Chapter 10
Impacts of Climate Change on Marine Resources in the Pacific Island Region

Johanna E. Johnson, Valerie Allain, Britt Basel, Johann D. Bell, Andrew Chin, Leo X. C. Dutra, Eryn Hooper, David Loubser, Janice Lough, Bradley R. Moore, and Simon Nicol

10.1 Introduction

10.1.1 Physical and Biological Features of the Region

The Pacific Island region encompasses 22 Pacific Island countries and territories (PICTs) that span much of the tropical and subtropical Pacific Ocean. The combined exclusive economic zones (EEZs) of PICTs cover an area of >27 million km^2, but only 2% of their combined jurisdictions is land (see Chaps. 1 and 2). PICTs are therefore often referred to as 'large ocean states'.

J. E. Johnson (✉)
C2O Pacific, Port Vila, Vanuatu

College of Science and Engineering, James Cook University, Townsville, QLD, Australia
e-mail: j.johnson@c2o.net.au

V. Allain
Pacific Community (SPC), Noumea, New Caledonia

B. Basel
C2O Pacific, Port Vila, Vanuatu

Ecothropic, San Cristóbal de las Casas, Chiapas, Mexico

J. D. Bell
Australian National Centre for Ocean Resources and Security, University of Wollongong, Wollongong, NSW, Australia

Conservation International, Arlington, VA, USA

A. Chin
College of Science and Engineering, James Cook University, Townsville, QLD, Australia

L. X. C. Dutra
CSIRO Oceans and Atmosphere Business Unit, Queensland BioSciences Precinct, St Lucia, Brisbane, QLD, Australia

School of Marine Studies, Faculty of Science, Technology and Environment, The University of the South Pacific, Suva, Fiji

L. Kumar (ed.), *Climate Change and Impacts in the Pacific*, Springer Climate,
https://doi.org/10.1007/978-3-030-32878-8_10

From an oceanographic and management perspective, the region is dominated by the Western and Central Pacific Ocean (WCPO), which supports vast areas of coastal and oceanic habitats and many species of fish, invertebrates and other animals. Given the scale of this ocean area, it is unsurprising that the region has the greatest dependence on marine resources in the world. These resources, particularly fish and invertebrates, provide a significant source of animal protein, income from artisanal fishing and tourism livelihoods and hold important cultural values for communities in the Pacific Islands region (Sect. 10.2). For example, fish consumption in the Pacific Islands has been a cornerstone of food security; per capita fish consumption in many PICTs is 3–5 times the global average, and, in rural areas, fish often supplies 50–90% of dietary animal protein (Bell et al. 2009; Bell et al. 2018a) The oceanic fisheries resources (mainly tuna) in the EEZs of PICTs also make major contributions to economic development in the region.

10.1.2 Ethnic and Cultural Diversity and Demography

People began to populate the Pacific Islands region approximately 50,000 years ago. Through successive migrations, these early wayfarers eventually established communities across the vast Pacific Ocean (Kayser 2010). Today, these communities exhibit immense cultural and linguistic diversity (Crowley 1999), are commonly governed by customary belief systems and laws that structure society, are the foundation of people's identity and underpin the use and management of natural resources (Hviding 1996).

In recognition of the variation in the physical nature, biogeography, ethnic origin and cultural differences among PICTs, the region is divided into three subregions—Melanesia, Micronesia and Polynesia.

E. Hooper
C_2O Pacific, Port Vila, Vanuatu

D. Loubser
Ecosystem Services Ltd, Wellington, New Zealand

J. Lough
Australian Institute of Marine Science (AIMS), Townsville, QLD, Australia

B. R. Moore
Institute for Marine and Antarctic Studies (IMAS), University of Tasmania, Hobart, TAS, Australia

National Institute of Water and Atmospheric Research (NIWA), Nelson, New Zealand

S. Nicol
Pacific Community (SPC), Noumea, New Caledonia

10.2 Importance of Marine Resources to the People in the Pacific

10.2.1 Cultural and Social Importance of Marine Resources

Given that 98% of the jurisdictions of PICTs is ocean, the majority of Pacific Island people share a high dependence on marine resources for food security (as a critical protein source), travel, economic development and as source of income to support livelihoods. This dependence has become deeply intertwined with cultural identity, religious beliefs and social structures (Hviding 1996). For example, in the Trobriand Islands of Papua New Guinea (PNG), origin stories, family relationships and ceremonies revolve around marine life (Ruddle 1998). More generally, there are examples of traditional fisheries management, customary restrictions (taboos), ceremonial fishing practices, the use of teeth and bones of marine animals as power symbols and sacred relationships between individuals and specific marine species that are guided by customary laws (Ruddle and Panayotou 1989; Hyndman 1993; Cinner and Aswani 2007; Whimp 2008; Friedlander et al. 2013; Veitayaki et al. 2014).

However, Pacific Island cultures are increasingly experiencing radical social, economical and political changes. Previously subsistence-based economies are being monetised. Building on the legacy of colonialism, leadership structures and religious authorities are changing as a result of urban migration and the presence of Abrahamic religions. Education systems are being transformed, population pressure on limited resources is rising and the forces of globalisation and technology are increasingly present (Ruddle 1993, 1998). These complex, and largely foreign, drivers of change are continually altering the traditional cultural relationships between communities and marine resources, even while communities continue to be heavily dependent upon the ocean for their wellbeing and livelihoods.

Traditionally, there is a wide range of capacity that communities have developed to cope with natural disasters, particularly cyclones. For example, surveys of women from Tanna Island in Vanuatu after tropical cyclone Pam said that they had known to start fastening down house roofing materials several hours before the cyclone, and there were a number of signs based on ‘traditional knowledge’ that the cyclone would significantly damage housing and resources (RESCCUE 2015). Many Pacific communities rely on traditional knowledge and other institutions of social capital, local governance, customary marine tenure and self-enforcement capacity to adapt to climate impacts and provide a resilient way forward (Heenan et al. 2015; Johnson et al. 2018).

10.2.2 Importance of Fisheries and Aquaculture for Food Security, Livelihoods and Economic Development

Fisheries are critical for food security, livelihoods and economic development in most PICTs (Bell et al. 2011; Gillett 2016; Gillett and Tauati 2018) (Table 10.1). Across the region, a range of small-scale fisheries target demersal fish and invertebrates associated with coastal habitats, and tuna and other large pelagic fish in nearshore waters, for food security and livelihoods (Pratchett et al. 2011; Johnson et al. 2017; Bell et al. 2018a). In some PICTs (e.g. Fiji, New Caledonia, Tonga and Vanuatu), these fisheries are supplemented by catches of deepwater snapper, grouper and emperors from reef slopes and seamounts. Recent estimates suggest that the total catch of small-scale coastal fisheries in the region is around 164,000 tonnes, worth approximately USD 453 million. These fisheries provide the primary or secondary source of income for an average of 50% of households in many coastal communities (Pinca et al. 2010; Gillett 2016; Bell et al. 2018a).

Industrial purse-seine and longline tuna fisheries make substantial contributions to economies and societies across the region. These fisheries target four species: skipjack tuna, yellowfin tuna, bigeye tuna and South Pacific albacore. Collectively, these industrial fisheries harvest an average of around 1.5 million tonnes of tuna each year from the exclusive economic zones (EEZs) of Pacific Island countries and territories (PICTs) and supply ~30% of the world's tuna (Williams et al. 2017). The licence fees obtained from distant fishing water operating within the EEZs of PICTs make significant contributions to economic development—eight countries and territories receive 10% to >90% of all their government revenue from these licence fees, with five of these countries receiving 45–60% of their revenue in this way (FFA 2016). Approximately 23,000 jobs have also been created through processing tuna onshore, crewing on tuna-fishing vessels and placing observers on purse-seine vessels (FFA 2016). PICTs have also been alerted to the need for tuna to make greater contributions to the supply of fish for local food security (Bell et al. 2015a).

To sustain and enhance the socio-economic benefits of tuna to the region, Pacific Island leaders endorsed a Regional Roadmap for Sustainable Pacific Fisheries in 2015. The Roadmap aims to improve the sustainability of industrial tuna fisheries, increase employment in the sector, add value to the catch and allocate more tuna for domestic food security (FFA and SPC 2015).

10.2.3 Importance of Marine Resources for Tourism

Coral reefs in many PICTs have strong potential to support the development and growth of sustainable tourism, particularly for small-scale ecotourism ventures that can provide income for local communities. This potential is based on the appeal of and access to clear water locations with diverse fish life and a high percentage of coral cover favoured by many tourists (Uyarra 2005).

Table 10.1 Estimates of average fresh fish consumption (kg/person/year) within coastal communities (from Pinca et al. 2010) and annual (2014) catches in tonnes and as percentage of total catch, for categories of coastal fisheries in Pacific Island countries and territories (PICTs)

PICT	Fish consumption (kg/person/year)	Demersal fish						Nearshore pelagic fish						Targeted invertebrates		Subsistence invertebrates		Total catch
		Subsistence		Commercial		Total		Subsistence		Commercial		Total						
		tonnes	%	tonnes	%	tonnes	%	tonnes	%	tonnes	%	tonnes	%	tonnes	%	tonnes	%	
Melanesia																		
Fiji	83.6	10,336	38.3	7070	26.2	17,406	64.5	2400	8.9	3030	11.2	5430	20.1	900	3.3	3264	12.1	27,000
New Caledonia	34.3	1827	37.7	840	17.3	2667	55.0	350	7.2	210	4.3	560	11.5	300	6.2	1323	27.3	4850
PNG	37.7	13,860	33.4	3124	7.5	16,984	40.9	14,000	33.7	2082	5.0	16,082	38.8	1294	3.1	7140	17.2	41,500
Solomon Islands	115.1	10,640	40.2	4317	16.3	14,957	56.5	6000	22.7	1850	7.0	7850	29.7	302	1.1	3360	12.7	26,468
Vanuatu	20.4	1434	36.7	685	17.5	2119	54.2	560	14.3	369	9.4	929	23.8	52	1.3	806	20.6	3906
Micronesia																		
FSM	81.4	2696	51.1	1136	21.5	3832	72.6	605	11.5	561	10.6	1166	22.1	28	0.5	254	4.8	5280
Guam	na	11	10.0	22	18.9	33	28.9	28	24.7	50	43.5	78	68.2	1	0.8	2	2.2	114
Kiribati	111.9	8026	42.2	5917	31.1	13,942	73.4	2280	12.0	1669	8.8	3949	20.8	14	0.1	1094	5.8	19,000
Marshall Islands	111.5	1980	44.0	895	19.9	2875	63.9	750	16.7	596	13.3	1346	29.9	9	0.2	270	6.0	4500
Nauru	52.8	71	19.0	44	11.9	115	30.9	134	36.0	118	31.6	252	67.6	1	0.3	5	1.3	373
CNMI	na	230	46.7	24	4.9	254	51.6	70	14.2	115	23.3	185	37.5	3	0.6	50	10.2	492
Palau	69.5	455	21.5	518	24.5	973	46.0	438	20.7	346	16.3	783	37.0	1	0.0	358	16.9	2115
Polynesia																		
American Samoa	na	68	42.0	29	18.1	97	60.1	36	22.2	13	7.8	49	30.0	0	0.0	16	9.9	162
Cook Islands	78.9	96	22.5	58	13.7	154	36.2	166	38.9	88	20.6	253	59.4	4	1.0	14	3.4	426

(continued)

Table 10.1 (continued)

PICT	Fish consumption (kg/person/ year)	Demersal fish						Nearshore pelagic fish						Targeted invertebrates		Subsistence invertebrates		Total catch
		Subsistence		Commercial		Total		Subsistence		Commercial		Total						
		tonnes	%	tonnes	%	tonnes	%	tonnes	%	tonnes	%	tonnes	%	tonnes	%	tonnes	%	
French Polynesia	59.2	1711	21.3	2203	27.5	3914	48.8	212	2.6	3042	38.0	3254	40.6	421	5.2	428	5.3	8016
Niue	33.5	20	12.0	2	1.3	22	13.4	123	74.7	9	5.3	132	80.0	0	0.0	11	6.6	165
Pitcairn Islands	na	4	45.9	1	9.6	5	55.5	1	10.0	2	19.3	3	29.3	0	4.4	1	10.8	9
Samoa	73.8	2160	21.6	1657	16.6	3817	38.2	1000	10.0	2723	27.2	3723	37.2	621	6.2	1840	18.4	10,000
Tokelau	na	126	31.5	14	3.5	140	35.0	198	49.5	22	5.5	220	55.0	4	1.0	36	9.0	400
Tonga	81.2	2052	29.7	2840	41.2	4892	70.9	300	4.3	368	5.3	668	9.7	692	10.0	648	9.4	6900
Tuvalu	142.4	792	55.2	126	8.8	918	64.0	284	19.8	171	11.9	455	31.7	3	0.2	60	4.2	1435
Wallis and Futuna	53.8	510	57.1	135	15.1	645	72.2	68	7.6	15	1.7	83	9.2	69	7.7	97	10.9	894
Total	–	59,104	36.0	31,658	19.3	90,762	55.3	30,001	18.3	17,447	10.6	47,448	28.9	4718	2.9	21,077	12.9	164,005

Adapted from Bell et al. (2018a)
Estimates for subsistence and commercial catches are shown for demersal fish and nearshore pelagic fish; targeted invertebrate fisheries are considered to be 100% commercial
na estimate not available

For PICTs with tourism capacity, healthy reefs with abundant fish life, sharks and rays act as a tourism attraction and provide significant income at national and local levels. For example, in the Great Barrier Reef, sharks are important tourism icons and key attractions (Stoeckl et al. 2010). Shark and ray tourism is likewise important in many PICTs, such as French Polynesia and Fiji (Brunnschweiler and McKenzie 2010; Clua et al. 2011), and could make a substantial contribution to GDP (Vianna et al. 2012) as they offer opportunities for snorkelers and non-swimmers. The non-extractive values of sharks and rays are instrumental in driving shark protection and promoting local ecotourism opportunities. For example, the entire EEZ of Palau has been declared a shark 'sanctuary', and large 'shark parks' have been established in many areas of the Pacific.

Reef tourism is expected to contribute to GDP on the macroscale in the form of employment and foreign exchange inflows (Beeton 2006) and help address food insecurity issues and environmental degradation on the microscale through flow-on benefits from local economic development (Dutra et al. 2011).

However, unless managed well, tourism may have unwanted consequences, such as habitat degradation through construction of infrastructure (e.g. airports, hotels and roads), overfishing to provide meals for tourists, unequal distribution of wealth and changes to local traditions and lifestyle (Dutra et al. 2011; Movono et al. 2018). Such outcomes would undermine the very features on which tourism depends (Hough 1990). Therefore, developing and promoting coral reefs as tourism destinations in PICTs strongly depends on sustainable management to ensure healthy coral reefs and communities, especially given the intricate relationship between resource dependence for food and income and healthy coastal ecosystems.

10.3 Vulnerability of Marine Resources to Climate Change

10.3.1 Impacts of Local Changes in Climate

Marine resources in the tropical Pacific Ocean are strongly influenced by their oceanic environment. This 'marine climate' encompasses water temperatures, salinity, nutrient availability, dissolved oxygen concentrations, aragonite saturation state (a measure of how easily calcifying marine organisms, such as corals, can extract calcium and carbonate ions from seawater to build their skeletons and shells), large- and small-scale water circulation patterns, waves and sea level. The spatial patterns of these features of the ocean vary seasonally and inter-annually. The inter-annual variations are driven primarily by El Niño-Southern Oscillation (ENSO; McPhaden et al. 2006) events (the major source of global inter-annual tropical climate variability with its epicentre in the ocean-atmosphere circulation system of the tropical Pacific), modulated on decadal time scales by the Inter-decadal Pacific Oscillation (IPO) (Power et al. 1999). Due to human interference in the global energy budget, the tropical Pacific marine climate has already warmed by ~1 °C since pre-industrial times. The magnitude of future climate-related changes is strongly dependent on global actions to constrain further additional warming in the oceans to 0.5–1.0 °C.

