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Atolls – the "biodiversity cool spots" vs hot spots: a critical new focus for research and conservation

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Abstract— This paper highlights the seriousness of the "biodiversity crisis" on atolls and the need to place greater research and conservation emphasis on atolls and other small island ecosystems. It presents a "snapshot" of the current status of atoll biodiversity, including associated marine biodiversity, and stresses that atolls are "biodiversity cool spots", which, apart from, in some cases, very considerable marine resources, have among the poorest and most highly threatened biodiversity inheritances on Earth. Atoll societies and ecosystems are also widely believed to be the most seriously threatened by global climate change and associated sea level rise. This paper is based on studies over the past twenty years conducted in the atolls of Tuvalu, Tokelau, Kiribati, the Marshall Islands and the Tuamotu Archipelago of French Polynesia. It stresses that atolls offer some of the greatest opportunities for integrated studies of simplified small-island ecosystems, especially studies that involve local communities and local researchers, as have been emphasized by the Pacific Asia Biodiversity Transect Network (PABITRA). It is suggested that, if we are really worried mutual capacity building and sustainability of islands as human support systems, we must place higher priority on research on, and the conservation of, the Earth's "cool spots", such as the atolls and other biodiversity-poor small islands. Emphasis is also placed on the importance of the protection, recording and application of indigenous knowledge, here referred to as "ethnobiodiversity", which when used in concert with the most up-to-date modern scientific knowledge, constitutes perhaps the most appropriate means of designing models for the sustainable use of small island ecosystems.

Introduction

Atolls are among the most beautiful, ecologically and culturally unique, and seemingly paradisiacal places on Earth. In truth, atoll life is very tough and cultural and economic sustainability depends largely on the informed use of a very limited biodiversity inheritance. This paper highlights the seriousness of the "biodiversity crisis" on the atolls of the tropical Pacific Ocean and the need for the Pacific-Asia Biodiversity Transect Network (PABITRA) to include atolls and other small island ecosystems as a major focus. It presents a "snapshot" of the

current status of atoll biodiversity and stresses that atolls are "biodiversity cool spots", which, apart from their, in some cases, very considerable marine resources, have among the poorest and most highly threatened and degraded biodiversity inheritances on Earth.

Atolls are small, geographically isolated, resource-poor islands scattered over vast expanses of the Pacific Ocean. Consequently, there is very little potential for modern economic development, and most atoll countries and local communities depend almost entirely on their limited biodiversity inheritance for their ecological, economic and cultural survival. They are also among the most economically, socially and ecologically vulnerable places on Earth, especially in terms of their biodiversity, to the forces of global change. They are also widely seen as being the ecosystems most seriously threatened by global climate change and associated sea level rise. Finally and sadly, despite the poverty, fragility and threatened status of atoll biodiversity and the obligate dependence of atoll peoples on atoll biodiversity for sustainable livelihoods, atolls and their biodiversity have received relatively limited attention and support from the international conservation and development community.

Most of the attention and monies of the global conservation and scientific communities have been focused on conservation in the developed world, the Earth's "biodiversity hotspots" and on globally endangered, often charismatic megafauna or "flagship species" and endemic plant and animal species that are threatened with extinction. This paper suggests that, if we are really worried about conservation for the long-term benefit of people and the health of the entire Earth ecosystem, we must give higher priority to the protection and enhancement of the Earth's "cool spots", the atolls and other small oceanic islands. Particular emphasis is placed on providing an understanding of the status of atoll biodiversity, not only from a scientific perspective, but also from the view of the indigenous atoll peoples who have owned and used it for millennia and who depend on their endangered plants and animals for their survival.

It is suggested that atolls and biodiversity-poor small islands be placed higher on the global biodiversity conservation agenda, and given higher priority under the UN Convention on Biological Diversity (CBD)'s newest "Work Programme on Island Biodiversity" (2006), the main objectives of which are the conservation, sustainable use and equitable sharing of the benefits of island biodiversity.

It is also suggested, and supported by Bridges & McClatchy (2005), that studies of atoll ecosystems constitute an important area for comparative ecosystem studies under PABITRA. As small, simple ecosystems that include all of the major "biological resource zones" under PABITRA, except mountains and surface freshwater ecosystems, atolls offer some of the greatest opportunities for integrated studies of simplified small-island ecosystems, especially studies that involve local communities and local researchers. It is suggested that, if we are really worried mutual capacity building and sustainability of islands as human

support systems, we must place higher priority on research on, and the conservation of both the Earth's "cool spots" and "hot spots".

Stress is also placed on the importance of the protection, recording and application of indigenous knowledge about atoll biodiversity, here referred to as atoll ethnobiodiversity, which, if used in concert with the most up-to-date scientific knowledge, could constitute the most appropriate means of designing models for the sustainable development of small-island ecosystems (Thaman 2004b). All of these objectives fall within the original vision of PABITRA in terms of comparing island ecosystems across the Pacific, with a focus on local people's perceptions and multiple ecosystem-use systems along the lines of the Hawaiian *ahu pua'a*, "summit to sea" or "ridge to reef" integrated ecosystem and land use approach (Mueller-Dombois et al. 1999). This approach applies just as strongly to atolls where the connectivity between terrestrial and marine ecosystems and with resident human populations is so apparent.

This paper is based on: 1) surveys of some of some of the available literature; and 2) in-depth studies and personal observations of the biodiversity and ethnobiodiversity of the atolls of Tuvalu, Tokelau, Kiribati, the Marshall Islands and the Tuamotu Archipelago of French Polynesia over the past twenty years.

Pacific Ocean Atolls – The Geographical Focus

The word atoll derives from the Mayalam word *atolu* or "reef" or *atollon*, which is the native name for the Maldive Archipelago (Newhouse 1980). The common dictionary definition of atoll varies from a "ring-like coral island inclosing a lagoon" (Bryan 1972) to "a circular coral reef or string of coral islands surrounding a lagoon". As stressed by Wiens (1962), Bryan (1953) and others, these definitions are far too simplistic because most groups of atolls and individual islands that are normally considered to be "atolls" consist, not only of "true atolls" with lagoons, but also of other small, single, lagoon-less, low-lying limestone islands, sometimes referred to as "table reefs". Some islands have multiple lagoons or numerous ponds or basins separated by reefs, sand bars, islets or portions of the main island. Most atolls are not really circular, but consist of a series of islets, often strung out in irregular directions, that surround, or partially surround a lagoon. The term "coral island" is also misleading because it has been applied to islands of biogenic origin that are, in truth, calcareous sand or limestone deposits in which coral may be an insignificant element or only one of many significant elements (Wiens 1962).

For the purposes of this paper, and adapting the definitions of Bryan (1953) and Wiens (1962), the term "atoll" refers to all low-lying oceanic limestone reef islands, with or without lagoons, that have formed on barrier reefs or in the shallow lagoons along the coastlines, or that encircled long-submerged ancient volcanoes, but which are not associated with a nearby high island or a continent. The term "islet" refers to the individual smaller islands or *motu* (a Polynesian name for reef islet) that are found on the reefs or in the lagoons of the main atoll

island. In other words, "atolls" include both "true atolls", the islets of which encircle, border or are found within a lagoon, and individual, separate low-lying limestone reef islands that have no lagoon or may have secondary or remnant "fossil" lagoons on the actual limestone island or islets.

