Conservation of Biodiversity in the Pacific Islands of Oceania: Challenges and Opportunities

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Pacific Island biodiversity has a notorious record of decline and extinction which continues due to habitat loss and degradation, invasive species, overexploitation, pollution, disease and human-forced climate change. In terrestrial systems, these global and local pressures are more acute because of relatively small land to sea area, high endemism and poor adaptations to resist predation. Regional policy and learning frameworks exist to combat biodiversity loss and environmental degradation, but implementation remains patchy across the 22 Pacific Island countries and territories (PICTs) within Oceania. PICTs are challenged by small, under-resourced government departments, limited data, and strong political will for rapid economic development at the cost of ecological sustainability. In this synthesis of the special issue, we identify the challenges and opportunities for biodiversity conservation on Pacific islands. We identified bright spots of implementation occurring through regional initiatives, knowledge-sharing networks, and community-based management. The challenge looms large, given the relatively small-scale efforts compared to the core drive for development of natural resources which continues to pervade island communities. Five key initiatives promise improved conservation effectiveness: 1) alignment of national biodiversity strategies to the Aichi Targets, under the Convention on Biological Diversity; 2) increased engagement with local communities to promote wise stewardship and local environmental monitoring; 3) dissemination of best practice guidelines for management through learning networks; 4) cost-benefit analyses that drive investment in biosecurity and invasive control; and 5) implementation of integrated island management that accounts for the multiple synergistic benefits of ecosystem management (e.g., climate adaptation, disaster risk reduction, improved health).

Key words: Pacific Island countries and territories, habitat loss, invasive species, overexploitation, pollution, disease, climate change, policy.

INTRODUCTION

GLOBAL commitments to halt biodiversity decline have proved ineffectual, with rates of species extinctions accelerating (Butchart *et al.* 2010), particularly on islands. While island isolation promotes high endemism and specialized flora and fauna (MacArthur and Wilson 1967), low alpha diversity, small population sizes, genetic bottlenecks and gaps in functional groups make this biodiversity highly vulnerable to natural and anthropogenic disturbances (Frankham 1998; Kier *et al.* 2009; Keppel *et al.* 2014). Habitat loss and degradation, invasive species, overexploitation, pollution, disease and human-forced climate change have profoundly impacted island biodiversity, particularly in the Pacific Islands of Oceania (Gibbons 2000; Steadman 2006; Kingsford *et al.* 2009).

The Pacific Island countries and territories (PICTs) of Oceania, spread across Melanesia, Micronesia and Polynesia, have uniquely naturally variable ecosystems, including tropical montane rainforests, open woodlands and grass savannahs, freshwater lakes and streams, salt marshes and mudflats, mangrove and coastal littoral forests, seagrass, fringing and offshore coral reefs, and deep sea trenches and abyssal plains (SPREP 2012). These island ecosystems have high species turnover and an unusual richness of endemic terrestrial and freshwater species, driven by their relatively small land area compared with sea area (Table 1; Kinch *et al.* 2010) and vast oceanic distances between land masses (Keppel *et al.* 2009, 2014; Woinarski 2010). The western edge of Oceania, including Papua New Guinea and Solomon Islands, within the Coral Triangle region, is broadly considered the centre of highest marine biodiversity on the planet (Veron *et al.* 2009). Marine species richness tapers off towards the eastern islands of Polynesia, with proportionally increasing endemism in some taxa (Hughes *et al.* 2002).

Pacific Islands were first impacted by humans when indigenous settlers arrived about 60 000 B.C. in Papua New Guinea, extending to 1 000 A.D. at more remote locations (Keppel *et al.* 2014). This settlement wave drove mass declines and extinctions of species ill-equipped to deal with humans and accompanying dog and rat predators; for example about 50% of indigenous birds (40 species) were eliminated from the Hawaiian Islands when Polynesians arrived (circa A.D. 400; McNeill 1994). These human communities relied on ecosystem services delivered through subsistence agriculture, fishing, and hunting, within strongly linked socio-ecological systems where remaining biodiversity was maintained through small-scale disturbance and cultivation (McNeill 1994; Berkes 2012; Thaman 2014). Where performed or revitalized, these customary practices still preserve species and genetic diversity (Johannes

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Table 1. Environmental context for 14 Pacific island countries and 8 territories (T), including estimated population in 2010, land area, approximate Exclusive Economic Zone (EEZ) area, central governance capacity, Human Development Index (HDI), and Environmental Vulnerability Index (EVI).

Country or Territory	Estimated Population[a]	Land area (km^2)[b]	~EEZ Area (km^2)[b]	Central Governance[c]	HDI[d]	EVI[e]
American Samoa (T)	65 896	197	390 000	Medium	n/a	Extremely vulnerable
Cook Islands	15 529	180	1 830 000	Very Low	n/a	n/a
Federated States of Micronesia	111 364	702	2 978 000	Very Low	n/a	Extremely vulnerable
Fiji	847 793	18 376	1 290 000	Low	Medium	Highly vulnerable
French Polynesia (T)	268 767	3 521	5 030 000	High	High	Extremely vulnerable
Guam (T)	187 140	549	218 000	Medium	n/a	Extremely vulnerable
Kiribati	100 835	726	3 550 000	Very Low	Medium	Extremely vulnerable
Marshall Islands	54 439	720	2 131 000	Very Low	Medium	Highly vulnerable
Nauru	9 976	21	320 000	Medium	Medium	Extremely vulnerable
New Caledonia (T)	254 525	19 103	1 740 000	High	High	Vulnerable
Niue	1 479	258	390 000	Very Low	n/a	Vulnerable
Northern Mariene Islands (T)	63 072	475	1 823 000	n/a	n/a	Extremely vulnerable
Palau	20 518	500	629 000	Low	High	Highly vulnerable
Papua New Guinea	6 744 955	461 690	3 210 000	Low	Low	At risk
Pitcairn Islands (T)	66	5	800 000	n/a	n/a	Vulnerable
Samoa	183 123	2 934	120 000	Low	Medium	Highly vulnerable
Solomon Islands	549 574	29 785	1 340 000	Very Low	Low	Vulnerable
Tokelau (T)	1 165	12	290 000	n/a	n/a	Highly vulnerable
Tonga	103 365	696	700 000	Low	Medium	Extremely vulnerable
Tuvalu	11 149	26	900 000	Very Low	Medium	Extremely vulnerable
Vanuatu	245 036	12 189	680 000	Low	Medium	Vulnerable
Wallis & Futuna (T)	15 256	124	300 000	High	n/a	Vulnerable