The most recent Intergovernmental Panel on Climate Change (IPCC) Assessment Report—IPCC-AR5 (2013)—provides strong evidence from observational records that the global ocean surface and subsurface climate is changing (Rhein et al. 2013). For the tropical Pacific, these changes include widespread warming of subsurface waters and sea surface temperatures (SST), especially in the western Pacific, freshening of surface waters in the western equatorial Pacific and under the major atmospheric convergence zones, expansion of the Western Pacific Warm Pool, strengthening of the South Pacific Gyre, increased stratification of the water column which limits vertical supply of nutrients to the surface, decreasing concentrations of dissolved oxygen, lowering of the aragonite saturation state and rising sea level (Cravatte et al. 2009; Durack and Wijffels 2010; Ganachaud et al. 2011; Heron et al. 2016; Lough et al. 2018). These changes are consistent with those expected in a warming climate system with an intensified hydrological cycle.

Based on numerical climate models, substantial changes in tropical Pacific Ocean circulation patterns, SST and vertical temperature structure are projected to continue over the twenty-first century with the magnitude of change related to the global trajectory of greenhouse gas emissions. Likely changes in major currents include weakening of the South Equatorial Current and South Equatorial Counter Current and strengthening of the Equatorial UnderCurrent in the western Pacific. The surface and subsurface oceans will continue to warm, and the Western Pacific Warm Pool will expand further eastwards and become fresher. Nutrient supply to surface waters through upwelling will decrease as stratification increases and the upper ocean mixed layer becomes shallower. Dissolved oxygen concentrations may increase near the equator but are likely to decrease at higher latitudes of the tropical Pacific. There will be continued decline of the aragonite saturation state and increase in sea levels (Ganachaud et al. 2011; BOM and CSIRO 2011, 2014; Lough et al. 2011, 2016; van Hooidonk et al. 2014).

Superimposed on these trends in average tropical Pacific marine climate over the twenty-first century, the region will continue to be impacted by severe weather events and inter-annual modulation of climate. Tropical cyclones are a major source of physical destruction to coastal marine ecosystems, such as coral reefs, seagrass and mangroves. Although there may be fewer tropical cyclones in the future (Christensen et al. 2013), those that do occur are likely to be more intense and destructive (such as Severe TC Pam which impacted Vanuatu in March 2015 and Severe TC Winston which impacted Fiji in February 2016). ENSO events will continue to cause substantial inter-annual disruptions of tropical Pacific climate, modulating SST, tropical cyclone, ocean circulation and rainfall patterns (Lough et al. 2011, 2016). There is mounting evidence that the more extreme El Niño and La Niña events (such as 1997–1998 and 2015–2016) will occur more frequently in the future (Power et al. 2013; Cai et al. 2015).

IPCC predictions expect global mean sea-level rise during the twenty-first century to exceed the rate observed during 1971–2010 for all Representative Concentration Pathway (RCP) scenarios (Table 10.2). This is principally because of

Table 10.2 RCP sea-level rise predictions

RCP	Minimum (m)	Maximum (m)
RCP2.6	0.26	0.55
RCP4.5	0.32	0.63
RCP6.0	0.33	0.63
RCP8.5	0.45	0.82

Source: Church et al. (2013)

increases in ocean warming and loss of mass from glaciers and ice sheets. Local sea-level rises in the Pacific follow the global IPCC predictions (i.e. 70 cm by 2070 and 100 cm by 2100) (Church et al. 2006).

Overall, the marine resources of the tropical Pacific are entering an era of potentially profound changes to the ocean that supports them, and will be increasingly subject to more extreme, and often more destructive, weather events, as described in earlier chapters.

10.4 Impacts of Climate Change on Marine Habitats

10.4.1 Oceanic Habitats and Food Webs

The projected changes in ocean circulation are expected to alter the timing, location and extent of the upwelling processes on which most oceanic primary productivity depends. Changes in the vertical structure of the water masses and in the depth and strength of the thermocline will also impact the availability of nutrients. The production of phytoplankton at the base of oceanic food webs is primarily constrained by the availability of nutrients (e.g. nitrogen), and/or micronutrients (e.g. iron). Because phytoplankton rapidly exhaust the limited nutrients of surface waters, substantial primary production occurs only where deep, nutrient-rich waters are brought to the surface by upwelling and eddies, or when the thermocline becomes shallower and/or weaker, allowing the diffusion of nutrients from the deep nutrient-rich water masses towards the surface (Le Borgne et al. 2011).

In turn, production of organisms at higher trophic levels in the food web (e.g. zooplankton, micronekton, mid-level and top predators) is constrained by variations in phytoplankton production, size structure and composition (Woodworth-Jefcoats et al. 2013) and directly by environmental factors such as temperature and ocean acidification.

A range of studies point to reduced phytoplankton production as the ocean warms in relation to nutrient supply. A 9–33% decrease in phytoplankton in the tropical western Pacific ecological provinces is projected under a high emissions scenario (Le Borgne et al. 2011) with subsequent decrease in zooplankton. Reduction of the phytoplankton biomass is also projected in the north Pacific by 2100, causing a decline in the biomass of zooplankton and all higher trophic level groups. At the global level, a 2–20% decrease in mean primary productivity is projected by 2100 under a high emissions scenario, including in the tropics (Henson et al. 2013; Steinacher et al. 2010).

Important differences in phytoplankton production are expected to occur within the tropical Pacific region (Sarmiento et al. 2004). However, there is still much uncertainty about the nature and extent of these changes (Chavez et al. 2011). For example, the low primary production subtropical gyres in the Pacific could expand by ~30% by 2100, and the productive Pacific Equatorial Divergence could contract by 28% (Polovina et al. 2011). In contrast, other models project increases in subsurface phytoplankton concentrations down to 100 m depth that could offset the decline in surface phytoplankton (Matear et al. 2015), and an increase in primary production as temperature increases (Taucher and Oschlies 2011). The latter projection is based on the positive impact of increased temperature on the microbial loop activity that degrades dying phytoplankton and increases the availability of recycled nutrients for new phytoplankton growth (Behrenfeld 2011). Other studies also demonstrate that the direct effect of temperature on phytoplankton might induce a greater demand for nitrogen which is already in limited supply (Toseland et al. 2013).

Knowledge about the impact of climate change on phytoplankton, zooplankton and micronekton is limited by several factors, including our poor understanding of marine system responses to multifactorial physicochemical climate drivers, the complexity of life cycles and species' interactions, the difficulties in representing all ecosystem functions at multiple levels (organism physiology, populations, communities) and the unknown potential of marine organisms to adapt behaviourally, physiologically, genetically and phenotypically to the unprecedented pace of current climate change (Behrenfeld et al. 2016; Hallegraeff 2010; Petitgas et al. 2012).

10.4.2 Coral Reefs

There is more than 160,000 km^2 of coral reef habitat in the Pacific Island region (Hoegh-Guldberg et al. 2011). Although coral reefs provide valuable ecosystem services in their own right, when they form a habitat mosaic with mangroves and seagrasses, they sustain a greater diversity of organisms and higher fisheries production and protect the coastline against erosion and storms more effectively (Veitayaki et al. 2017; Guannel et al. 2016; Moberg and Folke 1999; Zann 1994). Since the 1970s, the deterioration of coral reefs and associated coastal habitats such as mangroves and seagrasses has been accelerating (Albert et al. 2017; Guannel et al. 2016; Hassenruck et al. 2015). Climate change is currently the strongest driver affecting coral reef dynamics (Aronson and Precht 2016) through higher ocean temperatures, sea-level rise, ocean acidification, more intense storms and cyclones and the synergistic effects that climate drivers have with each other and with non-climate drivers, such as overfishing, sediment runoff and pollution. These impacts are expected to increase as the climate continues to change (Dutra et al. 2018).

In particular, increases in Pacific Ocean sea surface temperatures (SST) are causing widespread impacts on coral reefs due to thermal coral bleaching (Adjeroud et al. 2009; Cumming et al. 2000; Davies et al. 1997; Hughes et al. 2017; Kleypas et al. 2015; Lough 2012; Lovell et al. 2004; Mangubhai 2016; Obura and Mangubhai 2011; Rotmann 2001). There are several negative effects associated with mass bleaching events, including increased reef bioerosion (Chaves-Fonnegra et al. 2018), reduction of coral calcification rates (De'ath et al. 2009; Nurse et al. 2014) and changes in coral spawning events (Keith et al. 2016). Bleaching also affects colony size and timing of coral spawning (Paxton et al. 2016), slows swimming speed of coral larvae and reduces the number of viable recruits (Singh 2018). Increased SST acts synergistically with increased nutrients and sediment loads to amplify bleaching effects (Wiedenmann et al. 2012), affecting coral recovery period after bleaching.

Tropical cyclones are becoming more intense in the Pacific (Elsner et al. 2008), causing the loss of coral reef and mangrove areas (Guillemot et al. 2010; Johnson et al. 2016a; Mangubhai 2016; Singh 2018). Flood events associated with cyclones cause substantial soil erosion, leading to increased sediment and nutrient runoff onto coral reefs (Guillemot et al. 2010; Levin et al. 2015; Mangubhai 2016; Terry 2007; Veitayaki 2018). Pacific coral reefs stressed by pollution, overfishing and other climate change stressors may be slower to recover after cyclones (Zann 1994).

Oceans are becoming more acidic as they absorb the excess carbon dioxide from the atmosphere (Barros and Field 2014; Bates et al. 2014; Dore et al. 2009; IPCC 2014; Johnson et al. 2016b). Ocean acidification has been shown to weaken coral skeletons, slow coral growth, change the abundance and structure of coral communities (Enochs et al. 2015, 2016; Fabricius et al. 2011), decrease coral diversity and recruitment (Fabricius et al. 2011) and reduce the abundance of crustose coralline algae, an inducer of coral larval settlement (Fabricius et al. 2015). These negative effects on corals most likely facilitate macroalgae growth, causing a shift from a coral-dominated to algal-dominated state (Enochs et al. 2015).

Weaker reef systems will be far more susceptible to damage from other pressures, including bioerosion, eutrophication, coral disease, intense storms and thermal bleaching as corals become more fragile (Meissner et al. 2012; Nuttall and Veitayaki 2015; Szmant and Gassman 1990; van Hooidonk et al. 2014). Weakened coral skeletons due to ocean acidification can trigger stress-response mechanisms, which affect the rates of tissue repair, skeletal density, feeding rate, reproduction and early life stage survival (Albright and Mason 2013; Cooper et al. 2008; D'Angelo et al. 2012; Enochs et al. 2015; Fabry et al. 2008; Kroeker et al. 2010; Szmant and Gassman 1990).

Sea level has been gradually rising globally and accelerating in the last decades in some Pacific Islands (Dean and Houston 2013; Jevrejeva et al. 2009; Kench et al. 2018). Sea-level rise effects on Pacific Ocean coral reefs are complex and challenging to predict. In principle, this extra depth provides space for growth that may be beneficial to corals (van Woesik et al. 2015; Woodroffe and Webster 2014; Saunders et al. 2016). However, under all climate change scenarios, it is more likely that there will be more coastal erosion due to rising sea levels (Barros and Field 2014;

Kench et al. 2018), thus increasing turbidity and sedimentation in coastal waters, negatively affecting corals and other reef organisms, at least in the early inundation period until sea level stabilises (Brown et al. 2017a, b; De'ath and Fabricius 2010). Without sustained ecological recovery, very few reefs would be able to keep pace with projected sea-level rise, especially under RCP4.5 or RCP8.5, potentially resulting in reef submergence. This will lead to changes in wave energy regimes, increasing sediment mobility, shoreline change and island overtopping (Kench et al. 2015, 2018; Saunders et al. 2014).

There is also concern that the progressive degradation of coral reefs could increase the incidence of ciguatera fish poisoning and other problems related to toxic algae. The organisms responsible for ciguatera and ciguatera-like symptoms are dinoflagellate microalgae in the genera *Gambierdiscus*, *Prorocentrum* and *Ostreopsis*. These microalgae live as epiphytes on dead coral, turf algae and macroalgae and are ingested by grazing herbivorous fish. The microalgae produce a range of toxins that bioaccumulate through the food chain (Dalzell 1993; Roué et al. 2013). Greater availability of the preferred substrata of these microalgae—dead coral and macroalgae—resulting from increased coral bleaching events and cyclones of greater intensity will likely increase the incidence of ciguatera in the region (Pratchett et al. 2011; Rongo and van Woesik 2013).

10.4.3 Seagrass Meadows

Globally there are over 60 species of seagrasses, with 14 species and 1 subspecies recorded from the tropical Pacific (Ellison 2009). Species richness decreases from west to east with the greatest species richness being found in PNG. Seagrasses are absent or unreported from the Cook Islands, Nauru, Niue, Pitcairn Islands, Tokelau and Tuvalu (Waycott et al. 2011).

Evidence suggests that seagrasses are declining globally, mainly due to anthropogenic impacts (Short and Wyllie-Echeverria 1996; Orth et al. 2006; Waycott et al. 2009). Threats include sediment runoff affecting water quality, construction, dredging and landfill activities. In addition to these direct threats, there are increasing threats from climate change from increasing SST, ocean acidification, more intense storms and cyclones and sea-level rise.

Increasing concentrations of atmospheric CO_2, resulting in equivalent increases in seawater CO_2 levels, have the potential to cause seagrass production to increase. However, increasing CO_2 levels are also likely to increase the production of epiphytic algae on seagrass leaves, which may negatively impact seagrasses through shading and competition (Beer and Koch 1996).

Increases in SST are expected to stress seagrasses, resulting in distribution shifts (Hyndes et al. 2016) and changes in reproduction, growth rates and carbon balance (Short and Coles 2001). When temperatures approach the upper thermal limit for a species, productivity is reduced and eventually the plant will die (Coles et al. 2004). High temperatures can also increase the growth of epiphytes, which can outcompete seagrasses (see above). The thermal tolerance of the different species and their optimum temperature for photosynthesis will influence how they will cope with increased ocean temperatures.

As a result of increasing dissolved CO_2, the pH of seawaters will decrease due to the dissolved CO_2 forming an equilibrium with carbonic acid, which dissociates to add protons to the water which makes the water more acidic. Under expected future increased CO_2 concentrations, ocean acidification could be buffered locally by photosynthesis in seagrass stands (Beer et al. 2006). In turn, this could increase seagrass photosynthesis and productivity (Palacios and Zimmerman 2007).

Increased runoff, nutrient levels and wave power from more severe cyclones are expected to impact seagrasses, reducing photosynthesis and damaging the plants. Shallow-rooted and smaller seagrass species, such as *Halophila* spp., are more likely to be damaged by the increased wave action than deeper-rooted species such as *Enhalus acoroides*. Post cyclone, seagrasses do have the ability to re-establish quickly (Short et al. 2006).

Rising sea levels can adversely impact seagrasses due to increases in water depths, thereby reducing light and reducing photosynthesis and growth. However, increasing turbidity and seawater intrusions on land or into estuaries and rivers could favour landward migration providing there are no barriers to migration (Short and Neckles 1999; Waycott et al. 2011; Saunders et al. 2013).

10.4.4 Mangroves

Typically, mangroves are located along the shore and have a number of ecological roles, including buffering waves to create sheltered environments that support many species of fish and invertebrates (McLeod and Salm 2006). Mangroves also provide feeding areas for the adults of many species of demersal fish, some of which reside on reefs during the day and forage over this range of habitats at night (Nagelkerken and Van der Velde 2004).

Mangrove habitats are currently impacted due to careless land management in coastal catchments and through direct removal to construct coastal infrastructure (Lotze et al. 2006; Waycott et al. 2009). While poorly managed forestry, agriculture and mining operations can deliver toxic pollutants that damage mangrove areas, increased sedimentation from activities in catchments can increase the area of mangrove habitat and reduce the vulnerability of mangroves to SLR (Lovelock et al. 2015).

Although increased CO_2 emissions could enhance the growth of mangroves, sea-level rise is expected to cause significant reductions in their area because the trees cannot tolerate extended immersion in seawater. While some common mangroves, such as *Avicennia marina*, can display a high level of tolerance to waterlogging, responses are extremely variable as they relate to length of time immersed, depth of immersion, salinity, temperature and other environmental variables (Alongi 2015).

