Natural Disasters, Health and Wetlands: A Pacific Small Island Developing State Perspective

Aaron P. Jenkins and Stacy Jupiter

Abstract Natural disasters in the context of public health continue to be a challenge for small island developing states (SIDS) of the Pacific. Pacific SIDS are particularly sensitive to disaster risk given geographic isolation, developing economies, lack of adaptive capacity and the interaction of climate variability with rapid environmental change. Health risks are amplified by the high levels of dependence on wetland resources and population concentration along low-lying floodplains and coastal margins. Thus, the health consequences of disasters cannot be considered in isolation from their wetland ecosystem settings. Wetlands provide protective and essential provisioning services in disasters, yet can also become vehicles for poor health outcomes. In this chapter we review the direct and indirect health consequences of interruptions to wetland ecosystem services associated with disaster events and emphasize how longer-term health effects of natural disasters can be exacerbated when wetland services are lost. We examine patterns of ill health for those populations in Pacific SIDS that are associated with wetlands and provide examples of how wetlands can either mitigate or contribute to these health outcomes. Finally, we identify opportunities and examples of improved management of wetland ecosystems for human health benefits under local to regional-scale management frameworks. Greater understanding at the interface of wetland ecology and disaster epidemiology is needed to strengthen existing models of disaster risk management and wetland conservation. We suggest applying principles of Integrated Island Management (IIM) as regionally appropriate means to guide those seeking to build this understanding.

Keywords SIDS (Small Island Developing States) · Natural disasters · River basin modification · Flooding · Cyclones · Sea level rise · Water provisioning · Food provisioning · Livelihoods · Infectious disease · Physical hazards · Psychosocial well-being · Migratory aquatic faunas · Fisheries · Disaster risk reduction · Public health · Integrated island management

A. P. Jenkins (✉)
School of Natural Sciences, Edith Cowan University, Joondalup, WA 6027, Australia
e-mail: a.jenkins@ecu.edu.au

S. Jupiter
Wildlife Conservation Society, Suva, Fiji
e-mail: sjupiter@wcs.org

C. M. Finlayson et al. (eds.), *Wetlands and Human Health,* Wetlands: Ecology, Conservation and Management 5, DOI 10.1007/978-94-017-9609-5_9

Introduction

Natural disasters are disruptions to ecological systems that exceed people's capacity to adjust, thereby necessitating external assistance (Lechat 1976). They can be geophysical (earthquake, volcano, mass movement), meteorological (storm), hydrological (flood), climatological (extreme temperature, drought, wildfire), biological (epidemic, infestation, stampede) and extra-terrestrial (asteroid, meteorite) in nature (Below et al. 2009). Natural disasters currently affect over 200 million people annually, are frequently concentrated in and around wetland areas, and cause considerable loss of life and prolonged public health consequences (UNISDR 2005). Public health impacts of natural disasters are magnified by the interactions of urbanization, environmental degradation and climate change on floodplains, coastal margins and tectonically active areas (Kouadio et al. 2012).

Small island developing states (SIDS) in Oceania, encompassing Melanesia, Micronesia and Polynesia (Fig. 1), are particularly vulnerable to the impacts of natural disasters (Table 1). Five Pacific Island countries rank among the world's top 15 at-risk countries, including Vanuatu, Tonga, Solomon Islands, Papua New Guinea and Fiji (ADW 2012). In the context of disaster risk, vulnerability is defined as the state of susceptibility to harm from disturbance (Adger 2006) and is a function of exposure, sensitivity and adaptive capacity (IPCC 2007). Pacific SIDS have high expo-

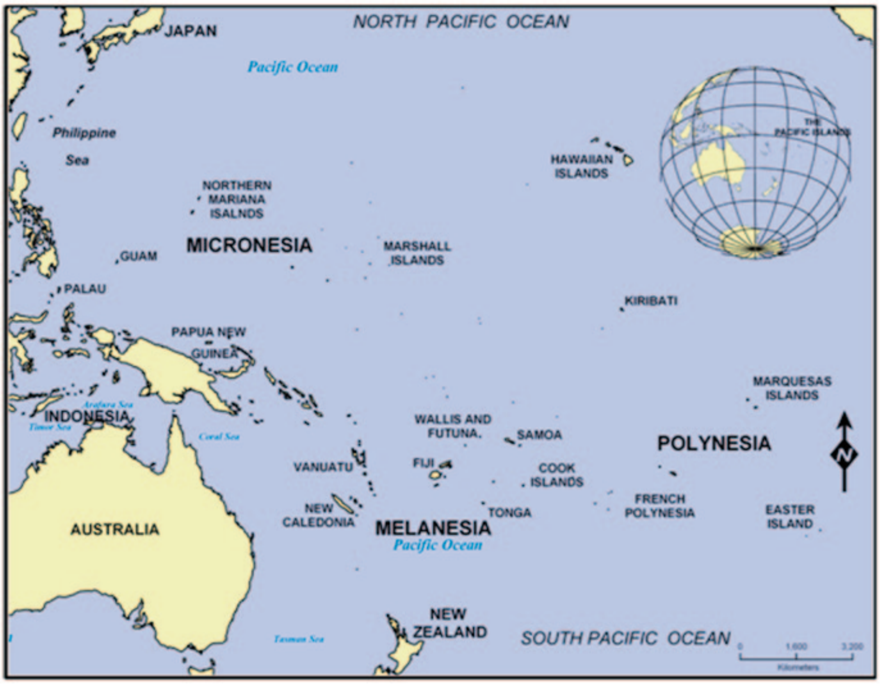

Fig. 1 Map of the Pacific Islands, showing its sub-regions and the principal island nations

Table 1 Pacific islands country estimated level of vulnerability to specific natural hazards including interacting effects. Vulnerability is depicted as high (H), medium (M) or low (L) as a function of exposure, sensitivity and adaptive capacity. Dashes indicate where the disaster type has not occurred, is unlikely to occur or cannot occur within the particular country. (Adapted from UNDP 2002)

Country	Tropical cyclones	Storm surges	Coastal floods	River floods	Drought	Earthquake	Landslide	Tsunami	Volcanic eruptions
Cook Islands	H	H	M	L	H	L	L	M	–
Federated States of Micronesia	M	M	H	H	L	L	M	–	–
Fiji	H	H	H	H	H	H	H	H	L
Kiribati	L	M	H	–	H	L	L	L	–
Republic of the Marshall Islands	H	H	H	–	H	L	L	L	–
Nauru	L	L	L	–	H	L	L	L	–
Niue	H	H	M	–	H	M	L	M	–
Palau	H	H	M	M	H	L	L	M	–
Papua New Guinea	H	H	H	H	H	H	H	H	H
Samoa	H	H	H	M	L	M	H	H	M
Solomon Islands	H	H	H	H	H	H	H	H	H
Tokelau	H	H	H	–	M	L	L	M	–
Tonga	H	H	H	L	H	H	L	H	H
Tuvalu	H	M	H	–	H	L	L	M	–
Vanuatu	H	H	H	H	H	H	H	H	H

sure to natural disasters, whose incidence and severity are on the rise (ABM and CSIRO 2011). Pacific SIDS are also particularly sensitive to disaster risk given the concentration of human populations along low-lying wetland areas (McIvor et al. 2012). Furthermore, the geographic isolation of many island communities results in low adaptive capacity, as they cannot easily access emergency services, freshwater and food following acute disturbance events (Barnett and Campbell 2010).

Following natural disasters, there are direct and indirect pathways to poorer health outcomes in wetland systems; those affected cover a broad spectrum of community members including immediate victims, rescue workers, those with lost property or livelihoods, families of the injured and those beyond the vicinity of the disaster (Galea 2007). The enormous economic costs of disasters also impact on the ability of SIDS to provide adequate recovery services: for example, annual losses from tropical cyclones and earthquakes are estimated to be as high as 6.6 % of national GDP in Vanuatu (Jha and Stanton-Geddes 2013). In this chapter we review the direct and indirect health consequences of interruptions to wetland ecosystem services associated with disaster events and emphasize how longer-term health effects of natural disasters can be exacerbated when wetland services are lost. We examine patterns of ill health for those populations in Pacific SIDS that are associated with wetlands and provide examples of how wetlands can either mitigate or contribute to these health impacts. Finally, we identify opportunities for improved management of wetland ecosystems for human health benefits under local to regional-scale management frameworks.