Most of these islands have maximum elevations below 3 to 4 m above sea level, although some may have limited areas of limestone pinnacles, coral rubble or windblown sand "dunes" that can reach elevations of up to 10 m (e.g., the raised limestone pinnacles on Tikehau Atoll in French Polynesia and the wind-blown dunes on Kiritimati Atoll in Kiribati). Excluded from this definition are raised limestone islands or "raised atolls" that have average elevations above 5 m, such as Angaur and the Rock Islands in Palau, Fais in Yap, Nauru, Banaba in Kiribati, Makatea in the Tuamotu Archipelago of French Polynesia, Henderson in the Pitcairn Group, most of the islands of the Tonga Group, Vatulele and a number of the islands the Lau group in the Fiji Islands, Aniwa in Vanuatu and Ouvea, Lifou and Mare in New Caledonia. Also excluded from this definition are "sunken atolls" without dry land, such as Middleton and Elizabeth Reefs in the Coral Sea off Australia; barrier reefs and associated islets surrounding islands, such as the islands of the main Chuuk (Truk) group and Borabora in the Society Islands of French Polynesia; and reef structures with associated islands such as those on the Great Barrier Reef off northeastern Australia (Thaman 2004a).

Globally there are more that 400 atolls (composed of thousands of individual islets) and small isolated individual low-lying limestone reef islands in the Earth's Oceans (Bryan 1953). Most are found in the tropics, especially the tropical Pacific Ocean, where ocean water temperatures are suitable for the growth of coral reefs. The geographical focus of the paper includes all of the atoll nations and those atolls and low-lying limestone reef islands found in the tropical Pacific Ocean that are considered part of the "cultural areas" of Melanesia, Polynesia and Micronesia. The main atoll groups in this area include the Marshall Islands, the Gilbert, Phoenix and Line Islands, the Tuvalu Islands (formerly the Ellice Islands), the Tokelau Islands, the Northern Cook Islands and the Tuamotu Archipelago, which has 77 atolls, the most of any single group (Bonvallot et al. 1994). There are also atolls in most of the other countries or island groups in the Pacific Islands, with Papua New Guinea, New Caledonia, Solomon Islands, Fiji, Palau and the Federated States of Micronesia, all having atolls. The largest group of atolls outside the Pacific Islands is the Maldives Archipelago in the Indian Ocean to the southwest of India. Those countries and territories with no reported true atolls include Samoa, Tonga, Vanuatu, Wallis and Futuna, Niue, Nauru and Kosrae.

Although the actual status of whether a given island falls within the above definition of atoll is relatively clear for most of the well-studied atolls of Polynesia and Micronesia, the status of many of the small islands included as possible atolls in the islands of Melanesia is uncertain due to the lack of detailed published information. In fact, Bryan (1953), listed the large limestone island of Ouvea in the Loyalty Islands just east of New Caledonia as the "world's largest

atoll", although by his definition, it is clearly not an atoll, but rather a large raised limestone island rising to a maximum elevation of 46 m, much more similar to some of the islands of Tonga, with large areas rising far above 5 to 10 m elevation.

Atolls as Biodiversity "Cool Spots"

"Biodiversity hotspots" are those areas with very high biological and ecosystem diversity and high levels of endemism. Biodiversity hotspots include continental areas such as Australia, Southeast Asia, tropical and southern Africa and the Amazon Basin; larger tropical continental islands, such as Cuba, Madagascar, and islands of the western Pacific and southeast Asia, such as the islands of Indonesia, Philippines, New Guinea and New Caledonia; and isolated high oceanic island archipelagos, such as the islands of Hawai'i and the Galapagos, that have historically served as laboratories of evolution and extinction. The biodiversity inheritances of these hotspots are, in most cases, under serious threat of extinction and degradation (Whittaker 1998). Some of these hot spot islands and relatively "hot" high islands (e.g., the highest, largest islands of Papua New Guinea, Solomon Islands, Fiji, Samoa, Cook Islands, Hawai'i, Palau and Pohnpei) have been the focus of PABITRA's main activities over the past decade.

The atolls and smaller low-lying "cool spot" islands, on the other hand have few, if any, endemic plants and animals, among the most impoverished terrestrial floras and faunas, and among the lowest ecosystem and habitat diversity on Earth. Moreover, their terrestrial floras and faunas are among the most highly degraded and threatened on Earth (Fosberg 1952, 1960, Thaman 1992b, 2004a). More seriously, from a sustainable development perspective, a high proportion of the economically, culturally and ecologically important terrestrial plants and animals are threatened and in danger of extirpation (local extinction). Although atoll marine environments are not as impoverished, atolls and other small islands generally have lower marine ecosystem diversity than larger islands and there is attenuation or drop off in the number of species from west to east as we move from Melanesia in the western Pacific to the small, more isolated atolls of the central Pacific (Kay 1980, 1999, Myers 1999). This marine biodiversity inheritance is, however, also under threat.

Whereas most island hot spots also have considerable natural resource endowments and some potential for modern economic export-oriented development and cash employment, most atolls do not, because of extremely limited land areas, poor soils, limited terrestrial resources, scarcity of fresh water, high vulnerability to natural disasters, extreme isolation and fragmentation, and very high population densities. One exception is in the fisheries sector, with some atoll nations having very extensive exclusive economic zones (EEZs) and some of the most substantial tuna and other pelagic or deep-slope fisheries resources on Earth. However, the development of these marine resources is severely limited by the lack of local technological, financial and human resources coupled with

the lack of land, water and isolation of the atolls from the major markets for fish. One exception is Tikehau Atoll, one of the closest atolls to highly urbanized Tahiti, which has developed a lucrative airfreight export trade in fresh reef fish over the past 30 years. Attempts at local commercial fishing fleet development and fish processing have, however, largely met with failure, with the main benefits coming from licensing fees and royalties paid to atoll governments and other "unofficial payments" made by foreign distant water fishing nations (DWFNs). Current estimates are that only 5 to 6% of the landed value of the tuna caught in Pacific Islands countries goes to these countries, with the balance going to DWFNs (Gillett & van Senten 2007).

The only real positive economic development, apart from limited tourism potential (including scuba diving and various ecotourism activities) on a very limited number of atolls, such as on some of the atolls in the Tuamotus close to Tahiti, has been the very successful development of black pearl mariculture in the Tuamotu Archipelago and the atolls of the Northern Cook Islands. This, however, is a very capital- and research-intensive industry and the recent downturn in the world market price for the black pearls coupled with disease outbreaks have setback the industry in some areas, such as in the Northern Cook atolls where there were bacterial disease outbreaks around the turn of the century (Duncan 2001).

Atoll Biodiversity

Despite the relative poverty of atoll biodiversity, it must be stressed that, regardless of the atoll type, size or degree of isolation, this limited biodiversity inheritance is critical to the continuing health and survival of each island's biodiversity itself and to the human communities that depend on it for their ecological, economic and cultural survival. This living inheritance includes: 1) island and ecosystem diversity, 2) species and taxonomic diversity, 3) genetic diversity, and, 4) ethnobiodiversity.

In terms of island diversity, there is an almost unbelievable diversity of atoll and low-lying limestone reef island types, and associated smaller individual islets, lagoons and marine areas found in the tropical Pacific Ocean. Each "atoll", whether a true atoll with a central lagoon or single low-lying reef island, contains its own unique biodiversity inheritance.

The ecosystem diversity found on these diverse islands consists of at least 23 natural and cultural terrestrial, freshwater and marine ecosystems (Appendix 1). Each of these atoll ecosystems contains its own species and "taxa" (e.g., types, groups, classes, families, genera, etc., in biological classification systems, such as vertebrates, invertebrates, mammals, sharks, finfish, shellfish, holothurians (bêche-de-mer), corals, fungi, palms, grasses, ferns and microorganisms) of wild and domesticated organisms. Genetic diversity includes all genetic types, breeds, cultivars or varieties of wild and domesticated or cultivated plants and animals found in atoll ecosystems (e.g., cultivars of giant

taro and taro, coconuts, breadfruit, pandanus, bananas or plantains, etc. and breeds of pigs, chickens, dogs, etc.).

