreting mud banks, and mangrove incursion into tidal saltmarsh. Mangrove expansion into saltmarsh habitat is a serious threat in New South Wales (NSW) since it may threaten valuable migratory shorebird roosting and feeding sites. However, it has not yet been determined what is driving these changes in the tidal wetlands of NSW.

In general, the unapproved clearing and destruction of mangroves in Australia has largely ceased, and mangroves are now generally protected, apart from some high risk sites close to major population centres. In general, there has been an increasing national awareness of the need to protect Australia's mangroves, and to maintain the unique biological diversity of this valuable natural habitat.

Legislation and governance for protection of mangroves in Australia

Australia has long recognized the special importance of mangroves to the marine environment. For instance, mangroves in New South Wales, although previously grouped with land trees, were officially recognized in 1887, as different and worth preserving. Later on, the responsibility for management of mangroves was transferred to the Fisheries Department. In general, Australia's mangrove resources are protected by a variety of means across Australia's various legal jurisdictions. Many mangrove areas are protected in formal conservation areas such as marine parks, national parks, fish habitat areas, game reserves, or flora/fauna reserves. The Commonwealth relies on a combination of its powers to give effect to its legislation through the 1995 Commonwealth Coastal Policy. It may also influence coastal zone activities by granting financial assistance to the States. The Commonwealth's power in relation to external affairs allows it also to legislate in giving effect to Australia's international obligations arising from international treaties and conventions. International and bi-lateral agreements, such as: the Convention for the Protection of World Cultural and Natural Heritage; the Convention on the Conservation of Biological Diversity; the Convention on the Conservation of Migratory Species of Wild Animals; the Ramsar Convention on Wetlands of International Importance; and, the World Heritage Convention have lead also to the reservation and protection of large areas of mangrove forests in Australia. Though it is difficult to determine the extent of mangroves protected in these areas, mangroves are included in at least 180 protected areas and protection extends over parts of approximately 28% of Australia's estuaries. In all, around 8% of Australia's mangrove communities are in protected areas. However, mangroves in Australia are protected by various other legislative and administrative mechanisms, for instance, the clearing of mangroves in Queensland and New South Wales is prohibited (Duke 2006).

Achievements in the protection of mangroves in Australia

Since the Coastal Zone Inquiry in 1993 (RAC 1993), several achievements have been made towards sustainable use and management of mangrove ecosystems. Unnecessary (unapproved) clearing and destruction of mangroves has effectively ceased and mangroves are generally effectively protected. However, mangroves continue to be threatened by human population pressures, not only by large-scale developments but also by more subtle human-induced changes to their habitat (Harty 1997). These impacts have been identified and are being managed through a multiple-use, integrated coastal zone management approach. Significant achievements have been made including the following:

- The development of coastal and wetland policies that recognise the need for integrated and ecosystem-based approaches;
- The development of national, State and regional level integrated management plans to control development activities within the coastal zone;
- Extensive mapping, characterisation and assessment of mangrove resources, coastal regions, estuaries and ecosytem bioregions;
- The development of a national representative system of reserves including marine and terrestrial parks and significant additions to the reserve system;
- Establishment of cooperative and collaborative initiatives for the integrated management of catchments, estuaries, and water quality;
- Ecosystem monitoring programs and ongoing programs of mangrove research;
- A relatively high level of community awareness of the value and importance of mangrove ecoystems;
- Community involvement in coastal management.

These achievements are tempered to a certain degree by limitations in the effectiveness of the implementation of relevant policies and strategies. For example, it has been estimated that while 20% of New South Wales' coast is under management plans the crucial areas around the major population centres are not covered (Westcott 2001). Similarly, plans of management for many of Australia's protected areas, including Ramsar sites, have not yet been prepared (Haynes et al. 1998).

Key challenges ahead & recommendations

Australians are generally aware that mangrove ecosystems play an important role as habitat to fish and crabs. Some are aware also of the more complex environmental conditions affecting this unique ecotone between land and sea. Less appreciated, however, are the details surrounding these relationships, the various benefits, the drivers of change, and their effects on an inherent vulnerability of mangroves. Recent education programs have been undertaken to address the situation and to improve public awareness of Australia's mangroves and their role in coastal and marine ecosytems. But, there is a long way to go. More research on mangroves is required urgently to improve the management of emerging issues like climate change, sea level rise, land use effects, invasive species, coupled with the unprecedented pressures and impacts of community sea-change expansion into coastal areas.

