No Room in the Ark? Climate Change and Biodiversity in the Pacific Islands of Oceania

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The islands of Pacific Oceania face unprecedented anthropogenic climate change within this century. Rising sea levels, increasing ocean acidification, warming land and sea temperatures, increasing droughts, and changes in the frequency and intensity of storms are likely to reorder or destroy ecosystems such as coral reefs, mangrove and montane forests, and coastal wetlands. For the developed nations, an array of measures could ameliorate these effects. Developing nations, whose economies may be significantly damaged by climate change, face major impacts on their citizens, identifying conservation of biodiversity as a lesser priority. Conservation in these countries may not succeed unless the rich nations are willing to pay for preservation of biodiversity hotspots or where preservation of biodiversity satisfies the needs of local communities, often through traditional management and land tenure systems in rural areas. These communities will need useable information, as well as technical advice on how to reduce stressors on changing ecosystems such as wetlands, mangrove forests and coral reefs, if they are going to achieve conservation. The resulting process if it involves local people may appear inefficient, relative to international expectations, but will be more effective over a wide area in conserving biodiversity.

Key words: community management, coral reefs, islands, mangroves, ocean acidification, parks, sea level rise, traditional knowledge

INTRODUCTION

ANTHROPOGENIC climate change represents a fearsome asymmetry between Pacific island states, especially those on atolls, and the inertia of powerful economies of distant developed nations, apparently locked on a course to change the world and Oceania forever. In this paper, Oceania includes the Pacific islands of Micronesia, Melanesia, and Polynesia, and excludes the countries of Australia, New Zealand and Papua New Guinea (Kingsford *et al.* 2009). Cumulatively, Oceania generates less than .01% of world CO_2 emissions (Boden *et al.* 2008). Consequently, the Pacific island states cannot change the trajectory of increasing atmospheric and oceanic CO_2. Perhaps quixotically, Tuvalu threatened to sue the United States and Australia in the International Court of Justice in 2002 because these countries failed to ratify the Kyoto Protocol on greenhouse gases, potentially submerging Tuvalu by rising sea levels (Jacobs 2005).

Oceania will be forced to adapt to climate change (Roy and Connell 1991; Mimura 1999), but many small states, especially those on atolls, lack the human or financial resources to craft proactive strategies (Pernetta 1992; Mimura *et al.* 2007; Kinch *et al.* 2010). Small islands are expected to lose more than 10% of their Gross National Product because of climate change (Berz 2001), further reducing their capacity to respond. In a worst case scenario for atolls, the primary coping strategies may be human movement, with populations increasing in remaining areas or emigrating to nearby rich countries such as Australia, New Zealand and the United States where they have no land tenure or ability to sustain traditional social systems (Barnett and Adger 2003; Locke 2009; Nunn 2009).

As the frequency of climate hazards continues to rise, conservation of nature in Oceania, could be a low priority, despite the region's rich biodiversity, unless directly tied to human needs (Mimura *et al.* 2007). Effective efforts to preserve biodiversity will need to reflect this reality. This paper examines the future of biodiversity in Oceania, reviewing the forces driving change, their possible effects on biodiversity, what can be done to address the problem and the ultimate prognosis. It focuses less on rich and more modernized areas such as Hawai'i and more on the atolls and rural areas spread throughout the Pacific.

THE FUTURE IS ALREADY PRESENT?

Driving Forces and Effects

Marine and coastal systems

Anthropogenic increases in ocean acidification, temperature and sea level will present major problems for the region's coral reefs, mangroves, and estuaries (Grantham *et al.*, this volume). Rising temperatures and associated factors lead to coral death (Jokiel and Brown 2004), while acidification reduces the calcium carbonate of coral and other marine organisms, a process not not fully understood but unlikely to prove beneficial (Doney *et al.* 2009). Coral ecosystems may become structurally simpler and less diverse in such acid conditions (Munday *et al.* 2010; Fabricius *et al.* 2011). The future of seagrass ecosystems is unclear: increased habitat