If one were to list all of the wild and domesticated terrestrial and aquatic plants and animals including subspecies, forms, varieties, cultivars, breeds, etc. for each atoll or marine ecosystem or Pacific Island atoll country, the magnitude of biodiversity for even some of the smallest, poorest "cool spot" atolls would be considerable, in some cases perhaps incomprehensible to a "Western-trained" economist or scientists, whereas traditional Pacific atoll peoples are more keenly aware of local biodiversity, including intra-specific variability and its importance to sustainability.

For example, preliminary analyses of the results of University of the South Pacific-based "Coral Reef Ethnobiodiversity of Pacific Island Atolls" component of the TOTAL Foundation "Coral Reef Biodiversity Programme", an initiative also supported by the Coral Reef Initiative in the Pacific Islands (CRISP), informants were able to identify and give local Kiribati vernacular names for approximately 82 small nearshore finfish, 75 large nearshore finfish, 62 small deepwater finfish, 40 large deepwater finfish, 20 sharks, 9 rays, 25 eels, 5 whales or dolphins, 5 sea turtles, 6 sea snakes or snake-like animals, 16 seabirds, 38 small shallow-water shellfish, 36 large shallow-water shellfish, 17 small deepwater shellfish, 10 large deepwater shellfish, 23 crabs, 9 lobsters or lobster-like crustaceans, 6 prawns or other crustaceans, 19 bêche-de-mer, 14 octopi, squids or nautili, 13 sea urchins or starfish, 10 sea worms, 19 hard corals, 5 soft corals, 4 sea anemones, 13 seaweeds or other marine plants, 9 other types of marine organisms and 34 types of bait. Most of these have now been correlated with the scientific names.

Moreover, if we superimpose genetic diversity on top specific diversity the picture is further enriched. In Kiribati, for example, there are reportedly over 200 named cultivars of pandanus, over 30 of *Cyrtosperma* taro and at least ten named coconut cultivars (Small 1972).

Ethnobiodiversity

Ethnobiodiversity is defined as the knowledge, uses, beliefs, resource-use systems and conservation practices, taxonomies and language that a given society or community, including the modern scientific community, has for its islands, ecosystems, species, taxa and genetic diversity. It is stressed that this final category or cultural "level" of atoll biodiversity must be seen as central to the definition of atoll biodiversity itself because, on the atolls, people and their knowledge, traditions and spirituality are seen as inseparable from their terrestrial, freshwater and marine ecosystems (e.g., as embodied in the Melanesia pidgin concepts of *kastom*/custom or *ples*/place; the all-encompassing pan-Polynesian concept of land/*fonua*, *fanua*, *fenua*, *henua* or *'enua*, depending on where you are; or the concepts of *te aba*, in Kiribati and *bwirej* in the Marshall Islands, all of which encompass land, sea and people), rather than seeing them as separate external entities (Thaman 2004b). It is this holistic view of ecosystems

and biodiversity, as reflected in the Hawaiian *ahu pua'a* system of ecosystem perception and management, that has been central to PABITRA's work over the last decade.

Atoll Ecosystems and Biodiversity in Detail

In terms of ecosystem diversity, larger wetter atolls, such as Jaluit in the Marshall Islands (399 cm rainfall $year^{-1}$), Funafuti in Tuvalu (338 cm/133 in), Butaritari in Kiribati (310 cm $year^{-1}$) and Ontong Java in the Solomon Islands have the most extensive areas of most of the major atoll ecosystems, such as mangroves, inland atoll forest and areas of coral reef, and the richest species diversity. As stressed by Fosberg (1974) and Stoddart (1992), species richness is related more to moisture availability and rainfall extremes rather than to island size or to the closeness of source areas of colonizing organisms, although those atolls in the far west, such as Ontong Java, have richer floras and marine biotas. For example, some of the most extensive areas of mangroves and freshwater swamps in Kiribati are found on Butaritari, which is the wettest and most westerly atoll in the main Gilbert group.

Ecosystems on the most highly urbanized atolls are the most degraded and under the most threat, with some of the more distant uninhabited atolls and islets having the most intact ecosystems and the greatest potential for designation as terrestrial and marine conservation areas. A case in point is the recent designation by the Kiribati government of atolls and marine area of the Phoenix Islands as the world's third largest marine protected area (PIPA 2007) and the declaration of uninhabited Ant (And) Atoll in Pohnpei State of the Federated States of Micronesia as a UNESCO Biosphere Reserve (CSP 2007).

Relatively undisturbed indigenous inland atoll forest is now absent on most atolls. Although there are small remnants of inland forest on the some inhabited atoll islets, it is now found almost exclusively in very small stands of trees on uninhabited atolls and less accessible uninhabited islets. Inland forest is the main habitat for most indigenous land birds and a wide range of sea birds, land crabs and insects and a limited range of reptiles and other indigenous invertebrates. Its removal has played a major role in the disappearance of many birds and other animals from the islands and islets of atolls.

Coastal shoreline or littoral vegetation on atolls has been severely modified as a result of hundreds and, in some cases, thousands of years of human habitation, including rapid urbanization on the main islands, the expansion of coconut planting into coastal areas and the selective removal of indigenous species for construction, boatbuilding, firewood and other purposes. There remains, however, a significant amount of coastal shoreline vegetation in various stages of disturbance on many atolls. The least disturbed areas of coastal shoreline vegetation are, again, found on isolated uninhabited islets. The vegetation consists mainly of widespread, ocean-dispersed, salt-tolerant pan-Pacific or pan-tropical plants.

The most widespread vegetation type on most atolls consists of the extensive areas of coconut-dominated agroforests and scrublands in various stages of maintenance. The term agroforest is used to describe those agricultural lands dominated by deliberately planted or protected useful trees. In the case of most atolls, agroforests are dominated almost exclusively by the coconut palm, although other useful indigenous trees are often protected and allowed to remain, and pandanus, breadfruit and sometimes bananas or other useful trees are planted, sometimes as small tree groves, in more favourable sites, usually near villages or residences (Thaman 1990, Thaman & Whistler 1996).

Coconut-dominated agroforests are particularly common on uninhabited islets, most of which were planted in coconut palms over the past century. Although far less important today than in the past, coconut plantations, in various states of maintenance constitute the main rural landscape. These range from recently replanted coconut palms to very rundown plantations with unproductive, senile palms or large areas where palms have died without replacement. There are also sites where inland scrub and only scattered palms dominate the landscape. In some areas dense stands of coconut palms with an almost continuous canopy are found on the best soils, both near the lagoon and along roads. In other areas, the palms are irregularly spaced and of a range of age-classes, including senile and younger palms and numerous seedlings that have sprouted from fallen nuts.

Excavated taro pits are a unique and specialized ecosystem found in the central parts of the larger islets of many atolls and in and around villages. These pits have been excavated to the level of the freshwater lens, through the limestone bedrock to depths of 1.5 to 3 m. As mentioned before, the artificially enriched soils in these pits, known as taro mucks, are fertile, swampy and very rich in organic material. The main crop planted in the taro pits is giant taro (*Cyrtosperma chamissonis*), although common taro (*Colocasia esculenta*), giant taro (*Alocasia macrorrhiza*), tannia or America taro (*Xanthosoma sagittifolium*) and bananas (*Musa* cultivars) are also occasionally planted. Coconut palms, pandanus, breadfruit, papaya, native fig (*Ficus tinctoria*) and other multipurpose plants are also planted or protected near pits. Shrubby species, such as *Morinda citrifolia* and *Premna serratifolia* are also found on the margins of the pits. Other multipurpose trees found near the pits include *Tournefortia argentea* and *Guettarda speciosa*, the leaves of which are an important component of the fertilizer or mulch. Weedy plants, some of which are culturally useful, are also found in or near these pits (Thaman 1990).

