Chapter 36D. South Pacific Ocean

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1. Introduction

The Pacific Ocean is the Earth's largest ocean, covering one-third of the world's surface. This huge expanse of ocean supports the most extensive and diverse coral reefs in the world (Burke et al., 2011), the largest commercial fishery (FAO, 2014), the most and deepest oceanic trenches (General Bathymetric Chart of the Oceans, available at www.gebco.net), the largest upwelling system (Spalding et al., 2012), the healthiest and, in some cases, largest remaining populations of many globally rare and threatened species, including marine mammals, seabirds and marine reptiles (Tittensor et al., 2010).

The South Pacific Ocean surrounds and is bordered by 23 countries and territories (for the purpose of this chapter, countries west of Papua New Guinea are not considered to be part of the South Pacific), which range in size from small atolls (e.g., Nauru) to continents (South America, Australia). Associated populations of each of the countries and territories range from less than 10,000 (Tokelau, Nauru, Tuvalu) to nearly 30.5 million (Peru; Population Estimates and Projections, World Bank Group, accessed at http://data.worldbank.org/data-catalog/population-projection-tables, August 2014). Most of the tropical and sub-tropical western and central South Pacific Ocean is contained within exclusive economic zones (EEZs), whereas vast expanses of temperate waters are associated with high seas areas (Figure 1). The eastern and western extremes of the ocean basin contain two major boundary currents: the poleward-flowing East Australian Current (EAC), which runs along Australia's North-West shelf in the west (Ridgway and Dunn, 2003) and the northward-flowing Humboldt Current, which runs along South America's continental shelf in the east (Montecino and Lange, 2009). The dominant shallow water ecosystems of the region are tropical coral reef and lagoon systems and mangrove communities in the sub-tropics and tropics and temperate rocky reefs and kelp beds in temperate zones. Other marine communities across tropical, sub-tropical and temperate zones include rocky intertidals, mudflats, seagrass beds, estuaries and salt marshes in inshore areas and seamount, hydrothermal vents and trenches in offshore zones. Five Large Marine Ecosystems (www.lme.edc.uri.edu) have been defined across the South Pacific Ocean, including the Humboldt Current, the northeast Australian shelf, east-central Australian shelf, southeast Australian shelf and New Zealand shelf.

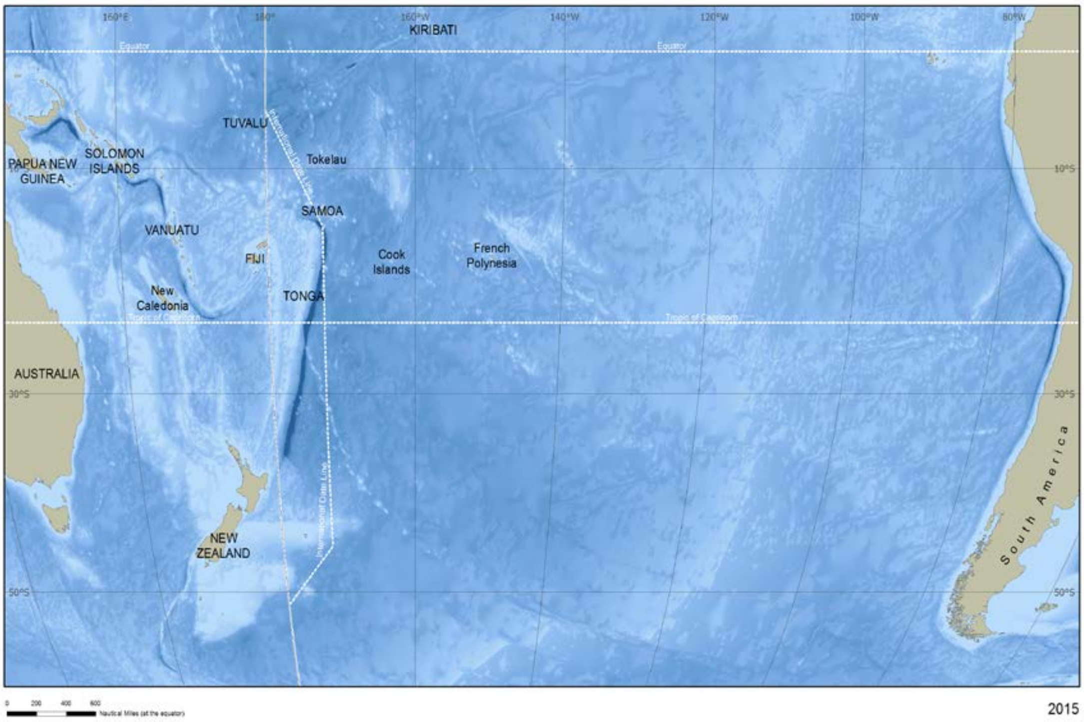

Figure 1. The South Pacific Ocean. Sources: Bathymetry extracted from the GEBCO Digital Atlas (GDA): IOC, IHO and BODC, 2003. Centenary Edition of the GEBCO Digital Atlas, published on CD-ROM on behalf of the Intergovernmental Oceanographic Commission and the International Hydrographic Organization as part of the General Bathymetric Chart of the Oceans, British Oceanographic Data Centre, Liverpool, U.K. More information at

http://www.gebco.net/data_and_products/gebco_digital_atlas/

Ocean and Sea names extracted from ESRI, DeLorme, HERE, GEBCO, NOAA, National Geographic, Geonames.org, and other contributors More information at

http://www.arcgis.com/home/item.html?id=0fd0c5b7a647404d8934516aa997e6d9.

With the kind assistance of the FAO.