Mangroves and other coastal ecosystems trap and vertically deposit sediment, allowing them to raise substrate levels, reduce inundation and maintain conditions for plant growth (Kirwan and Megonigal 2013). This ability to adapt is being compromised however by increasing anthropogenic impacts (e.g. dam building and water extraction for irrigation) on upstream river systems, reducing the delivery of sediments to mangrove habitats (Lovelock et al. 2015) and their ability to deposit substrate. In addition, the pace of SLR is expected to be greater than the ability of mangroves to 'keep up' under mid to high RCPs (Lovelock et al. 2015).

While the physiological impacts of climate change on mangroves are significant, the ecological impacts are also marked. Steep terrain of volcanic islands in the western Pacific, where most mangroves occur (Waycott et al. 2011), will prevent landward migration with sea-level rise. Where the terrain is suitable, rapid sea-level rise could outstrip the capacity of mangroves to migrate. By 2050, the area of mangroves across all PICTs could be reduced by 50% under a high emissions scenario (Waycott et al. 2011). The ecological benefits of maintaining mangroves as a buffer against climate change-related impacts are significant. The protection of coastlines by mangroves against storm surges was well documented during the 2005 boxing day tsunami (Rabinovich et al. 2015) and the same holds true of the protection of coastlines by mangroves during cyclonic events (Marois and Mitsch 2015).

While the global distribution of mangroves is decreasing, due to a variety of anthropogenic causes, there is evidence that climate change is causing a poleward shift in the distribution of mangroves. Poleward migration is extending the latitudinal limits of mangroves due to warmer winters and decreasing frequency of extreme low temperatures in subtropical areas. This may, however, result in a decline in mangrove area, structural complexity and/or in functionality in the tropical Pacific as warming conditions exceed the physiological limits of some mangrove species (Godoy and de Lacerda 2015; Alongi 2015).

The value of mangrove forests goes beyond their value for mitigating the effects of climate change through their ability to sequester large volumes of carbon. Mangroves have a value in supporting the adaptation of coastal communities to the already visible impacts of climate change. Mangroves and, to a lesser extent, seagrass have long played a role in the subsistence economy of many Pacific Island communities. The value of these services has been estimated in a number of studies (Pascal 2014; Warren-Rhodes et al. 2011). In Vanuatu, estimates are that subsistence fisheries and wood collection make up around 14% of the total value of the services provided by mangrove ecosystems (Pascal 2014). And the minimum annual subsistence value from mangroves in the Solomon Islands is estimated to be SBD $2500–10,718/household/year, which represented 38–160% of annual cash incomes (Warren-Rhodes et al. 2011).

Lal (2003) does question the validity of economic valuation of mangroves, particularly in light of ecosystem fragmentation and paucity in understanding of these ecosystems across the Pacific. What is clear, however, in those island states that have mangrove forests, that there is a significant value to the subsistence livelihoods of communities who utilise the goods and services provided by these ecosystems.

The loss of these systems, either by climate change or through development and other pressures, will compromise the resilience of communities to a wider range of environmental stressors than just climate change.

10.5 Impacts of Climate Change on Fish and Invertebrates

10.5.1 Coastal Fisheries

Climate change and ocean acidification are expected to have a range of indirect and direct effects on coastal fish and invertebrates in the region and the fisheries they support. Overall, recent modelling of expected changes in abundance and distribution of demersal fish in the tropical Pacific indicates that significant decreases in production may occur, with declines exceeding 50% under RCP8.5 projected by 2100 (Asch et al. 2017). The effects of increased CO_2 emissions on the productivity of invertebrates in the region have received less attention, but one analysis projects decreases of 5% by 2050 and 10% by 2100 and reductions in quality and size due to reduced aragonite saturation levels (Pratchett et al. 2011).

Indirect Effects

Indirect effects of climate change will occur through the changes to coastal fish habitats (see Sect. 10.3.1). Declines of coral-dependent species are expected, following declines in live coral cover. Increased cover of turf and macroalgae may provide more favourable conditions for some herbivorous species, leading to increases in their abundance, at least in the short term (Johnson et al. 2017). Accordingly, these species are expected to become even more dominant in catches and will become the primary focus for many fishers. Declines in live coral cover and increases in cover of dead coral and algae are expected to result in increased occurrence of ciguatera fish poisoning, furthering localised shortfalls in fish supply (Pratchett et al. 2011; Johnson et al. 2017). Changes in the strength of ocean currents are likely to result in changes to spatial and temporal patterns of larval dispersal and settlement, with impacts on recruitment.

Direct Effects

Increases in SST and associated changes have decreased global fisheries production (Free et al. 2019) and are expected to have significant effects on demersal fish and invertebrates in the Pacific Island region (Munday et al. 2008; Pratchett et al. 2011; Asch et al. 2017; Johnson et al. 2017). For example, projected increases in SST are likely to exceed the optimum thermal levels of many species, as well as alter individual performance, leading to changes in abundance, distribution, growth, reproduction and mortality (Pratchett et al. 2011). Reductions in pelagic larval duration due to increases in SST, combined with altered ocean currents, may reduce connectivity of fish populations among islands. Seasonal changes in temperature may lead to alterations in spawning time for certain species (Munday et al. 2008), potentially resulting in a mismatch between timing of spawning and optimal conditions for larval survival and dispersal.

Ocean acidification is likely to have significant negative impacts on coastal fisheries resources of the Pacific Islands. For demersal fish, increased boldness and activity (Munday et al. 2013), altered auditory preferences (Simpson et al. 2011), loss of lateral movement (Domenici et al. 2012) and impaired olfactory function (Munday et al. 2009; Cripps et al. 2011; Devine et al. 2012) have been observed in individuals raised in elevated CO_2. These changes are expected to alter the homing and settlement success of juveniles and their ability to detect and avoid predators, with implications for connectivity, survivorship and population replenishment. For gastropod and bivalve molluscs and echinoderms, lower aragonite saturation levels are expected to reduce calcification rates, making individuals more vulnerable to predation (Pratchett et al. 2011), leading to declines in the abundance of bivalves and gastropods gleaned for local consumption and the size and quality of products for export.

10.5.2 Oceanic (Tuna) Fisheries

The direct and indirect effects of climate change on tuna are expected to be more difficult to observe than for coral reef fish because climatic variability has strong effects on the distributions of these species (Hobday and Evans 2013). This is particularly the case for skipjack tuna—the locations where the best catches of this species are made in the Western and Central Pacific Ocean (WCPO) can vary by up to 4000 km due to ENSO events (Lehodey et al. 1997). The projected effects of climate change on all four species of tuna are being assessed with a spatial ecosystem and population dynamics model (SEAPODYM) (Lehodey et al. 2008). Preliminary analyses indicate that there will be an eastward and poleward shift in distribution and a reduction in total biomass, for both skipjack and yellowfin tuna under the RCP8.5 emissions scenario (Fig. 10.1) (Lehodey et al. 2013, 2017). At the scale of the EEZs of PICTs, abundances are generally expected to decrease west of 170 °E and increase east of 170 °E. By 2050, the greatest decreases in abundances of skipjack and yellowfin tuna, relative to 2005, are projected to occur for PNG, the Federated States of Micronesia, Nauru and Palau (Bell et al. 2018b). These patterns are expected to persist and intensify by 2100. East of 170 °E, substantial increases in biomass relative to 2005 are projected to occur for skipjack tuna in Vanuatu, New

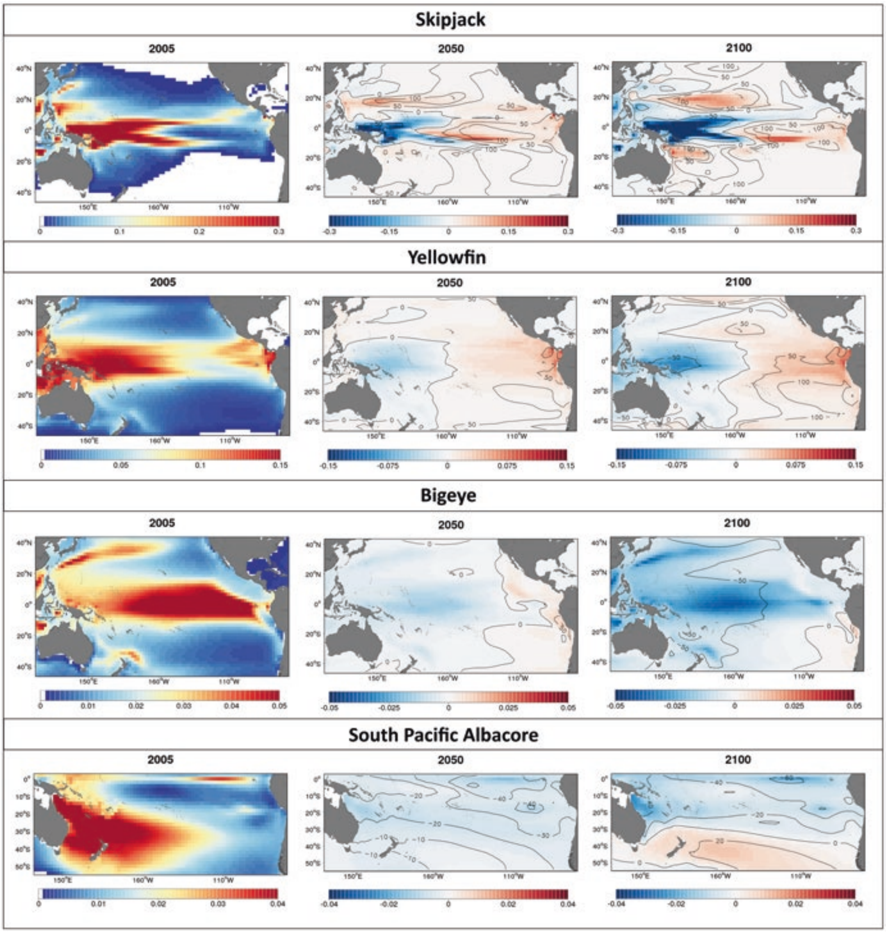

Fig. 10.1 Average historical (2005) distributions of skipjack, yellowfin and bigeye tuna and South Pacific albacore (t/km²) in the tropical Pacific Ocean, and projected changes in biomass of each species relative to 2005 under the RCP8.5 emissions scenario for 2050 and 2100, simulated using SEAPODYM. Isopleths in the projections for 2050 and 2100 represent the relative percentage change in biomass caused by climate change (*Source*: Bell et al. 2018b)

Caledonia, Pitcairn Islands and French Polynesia and for yellowfin tuna in French Polynesia (Bell et al. 2018b).

The responses of bigeye tuna and South Pacific albacore to climate change are expected to differ from the responses by skipjack and yellowfin tuna. Strong decreases in biomass of bigeye tuna are projected to occur in the EEZs of all PICTs, with the declines exceeding 60% in the waters of several PICTs by 2100 (Fig. 10.1). For South Pacific albacore, larvae and juveniles are expected to move poleward towards the Tasman Sea after 2050 (Fig. 10.1), resulting in a decrease in the Coral Sea by 2050. As a consequence, the biomass of adult albacore is projected to decline by ~30%, relative to the year 2000. However, this decline could be reversed after 2080, when the north Tasman Sea is expected to become a spawning area for this species (Lehodey et al. 2015).

The impacts of ocean acidification on tuna and other large pelagic fish species are not yet clearly understood. Preliminary behavioural experiments and simulation modelling indicate that the effects of ocean acidification on mortality of tuna are likely to be lower than the impacts of temperature increases for the expected average increase in ocean acidity by 2100 (Lehodey et al. 2017; Laubenstein et al. 2018; Watson et al. 2018; WCPFC 2018). However, recent projections of ocean acidification suggest that seasonal and spatial variability in acidity levels may have been underestimated previously and that some areas are likely to be more acidic than expected (McNeil and Sasse 2016; Kwiatkowski and Orr 2018). The extremes of the projected variability in ocean acidification (McNeil and Sasse 2016) fall within the range that resulted in mortalities and deformities in experimental trials on yellowfin tuna (Bromhead et al. 2015; Frommel et al. 2016). The areas to the east of 170° where tuna are projected to be less impacted by increasing ocean temperatures coincide with areas where seasonal extremes in ocean acidity are expected to occur. It is possible, therefore, that the quality of areas expected to provide a refuge from temperature stress could be compromised by ocean acidification.

10.5.3 Sharks and Rays

More than 130 species of sharks and rays are believed to occur in the Pacific (Lack and Meere 2009) although this is likely to be an underestimate. Sharks and rays are important in Pacific fisheries, but they also have a wide range of social and cultural values (e.g. Hylton et al. 2017) and tourism values (Vianna et al. 2012) and are crucial for the livelihoods of some communities (e.g. in PNG; Vieira et al. 2017).

The main pressure facing sharks and rays in the Pacific is fishing, which includes large-scale industrial fishing and more localised impacts from small-scale fisheries. However, long-term, accurate data on the catch of sharks in these fisheries are limited, especially from coastal fisheries, and there is great uncertainty about species-specific catch rates, catch fate and trade (Clarke et al. 2006). Furthermore, some species may be subject to additional pressures from habitat loss and degradation, especially when important habitats such as nursery grounds are threatened. There are several indications that sharks are under significant pressure in the Pacific (Lack and Meere 2009; Clarke et al. 2013). As a result, several species of pelagic sharks have been listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

The diversity of shark and ray species and their associated biological and ecological traits mean that predicted climate change impacts vary greatly among species. A comprehensive risk assessment for tropical sharks and rays identified both direct and indirect pressures and a spectrum of vulnerability across species (Chin et al. 2010). In general, sharks and rays are relatively large and mobile species that are fairly adaptable and resilient. This means they can respond to changing conditions by moving to more favourable conditions and exploit new resources (Chin and Kyne 2007).

Pelagic sharks are highly dependent on food resources and associated oceanographic factors. As such, oceanographic changes and shifts in prey distribution will likely affect pelagic sharks (Chin et al. 2010). Furthermore, increased unpredictability in the timing and location of upwellings could affect provisioning and survival. However, pelagic sharks are highly adaptable and may be able to respond to changing conditions and prey distribution.

Coastal sharks occur on mud and sand flats, reef flats, seagrass beds, coral reefs and reef lagoons. These habitats are highly exposed to climate change impacts such as storms, sea-level rise and significant changes in environmental envelopes (e.g. temperature, salinity, pH). Climate impacts that reduce the availability of suitable habitats and prey may have indirect effects on coastal sharks and rays (Chin et al. 2010). Increased rainfall and runoff and increasing temperatures may cause direct physiological stress that affect shark movement, development and behaviour (Schlaff et al. 2014; Heinrich et al. 2014). Overall, some coastal species may be able to adapt to changing conditions, but changes in local abundance and distribution are likely. Other species with specific habitat requirements may experience declines if those habitats are degraded or lost, especially in spatially small and/or isolated locations that have limited habitat availability. Deepwater sharks are extremely poorly understood, and climate change effects on these species cannot be reliably predicted.

A central factor in predicting climate change effects on sharks and rays in the Pacific Island region is the assumption that many species are able to physiologically tolerate a range of conditions, and when limits are exceeded, relocate to more favourable conditions. Certainly these adaptive behaviours are already widely evident (Schlaff et al. 2014; Chin et al. 2010). Nevertheless, these assessments are largely theoretical and many unknowns remain, such as effects of increased temperature and ocean acidification on shark and ray physiology. Recent experimental data suggest that these changes may have significant impacts on some sharks and rays, affecting body condition, growth, pigmentation and the ability to detect and pursue prey (Gervais et al. 2016; Rosa et al. 2017). However, some species may be tolerant of extreme conditions (Heinrich et al. 2014). The limited available information suggests that sharks and rays exposed to extreme environmental ranges, such as a reef flat specialist like the epaulette shark *Hemiscyllium ocellatum*, may be able to physically tolerate increased temperature and acidity much better than species such as pelagic sharks (Heinrich et al. 2014), but effects on other key traits such as hunting ability are still largely unexplored.