[a] Source: SPC 2010.
[b] Source: Gillett 2010. Note: values for EEZs (200 nm) should be regarded as estimates only as some Pacific Island Countries and Territories have not formalized their EEZs boundaries.
[c] Rankings are based on World Bank Governance Indicators (accessed from: http://databank.worldbank.org/data/views/variableselection/selectvariables.aspx?source=worldwide-governance-indicators). The 2012 percentile ranking of country government effectiveness and regulatory quality was averaged and grouped into the following categories: 0–25% = very low; 25.1–50%: low; 50.1–75%: medium; 75.1–100%: high.
[d] The HDI is a composite index based on relative measures of life expectancy, literacy, education, standards of living, and quality of life for countries worldwide (UNDP 2013). n/a = data not available.
[e] The EVI is a composite index based on 50 indicators that describe three overall aspects of environmental vulnerability (hazards, resistance, damage), measured across the following sectors: climate change, biodiversity, water, agriculture and fisheries, human health aspects, desertification, and exposure to natural disasters (accessed from: http://www.sopac.org/index.php/environmental-vulnerability-index) (Pratt *et al.* 2004). n/a = data not available.

2002; Jupiter *et al.* 2014a; Thaman 2014). The subsequent European settlement wave (from about the 18th century) drove rapid biodiversity decline through loss of traditional ecological knowledge (Léopold *et al.* 2010), increased population pressure (e.g., from six to ten million people in Oceania from 1990–2011; SPREP 2012), increased access to markets, spread invasive alien species (Keppel *et al.* 2014), and increased frequency of natural disasters associated with climate change (ABM and CSIRO 2011; Kingsford and Watson 2011a).

The stakes are high. Functioning ecosystems support the livelihoods, well-being, culture and economies of Pacific Island communities and nations (SPREP 2012, 2014). Given the combination of environmental changes, population growth and climate impacts, projections suggest that subsistence agriculture and coastal fisheries will not support the food needs of most Pacific countries by 2030 (Bell *et al.* 2009; Barnett 2011). PICTs must grapple with the tough task of meeting national and international biodiversity commitments with low central governance capacity and high environmental vulnerability (Table 1). Recognizing the enormous value of biodiversity and natural resources to Pacific Islanders, a wealth of regional and national policy frameworks promote biodiversity conservation and sustainable use, supported by a growing number of learning and knowledge sharing networks that funnel resources and technical support for environmental management (Table 2). Yet despite these efforts, globalized trade, development pressures and demographic shifts keep transforming landscape/seascapes, affecting Pacific biodiversity and reducing socio-ecological resilience to environmental and climate change (Barnett and Campbell 2010; Schwarz *et al.* 2011). Moreover, management implementation is hampered by limited data availability, poor collaboration among stakeholders, limited and mismanaged funding, and low political and public will (Lees and Siwatibau 2009; Keppel *et al.* 2012; Jupiter *et al.* 2014b).

The papers in this special issue specifically address these problems and opportunities to redress this imbalance. Keppel *et al.* (2014) review the major drivers of terrestrial biodiversity loss across Oceania, identifying management pathways through policies linked to clear national targets with specific, quantifiable outcomes. Meyer (2014) focuses on the often overlooked but severe impacts of invasive alien plants, with calls for increased vigilance through

Table 2. Guiding regional policy and learning and knowledge frameworks, their instruments and relevant coordinating institutions supporting environmental management and biodiversity conservation in Pacific island countries and territories. SPREP = Secretariat of the Pacific Regional Environment Programme, PIFS = Pacific Islands Forum Secretariat, SPC = Secretariat of the Pacific Community, IUCN–ORO = International Union for the Conservation of Nature – Oceania Regional Office, FFA = Forum Fisheries Agency, SOPAC = Pacific Islands Applied Geoscience Commission.

Policy Framework	Instrument (year ratified or adopted)	Coordinating Institution	Objectives relevant to environmental management and conservation
Sustainable development	The Pacific Plan for Strengthening Regional Cooperation and Integration (2007)	PIFS	Enhance and stimulate economic growth, sustainable development, good governance and security for Pacific countries through regionalism, including through improved natural resource and environmental management.
	Convention for the Protection of the Natural Resources and Environment of the South Pacific (Noumea Convention) (1986)	SPREP	Platform to develop bilateral or multilateral agreements, including regional or sub-regional agreements, for the protection, development and management of the marine and coastal environment.
	The Pacific Islands Regional Oceans Policy (PIROP) and Framework for Integrated Strategic Action (2005)	SPC	Sustainable use of Pacific Ocean and its resources through improved understanding of ocean systems, sound management, and partnerships to promote cooperation and ocean health. Call for establishment of a regional Pacific Oceans Policy Office.
	Pacific Oceanscape Framework (2010)	PIFS	Supports implementation of the PIROP, with emphasis on those elements that relate to integrated ocean management and biodiversity conservation. Calls for establishment of Pacific Regional Ocean Commissioner.
	Coral Triangle Initiative (CTI) on Coral Reef, Fisheries and Food Security. Regional Plan of Action[a]	CTI Secretariat	A multilateral partnership between the six Coral Triangle Countries of Solomon Islands, Papua New Guinea, Indonesia, Timor Leste, Malaysia and Philippines to build high level political commitments towards the sustainable management of marine and coastal resources in the global centre of marine biodiversity.
Biodiversity conservation	Draft Regional Framework [Action Strategy] for Nature Conservation and Protected Areas in the Pacific Islands Region 2014–2020	SPREP	Conservation of biodiversity and the natural environment to promote sustainable use and preservation of Pacific heritage. Provides guidance to achieve CBD Aichi Targets of through the implementation of NBSAPs and other international, regional and local conservation initiatives.
	Regional Wetlands Action Plan for the Pacific Islands 2011–2013	SPREP	Promote the importance of wetland conservation in the Pacific Islands region through management, capacity building, research and monitoring.
	National Biodiversity Strategy and Action Plans (NBSAPs)	Environment departments	Parties to the CBD are required to develop national plans to uphold the three pillars of the CBD (biodiversity conservation, sustainable use, equitable benefits sharing) and align to Aichi Targets. All PICTs have ratified except: US — signed only; Kiribati, Niue, Palau, Tonga — acceded (SPREP 2014).
Climate change & disaster risk reduction	Pacific Islands Framework for Action on Climate Change 2006–2015	SPREP	Ensure that Pacific Island peoples and communities build their capacity to be resilient to the risks and impacts of climate change.
	Pacific Disaster Risk Reduction and Disaster Management Framework for Action 2005–2015.	SOPAC	Building the resilience of Pacific Island communities to disasters through the development and strengthening of national disaster risk reduction and management, and its integration into national planning and decision making.
	[Draft] Strategy for Climate and Disaster Resilient Development in the Pacific (SRDP) 2016 onwards	SPC, SPREP	Facilitate, coordinate and guide actions that will enhance the resilience of development outcomes to natural and technological hazards, including those related to climate extremes, variability and change.