Physical processes of the basin play an important role in driving shelf and coastal marine processes and climate across the region. Northern parts of the South Pacific Ocean are dominated by a basin-scale sub-tropical gyre, whose northern branch forms the South Equatorial Current (SEC; Figure 2; Reid, 1997). The SEC is predominantly driven by prevailing easterly trade winds and as water moves from the east to the west, a thick layer of warm water (>29°C), the Western Warm Pool (WWP) is formed west of ~170˚E (Picaut et al., 1996). As the westward-flowing SEC encounters islands and land masses, it splits into several currents and jets, some of which, particularly the New Guinea Coastal Under-current (NGCU), contribute to the Equatorial Under-Current (EUC; Figure 2). The EUC contributes significantly to equatorial thermocline waters and is thought to modulate the El Niño-Southern Oscillation (ENSO; Grenier et al., 2011). The EUC is also the primary source of iron in the photic layer of the region, and variability in the EUC drives regional biological productivity (Ryan et al., 2006). Once the jets meet the land mass of Australia, they form the poleward-flowing western boundary current, the East Australian Current (EAC).

As the EAC flows south along the Australia’s North-West shelf, eddies separate from the main body of the EAC, forming a region of upwelling and downwelling. Outflow from the EAC forms a band of zonal eastward flow, the Tasman Front. The band of zonal eastward flow associated with the Tasman Front contributes to the East Auckland Current and eventually to the subtropical gyre moving northward and contributing to the SEC.

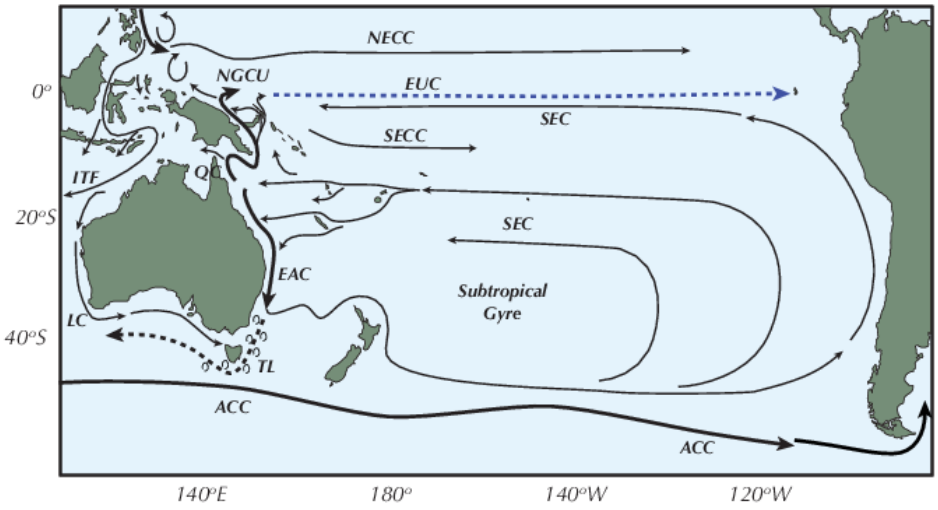

Figure 2. Major currents of the South Pacific Ocean. NECC: North Equatorial Counter-Current; NGCU: New Guinea Coastal Under-current; EUC: Equatorial Under-Current; SEC: South Equatorial Current; SECC: South Equatorial Counter-Current; ITF: Indonesian Through-Flow; QC: Queensland Current; EAC: East Australian Current; LC: Leeuwin Current; ACC: Antarctic Circumpolar Current.

The eastern boundary of the gyre combines waters from the trans-Pacific West Wind Drift (WWD) with a northward-flowing arm of the Antarctic Circumpolar Current. At its arrival on the South American coast, the WWD diverges into the poleward-flowing Cape Horn Current and the northward-flowing Humboldt or Peru-Chile Current (PCC) which flows along western South America (Strub et al., 1998). Similarly to the EAC, the PCC is characterized by significant mesoscale variability in the form of fronts, eddies and filaments (Hill et al., 1998; Montecino and Lange, 2009), which intensify closer to the coast. The Humboldt Current system is highly productive due to the combined effect of advection of nutrient-rich waters from the south and upwelling. Cool, nutrient-rich waters are brought to the surface north of ~40˚S as a result of coastal upwelling driven by winds and the impingement of the subtropical gyre along the coast (Morales et al., 1996; Montecino and Lange, 2009). Upwelling occurs seasonally across the ~30˚S-40 ˚S region (Strub et al., 1998; Shaffer et al., 1999), whereas in Northern Chile and off the Peruvian coast, upwelling is permanent (Hill et al., 1998; Vasquez et al., 1998). As the EUC encounters the Galápagos Islands it splits: one arm forms an under-current that reaches South America near the equator and becomes the poleward-flowing Gunther or Peru-Chile Under-Current, which flows beneath the PCC across the slope and outer shelf. The other arm flows to the southeast of the Galápagos Islands and forms the poleward-flowing Peru-Chile Counter-Current which divides the PCC into two branches: a coastal and an oceanic branch (Strub et al., 1998).

The physical dynamics of the region vary markedly with ENSO: during La Niña, stronger trade winds increase the intensity of the SEC, pushing the WWP west, and upwelling and productivity in the Pacific Equatorial Divergence (PEQD) increase. During El Niño, trade winds weaken, the SEC weakens, allowing the WWP to extend east and upwelling and productivity in the PEQD decrease (Ganachaud et al., 2011). Shifts in the intensity of the SEC have flow-on effects for both basin-scale circulation and shelf systems at the basin edges where shifts result in weakening/strengthening of the boundary currents.