10.6 Impacts of Changes to Marine Resources on Communities and Culture

10.6.1 Impacts of Changes to Marine Resources on Communities and Culture

Given the social and cultural importance of marine resources in the Pacific Island region (Friedlander et al. 2013; Kittinger 2013), the changes described above are causing a spectrum of impacts on communities and cultures.

Coastal communities are highly dependent on marine resources for local subsistence (Bell et al. 2009). A reduction in local catch due to climate impacts results in a reduction of protein sources for local populations, especially those that are not integrated into market economies. For these subsistence-based and traditional communities, a decrease in traditional protein sources leads to the need to acquire other dietary protein (Bell et al. 2009). One strategy to meet this need may be using aquaculture systems or raising poultry and/or livestock for local consumption. In some communities, this change could constitute a disruption in local culture and identity. For example, in some communities on the northern coast of Efate, Vanuatu, community members were resistant to developing these alternative protein sources because of a conflict with their identity as fishermen. An alternative strategy for acquiring protein sources is purchasing protein. For subsistence communities, this strategy signifies entering the market economy and generating cash income. Income generation may come in the form of monetising local resources, which can create added pressure on already vulnerable local marine resources, or emigration to urban centres for gainful employment (Craven 2015).

These impacts create a cascade of other effects on communities and culture. In many parts of the Pacific, men and community leaders are often the individuals who emigrate. In tight-knit and small communities that are common in much of the Pacific, the temporary or permanent absence of these individuals leaves a gap in leadership structures and social networks, leading to a breakdown or dilution of local governance, traditional knowledge and social cohesion (Craven 2015). Emigration also results in greater external influences in communities (Maron and Connell 2008), which can displace traditional leadership and affect customary beliefs, culture and marine resource management.

The shift to cash-based rather than subsistence-based economies alters traditional diets, which are linked to cultural identity. Changes in diet are often accompanied by negative health impacts, including diabetes, resulting from increased consumption of sugar and processed foods (Evans et al. 2001). The increased use, or introduction, of alcohol is also common and can result in further social impacts including possible increases in domestic violence (Leonard 2001; WHO 2005; Livingston 2011).

Consequentially, impacts of changes to marine resources reverberate throughout Pacific Island communities, including the loss or dilution of traditional knowledge, local practices, social cohesion and values. In the context of climate adaptation, this is especially significant because of the important role of traditional and local knowledge in assisting communities in adapting to climate-related challenges (Adger et al. 2013).

The result is a reduction in community resilience. In light of climate-related challenges, actively working to increase community resilience will be of escalating importance. Additionally, actively increasing the resilience of communities that depend on and manage marine resources is an important component for increasing the resilience of the marine ecosystems that they locally manage (Berkes et al. 2000; Kittinger 2013). If approached appropriately, implementing adaptation actions to increase community resilience can also contribute to the resilience of marine resources to climate-related impacts (Adger et al. 2013).

10.6.2 Impacts of Changes to Marine Resources on Tourism and Aquaculture

Climate change will affect many tourism sectors from reef-based activities to cruise ships, large resorts, ecotourism ventures and sports fishing. This will be in the form of direct impacts of sea-level rise and more intense storms damaging coastal infrastructure including resorts and maritime facilities (Guannel et al. 2016) and reducing visitation indirectly due to degradation of coastlines and reef habitats (War Sajjad et al. 2014). In addition, climate change is expected to negatively affect aesthetics, cultural connections between traditional communities and their marine environments, spiritual values and other ecosystem services that contribute to industries and human wellbeing (Hughes et al. 2017; Johnson et al. 2016b).

Aquaculture is an important industry in many PICTs and includes farming marine and coastal species to support livelihoods, growing freshwater species for local food security and the hatchery rearing of juveniles for restocking programmes to replenish depleted fisheries for high-value marine invertebrates (Bell et al. 2005; Pickering et al. 2011). The main marine and coastal species grown to produce commodities for export or sale to lucrative local markets are black-lipped pearl oysters (*Pinctada margaritifera*) in French Polynesia, Cook Islands and Fiji, and penaeid shrimps in New Caledonia. The culture of seaweed (*Kappaphycus alvarezii*) has also been established for the benefit of marginalised coastal communities in the outer-island provinces of Fiji, Kiribati, PNG and Solomon Islands. Nile tilapia (*Oreochromis niloticus*) is grown for local food in inland and coastal locations, mainly in PNG, Fiji and Vanuatu and to a lesser extent in the Cook Islands, Samoa, American Samoa, Guam, Saipan and Northern Marianas. Milkfish (*Chanos chanos*) is also produced for this purpose but at a much smaller scale (Johnson et al. 2017).

In 2010, the value of aquaculture production in the Pacific Island region was estimated to be USD 200–250 million (Ponia 2010). Farming of black pearls, shrimp and seaweed provides thousands of people with full-time or part-time work (Bell et al. 2011; Pickering et al. 2011). Both coastal and freshwater aquaculture in the tropical Pacific are expected to be affected by climate change, particularly commodities with calcareous shells that will be impacted by ocean acidification. Under a high emission scenario, coastal aquaculture is projected to be directly vulnerable to increasing rainfall and cyclone intensity, higher SST, ocean acidification and sea-level rise and indirectly vulnerable to changes in supporting habitats (Pickering et al. 2011). Climate change is also expected to affect the viability of coastal aquaculture enterprises due to (1) greater temperature stress likely to increase the vulnerability of several species to pathogens and parasites (Yukihira et al. 2000; Pouvreau and Prasil 2001), or harmful algal blooms, and (2) effects of global warming on the production of fishmeal elsewhere in the world that is likely to increase the cost of high-protein formulated feeds for carnivorous species, affecting the economic viability of fish and shrimp farming.

Climate change may also affect future opportunities for development of the non-extractive industries, e.g. catch and release sports fishing and ecotourism, being planned to take pressure off coastal fisheries. For PICTs with tourism capacity, healthy marine ecosystems are necessary to deliver tourism attractions and provide income at national and local levels. Climate change impacts on marine habitats and species will affect the opportunities for new tourism businesses and the success of current ventures.

10.6.3 Impacts on Economic Development and Government Revenue

Redistribution of skipjack and yellowfin tuna (Fig. 10.1) is expected to result in lower catches across the prime fishing grounds by 2050. The reduced catches could affect licence revenues from purse-seine fishing and potentially the plans to increase employment based on fish processing if it becomes more difficult to deliver the tuna required by canneries in PNG and Solomon Islands to operate efficiently (Bell et al. 2018b). Other possible negative impacts on economic development may occur from the eastward redistribution of bigeye tuna and poleward movement of South Pacific albacore (Fig. 10.1) if a greater proportion of longline fishing eventually occurs outside the EEZs of PICTs.

On the other hand, the projected eastward redistribution of skipjack and yellowfin tuna due to climate change could result in opportunities for PICTs in the eastern WCPO, e.g. French Polynesia, and PICTs in the subtropics, e.g. Vanuatu and Fiji, to obtain increased economic benefits. However, although the percentage increases in catch could be substantial in these EEZs, the scale of benefits is likely to be modest because present-day catches are low (Bell et al. 2018b).

10.7 Adaptation Options

10.7.1 Community-Based Adaptation and Resilience

Given the impacts previously discussed, the present and future wellbeing of many Pacific Island communities depends on reducing community vulnerability and increasing resilience. Resilience is the capacity of a human or natural system to endure the impacts of a stress (e.g. a cyclone or an economic crisis) and adapt, with the potential of the system transforming into something new or stronger (Béné et al. 2012; Folke et al. 2002; Frankenberger et al. 2014). Resilience can be fortified through adaptation planning and implementation in accordance with the specific characteristics (including geography, governance and culture) of the community in question (Adger et al. 2013).

Community-based adaptation (CBA) refers to participatory processes that involve the local population in all levels of adaptation planning and implementation. As a result, adaptation planning is directed by the community members according to local knowledge, priorities and cultural values while being complemented by climate and natural resource management science (Reid 2015; Forsyth 2017).

Consequentially, CBA processes also reinforce local capacity, traditional knowledge and governance structures. Simultaneously CBA increases the likelihood of positive adaptation outcomes by empowering resource managers rather than increasing community dependence on external aid (Aalst et al. 2008; Berkes et al. 2000). CBA often incorporates the low-cost and low-tech adaptation strategy of ecosystem-based adaption (EBA), which increases resilience by protecting and strengthening ecosystem services and biodiversity (CBD 2009; Reid 2015). The combination results in a place-specific and locally driven socio-ecological approach to adaptation.

In recent years, the scientific and development community has progressed a variety of community-based vulnerability assessment and adaptation planning tools (McLeod et al. 2015). The CBA tool *Adapting to a Changing Climate: Guide to Local Early Action Planning* (LEAP) *and Management Planning* was developed by the Micronesia Conservation Trust in a collaborative process among scientific experts, resource managers, conservation practitioners and community members. It has been adapted over time, based on the experience of practitioners and field tests (Gombos et al. 2013).

The LEAP is particularly appropriate for small communities that have control over the governance of their local natural resources, high dependence on natural resources and limited economic opportunities. Combined with a low cost for implementation per community (McLeod et al. 2015), the LEAP is a suitable CBA tool for the socio-economic and cultural characteristics of many communities in the Pacific Island region. The tool has been successfully implemented in Solomon Islands, PNG, Timor-Leste, the Philippines, Indonesia and Malaysia (Wongbusarakum et al. 2015; Jolis et al. 2014), among other locations including the Caribbean nation of Cuba (Basel et al. 2018).

The LEAP builds awareness about climate change impacts by explaining climate science within the context of local experience. The process also engages communities in a participative planning process based on local knowledge, skills and resources, with the support of additional technical expertise as necessary. The four stages of the LEAP process are: (1) getting ready for raising awareness and planning, (2) understanding climate change and your climate story, (3) carrying out a field-based threat and vulnerability assessment and (4) finalising your Local Early Action Planning (Gombos et al. 2013).

The cross-sectorial approach of the LEAP addresses both social and ecological factors, allowing for integrated adaptation actions. Instead of only assessing marine resources and management, the tool includes all social and natural resources the community depends upon. These include terrestrial resources whose management has direct impacts (e.g. contamination) and indirect impacts (e.g. resource pressure and over-extraction) on marine resources. The result is a comprehensive planning process designed to maximise benefits and avoid maladaptation or unintended consequences that could otherwise result from adaptation actions (Wongbusarakum et al. 2015).

For any CBA tool to be effective, including the LEAP, it is important that programmes and facilitators account for inherent structural inequalities in communities, including but not limited to gender, land tenure, sustainable livelihood options and possible positive or negative repercussions of adaptation actions (Forsyth 2017). It is also important for adaptation actions to be supported by regional and national policies and programmes (Reid 2015) and to take into account potential political, economic and social drivers of vulnerability (Forsyth 2017). For the LEAP, this signifies the need for an appropriately experienced facilitation team and the inclusion of these considerations in programme planning and implementation. Field experience indicates that the tool is most effective when (1) adapted to the specific community educational and cultural context, (2) enhanced by the ample use of experiential learning activities and (3) used in conjunction with 'Semi-Quantitative Assessment of Vulnerability to Climate Change' (Johnson et al. 2016c; Basel et al. 2018).

10.7.2 Adaptations for Food Security

A range of practical adaptations have been proposed for maintaining the important role fish plays in food security in the Pacific Island region (SPC 2008; Bell et al. 2009, 2011, 2018a). Summarised below, these adaptations can be categorised into two broad groups: those that focus on minimising the gap between sustainable harvests from coastal fish habitats and the quantities of fish recommended for good nutrition of growing human populations and those that focus on filling the gap (for a full description, see Bell et al. 2018a).

Adaptation Options to Minimise the Gap

1. *Manage and restore catchment vegetation*, through maintaining good coverage of vegetation on slopes and wide riparian buffer zones to reduce damage to coastal habitats through increased turbidity, sedimentation and eutrophication from runoff and erosion.
2. *Minimise other degradation of coastal habitats*, including through maintaining water quality by controlling pollution from sewage, chemicals and waste and eliminating activities that reduce the structural complexity and extent of habitats, such as destructive fishing practices or excessive harvesting of mangrove timber for firewood.
3. *Provide for landward migration of mangrove habitats*, by preventing infrastructure development in low-lying areas, allowing for inundation of low-lying areas suitable for mangrove colonisation, and planting young trees to fast-track mangrove establishment.
4. *Sustain production of coastal demersal fish and invertebrates*, by strengthening of community-based ecosystem approaches founded on 'primary' fisheries management practices and simple harvest controls, such as size limits, spatial and temporal closures and gear restrictions (Cochrane et al. 2011).
5. *Maximise the efficiency of spatial management*, by ensuring areas protected from fishing are designed to account for the ecology of target fish species and that habitat mosaics and migration corridors important for connectivity are preserved.
6. *Diversify catches of coastal demersal fish*, by transferring effort to species expected to increase in local abundance with climate change while ensuring production is maintained within sustainable bounds.

Adaptations to Fill the Gap

1. *Transfer coastal fishing effort from demersal fish to nearshore pelagic fish*, particularly tuna, through the deployment of nearshore fish aggregation devices (FADs).
2. *Expand fisheries for small pelagic species,* such as mackerel, anchovies, pilchards, sardines, scads and fusiliers, through use of alternative fishing technologies (e.g. the 'bagan' fishing platform used in Southeast Asia) at sustainable levels.
3. *Extend the shelf life of fish harvests*, by training communities in how to improve traditional methods for smoke curing, salting and drying of small pelagic fish.
4. Increase access to small tuna and by-catch offloaded by industrial fleets during transhipping operations.

10.7.3 Adaptations for Livelihoods

Coral reef degradation directly affects the livelihoods of Pacific Islanders through reduced local income and inflow of foreign exchange due to the decline of fisheries and associated increase in food insecurity (Zeller et al. 2015; Bell et al. 2018a). Habitat degradation negatively affects reef-based tourism (War Sajjad et al. 2014), increases the risk of property damage due to reduced coastal protection provided by coral reefs (Guannel et al. 2016) and promotes substantial negative changes on aesthetics, cultural connections between Pacific Islanders and their marine environments, spiritual values and other ecosystem services that contribute to human wellbeing (Johnson et al. 2016b; Hughes et al. 2017).

Many of the adaptations described in Sect. 10.4.2 will also assist coastal communities to continue to engage in catching and selling fish at local and urban markets to support their needs for cash income. As human populations continue to grow, the only marine resources capable of supporting more livelihoods will be the oceanic fish species. Expanding the use of nearshore FADs to make them part of national infrastructure for both food security and income generation will be an essential adaptation for harnessing the potential to create more livelihoods for coastal communities (Bell et al. 2015a, b).

There is scope for marine aquaculture to provide more livelihoods, for example, through the culture of wild-caught milkfish in atoll nations and the coastal areas of high islands (Pickering et al. 2011). However, on high islands, the availability of freshwater and the simplicity of farming Nile tilapia mean that the most practical way of generating income through aquaculture in Melanesia will be in small ponds (Johnson et al. 2017).

While traditional systems of resources management implemented in many PICTs have historically been effective at protecting habitats and maintaining fisheries because the harvest of marine resources is strongly controlled, accelerated population growth and increasing resource demand are undermining traditional management systems. Therefore, traditional management needs to be supported by more formal sustainable management to address these existing pressures and the projected effects of climate change in the future. For example, marine protected areas (MPAs) are commonly applied but are rarely compared to other management options or assessed for their cost-effectiveness or feasibility. The Noumea Strategy (SPC 2015) clearly states that over-reliance on site-based approaches, such as MPAs, is unlikely to achieve widespread goals of fisheries management and hence proposes other ecosystem-based fundamental approaches. This creates positive flow-on effects on reef-related livelihoods, such as fisheries and tourism, which can be greatly improved when local communities are engaged in the development and adoption of conservation measures in line with traditional governance structures and values.

Increased tourism can benefit communities under stress from climate change but only if managed appropriately. The economic benefits expected from tourism may not reach local communities as anticipated where the benefits rely on intermediaries, such as travel agents and airlines. In such situations, people from remote communities have little control over the industry from which they hope to benefit (Rugendyke and Connell 2008).Therefore, tourism initiatives in PICTs should be planned to enhance not only national economic and employment benefits but also the wellbeing of the communities that host the activities.