Research readiness

The Australian government is directly involved in research and it funds several research organizations. In total, Australia allocates around 7% of its research and development funding to marine science and technology. There are a number organisations currently

conducting research and monitoring with direct and/or indirect relevance to mangrove ecosystems and their management. Many of these organisations are funded in part by the Commonwealth and State governments, coupled with Industry support. These organizations include:- 1) Universities most active in mangrove research today are the University of Queensland, Griffith University, Charles Darwin University, James Cook University, Australian Catholic University, Australian National University, Flinders University and Central Queensland University; 2) the Australian Institute of Marine Science, based in Queensland, Western Australia and the Northern Territory, was arguably the lead organization for mangrove research in Australia, and possibly the world, between 1975 and 1995; and, 3) the Commonwealth Scientific and Industrial Research Organization (CSIRO) supports a number of Cooperative Research Centres (CRCs) with research targets developed in collaboration with government agencies, industry, universities and local organisations. Of particular relevance to mangrove ecosystems and management until recently had been the CRC for Coastal Zone, Estuary and Waterway Management (Coastal CRC). In very recent times, a major shift in environmental management strategy and funding has been the National Heritage Trust (NHT) Program in conjunction with the establishment of regional Natural Resource Management (NRM) groups around the country. This national initiative is designed to promote and facilitate broad community education, monitoring and targeted research on key natural resources, including mangroves and tidal wetlands.

Recommendations to address knowledge gaps and social awareness

Key recommendations include:-

1) Full description of mangrove plant and animal species, their character, biomass, physiology, limits of tolerance and growth and phenological processes;
2) Elevation measures associated with key mangrove and tidal wetland vegetation ecotones, in particular – water/mangrove, mangrove/saltmarsh & mangrove/upland;
3) Functional ecological processes (trophic linkages) within mangrove ecosystems;
4) Impacts of pollutants (oil, herbicides) on growth and survival of mangroves;
5) Impacts of storm disturbance on growth and survival of mangroves;
6) Effects of sea level rise;
7) Identify and describe the key indicators of change within mangroves;
8) Case studies of vegetation change in tidal wetlands, based on remote sensing imagery, and possible links with climate change;
9) Restoration and remediation of damaged mangrove habitat;
10) Using mangrove and tidal wetland habitat to monitor sea level and climate change;
11) Prepare a community-based monitoring manual with full community participation;
12) Engage local communities & environmental managers in a mangrove watch program – to raise awareness of the benefits of mangroves, to give community a great appreciation of the way mangrove ecosystems function.

Recommendations for improved policy-making

Recommendations to improve coastal zone and mangrove management are targeted at the three most significant barriers to good policy-making and governance (see Table 2). It is suggested that coastal management needs to identify the mechanisms and then design, implement and monitor performance by various resource users to ensure they meet the agreed standards of ecologically sustainable use of coastal ecosystems (reviewed by ASEOC 2001).

Table 2: The 3 barriers to good policy-making with recommendations.

Barrier	Recommendation
Lack of integration between and across governments	Recognition by Government that the lack of integration in coastal management leads to significant inefficiencies and ineffective management. Continue efforts to restructure natural resource management with a focus at the regional and local levels, with an increased emphasis on enhancing policy integration between levels of government and among agencies responsible for achieving improved coastal outcomes.
Inadequate and inappropriate public consultation	Develop appropriate public participation procedures including representative steering groups with defined decision-making roles and responsibilities that recognise site-specific local conditions, the need for adequate time & resources, and have representation from key stakeholders including affected local communities and government agencies.
The lack of resources and the inefficient application of existing resources	Recognition by Government that current levels of funding for coastal policy development and its implementation does not meet the community's expectations and is causing ineffective coastal management. All three levels of government need to work together to ensure existing resources are used effectively and that additional resources be made available to meet the expectations of the community.

Source: (adapted from Middle 2004; McEwin pers.com).

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Table 1. Occurrence of mangrove species & named variants in the Australasian region - being the Indian Ocean (Ind.), SW Pacific Ocean and NW Pacific Ocean. Area estimates were taken mostly from Gillman et al. (2006). Introduced species are underlined.