Impacts on Water Provisioning

It is well recognised that wetlands play a key role in the hydrological cycle, influencing both quantity and quality of available fresh water (Costanza et al. 1997; Maltby and Acreman 2011). Wetlands influence groundwater recharge, base flow maintenance, evaporation and flooding. Wetland condition also influences the quality of fresh water available for personal hydration, agriculture and industry through processes of erosion control, water purification, nutrient retention and export (Cherry 2012). Clean water on many small tropical islands is limited and vulnerable, with heightened susceptibility to contamination from inadequate sanitation and treatment facilities (Falkland 1999). The occurrence of natural disasters often results in increased contamination of water resources and disruption to water distribution and treatment facilities. Low-lying islands and atolls that rely on shallow and fragile groundwater lenses are often the most seriously affected (Dupon 1986).

Tropical storms, cyclones and associated flooding are among the most common natural disasters in the region. The Pacific region has the highest frequency of recorded cyclones, with 45 % of all cyclones reported from 1980 to 2009 (Doocy et al. 2013). Fiji alone has reported 124 natural disasters in the past 37 years, with tropical cyclones accounting for 50 % of these events (Lal et al. 2009). There is an average of five to six tropical cyclones annually in the South Pacific (Gupta 1988), resulting in major consequent impacts on freshwater provisioning and therefore acute and chronic impacts on human health. Impacts arise from direct damage to infrastructure and indirect flood-associated pollution in wetland areas from which people access water for drinking, cooking and bathing (Ellison 2009; Young et al. 2004).

For example, with wind speeds of 80–110 knots and rainfall of 300–400 mm/day, Cyclone Ami in 2003 had devastating effects on Fiji, in particular on the islands of Vanua Levu, Taveuni and the eastern islands of the Lau Group (Mosley et al. 2004). A month after the cyclone subsided, a study conducted on drinking water quality on the island of Vanua Levu showed nearly 75 % of samples did not conform to World Health Organisation (WHO) guideline values for safe drinking water (Mosley et al. 2004). This was most likely from the large amounts of silt and debris entering the water supply sources during the cyclone. Turbidity and total coliform levels had increased by 56 and 62 %, respectively, from pre-cyclone levels and poor water treatment led to this contamination being transferred through the reticulation system (Mosley et al. 2004). Communities were unaware that they were drinking water that was inadequately treated. This study also demonstrated that a simple paper strip water-quality test kit (for hydrogen sulphide, H_2S) correlated well with the lab based tests. WHO has subsequently been distributing these simple kits to remote communities to allow water supply testing post natural disaster.

The impact from storm surges on freshwater provisioning is amplified by sea level rise, which propagates storm damage further inland. While immediate damage is increased by this interaction, the compounding long-term issue of saltwater intrusion into the groundwater supply is serious (Sherif and Singh 1996). The shallow freshwater lens on atolls is the only source of fresh water other than rainwater. After a Category 5 cyclone swept a storm surge across remote Pukapuka Atoll in the Northern Cook Islands, the freshwater lens took 11 months to recover to potable conditions and remnants of the saltwater plume were still present 26 months after the saltwater incursion (Terry and Falkland 2009).

Low-lying atolls are also particularly susceptible to drought as they rely almost entirely on rainfall as a source of freshwater. In the latter part of 2011, Tuvalu declared a state of emergency after receiving less than normal rainfall for six months. Households were rationed two buckets of water a day (40 L) and the state hospital limited admissions to cope with the water rationing (NIWA 2012). The Red Cross declared that drought conditions had also caused contamination of the limited groundwater supplies (IFRC 2013). International aid agencies responded by shipping bottled water, supplying a desalination plant and increasing the number of water storage tanks in the country. This drought was attributed to La Niña, when the cooling of the surface temperature of the sea around Tuvalu leads to reduced rainfall (Salinger and Lefale 2005). A few months later, the atoll country of Tokelau also declared a state of emergency due to drought under similar circumstances of climate and geomorphological vulnerability. The Republic of the Marshall Islands, another low-lying atoll country, declared a state of disaster due to drought conditions in May 2013, with 6400 people across 15 atolls facing health, environmental, social and economic hardships due to the dry weather (IFRC 2013). Water supplies there are primarily generated by reverse osmosis units and rainwater catchments, both generally poorly maintained and limited in number (IFRC 2013).

Minimizing pollutants from reaching toxic levels in groundwater for drinking purposes is invaluable in the context of disaster recovery. Wetlands such as marshes and riparian vegetation contribute to the natural filtration of water and to the improvement of its quality (Norris 1993; Lowrance et al. 1997). The slowing of floodwaters by wetland systems allows for sediments to deposit (trapping metals and organic compounds), pollutants and nutrients to be processed, and pathogens to lose their viability or be consumed by other organisms in the ecosystem (Millennium Ecosystem Assessment 2005). High levels of nutrients in the water column, commonly associated with agricultural runoff and sewage effluent, such as phosphorus and nitrogen, can be substantially reduced or transformed by assimilation, sedimentation and other biological processes in wetlands (Dillaha et al. 1989; McKergow et al. 2003), though during periods of high flow (i.e., during heavy storms and where basins are more channeled and the gradient is steep), the extent of pollutant storage will be lower (Gaudet 1978). By contrast, losses of wetland systems can contribute to spread of waterborne bacteria. For example, a recent study in Hawaiian streams demonstrated that reductions in riparian canopy cover were associated with *Enterococcus* increases in stream water where each 1 % decrease in riparian vegetation was associated with a 4.6 % increase of *Enterococcus* (Ragosta et al. 2010).

Well-managed wetlands in disaster prone island river basins can be relied upon to mitigate some water pollution problems, however every wetland has a finite capacity to assimilate pollutants and may rapidly overload during a cyclone or flooding event (Gaudet 1978). Despite this, wetlands have a key role to play in integrated catchment-based disaster reduction and recovery strategies to address water quality issues.

Impacts on Transmission of Infectious Disease

A number of authors have predicted that climate-induced disasters will increase the incidence of infectious diseases caused by vector-borne and waterborne parasites and pathogens (Patz et al. 1996; Colwell 1996; Harvell et al. 2002; Patz et al. 2004), though this has also been challenged (Ostfeld 2009; Harper et al. 2012). Wetland alteration and other environmental damage caused by natural disasters can act as persistent drivers of infectious disease. Floods, for example, create conditions that allow mosquitoes to proliferate and increase the amount of human-mosquito contact (Gubler et al. 2001). The condition of wetlands prior to, during and after disaster events can also contribute to the collection of stagnant or slow moving water that favors mosquito breeding and associated vector-borne diseases. River-basin deforestation, river damming and rerouting all have been attributed to enhancing conditions for flooding and vector proliferation (Ahern et al. 2005). Storm surges in combination with sea level rise can also alter predominantly freshwater wetlands into increasingly brackish areas and subsequently increase breeding areas for the salt tolerant malaria vector, *Anopheles sundaicus* (Krishnamoorthy et al. 2005). In the endemic zones of the Pacific, malaria is identified as among the top five causes of non-traumatic death post-disasters (WHO 2013).

There are clear relationships between natural disasters and waterborne diseases when extremes in the hydrologic cycle cause both water shortages and floods, both of which are associated with increased diarrheal diseases (Patz et al. 2004). Within periods of water shortage, poor hygiene and the likelihood of multiple uses of the same water source (e.g., cleaning, bathing, drinking) is a major contributor to disease transmission, while other mechanisms such as concentration of pathogens may also be important (Lipp et al. 2002). The Republic of the Marshall Islands, Tokelau and Tuvalu have all experienced drought disasters since 2011, and both Tokelau and Tuvalu have experienced substantial associated diarrhea outbreaks as limited water resources became contaminated (WHO 2013).

During periods of flooding and heavy rainfall, fecal matter and associated pathogens flush from the land and contaminate drinking water sources. For example, a typhoon in Chuuk, Federated States of Micronesia, in 1971, prevented the use of the usual groundwater sources. Chuuk communities were forced to use alternative water sources, which were contaminated by pig feces, leading to an outbreak of balantidiasis (Walzer et al. 1973). In countries like Fiji, clear associations have been made with regard to increased rainfall and diarrhea cases (Singh et al. 2001) and post cyclone spikes in waterborne diseases such as typhoid have also been documented (Scobie 2011).