Interaction of the easterly trade winds and ocean currents with island topography modifies the flow of water downwind of the islands, creating counter-currents, eddies and upwelling. This results in enhanced mixing of deeper nutrient-rich waters with surface waters, increasing biological production and enriching coastal waters (Ganachaud et al., 2011). For many South Pacific islands, these processes support rich coastal ecosystems in regions which would otherwise be regarded as oligotrophic.

Coordinated assessments of the state of the environment (including the marine environment) have been undertaken by several countries over the last decade, including: Australia (State of the Environment Committee, 2011), French Polynesia (Gabrie et al., 2007), Kiribati (Ministry of Environment Lands and Agricultural Development, 2004), New Zealand (Ministry for the Environment, 2007), Palau (Sakuma, 2004), Peru (World Bank, 2006), Samoa (Ministry of Natural Resources and Environment, 2013), the Solomon Islands (Ministry of Environment Conservation and Meteorology, 2008) and Vanuatu (Mourgues, 2005). A number of regional assessments have also been undertaken: The State of the Environment in Asia and Pacific 2005 (UNESCAP, 2005), the Pacific Environment Outlook (McIntytre, 2005), the Global International Waters Assessment (UNEP, 2006a), including the Global Assessment and Synthesis Reports from the Millennium Ecosystem Assessment (www.unep.org/maweb/en/Global; UNEP 2006b), the Pacific Ocean Synthesis (Center for Ocean Solutions, 2009), the UNEP Large Marine Ecosystems Report (Sherman and Hempel, 2009), the Global Biodiversity Outlook (Secretariat of the Convention on Biological Diversity, 2010), the Global Environment Outlook (UNEP, 2012) and the Pacific Environment and Climate Change Outlook (SPREP, 2012). This chapter summarizes the available assessments and current knowledge from peer-reviewed literature on the status of, immediate and long-term concerns for, and threats to the coastal and shelf marine ecosystems of the South Pacific Ocean.

2. Status and trends of biodiversity

Across the South Pacific Ocean, the most reliable time-series of the status of biodiversity across the region from which trends can be derived are largely limited to high-level indicators, including some oceanographic parameters (e.g., sea-surface temperatures, sea level) and industrial commercial fisheries (e.g., tuna, anchoveta). Indicators of pressures and impacts are similarly limited to high-level indicators of population and socio-economic measures. Long-term monitoring initiatives (e.g., those spanning multiple decades) are sparse and are largely limited to within-country monitoring of a few indicators associated with specific objectives. The TAO/TRITON array, which consists of approximately 70 moorings deployed across the tropical Pacific Ocean to collect primarily physical and meteorological data, can be considered the most extensive ocean observation system currently functional in the South Pacific Ocean. For a short period in the late 1990s, biological and chemical sensors (i.e., continuous pCO_2 analyzers, three biospherical irradiance meters, nitrate analyzers, and PAR sensors) were added to several buoys. This enabled continuous monitoring of biological productivity during deployment, improving understanding of biophysical coupling from inter-annual (ENSO events) to intra-seasonal (tropical instability waves) time scales (e.g., Chavez et al., 1998; Chavez et al., 1999; Strutton et al., 2001). More recently, several regional alliances and programmes under the Global Ocean Observing System (GOOS), including the Australian Integrated Marine Observing System (www.imos.org.au; see Lynch et al., 2014), Pacific Islands Global Ocean Observing System (PI-GOOS) and GOOS Regional Alliance for the South-East Pacific region (GRASP) are expanding physical and biological monitoring of ecosystems across the South Pacific Ocean.

2.1 Primary producers

High inter-annual variability in surface chlorophyll concentrations throughout the South Pacific Ocean tends to be associated with the eastern boundary upwelling of the Humboldt Current system, restricted regions east of New Zealand, around islands and in coastal margins where variability in local dynamics is high (Dandonneau et al., 2004). Although information on the assemblages of plankton is available for most coastal and shelf regions across the South Pacific Ocean, data on seasonal and inter-annual variability or longer-term trends are sparse.

In the western equatorial region, during the northwest monsoon, an area of upwelling develops along the coast of Papua New Guinea (Ueki et al., 2003), bringing nutrient-rich waters to the surface and resulting in increased concentrations of surface chlorophyll which are evident in satellite imagery (Messié and Radenac, 2006). This pool of nutrient- and chlorophyll-rich waters advects eastward during westerly wind events with concentrations of phytoplankton rapidly declining as the oligotrophic waters of the WWP are reached. This decline in concentration is thought to be associated with low nitrate concentrations in surface waters resulting from a stratified salinity layer at the base of the WWP that creates a barrier layer to nutrients (Messié and Radenac, 2006). Shifts in the nitrocline depth, which allow mixing of surface waters with deep nutrient-rich waters associated with eastward expansion of the WWP during La Niña events, contribute to positive primary production anomalies observed in the western equatorial Pacific Ocean (Radenac et al., 2001; Turk et al., 2001; Messié et al., 2006). This is further enhanced by changes in NGCU circulation which enhances iron transport from the shelf and upper slope of Papua New Guinea to the EUC (Ryan et al., 2006). Diatoms in the region have been observed to increase their concentration fourfold as a result of this increased nutrient input (Rousseaux and Gregg, 2012).

In situ sampling across the shelf region of north-eastern Papua New Guinea has recorded a phytoplankton community during the austral summer dominated by nanoeucaryotes and *Prochlorococcus* (Everitt et al., 1990; Higgins et al., 2006). Variability in phytoplankton community assemblages has been observed to be high with a gradient in concentrations from the coast (high) to waters further offshore (low). High nitrogen-fixation rates have also been observed in coastal regions of north-east Papua New Guinea, associated with nanoplankton cyanobacteria and *Trichodesmium* spp. (Bonnet et al., 2009). Across the western equatorial region, nitrogen fixation is dominated by fractions of less than 10 mm associated with unicellular photosynthetic diazotrophs.