Any intervention in PICTs looking into improving livelihoods needs to consider local development aspirations, potential social, economic and environmental costs and benefits, local dynamics of village governance, social rules and protocols, and traditional forms of knowledge that can inform long-term solutions (Remling and Veitayaki 2016).

Another important factor is that tenure and associated political systems differ substantially across PICTs (Aswani et al. 2017). As a result, it is not possible to apply measures and strategies uniformly across the Pacific. Local environmental, social and governance contexts must be considered when implementing adaptation programmes (Dutra et al. 2018).

Building capacity is essential for improving local understanding about the complexities involved in climate change and adaptation, as well as for helping communities prepare for the future. Such capacity should be built around practical discussions, for example, how to manage receding shorelines and processes to rehabilitate coastal habitats and protect local forests, water catchment areas and food sources. Coastal communities in PICTs understand that only a healthy environment surrounding coral reef systems can support their basic needs for food, income and clean water in the long term, and understand the benefits of healthy ecosystems as a buffer for climate change (Remling and Veitayaki 2016; Veitayaki in press; Heenan et al. 2015).

10.7.4 Economic Development and Government Revenue

Two main types of adaptations could assist PICTs in the central and eastern areas of the WCPO to harness greater economic benefits from the projected eastward migration of skipjack and yellowfin tuna, and PICTs in the western areas of the WCPO to reduce the potentially negative implications for their economies. The first involves development of flexible management measures to allow fishing effort to shift east, while ensuring that large quantities of tuna can still be channelled through the established and proposed fish processing operations in the west. The second is optimising the productivity and value of tuna resources across the region.

The vessel day scheme (VDS) (Havice 2013) for managing purse-seine fishing effort across the EEZs of the eight Pacific Islands countries—the Parties to the Nauru Agreement (PNA)—that yield ~30% of the world's tuna already provides much of the flexibility to maintain the socio-economic benefits that PICTs receive from skipjack tuna as it responds to climate variability and climate change (Bell et al. 2011). The VDS allows licence revenues to be shared among PNA member countries regardless of the effects of ENSO phase on the best locations for catching this species. The VDS will also adjust the number of fishing days that PICTs can sell to foreign fleets as climate change alters the distribution of skipjack tuna. The global sourcing provisions of the Interim Economic Partnership Agreement that PNG has with the European Commission also allows fish to be delivered to the nation's canneries, regardless of where they are caught.

Finding ways to add more value to skipjack tuna would allow PICTs to offset the consequences of lower projected catches caused by climate change. Value-adding would create the opportunity to increase licence fees, helping PICTs to obtain more government revenue in the short term, and to maintain the present-day contributions of licence fees to economies when abundances of skipjack tuna decline due to climate change.

Similarly, investments in seasonal forecasting tools may assist industry and fisheries administrations with balancing the immediate consequences of climate variability and change (Hobday et al. 2018). Such tools would allow industry to plan and prepare for reduced access to resources in poor years (e.g. diversify processing operations to add more value to reduced catches) and maximise access and opportunities in good years. Forecasting used in this manner has the potential to increase the resilience of industries, and enable them to remain economically viable when operational circumstances are affected by climate change.

At the broader level of regional management, arrangements are needed to optimise sustainable catches both now and as the distributions of tuna stocks change. For this to happen, the Western and Central Pacific Commission (WCPFC) needs to negotiate the adoption of adequate conservation and management measures that reduce fishing mortality to sustainable levels across all the EEZs and high seas (Hanich and Tsamenyi 2014). New approaches, based on implementing decision-rules that transparently and equitably distribute the conservation burden in accordance with pre-agreed principles are required (Hanich and Ota 2013). It will also be important to limit investments in vessels operated by distant water nations fishing on the high seas (which are not covered by the VDS), and effort creep by such vessels (McIlgorm 2010).

Ultimately, the eastward redistribution of tuna may make it necessary to consider an amalgamation of WCPFC and the Inter-American Tropical Tuna Commission, which is the regional fisheries management organisation for the Eastern Pacific Ocean.

10.8 Future Research

Priority knowledge gaps to better increase our understanding of the effects of climate change on ***coastal resources***, particularly coastal fisheries, and the consequences for food security and livelihoods include:

1. Monitoring shifts in the distributions of species, and the effects of climate-induced changes in species composition on ecosystems, by establishing long-

term monitoring at specific sites to measure distributional shifts and biological impacts as well as environmental conditions, such as pH, SST and habitat condition.
2. Further examination of the synergistic effects of increasing ocean acidification, SST and other anthropogenic stressors, on the biology and ecology of demersal fish and invertebrates, and the ability of target fisheries species to adapt to these changes.
3. Undertaking a cost-benefit analysis of the key adaptation options for food security to inform sustainable and adaptive management, noting that a holistic approach needs to incorporate a range of adaptation tools.

Dedicated sampling programmes will be needed to monitor the effects of climate change on key coastal habitats, coral reefs and target species, and the fisheries they support, to provide information for adaptive management. These programmes will require an experimental approach that controls for the effects of other stressors, such as fishing pressure, poor land management practices and pollution (SPC 2013). Importantly, the status of coastal resources in PICTs is either uncertain or impacted due to rapidly growing human populations and other pressures, such as coastal development. Therefore, there is an urgent need to better understand the most effective options for sustainable management of coastal resources to address these existing pressures recognising that the expected effects of climate change will potentially exacerbate these impacts. For example, marine protected areas (MPAs) are commonly applied but are rarely compared to other management options or assessed for their cost-effectiveness or feasibility. The Noumea Strategy (SPC 2015) clearly states that over-reliance on site-based approaches, such as MPAs, is unlikely to achieve widespread goals of fisheries management and hence proposes other ecosystem-based fundamental approaches.

Much of the research needed to improve knowledge of the projected effects of climate change on ***tuna fisheries*** in the WCPO centres around strengthening SEAPODYM. In particular, research is needed to improve the biogeochemical component of SEAPODYM and estimates of future fishing effort, which need to be coupled to projections from an ensemble of global climate models to estimate catches of the four species of tuna under various climate change scenarios (Lehodey et al. 2011). Increased access to operational fisheries data is also needed to validate SEAPODYM—the more closely the resolution of the industrial fisheries catch data matches the resolution of the environmental data, the better the predictive performance of the SEAPODYM model.

Another important gap in knowledge is the spatial structure of stocks (i.e. number of separate self-replenishing populations) within the ranges of the four tropical tuna species. Recent analysis of conventional tagging data indicates that there could be at least three separate stocks of bigeye tuna across the tropical Pacific Ocean, with the possibility of up to another six stocks (Schaefer et al. 2015). In addition, recent genetic analyses of the population structure of yellowfin tuna indicate the potential for separate stocks between the western Pacific (Australia) and central Pacific (Tokelau) (Grewe et al. 2015). Furthermore, archival tagging studies indicate that the maximum displacement of an individual yellowfin tuna was ~1350 km (Schaefer et al. 2011). Once the spatial stock structure of each tuna species has been identified, SEAPODYM can be used to model the response of each separate tuna stock to climate change and ocean acidification. The finer-scale understanding of tuna stock structure will improve stock assessment and enable regional fisheries managers to identify which countries share each stock and how much of each stock occurs in high seas areas.

Sharks and rays in many areas of the Pacific are already heavily impacted by human activities, and it is difficult to disentangle climate change impacts from existing threats and impacts. Nevertheless, securing the future of the Pacific's sharks and rays in a changing climate would be aided by the following targeted research:

1. A systematic review of the diversity and status of sharks and rays in each PICT to describe biodiversity and identify key threats
2. For highest-risk species, targeted interdisciplinary research to identify, trial and evaluate management options
3. Improved data on the extent of the most significant existing threats, i.e. fishing, specifically, improved data on catch composition and fate, risk assessment and improved stock assessment, especially for small-scale fisheries that are not well studied and generally undervalued

The challenges facing sharks and rays are complex due to their biological and ecological diversity, the dearth of information for many species, the range of uses and values and the interactions they have with fisheries and communities. This means that case-by-case research and conservation programmes need to be devised to tailor management and conservation actions to specific contexts (Dulvy et al. 2017).

10.9 Conclusions

The greatest challenges for Pacific people are likely to be from sea-level rise, loss of coastal habitats, declining productivity of demersal fish and invertebrates and an eastward shift in distribution of some tuna species as a result of climate change. Changes in ocean temperature and water circulation are expected to impact coastal ecosystems, reducing fish and invertebrate productivity. Warming temperatures and ocean acidification could also affect dispersal and settlement of larvae, affecting colonisation and connections between coral reef and seagrass areas, fish behaviour and growth. Habitat declines, particularly of coral reefs, are already occurring and will impact on the species, communities and industries that depend on these ecosystems. Impacts will be complex, widespread and difficult to accurately predict.

Invertebrates such as trochus, green snails and pearl oysters are likely to decline as lower pH weakens their shells, reduces growth and causes higher mortality. Climate change effects on coastal fisheries will largely be due to the indirect impacts of changes in the extent and condition of coastal fish habitats. Resulting declines in coastal fish and invertebrate populations will widen the gap between fish needed by growing human populations and sustainable harvests, with shortages expected in some Pacific nations (e.g. Papua New Guinea, Solomon Islands) by 2035 and ecosystem-based fisheries management to support sustainable fisheries stocks. Alternative incomes will be needed where fishing operations are negatively affected.

The projected slow-onset declines in coastal fisheries productivity due to climate change have important implications for the food security of PICTs. The magnitude of the loss and damage and whether it can be mitigated depend on the severity of coral reef decline (that provides much of the coastal fisheries production across the region), as well as population growth, the area of coral reef per capita and the distance of reefs from population centres.

Adaptations for maintaining the important role of fish for food security in the region (SPC 2008; Bell et al. 2011) centre on minimising the gap between the quantities of fish required for good nutrition and the fish available from coastal habitats due to population growth and productivity declines (1) using appropriate best management of coastal fish habitats and stocks, (2) increasing access to tuna for rural and urban populations and (3) boosting pond aquaculture. The implications of the projected changes in production of coastal fisheries and aquaculture for sustainable livelihoods are that (1) livelihoods may need to switch from one resource to another and (2) more flexible arrangements may be needed for operating fishing and aquaculture ventures.

The four species of tropical tuna are expected to have relatively low vulnerability to the projected physical and chemical changes to the WCPO and to alterations in oceanic food webs, because they can move to areas with their preferred temperature conditions (Bell et al. 2013, 2018b). This conclusion is tempered, however, by the unknown effects of ocean acidification, which may comprise the more favourable temperature conditions for tuna expected to occur further to the east. The projected changes in distribution and decreased productivity of tuna underscore the need for effective management. The small national economies with a high dependence on licence fees are likely to be vulnerable to these changes by 2050. It is possible, however, that the plans to improve the value of tuna in the Regional Roadmap for Sustainable Pacific Fisheries could maintain existing levels of government revenue from licence fees even though catches decline.

Addressing the implications of climate change for Pacific Island nations requires resourcing as well as financial commitment for effective implementation. Inadequate resourcing has been an ongoing issue for local PICT capacity to implement climate change adaptation and mitigation actions, something that is needed for resilient coastal ecosystems and communities. In many cases, this will require the development and implementation of basic but robust management systems and will also require significant education and awareness-raising as well as enforcement at all levels—from government to individual communities.

References

Aalst MK, Cannon T, Burton I (2008) Community level adaptation to climate change: the potential role of participatory community risk assessment. Glob Environ Change 18(1):165–179. https://doi.org/10.1016/j.gloenvcha.2007.06.002

Adger WN, Barnett J, Brown K, Marshall N, O'Brien K (2013) Cultural dimensions of climate change impacts and adaptation. Nat Clim Change 3(2):112

Adjeroud M, Michonneau F, Edmunds PJ, Chancerelle Y, de Loma TL, Penin L, Thibaut L, Vidal-Dupiol J, Salvat B, Galzin R (2009) Recurrent disturbances, recovery trajectories, and resilience of coral assemblages on a South Central Pacific reef. Coral Reefs 28:775–780

Albert S, Saunders MI, Roelfsema CM, Leon JX, Johnstone E, Mackenzie JR, Hoegh-Guldberg O, Grinham AR, Phinn SR, Duke NC, Mumby PJ, Kovacs E, Woodroffe CD (2017) Winners and losers as mangrove, coral and seagrass ecosystems respond to sea-level rise in Solomon Islands. Environ Res Lett 12:094009

Albright R, Mason B (2013) Projected near-future levels of temperature and pCO_2 reduce coral fertilization success. PLoS One 8:e56468

Alongi DM (2015) The impact of climate change on mangrove forests. Curr Clim Change Rep 1(1):30–39

Aronson RB, Precht WF (2016) Physical and biological drivers of coral-reef dynamics. Coral Reefs World 6:261–275

Asch RG, Cheung WWL, Reygondeau G (2017) Future marine ecosystem drivers, biodiversity, and fisheries maximum catch potential in Pacific Island countries and territories under climate change. Mar Policy 88:285–294

Aswani S, Albert S, Love M (2017) One size does not fit all: critical insights for effective community-based resource management in Melanesia. Mar Policy 81:381–391

Barros V, Field C (2014) Climate change 2014 impacts, adaptation, and vulnerability part A: global and sectoral aspects working group II contribution to the fifth assessment report of the Intergovernmental Panel on Climate Change Preface. Climate change 2014: impacts, adaptation, and vulnerability, pt A: global and sectoral aspects, pp Ix–Xi

Basel B, Fernández M, Correa López P (2018) Informe: Fuertes y Preparados Frente al Cambio Climático en el Naranjo del Toa, 15 al 17 de enero del 2018. Unidad de Servicios Ambientales Alejandro de Humboldt, Departamento de Conservación, Ministerio de Ciencia, Tecnología, y Medio Ambiente, Baracoa

Bates NR, Astor YM, Church MJ, Currie K, Dore JE, Gonzalez-Davila M, Lorenzoni L, Muller-Karger F, Olafsson J, Santana-Casiano JM (2014) A time-series view of changing surface ocean chemistry due to ocean uptake of anthropogenic CO_2 and ocean acidification. Oceanography 27:126–141

Beer S, Koch E (1996) Photosynthesis of seagrasses vs. marine macroalgae in globally changing CO_2 environments. Mar Ecol Prog Ser 141:199–204

Beer S, Mtolera M, Lyimo T, Björk M (2006) The photosynthetic performance of the tropical seagrass Halophila ovalis in the upper intertidal. Aquat Bot 84:367–371

Beeton S (2006) Community development through tourism. Landlinks Press, Canberra

Behrenfeld MJ, O'Malley RT, Boss ES, Westberry TK, Graff JR, Halsey KH, Milligan AJ, Siegel DA, Brown MB (2016) Revaluating ocean warming impacts on global phytoplankton. Nat Clim Change 6:323–330. https://doi.org/10.1038/nclimate2838

Behrenfeld M (2011) Biology: uncertain future for ocean algae. Nat Clim Chang 1:33–34. https://doi.org/10.1038/nclimate1069

Bell JD, Rothlisberg PC, Munro JL, Loneragan NR, Nash WJ, Ward RD, Andrew NL (2005) Restocking and stock enhancement of marine invertebrate fisheries. Adv Mar Biol 49:1–370

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

Bell JD, Johnson JE, Hobday AJ (eds) (2011) Vulnerability of tropical Pacific fisheries and aquaculture to climate change. Secretariat of the Pacific Community, Noumea, 925pp

Bell JD, Ganachaud A, Gehrke PC, Griffiths SP, Hobday AJ, Hoegh-Guldberg O, Johnson JE, Le Borgne R, Lehodey P, Lough JM, Matear RJ, Pickering TD, Pratchett MS, Sen Gupta A, Senina I, Waycott M (2013) Mixed responses of tropical Pacific fisheries and aquaculture to climate change. Nat Clim Change 3:591–599