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and production resulting from elevated CO_2 levels may benefit them, but increasing turbidity and limits to upper thermal tolerance may reduce their extent and distribution (Björk *et al.* 2008). Species such as the dugong *Dugong dugon* and salt water crocodile *Crocodylus porosus* may encounter upper thermal constraints in marine habitats (Grigg and Seebacher 2001). The dugong, already restricted to relict populations in Oceania (Marsh *et al.* 2002), depends on sea grasses which may have shift or reduce in distribution (Björk *et al.* 2008). Already 55 % of coral reef fish species in Oceania are overfished (Newton *et al.* 2007), with larval fish survival threatened by further acidification (Munday *et al.* 2010). On the high seas, ranges of tuna *Thunnus* spp. will extend eastward with the expansion of the Western Pacific Warm Pool (Lehodey *et al.* 2003).

Sea levels are rising at an increasing rate in the tropical Pacific (Church *et al.* 2006). The magnitude of future rise is unknown, but may range from 0.5 to 5 m in this century, but probably closer to one metre (Hansen 2007; Fletcher 2009). In addition, the rise will probably vary geographically, the pattern of the last decade, with the tropical western Pacific experiencing some of the greatest rise (Fletcher 2009). Even sea level at the low end of the range will damage or destroy habitats such as brackish marshes, deltaic and estuarine mangrove forests, and anachaline pools which will not be able to migrate inland on high islands if they back up on steeply rising terrain, seawalls or inhabited areas (Alongi 2002; Agrawala *et al.* 2003). Sea level rise will additionally affect atolls and beaches through erosion or shifting geomorphology, so that sea turtles (Chelonioidea), salt water crocodiles, monk seals *Monachus schauinslandi*, and ground-nesting seabirds will need to disperse from low-lying or eroding sites to remaining suitable haul out or nesting habitats (Baker *et al.* 2006; Fuentes *et al.* 2011). Increases in air and ground temperatures may affect remaining nesting sites, especially for nesting sea turtles and salt water crocodiles and sex determination of their eggs (Miller 1985; Spotila and Standora 1985; Webb *et al.* 1987; Grigg and Seebacher 2001).

Terrestrial and freshwater systems

For terrestrial systems, sea level rise will affect atolls and beaches through erosion or shifting geomorphology. Human populations are expected to double in some parts of Oceania in the next 30 years (Kingsford *et al.* 2009) and they are likely to concentrate in areas of higher ground where additional natural habitats will need to be cleared for housing, farming or disease control (Wickham *et al.* 2009). This human activity, aggravated by the effects of floods, droughts and tropical cyclones, will probably reduce biodiversity and ecosystem services.

Inland lakes on low islands may be affected as freshwater lenses are forced inland and closer to the surface because of saline intrusion (Burns 2002; White *et al.* 2007). Even slight salinization may have major effects on lacustrine ecosystems (Schabetsberger *et al.* 2009). Changes in freshwater lenses or rainfall may also put more pressure on existing lakes as water resources for human populations, adversely affecting freshwater ecosystems (Schabetsberger *et al.* 2009).

Droughts in some island groups may become more frequent, increasing fire frequency and intensity which, in the presence of alien grasses, can transform native forests into grasslands (D'Antonio and Vitousek 1992; Allen 2000). Temperature rise appears likely to be greater at higher than lower elevations and, combined with changes in rainfall, will change plant and animal communities and disease frequency (Benning *et al.* 2002; Loope and Giambelluca 1998; Still *et al.* 1999). Changes in the frequency and intensity of tropical storms and droughts may permanently alter forest cover and secondary succession patterns and reduce the number of mature trees suitable for cavity-nesting species (Lohse *et al.* 1995; Franklin 2007; Mimura *et al.* 2007; Woinarski 2010).

WHAT CAN BE DONE?

Current initiatives for conservation and climate change

Two early agreements on the preservation of biodiversity in the Pacific form the basis for responses to climate change. The 1976 (effective 1990; suspended 2006) Apia Convention on Conservation of Nature in the South Pacific called for the creation and maintenance of areas representative of natural ecosystems, as well as areas of cultural, historical, scientific or aesthetic interest (http://www.spc.org.nc/coastfish/Asides/conventions/apia.htm). Few states joined as members and a budget of only US $5,000 in 2001 limited activities. The 1986 (effective 1990) Convention for the Protection of the Natural Resources and Environment of the Pacific Islands Region and Associated Protocols (Nouméa Convention) was "a comprehensive umbrella agreement for the protection, management and development of the marine and coastal environment of the Pacific Islands region." It led to the formation of Secretariat for the Pacific Regional Environmental Program (see below).