Further to the south in the western Pacific Ocean (south of ~23˚S) and in the region of New Caledonia, seasonal enrichment of surface chlorophyll concentrations during the austral winter months has been observed and is associated with surface cooling and vertical mixing (Dandonneau and Gohin, 1984; Menkes et al., 2015). Assemblages are dominated by the cyanobacteria *Prochlorococcus,* with lower concentrations of *Synechococcus* and picoeukaryotes (Dandonneau et al., 2004; Menkes et al., 2015). Around the New Caledonian and Vanuatu archipelagos, blooms of *Trichodesmium* spp. are often reported during the austral summer months and have been associated with increased nutrient inputs from islands as a result of seasonal patterns in rainfall (Rodier and Le Borgne, 2008; Le Borgne et al., 2011), although direct linkages between *Trichodesmium* blooms and seasonal land-based nutrient input are not clear (Peter Thompson, CSIRO, pers. comm., 21 August 2014). In contrast to the productivity observed around high islands, such as Papua New Guinea, New Caledonia and Vanuatu, productivity around low islands and coral atolls is rarely enhanced. This is because in general these islands and atolls release very few sediments and nutrients into coastal and shelf regions (Le Borgne et al., 2011).

Overall, a distinct latitudinal gradient in phytoplankton is observed in eastern Australian coastal and shelf waters: higher concentrations of the picoplankton *Prochlorococcus* and *Synechococcus* are found in the north, which gradually decline to the south (Thompson et al., 2011). Tropical shelf waters are typified by phytoplankton communities similar to those observed in the oligotrophic waters of the northern Coral Sea and those around New Caledonia and southern parts of the Coral Sea. The Great Barrier Reef lagoon supports a high diversity of nanoplankton and picoplankton species, which demonstrate a seasonal progression in community structure and biomass across the austral summer months (chlorophyll *a* concentrations have been observed to increase by up to 50 per cent). In outer regions of the lagoon this is associated with intrusion of nutrient-enriched Coral Sea water (Furnas and Mitchell, 1986; Brodie et al., 2007) and in inner regions associated with sediment-laden river plumes (Revelante et al., 1982). Surface chlorophyll concentrations are frequently, although not always, higher in lagoon regions of the Great Barrier Reef than in adjacent shelf regions (Furnas et al., 1990). Assessments of surface chlorophyll *a* concentrations throughout the Great Barrier Reef lagoon suggest that relatively short (5 – 8 years) time-series may provide spurious estimates of longer-term trends, given the high variability in multi-year patterns (Brodie et al., 2007).

In general, phytoplankton assemblages in the EAC are diatom-dominated in inshore regions; flagellates dominate offshore regions (Young et al., 2011). Assemblages associated with the mesoscale features of the EAC are highly variable with distinct spatial separation of phytoplankton species observed across individual eddy systems (Jeffrey and Hallegraeff, 1980; Jeffrey and Hallegraeff, 1987). Further south, across the temperate neritic province, episodic phytoplankton blooms driven by seasonal intrusions of nitrate-rich water into the euphotic zone occur (Hallegraeff and Jeffrey, 1993; Bax et al., 2001). These seasonal blooms can include diatoms such as *Pseudonitzschia*, which is responsible for amnesic shellfish poisoning (Hallegraeff, 1994), *Thalassiosira partheneia* (Bax et al., 2001), and also coccolithophorids (e.g., Figure 3).

Waters around the north of New Zealand typically demonstrate similar seasonal patterns in chlorophyll concentrations to those observed in the broader Tasman Sea: higher concentrations in the austral spring and autumn and lowest in the winter. Phytoplankton maximas in north-eastern New Zealand shelf regions have been associated with diatom blooms with community succession to dinoflagellates, nanoflagellates and picophytoplankton as blooms decline (Chang et al., 2003). Along the west coast, diatoms are most abundant close to shore, phytoflagellates most abundant seaward of shore areas and dinoflagellates most abundant in areas further offshore (Chang, 1983). In the High-Nitrate-Low-Chlorophyll (HNLC) subantarctic waters southeast of New Zealand, episodic elevated chlorophyll events have been observed (Boyd et al., 2004) with phytoplankton assemblages dominated by cyanobacteria (Bradford-Grieve et al., 1997) and diatoms (Boyd et al., 1999).

Figure 3. A coccolithophorid bloom in the coastal waters of north-east Tasmania, Australia. Photo taken in October 2004. Image courtesy of CSIRO, Australia.

Declines in austral spring bloom biomass and growth rates of chlorophyll *a* along the south-eastern Australian region have been suggested to be associated with a long-term decrease in dissolved silicate concentrations. This decrease is thought to be driven by increased intensity in the EAC (Thompson et al., 2009) associated with decadal climate variability (see Section 3). Range expansion of some species has also been reported (Hallegraeff, 2010). The drivers of these expansions have not been established and may be associated with eutrophication, ballast water translocation or oceanographic changes associated with a changing climate (see also Section 3).

Further east in the waters of the PCC, marine ecosystem dynamics are driven by intra-seasonal, annual and inter-annual changes in the upwelling systems that typify the region (Alheit and Niquen, 2004; Montecino and Lange, 2009). Productivity is highest in inshore areas of high upwelling. Coastal upwelling regions off Peru are mainly composed of early successional stages of small diatoms (5-30 nm) with high re-production rates, whereas in later successional stages, they are characterized by larger species (Tarazona et al., 2003). Small phytoplankton, including nano- and picoplankton, have been reported to account for a large proportion (> 60 per cent) of the primary production and chlorophyll *a* concentration in the coastal waters between 18^{o}S and 30^{o}S. (Escribano et al., 2003).