Table 2 continued overleaf

Table 2 continued

Policy Framework	Instrument (year ratified or adopted)	Coordinating Institution	Objectives relevant to environmental management and conservation
Pollution	Pacific Islands Regional Marine Spill Contingency Plan (PACPLAN) (2000)	SPREP	Prevent and minimize damage to marine and coastal environments and resources from major marine spills, and to hasten the recovery of any damaged environment and resources.
	A Regional Strategy to Address Marine Pollution from World War II Wrecks (2002)	SPREP	Prevent and minimize damage to marine and coastal environments as a result of marine spills from World War II Wrecks, and ensure the sanctity of these sites as war memorials and gravesites.
	Pacific Ocean Pollution Prevention Programme (PACPOL) Strategy 2010–2014	SPREP	Protect public health, safety, environment and natural resources from the effects of ship sourced marine pollution through prevention, control, monitoring, mitigation and management.
	Pacific Regional Solid Waste Management Strategy 2010–2015	SPREP	Adoption of cost-effective and self-sustaining solid waste management systems to protect the environment.
Invasive species	Guidelines for Invasive Species Management in the Pacific (2008)	SPREP	Support PICTs in developing invasive species work and guide regional and international agencies in delivering assistance.
	Shipping-related Introduced Marine Pests in the Pacific Islands: a Regional Strategy (2005)	SPREP	Prevent, minimize and control the introduction of shipping related pests through assessments and monitoring of current and potential risks, build capacity to respond and take actions and building mechanisms for regional collaboration and coordination.
Migratory species (of commercial value)	Convention for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean (Honolulu Convention) (2000)	FFA	Conserve and manage highly migratory fish species to ensure long term sustainability while promoting optimum utilization.
	Regional Tuna Management and Development Strategy 2009–2014	FFA	Ensure sustainable oceanic fish stocks and ecosystems of highly migratory fisheries species through improved integration of science in decision making and fisheries planning, stronger monitoring control and enforcement, reduced illegal, unregulated and unreported (IUU) fishing, and increased technical management capacity.
	Nauru Agreement Concerning Cooperation in the Management of Fisheries of Common Interest (1982)	FFA	Establish a coordinated approach to the fishing of common stocks by foreign fishing vessels within the EEZs of Federated States of Micronesia, Kiribati, the Marshall Islands, Nauru, Palau, Papua New Guinea, Solomon Islands, and Tuvalu.
Learning and knowledge sharing networks	Marine Sector Working Group	FFA	Serve as the interim support mechanism for implementing Pacific Oceanscape Framework
	Pacific Islands Roundtable for Nature Conservation (1997)	IUCN-ORO[b]	Serves as a forum for a network of non-government organizations, donors and regional organizations to collaborate and coordinate on the implementation of the Action Strategy for Nature Conservation in the Pacific Island Region.
	Pacific Climate Change Roundtable (2013)	SPREP	Strengthen coordination of regional organizations to support regional climate change priorities.
	Pacific Invasives Partnership (2008)	SPREP	Strengthen the capacity of Pacific Island Countries and Territories to effectively manage invasive species threats. Formed in 2008 through a merger between the Pacific Invasives Initiatives and the Pacific Invasives Learning Network
	Locally Managed Marine Area (LMMA) Network (2000)	LMMA Council	Network of practitioners involved in community-based marine conservation projects in the Indo-Pacific who share information on best practices for management.

Policy Framework	Instrument (year ratified or adopted)	Coordinating Institution	Objectives relevant to environmental management and conservation
Learning and knowledge sharing networks	Pacific Regional Environmental Economists Network (PREEN) (2009)	SPC, SOPAC	Network of professionals working together to promote and mainstream the use of economics in environmental management within the Pacific region. Provides a forum to exchange information and access peer support and advice.

[a] Applies only to Solomon Islands and Papua New Guinea
[b] The Secretariat is rotated between different organizations

biosecurity and increased understanding of island ecosystem functioning, including native-alien species interactions. Both Jupiter *et al.* (2014a) and Thaman (2014) emphasize the importance of maintaining traditional practice through customary management of locally-managed marine areas and agrobiodiversity systems to preserve important ecosystem services for Pacific Islanders. Finally, Jupiter *et al.* (2014b) advocate increased integrated island management to cost-effectively and efficiently conserve biodiversity, while simultaneously achieving benefits for climate change adaptation, disaster risk reduction and human health.

In this synthesis, we review these contributions and current knowledge of major conservation problems and potential solutions on Pacific Islands. We summarize the environmental context for the 22 PICTs, including their land area, exclusive economic zone size, population, governance capacity, development status and environmental vulnerability (Table 1). We examine impacts, challenges and opportunities for conservation of biodiversity on Pacific Islands across terrestrial, freshwater and marine ecosystems through the lens of the major threatening processes (Kingsford *et al.* 2009) and highlight regional policy frameworks and learning networks that provide support for management solutions (Table 2). Finally, we discuss the applicability and relevance of broad policy options (see Kingsford *et al.* 2009) and local management to effectively deal with Pacific Island biodiversity conservation (Table 3).