Mangroves of Australasia	**I**	**n**	**d.**		**S**	**W**		**P**	**a**	**c**	**i**	**f**	**i**	**c**				**N**	**W**		**P**	**a**	**c.**	
	WNG, Ind	WA/Aust.	NT,/Aust.	E/Aust.	PNG	Solomons	Vanuatu	N/Cal ed.	Fiji	Tonga	Nauru	Kiribati	Tuvalu	Samoas	Niue	FrenchP	N/Zealand	Palau	Yap/FSM	Guam	E/FSM	N/Marina	Marsha	Hawaii
Acanthus ebracteatus subsp. *ebarbatus* (Ab), *ebracteatus* (Ae)	Ae	Ab	Ab	Ae	Ae	Ae												Ae						
Acanthus ilicifolius (Af)	Af		Af	Af	Af	Af																		
Acanthus volubilis (Av)	Av				Av																			
Acrostichum aureum (Au)	Au				Au																			
Acrostichum speciosum (As)	As	As	As	As	As	As												As	As					
Aegialitis annulata (An)	An	An	An	An	An																			
Aegiceras corniculatum (Ac)	Ac	Ac	Ac	Ac	Ac	Ac																		
Avicennia alba (Aa)	Aa				Aa													Aa	Aa					
Avicennia integra (Ai)			Ai																					
Avicennia marina var. *marina* (Am), *eucalyptifolia* (Ay), *australasica* (Al)	Ay	Am /Ay	Ay	Ay/ Al	Ay	Ay	Ay	Ay									Al			Ay				
Avicennia officinalis (Ao)	Ao				Ao																			
Avicennia rumphiana (Ar)	Ar				Ar																			
Barringtonia racemosa (Br)	Br			Br	Br																			
Bruguiera cylindrica (Bc)	Bc			Bc	Bc	Bc																		
Bruguiera exaristata (Be)	Be	Be	Be	Be	Be																			
Bruguiera gymnorhiza (Bg)	Bg		Bg	Bg	Bg	Bg	Bg	Bg	Bg	Bg	Bg	Bg	Bg	Bg				Bg	Bg	Bg	Bg	Bg	Bg	
Bruguiera hainesii (Bh)	Bh				Bh																			
Bruguiera parviflora (Bp)	Bp	Bp	Bp	Bp	Bp		Bp																	
Bruguiera X *rhynchopetala* (Bx)				Bx	Bx																			
Bruguiera sexangula (Bs)	Bs		Bs	Bs	Bs			Bs																Bs
Camptostemon philippense (Cp)	Cp																							
Camptostemon schultzii (Cs)	Cs	Cs	Cs	Cs	Cs																			
Ceriops australis (Ca)	Ca	Ca	Ca	Ca	Ca																			
Ceriops decandra (Cd)	Cd		Cd	Cd	Cd																			
Ceriops tagal (Ct)	Ct		Ct	Ct	Ct	Ct	Ct	Ct										Ct	Ct					
Cynometra iripa (Ci)	Ci		Ci	Ci	Ci													Ci						
Diospyros littorea (Dl)	Dl	Dl	Dl	Dl	Dl																			
Dolichandrone spathacea (Ds)	Ds			Ds	Ds	Ds												Ds	Ds					
Excoecaria agallocha var. *ovalis* (Eo), *agallocha* (Ea)	Ea	Eo	Eo/ Ea	Ea	Ea	Ea	Ea	Ea	Ea	Ea					Ea			Ea	Ea					
Excoecaria indica (Ei)	Ei				Ei																			
Heritiera littoralis (Hl)	Hl			Hl	Hl	Hl	Hl	Hl	Hl	Hl								Hl	Hl	Hl	Hl			
Lumnitzera littorea (Ll)	Ll		Ll	Ll	Ll	Ll	Ll	Ll	Ll	Ll		Ll						Ll	Ll	Ll	Ll	Ll	Ll	
Lumnitzera racemosa (Lr)	Lr	Lr	Lr	Lr	Lr																			
Lumnitzera X *rosea* (Lx)				Lx																				
Nypa fruticans (Nf)	Nf		Nf	Nf	Nf	Nf												Nf	Nf	Nf	Nf			
Osbornia octodonta (Oo)	Oo	Oo	Oo	Oo	Oo																			
Pemphis acidula (Pa)	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa	Pa								Pa	Pa	Pa	Pa	Pa	Pa	
Rhizophora apiculata (Ra)	Ra		Ra	Ra	Ra	Ra	Ra	Ra										Ra	Ra	Ra	Ra			
Rhizophora X *lamarckii* (Rx)	Rx		Rx	Rx	Rx	Rx	Rx	Rx										Rx	Rx	Rx	Rx			
Rhizophora mangle (Rg)																Rg							Rg	Rg
Rhizophora mucronata (Rm)	Rm			Rm	Rm	Rm	Rm											Rm	Rm		Rm			
Rhizophora samoensis (Ro)								Ro	Ro	Ro				Ro										
Rhizophora X *selala* (Re)								Re	Re	Re														
Rhizophora stylosa (Rs)	Rs	Rs	Rs	Rs	Rs	Rs	Rs	Rs	Rs	Rs	Rs	Rs	Rs					Rs	Rs	Rs	Rs			
Scyphiphora hydrophylacea (Sh)	Sh	Sh	Sh	Sh	Sh	Sh		Sh										Sh	Sh					
Sonneratia alba (Sa)	Sa	Sa	Sa	Sa	Sa	Sa	Sa	Sa										Sa	Sa		Sa	Sa	Sa	
Sonneratia caseolaris (Sc)	Sc			Sc	Sc	Sc	Sc																	
Sonneratia X *gulngai* (Sx)				Sx	Sx		Sx																	
Sonneratia lanceolata (Sl)	Sl		Sl	Sl	Sl																			
Sonneratia ovata (So)	So				So																			
Sonneratia X *urama* (Su)	Su		Su		Su																			
Xylocarpus granatum (Xg)	Xg	Xg	Xg	Xg	Xg	Xg	Xg	Xg	Xg	Xg		Xg		Xg				Xg	Xg	Xg	Xg	Xg	Xg	
Xylocarpus moluccensis (Xm)	Xm	Xm	Xm	Xm	Xm																			
TAXA in Region	46	19	32	39	47	22	16	16	9	9	2	4	2	3	1	1	1	19	17	10	11	5	6	2
Mangrove Area (km^2)	?	2517	4616	4400	3728	642	28	203	410	92	0.01	3	0.4	8	0.01	0.01	287	45	10	0.7	76	0.1	0.04	?