South of ~30˚S, where upwelling is seasonal, coastal surface chlorophyll *a* concentrations demonstrate a maximum in the austral summer. Further offshore, concentrations are out of phase with upwelling events, demonstrating a winter maximum potentially associated with offshore advection of productivity away from coastal regions by eddy systems (Morales et al., 2007). Assemblages are diatom- and silico-flagellate-dominated; similar assemblages are observed offshore associated with coastally derived filaments and eddy systems. Assemblages demonstrate little variability throughout the year. The northern Coquimbo upwelling system, despite being an area of persistent upwelling, demonstrates lower production than the more southern Antofagasta and Concepción Shelf areas where production values have been reported to be some of the highest in the ocean (Daneri et al., 2000). Abundances vary considerably, both temporally and spatially, in response to high variability in upwelling systems and associated coastally derived filaments and eddy systems (Daneri et al., 2000; Morales et al., 2007). Such variability makes describing trends in productivity associated with climate variability (such as ENSO) difficult over shorter time scales (Daneri et al., 2000).

2.2 Zooplankton communities

Within coastal mangrove and seagrass systems in the tropics and sub-tropics, the composition of zooplankton communities is principally controlled by diel changes in tidal flows and seasonal changes in salinities, influenced by the seasonal outflow of freshwater from estuaries or seasonal changes in rainfall in coastal lagoon systems (Grindley, 1984; Duggan et al., 2008). Estimates of the biomass of zooplankton in inshore and estuarine systems tend to be much higher than adjacent coastal regions – tropical Australian mangrove and seagrass habitats have been recorded as having a zooplankton biomass an order of magnitude higher than adjacent embayments (Robertson et al., 1988). Similar spatial gradients in abundance have been recorded elsewhere in the subtropical western Pacific Ocean (Kluge, 1992; Champalbert, 1993; Le Borgne et al., 1997; Carassou et al., 2010).

Within coral reef systems, abundances of zooplankton can vary in relation to the structure of reef/lagoon systems. Enclosed and semi-enclosed atolls (e.g., the Tuamoto archipelago in French Polynesia) have higher densities of zooplankton species than lagoon systems that are more open and have regular exchange of waters with adjacent open oceans (e.g., Uvea lagoon in New Caledonia and the Great Barrier Reef lagoon in Australia; Le Borgne et al., 1997; Niquil et al., 1998).

Composition of zooplankton in tropical and subtropical coastal regions can vary on scales of metres; assemblages in mangrove forests, mangrove streams, coral mounds and sandy floor areas vary distinctly (Jacoby and Greenwood, 1988; Robertson et al., 1988). Mangrove systems have been observed to contain higher amounts of meroplankton species than seagrass habitats, which are more similar to habitats further offshore in bay and lagoon areas (Robertson et al., 1988). Reef systems have been observed to comprise a mix of resident, swarming and demersal species, most of which associate with benthic communities during the day, ascending into the water column during the night. The resident demersal component of zooplankton communities on reef systems can be 5-20 times more abundant than pelagic communities (Alldredge and King, 1977; Roman et al., 1990). In the western Pacific Ocean, cyclopoid copepods, such as *Oithona* spp., and calanoid copepods, such as *Parvocalanus* spp., have been recorded as being numerically the most abundant taxa across all habitats (Robertson and Howard, 1978; Saisho, 1985; Jacoby and Greenwood, 1988; Robertson et al., 1988; Roman et al., 1990; Kluge, 1992; Robertson and Blaber, 1993; Le Borgne et al., 1997; McKinnon and Klumpp, 1998; Duggan et al., 2008). Abundances of zooplankton in the tropical coastal waters of northern Peru are some of the highest recorded in the eastern Pacific Ocean and are associated with high primary production resulting from coastal upwelling across the region (Fernández-Álamo and Färber-Lorda, 2006).

Zooplankton communities in tropical and subtropical habitats demonstrate high variability across tidal to seasonal time scales (Jacoby and Greenwood, 1988; Hamner et al., 2007). The biomass of most communities tends to be highest in the austral summer in the western Pacific Ocean and is associated with peaks in primary productivity (see Section 2.1) and seasonal spawning of invertebrate and vertebrate plankton predators. Not all species demonstrate peaks in abundance during the austral summer; some species demonstrate a peak in the austral winter (Jacoby and Greenwood, 1988). In the eastern Pacific Ocean, increased zooplankton in coastal upwelling regions occurs after winter wind-driven production with peaks in October–December (Fernández-Álamo and Färber-Lorda, 2006).

Inter-annually, zooplankton community structure and abundances in tropical and sub-tropical habitats vary in association with rainfall, associated terrestrial run-off and turbulence, water temperatures, adjacent offshore upwelling in the western Pacific Ocean (Robertson et al., 1988; McKinnon and Thorrold, 1993) and inter-annual variability in upwelling in the eastern Pacific Ocean associated with ENSO. Although clear patterns associated with ENSO cycles are not yet established (Alamo and Bouchon, 1987; Fernández-Álamo and Färber-Lorda, 2006), zooplankton abundances have been observed to be higher during ‘‘cold’’ decades, particularly in the 1960s, than more recent ‘‘warm’’ decades and have been associated with regime shifts in fish communities in the region (see Section 2.4; Figure 4; Ayón et al., 2004). Similar shifts in the size distribution of zooplankton have also been observed in the eastern Pacific Ocean with smaller zooplankton dominating during warmer, lower upwelling conditions (Ayón et al., 2011).