Damage to sanitation and sewage infrastructure associated with tropical storms and flooding also imposes serious infectious disease risk. The risks of spread of waterborne infectious diseases magnifies with lack of clean water, poor sanitation, poor nutritional status and population displacement (Dennison and Kiem 2009). Outbreaks of diarrheal illness are common after floods in low and high-income countries alike, while developing countries with poor water and sanitation infrastructure also commonly suffer from outbreaks of cholera, typhoid and other waterborne microbial diseases (Cabral 2010). In several Pacific island countries, including Fiji and Samoa, flooding events following cyclones and prolonged rainfall have been linked to outbreaks of several waterborne bacterial diseases (e.g. leptospirosis, shigellosis, typhoid), resulting in costly disaster response measures (Jenkins 2010). The probability of infectious disease increases following tropical cyclone events in proportion to disruption of public health services and the health-care infrastructure, damage to water and sanitation networks, changes in population density (especially in crowded shelters), population displacement and migration, increased environmental exposure due to damage to dwellings, and ecological changes (Shultz et al. 2005).

As people and animals are driven together in dry areas, increased contact with rodents and livestock often results in outbreaks of the bacterial infection leptospirosis (Gaynor et al. 2007; Lau et al. 2010; 2012). Leptospirosis, a bacterial disease, can be transmitted by direct contact with contaminated water. Rodents, in particular, shed large amounts of the pathogenic bacteria in their urine, and transmission occurs through contact of the skin and mucous membranes with water, damp soil or vegetation (such as sugar cane), or mud contaminated with rodent urine (Watson et al. 2007). Flooding facilitates spread of bacteria because of the proliferation of rodents and the proximity of rodents to humans on shared high ground. In 2012, Fiji

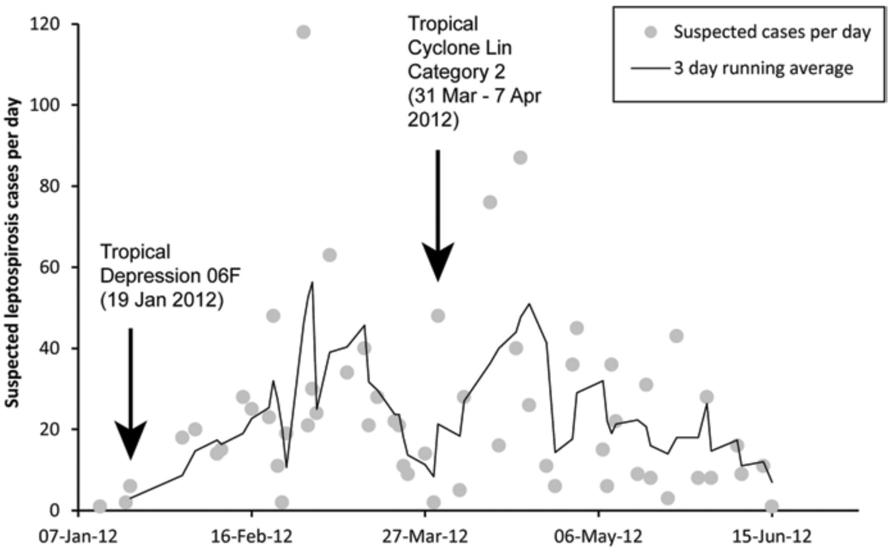

Fig. 2 Suspected leptospirosis cases after sequential flooding disasters following tropical storm events—Western Division, Fiji, 2012. (Reprinted with permission from WHO 2013)

was impacted by flooding from sequential tropical depressions that caused widespread flooding impacting much of Western Viti Levu in January 2012 and again in March 2012. These events resulted in substantial population displacement and significant post-disaster increases in leptospirosis cases three to eight weeks following each of the major flooding episodes (Fig. 2). Conservative estimates place the number of cases at 300 and the number of deaths at 25 (WHO 2013).

In the context of natural disasters such as tropical cyclones and large storms, river basin modification via logging, mining and agriculture can exacerbate the environmental exposure of communities to infectious disease (Patz 2000; Patz et al. 2004; Horwitz et al. 2012; Myers et al. 2013). The combination of increases in the severity of severe storms and rainfall and increased landscape modification is already having a notable impact on disease transmission. Around 3 % of forests are lost each year with serious consequences both on land and in adjacent water drainages (Hansen et al. 2010). Change in the diversity and abundance of species, soil dynamics, water chemistry, hydrological cycles and new forest fringe habitats creates new disease exposure dynamics (Myers and Patz 2009). Construction of dams and irrigation systems in river basins also contribute to disease emergence. Dams and irrigation have been associated with rises in schistosomiasis (Malek 1975), Rift Valley fever, filariasis, leishmaniasis, dracunculosis, onchocerciasis, and Japanese encephalitis (Harbin et al. 1993; Jobin 1999). Road building, commonly associated with logging enterprises in Pacific SIDS, has also been linked to increased incidence of dengue fever (Mackenzie et al. 2004) and diarrheal disease (Eisenberg et al. 2006).

In the Pacific Islands context, this increased environmental exposure results from interacting processes of flooding and sea level rise as river basin modification acts in concert with a changing global climate (Nicholls et al. 2007). Flooding and erosion rates are often accelerated by forest clearance (e.g. Likens et al. 1970; Costa et al. 2003). Deforestation within river basins is a major cause of flooding and landslide activity during periods of high rainfall and major storms and can prime the basin for future floods through increased sediment deposition (Cockburn et al. 1999). Where land is cleared, grazed or tilled, changes in compaction, infiltration and vegetative cover may lead to increased soil erosion and runoff (Pimentel et al. 1993; Roth 2004). A comprehensive 56 country study of forest cover and flood risk demonstrated that a 10 % loss of natural forest cover can result in a 4–28 % increase in flood frequency and a 4–8 % increase in flood duration (Bradshaw et al. 2007). The Western Pacific is also experiencing significant sea level rise (Church et al. 2006), and this interaction of river flooding and sea level rise can produce substantial increases in flood risk to populations and infrastructure. Overall, the small islands of the Pacific Ocean are among the most vulnerable to flooding (Nicholls et al. 1999) precisely because of this interaction between deforestation, wetland ecosystem degradation and climate impacts such as sea level rise and increased frequency of tropical storms (Knutson et al. 2010). Fiji, for example, has experienced an increased frequency and magnitude of flooding over the past few decades, attributable to the aforementioned combination of factors and particularly affecting populations living in river deltas and on flood plains (Lata and Nunn 2012).

Impacts on Food Provisioning and Livelihoods

Wetland ecosystems and the resources they provide are central to the food provisioning and livelihoods of Pacific island peoples. These food provisioning services can be severely impacted by various natural disasters. Health issues associated with malnutrition in the wake of disasters occur through reduced caloric, protein or micronutrient intake or ingesting toxic levels of trace elements (Cook et al. 2008). Incidence of malnutrition in Pacific SIDS is predicted to become more prolonged and widespread due to impacts associated with climate change and associated climate-induced disasters (Barnett 2007). Impaired nutritional intake is also a risk factor for mortality from infectious diseases, such as gastroenteritis and measles, which are often also more common in the post-disaster phase (Cook et al. 2008).

Natural disasters, such as tropical cyclones and severe storms, cause significant loss in agricultural production each year in the Pacific. More than 80 % of the population of the Pacific islands is rural and about 67 % depend on agriculture for their livelihoods (ADB and IFPRI 2009). Crop production for subsistence and commercial use is heavily dependent on wetlands, often located on fertile floodplain areas. Cyclone Ami, for example, caused over US$ 35 million in lost crops in Fiji in 2003 (Mackenzie et al. 2005). In Tuvalu saltwater intrusion from storm surge affected communal crop gardens on six of Tuvalu's eight islands and destroyed 60 % of

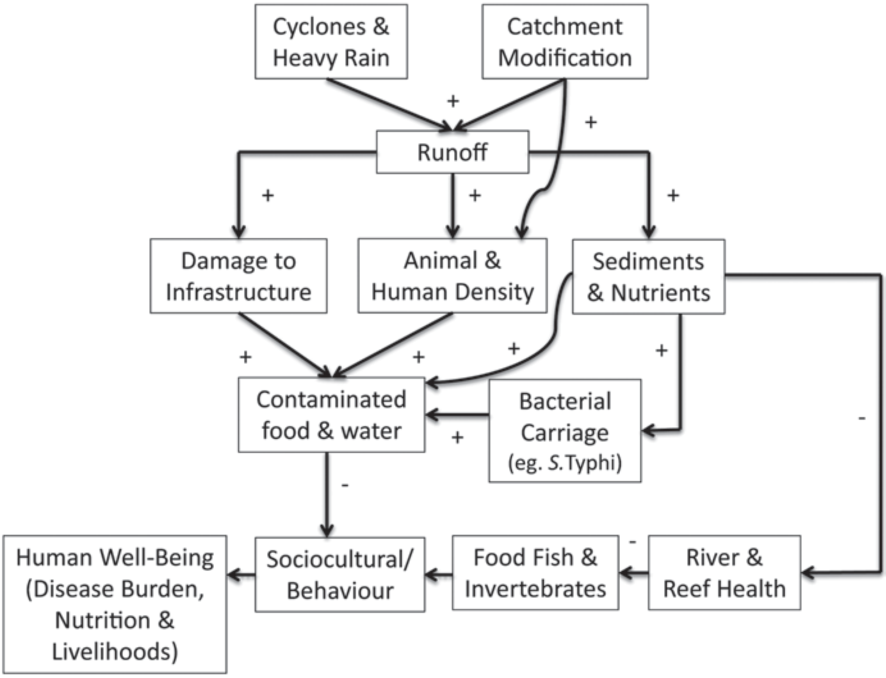

Fig. 3 Generalized conceptual model of mechanisms determining health and livelihood outcomes during cyclones or heavy rainfall in the context of high island river basins. + and − indicate positive and negative contribution or affect on the following factor and *dotted lines* show the mediating effect of socio-cultural behaviour