Due to rapid urbanization, houseyard and urban gardens are now one of the most widespread and productive ecosystems and vegetation types on more urbanised atolls These ecosystems include houseyard gardens around dwellings or workplaces, as well as landscaping at hotels, resorts, and government and non-government developments, parks, lawns, hedges and living fencing and roadside plantings. These gardens are characterized by permanent horticulture of a mixture of trees, shrubs and other perennials, and sometimes short-term annuals

(Thaman 1987). Houseyard and urban gardens are found in both towns and smaller villages on atolls.

Houseyard and urban gardens usually contain a greater proportion of non-indigenous plants than other vegetation types. These include a wide range of both aboriginal and recently introduced species. The dominance of recently introduced ornamental species is very pronounced, with between one-third to over one-half of all plants in the houseyard gardens in more urbanised areas of Majuro, Marshall Islands, the villages in Tokelau, Tuherahera Village on Tikehau Atoll in the Tuamotus being recently introduced ornamentals. Indigenous and aboriginally-introduced plants and food plants are, however, also important components of most houseyard gardens, which serve as areas where culturally important medicinal plants and other important plants can be protected for household use. The most common food plants in less-urbanized areas include coconut palms, breadfruit, bananas, pandanus, papaya and an occasional lime tree. Pumpkins (*Cucurbita pepo*) are also occasionally planted, especially in the larger houseyard gardens and villages in Laura, on Majuro Atoll in the Marshall Islands and sometimes found as volunteer plants around garbage dumps and pig sties (Thaman 1995, 2002).

There are also an increasing number of intensive vegetable gardens on some of the more urbanized atolls. The soils of these gardens have been enriched by adding organic materials, such as pulverized coconut husk or decaying logs, animal manure, sand or soil from more fertile sites and imported fertilizers and manures. The gardens include the larger commercial and experimental vegetable farms at Laura and in a number of other locations. Some of these intensive farms have utilized fairly sophisticated hydroponic or drip irrigation systems. Such gardening is very capital and labor intensive on atolls and many such attempts at vegetable gardening have failed in extremely harsh atoll conditions, despite often very sizeable inputs of aid money and expertise, most notably from the governments of China and Taiwan.

In terms of domestic animals, there are normally no large grazing animals, such as cows, horses and goats on atolls. Lack of water, space and fodder dictate this. The only animals raised for food are pigs and chickens and, in some areas, formerly dogs. These are normally kept in pens near villages, tethered or allowed to range free. The pens, which are often located near the sea, can be a source of nutrient pollution, which is one of the major negative factors affecting the health of coral reefs and humans.

Long settlement, destruction during World War II, increasing urbanization and development of modern a transportation network, and the widespread practice of keeping villages and plantations clean by continuous burning, sweeping and clearing vegetation, have led to the creation of extensive areas of highly disturbed, ruderal vegetation on many of the more urbanized atolls. These include roadsides, path sides, waste places, playing fields, open lots, unpaved areas around parking lots, airports and landing strips and other areas that are continually disturbed. The dominant species in most areas are a wide range of

easily-dispersed, fast-growing herbaceous weedy species (grasses, sedges and forbs), and, occasionally, some weedy sub-shrubs and shrubs. Most of these weedy species are recently introduced exotic species, although some indigenous species are also found in these areas.

On atolls, there is no surface water in the form of rivers and lakes, with the only real surface water being in the form of limited areas of freshwater marshes and brackish ponds that are found on some atolls, such as extensive system of landlocked hypersaline ponds on Kiritimati (Christmas) Atoll in the Line Islands of Kiribati. Many of these are polluted, affected by saltwater incursion, decreasing in size or being reclaimed and are under threat as critical "wetland habitats" on atolls.

Although the most extensive systems of coral reefs, intertidal flats, seagrass beds and other important marine ecosystems are again found off the larger Melanesian islands of Papua New Guinea, New Caledonia, Solomon Islands and Fiji, there are extensive areas of fringing reefs, patch reefs and some barrier reefs surrounding almost all of the true Pacific Island atolls. Particularly extensive reef systems are found in some of the larger atoll countries, such as the Marshall Islands, Kiribati and the Tuamotus and some of the reefs associated with atolls of the Western Pacific in Papua New Guinea, Solomon Islands, New Caledonia and Palau. The atolls of Palau and the Federated States of Micronesia have particularly high marine species diversity. There is, however, more limited diversity of coral reef types and other intertidal and subtidal marine ecosystem diversity associated with lagoon-less low-lying limestone reef islands. Sea grass beds, extremely important habitats and food sources for dugongs, sea turtles, and a wide range of other marine organisms in Melanesia, Micronesia and Western Polynesia, are not found on atolls to the east of Micronesia, Tonga and Samoa (Dahl 1980).

Maricultural production of milkfish was practiced traditionally in Nauru and Hawai'i and possibly elsewhere. Today there is some mariculture of *Echeuma* seaweed in Kiritimati. Black-lipped pearl oysters, for cultured pearl production in the Northern Cook Islands and the Tuamotus, are critical to the local economy and a major money earner, and there is modern maricultural production of milkfish in Kiribati on both Tarawa and Kiritimati. There is limited freshwater aquaculture of tilapia in Kiribati, although tilapia is seen as a pest and a hindrance to the mariculture of milkfish in both Nauru and Kiribati (Gillett 1989).

Importance of Ethnobiodiversity and the Cultural Importance of Atoll Biodiversity

Although endemism and rare life forms in the "biodiversity hot spots" are of great interest to scientists and are often the main focus of developed-country conservation programs, they are often not among the most culturally useful resources to local communities. Endemic plants and animals are most commonly found on remote mountains and in less accessible, less-visited and less-used

areas, and often do not even have local vernacular names or uses. As a result, it is often the more accessible, non-endemic plants and animals, including genetic varieties of staple food plants, often the very same plants that are found near or in villages or towns, in coastal areas and on atolls that are of greatest cultural importance. They are also the species that are commonly overexploited or endangered and are in need of conservation or protection in the eyes of local communities.

When we attempt to catalogue all the ecological services, uses (the "bio-utility") and economic value of all taxa in all atoll ecosystems to a given community, the true value of atoll biodiversity becomes very apparent. The overall long-term economic benefit of the conservation or restoration of this "useful" biodiversity is normally far greater than any proposed "income" or "enterprise" generating developments that are commonly linked to conservation initiatives. Thus, the main "selling point" or incentive for biodiversity conservation and associated research, should be its conservation as the economic and cultural foundation for sustainable long-term livelihoods, rather than the "scientific" value or the, often short-term, aid-funded, replacement value provided by "enterprise development" or "debt for nature swaps". This is not to say that nature conservation for scientific or international "ethical" reasons or sustainable enterprise development initiatives are not useful ingredients in nature conservation initiatives, but, rather, that they should enhance the existing value of biodiversity rather than replacing the sustainable long-term provision of culturally valuable services and products as the main motivating factor. If we accept this to be the case, then atoll biodiversity should receive greater priority on the world conservation stage.

Although extremely limited in extent and species-level diversity, the vegetation and flora of atolls constitute a critical ecological and cultural resource. This is particularly true for the indigenous species, virtually all of which have wide cultural utility within atoll subsistence economies. Trees, for example, serve a wide range of functions and are of wide importance to people who live on atolls (Table 1).