Bell JD, Allain A, Allison EH, Andréfouët S, Andrew NL et al (2015a) Diversifying the use of tuna to improve food security and public health in Pacific Island countries and territories. Mar Policy 51:584–591

Bell JD, Albert A, Andréfouët S, Andrew NL, Blanc M et al (2015b) Optimising the use of near-shore fish aggregating devices for food security in the Pacific Islands. Mar Policy 56:98–105

Bell JD, Cisneros-Montemayor A, Hanich Q, Johnson JE, Lehodey P, Moore BR et al (2018a) Adaptations to maintain the contributions of small-scale fisheries to food security in the Pacific Islands. Mar Policy 88:303–314

Bell JD, Allain A, Sen Gupta A, Johnson JE, Hampton J, Hobday AJ, Lehodey P, Lenton A, Moore BR, Pratchett MS, Senina I, Smith N, Williams P (2018b) Chapter 14: Climate change impacts, vulnerabilities and adaptations: Western and Central Pacific Ocean marine fisheries. In: Barange M, Bahri T, Beveridge M, Cochrane K, Funge-Smith S, Poulain F (eds) Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge, adaptation and mitigation options. FAO fisheries technical paper 627

Béné C, Wood RG, Newsham A, Davies M (2012) Resilience: new utopia or new tyranny? Reflection about the potentials and limits of the concept of resilience in relation to vulnerability reduction programmes. IDS working paper #405

Berkes F, Colding J, Folke C (2000) Rediscovery of traditional ecological knowledge as adaptive management. Ecol Appl 10(5):1251–1262. https://doi.org/10.2307/2641280

BOM and CSIRO (2011) Climate change in the Pacific: scientific assessment and new research, Regional overview, vol 1. Australian Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organisation, Melbourne, 257pp

BOM and CSIRO (2014) Climate variability, extremes and change in the Western Tropical Pacific: new science and updated country reports. Pacific-Australia climate change science and adaptation planning program technical report. Australian Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organisation, Melbourne, 358pp

Bromhead D, Scholey V, Nicol S, Margulies D, Wexler J, Stein M, Hoyle S, Lennert-Cody C, Williamson J, Havenhand J, Ilyina T, Lehodey P (2015) Ocean acidification impacts on tropical tuna populations. Deep Sea Res II 113:268–279

Brown CJ, Jupiter SD, Albert S, Klein CJ, Mangubhai S, Maina JM, Mumby P, Olley J, Stewart-Koster B, Tulloch V, Wenger A (2017a) Tracing the influence of land-use change on water quality and coral reefs using a Bayesian model. Sci Rep-UK 7:4740

Brown CJ, Jupiter SD, Lin HY, Albert S, Klein C, Maina JM, Tulloch VJD, Wenger AS, Mumby PJ (2017b) Habitat change mediates the response of coral reef fish populations to terrestrial run-off. Mar Ecol Prog Ser 576:55–68

Brunnschweiler JM, McKenzie J (2010) Baiting sharks for marine tourism: comment on Clua et al. (2010). Mar Ecol Prog Ser 420:283–284

Cai W, Santoso A, Wang G, Yeh S-W, An S-I, Cobb KM et al (2015) ENSO and greenhouse warming. Nat Clim Change 5:849–859

Chaves-Fonnegra A, Riegl B, Zea S, Lopez JV, Brandt M, Smith T, Gilliam DS (2018) Bleaching events regulate shifts from coral to excavating sponges in algae-dominated reefs. Glob Change Biol 24:773–785

Chavez FP, Messié M, Pennington JT (2011) Marine primary production in relation to climate variability and change. Annu Rev Mar Sci 3:227–260. https://doi.org/10.1146/annurev.marine.010908.163917

Chin A, Kyne PM (2007) Chapter 13: vulnerability of Chondrichthyan fishes of the Great Barrier Reef to climate change. In: Johnson JE, Marshall PA (eds) Climate change & the Great Barrier Reef. Great Barrier Reef Marine Park Authority, Townsville, pp 393–425

Chin A, Kyne PM, Walker TI, McAuley RB (2010) An integrated risk assessment for climate change: analysing the vulnerability of sharks and rays on Australia's Great Barrier Reef. Glob Chang Biol 16(7):1936–1953

Christensen JH, Krishna KK, Aldrian E, An S-I, Cavalcanti IFA, de Castro M et al (2013) Climate phenomena and their relevance for future regional climate change. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J et al (eds) Climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

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

Church JA, Clark PU, Cazenave A, Gregory JM, Jevrejeva S, Levermann A, Merrifield MA, Milne GA, Nerem RS, Nunn PD, Payne AJ, Pfeffer WT, Stammer D, Unnikrishnan AS (2013) Sea level change. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) Climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

Cinner JE, Aswani S (2007) Integrating customary management into marine conservation. Biol Conserv 140(3–4):201–216

Cochrane KL, Andrew NL, Parma AM (2011) Primary fisheries management: a minimum requirement for provision of sustainable human benefits in small-scale fisheries. Fish Fish 12(3):275–288

Coles R, McKenzie L, Campbell S, Mellors J, Waycott M, Goggin L (2004) Seagrasses in Queensland waters. CRC Reef Research Centre Brochure, Townsville, 6pp

Convention on Biological Diversity (CBD) (2009) Connecting biodiversity and climate change mitigation and adaptation: report of the second ad hoc technical expert group on biodiversity and climate change (CBD technical series no. 41). Secretariat of the Convention on Biological Diversity, Montreal

Clarke SC, McAllister MK, Milner-Gulland EJ, Kirkwood GP, Michielsens CG, Agnew DJ, ... Shivji MS (2006) Global estimates of shark catches using trade records from commercial markets. Ecol Lett 9(10):1115–1126

Clarke SC, Harley SJ, Hoyle SD, Rice JS (2013) Population trends in Pacific Oceanic sharks and the utility of regulations on shark finning. Conserv Biol 27(1):197–209

Clua E, Buray N, Legendre P, Mourier J, Planes S (2011) Business partner or simple catch? The economic value of the sicklefin lemon shark in French Polynesia. Mar Freshw Res 62(6):764–770

Cooper TF, De'ath G, Fabricius KE, Lough JM (2008) Declining coral calcification in massive Porites in two nearshore regions of the northern Great Barrier Reef. Glob Change Biol 14:529–538

Cravatte S, Delcroix T, Zhang D, McPhaden M, Leloup J (2009) Observed freshening and warming of the western Pacific Warm Pool. Clim Dyn 33:565–589

Craven LK (2015) Migration-affected change and vulnerability in rural Vanuatu. Asia Pac Viewpoint 56:223–236. https://doi.org/10.1111/apv.12066

Cripps IL, Munday PL, McCormick MI (2011) Ocean acidification affects prey detection by a predatory reef fish. PLoS One 6:e22736

Crowley T (1999) Linguistic diversity in the Pacific. J Socioling 3(1):81–103. https://doi.org/10.1111/1467-9481.00064

Cumming RL, Toscano MA, Lovell ER, Carlson BA, Dulvy NK, Hughes A, Koven JF, Quinn NJ, Sykes HR, Taylor OJS, Vaughn D (2000) Mass bleaching in the Fiji Islands. In: Moosa MK, Soemodihardjo S, Soegiarto A, Rominihtarto K, Nontji A, Soekarmo, Surharsono (eds) Proceedings of the ninth international coral reef symposium, Bali, 23–29 Oct 2000, pp 1161–1169

D'Angelo C, Smith EG, Oswald F, Burt J, Tchernov D, Wiedenmann J (2012) Locally accelerated growth is part of the innate immune response and repair mechanisms in reef-building corals as detected by green fluorescent protein (GFP)-like pigments. Coral Reefs 31:1045–1056

Dalzell P (1993) Management of ciguatera fish poisoning in the South Pacific. South Pacific Commission, Noumea, New Caledonia
Davies JM, Dunne RP, Brown BE (1997) Coral bleaching and elevated sea-water temperature in Milne Bay Province, Papua New Guinea, 1996. Mar Freshwater Res 48:513–516
De'ath G, Fabricius K (2010) Water quality as a regional driver of coral biodiversity and macroalgae on the Great Barrier Reef. Ecol Appl 20:840–850
De'ath G, Lough JM, Fabricius KE (2009) Declining coral calcification on the Great Barrier Reef. Science 323:116–119
Dean RG, Houston JR (2013) Recent sea level trends and accelerations: comparison of tide gauge and satellite results. Coast Eng 75:4–9
Devine B, Munday PL, Jones GP (2012) Homing ability of adult cardinalfish is affected by elevated carbon dioxide. Oecologia 168:269–276
Domenici P, Allan B, McCormick MI, Munday PL (2012) Elevated carbon dioxide affects behavioural lateralization in a coral reef fish. Biol Lett 8:78–81
Dore JE, Lukas R, Sadler DW, Church MJ, Karl DM (2009) Physical and biogeochemical modulation of ocean acidification in the central North Pacific. Proc Natl Acad Sci U S A 106:12235–12240
Durack PJ, Wijffels SE (2010) Fifty-year trends in global ocean salinities and their relationship to broad-scale warming. J Clim 23:4342–4362
Dutra LXC, Haworth RJ, Taboada MB (2011) An integrated approach to tourism planning in a developing nation: a case study from Beloi (Timor-Leste). In: Dredge D, Jenkins J (eds) Stories of practice: tourism policy and planning. Ashgate, Farnham, pp 269–293
Dutra LXC, Haywood MDE, Singh SS, Piovano S, Ferreira M, Johnson JE, Veitayaki J, Kininmonth S, Morris CW (2018) Impacts of climate change on corals relevant to the Pacific Islands. In: Townhill B, Buckley P (eds) Pacific marine climate change report card. Commonwealth Marine Economies Programme, London, pp 132–258
Dulvy NK, Simpfendorfer CA, Davidson LN, Fordham SV, Bräutigam A, Sant G, Welch DJ (2017) Challenges and priorities in shark and ray conservation. Curr Biol 27(11):R565–R572
Ellison JC (2009) Wetlands of the Pacific Island region. Wetl Ecol Manag 17:169–206
Elsner JB, Kossin JP, Jagger TH (2008) The increasing intensity of the strongest tropical cyclones. Nature 455:92–95
Enochs IC, Manzello DP, Donham EM, Kolodziej G, Okano R, Johnston L, Young C, Iguel J, Edwards CB, Fox MD, Valentino L, Johnson S, Benavente D, Clark SJ, Carlton R, Burton T, Eynaud Y, Price NN (2015) Shift from coral to macroalgae dominance on a volcanically acidified reef. Nat Clim Change 5:1083
Enochs IC, Manzello DP, Kolodziej G, Noonan SHC, Valentino L, Fabricius KE (2016) Enhanced macroboring and depressed calcification drive net dissolution at high-CO_2 coral reefs. Proc R Soc B Biol Sci 283. https://doi.org/10.1098/rspb.2016.1742
Evans M, Sinclair RC, Fusimalohi C, Liava'a V (2001) Globalization, diet, and health: an example from Tonga. Bull World Health Organ 79(9):856–862
Fabricius KE, Langdon C, Uthicke S, Humphrey C, Noonan S, De'ath G, Okazaki R, Muehllehner N, Glas MS, Lough JM (2011) Losers and winners in coral reefs acclimatized to elevated carbon dioxide concentrations. Nat Clim Change 1:165–169
Fabricius KE, Kluibenschedl A, Harrington L, Noonan S, De'ath G (2015) In situ changes of tropical crustose coralline algae along carbon dioxide gradients. Sci Rep-UK 5:9537
Fabry VJ, Seibel BA, Feely RA, Orr JC (2008) Impacts of ocean acidification on marine fauna and ecosystem processes. ICES J Mar Sci 65:414–432
FFA [Forum Fisheries Agency] (2016) Tuna development indicators 2016. Pacific Islands Forum Fisheries Agency, Honiara
FFA and SPC (2015) Future of Pacific fisheries: a regional roadmap for sustainable Pacific fisheries. Pacific Islands Forum Fisheries Agency, Pacific Community, Honiara, Noumea
Folke C, Carpenter S, Elmqvist T, Gunderson L, Holling CS, Walker B (2002) Resilience and sustainable development: building adaptive capacity in a world of transformations. Ambio 31(5):437–440

Forsyth T (2017) Community-based adaptation to climate change. Oxford research encyclopedia of climate science. https://doi.org/10.1093/acrefore/9780190228620.013.602

Frankenberger TR, Constas MA, Nelson S, Starr L (2014) Nongovernmental organizations' approaches to resilience programming. http://www.ifpri.org/publication/nongovernmental-organizations-approachesresilienc-programming

Free CM, Thorson JT, Pinsky ML, Oken KL, Wiedenmann J, Jensen OP (2019) Impacts of historical warming on marine fisheries production. Science 363:979–983

Friedlander AM, Shackeroff JM, Kittinger JN (2013) Customary marine resource knowledge and use in contemporary Hawai'i. Pac Sci 67(3):441–460

Frommel AY, Margulies D, Wexler JB, Stein MS, Scholey VP, Williamson JE, Bromhead D, Nicol S, Havenhand J (2016) Ocean acidification has lethal and sub-lethal effects on larval development of yellowfin tuna, Thunnus albacares. J Exp Mar Biol Ecol 482:18–24

Ganachaud AS, Sen Gupta A, Orr JC, Wijffels SE, Ridgway KR, Hemer MA et al (2011) Observed and expected changes to the tropical Pacific Ocean. In: Bell JD, Johnson JE, Hobday AJ (eds) Vulnerability of tropical Pacific fisheries and aquaculture to climate change. Secretariat of the Pacific Community, Noumea, pp 101–187

Gillett R (2016) Fisheries in the economies of Pacific Island countries and territories. Pacific Community, Noumea

Gillett R, Tauati MI (2018) Fisheries of the Pacific Islands: regional and national information. Fisheries and aquaculture technical paper no. 625. Food and Agriculture Organization of the United Nations, Apia

Godoy MD, de Lacerda LD (2015) Mangroves response to climate change: a review of recent findings on mangrove extension and distribution. An Acad Bras Cienc 87(2):651–667

Gombos M, Atkinson S, Wongbusarakum S (2013) Adapting to a changing climate: guide to local early action planning (LEAP) and management planning. Micronesia Conservation Trust, Pohnpei

Grewe PMP, Feutry PPL, Hill PL et al (2015) Evidence of discrete yellowfin tuna (Thunnus albacares) populations demands rethink of management for this globally important resource. Sci Rep 5:16916. https://doi.org/10.1038/srep16916

Gervais C, Mourier J, Rummer J (2016) Developing in warm water: irregular colouration and patterns of a neonate elasmobranch. Mar Biodivers 4:743–744

Guannel G, Arkema K, Ruggiero P, Verutes G (2016) The power of three: coral reefs, seagrasses and Mangroves protect coastal regions and increase their resilience. PLoS One 11:e0158094

Guillemot N, Chabanet P, Le Pape O (2010) Cyclone effects on coral reef habitats in New Caledonia (South Pacific). Coral Reefs 29:445–453

Hanich Q, Ota Y (2013) Moving beyond rights based management: a transparent approach to distributing the conservation burden in tuna fisheries. Int J Mar Coast Law 28:135

Hanich Q, Tsamenyi M (2014) Progress in the implementation of conservation and management measures for bigeye and yellowfin tunas in the western and central pacific: sharing the conservation burden and benefit. In: Lodge MW, Nordquist MH (eds) Law of the sea: Liber amicorum Satya Nandan. Brill/Nijhoff, Leiden/Boston, pp 358–380

Hallegraeff GM (2010) Ocean climate change, phytoplankton community responses, and harmful algal blooms: a formidable predictive challenge1. J Phycol 46:220–235. https://doi.org/10.1111/j.1529-8817.2010.00815

Hassenruck C, Hofmann LC, Bischof K, Ramette A (2015) Seagrass biofilm communities at a naturally CO_2-rich vent. Environ Microbiol Rep 7:516–525

Havice E (2013) Rights-based management in the Western and Central Pacific Ocean tuna fishery: economic and environmental change under the Vessel Day Scheme. Mar Policy 42:259–267