traditional pit gardens (ADB and IFPRI 2009). High risk of flooding in river catchments also threatens food production. Heavy flooding of the Wainibuka and Rewa rivers in Fiji in April 2004 damaged between 50 and 70 % of crops (Fiji Government 2004). During the January 2009 floods in Fiji, crops were destroyed and many did not have another source of income to buy food, medical supplies or send children to school (Lal et al. 2009). Drought also presents problems for agriculture everywhere in the region, particularly given the lack of irrigation (Barnett 2007).

River basin modification also affects the food provisioning services that assist communities in the disaster recovery process. Aspects of the relationships between river basin modifications, natural disasters, infectious disease risk and food provisioning are hypothesized in Fig. 3. In a recent Fijian study, a dam constructed in the upper catchment of the Nadi River basin as part of a flood mitigation project (Fig. 4) helped to reduce the frequency of local floods but also resulted in a significant reduction in the availability of fish for local community subsistence (Jenkins and Mailautoka 2011). The dam construction didn't account for the highly migratory nature of insular fish faunas and compounded the long-term nutritional vulnerability of the community.

The highly migratory fish faunas of island systems are disproportionately affected due to a greater probability of encountering obstacles such as dams or other

Fig. 4 A dam constructed to minimize flooding in the upper Nadi Basin in Fiji. Note low water levels and impassability to freshwater fauna. Photo credit: Vinesh Kumar

hydrological modifications, predation by non-native species and degraded water quality. These vulnerable species include ones with the greatest socio-economic value to communities. Jenkins et al. (2010) demonstrated the notable absence from degraded catchments of fishes that traditionally formed staple diets of inland communities. Other notably absent species in heavily modified catchments include many migratory species that form important commercial and cultural fisheries for Pacific islanders. These effects are largely seasonal and magnified in degraded catchments, with pronounced negative impacts during heavy rainfall and severe storms on food-provisioning services and biodiversity (Jenkins and Jupiter 2011). These effects will likely become more severe under predicted future climate scenarios (ABM and CSIRO 2011). Community bans on harvesting and clearing within riparian wetlands can be effective at maintaining fish diversity even in areas where forests have previously been extensively cleared (Jenkins et al. 2010). However, these benefits are rapidly removed once the ban has been lifted and food fish from rivers again become scarce (Jenkins and Jupiter 2011).

Managing river basins to minimize runoff and consequent eutrophication downstream will also provide greater availability of aquatic resources of value such as fisheries. This applies to both within river and downstream coral reef ecosystems. Fabricius (2005) reviewed the negative impacts to coastal coral reefs (e.g. increases in downstream macroalgal cover) associated with impacts of reduced water quality from adjacent, highly modified river basins. Letourneur et al. (1998) showed a decrease in commercial reef fish species richness and biomass with increasing exposure to terrestrial runoff from rivers in New Caledonia. While fishing pressure is certainly a mediating factor in availability of fisheries resources from coral reefs, Wilson et al. (2008) noted from a study in Fiji that habitat loss, in part due to changes in water quality, is currently the overriding agent of change.

Dependence on coral reefs and coral reef fisheries is high in most Pacific SIDS, not only for dietary needs but also for both subsistence and market-based economies (Gillett 2009; Bell et al. 2009). Forty-seven percent of coastal households list fishing as the primary or secondary source of income and in rural communities the subsistence fishery accounts for 60–90 % of all fish caught (Gillett 2009). Direct impact on coral reef habitat that supports coral reef fisheries production can have a devastating impact on food security. For example, in Solomon Islands an 8.1 magnitude earthquake followed by a tsunami in April 2007 resulted in rapid, massive uplift of large sections of coral reefs and mangrove ecosystems in areas of Western Province, and severe damage to reefs of western Choiseul from wave energy. Monitoring data from impacted Choiseul coral reef systems show significant decreases in the availability of food fish and invertebrates, as well as a reduction in hard coral cover (Hamilton et al. 2007).

Impacts as Sites of Physical Hazards

At least 1 % of the global coastal wetland estate is lost each year primarily by direct reclamation (Nicholls et al. 1999), and these losses may have profound impacts on ecosystem services related to coastal protection. There is a body of evidence suggesting that coastal wetland ecosystems (including mangrove forests, coral reefs and salt marshes) can help to reduce the direct risk of damage and injuries associated with some natural disaster events (e.g. Danielsen et al. 2005; Das and Vincent 2009). The immediate injuries recorded during disasters in the proximity of coastal wetland systems include lacerations, blunt trauma, sprains/strains and puncture wounds, often in the feet and lower extremities, which become susceptible to infection (Ahern 2005; Shultz et al. 2005; Hendrickson et al. 1997). However the precise extent to which mangroves and other coastal vegetation ecosystems serve as bio-shields is debated (Bayas et al. 2011), and the role of coastal wetland vegetation in wave impact and storm surge mitigation still remains controversial (Geist et al. 2006; Iverson and Prasad 2007; Kaplan et al. 2009).

Data on the extent of coastal vegetation and impacts on Pacific Islands post-tsunami are limited, yet some lessons can be learned from examples from South East Asia. In the coastal regions of western Aceh in 2004, the potential for mitigating tsunami impacts appeared limited as a result of the massive energy released by waves with heights exceeding 20 m (Cochard 2011). Studies do suggest, however, that coastal wetland vegetation appears to reduce casualties and damage (Kathiresan and Rajendran 2005; Bayas et al. 2011). Bayas et al. (2011) reported loss of life decreased by 3–8 % behind coastal vegetation, indicating that trees may have slowed and/or diverted the waves, thereby allowing greater opportunity to escape to safety. In contrast, when plantations or forests were situated behind villages there was a 3–5 % increase in the number of casualties (Bayas et al. 2011). Similarly, 2100 people were killed and at least 800 were severely injured following a 1998 tsunami in eastern Saundaun Province, Papua New Guinea, where villages were located directly on sand spits in front of the mangroves surrounding the lagoon (Dengler and Preuss 2003). Given these mixed outcomes, mangrove planting as a tsunami mitigation measure has received criticism for failing to control for confounding factors such as distance from shoreline (Kerr and Baird 2007; Baird et al. 2009). One recent review concluded that the value of coastal vegetation as a tsunami buffer is minor (Baird and Kerr 2008), with the authors suggesting that the claim that coastal wetland vegetation can act as a bio-shield gives false hope to vulnerable communities.

Recent experimental studies show that mangroves can reduce the height of wind and swell waves over relatively short distances (McIvor et al. 2012), though these coastal protection services are likely nonlinear and vary with habitat area and width (Barbier et al. 2008). Wave height can be reduced by 13–66 % over 100 m of mangroves. However, most studies have measured the attenuation of only relatively small waves (wave height < 70 cm) and further research is needed to measure the attenuation of larger wind and swell waves by mangroves. In addition, the ability of mangroves to provide coastal defense services is dependent on their capacity to adapt to projected rates of sea level rise (McIvor et al. 2012). Recent evidence suggests that mangrove surface soils are rising at similar rates to sea level in a number of locations (McIvor et al. 2013). However, data are only available for a small number of sites and mostly over short time periods. To allow for continued mangrove protection, wetland managers need to monitor the conditions allowing mangroves to persist and adapt to changing sea levels. This requires monitoring the maintenance of sediment inputs, protection from degradation and the provision of adequate space for landward migration (McIvor et al. 2012). The removal of coastal wetland vegetation may be a greater short-term threat to other services such as storm surge abatement and fisheries supply than sea level rise. It is important for concerned communities of practitioners to be promoting mangroves and coastal wetland vegetation as more than a bio-shield but also as an important source of livelihood provisioning that can assist in the medium to long-term disaster recovery process (Bayas et al. 2011). Artificial protection structures like seawalls cannot provide the nursery and fisheries benefits of natural systems, such as mangroves and coral reefs that can assist in hastening community recovery.