In terms of cultural utility, an analysis of 140 species of widespread coastal littoral and mangrove vascular plants showed that there are some 75 different purpose/use categories for these plants, almost all of which are found on atolls somewhere in the Pacific Islands (Thaman 1992a). The total number of usages for the 140 plants was 1024, an average of 7.3 purpose/use categories per plant (Appendix 2), ranging from no reported uses for only two species to as many as 125 uses for the coconut if distinct uses within categories (e.g., tools with distinct functions or different medicinal uses for different plant parts) are counted. Another 17 species have 20 or more reported uses, and 29 species have at least 7 uses each (Appendix 3). Moreover, the list does not include the more strictly ecological functions of coastal plants, such as shade, protection from wind, sand and salt spray, erosion and flood control, coastal reclamation, animal and plant habitats, and soil improvement (Table 1), all of importance to Pacific societies,

particularly in light of the increased susceptibility of atoll coastal areas to predicted increases in sea level due to global warming, El Niño events and other extreme events.

Table 1. Ecological and cultural functions and uses trees on atolls, adapted from Thaman and Clarke (1993).

ECOLOGICAL		
Erosion Control	Soil Improvement	Animal/Plant Habitats
Wind Protection	Marine Spawning Grounds	Flood/Runoff Control
Coastal Reinforcement	Wild Animal Food	Weed/Disease Control
Shade	Water Purification	Protection from Salt Spray
CULTURAL/ECONOMIC		
Timber (commercial)	Brooms	Prop or Nurse Plants
Timber (subsistence)	Parcelization/Wrapping	Staple Foods
Fuelwood	Abrasive	Supplementary Foods
Boatbuilding(canoes)	Illumination/Torches	Wild/Snack/Emergency
Sails	Insulation	Foods
Tools	Decoration	Spices/Sauces
Weapons Hunting	Body Ornamentation	Teas/Coffee
Containers	Cordage/Lashing	Non-alcoholic Beverages
Woodcarving	Glues/Adhesives	Alcoholic Beverages
Handicrafts	Caulking	Stimulants
Fishing Equipment	Fiber/Fabric	Narcotics
Floats	Dyes	Masticants/Chewing Gum
Toys	Meat Tenderizer	Preservatives
Plaited Ware	Hats	Aphrodisiacs
Toilet Paper	Baskets	Fertility Control
Medicines	Commercial/Export	Abortifacients
Brush/Paint Brush	Products	Scents/Perfumes
Musical Instruments	Ritual Exchange	Recreation
Cages/Roosts	Poisons	Magico-religious
Tannin	Insect Repellents	Totems
Rubber	Deodorants	Subjects of Mythology
Oils	Embalming Corpses	Secret Meeting Sites
Fire Making	Lovemaking Sites	Toothbrush
Switch for Children/ Discipline		

In terms of specific uses, the most widely reported uses are for medicine, general construction, body ornamentation, fuelwood, ceremony and ritual, cultivated or ornamental plants, toolmaking, food, boat or canoe making, dyes or

pigments, magic and sorcery, fishing equipment, cordage and fiber, games or toys, perfumes and scenting coconut oil, fertilizer and mulching, woodcarving, weapons or traps, food parcelization or wrapping, subjects of legends, mythology, songs, riddles, and proverbs, domesticated and wild animal feed, handicrafts, cooking equipment, clothing, fish poisons, items for export or local sale, adhesives or caulking, and musical instruments, all of which were reported for at least eleven species (Appendix 2).

Examples of the medicinal, ceremonial or spiritual and body ornamentation or perfumery use of coastal plants are provided below. To provide greater detail on those plants of particular importance for specific purposes is beyond the scope of this paper, but such details can be found in Thaman (1992a).

Medicinal use was the most widespread with 113 species (81%) reportedly used medicinally, in at least one area of the Pacific. Of these 113 species, almost a quarter (27) are used medicinally for a variety of purposes, often the same purposes, wherever they are found throughout the Pacific, as well as in southeast Asia, the ancestral homeland of Pacific peoples (Perry & Metzger 1980). Importantly, the effectiveness of these medicines has been recorded scientifically in writing by Chinese "doctors" and Indian Auryvedic medicinal practitioners for over 800 years. Most of these medicines have been tested and documented much more thoroughly than most of the "modern" medicines that we buy from chemists or drug stores, many of which have known side effects and have only been tested extensively on laboratory animals. Moreover, for most rural Pacific Island communities, apart from the 3 P's (penicillin, Panadol/paracetamol and Pepto Bismol/Enos), there is little or no access to modern medicines and an almost exclusive dependence on traditional medicines to treat all diseases, sicknesses, injuries and other complaints. This is supported by a recent study in the Marshall Islands where there are only about 55 indigenous plants, which showed that sixty-six plants, including almost all of the indigenous atoll plants, were used medicinally by at least one of over 50 participants in workshops conducted in 2001 and 2002 (Taafaki et al. 2006). To replace these with modern medicines is almost impossible.

The ceremonial and spiritual importance of plants can not be overstated, with 40 species having ceremony or ritual importance, 29 used in magic and sorcery, and 18 featuring legends, mythology, songs, riddles, or proverbs. Those of more ceremonial importance, include species used in ceremonies or rituals associated with death, war and peace, human sacrifice and cannibalism, circumcision or coming of age, house or temple building, canoe making and launching, fishing, planting cycles, lovemaking, wave making or control of sea state, prayer sessions, as well as species serving as symbols or totems and mediums for communicating with spirits or gods or those planted in sacred groves or burial grounds. Others are associated with times of revelry or are used in the production of baskets, mats, and other articles reserved for ceremonial exchange or dress.

The importance of body ornamentation and perfumery is attested to by the considerable time and expense devoted by most societies (very extravagant expenditures in the case of more affluent societies) to clothing, jewelry, perfumes, and other items of personal adornment. Pacific island societies, similarly, placed great importance on plant products for body ornamentation and perfumery, with 44% (62 of 140) of all coastal species being used in body ornamentation and 21 species used to scent coconut oil or for perfumery.

Many places, such as Hawaii or Tahiti, are commonly associated with flower leis or sweet smelling flowers, such as the tiare Tahiti (*Gardenia taitensis*). The Kiribati, Tuvaluan, Tokelauan, Marshall Islands, Northern Cook Island and Tuamotuan equivalents of the Hawaiian lei, are all of great social, ceremonial, magical or spiritual importance to local atolls communities. Koch (1983) stresses their importance in Kiribati and Tuvalu and noted that ornaments used for special occasions in Tuvalu are now almost exclusively made of plants because "the longer-lasting ornaments succumbed to the puritanical zeal of the Samoan missionaries."

Because of their very limited and infertile soils, Pacific atoll societies have evolved sophisticated systems of fertilization and mulching using the leaves from at least 18 coastal plants. It is in atolls of Micronesia in the Marshall Islands and Kiribati, where the practice has attained the greatest sophistication, with the leaves of *Guettarda speciosa*, *Tournefortia argentea* and *Sida fallax*, often applied in pandanus baskets, with other leaves and topsoil, as part of an elaborate mulching system for giant swamp taro *Cyrtosperma chamissonis*, pandanus, and breadfruit (Small, 1972, Thaman 1990).

With specific reference to the Marshall Islands, preliminary analyses of available data indicate 168 use categories for 37 of the 58 indigenous species and 303 uses for 283 introduced species, the majority of which are ornamentals or food plants. This is a clear indication of the value of both indigenous and introduced plants to atoll peoples. It must be stressed that the analyses are based on traditional uses, many of which have lapsed or are only employed in emergency, because modern technology has pre-empted them. Modern medicine, clothing, fishing lines, matches, crockery, plastic bags, soap, and emergency food rations (food aid) have, for example, replaced traditional plant-derived products. Moreover, many of the current generation, schooled in the modern educational system and living in the cash economy, often know few of the traditional uses of plants, let alone their vernacular names. This loss of knowledge has undoubtedly contributed to a loss of appreciation for and indirectly to the degradation of the indigenous and long-established vegetation and flora of atolls.