HABITAT LOSS AND DEGRADATION

The impacts to Pacific terrestrial, freshwater and marine biodiversity from habitat loss and degradation are well-documented (Kingsford *et al.* 2009). The first settlers probably did not cause significant habitat loss, although extinction of species from predation or disease would have affected the functionality of ecosystems (Keppel *et al.* 2014). Following European arrival, the landscape was dramatically transformed from native forests to commercial agriculture and forestry (McNeill 1994). The impacts were dramatic. There is now little primary forest left across the Pacific and over 1500 terrestrial species listed on the IUCN Red List of threatened species (Morrison 2012; Keppel *et al.* 2014). Replacement of traditional polyculture systems with monoculture cropping severely impacted agrobiodiversity and increased vulnerability of food production to disease and invasive species (Thaman 2014). The annual rate of forest conversion in Oceania (0.4%) is just over three times the global average (0.14%; SPREP 2014). Loss of forest drives serious declines in species richness and abundance in terrestrial ecosystems (Keppel *et al.* 2014), as well as freshwater invertebrate and fish communities (Haynes 1999; Jenkins *et al.* 2010). Moreover, river regulatory structures (e.g., dams, culverts and water diversions) sever connectivity, affecting upstream migration for the high proportion of diadromous fish in the Pacific, needing freshwater and marine habitats for their life cycles (Jenkins *et al.* 2010). Downstream runoff from land-based activities continues to damage corals (Golbuu *et al.* 2003) and sensitive juvenile fish habitat for commercially important reef fish (e.g., bumphead parrotfish *Bolbometopon muricatum* and humphead wrasse *Cheilinus undulatus*, R. Hamilton, personal communication). Nearly 50% of the coral reefs across the Pacific are classified as threatened (Burke *et al.* 2011), with strong regional declines in coral cover (Bruno and Selig 2007).

Most contemporary habitat loss and degradation is caused by commercial and natural resource development (e.g., forestry, river regulation), now legally requiring environmental impact assessments (EIA) in most PICTs, except Nauru, Niue and Tuvalu (SPREP 2012). However, government capacity and resources are limited for their review, implementation (e.g., developing conditions for approval integrating environmental objectives), and monitoring compliance (Table 3; Maragos 1993; Lane 2008), though there are opportunities for improvement (Table 3). Most Pacific Islands are under indigenous land tenure (Ward and Kingdon 1995); as such, strengthening awareness and leadership of landowners can improve environmental decision-making for lease agreements for logging, mining, development or other extractive activities. Local communities could monitor compliance with EIA conditions, potentially reducing offences if prosecutions and fines are delivered (Table 3). Furthermore, local

Table 3. Summary of current major threats to biodiversity affecting Pacific Island countries and territories (PICTs), relevant broad policy options recommended by Kingsford *et al.* (2009), their relevance to conservation for Pacific Islands and other potential local solutions.

Threatening process	Broad policy options (adapted from Kingsford *et al.* 2009)	Relevance and progress	Way forward
(1) Habitat loss and degradation	Develop or strengthen legislation, education and community outreach to stop or reduce land clearing, mining and unsustainable logging through education, incentives and compensation for landowners that will encourage private conservation.	Most environment legislation remains weak and poorly able to halt or mitigate anthropogenic threats.	Environmental Impact Assessments, required in most PICTs, must be critically reviewed and approvals granted with conditions for development that are monitored and enforced. Involving local communities in monitoring compliance may reduce future offences.
		Although a large proportion of land in PICTs is under customary tenure, land-owners are unaware of consequences of land clearing.	Strengthening awareness and leadership of landowners may improve environmental decision-making for lease agreements.
	Establish new protected areas for habitats that are absent or poorly represented, aligned with CBD Aichi Target commitments and manage threats within and outside protected areas.	Most PICTs are currently aligning their BSAPs to the CBD Aichi Targets, including setting targets for protected area establishment.	Under the Micronesia Challenge, Micronesian countries and territories have already committed to effectively conserve at least 30% of nearshore marine resources and 20% of terrestrial resources by 2020. Recognition of locally-managed marine areas can contribute substantially to achievement of national protection targets (e.g., in Fiji). New initiatives, such as the Big Oceans Initiative and Reducing Emissions from Deforestation and Forest Degradation (REDD+) schemes, can assist countries to meet targets as long as management measures are effective and adequately financed.
	Improve mechanisms for transparent and evidence-based state of environment reporting on biodiversity.	State of Conservation in Oceania 2013 report released (SPREP 2014)	Regular, quantitative state of the environment reporting is essential (Keppel *et al.* 2014), using indicators developed for the State of Conservation in Oceania report to track progress against a baseline.
(2) Invasive species	Avoid deliberate introduction of exotic species; improve regulation of aquarium, nursery, agricultural and pet trades; ensure consistent legal definitions for invasive species; and implement biosecurity across the region.	Most PICTs have national policies for invasives committed to Aichi Target 9: "By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated and measures are in place to manage pathways to prevent their introduction and establishment", but implementation is poor and patchy.	Existing legislation should be strengthened and new laws developed to create disincentives for deliberate or accidental species introductions. Substantial training for monitoring and surveillance is necessary. Prioritization of Pacific invasive species for biocontrol should be coordinated through a regional approach, aligned to the Guidelines for Invasive Species Management (Table 2).