In addition, the Convention on Biological Diversity (Article 6) requires the development of National Biodiversity Strategies and Action

Plans (NBSAPs) for "the conservation and sustainable use of biological diversity" and the integration of such plans into national activities (Carter 2007). Unfortunately, by 2007 only 11 of 14 countries had completed such plans and only half of these set measurable outcomes, primarily because of lack of funds and capacity (Carter 2007).

A formidable and ever changing array of programmes has since evolved to assist the Pacific islands in adapting to climate change (Table 1). With their often-limited life spans, grey literature publications and unstable internet presences, it is sometimes hard to fully appreciate resultant activities and impact. Many programmes focused on assessment of problems and risk, and assistance with development of policies and infrastructure to respond to change. Some set unrealistic goals such as "By 2010, 80% of the genetic diversity of domesticated and wild island species is conserved and the associated knowledge of indigenous and local communities maintained" (UNEP 2004). Some programmes are inactive between meetings or the nations involved may commit to obligations that cannot be honored because of a lack of resources or political will (Turnbull 2004, Chasek 2010).

The most relevant programme for biodiversity is the Secretariat for the Pacific Regional Environmental Program (SPREP), a 25-nation consortium to "serve as the conduit for concerted environmental action at the regional level" through two programmes: Island Ecosystems and Pacific Futures. It has supported action plans for protected areas (SPREP 1985, 1999a, 2009), nature conservation (SPREP 1999b), invasive species (Sherley *et al.* 2000), marine systems (Kinch *et al.* 2010), and wetlands (SPREP 2011). For climate change, it has documented countries' individual capacities for response (Wickham *et al.* 2009) and adaptation strategies to conserve species and ecosystems (Stolton and Dudley 2011 Brooks 2011). SRREP also serves as the secretariat for the Nouméa Convention and efforts such as The Pacific Islands Framework for Action on Climate Change and the Pacific Islands Climate Change Assistance Program (see Table 1).

SPREP and other organizations provide useful lists of needed actions and policies, avoiding the necessity for inconsistent and redundant efforts across the region. The organizations are advocates and conduits for international funding, such as through the Global Environment Facility (Chasek 2010) or the Pacific Islands Climate Change Assistance Program, International Climate Change Adaptation Initiative, and Global Climate Change Alliance (Table 1). They also effectively distribute information, albeit much of it unpublished "grey literature", with variable quality and limited distribution (Calver and King 1999). Collating and disseminating information on adaptive strategies may be the most cogent reason for their existence (Barnett and Campbell 2010).

Challenges to effective conservation in the face of climate change

Information and capacity

We know relatively more about the physical than biological environmental attributes of Oceania because of satellite coverage of temperature, sea level and mapping, but resulting data sets, maps and modelling are often at too coarse a scale to be useful for many island states, much less local island communities (Kelman and West 2009). Our ability to detect even large changes in marine environments is similarly limited because of the scarcity of shipboard or shore-based monitoring across the vast region (McKinley 2006; McPhee 2010). We remain only at the initial stage of biological inventory, with few recent monitoring programmes (Burns 2002; Gilman *et al.* 2006; Ellison 2009; Gillett 2009); such surveys have already provided important insights for planning. For example, selection of additional coral reef Marine Protected Areas (MPAs) in Oceania should focus on the most resilient, either because they are already adapted to hot water areas or are in areas least likely to experience major gains in water temperatures (McLeod *et al.* 2010).

There remains a lack of science concerning ecological threats, with only 11% of such studies in Oceania not focused on Australia, New Zealand and Hawaii (Kingsford *et al.* 2009). Finally, much of the information generated does not reach or is not used at the local level where communities decide (Barnett 2001; Nunn 2009; Barnett and Campbell 2010).

We need to look more at information requirements: usefulness for decisions and usability for those who can use it. Unfortunately, these requirements may be culture and even site specific, not necessarily amenable to broad generalities and big programmes.