Of particular concern on atolls is the abandonment of traditional food and beverage crops for imported foods such as sugar, white rice and flour, cookies and biscuits, noodles, canned fish, soft drinks, alcohol, tea and coffee, which has led over the past 25 years to dangerous levels of food dependency and some of the highest or most rapidly increasing incidences in the world of vitamin and mineral deficiency and nutrition related diseases. Diseases such as iron-

deficiency anemia, vitamin-A deficiency-induced night blindness, diabetes, cardiovascular disease, hypertension and stroke, gout and hyperuricemia, some forms of cancer and dental disease, which were rarely encountered in the past, are now serious causes of morbidity and mortality in the more urbanized atoll countries where western diets and life styles have replaced traditional diets and lifestyles (Parkinson 1982, Rody 1982, Coyne 1984, Thaman 1982, 1988).

Current Status of Atoll Biodiversity

The impoverished terrestrial and less-impoverished marine biodiversity inheritances that atoll peoples have as the capital needed for future generations, are under serious threat. There are frightening signs of the loss or endangerment of this living inheritance that has supported atoll societies for millennia. These include a wide range of terrestrial and marine ecosystems and species that are now rare or endangered and under threat. As stressed by Kirch (1982), Flenley & King (1984) and Steadman (1995), this is not a new phenomenon, but rather a phenomenon that began long before European contact with the Pacific Islands, when the early Pacific Islanders severely deforested some Pacific Islands and Easter Island (Rapa Nui), brought many bird species to extinction or extirpation (local extinction) throughout much of Polynesia, and brought to extirpation some species of giant clams. The process has, however, intensified, and the identification of the ecosystems, species and genetic resources that are rare, endangered or in need of protection or re-establishment is critical to the success of biodiversity conservation efforts and for the maintenance of cash and non-cash incomes in the Pacific Islands, at all levels (regional, national and local). This would also include the identification of ecosystems, plants and animals that are of particular economic or cultural importance as a basis for the promotion of ecologically, culturally and economically sustainable development. An attempt to do this for the entire Pacific is shown in Tables 2 and 3.

As can be seen from Tables 2 and 3, most atoll ecosystems and a wide range of terrestrial and marine organisms, and genetic or cultivars varieties of traditional food and other multi-purpose plants are declining in abundance and under threat of either "economic extinction" or extirpation and in need of some form of protection. The severity of the situation is greatest on those more urbanized atolls where both the biodiversity and the local knowledge of biodiversity are most threatened. Although many of these same ecosystems and organisms are endangered on the larger high volcanic and raised limestone islands, the need for their protection, sustainable use and restoration is, arguably, far greater on atolls where there is less ecosystem and biotic diversity, much more limited areas of each ecosystem type, smaller, genetically less diverse populations of individual species, and much higher human population densities. There is, thus, a serious need to protect designated ecosystems and specific endangered organisms, at the regional, national and local atoll and community level throughout the Pacific.

Table 2. Atoll ecosystems that are threatened and in need of protection in the Pacific Islands.

Ecosystem	Seriousness
Uninhabited atolls and islets	+++
Coastal littoral and mangrove forests	+++
Inland atoll forests and tree groves	+++
Wetlands/swamps	++
Agroforests/tree groves	++
Intensive agricultural areas/taro pits	+++
Houseyard and village gardens	++
Freshwater lens/water table	+++
Intertidal zone and seagrass beds	+++
Lagoons	+++
Reef passages	+++
Coral reefs	+++

+++ = of serious widespread concern and in need of immediate protection
++ = of some widespread concern or of serious concern in specific areas

Table 3. Terrestrial and marine plants and animals that are rare, endangered or in short supply, and in need of protection in the atolls of the Pacific Islands.

Category	Seriousness
Terrestrial Organisms	
Native coastal littoral plants	+++
Mangrove plants	+++
Native inland trees and plants	+++
Cultivated trees and plants	+++
Plant cultivars/varieties	+++
Native insects/arthropods	+++
Land crabs	+++
Molluscs/land snails	++
Other native invertebrates	+++
Native reptiles	++
Native birds	+++
Humans (ethnobiological knowledge)	+++
Marine Organisms	
Seaweeds (marine macro-algae)	++
Sea grasses	+++
Stony reef-forming corals	+++
Shellfish (giant clams, trochus, turban snail, pearl oyster, triton)	+++

Table 3, cont'd.

Category	Seriousness
Octopus and squid	++
Bêche-de-mer/holothurians	+++
Crabs, lobsters, mantis shrimp	+++
Eels (conger, moray)	++
Large demersal finfish (rockcods, wrasses, parrotfish)	+++
Other reef and lagoon fish (mullets, scad mackerels, etc.)	+++
Sharks and rays	+++
Billfishes	+++
Tuna species (big-eye tuna)	++
Turtles	+++
Sea birds	+++
Mammals (whales, dolphins)	+++

+++ = of serious widespread concern and in need of immediate protection
++ = of some widespread concern or of serious concern in specific areas

Many marine species are overfished for short-term export or local sale and the sustainability of even what seemed to be an inexhaustible tuna fishery is increasingly questionable. Because of low incomes and scarcity of foreign exchange on atolls coupled with the high market value of many marine products in East Asia and North America, there has been increasing pressure to market shark fin, bêche-de-mer, giant clam, large coral reef fish, deepwater snappers, aquarium fish, live coral and a number of other marine products, many of which are endangered and listed on the IUCN Red List of endangered species or on the CITES list of restricted exports (Thaman 2004a).

Throughout the atolls of the Pacific there is an increasingly wide range of wild and cultivated trees and other plants of critical cultural, economic and ecological value that are in need of some form of protection or replanting. Surveys of plants used for specific purposes in Kiribati, Tuvalu and the Marshall Islands show that there is particular concern over the loss or scarcity of a wide range of trees and plants used for house building, woodcarving, medicine, body ornamentation and sacred purposes. Even the more common fruit trees, such as coconut palms, papaya, breadfruit and pandanus are reported to be increasingly scarce on many atolls. In Kiribati most villages report the scarcity of pandanus varieties valued for the construction of traditional houses and ceremonial meeting houses (*maneaba*). Traditional named cultivated varieties ("cultivars") of important tree crops and taros on atolls are rare or are no longer cultivated because of overemphasis on monoculture, disease, tropical cyclones, drought, failure to replant, lack of planting material, and increasing dependence on or taste for imported foods.

The loss or endangerment of medicinal plants is a major concern throughout most areas, particularly in and around urban areas, but also in many rural areas. Results from a recent medicinal plant workshop in the Marshall Islands showed that 38 of a total 61 medicinal plants were considered to be rare or in short supply by some of the 45 female participants (Taafaki et al. 2006). The loss of medicinal plant biodiversity is a serious problem because few if any modern medicines are available in rural villages or to poor urban communities. Few medicines are to be found in outer island dispensaries, with almost all sicknesses and injuries being treated using traditional herbal medicine.

A large number of indigenous birds, some reptiles (e.g. lizards and geckos) and a number of invertebrate land animals are considered rare or endangered and in need of protection on atolls. Land birds most often mentioned as being rare or endangered include larger land birds such as doves and pigeons and lorikeets, which are found on some atolls. Also seriously endangered in some areas is a wide range of sea birds or migratory birds that used to be extremely abundant in coastal areas and on uninhabited islands throughout the Pacific. Many of these birds and their eggs were important in the local diet and are now considered to be rare or endangered by most atoll communities. These include noddies, terns, tattlers, godwits, plovers, frigate birds, boobies, tropic birds, petrels and shearwaters. As stressed by Steadman (1995), on many small islands in Polynesia and Micronesia, up to half of the resident land birds, almost all of which depend on indigenous forests and trees for their survival, have become extinct or extirpated (locally extinct) since the time of the first habitation of the islands by Pacific Islanders. Some species, such as frigate birds, are also kept as pets and of critical importance to atoll people as a sign to fishermen of the existence of schools of fish. Studies in the early 1990s showed that the loss of seabirds was considered the second most serious environmental concern in Tuvalu (Thaman & Neemia 1991).