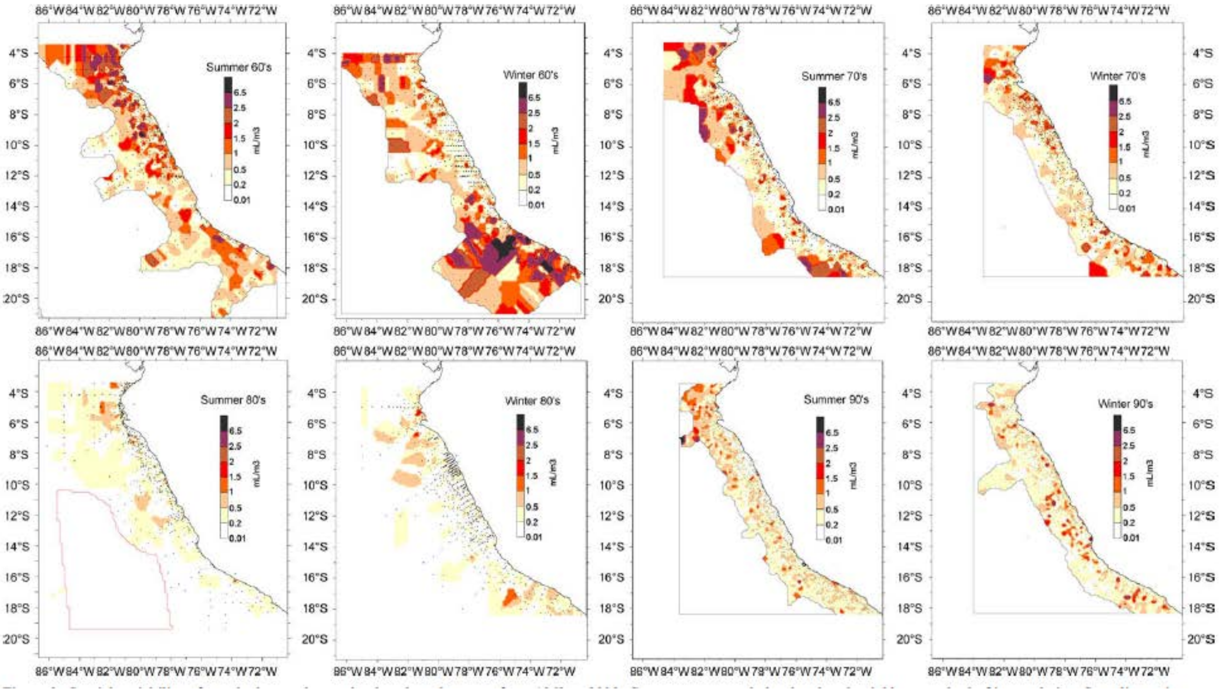

Figure 4. Spatial and temporal variability in zooplankton biomass in the tropical and subtropical coastal waters of the eastern South Pacific Ocean. Reproduced from Ayón et al., 2004.

Zooplankton communities in temperate waters of the South Pacific Ocean, similarly to those in the tropics and sub-tropics, are dominated by copepod species (Tranter, 1962; Bradford, 1972; Escribano et al., 2007). Swarming gelatinous species, such as salps, can also dominate; increased abundance of salps is associated with declines in copepod abundances (Tranter, 1962). In the western South Pacific Ocean, assemblages and abundances are spatially and temporally highly variable, reflecting high variability in the physical features and primary productivity of the EAC. Eddy systems associated with the EAC can contain distinct abundances and assemblages of taxa in comparison to adjacent waters and other eddies, which evolve, becoming less distinct as the eddy ages (Griffiths and Brandt, 1983; McWilliam and Phillips, 1983; Tranter et al., 1983; Young, 1989). Further south, the shelf waters off south-eastern Australia are dominated by the euphausid *Nyctiphanes australis;* peaks in abundance occur in the austral autumn months in association with seasonal upwelling onto shelf regions and resulting peaks in primary production (Young et al., 1996). The temperate zooplankton communities of east New Zealand waters are also typified by *N. australis*, gelatinous zooplankton and copepod species (Jillet, 1971; Jillet, 1976; Bradford, 1972). Peaks in abundance vary between species, but most species have been observed to demonstrate peaks in abundance in the late austral winter/early spring (Bradford, 1972). Shifts in the composition of zooplankton communities from predominantly cold water species to more warm water species have been reported from the shelf waters off south-eastern Australia and have been associated with large shifts in regional oceanography (Johnson et al., 2011).

In the eastern South Pacific Ocean, temperate zooplankton communities are dominated by copepods, euphausids and gelatinous zooplankton (Escribano et al., 2007). Community composition in coastal and shelf regions off Peru tends to correspond with large oceanographic features throughout the region; coastal upwelled waters are comprised of copepod species and meroplanktonic larvae. Waters further offshore are largely comprised of large holopankters, such as euphausids, copepods, siphonophores and chaetognaths (Tarazona et al., 2003; Fernández-Álamo and Färber-Lorda, 2006; Ayón et al., 2011). In the coastal regions of central Chile, where assemblages are influenced by subantarctic waters, copepods dominate offshore shelf regions, whereas euphausids dominate the fjord region (Escribano et al., 2003). Abundances of zooplankton in the region are both strongly and positively associated with the vertical distribution of the oxygen minima zone. Abundances of gelatinous zooplankton have been observed to peak in the austral winter and spring: copepods demonstrate a peak in the austral spring and summer in association with seasonal upwelling conditions. Euphausids, dominated by the endemic *Euphausia mucronata*, demonstrate little seasonal variability in abundances (Gonzalez and Marin, 1998; Escribano et al., 2007). Little inter-annual variability in species assemblages and abundances has been observed in the region, although shifts in species assemblages of zooplankton in coastal Chilean waters have been associated with ENSO phase. Species alternate between copepods and euphausids during upwelling events associated with La Niña and cyclopoid copepods during warmer events associated with El Niño (Hidalgo and Escribano, 2001).