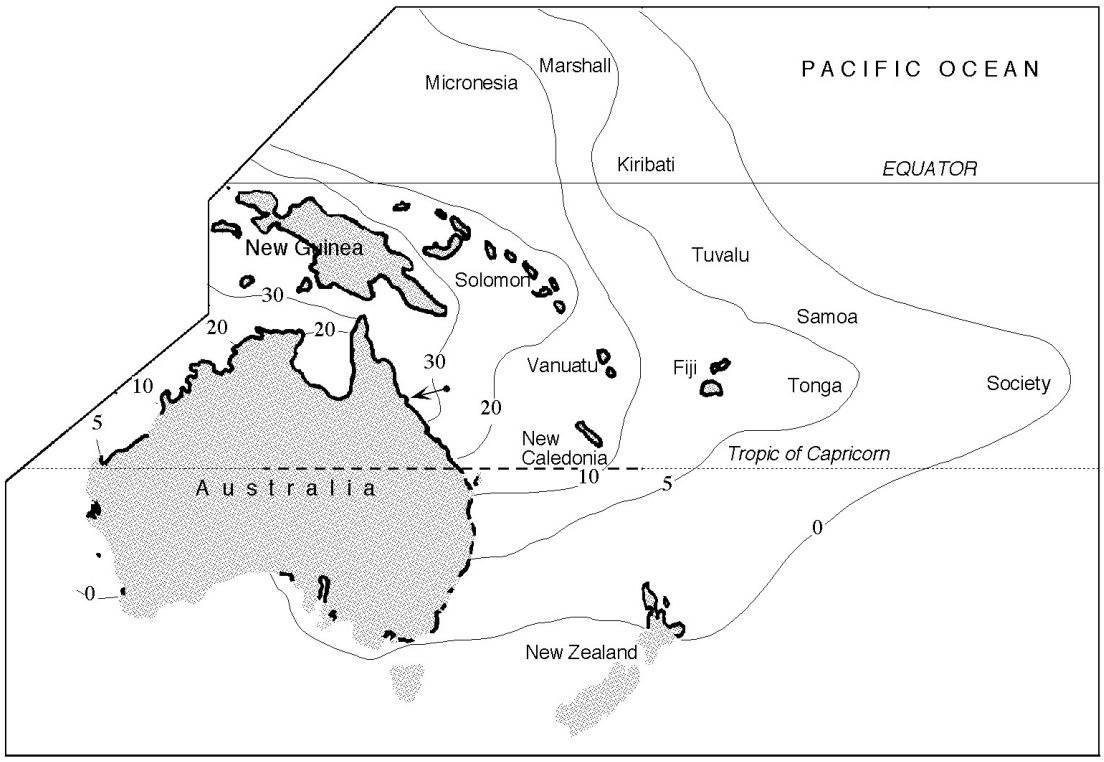

Figure 1. Distribution of mangroves (dark line along coastal margins) and mangrove species numbers (isohytes) across the Australasian region (source: Duke et al., 1998).