Impacts on Psychosocial Well-Being

Wetlands are of great cultural and social significance to Pacific Islanders and play a crucial role in mediating psychosocial health and well-being. The use of wetlands and wetland ecosystem services is arguably an important aspect of Pacific cultural identity (Strathern et al. 2002). Pacific authors argue that notions of well-being are linked closely to cultural identity (McMullin 2005), that illness is often seen as an inevitable disruption to life and social systems (Drummond and Va'ai-Wells 2004), and that health gives meaning to an individual's place and actions within a community context (Ewalt and Mokuau 1995). Thus, if Pacific Islanders lose their wetland services, they are at risk of a diminution of cultural identity and social well-being.

Some authors note an ecology driven model of well-being that is based on the vitality and abundance of natural resources relied upon for subsistence and cultural practices (McGregor et al. 2003). Within this ecological model, the collective family unit forms the core social unit within which the individual lives and interacts, which is interdependent upon the lands and associated resources for health (physical, mental and emotional) and social well- being. In both cases, the myriad wetland ecosystems of the Pacific are the settings for health where cultural identity, subsistence life and social systems co-exist (*sensu* Horwitz and Finlayson 2011).

While descriptions of psychosocial issues surrounding disasters in Pacific SIDS are relatively scant, it is well documented that populations exposed to natural disasters are affected by a variety of mental health issues (eg. Cook et al. 2008; Shultz et al. 2005). The exposure to loss of life or loved ones, social displacement and economic loss have wide-ranging health effects and contribute to persistent post-traumatic stress disorder (PTSD) and depression (Cook et al. 2008). Persistent PTSD was documented in New Zealand after Cyclone Bola in 1988 (Eustace et al. 1999). When a succession of five typhoons struck Guam in 1992, persons who had acute stress disorder following the initial typhoon were significantly more likely to have progressed to PTSD or depression after the full series of typhoons (Staab et al. 1996). Increases in the rates of suicide and child abuse have also been reported post-cyclones (Shultz et al. 2005) and significant evidence exists post-flooding that children experience long-term increases in PTSD, depression, and dissatisfaction with life (Ahern et al. 2005). Addressing chronic care injuries and psychosocial well-being in the aftermath of these types of disasters can span several generations. Galea et al. (2005) suggested that over a third of initial cases of post-disaster PTSD can persist for more than a decade. As Pacific SIDS are particularly sensitive to disaster risk given the concentration of people along low-lying, wetland areas (e.g. McIvor et al. 2012), post-disaster mental health issues may also be concentrated in these vulnerable populations.

Well-managed wetlands may help to mitigate the psychosocial stress and mental health issues associated with natural disasters. Damaged wetland systems and the community awareness and perception of this damage may result in pathological mental health outcomes as outlined above. A recent study on Pacific Island families showed that those families located in neighborhoods with perceived higher levels of environmental pollution (including wetland degradation), noise and reduced safety were more than twice as likely to have psychological morbidity, with mothers 7.3 times more likely to be affected (Carter et al. 2009).

While the loss of loved ones, income, livelihood options and displacement all contribute to mental distress, the loss of a "sense of place" is also emerging as an important mental health consideration. Albrecht (2005) has used the particular term "solastalgia" for the pain or sickness caused by the loss or, or inability to derive, solace connected to the present state of one's home environment. This concept of solastalgia is illuminated in any case where the environment has been negatively affected by forces that undermine a personal and community sense of identity, belonging and control (Horwitz et al. 2012). This concept is of particular relevance in the context of natural disasters and for the Pacific Islands where cultural identity and factors of spiritual significance are closely tied with local environmental conditions (McMullin 2005; McGregor et al. 2003).

Evidence is also emerging that people actively involved in local conservation projects report better general health and a sense of community belonging than those who were not involved (Moore et al. 2006). Wetlands managers and public health practitioners need to recognize the need to align wetland conservation and restoration efforts with the potential effects on mental health in both the disaster prevention and recovery contexts. Managing wetlands in the wake of natural disasters to minimize the future damage to livelihoods or exposure to pathogens and improve community solidarity in the recovery process are likely to positively contribute to the mental well-being and the speed of recovery in the affected population.

Managing Wetlands for Disaster Risk Reduction and Public Health

The health consequences of disasters cannot be considered in isolation from the wetland ecosystems in which they occur. Wetlands can help to provide protective and essential provisioning services during and following disasters, though in some conditions, they can also become a setting for disease spread and exacerbate harmful conditions. Evidence-based management of wetland conditions surrounding disaster events is important for both disaster response and prevention well beyond the time and place of the disaster itself. The identification and management of short-term health impacts surrounding disasters often captures the attention and financial assistance while many intermediate to long-term impacts are overlooked (Cook et al. 2008). Recovery from disasters such as tropical cyclones, flooding, or tsunamis around wetland areas is commonly a protracted process. Disaster risk reduction strategies must factor in the medium- to longer-term preventative and recovery processes that integrate traditional public health interventions with wetland conservation and restoration, land use planning and climate change adaptation.

Opportunities and Examples of Good Practice at Regional, National and Local Levels

At a global level, following the World Conference for Disaster Reduction, the United Nations General Assembly produced the Hyogo Framework for Action in 2005, a 10-year framework bringing different sectors and actors under a common global system of coordination to reduce disaster losses (UNISDR 2005). In the context of managing wetlands for public health in the face of disasters, the focus of policy makers seeking to integrate wetland management with disaster risk reduction under the Hyogo Framework should focus on Priority Action 4 "*Reducing the underlying risk factors"* by targeting the appropriate sectoral development planning and programs. Implementing agencies of this framework can act through global alliances such as Partnership for Environment and Disaster Risk Reduction (PEDRR) to advocate the importance of wetland management in achieving health outcomes through Priority Action 4.

At the Pacific regional level, the current policy framework for disaster management is the Pacific Disaster Risk Reduction and Disaster Management Framework (PDRRDMF) for Action 2005–2015. The Secretariat of the Pacific Community's Applied Geoscience Commission works to support countries to adapt this framework and implement priorities at a national and sectoral level. This often comes in the form of developing National Action Plans and more recently Joint National Action Plans which seek to address both disaster and climate change risks (SOPAC 2013). Work is underway to develop a new Strategy for Disaster and Climate Resilient Development in the Pacific (SRDP) to succeed the current PDRRDMF and 'Pacific Islands Framework for Action on Climate Change', both due to expire in 2015. The replacement strategy will combine the two inter-related fields of disaster risk reduction and climate change adaptation. Within the implementation of this framework, there will be opportunities for countries to tailor national strategies around managing and restoring wetlands to reduce disaster risk and improve adaptive capacity of coastal communities.

The Ramsar Convention on Wetlands provides another international policy framework for the management of wetlands and their associated services. Aligned with the Ramsar Convention, the Pacific regional framework for wetlands management is the Regional Wetlands Action Plan for the Pacific 2011–2013. Goal 1.4 calls for "*Precise linkages between ecosystem health and human health in the Pacific to be investigated*" and "*Improved engagement between wetland decision makers and human health sectors*", but underlying strategies and objectives have not been explicit in this regard. The challenge is for countries and territories to embed specific objectives for wetland management for health outcomes in the implementation of their respective National Biodiversity Strategies and Action Plans, which typically cover commitments under the Ramsar Convention.

Important learning opportunities exist within some local approaches to island wetlands management collated with a handbook of good practice in Pacific Integrated Island Management (IIM) (Jupiter et al. 2013). IIM is an approach that calls for "sustainable and adaptive management of natural resources through coordinated networks of institutions and communities that bridge ecosystems and stakeholders with the common goals of maintaining ecosystem services and securing human health and well-being" (Jupiter et al. 2013). Five of the ten guiding principles of IIM are particularly relevant for those seeking to integrate island wetland management into disaster risk management systems: adopt a long-term integrated approach to ecosystem management; maintain and restore connectivity between complex social and ecological systems; incorporate stakeholders through participatory governance with collective choice arrangements, taking into consideration gender and social equity outcomes; recognize uncertainty and plan for adaptive management through regular monitoring, evaluation and review leading to evidence-based decision-making; and organize management systems in nested layers across sectors, social systems and habitats. Box 1 illustrates these principles applied to the management of the Takitumu Lagoon, Cook Islands, for coupled health and environmental outcomes.