Threatening process	Broad policy options (adapted from Kingsford *et al.* 2009)	Relevance and progress	Way forward
(2) Invasive species (continued)	Implement invasive species control by: assessing effective-ness of control programmes and determining invasion potential; developing cost-effective technologies; eradicating invasive species from islands with concentrated populations of endemic or threatened species.	Cost-benefit analyses are driving investment in biosecurity campaigns and invasive control.	Research should be focussed on increased under-standing of island ecosystem functioning, including native-alien species interactions, to identify future pathways for invasion (Meyer 2014).
		Small scale island eradications have been successful, particularly for invasive mammals.	Regional learning networks (e.g. Pacific Invasives Partnership, Table 2) should continue to disseminate technical expertise and toolkits, promote information exchange, focus funding and coordinate field programmes for invasives management.
	Establish regulations and enforcement for exchange or treatment of ocean ballast and regularly implement antifouling procedures.	Regional strategy developed for shipping-related introduced marine pests (Table 2).	Implementation of the regional strategy can be improved through development of national action plans.
(3) Overexploitation	Implement restrictions on harvest of overexploited species to maintain sustainability, with local input and involvement.	Poor quality and insufficient data severely hamper development of effective regulation measures.	Best practice guidelines on harvest limits that integrate traditional ecological knowledge should be disseminated through learning networks (e.g., LMMA, Table 2) and implemented by local communities to regulate extraction in the absence of rigorous monitoring data.
	Support international treaties for fisheries protection within EEZs and in the high seas with proper enforcement and denial of vessel docking for illegal fishing; avoid perverse subsidies and improve labelling of sustainable fisheries; and license exports of aquarium fish taken from captive breeding programmes or areas effectively managed for conservation.	Strong regional policy agreements (e.g. Nauru Agreement, Table 2) developed through cooperation among PICTs to control resource use by outsiders.	Develop regional high level political commitments to address inshore fisheries. Developing stronger regional and national reporting systems to better control import and export of marine products and reduce illegal unregulated and unreported fisheries.
	Ensure conservation of species (e.g., turtles, corals) receives legislative and education support within PICTs.	Regional recovery plans developed (e.g., for Oceania humpback whales *Megaptera novaeangliae* and sharks).	PICTs should continue to develop and implement recovery plans for other critically endangered and threatened species, linked to regional plans for those species that are highly migratory.
	Control unsustainable illegal logging and wildlife harvesting through local incentives and cessation of international trade.	Only 6 Pacific independent countries have signed the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).	Other PICT governments should be encouraged to ratify CITES and develop national implementation plans to regulate trade of controlled species.
		NBSAPs are being aligned to the new CBD Strategic Plan (i.e. Targets 3 and 6), eliminating perverse incentives harmful to biodiversity and promoting sustainable management of fish and invertebrate stocks.	Economic incentives, market-based solutions and adequate controls in international trade, documented and monitored in NBSAPs, can encourage and support sustainable use of natural resources.

Table 3 continued overleaf

Table 3 continued

Threatening process	Broad policy options (adapted from Kingsford *et al.* 2009)	Relevance and progress	Way forward
(4) Pollution	Decrease pollution through incentives and education; reduce and improve treatment of domestic, industrial and agriculture waste; and rehabilitate polluted areas.	The high proportion of general waste composed of organic material is increasingly viewed as a wasted resource that could be recycled and re-used (SPREP 2012).	Incentive-based local recycling and re-use programmes should be encouraged and replicated.
	Establish legislation, regulations and financial bonds to reinforce polluter-pays principles; strengthen government regulations to minimize impacts of mining waste.	Three decades of investment in regional policy to improve management of pollution has not yet resulted in enduring and effective waste management systems and compliance with national regulations.	PICT governments need to hold polluters accountable and deliver stronger fines for offences.
	Establish regulations, education programmes, clean-ups, labelling and use of biodegradable packaging to reduce discarded fishing gear and plastics.	Public awareness campaigns largely focus on clean-ups as opposed to prevention. Plastics still widely used when alternative materials are often available.	Cradle to grave economics, education and greater use of biodegradable products are needed to reduce waste flow.
(5) Disease	Establish early-detection programmes for pathological diseases and biosecurity controls to reduce translocation.	Disease management is hampered by poor capacity, few biosecurity staff and limited data.	PICTs should adopt pro-active management for health benefits as an ecosystem service (e.g., through integrated island management; Jupiter *et al.* 2014b)
	Establish remote communities of organisms (captive) not exposed to disease in severe outbreaks.	To conserve, protect and best utilize plant genetic resources, the Secretariat of the Pacific Community established the Regional Germplasm Centre (RGC) in 1998 (now the Centre for Pacific Crops and Trees) and the Pacific Agricultural Plant Genetic Resources Network.	Pacific regional organizations can continue to help preserve agrobiodiversity through sharing and dissemination of disease-resistant varieties.
	Identify causes, risk-assessment methods and preventative methods for pathogens and zoonotic diseases; increase research into causal impacts of environmental change on human health at relevant scales; improve coordination across health and environmental monitoring and surveillance systems; and restore ecological systems where appropriate.[a]	Regional Wetlands Action Plan for the Pacific (Table 2) calls for investigation of the linkages between ecosystem health and disease, though to date research has been extremely limited.	Focussed assessments on the impacts of changing ecosystem structure and function on disease emergence could be included under the emerging Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) and corresponding regional policy platforms.
(6) Human-force climate change	Reduce global greenhouse gas emissions.	Small, low-lying Pacific countries (e.g., Tuvalu) have taken a leadership role in aggressively negotiating for global agreement on legally binding protocols to cut emissions through the UN Framework Convention on Climate Change.	In the absence of global commitments, PICTs can continue to document climate change impact with rigorous data on areas affected by sea level rise.
	Identify, assess and protect important climate refugia (ecological and evolutionary).	Some countries have evaluated range restrictions likely to result from climate impacts (e.g., Lipsett-Moore *et al.* 2010).	More efforts to identify range shifts and refugia are warranted, coupled with action to protect sensitive species and ecosystems.
	Ameliorate the impacts of climate change through strategic management of other threatening processes.	PICTs are mainstreaming climate change concerns into national adaptation programmes of action to reduce vulnerabilities through management of local threats.	The Secretariat of the Pacific Environment Programme should be held to its regional target to strengthen by 2015 the capacity of all PICTs to respond to climate change through policy improvement, implementation of adaptation measures, enhanced ecosystem resilience (SPREP 2012).

[a] New policy recommendation not considered in Kingsford *et al.* (2009)

restoration should be central to community-based natural resource management in the Pacific (e.g. Jupiter *et al.* 2014a), recognizing that restoration at appropriate scales and with native species is challenging unless the threat is removed (Keppel *et al.* 2014; Meyer 2014).