2.3 Benthic communities

Benthic communities across the South Pacific Ocean occupy a diverse range of habitats, including estuaries, mangroves, rocky intertidals, seagrass beds, kelp forests, soft bottoms (ranging from sandy to muddy), coral reefs and rocky reefs, and form one of the richest assemblages of species in the marine environment (Snelgrove, 1999). Many species are subject to recreational, artisanal and commercial fisheries. These include bivalves (e.g., giant clams, scallops) echinoderms (e.g., sea cucumbers, sea urchins) and gastropods (e.g., *Trochus*, abalone). Benthic fish and macro-invertebrates are discussed in Section 2.4.

Given the diversity of benthic community habitats across the South Pacific Ocean, few have been sampled comprehensively. Most assessments have focused on classification and documentation of the sediments or plants forming the basis of a habitat type or on individual species, rather than on benthic community assemblages (e.g., Kennelly, 1987; Heap et al., 2005; Fisher et al, 2011; Waycott et al, 2009). Because of a lack of assessments, surveys often discover previously undescribed species that may only be documented once in a survey (Snelgrove, 1999; Williams et al., 2010). Establishing trends in benthic communities in most regions is at present difficult, in large part due to the sparse data available across all habitat types and the high variability in faunal assemblages associated with each habitat (e.g., Waycott et al., 2005).

Coral reef communities are one of the better documented benthic communities throughout the South Pacific Ocean. Although 75 per cent of the world’s coral reefs are found in the Indo-Pacific region, few long-term trends have been documented for these communities (Bruno and Selig, 2007). Densities of species in coral reef communities exhibit considerable variability spatially across multiple scales and reflect larval dispersion, recruitment success, competition for substrate and local environmental conditions. Community structure within reef communities tends to follow a nutrient gradient and is also associated with proximity to inner lagoon or outer open-ocean regions.

Coral reef assemblages attenuate gradually in diversity with increasing distance from the Coral Triangle; 60 genera of reef-building (hermatypic) corals have been reported at 9˚S in comparison to 18 genera at 30˚S (Wells, 1955; Veron, et al. 1974; Bellwood and Hughes, 2001). Eastern South Pacific coral reefs are low in diversity; however, most species within these communities are unique (Glynn and Ault, 2000). In areas where water temperatures seasonally drop to below 18˚C, hermatypic corals become sparse: coral reef communities give way to rocky reef and soft substrate communities (Veron, 1974). Factors suggested to be associated with attenuation of coral reef communities include water temperature, aragonite saturation, light availability, larval dispersal and recruitment, and competition with other species, including macroalgae (Harriott and Banks, 2002).

Overall, coral communities across the South Pacific Ocean are considered to be generally healthy (Burke et al., 2011), although coral cover is gradually declining (Bruno and Selig, 2007). Exposure and resilience to disturbance vary depending on reef type and location; major drivers of changes in species densities, assemblages and spatial distributions are associated with natural phenomena such as storms and cyclones, outbreaks of natural predators (e.g., crown-of-thorns starfish) and seasonal local coral bleaching events (Chin et al., 2011; Hoegh-Guldberg et al., 2011). Coral reef communities in the eastern South Pacific Ocean recorded the earliest mass bleaching and mortality of any region; widespread losses are linked to high ocean temperature anomalies that occur during El Niño events (Glynn and Ault, 2000; Burke et al., 2011).

Coral cover from reefs in the Indo-Pacific region has been declining relatively uniformly since records began in the 1960s and 1970s; yearly estimates of loss average 1 – 2 per cent over the last 20 years (Bruno and Selig, 2007). Hard coral cover on the Great Barrier Reef has declined from 28.0 per cent in 1985 to 13.8 per cent in 2012; the rate of decline is increasing in recent years (De’ath et al., 2012; Figure 5). Declines have been most severe on reefs south of 20˚S, particularly since 2006, and on areas of inshore reefs which have been documented to have declined by 34 per cent since 2005 (GBRMPA, 2014). Tropical cyclones, coral predation by the crown-of-thorns starfish and coral bleaching have accounted for 48 per cent, 42 per cent and 10 per cent, respectively, of declines observed; elevated loads of nutrients, sediments and pollutants via terrestrial run-off affect reef resilience and the potential for recovery (De’ath et al., 2012; Wiedenmann et al., 2013).

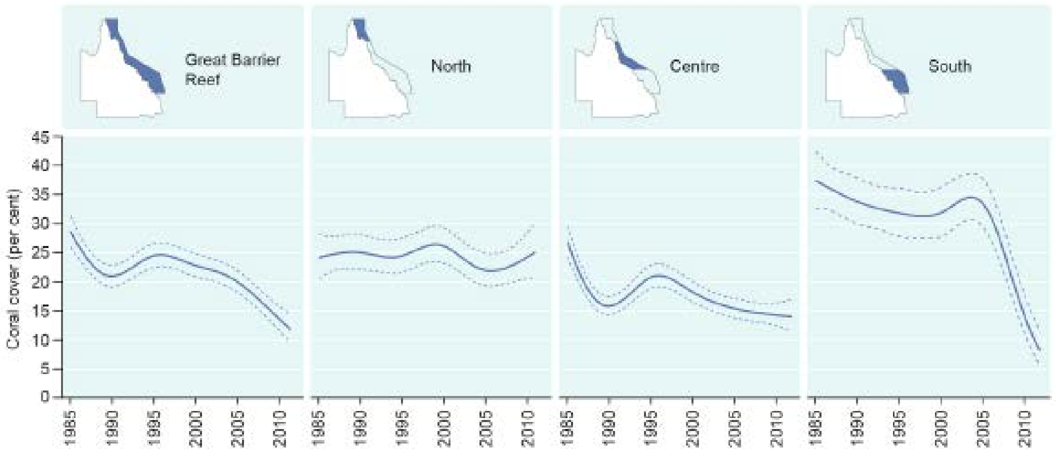

Figure 5. Estimates of hard coral cover across the Great Barrier Reef 1986 – 2012, based on data collected from 214 reefs. Dashed lines represent the standard error. Taken from Great Barrier Reef Marine Park Authority (2014) (modified from De'ath et al. (2012).