Land crabs, especially the coconut crab and larger land hermit crabs are also now either absent or rare on many atoll islets. The coconut crab, in particular, which used to be very common in the past on many atolls, is now extirpated on most atolls and should be given some form of protection.

Although forest removal and hunting have historically been the main causes the loss of birds, land crabs, and larger reptiles, the introduction of pigs, rats, dogs and cats have seriously threatened populations of a wide range of birds, particularly ground-nesting birds, and a wide range of other invertebrates. The situation is most serious, however, on Guam, where the accidental introductions of the brown tree snake near the end of World War II has led to the virtual extinction of almost all indigenous land birds and the serious endangerment of flying foxes and lizards and geckos (Rodda & Fritts 1993, Quammen 1996). In Hawaii, Tonga and in the southern atolls of Palau and possibly other areas, introduced ants have also played a major role in the reduction of indigenous bird populations and/or threaten indigenous invertebrate fauna (CGAPS 1996; Wetterer et al. 1997). Atolls, although not currently affected by the brown tree

snake and some of the more destructive ant species, must strengthen their quarantine service to ensure that these pests are not introduced.

As can be seen, almost all indigenous birds should be given some form of protected status on atolls and their preferred habitats, tree groves, remaining areas of coastal, mangrove and inland forest and uninhabited islands given protected status. Of particular concern has been the widespread removal of groves of *Pisonia grandis*, the preferred rookery species for a wide range of sea birds. In many cases *Pisonia* groves have been cleared, beginning in the early colonial period, to make way for the expansion of coconut (copra) plantations onto the fertile, guano rich soils that had resulted from the thousands of generations of seabirds that had occupied the groves prior to their removal. Another probable cause of bird decline is the increasing scarcity of small fish, the main food of seabirds.

A large range of marine vertebrates are increasingly rare, endangered or in short supply in many Pacific Island countries. The most highly threatened species, and those in need of some form of immediate protection, include: whales and dolphins; all marine turtles, due to destruction of nesting sites and overexploitation of eggs and live animals; sharks and rays, which are currently overfished, both by local fishers, local commercial fishers, and most seriously, foreign fishing fleets; eels, particularly the conger, small moray eels found on reef flats, and the large deeper water moray eels; a number of smaller reef and lagoon fish due to the indiscriminate use of fish poisons, small-mesh gillnets and overfishing in general; and a number of large, commercially-important finfish commonly targeted by spearfishers, hook-and-line fishers, deepwater line fishers, and cyanide fishing for the live-fish export market, the most common being large rockcods, coral trout or groupers, large parrotfishes, the humphead wrasse, large trevallies, jobfishes and deepwater snappers, and billfish, which are commonly caught by longline vessels.

There are a large number of shellfishes, bêche-de-mer, lobsters, crabs and other marine invertebrates that are rare, endangered or overexploited throughout the Pacific. Shellfishes most commonly reported to be rare or endangered by local communities were giant clams, turban snails, a variety of other clams, black-lip pearl oysters, spider conch, triton shell, ark shell, topshells or trochus, venus clams and mussels. The declining yields of these shellfishes constitute a serious nutritional and economic problem, as they are some of the most reliable nutritional and commercial resources for low-income coastal communities. For some species, such as the triton trumpet shell (*Charonia tritonis*), a major predator of the crown-of-thorns starfish (*Acanthaster planci*), there is a need for a total ban on exploitation, whereas for others, e.g., giant clams (Tridacnidae), turban snails (*Turbo* spp.), ark shell (*Anadara* spp.) and venus clams (*Periglypta* spp.) there is a need for the establishment of local reserves, commercial or seasonal protection, until such time as stocks of a given species in given areas recover. In the case of the commercial trochus (*Trochus niloticus*), in areas where they have been introduced, such as Tuvalu, Tokelau and Tonga, once they have

established as a commercially viable resource, exploitation should only be allowed during a one-week or one- or two-day season (as is done in Pohnpei and the Northern Cook Islands) to ensure sustainable exploitation of this potentially extremely valuable commercial resource. Recent reports from Palau indicate that populations of trochus were so low that the 2004 harvest season was cancelled.

Bêche-de-mer (sea cucumbers) are overexploited, some seriously, in most countries due to the recent drive over the past 20 years to export these species to East Asian markets. All species should be given some protected status until such time as stocks recover, with some species being reserved for local consumption or limited local sale until stocks recover. As divers are forced to go deeper and stay underwater longer, there have been numerous cases throughout the Pacific of death and decompression sickness associated with diving for bêche-de-mer, which itself constitutes a serious threat to human biodiversity.

Other marine invertebrate also considered to be rare or endangered in some areas include lobsters (especially the slipper lobster), a wide range of crabs, the cake urchin, sea anemones, sea hares, octopus and squid, all of which are delicacies and/or important commercial species and sources of cash income to local communities. They are in need of some form of protection, at least the designation of some local marine reserves or the enforcement of seasonal or size restrictions on their exploitation.

Given the highly threatened status and obligatory dependence that atoll peoples have on biodiversity for their economic and cultural survival, it is suggested that, in accordance with the original PABITRA plan (Mueller-Dombois et al. 1999), the network should expand its emphasis on the biodiversity "hot spot" high islands of the Pacific to include greater emphasis on the of atolls and other small "cool spot" islands as was proposed by Bridges & McClatchy (2005) in their comparative study of plant diversity on seven atoll islets of Ailinginae Atoll in the Marshall Islands. They stress that inclusion of atoll sites: "will provide a broader range of opportunities to understand the function and structure of island ecosystems, including the role of people in these settings, while adding little additional cost to the overall project." The small size and almost infinite variety, size and shape of the atolls, individual islets and lagoons, variable distance from the Malesian center of island and marine biodiversity and other large-island sources of colonizing organisms, limited populations of terrestrial and freshwater organisms, relatively rich and accessible marine environments, and perhaps most important, the richness of atoll ethnobiodiversity, make atolls ideal laboratories for testing the island biogeography theory (MacArthur & Wilson 1967, Sauer 1969) and studying ecosystem processes, particularly linkages and interconnectivity between island and marine ecosystems and the functioning and sustainability of island ecosystems. Atolls also offer particularly good laboratories for studying the critical importance of freshwater resources on islands, another of the emphases of PABITRA's trans-ecosystem objectives. In the case of atolls, these resources

consist of very limited and fragile groundwater resources in the form of a freshwater lens.

There is also a relatively large body of existing knowledge on atolls and their associated marine biodiversity. This includes works produced over the last century on atolls of the North Pacific by German, Japanese and American scientists, work in the Tuamotus by mainly French Scientists, work in Solomon Islands, Kiribati, Tuvalu, Northern Cook Islands by English, Australian, New Zealand, Japanese and Pacific Island scientists, and work on Asian and Indian Ocean atolls by Asian, Maldivian and other scientists. Particularly important sources are for the Pacific are the *Atoll Research Bulletin* (1951 to present), *Micronesica* (1964 to present) and the publications of ORSTOM (Institut Français de Reserche Scientifique pour le Développement en Coopération, now IRD). Unfortunately, most of these works are by atoll visitors rather than knowledgeable residents. This gap offers a great opportunity for PABITRA to, as it has done so well over the past decade on high islands, build capacity among local atoll peoples to analyze and sustainably manage their own ecosystems.