Box 1: Takimutu Lagoon Health Report Card, Rarotonga

The Takitumu district of the high island of Rarotonga, Cook Islands, has developed an integrated ecosystem-based management plan encompassing high island forests, streams, coastal plains and the coral reef lagoon (Dakers and Evans 2007). Advisory committees were established across several sectors to deliver the components of the management plan including government, donor and local leader steering committees, a technical advisory group for issues surrounding environmental monitoring and an inter-departmental committee for within government coordination. In particular, declining stream and lagoon water quality associated with piggery waste was a focal issue around which environmental and health sector authorities could engage. A Takitumu Lagoon Health Report Card was produced for each village for overall water quality, bacterial load, ciguatera in landed fishes, lagoon faunal abundance, adjacent stream water quality, stream bacterial load and safety of groundwater, and then it was shared widely with communities and relevant stakeholders. As a result of this focused attention on connectivity across wetland systems, new Public Health (Sewage) Regulations and an associated Code of Practice were developed. In addition, improvements were made in the system for assessing and approving changes to existing land use through a tightening of regulations needed for planning consent by the Environment Authority. This example demonstrates how IIM planning across multiple island wetland habitats can successfully bring together a wide range of stakeholders around shared concerns of public health and environmental quality (Jupiter et al. 2013). It also demonstrates that synthesizing high quality technical information around these shared concerns is catalytic in garnering both community support and effecting policy change relevant to both wetlands management and public health, thus strengthening the resilience of the community to environmental exposure to disaster risks.

Conclusions and Further Research Needs

Natural disasters are a continuing and growing threat to public health with particular impact on the small developing nations of the Pacific. Disasters affect human health and the ecological properties of wetlands in ways that are not always obvious or expected in the medium- to long-term. While wetlands can mitigate the effects of some disaster related health issues, they can also exacerbate ill health in affected populations. The extent to which specific wetland contexts and types can facilitate disaster mitigation and recovery is generally poorly studied. Building greater understanding at the interface of wetland ecology and disaster-related epidemiology is needed to strengthen existing models of disaster risk management and wetland conservation. Health surveillance systems should incorporate aspects of wetland quality and key provisioning services alongside routine disease surveillance and continue to collect this information in the weeks, months and years following a disaster. This will provide policy makers and managers the tools to monitor and evaluate the longer acting health consequences of interventions in various wetland disaster settings.

A precautionary approach is encouraged for wetland managers to provide careful evidence-based recommendations with regard to the extent of services to expect from wetlands surrounding natural disaster events. While being cautious with advice, wetland managers and scientists must also be proactive in seeking collaboration with public health and disaster risk management arenas to enhance both prevention and recovery strategies. To help manage the impacts of physical hazards, wetland scientists can determine the extent of damage to wetland systems and assist in adapting built and natural infrastructure around wetlands to minimize risks. Wetland ecologists should assist public health authorities in the identification of environmental reservoirs and exposure routes to infectious diseases for humans, livestock and other wildlife. The traditional core work of protecting and restoring important wetland types, such as riparian vegetation and mangroves, can help mitigate community exposure to water contamination and storm surge and also help provide long term livelihood benefits such as fisheries and psychosocial benefits such as exercise and community engagement.

References

ADB and IFPRI (2009) Building climate resilience in the agricultural sector of Asia and the Pacific. Asian Development Bank, Manila

Adger WN (2006) Vulnerability. Global Environ Change 16:268–281

ADW (2012) World risk report 2012. http://www.ehs.unu.edu/file/get/10487. Accessed 12 Feb 2014

Ahern M, Kovats RS, Wilkinson P, Few R, Matthies F (2005) Global health impacts of floods: epidemiologic evidence. Epidemiol Rev 27:36–46

Albrecht G (2005) Solastalgia: a new concept in human health and identity. Philos Activ Nat 3:41–55

Australian Bureau of Meteorology and CSIRO (2011) Climate change in the Pacific: scientific assessment and new research. Volume 1: regional overview. Pacific Climate Change Science Program, Aspendale

Baird A, Kerr A (2008) Landscape analysis and Tsunami damage in Aceh: comment on Iverson and Prasad (2007). Landsc Ecol 23:3–5

Baird AH, Bhalla RS, Kerr AM, Pelkey NW, Srinivas V (2009) Do mangroves provide an effective barrier to storm surges? Proc Natl Acad Sci U S A 106(40):E111

Barbier EB, Koch EW, Silliman BR, Hacker SD, Wolanski E, Primavera J, Granek EF, Polasky S, Aswani S, Cramer LA, Stoms DM, Kennedy CJ, Bael D, Kappel CV, Perillo GME, Reed DJ (2008) Coastal ecosystem-based management with nonlinear ecological functions and values. Science 319:321–323

Barnett J (2007) Food security and climate change in the South Pacific. Pac Ecol 2007:32–36

Barnett J, Campbell J (2010) Climate change and small island states: power, knowledge and the South Pacific. Earthscan Ltd., London

Bayas JC, Marohn C, Dercon G, Dewi S, Piepho PH, Laxman J, van Noordwijk M, Cadisch G (2011) Influence of coastal vegetation on the 2004 tsunami wave impact in West Aceh. Proc Natl Acad Sci U S A 108(46):18612–18617

Bell JD, Kronen M, Vunisea A, Nash WJ, Keeble G, Demmke A, Pontifex S, Andrefouet S (2009) Planning the use of fish for food security in the Pacific. Mar Policy 33(1):64–76

Below R, Wirtz A, Debarati G (2009) Disaster category classification and peril terminology for operational purposes. WHO Centre for research on the epidemiology of disasters (CRED) and Munich Reinsurance Company (Munich RE) Working paper 264. Université catholique de Louvain, Brussels

Bradshaw CJA, Sodhiw NS, Pehwz KSH, Brook BW (2007) Global evidence that deforestation amplifies flood risk and severity in the developing world. Glob Change Biol 13(11):2379–2395

Cabral JPS (2010) Water microbiology, bacterial pathogens and water. Int J Environ Res Public Health 7:3657–3703

Carter S, Williams M, Paterson J, Iusitini L (2009) Do perceptions of neighbourhood problems contribute to mental health. Findings from the Pacific Islands Families study. Health Place 15(2):622–630

Cherry JA (2012) Ecology of wetland ecosystems: water, substrate, and life. Nat Educ Know 3(10):16

Church JA, White NJ, Hunter JR (2006) Sea-level rise at tropical Pacific and Indian ocean islands. Glob Planet Change 53(3):155–168

Cochard R (2011) On the strengths and drawbacks of Tsunami-buffer forests. Proc Nat Acad Sci U S A 108(46):18571–18572

Cockburn A, Clair J St, Silverstein K (1999) The politics of "Natural" disaster: who made Mitch so bad? Int J Health Serv 29(2):459–462

Colwell RR (1996) Global climate and infectious disease: the cholera paradigm. Science 274(5295):2025–2031

Cook A, Watson J, van Buynder P, Robertson A, Weinstein P (2008) 10th anniversary review: natural disasters and their long term impacts on the health of communities. J Environ Monitor 10(2):167–175

Costa MH, Botta A, Cardille JA (2003) Effects of large-scale changes in land cover on the discharge of the Tocantins River, Southeastern Amazonia. J Hydrol 283(1–4):206–217

Costanza R, D'Arge R, De Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P, van den Belt M (1997) The value of the world's ecosystem services and natural capital. Nature 387:253–260

Dakers A, Evans J (2007) Wastewater management in Rarotonga: it is not just a matter of a technological fix? In: Patterson RA (ed) Proceedings of the workshop on innovation and technology for on-site systems. Armidale

Danielsen F, Sorensen MK, Olwig MF, Selvam V, Parish F, Burgess ND, Hiraishi T, Karunagaran VM, Rasmussen MS, Hansen LB, Quarto A, Suryadiputra N (2005) The Asian Tsunami: a protective role for coastal vegetation. Science 310(5748):643

Das S, Vincent JR (2009) Mangroves protected villages and reduced death toll during Indian super cyclone. Proc Natl Acad Sci U S A 106(18):7357–7360

Dengler L, Preuss J (2003) Mitigation lessons from the July 17 1998 Papua New Guinea Tsunami. Pure Appl Geophys 160(10):2001–2031

Dennison L, Kiem M (2009) The health consequences of flooding. Stu Br Med J 17:110–111

Dillaha TA, Reneau RB, Mostaghimi S, Lee D (1989) Vegetative filter strips for agricultural non-point source pollution control. T Am Soc Agri Eng 32:513–519