Planning for adaptation in the face of uncertainty

Anthropogenic climate change is coming, but there is still considerable uncertainty about where, when and how much but adaptations to protect biodiversity must proceed despite such uncertainty. Unless we are willing to deal with the root causes, we have to ameliorate the symptoms, with three main approaches. First, there are "no regrets" strategies that make sense

Table 1. A partial list of international organizations and programmes addressing climate change issues in Oceania with number of participating countries, dates of initiation and termination and web site.

Programs	Description	Reference
Alliance of Small Island States (AOSIS)	A coalition of small island developing states (SIDS) lobbying at the international level on climate change issues. 43 countries, 1991.	http://aosis.info/
Assessments of Impacts and Adaptation to Climate Change (AIACC)	"to enhance the scientific capacity of developing countries to assess climate change vulnerabilities and adaptations, and generate and communicate information useful for adaptation planning and action." 45 nations, 2001-2007.	http://www.essp.org/fileadmin/redakteure/pdf/others/AIACC_20summary.pdf
Global Climate Change Alliance, Small Island States Project, Secretariat of the Pacific Community (GCCA SIS)	"promote the development of long term strategies and approaches to adaptation planning and . . . pave the way for more effective and coordinated delivery of aid for climate change response at the national and regional level." Nine states, 2011-2015.	http://www.spc.int/en/component/content/article/216-about-spc-news/740-114-m-climate-resilience-project-will-help-nine-pacific-small-island-states.html.
International Climate Change Adaptation Initiative	"to meet high priority climate adaptation needs in vulnerable countries in our region" through funding, training, science and community-based adaptation programs. Fourteen countries, 2008-2013.	http://www.climatechange.gov.au/en/government/initiatives/international-climate-change-adaptation-initiative.aspx
National Adaptation Programme of Action (NAPA), United Nations Framework Convention on Climate Change, (UNCCC)	"to identify priority activities that respond to their urgent and immediate needs to adapt to climate change." Only Kiribati, Samoa, Tuvalu and Vanuatu have produced these. 1994.	http://unfccc.int/national_reports/napa/items/2719.php
Pacific Adaptation to Climate Change Project (PACC)	"improve technical capacities to support appropriate adaptation centric policies, demonstrate cost-effective adaptation techniques in key sectors, and promote regional cooperation." 13 countries, 2009-2014.	http://www.undp.org.ws/FocusAreas/ClimateChangeandEnvironment/PacificAdaptationtoClimateChangePACC/tabid/6362/language/en-US/Default.aspx
Pacific Climate Change Science Program (PCCSP)	"providing regional and national climate projections" 14 Pacific countries, ?—2011.	http://www.cawcr.gov.au/projects/PCCSP/
Pacific Climate Information System (PaCIS)	"provides a programmatic framework to integrate ongoing and future climate observations, operational forecasting services and climate projections, research, assessment, data management, outreach, and education to address the needs of American Flag and U.S.-Affiliated Pacific Islands." One country? 2006.	http://noaaclimatepacis.org/#dataServices/noaaPartners
Pacific Islands Climate Change Assistance Program (PICCAP)	"Designed to strengthen capacities of participating countries in terms of training, institutional strengthening and planning activities to enable meeting of reporting commitments under UNFCCC" 10 countries, 1997-2001?	http://unfccc.int/files/meetings/workshops/other_meetings/application/pdf/new_zealand.pdf
Pacific Islands Climate Change Cooperative (PICCC)	"The PICCC provides a range of scientific and technical tools to help managers in Hawai'i, the Mariana Islands, American Samoa, and other Pacific Island groups make informed decisions for landscape-scale conservation of natural and cultural resources including climate models at the archipelagic and island scales, ecological response models, and implementation and monitoring strategies for island species, resources, and communities." ?? nations, 2009.	http://piccc.net/
Pacific Islands Framework for Action on Climate Change (PIFACC).	"to ensure that Pacific Island peoples and communities build their capacity to be resilient to the risks and impacts of climate change. . ." 25 members, 2006-2015 http://www.sprep.org/climate_change/pycc/documnets/PIFACC.pdf	http://www.sprep.org/climate_change/pycc/documents/PIFACC.pdf

Table 1. continued.