Designation and implementation of well-managed protected areas is arguably the best mechanism available to stop habitat loss in marine and terrestrial environments. PICTs could increase their protected area networks to "at least 17 per cent of terrestrial and inland water areas, and 10 per cent of coastal and marine areas" that are effectively managed (Table 3). This aligns their National Biodiversity Strategies and Action Plans (NBSAPs) with the Convention of Biological Diversity (CBD) Strategic Plan 2011–2020 (UNEP/CBD 2010) (Table 2). Under the Micronesia Challenge, the Federated States of Micronesia, Palau, Guam, Commonwealth of the Northern Marianas Islands and Marshall Islands have committed to establishing at least 30% of nearshore marine resources and 20% of terrestrial resources by 2020, guided by national frameworks (e.g., Reimaanlok Plan for the Marshall Islands; Baker *et al.* 2011). Fiji committed to effectively protecting 30% of its inshore and offshore marine ecosystems, making considerable progress through locally-managed marine areas involving communities (Mills *et al.* 2011; Jupiter *et al.* 2014a). The global Big Oceans Initiative, a learning network for managers and partners, is focusing on effective management of large-scale (>240 000 km^2) marine managed areas, involving Kiribati, Cook Islands and Northern Mariana Islands (Big Ocean and WCPA-Marine 2014). The Pacific Islands also have innovative financing mechanisms for protected terrestrial areas; for example, there are conservation trusts potentially linked to international carbon markets for terrestrial areas (Jupiter *et al.* 2014b), although these still require considerable development (Table 3).

INVASIVE SPECIES

Pacific island flora and fauna are particularly vulnerable to invasive alien species, given historical absence of mammalian predators, grazing herbivores and aggressive weeds (SPREP 2014). On many Pacific Islands, the number of introduced plant species now equals or exceeds native and endemic species (Meyer 2014). Predatory animal invaders have decimated populations of birds, molluscs and aquatic insects, while grazing by feral ungulates, competition by invasive alien plants, and seed predation by rats have reduced native vegetation communities (Elton 1958; Loope and Mueller-Dombois 1989; Meyer 2014). Invasive alien species also transform and modify ecosystem processes and functions (Simberloff 2013; Meyer 2014), facilitating other invasions (Simberloff and Von Holle 1999). Their economic impact on ecosystem services can be substantial. For example, the invasive tree *Miconia calvescens* is estimated to cause US$137 million annually in lost ground water recharge services in Hawai'i (Kaiser and Roumasset 2002). Pacific Island agrobiodiversity systems have been particularly affected by invasive species, particularly root and fruit crops from introduced pests (Thaman 2014).

Most PICTs are signatories to the CBD (Table 2), committing them to control of invasive species under Aichi Target 9 (Table 3; UNEP/CBD 2010). This commitment is supported by national policies and strategies (SPREP 2012), but implementation is poor and patchy. Only nine Pacific countries have laws for invasive alien species, leaving most countries with little management (SPREP 2014). Island-scale eradications of invasive mammals can be successful, but the costs are high and success is not guaranteed (Pierce and Kerr 2013). Eradication of invasive alien plants remains particularly challenging given persistent seed banks (Meyer 2014). Prevention of invasive species establishment and early detection of new arrivals is a priority for PICTs (Loope *et al.* 2013), but requires substantial training for monitoring and surveillance (Table 3).

Cost-benefit analyses can drive investment in biosecurity campaigns and invasive control (Meyer 2014). For example, local stakeholders growing copra for coconut oil on Rimatara and Ua Huka islands of French Polynesia were convinced to stop invasion of black rats *Rattus rattus*, when they learned that the annual costs for biosecurity control would be less than 10% of projected annual costs of damage to crops if the rats invaded (Jupiter *et al.* 2013). Programmes exist to identify other high risk invasive species (e.g., red imported fire ant *Solenopsis invicta*; Sutherst and Maywald 2005), stimulating targeted biosecurity programmes (e.g., Sarnat and Caginitoba 2007). Prioritization of Pacific invasive species for bio-control is occurring (e.g., Paynter 2010), but should be coordinated regionally (Table 3; Sherley 2000; Meyer 2014). Regional knowledge sharing networks (e.g., Pacific Invasives Partnership, Table 2) disseminate technical expertise and toolkits, promote information exchange, and help focus funding and coordinate field programmes (Table 3). The Pacific Invasives Partnership works with PICTs, regional agencies and non-government organizations to implement the 'Guidelines for Invasive Species Management in the Pacific' (Tye 2009), a 2008 regional strategy endorsed by all country members of the Secretariat of the Pacific Regional Environment Programme (SPREP) and Secretariat of the Pacific Community (SPC).

OVEREXPLOITATION

Unsustainable use of terrestrial and marine resources continues at unprecedented rates in the Pacific, significantly reducing biodiversity and productivity, and impacting the flow of essential ecosystem services for Pacific Islanders (Keppel *et al.* 2014; Thaman 2014). Much of this is driven by increased consumer demand, poor or corrupt governance, poverty, few livelihood alternatives (especially in remote isolated islands), and inadequate incentives for conserving natural resources or managing them sustainably (Woinarski 2010). Forests are often overharvested for timber, fuel, materials, food, or medicines, and replaced with simple forest ecosystems or monoculture agriculture (Keppel *et al.* 2014). Culturally and economically valuable plant species like the Mollucan ironwood *Intsia bijuga*, extensively used for timber and for carving, are particularly vulnerable and have become locally extinct on many Pacific Islands (SPREP 2014).