Doocy S, Dick A, Daniels A, Kirsch TD (2013) The human impact of tropical cyclones: a historical review of events 1980–2009 and systematic literature review. PLOS Curr Disaster. doi:10.1371/s2664354a5571512063ed29d25ffbce74
Drummond W, Va'ai-Wells O (2004). Health and human development models across cultures. Nagare Press, Palmerston North
Dupon JF (1986) Atolls and the cyclone hazard: a case study of the Tuamotu islands. South Pacific Regional Environment Programme (SPREP)/South Pacific Commission (SPC), Apia and Noumea
Eisenberg NS, Cevallos W, Ponce K, Levy K, Bates SJ, Scott JC, Hubbard A, Vierira N, Endara P, Espinel M, Trueba G, Riley LW, Trostle J (2006) Environmental change and infectious disease: How new roads affect the transmission of diarrheal pathogens in rural Ecuador. PNAS 103(51):19460–19465
Ellison JC (2009) Wetlands of the Pacific islands region. Wet Ecol Manage 17(3):169–206
Eustace KL, MacDonald C, Long NR (1999) Cyclone Bola: a study of the psychological aftereffects. Anxiety Stress Copin 12(3):285–298
Ewalt PL, Mokuau N (1995) Self-determination from a Pacific perspective. Soc Work 40(2):168–175
Fabricius KE (2005) Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. Mar Pollut Bull 50(2):125–146
Falkland T (1999) Water resources issues of small island developing states. Nat Resour Forum 23(3):245–260
Fiji Government (2004) Preliminary estimates of flood affected areas. Press release 17 April, Suva
Galea S (2007) The long-term health consequences of disasters and mass traumas. Can Med Assoc J 176(9):1293–1294
Galea S, Nandi A, Vlahov D (2005) The epidemiology of post- traumatic stress disorder after disasters. Epidemiol Rev 27(1):78–91
Gaudet JJ (1978) Effects of a tropical swamp on water quality. Verhan Internat Vereinigung Limnol 20:2202–2206
Gaynor K, Katz A, Park S, Nakata M, Clark T, Effler P (2007) Leptospirosis on Oahu: an outbreak associated with flooding of a university campus. Am J Trop Med Hyg 76:882–885
Geist EL, Titov VV, Synolakis CE (2006) Tsunami: wave of change. Sci Am 294:56–63
Gillett R (2009) The contribution of fisheries to the economies of Pacific island countries and territories. Asian Development Bank, Suva
Gubler DJ, Reiter P, Ebi KL, Yap W, Nasci R, Patz JA (2001) Climate variability and change in the United States: potential impacts on vector- and rodent-borne diseases. Environ Health Perspect 109(2):223–233
Gupta A (1988) Large floods as geomorphic events in the humid tropics. In: Baker VR, Kochel RC, Patton PC (eds) Flood geomorphology. Wiley, New York, pp 301–315
Hamilton R, Ramohia P, Hughes A, Siota C, Kere N, Giningele M, Kereseka J, Taniveke F, Tanito N, Atu W, Tanavalu L (2007) Post-Tsunami assessment of Zinoa marine conservation area, South Choiseul, Solomon Islands. TNC Pacific Island Countries Report No. 4/07
Hansen MC, Stehman SV, Potapov PV (2010) Quantification of global gross forest cover loss. Proc Natl Acad Sci U S A 107(19):8650–8655
Harbin M, Faris R, Gad AM, Hafez ON, Ramzy R, Buck AA (1993) The resurgence of lymphatic filariasis in the Nile delta. Bull World Health Organ 71(1):49–54
Harper SL, Friedrich B, Hacker J, Hasnain SE, Mettenleiter TC, Schell B (2012) Climate change and infectious diseases. Epidemiol Infect 140(4):765
Harvell CD, Mitchell CE, Ward JR, Altizer S, Dobson A, Ostfeld RS, Samuel MD (2002) Climate warming and disease risks for terrestrial and marine biota. Science 296(5576):2158–2162
Hendrickson LA, Vogt RL, Goebert D, Pon E (1997) Morbidity on Kauai before and after Hurricane Iniki. Prev Med 26(5):711–716
Horwitz P, Finlayson M (2011) Wetlands as settings for human health: incorporating ecosystem services and health impact assessment into water resource management. Bioscience 61:678–688

Horwitz P, Finlayson M, Weinstein P (2012) Healthy wetlands, healthy people: a review of wetlands and human health interactions. Ramsar Technical Report No 6. Secretariat of the Ramsar Convention on Wetlands, Gland & The World Health Organization, Geneva

IFRC (2013) Emergency appeal: Republic of the Marshall Islands/Pacific drought. Emergency appeal n° MDRMH001, GLIDE n° DR-2013-000053-MHL 20 December 2013

IPCC (2007) Climate change 2007: the physical science basis. Interngovernmental Panel on Climate Change, Geneva, Switzerland

Iverson LR, Prasad AM (2007) Modeling Tsunami damage in Aceh: a reply. Landscape Ecol 23:7–10

Jenkins K (2010) Post cyclone Tomas support to typhoid fever control in Fiji March 2010. Fiji Health Sector Improvement Program, Suva, Fiji

Jenkins AP, Mailautoka K (2011) Fishes of Nadi basin and bay: conservation ecology and habitat mobility. In: Askew N, Prasad, SR (eds) Proceedings of the Second Fiji Conservation Science Forum 2011. Wildlife Conservation Society Fiji Program, Suva

Jenkins AP, Jupiter SD (2011) Spatial and seasonal patterns in freshwater ichthyofaunal communities of a tropical high island in Fiji. Environ Biol Fish 91(3):261–274

Jenkins AP, Jupiter SD, Qauqau I, Atherton J (2010) The importance of ecosystem-based management for conserving migratory pathways on tropical high islands: a case study from Fiji. Aquat Conserv 20(2):224–238

Jha AK, Stanton-Geddes Z (2013) Strong, safe, and resilient: a strategic policy guide for disaster risk management in East Asia and the Pacific. Directions in development. World Bank, Washington, DC. doi:10.1596/978-0-8213-9805-0

Jobin W (1999) Dams and disease: ecological design and health impacts of large dams, canals, and irrigation systems. E & FN Spon, London

Jupiter SD, Jenkins AP, Lee Long WJ, Maxwell SL, Watson JEM, Hodge KB, Govan H, Carruthers TJB (2013) Pacific integrated island management—principles, case studies and lessons learned. Secretariat of the Pacific Regional Environment Programme (SPREP), Apia

Kaplan M, Renaud FG, Lüchters G (2009) Vulnerability assessment and protective effects of coastal vegetation during the 2004 Tsunami in Sri Lanka. Nat Hazard Earth Syst 9:1479–1494

Kathiresan K, Rajendran N (2005) Coastal mangrove forests mitigated Tsunami. Estuar Coast Shelf Sci 65(3):601–606

Kerr AM, Baird AH (2007) Natural barriers to natural disasters. Bioscience 57(2):102–103

Knutson TR, McBride JL, Chan J, Emanuel K, Holland G, Landsea C, Held I, Kossin JP, Srivastava AK, Sugi M (2010) Tropical cyclones and climate change. Nat Geosci 3(779):157–163

Kouadio IK, Aljunid MS, Kamigaki T, Hammad K, Oshitani H (2012) Infectious diseases following natural disasters: prevention and control measures. Expert Rev Anti-infect Therap 10(1):95–104

Krishnamoorthy K, Jambulingam P, Natarajan R, Shriram AN, Das PK, Sehgal SC (2005) Altered environment and risk of malaria outbreak in South Andaman, Andaman & Nicobar Islands, India affected by Tsunami disaster. Malaria J 4:32

Lal PN, Singh R, Holland P (2009) Relationship between natural disasters and poverty: a Fiji case study. SOPAC miscellaneous report No. 678. International Strategy for Disaster Reduction, Suva

Lata S, Nunn P (2012) Misperceptions of climate-change risk as barriers to climate-change adaptation: a case study from the Rewa Delta, Fiji. Clim Change 110:169–186

Lau CL, Smythe LD, Craig SB, Weinstein P (2010) Climate change, flooding, urbanisation and leptospirosis: fuelling the fire? Trans R Soc Trop Med Hyg 104:631–638

Lau CL, Clements ACA, Skelly C, Dobson AJ, Smythe LD (2012) Leptospirosis in American Samoa—estimating and mapping risk using environmental data. PLoS Negl Trop Dis 6(5):e1669. doi:10.1371/journal.pntd.0001669