Programs	Description	Reference
Pacific Islands Regional Ocean Policy (PIROP)	"a regional effort to achieve responsible ocean governance. It is based on existing international and regional agreements that establish a broad framework for regional cooperation and coordination to sustainably manage and conserve the ocean ecosystem in the region. It provides the basis for the harmonization of national and regional actions, for the next five years." 22 nations, 2002 -.	http://www.sprep.org/legal/documents/PIROP.pdf
Pacific Regional Integrated Sciences and Assessments (Pacific RISA)	"to enhance Pacific communities' abilities to understand, plan for, and respond to changing climate conditions . . . though interdisciplinary research and partnership with local, national, and regional stakeholders." One nation, 1995.	http://www.pacificrisa.org/cms/
Secretariat for the Pacific Regional Environment Program (SPREP)	"to promote co-operation in the South Pacific region and to provide assistance in order to protect and improve its environment and to ensure sustainable development for present and future generations." 25 members, 1982 (effective 1995).	http://www.sprep.org/

even if climate change failed to have major effects (Heltberg *et al.* 2009). Managing non-climatic stressors such as pollution, erosion and over exploitation of marine and forest resources are "no regret" options that will reduce climate change effects and result in more time for adaptation for coral reefs (Bruno and Selig 2007; Anthony *et al.* 2011; Kelly *et al.* 2011), mangroves (Gilman *et al.* 2006), forests (Woinarski 2010), and suites of organisms such as fish (Foale 2008) and sea turtles (Fuentes *et al.* press).

Strengthening existing networks of areas that protect a range of ecosystems (Olson and Dinerstein 1998; Brooks *et al.* 2002) is another "no regrets" option. Such external models of protected areas (e.g., national parks) often fail in Oceania, even without the challenges of climate change, because they are too small, too poorly supported and, critically, are unresponsive to the resource needs of surrounding local communities (Carew-Reid 1990; Sheppard 1997). There is considerable focus now on protected areas meeting expectations for local communities. There are already at least 1,232 Marine Protected Areas (MPAs or) locally managed marine areas (LMMAs), covering 34 000 km^2 in the Pacific (Govan *et al.* 2009), many managed according to traditional beliefs and decision-making which may not reflect biodiversity conservation or sustainable development ethics, but the needs of the local users (Foale 2008). Such traditionally managed areas have higher measures of "effective conservation" than national parks and may be more effective than marine parks when enforcement capability is limited (McClanahan *et al.* 2006).

Second, there are more intensive efforts that present a high risk but may be more effective than "no regret" efforts. These include the establishment of legal setbacks to infrastructure to allow migration of mangrove with sea level rise (Gilman *et al.* 2006) or "planned retreats" which integrate social, economic and ecological measures for rising sea levels (Gilman *et al.* 2007). Restoration and creation of new mangrove habitats has not always been successful, but the techniques exist and could be applied widely if the capacity was available (Lewis 2005; Gilman *et al.* 2006). Other more focused but often untested measures could include shading turtle nesting sites to reduce heat at beaches, nest relocation, and massive artificial incubation programmes (Hamann *et al.* 2007; Fuentes *et al.* press). Efforts to protect coral reefs might include pumping water from deep offshore to cool them (Von Herzen 2010). Crushed shell material could be returned to beaches to raise the inshore pH (Kelley *et al.* 2011). This raises the general question of whether wide scale 'liming' could be used on coral reefs. The economics of many of these options would probably limit them to a few small areas in rich countries, even if they should prove to be highly effective.

On the coast, there is a need for advanced, systemic planning for the creation of "arks", elevated sites that could be occupied by nesting sea birds, sea turtles, and resting monk seals, as rising sea levels remove low sites (Hamann *et al.* 2007; Duffy 2010; Fuentes *et al.* 2010). One suggestion calls for permanently parking de-oiled aircraft carriers, particularly the appropriately named H. M. S. *Ark Royal,* and other large ships adjacent to important low seabird islands as alternative sites (B. Flint, pers. comm.).