In marine systems, 'boom and bust' exploitation has nearly collapsed many reproductive fish and invertebrate populations and altered foodweb relationships, affecting ecosystem productivity and food security (Bell *et al.* 2009; Kinch *et al.* 2010; Purcell *et al.* 2014). Top predators are particularly vulnerable to direct fishing impacts and as bycatch (Friedlander and DeMartini 2002), with over a third of sharks and rays in the southwest Pacific region threatened with extinction (SPREP 2014). Species not requiring refrigeration are becoming so rare or reduced as to be reproductively unviable (Teh *et al.* 2009; Purcell *et al.* 2014), including at least 20 species of commercially targeted sea cucumbers (Purcell 2014). Major pelagic fisheries are internationally controlled and subsidized (Sumaila *et al.* 2014). Despite the potential value of these fisheries to PICT economies (Gillett 2010), subsidized international fishing fleets have affected markets by skewing prices. They have also exploited fisheries beyond ecological limits (Sumaila *et al.* 2014), including many tuna species (e.g., skipjack *Katsuwonus pelamis*, yellowfin *Thunnus albacares*, bigeye *T. obesus*, albacore *T. alalunga*). Domestic fleets have insufficient infrastructure and often lack access to international markets or have inadequate business capacity to compete (Hannesson 2008). Further, there are complex socio-political interactions involving international funding for domestic capital infrastructure (e.g. schools, roads) in exchange for fishing leases (e.g. in the Cook Islands).

Pressures on terrestrial and marine resources will continue as human populations increase by 40% by 2030 (SPC 2010, Table 1). Poor quality data for inshore and offshore fisheries and little enforcement capacity within large Exclusive Economic Zones (EEZs) severely hamper effective regulation to meet sustainability benefits (e.g., GDP, employment and nutrition; Teh *et al.* 2009; Gillett 2010; Pauly and Zeller 2014). Better regulation through implementation of national and regional policies could reduce or reverse fisheries declines (Table 3). For example, regional Parties to the Nauru Agreement (Table 2) control 25–30% of the world tuna supply and 60% of the western and central Pacific supply. They have developed a vessel day scheme to limit the number of days fished, which benefits agreement members through increased revenue and sustainable fishing levels (Sumaila *et al.* 2014). For inshore fisheries, the 2008 Pacific Islands Regional Coastal Fisheries Management Policy (Apia Policy), endorsed by all heads of fisheries, focused on improved sustainable yields and maintenance of ecosystem function. Hundreds of Pacific Island communities also engage in bottom-up management of their coastal and marine resources, with technical support and resources from the Locally-Managed Marine Area network (Jupiter *et al.* 2014a).

At an international scale, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) can protect species vulnerable to overexploitation by controlling trade, but only six Pacific Island countries are signatories (Palau, Papua New Guinea, Solomon Islands, Vanuatu, Fiji, Samoa). Economic incentives, market-based solutions and adequate controls in international trade, documented in existing (NBSAPs), offer potential solutions to encourage and support sustainable use of natural resources (Table 3). Overharvesting of Pacific species could be reduced by aligning NBSAPs to the new CBD Strategic Plan (i.e., Targets 3 and 6), eliminating perverse incentives harmful to biodiversity and promoting sustainable management of fish and invertebrate stocks (UNEP/CBD 2010). Programmes are underway to assist PICTs to review and update their NBSAPs (SPREP 2014).

POLLUTION

Globalization is accelerating development, urbanization and consumerism across the Pacific Islands, increasing liquid, solid and hazardous wastes that undermine ecosystem health and impact on food, water and health security (Kingsford *et al.* 2009; SPREP 2014). Pollution comes from land-based sources, including industrial waste, chemical waste, pesticide run-off, sedimentation, urban run-off, plastic debris, as well as nutrient pollution from fertilizer run-off and sewage waste (SPREP 1999). Many plastics are broken down into small particles, ingested by seabirds and marine animals, bio-

accumulating in food webs (Gregory 1999; SPREP 2014). Larger plastic pieces concentrate in big ocean gyres such as in the northern Pacific Ocean (SPREP 2014). Increased reliance on imported goods has increased ship-based pollution from discharge of sewage and waste oil, disposal of plastic, oil spills, and toxic chemical leaching from anti-fouling paints. Inaccurate navigation charts and poor practice leads to ship grounding and sinking; with limited options for removal, abandoned ships leach chemicals and other pollutants, sometimes devastating coral reef ecosystems (Work *et al.* 2008; Kelly *et al.* 2012).

The Pacific Islands have experienced nearly three decades of investment to improve management of pollution, through national and regional waste management infrastructure, and sustainable waste management systems (Table 2). In 2000, all 22 PICTs and four supporting countries (Australia, New Zealand, France, USA) adopted the "Regional Marine Spill Contingency Plan", and subsequently reflected commitments in country specific contingency plans. Regional strategies exist for ship-based pollution, solid waste management and disposal of medical waste (Table 2). Pollution continues to be a central strategy for regional organizations, like the Secretariat of the Pacific Environment Programme. Despite these measures, control and management of point source and diffuse pollutants is increasing across PICTs due to their limited land area (Table 1), narrow land-sea interfaces, and inability to cover costs of waste treatment or disposal. The other PICTs only have non-statutory documents relating to the pollution and waste, with no supporting laws (e.g., American Samoa, Cook Islands, Marshall Islands, Wallis and Futuna) or no legislation or policy governing pollution and waste (e.g., Federated States of Micronesia, French Polynesia, New Caledonia, Pitcairn Islands) (SPREP 2014). Opportunities to address pollution impacts to human and ecosystem health include: cradle to grave economics; education; enforcement of laws and best practices to prevent, reduce or eliminate waste; and encouragement of the use of biodegradable products and sustainable energy (Table 3).

DISEASE

Human arrival and alteration of native systems brought novel pathogens and disease to the Pacific Islands, leading to population decline and species loss (Keppel *et al.* 2014; Meyer 2014). For example, mass mortality of flying foxes *Pteropus* spp. from diseases of unknown origin occurred in Fiji, Solomon Islands, New Caledonia and Federated States of Micronesia (Mickleburgh *et al.* 2002). Socioeconomic impacts of disease on agrobiodiversity are profound (Thaman 2014). For example, taro leaf blight *Phytophthora colocasiae* decimated agriculture production of native cultivars in many countries (e.g., Solomon Islands, Samoa, Fiji; Misra *et al.* 2008), and introduced and native nematodes damaged crops across major food staples (Bridge 1988), resulting in loss of food and/or livelihoods.