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Appendix 1. Terrestrial, freshwater and marine ecosystems of the Pacific Island atolls that constitute the major resource-use zones and could serve as the focus for community-based, national and regional biodiversity conservation. Adapted from Thaman (1999).

Atoll Ecosystems	
Terrestrial and Freshwater	Marine
Inland Atoll Forest	Mangroves
Coastal Strand Vegetation	Fishponds/Maricultural Areas
Mangroves	Intertidal Flats
Agroforests and Tree Groves	Lagoons
Coconut Plantations	Coral Reefs
Scrubland/Herb-land	Island Shelf/Reef Platform/Seamounts
	Ocean Floor
Excavated taro pits	Open Ocean
Intensive vegetable gardens	
Houseyard and Urban Gardens	
Intensive Livestock Holdings	
Ruderal Sites	
Wetlands/Swamps	
Wells/Freshwater lens	
Fishponds/Aquaculture	
Beaches and Dunes	
Bare Limestone Rock	
Built/Urban	

Appendix 2. Frequency of the usage for specified purposes of 140 Pacific Island coastal plant species based on surveys of the literature and in-the-field surveys (Thaman 1992a).

	Plant life form / Number of species						
Purpose/Use	Ferns /10	Herbs /17	Grasses & Sedges /11	Vines & Lianas /14	Shrubs /26	Trees /62	Total /140
Medicinal/Health	6	15	7	11	23	51	113
General Construction	-	-	-	-	6	54	60
Body Ornamentation	6	8	3	7	12	26	62
Firewood/Fuel	-	-	-	-	8	43	51
Ceremony/Ritual	3	4	-	5	6	23	41
Cultivated/Ornamental	4	3	-	2	10	20	39
Tools/Toolmaking	-	-	-	-	4	33	37
Emergency/Famine Foods	4	5	2	2	4	18	35
Boat/Canoe Building	-	-	1	-	3	30	34
Dyes/Pigments	-	-	-	2	4	24	30
Magic/Sorcery	1	6	1	1	6	14	29
Fishing Equipment	-	1	2	-	8	17	28
Cordage/Fiber	2	2	2	6	3	10	25
Games/Toys	-	-	1	4	4	16	25
Supplementary Foods	2	2	-	2	3	14	23
Scenting Oil/Perfumery	1	1	1	1	6	11	21
Fertilizer/Mulching	1	2	2	1	4	11	21
Weapons/Traps	-	-	-	-	6	14	20
Woodcarving	-	-	-	-	1	18	19
Food Parcelization	3	1	-	3	1	11	19
Animal Feed	1	4	-	3	2	9	19
Legends/Mythology	-	-	-	-	3	15	18
Handicrafts	1	1	3	2	1	9	17
Clothing	-	1	3	-	1	9	14
Musical Instruments	-	-	-	-	1	13	14
Cooking Equipment	-	-	-	-	1	12	13
Fish Poisons	-	-	-	3	4	4	11
Export/Local Sale	-	1	-	-	2	8	11
Adhesive/Caulking	-	1	-	1	-	9	11
Fire by Friction	-	-	-	-	1	8	9
Soap/Shampoo	-	1	-	3	3	2	9
Containers	-	-	-	-	1	7	8

Appendix 2, cont'd.

	Plant life form / Number of species						
Purpose/Use	Ferns /10	Herbs /17	Grasses & Sedges /11	Vines & Lianas /14	Shrubs /26	Trees /62	Total /140
Repellents/Fumigants	-	-	-	-	2	6	8
Wild Animal Foods	-	-	-	-	3	5	8
Tannin/Preservatives	-	-	-	-	1	6	7
Antitoxins	-	1	-	1	1	4	7
Living Fences/Hedges	-	1	-	-	1	5	7
Staple Foods	-	1	-	-	-	5	6
Drinks/Beverage	-	1	-	2	1	1	5
Strainers/Filters	-	-	2	-	-	3	5
Toilet Paper	-	-	-	-	1	4	5
Land Reclamation	-	-	-	-	-	5	5
Calendars/Clocks	-	-	-	-	-	5	5
Contraceptives/ Abortifacients	-	-	-	-	3	2	5
Thatching/Roofing	-	-	-	-	1	3	4
Illumination	-	-	-	-	-	4	4
Combs	-	-	-	-	-	4	4
Animal Cages/Roosts	-	-	-	-	-	4	4
Oils/Lubricants	-	-	-	-	-	3	3
Brushes	-	-	-	-	-	3	3
Fans	-	-	-	-	-	3	3
Corks	-	-	-	-	-	3	3
Fishing Bait	-	-	-	-	-	3	3
Other Uses*	-	-	2	-	5	27	34
TOTAL	**35**	**63**	**32**	**62**	**161**	**671**	**1024**
Species with no reported uses	-	1	1	-	-	-	2

* Other uses include stimulants/teas, flavoring/spices, ear cleaners, splints, aphrodisiacs, hair remover, masticants/chewing gum, abrasives, tooth brushes, cigarette wrappers, coconut climbing bandages or harnesses, measuring tapes, fireworks, windbreaks, sand screens, ladders, walking sticks, tethering posts, punishment/torture, communication/language, and computation or counting.

Appendix 3. Coastal plant species of particular cultural utility based on the number of different uses from throughout the Pacific Islands, not including ecological functions and services, with local names from Majuro Atoll in the Marshall Islands (Thaman 1992a, Taafaki et al. 2006).

Scientific Name (Marshallese Name)	Uses	Scientific Name (Marshallese Name)	Uses
Cocos nucifera (**ni**)	125	*Bruguiera gymnorrhiza* (**joñ**)	16
Hibiscus tiliaceus (**lo**)	57	*Nypa fruticans* **	14
Pandanus tectorius (**bõb**)	53	*Barringtonia asiatica* (**wõp**)	14
Calophyllum inophyllum (**lukwej**)	43	*Mammea odorata* **	14
Cordia subcordata (**kõno**)	40	*Intsia bijuga* (**kubõk**)	13
Guettarda speciosa (**utilomar**)	36	*Cycas circinalis* (**nibaam**)	13
Scaevola sericea (**kõnnat**)	32	*Gardenia taitensis* (?)	12
Pemphis acidula (**kõñe**)	30	*Sida fallax* (**kio**)	11
Thespesia populnea (?)	26	*Triumfetta procumbens* (**atat**)	11
Rhizophora spp. (**bulabõl**)*	25	*Vitex* spp. (**utoõnamnam**)	11
Tournefortia argentea (**kiden**)	23	*Dodonaea viscosa* *	11
Casuarina equisetifolia (**nidil, pain**)	22	*Santalum* spp.**	10
Premna serratifolia (**kaar**)	22	*Entada phasioloides**	10
Morinda citrifolia (**nen**)	22	*Cerbera manghas**	10
Pipturus argenteus (**armwe**)	21	*Clerodendrum inerme* (**wulej**)	10
Terminalia catappa (**kotõl**)	21	*Cassytha filiformis* (**kaõnõn**)	10
Ficus tinctoria (**tõpdo**)	21	*Tacca leontopetaloides* (**makmõk**	10
Ficus prolixa **	20	*Crinum asiaticum* (**kieb**)	9
Erythrina variegata (?)	19	*Ficus obliqua* **	8
Inocarpus fagifer (**kurak**)	18	*Phymatosorus grossus* (**kino**)	8
Hernandia nymphaeifolia (**piñpiñ**)	18	*Neisosperma oppositifolium* (**kõjbar**)	8
Lumnitzera littorea (**kimeme**)	17	*Metroxylon* spp. **	7
Pisonia grandis (**kañal**)	17	*Ipomoea pes-caprae* (**topo, markinenjojo**)	7

? = present in Majuro, but name not known or doesn't exist
* = present in the Marshall Islands, but not on Majuro
** = not present in the Marshall Islands