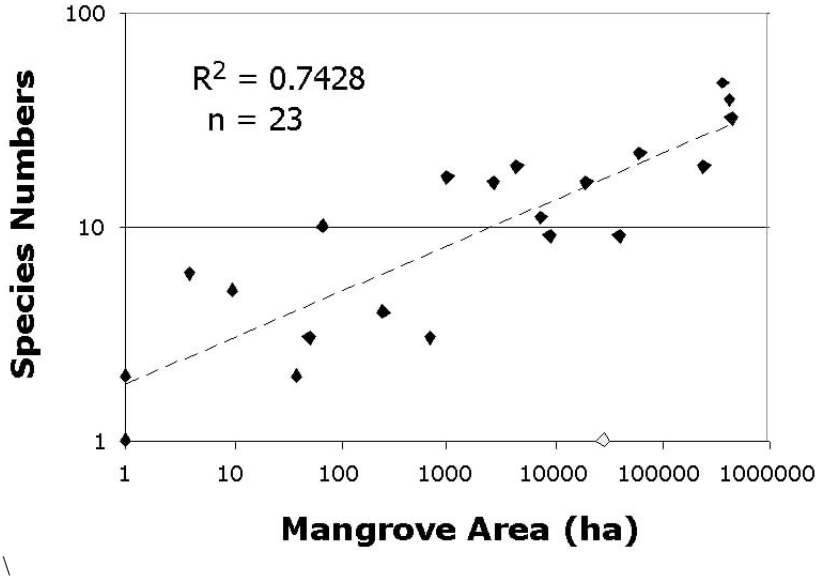

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Figure 2. Species-area relationship for mangroves of the 23 major islands through the Australasian region. Note that New Zealand (the unshaded data point) was excluded from the line of best fit regression because of its fringing high latitude location. (source data: Gilman et al. 2006).

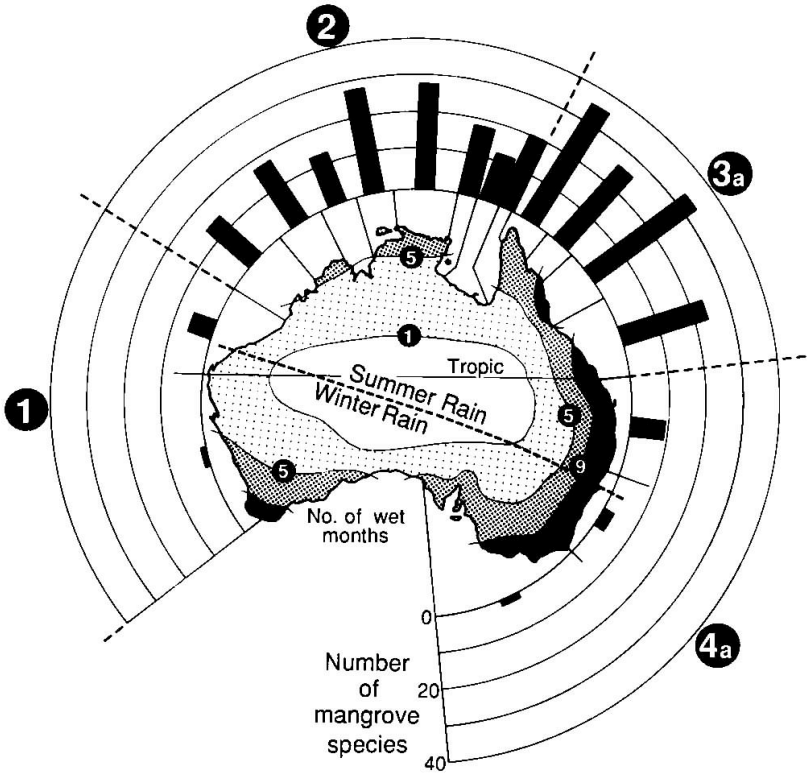

Figure 3. Histograms of species numbers for sections of the Australian coastline, compared with climate condition and numbers of wet months (source: Duke et al., 1998).