Heenan A, Pomeroy R, Bell J, Munday P, Cheung W, Logan C, Brainard R, Amri AY, Alino P, Armada N, David L, Guieb R, Green S, Jompa J, Leonardo T, Mamauag S, Parker B, Shackeroff J, Yasin Z (2015) A climate-informed, ecosystem approach to fisheries management. Mar Policy 57:182–192

Henson SA, Cole H, Beaulieu C, Yool A (2013) The impact of global warming on the seasonality of ocean primary productivity. Biogeosciences 10:4357–4369. https://doi.org/10.5194/bg-10-4357-2013
Heinrich DDU, Rummer JL, Morash AJ, Watson S-A, Simpfendorfer CA, Heupel MR, Munday PL (2014) A product of its environment: the epaulette shark (Hemiscyllium ocellatum) exhibits physiological tolerance to elevated environmental CO_2. Conserv Physiol 2:cou047
Heron SF, Maynard J, van Hooidonk R, Eakin CM (2016) Warming trends and bleaching stress of the world's coral reefs 1985–2012. Sci Rep 6:38402. https://doi.org/10.1038/srep38402
Hobday AJ, Evans K (2013) Detecting climate impacts with oceanic fish and fisheries data. Clim Change 119:49–62
Hobday A, Spillman CM, Eveson JP, Hartog JR, Zhang X, Brodie S (2018) A framework for combining seasonal forecasts and climate projections to aid risk management for fisheries and aquaculture. Front Mar Sci 5(137):1–9
Hoegh-Guldberg O, Andrefouet S, Fabricius KE, Diaz-Pulido G, Lough JM, Marshall PA, Pratchett MS (2011) Vulnerability of coral reefs in the tropical Pacific to climate change. In: Bell J, Johnson JE, Hobday AJ (eds) Vulnerability of tropical Pacific fisheries and aquaculture to climate change. Secretariat of the Pacific Community, Noumea
Hough M (1990) Out of place: restoring identity to the regional landscape. Yale university press, New Haven
Hughes TP, Kerry JT, Alvarez-Noriega M, Alvarez-Romero JG, Anderson KD, Baird AH, Babcock RC, Beger M, Bellwood DR, Berkelmans R, Bridge TC, Butler IR, Byrne M, Cantin NE, Comeau S, Connolly SR, Cumming GS, Dalton SJ, Diaz-Pulido G, Eakin CM, Figueira WF, Gilmour JP, Harrison HB, Heron SF, Hoey AS, Hobbs JPA, Hoogenboom MO, Kennedy EV, Kuo CY, Lough JM, Lowe RJ, Liu G, McCulloch MTM, Malcolm HA, McWilliam MJ, Pandolfi JM, Pears RJ, Pratchett MS, Schoepf V, Simpson T, Skirving WJ, Sommer B, Torda G, Wachenfeld DR, Willis BL, Wilson SK (2017) Global warming and recurrent mass bleaching of corals. Nature 543:373
Hviding E (1996) Guardians of Marovo Lagoon: practice, place, and politics in maritime Melanesia, Pacific Islands monograph series, 14. University of Hawaii Press, Honolulu, HI
Hylton S, White WT, Chin A (2017) The sharks and rays of the Solomon Islands: a synthesis of their biological diversity, values and conservation status. Pac Conserv Biol 23:324–334
Hyndes GA, Heck KL Jr, Vergés A, Harvey ES, Kendrick GA, Lavery PS, Wernberg T (2016) Accelerating tropicalization and the transformation of temperate seagrass meadows. Bioscience 66(11):938–948
Hyndman D (1993) Sea tenure and the management of living marine resources in Papua New Guinea, 4th edn., vol 16, Dec. Pacific Studies
IPCC [Intergovernmental Panel on Climate Change] (2014) In: Team CW, Pachauri RK, Meyer LA (eds) Climate change 2014: synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, p 151
IPCC [Intergovernmental Panel on Climate Change] AR5 (2013) In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) Climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, 1535pp. https://doi.org/10.1017/CBO9781107415324
Jevrejeva S, Grinsted A, Moore JC (2009) Anthropogenic forcing dominates sea level rise since 1850. Geophys Res Lett 36:L20706
Johnson J, Welch D, Fraser A (2016a) Climate change impacts in North Efate, Vanuatu. Vanuatu RESCCUE project, Noumea
Johnson JE, Bell JD, Sen Gupta A (2016b) Pacific Islands ocean acidification vulnerability assessment. SPREP, Apia

Johnson JE, Welch DJ, Maynard JA, Bell JD, Pecl G, Tobin A, Robins J, Saunders T (2016c) Assessing and reducing vulnerability to climate change: moving from theory to practical decision-support. Mar Policy 74:220–229. https://doi.org/10.1016/j.marpol.2016.09.024

Johnson JE, Bell JD, Allain V, Hanich Q, Lehodey P, Moore B, Nicol S, Pickering T (2017) The Pacific Islands: fisheries and aquaculture and climate change. In: Philips B, Ramirez M (eds) Implications of climate change for fisheries and aquaculture: a global analysis. Wiley Publications, New York, pp 333–379

Johnson JE, Monnereau I, Welch DJ, McConney P, Szuster B, Gasalla MA (2018) Climate change adaptation: vulnerability and challenges facing small-scale fisheries in small islands. In: FishAdapt conference proceedings, Food and Agriculture Organization of the United Nations, FAO Fisheries and Aquaculture proceedings no. x. FAO, Rome

Jolis G, Sumampouw M, Saleh E, Razak FRA (2014) Vulnerability assessment and local early action planning (Va-Leap) for climate change adaptation in the Malaysian coral triangle area: a case study from Selakan Island, Semporna, Sabah, Malaysia. In: International conference on marine science & aquaculture (ICOMSA), 2015, Kota Kinabalu, Sabah, Malaysia

Kayser M (2010) The human genetic history of oceania: near and remote views of dispersal. Curr Biol 20(4):R109–R201. https://doi.org/10.1016/j.cub.2009.12.004

Keith SA, Maynard JA, Edwards AJ, Guest JR, Bauman AG, van Hooidonk R, Heron SF, Berumen ML, Bouwmeester J, Piromvaragorn S, Rahbek C, Baird AH (2016) Coral mass spawning predicted by rapid seasonal rise in ocean temperature. Proc Biol Sci 283:20160011–20160019

Kench PS, Thompson D, Ford MR, Ogawa H, McLean RF (2015) Coral islands defy sea-level rise over the past century: records from a central Pacific atoll. Geology 43:515–518

Kench PS, Ford MR, Owen SD (2018) Patterns of island change and persistence offer alternate adaptation pathways for atoll nations. Nat Commun 9:605

Kirwan ML, Megonigal JP (2013) Tidal wetland stability in the face of human impacts and sea-level rise. Nature 504(7478):53

Kittinger JN (2013) Human dimensions of small-scale and traditional fisheries in the Asia-Pacific region. Pac Sci 67(3):315–325

Kleypas JA, Castruccio FS, Curchitser EN, McLeod E (2015) The impact of ENSO on coral heat stress in the western equatorial Pacific. Glob Change Biol 21:2525–2539

Kroeker KJ, Kordas RL, Crim RN, Singh GG (2010) Meta-analysis reveals negative yet variable effects of ocean acidification on marine organisms. Ecol Lett 13:1419–1434

Kwiatkowski L, Orr JC (2018) Diverging seasonal extremes for ocean acidification during the twenty-first century. Nat Clim Change 8:141–145. https://doi.org/10.1038/s41558-017-0054-0.

Lack M, Meere F (2009) Regional action plan for sharks: guidance for Pacific Island Countries and Territories on the conservation and management of sharks

Lal P (2003) Economic valuation of mangroves and decision-making in the Pacific. Ocean Coast Manag 46(9–10):823–844

Laubenstein TD, Rummer JL, Nicol S, Parsons DM, Pether SMJ, Stephen Pope S, Smith N, Munday PL (2018) Correlated effects of ocean acidification and warming on behavioral and metabolic traits of a large Pelagic fish. Diversity 10:35. https://doi.org/10.3390/d10020035.

Le Borgne R, Allain V, Griffiths SP, Matear RJ, McKinnon AD, Richardson AJ, Young JW (2011) Vulnerability of open ocean food webs in the tropical Pacific to climate change. In: Bell JD, Johnson JE, Hobday AJ (eds) Vulnerability of tropical Pacific fisheries and aquaculture to climate change. Secretariat of the Pacific Community (SPC), Noumea, pp 189–249

Lehodey P, Bertignac M, Hampton J, Lewis A, Picaut J (1997) El Niño-Southern Oscillation and tuna in the western Pacific. Nature 389:715–718

Lehodey P, Senina I, Murtugudde R (2008) A spatial ecosystem and populations dynamics model (SEAPODYM)—modeling of tuna and tuna-like populations. Prog Oceanogr 78:304–318

Lehodey P, Hampton J, Brill RW, Nicol S, Senina I, Calmettes B, Pörtner HO, Bopp L, Ilyina T, Bell JD, Sibert J (2011) Vulnerability of oceanic fisheries in the tropical Pacific to climate change. In: Bell JD, Johnson JE, Hobday AJ (eds) Vulnerability of tropical Pacific fisheries and aquaculture to climate change. Secretariat of the Pacific Community, Noumea, pp 433–492

Lehodey P, Senina I, Calmettes B, Hampton J, Nicol S (2013) Modelling the impact of climate change on Pacific skipjack tuna population and fisheries. Clim Change 119:95–109
Lehodey P, Senina I, Nicol S, Hampton J (2015) Modelling the impact of climate change on South Pacific albacore tuna. Deep-Sea Res II 113:246–259
Lehodey P, Senina I, Calmettes B, M. Dessert, S. Nicol, J. Hampton, N. Smith, T. Gorgues, O. Aumont, M. Lengaigne, C. Menkes, M. Gehlen. (2017) Modelling the impact of climate change including ocean acidification on Pacific yellowfin tuna. Western and Central Pacific fisheries commission scientific committee, thirteenth regular session, Rarotonga, Cook Islands, 9–17 Aug 2017
Leonard K (2001) Domestic violence and alcohol: what is known and what do we need to know to encourage environmental interventions? J Subst Use 6(4):235–247. https://doi.org/10.1080/146598901753325075
Levin LA, Liu KK, Emeis KC, Breitburg DL, Cloern J, Deutsch C, Giani M, Goffart A, Hofmann EE, Lachkar Z, Limburg K, Liu SM, Montes E, Naqvi W, Ragueneau O, Rabouille C, Sarkar SK, Swaney DP, Wassman P, Wishner KF (2015) Comparative biogeochemistry-ecosystem-human interactions on dynamic continental margins. J Mar Syst 141:3–17
Livingston M (2011) A longitudinal analysis of alcohol outlet density and domestic violence. Addiction 106(5):919–925. https://doi.org/10.1111/j.1360-0443.2010.03333.x
Lough JM (2012) Small change, big difference: sea surface temperature distributions for tropical coral reef ecosystems, 1950–2011. J Geophys Res Oceans 117. https://doi.org/10.1029/2012JC008199
Lough JM, Meehl GA, Salinger MJ (2011) Observed and projected changes in surface climate of the tropical Pacific. In: Bell JD, Johnson JE, Hobday AJ (eds) Vulnerability of tropical pacific fisheries and aquaculture to climate change. Secretariat of the Pacific Community, Noumea, pp 49–99
Lough JM, Sen Gupta A, Power SB, Grose MR, McGree S (2016) Observed and projected changes in surface climate of tropical Pacific Islands. In: Taylor M, McGregor A, Dawson B (eds) Vulnerability of Pacific Island agriculture and forestry to climate change. Secretariat of the Pacific Community, Noumea, pp 47–101
Lough JM, Anderson KD, Hughes TP (2018) Increasing thermal stress for tropical coral reefs: 1871–2017. Sci Rep 8:6079. https://doi.org/10.1038/s41598-018-24530-9
Lovell E, Sykes H, Deiye M, Wantiez L, Carrigue C, Virly S, Samuelu J, Solofa A, Poulasi T, Pakoa K, Sabetian A, Afzal D, Hughes A, Sulu R (2004) Status of coral reefs in the South West Pacific: Fiji, Nauru, New Caledonia, Samoa, Solomon Islands, Tuvalu and Vanuatu. In: Wilkinson C (ed) Status GCRMN, Townsville
Lovelock CE, Cahoon DR, Friess DA, Guntenspergen GR, Krauss KW, Reef R, Saintilan N (2015) The vulnerability of Indo-Pacific mangrove forests to sea-level rise. Nature 526(7574):559
Lotze HK, Lenihan HS, Bourque BJ, Bradbury RH et al (2006) Depletion, degradation, and recovery potential of estuaries and coastal seas. Science 312:1806–1809
Mangubhai S (2016) Impact of tropical cyclone Winston on coral reefs in the Vatu-i-Ra Seascape, report no. 01/16, Suva, Fiji, 27pp
Marois DE, Mitsch WJ (2015) Coastal protection from tsunamis and cyclones provided by mangrove wetlands—a review. Int J Biodiver Sci Ecosyst Serv Manag 11(1):71–83
Maron N, Connell J (2008) Back to Nukunuku: employment, identity and return migration in Tonga. Asia Pac Viewpoint 49(2):168–184
Matear RJ, Chamberlain MA, Sun C, Feng M (2015) Climate change projection for the western tropical Pacific Ocean using a high-resolution ocean model: implications for tuna fisheries. Deep-Sea Res II Top Stud Oceanogr 113:22–46. https://doi.org/10.1016/j.dsr2.2014.07.003
McIlgorm A (2010) Economic impacts of climate change on sustainable tuna and billfish management: insights from the Western Pacific. Prog Oceanogr 86(1–2):187–191
Mcleod E, Margles Weis SW, Wongbusarakum S, Gombos M, Dazé A, Otzelberger A, Hammill A, Agostini V, Urena Cot D, Wiggins M (2015) Community-based climate vulnerability and adaptation tools: a review of tools and their applications. Coast Manag 43(4):439–458

McNeil BI, Sasse TP (2016) Future ocean hypercapnia driven by anthropogenic amplification of the natural CO_2 cycle. Nature 529:383–386

McLeod E, Salm RV (2006) Managing mangroves for resilience to climate change. International Union for Conservation of Nature, Gland, Switzerland

McPhaden MJ, Zebiak SE, Glantz MH (2006) ENSO as an integrating concept in earth science. Science 314:1740–1745

Meissner KJ, Lippmann T, Sen Gupta A (2012) Large-scale stress factors affecting coral reefs: open ocean sea surface temperature and surface seawater aragonite saturation over the next 400 years. Coral Reefs 31:309–319

Moberg F, Folke C (1999) Ecological goods and services of coral reef ecosystems. Ecol Econ 29(2):215–233

Movono A, Dahles H, Becken S (2018) Fijian culture and the environment: a focus on the ecological and social interconnectedness of tourism development. J Sustain Tour 26:451–469

Munday PL, Jones GP, Pratchett MS, Williams A (2008) Climate change and the future of coral reef fisheries. Fish Fish 9:261–285

Munday PL, Dixson DL, Donelson JM, Jones GP, Pratchett MS, Devitsina GV, Doving KB (2009) Ocean acidification impairs olfactory discrimination and homing ability of a marine fish. Proc Natl Acad Sci U S A 106:1848–1852

Munday PL, Pratchett MS, Dixson DL, Donelson JM, Endo GGK, Reynolds AD, Knuckey R (2013) Elevated CO_2 levels affects the behaviour of an ecologically and economically important coral reef fish. Mar Biol 160:2137–2144

Nagelkerken I, Van der Velde G (2004) Relative importance of interlinked mangroves and seagrass beds as feeding habitats for juvenile reef fish on a Caribbean island, Marine Ecology Progress Series, vol 274, pp 153–159

Nurse LA, McLean RF, Agard J, Briguglio LP, Duvat-Magnan V, Pelesikoti N, Tompkins E, Webb A (2014) Small Islands. In: Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Climate change 2014: impacts, adaptation, and vulnerability. Part B: regional aspects. Contribution of working group II to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp 16133–16654