Lechat MF (1976) Disaster epidemiology. Ann Soc Belge Med Trop 56(4–5):193–197

Letourneur Y, Kulbicki, Labrosse P (1998) Spatial structure of commercial reef fishes along a terrestrial runoff gradient in the northern lagoon of New Caledonia. Environ Biol Fish 51:141–159

Likens GE, Bormann FH, Johnson NM, Fisher DW, Pierce RS (1970) Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed-ecosystem. Ecol Monogr 40(1):23–47
Lipp EK, Huq A, Colwell RR (2002) Effects of global climate on infectious disease: the cholera model. Clin Microbiol Rev 15(4):757–770
Lowrance RR, Altier LS, Newbold JD, Schnabel RR, Groffman PM, Denver JM (1997) Water quality functions of riparian forest buffer systems in the Chesapeake Bay Watershed. Environ Manage 21:687–712
Malek EA (1975) Effect of Aswan high dam on prevalence of schistosomiasis in Egypt. Trop Geogr Med 27(4):359–364
Maltby E, Acreman MC (2011) Ecosystem services of wetlands: pathfinder for a new paradigm. Hydrolog Sci J 56(8):1–19
Mackenzie JS, Gubler DJ, Petersen LR (2004) Emerging flaviviruses: the spread and resurgence of Japanese encephalitis, West Nile and dengue viruses. Nat Med 10(12):98–109
Mackenzie E, Prasad B, Kaloumaira A (2005) Economic impact of natural disasters on development in the Pacific. University of the South Pacific, Suva
McGregor DP, Morelli PT, Matsuoka JK, Rodenhurst R, Kong N, Spencer MS (2003) An ecological model of native Hawaiian well-being. Pac Health Dialog 10(2):106–128
McIvor AL, Möller I, Spencer T, Spalding M (2012) Reduction of wind and swell waves by mangroves. Natural Coastal Protection Series: Report 1. Cambridge Coastal Research Unit Working Paper 40. The Nature Conservancy and Wetlands International
McIvor AL, Spencer T, Möller I, Spalding M (2013) The response of mangrove soil surface elevation to sea level rise. Natural Coastal Protection Series: report 3. Cambridge Coastal Research Unit Working Paper 42.The Nature Conservancy and Wetlands International
McKergow LA, Weaver DM, Prosser IP, Grayson RB, Reed AEG (2003) Before and after riparian management: sediment and nutrient exports from a small agricultural catchment, Western Australia. J Hydrol 270(1):253–272
McMullin J (2005) The call to life: revitalizing a healthy Hawaiian identity. Soc Sci Med 61(4):809–820
Millennium Ecosystem Assessment (2005) Ecosystems and human well-being: synthesis. Island Press, Washington, DC
Moore M, Townsend M, Oldroyd J (2006) Linking human and ecosystem health: the benefits of community involvement in conservation groups. Ecohealth J 3(4):255–261
Mosley LM, Sharp DS, Singh S (2004) Effects of a tropical cyclone on the water quality of a remote Pacific island. Disasters 28(4):393–405
Myers SS, Patz J (2009) Emerging threats to human health from global environmental change. Ann Rev Env Res 34:223–252
Myers SS, Gaffikin L, Golden CD, Ostfeld RS, Redford KH, Ricketts TH, Turner WR, Osofsky SA (2013) Human health impacts of ecosystem alteration. Proc Natl Acad Sci U S A. www.pnas.org/cgi/doi/10.1073/pnas.1218656110
Nicholls RJ, Hoozemans MJF, Marchand M (1999) Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses. Glob Env Change 9(1):69–87
Nicholls RJ, Wong PP, Burkett VR, Codignotto J, Hay JE, McLean RF, Ragoonaden S, Woodroffe CD (2007) Coastal systems and low-lying areas. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Climate change 2007: impacts, adaptation and vulnerability. Cambridge University Press, Cambridge
NIWA (2012) Island climate update 140. http://www.niwa.co.nz/climate/icu/island-climate-update-140-may-2012. Accessed 12 Jan 2014
Norris V (1993) The use of buffer zones to protect water quality: a review. Water Resour Manage 7:257–272
Ostfeld RS (2009) Climate change and the distribution and intensity of infectious diseases. Ecology 90(4):903–905
Patz JA (2000) Climate change and health: new research challenges. Ecosyst Health 6(1):52–58

Patz JA, Epstein PR, Burke TA, Balbus JM (1996) Global climate change and emerging infectious diseases. J Am Med Ass 275(3):217–223

Patz JA, Daszak P, Tabor GM, Aguirre AA, Pearl M, Epstein J (2004) Unhealthy landscapes: policy recommendations on land use change and infectious disease emergence. Environ Health Perspect 112(10):1092–1098

Pimentel D, Allen J, Beers A, Guinand L, Hawkins A, Linder R, McLaughlin P, Meer B, Musonda D, Perdue D, Poisson S, Salazar R, Siebert S, Stoner K (1993) Soil erosion and agricultural productivity. In: Pimentel D (ed) World soil erosion and conservation. Cambridge University Press, Cambridge

Ragosta G, Evensen C, Atwill ER, Walker M, Ticktin T, Asquith A, Tate KW (2010) Causal connections between water quality and land use in a rural tropical island watershed. Ecohealth 7(1):105–113

Roth CH (2004) A framework relating soil surface condition to infiltration and sediment and nutrient mobilization in grazed rangelands of northeastern Queensland, Australia. Earth Surf Proc Land 29:1093–1104

Salinger MJ, Lefale P (2005) The occurrence and predictability of extreme events over the Southwest Pacific with particular reference to ENSO. In: Sivakumar MVK, Motha RP, Das HP (eds) Natural disasters and extreme events in agriculture. Springer, Berlin, pp 39–49

Scobie H (2011) Preliminary report: impact assessment of the 2010 Mass Typhoid Vaccination Campaign, Republic of Fiji. Centers for Disease Control and Prevention, World Health Organization, Fiji Ministry of Health, Australian Agency for International Development, Suva, Fiji

Sherif MM, Singh VP (1996). Saltwater intrusion. In: Singh VP (ed) Hydrology of disasters, vol 18. Klewer Academic Publishers,, Dordrecht, pp 269–319

Shultz JM, Russell J, Espinel Z (2005) Epidemiology of tropical cyclones: the dynamics of disaster, disease, and development. Epidemiol Rev 27(1):21–35

Singh RBK, Hales S, de Wet N, Raj R, Hearnden M, Weinstein P (2001) The influence of climate variation and change on diarrheal disease in the Pacific Islands. Environ Health Persp 109:155–159

SOPAC (2013) Regional progress report on the implementation of the Hyogo Framework for Action (2011–2013). Secretariat of the Pacific Community, Suva

Staab JP, Grieger TA, Fullerton CS (1996) Acute stress disorder, subsequent posttraumatic stress disorder and depression after a series of typhoons. Anxiety 2(5):219–225

Strathern A, Stewart PJ, Carucci LM, Poyer L, Feinberg R, Macpherson C (2002) Oceania: an introduction to the cultures and identities of Pacific Islanders. Carolina Academic Press, Durham

Terry JP, Falkland AC (2009) Responses of atoll freshwater lenses to storm-surge overwash in the Northern Cook Islands. Hydrogeol J 18(3):749–759

UNDP South Pacific Office (2002) Natural disaster risk reduction in Pacific Island countries, final report for international decade for natural disaster reduction 1990–2000. United Nations Development Programme, Fiji

United Nations International Strategy for Disaster Reduction (UNISDR) (2005) Hyogo Framework for Action 2005–2015: building the resilience of nations and communities to disasters. http://www.unisdr.org/wcdr. Accessed 10 Jan 2014

Walzer PD, Judson FN, Murphy KB, Healy GR, English DK, Schultz MG (1973) Balantidiasis outbreak in Truk. Am J Trop Med Hyg 22(1):33–41

Watson JT, Gayer M, Connolly MA (2007) Epidemics after natural disasters. Emerg Infect Dis 13(1):1–5

Wilson SK, Fisher R, Pratchett MS, Graham NAJ, Dulvey NK, Turner RA, Cakacaka A, Polunin NVC, Rushton SP (2008) Exploitation and habitat degradation as agents of change within coral reef fish communities. Glob Change Biol 14(12):2796–2809

WHO (2013) Outbreak surveillance and response priorities for mitigating the health impact of disaster. Tenth Pacific health ministers meeting. Agenda Item 9. http://www.wpro.who.int/southpacific/pic_meeting/2013/documents/PHMM_PIC10_9_Outbreak. Accessed 10 Jan 2014

Young S, Balluz L, Malilay J (2004) Natural and technologic hazardous material releases during and after natural disasters: a review. Sci Total Environ 322(1–3):3–20