There can also be direct and indirect impacts on human health and ecosystem services (Myers *et al.* 2013; Redford *et al.* 2014). For instance, reductions in riparian canopy cover were associated with substantially increased *Enterococcus* spp. bacteria in Hawaiian streams, an indicator of faecal contamination and poor water quality (Ragosta *et al.* 2010). Incidence of ciguatera (fish poisoning largely caused by toxic benthic algae *Gambierdiscus* spp.) increased across the Pacific by 60% over the past 30 years, reflecting increased coral reef degradation (Skinner *et al.* 2011). Human disease risk may be exacerbated, fuelled by population increases, climate change and increased livestock interactions. For example, the rapid spread of Japanese encephalitis across Papua New Guinea may have been caused by the proximity of domestic pigs, availability of mosquito breeding sites, and dense human habitation (Mackenzie *et al.* 2001). The increased risk of dengue fever across PICTs is affected by the changing climate (Kolivras 2010).

Management of plant, animal and human disease is hampered by poor capacity, few biosecurity staff and limited data (SPREP 2014). Further, unpredictable climate-related natural disasters can trigger disease (Jenkins and Jupiter in press). Pacific Island governments have mostly reacted to diseases, rather than pro-actively managing for health benefits as an ecosystem service (Charron 2012; Jupiter *et al.* 2014b). The Regional Wetlands Action Plan for the Pacific (Table 2), aligned to the Ramsar Convention on Wetlands, calls for investigation of the linkages between ecosystem health and human health (Table 3). There is potential to assess impacts of changing ecosystem structure and function on disease emergence under the emerging Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES; Redford *et al.* 2014).

HUMAN-FORCED CLIMATE CHANGE

Few places on the planet are as vulnerable as the Pacific Islands to human-forced climate change impacts, particularly rising sea levels (Kingsford and Watson 2011a). Many ecosystems are threatened by considerable and rapid change in temperature and sea level rise (IPCC 2013). Proportionally small land areas (Table 1) and multiple synergistic threats (Table 3) cause acute and chronic impacts on the people, biodiversity

and ecosystem services of the Pacific Islands, across all three realms, terrestrial, freshwater and marine (Kingsford and Watson 2011a). Low-lying islands are particularly vulnerable to increasing frequency and intensity of storm surges that inundate coastal lands, affecting the viability of many organisms, particularly agrobiodiversity (Barnett 2011). Freshwater ecosystems are particularly affected by sea level rise, which will increase saltwater incursions, destroying freshwater lenses (Morgan and Werner 2014) and their dependent organisms (Jenkins *et al.* 2011), and affecting water security. For marine areas, the dual impacts of rising temperatures and ocean acidification are already severely affecting estuarine communities and the ability of many coral reef communities to survive (Grantham *et al.* 2011).

The Pacific Islands and their people and biodiversity are largely dependent on decisions about fossil fuel use and deforestation made by larger and wealthy regions across the world. Reducing effects of climate change requires a global commitment to reduce greenhouse gases substantially so that they do not continue to force up temperatures and increase sea levels (Kingsford and Watson 2011b). Pacific Island leaders have opportunities, albeit relatively few, to continue to mount their case at international forums. This can continue to be reinforced with rigorous data on areas affected by climate change across the many different nations and islands (Table 3).

Climate adaptation will increasingly become critical to the future existence of many of the Pacific island environments, their people and dependent biodiversity (Kingsford *et al.* 2009). Many Pacific Island governments have developed national climate adaptation strategies and actions plans, considering future climate scenarios, with dedicated institutions to coordinate and implement adaptation measures. Some Pacific governments are making provisions for citizens to migrate as climate refugees; for example, the Kiribati Government has secured land in Fiji in anticipation of relocation. There is significant targeted aid for the Pacific Islands aimed at building greater resilience to climate change impacts. Planning for biodiversity based on future scenarios must be integrated across sectors, providing for climate refugia and limiting development in sensitive areas (Lipsett-Moore *et al.* 2010). Improved management of protected areas and buffering coastal communities with vegetation that can resist some of the impacts of storm surges will be critical (Jupiter *et al.* 2014b). Climate change is affecting most aspects of the lives of Pacific Islanders and it is challenging to build resilience or accommodate change given the size of land, reliance on natural resources, the size and vulnerability of their economics and the lack of options. It requires a monumental cross-sectoral effort waged at local and international scales.

CONCLUSIONS

The response of Pacific Island governments to environmental challenges threatening biodiversity has mainly focussed on adopting a range of policy and legislative instruments at the international, regional, national and local level to tackle habitat loss and degradation, invasive species, overexploitation, pollution, disease and human-forced climate change (Table 2; SPREP 2012). The enthusiasm by which these instruments have been adopted has yet to be matched with equal attention to implementation, monitoring and enforcement. There are tangible opportunities for improving Pacific island biodiversity conservation (Table 3), including six broad areas of opportunity: local engagement; revitalization of traditional practices; environmental reporting; improved knowledge; economic incentives; and integrated island management. Dialogue with local communities is critical, given they have the most to gain from improvements to ecosystem services derived from biodiversity, but also have the most to lose. This can be considerably progressed, for example, by encouraging preservation of agro-biodiversity through maintenance of traditional ecological knowledge and sharing and dissem-ination of disease-resistant varieties (Thaman 2014). There is also an urgent need to understand the condition of our biodiversity and ecosystem services through regular state of environment reporting for education and assessing management effectiveness (Keppel *et al.* 2014), as well as new research on biodiversity and ecosystem services, essential for Pacific Island ecosystems and their people. Research focussed on increased understanding of island ecosystem functioning, including native-alien species interactions, is essential to identify future pathways for invasion and guide training programmes for national biosecurity staff (Meyer 2014). Given the importance placed by Pacific Island governments on economic development, economic incentives and market-based solutions can encourage and support sustainable use of natural resources and reduce waste. Integrated island management offers considerable cost-effectiveness and efficient ways to simultaneously manage for biodiversity, climate adaptation, disaster risk reduction and health services (Jupiter *et al.* 2014b). Managers, decision-makers and local communities need to be better informed about the options for action and the consequences of their choices, and better recognize the close relationships and interdependence between the environment, social systems and economy in the Pacific. In the absence of informed and urgent action, Pacific Island biodiversity and traditional ecological knowledge will continue to decline.

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