Finally, for the third type of adaptation, building general human and governmental capacity to respond to the unexpected represents the best strategy, since the specifics of climate change are difficult to predict (Berkes and Folke 1998). Local communities need information and capacity to implement decisions, as well as opportunities to learn from the experiences of other communities (Nunn 2009). Communication and implementation at the local level require resources to be successful, and external financial support will be essential (Pernetta 1992), although it may come with external agendas that hinder. Donor agencies will also face tradeoffs between accountability and the need to understand or at least tolerate the needs and agendas of a large number of small communities (Carbon Market Solutions 2010). Non-governmental organizations (NGOs) could play a crucial role as intermediaries, operating either by theme (e.g., forestry or watershed protection) or by region.

Prospects for Future Biodiversity

We will probably have little success predicting the response of particular ecosystems and their individual component species to climate change. Dramatic changes in populations of existing species or the introduction of new invasive species will likely alter ecosystems unexpectedly. We can broadly predict simplified ecosystems, relict species and ecosystems reduced to refuges, and increases in species and communities that can coexist with increased human demands.

The extent of future damage caused by anthropogenic climate change may best predicted by proximity to sea level. Coral reefs, beaches, mangrove swamps and estuaries will suffer the most damage, if not complete loss in many areas. On land, low-elevation "natural" environments, already limited, will be further reduced as an increased human population compensates for living space lost to the sea. Habitable living areas will be restricted by absence of potable water, as salt intrusion pushes freshwater lenses to the surface. Montane forested areas, while hotter and perhaps drier than before, may suffer less direct damage than habitats at low elevations because of low human pressure, tradition, and perhaps because of the societal need to maintain watersheds. Individual forest species may be displaced or disappear because of increased fire, invasive species, disease or thermal tolerances. The offshore marine environment may suffer proportionately less than inshore, but the results of major changes in atmospheric circulation will be significant (Vecchi *et al.* 2006), even if difficult to observe.

Several socioeconomic factors may also reduce effectiveness of conservation of biodiversity in Oceania. The relatively resource-rich intergovernmental agencies (IGOs) tend to respond with a top down approach to climate change. This is good for risk assessment, capacity building of governments and increasing the collection and dissemination of information (Hay and Mimura 2006), but generalities from the coarse-grain approaches of IGOs may not be useful locally (Kelman and West 2009). Second, many governments lack either the will or the resources to manage climate change effectively, except sometimes where they focus on human needs.

Ultimately, most adaptation is local, with a bottom-up approach facilitated or limited by local choices, human and in-kind resources and available information. Persistent traditional knowledge may be an effective framework from which to inform responses to climate change (Hoffmann 2002; Mercer *et al.* 2007; Foale 2008; Kelman and West 2009), but it may be a hindrance when environmental change falls outside the range of traditional experience or when change removes the social context in which traditional knowledge can successfully operate (cf. Merlin and Raynor 2005) and when local communities poorly value biodiversity that is not used (Foale 2008; Anon. 2009).

Conservation of biodiversity may best "piggy back" onto such community climate adaptations by providing practical information to local communities on how to reduce stressors such as erosion, overfishing or pollution. We need to be mindful that these same stressors may be the inevitable byproducts of human adaptation to climate change. We have to be able to show how preserving or restoring whole ecosystems will provide more beneficial environmental services than simple planting of mangroves (cf. Ghazanfar 2001).

Alternatively, international conservation efforts may have to "pay to play" by financing traditional parks that protect a range of ecosystems (Olson and Dinerstein 1998; Brooks *et al.* 2002) but this traditional western approach has a poor track record in Oceania (Sheppard 1997) and equally poor prospects for the future (Mora and Sale 2011) without massive infusions of outside funds.

Essentially, we can chose to invest international resources in widespread local efforts that will save considerable biodiversity inefficiently, relative to external expectations but are more likely to endure. Or, we can support fewer but more efficient projects, more likely to efficiently achieve international goals, but requiring continuing major external support to survive. We could do both with sufficient knowledge for informed decisions. In reality, we lack both the knowledge and the resources.

While the survival of much biodiversity and many human communities is at risk in Oceania, the Pacific has always been a place of change (Nunn 2007), and both humans and nature may well surprise us with unexpected resilience. Whether this will be because of or despite our best efforts will be a conclusion that can only be drawn by our children's children, looking back on what is still yet to come.

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