Nuttall P, Veitayaki J (2015) Oceania is vast, Canoe is centre, Village is anchor, Continent is margin. In: Smith HD, De Vivero JLS, Agardy TS (eds) Routledge handbook of ocean resources and management. Routledge, London, pp 560–575

Obura D, Mangubhai S (2011) Coral mortality associated with thermal fluctuations in the Phoenix Islands, 2002–2005. Coral Reefs 30:607–619

Orth RJ, Curruthers TJB, Dennison WC, Duarte CM, Fourqurean JW, Heck KL, Hughes AR, Kendrick GA, Kenworthy WJ, Olyarnik S, Short FT, Waycott M, Williams SL (2006) A global crisis for seagrass ecosystems. Bioscience 56:987–996

Palacios SL, Zimmerman RC (2007) Response of eelgrass Zostera marina to CO_2 enrichment: possible impacts of climate change and potential for remediation of coastal habitats. Mar Ecol Prog Ser 344:1–13

Pascal N (2014) Economic valuation of mangrove ecosystem services in Vanuatu: case study of Crab Bay (Malekula Is.) and Eratap (Efate Is.)—summary report. IUCN, Suva, Fiji, 18pp

Paxton CW, Baria MVB, Weis VM, Harii S (2016) Effect of elevated temperature on fecundity and reproductive timing in the coral Acropora digitifera. Zygote 24:511–516

Pickering T et al (2011) Vulnerability of aquaculture in the tropical Pacific to climate change. In: Bell JD, Johnson JE, Hobday AJ (eds) Vulnerability of tropical Pacific fisheries and aquaculture to climate change. Secretariat of the Pacific Community, Noumea

Pinca S, Kronen M, Friedman K, Magron F, Chapman L, Tardy E, Pakoa K, Awira R, Boblin P, Lasi F (2010) Regional assessment report: profiles and results from survey work at 63 sites across 17 Pacific island countries and territories. Secretariat of the Pacific Community, Noumea, 512 pp

Petitgas P, Rijnsdorp AD, Dickey-Collas M, Engelhard GH, Peck MA, Pinnegar JK, Drinkwater K, Huret M, Nash RDM (2012) Impacts of climate change on the complex life cycles of fish. In: Fisheries & Oceanography

Polovina JJ, Dunne JP, Woodworth PA, Howell EA (2011) Projected expansion of the subtropical biome and contraction of the temperate and equatorial upwelling biomes in the North Pacific under global warming. ICES J Mar Sci. J, Cons

Ponia B (2010) A review of Pacific aquaculture in the Pacific Islands 1998–2007: tracking a decade of progress through official and provisional statistics. Secretariat of the Pacific Community Aquaculture technical report, Noumea

Pouvreau S, Prasil V (2001) Growth of the black-lip pearl oyster, Pinctada margaritifera, at nine culture sites of French Polynesia: synthesis of several sampling designs conducted between 1994 and 1999. Aquat Living Resour 14:155–163

Power S, Casey T, Folland C, Colman C, Mehta V (1999) Interdecadal modulation of the impact of ENSO on Australia. Clim Dyn 15:319–324

Power S, Delage F, Chung C, Kociuba G, Keay K (2013) Robust twenty-first-century projections of El Niño and related precipitation variability. Nature 502:541–545

Pratchett MS, Munday PL, Graham NAJ, Kronen M, Pinca S, Friedman K, Brewer TD, Bell JD, Wilson SK, Cinner JE, Kinch JP, Lawton RJ, Williams AJ, Chapman L, Magron F, Webb A (2011) In: Bell JD, Johnson JE, Hobday AJ (eds) Vulnerability of tropical Pacific fisheries and aquaculture to climate change. Secretariat of the Pacific Community, Noumea, pp 493–576

Rabinovich AB, Geist EL, Fritz HM, Borrero JC (2015) Introduction to "Tsunami science: ten years after the 2004 Indian Ocean tsunami. Volume I". Pure Appl Geophys 172(3–4):615–619

Reid H (2015) Ecosystem- and community-based adaptation: learning from community-based natural resource management. Clim Dev 8(1):4–9. https://doi.org/10.1080/17565529.2015.1034233

Remling E, Veitayaki J (2016) Community-based action in Fiji's Gau Island: a model for the Pacific. IJCCSM 8(3):375–398

RESCCUE [Restoration of Ecosystem Services and Climate Change Adaptation] (2015) Initial diagnosis document: Vanuatu. Report to the Pacific Community (SPC), Noumea, 120pp

Rhein M, Rintoul SR, Aoki S, Campos E, Chambers D, Feely RA (2013) Observations: ocean. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J et al (eds) Climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

Rotmann S (2001) Coral bleaching event on Lihir Island, Feb–Mar 2001

Rongo T, van Woesik R (2013) The effects of natural disturbances, reef state, and herbivorous fish densities on ciguatera poisoning in Rarotonga, southern Cook Islands. Toxicon 64:87–95

Rosa R, Rummer JL, Munday PL (2017) Biological responses of sharks to ocean acidification. Biol Lett 13(3):20160796

Roué M, Cruchet P, Ung A, Darius T, Chinain M, Laurent D (2013) Giant clams: new vectors of ciguatera. Toxicon 75(SI):206–206

Ruddle K (1993) External forces and change in traditional community-based fishery management systems in the Asia-Pacific region. Maritime Anthropol Stud 6(1–2):1–37. Accessed 26 Apr 2018

Ruddle K (1998) The context of policy design for existing community-based fisheries management systems in the Pacific Islands. Ocean Coast Manag 40(2–3):105–126. https://doi.org/10.1016/s0964-5691(98)00040-4

Ruddle K, Panayotou T (1989) The organization of traditional inshore fishery management systems in the Pacific. In: Rights based fishing. Springer, Dordrecht, pp 73–93. https://doi.org/10.1007/978-94-009-2372-0_4

Rugendyke B, Connell J (2008) 15 marginal people and marginal places. In: Tourism at the grassroots: Villagers and visitors in the Asia-Pacific, vol 274

Saunders MI, Leon J, Phinn SR, Callaghan DP, O'Brien KR, Roelfsema CM, Lovelock CE, Lyons MB, Mumby PJ (2013) Coastal retreat and improved water quality mitigate losses of seagrass from sea level rise. Glob Change Biol 19:2569–2583. https://doi.org/10.1111/gcb.12218

Saunders MI, Leon JX, Callaghan DP, Roelfsema CM, Hamylton S, Brown CJ, Baldock T, Golshani A, Phinn SR, Lovelock CE, Hoegh-Guldberg O, Woodroffe CD, Mumby PJ (2014) Interdependency of tropical marine ecosystems in response to climate change. Nat Clim Change 4:724

Saunders MI, Albert S, Roelfsema CM et al (2016) Coral Reefs 35:155. https://doi.org/10.1007/s00338-015-1365-0

Sarmiento JL, Gruber N, Brzezinski MA, Dunne JP (2004) High-latitude controls of thermocline nutrients and low latitude biological productivity. Nature 427(6969):56

Schaefer K, Fuller D, Block B (2011) Movements, behavior, and habitat utilization of yellowfin tuna (Thunnus albacares) in the Pacific Ocean off Baja California, Mexico, determined from archival tag data analyses, including unscented Kalman filtering. Fish Res 112:22–37

Schaefer K, Fuller D, Hampton J, Caillot S, Leroy B, Itano D (2015) Movements, dispersion, and mixing of bigeye tuna (Thunnus obesus) tagged and released in the equatorial Central Pacific Ocean, with conventional and archival tags. Fish Res 161:336–355

Schlaff AM, Heupel MR, Simpfendorfer CA (2014) Influence of environmental factors on shark and ray movement, behaviour and habitat use: a review. Rev Fish Biol Fish 24(4):1089–1103

Short FT, Coles R (eds) (2001) Global seagrass research methods. Elsevier, Amsterdam, 482pp

Short FT, Neckles HA (1999) The effects of global climate change on seagrasses. Aquat Bot 63(3–4):169–196

Short FT, Wyllie-Echeverria S (1996) Natural and human-induced disturbance of seagrasses. Environ Conserv 23:17–27

Short FT, Koch E, Creed JC, Magalhaes KM, Fernandez E, Gaeckle JL (2006) SeagrassNet monitoring across the Americas: case studies of seagrass decline. Mar Ecol 27:277–289

Simpson SD, Munday PL, Wittenrich ML, Manassa R, Dixson DL, Gagliano M, Yan HY (2011) Ocean acidification erodes crucial auditory behaviour in a marine fish. Biol Lett 7:917–920

Singh S (2018) Contribution of Symbiodinium clades to Pocillopora's response to thermal stress in Fiji and French Polynesia. MSc thesis, The University of the South Pacific, Suva

SPC [Secretariat of the Pacific Community] (2008) Fish and food security. Policy Brief 1/2008. Secretariat of the Pacific Community, Noumea

SPC [Pacific Community] (2008) Fish and food security: Policy Brief 1/2008. Secretariat of the Pacific Community, Noumea, New Caledonia

SPC [Pacific Community] (2013) Status report: Pacific Islands Reef and nearshore fisheries and aquaculture. Secretariat of the Pacific Community, Noumea, New Caledonia

SPC [Pacific Community] (2015) A new song for coastal fisheries – Pathways to change: the Noumea strategy. Pacific Community, Noumea, New Caledonia

Stoeckl N, Birtles A, Farr M, Mangott A, Curnock M, Valentine P (2010) Live-aboard dive boats in the Great Barrier Reef: regional economic impact and the relative values of their target marine species. Tour Econ 16:995–1018

Steinacher M, Joos F, Frölicher TL, Bopp L, Cadule P, Cocco V, Doney SC, Gehlen M, Lindsay K, Moore JK, Schneider B (2010) Projected 21st century decrease in marine productivity: a multi-model analysis. Biogeosciences 7(3):979–1005

Szmant AM, Gassman NJ (1990) The effects of prolonged bleaching on the tissue biomass and reproduction of the reef coral Montastrea annularis. Coral Reefs 8:217–224

Taucher J, Oschlies A (2011) Can we predict the direction of marine primary production change under global warming? Geophys Res Lett 38:L02603. https://doi.org/10.1029/2010GL045934

Terry JP (2007) Tropical cyclones: climatology and impacts in the South Pacific. Springer, New York

Toseland ADSJ, Daines SJ, Clark JR, Kirkham A, Strauss J, Uhlig C, Lenton TM, Valentin K, Pearson GA, Moulton V, Mock T (2013) The impact of temperature on marine phytoplankton resource allocation and metabolism. Nat Clim Chang 3(11):979

van Hooidonk R, Maynard JA, Manzello D, Planes S (2014) Opposite latitudinal gradients in projected ocean acidification and bleaching impacts on coral reefs. Glob Change Biol 20:103–112

van Woesik R, Golbuu Y, Roff G (2015) Keep up or drown: adjustment of western Pacific coral reefs to sea-level rise in the 21st century. R Soc Open Sci 2:150181

Veitayaki J (2018) Ocean in US: security of life in the world's largest ocean. University of Hawaii Press, Honolulu, HI

Veitayaki J, Breckwoldt A, Sigarua T, Bulai NAR (2014) Living from the sea: culture and marine conservation in Fiji. Taukei Trust Fund Board, Suva

Veitayaki J, Waqalevu V, Varea R, Rollings N (2017) Mangroves in small island development states in the Pacific: an overview of a highly important and seriously threatened resource. In: Participatory mangrove management in a changing climate. Springer, Tokyo, pp 303–327

Vianna GMS, Meekan MG, Pannell DJ, Marsh SP, Meeuwig JJ (2012) Socio-economic value and community benefits from shark-diving tourism in Palau: a sustainable use of reef shark populations. Biol Conserv 145:267–277

Vieira S, Kinch J, White W, Yaman L (2017) Artisanal shark fishing in the Louisiade Archipelago, Papua New Guinea: socio-economic characteristics and management options. Ocean Coast Manag 137:43–56

Uyarra E (2005) Knowledge, diversity and regional innovation policies: theoretical issues and empirical evidence of regional innovation strategies. Manchester, Prest, Discussion Paper Series, 05–16

War Sajjad A, Kumar A, Vyas V (2014) Assessment of riparian buffer zone of Chandni Nalla-A stream in Narmada Basin, India. Adv Appl Sci Res 5(2):102–110

Warren-Rhodes K, Schwarz AM, Boyle LN, Albert J, Agalo SS, Warren R et al (2011) Mangrove ecosystem services and the potential for carbon revenue programmes in Solomon Islands. Environ Conserv 38(4):485–496

Watson SA, Allan BJM, McQueen DE, Nicol S, Parsons DM, Pether SMJ, Pope S, Setiawan AN, Smith N, Wilson C, Munday PL (2018) Ocean warming has a greater effect than acidification on the early life history development and swimming performance of a large circumglobal pelagic fish. Glob Change Biol 24:4368–4385. https://doi.org/10.1111/gcb.14290

Waycott M, Duarte CM, Carruthers TJB, Orth RJ, Dennison WC, Olyarnik S, Calladine A, Fourqurean JW, Heck KL Jr, Hughes AR, Kendrick GA, Kenworthy WJ, Short FT, William SL (2009) Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proc Nat Acad Sci U S A 106:12377–12381

Waycott M, McKenzie LJ, Mellors JE, Ellison JC, Sheaves MT, Collier C, Schwarz A-M, Webb A, Johnson JE, Payri CE (2011) Vulnerability of mangroves, seagrasses and intertidal flats. In: Bell JD, Johnson JE, Hobday AJ (eds) Vulnerability of tropical Pacific fisheries and aquaculture to climate change in the tropical. Secretariat of the Pacific Community, Noumea

WCPFC (2018) Western and Central Pacific Fisheries Commission,13th Regular Session of the Scientific Committee. Ecosystems and Bycatch Mitigation Theme. Working Paper: Lehody, P., ISenina, I., Calmettes, B., Dessert, M., Nicol, S., Hampton, J., Smith, N., Gorgues, T., Aumont, O., Lengaigne, M., Menkes, C., Gehlen, M. Modelling the impact of climate change including ocean acidification on Pacific yellowfin tuna

Whimp G (2008) Cetaceans and citations: a survey of the English literature on the role of cetaceans in South Pacific island cultures. Tuhinga 19:169–184. Accessed 26 Apr 2018

WHO [World Health Organization] (2005) Multi-country study on women's health and domestic violence against women: summary report of initial results on prevalence, health outcomes and women's responses. World Health Organization, Geneva

Wiedenmann J, D'Angelo C, Smith EG, Hunt AN, Legiret F-E, Postle AD, Achterberg EP (2012) Nutrient enrichment can increase the susceptibility of reef corals to bleaching. Nat Clim Change 3:160–164

Williams P, Terawasi P Reid C (2017) Overview of tuna fisheries in the Western and Central Pacific Ocean, including economic conditions—2016. In: 13th Scientific committee regular session, WCPFC-SC13-2017/GN-WP-01, 66pp (also available at https://www.wcpfc.int/node/29889).

Wongbusarakum S, Gombos M, Parker B, Courtney C, Atkinson S, Kostka W (2015) The local early action planning (LEAP) tool: enhancing community-based planning for a changing climate. Coast Manag 43(4):383–393. https://doi.org/10.1080/08920753.2015.1046805

Woodroffe CD, Webster JM (2014) Coral reefs and sea-level change. Mar Geol 352:248–267

Woodworth-Jefcoats PA, Polovina JJ, Dunne JP, Blanchard JL (2013) Ecosystem size structure response to 21st century climate projection: large fish abundance decreases in the central North Pacific and increases in the California Current. Glob Change Biol 19:724–733. https://doi.org/10.1111/gcb.12076

Yukihira H, Lucas JS, Klump DW (2000) Comparative effects of temperature on suspension feeding and energy budgets of the pearl oysters Pinctada margaritifera and P. maxima. Mar Ecol Prog Ser 195:179–188

Zann LP (1994) The status of coral reefs in South Western Pacific Islands. Mar Pollut Bull 29:52–61

Zeller D, Harper S, Zylich K, Pauly D (2015) Synthesis of underreported small-scale fisheries catch in Pacific island waters. Coral Reefs 34(1):25–39