Local declines in species densities, assemblages and spatial distributions are increasingly being observed, particularly in areas close to population centres where over-fishing, pollution from terrestrial run-off and sewage, and damage from coastal developments are occurring (see Section 3). Bleaching events are becoming more widespread, increasing in intensity and frequency as surface waters of the South Pacific Ocean warm with long-term climate change (Burke et al., 2011; Chin et al., 2011; Hoegh-Guldberg et al., 2011). Recovery from bleaching events is possible if local factors which affect reef systems, such as coastal runoff and overfishing, are minimized (Figure 6); however, as marine conditions alter with climate change, the ability of coral reefs to recover from bleaching events is expected to decline (see section 3.1; De'ath et al., 2012).

Monitoring of approximately 30 intertidal seagrass meadows along the central and southern coast of the Great Barrier Reef suggests that their overall abundance, reproductive effort and nutrient status have all declined. Although shallow subtidal seagrass meadows are less extensively monitored, many sites also show signs of declines in abundance. Causes for these declines include cyclones and poor water quality (GBRMPA, 2014).

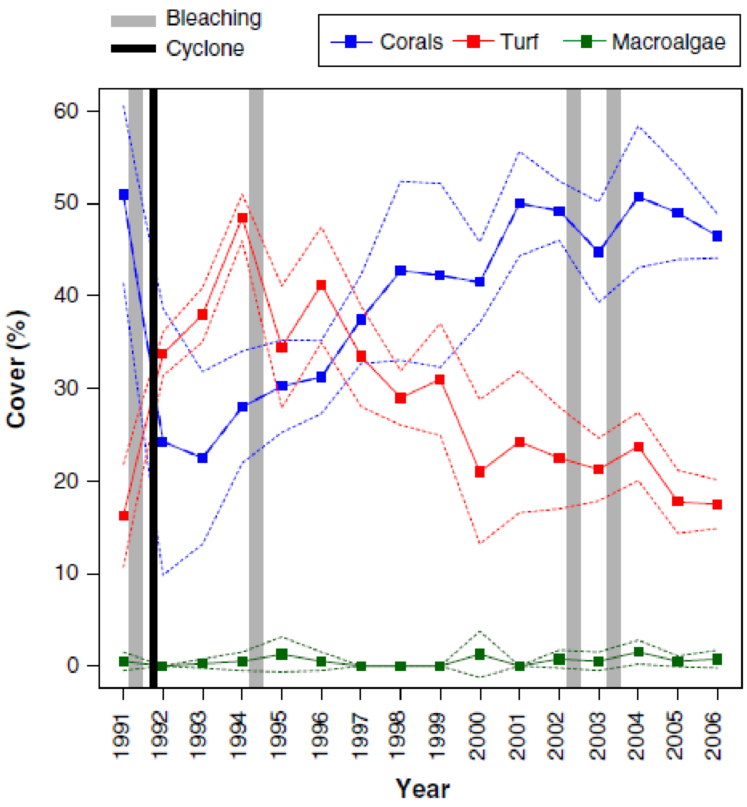

Figure 6. Variation in coral, turf and macroalgal cover at the Tiahura outer reef sector, French Polynesia, 1991 – 2006, in relation to coral bleaching and cyclone events. Dotted lines indicate the standard deviation. Taken from Adjeroud et al., 2009; with permission of Springer.

Across temperate regions, benthic communities of rocky intertidal and rocky reef habitats are reasonably well documented, although studies are often local and only include assessments of a few sites. In the western South Pacific Ocean, subtidal coastlines are typified by patches of common kelp, ascidians and crustose coralline algae barrens, which are often associated with the sea urchin *Centrostephanus rodgersii* (Connell and Irving, 2008). Other herbivores common in these habitats include limpets and topshells (Underwood et al., 1991). Community assemblages vary with depth; sponges, ascidians and red algae are more abundant in deeper sheltered areas (Underwood et al., 1991). In protected areas where removal of urchin predators is restricted and predator populations are provided with the opportunity to increase, sea urchin barrens demonstrate a decline and macroalgal forests are more extensive (Babcock et al., 1999; Shears and Babcock, 2003; Barrett et al., 2009). This suggests that removal of urchin predators (e.g., via fishing) can have widespread effects on community structure in subtidal habitats (Connell and Irving, 2008). Declines in the density of giant kelp beds and increased densities of sea urchins and urchin barrens have also been associated with increased southward larval advection of urchin larvae following shifts in large oceanographic features throughout the south-eastern Australian region (Johnson et al., 2011). Commercial and recreational fishing practices have been associated with declines in benthic communities. Oyster reef communities in south-eastern Australia have been largely destroyed by fishing and mining practices: over 60 per cent are considered functionally extinct, and of the remaining, 90 per cent of the original area of the reef is lost (Beck et al., 2011). The flow-on impacts of such reductions include reduced habitat and food sources for other species and reduced water-filtering capacity, resulting in a reduction in overall water quality (Beck et al., 2011).

Estuarine and coastal soft-sediment benthic communities have been routinely monitored, mostly by councils and unitary authorities, at over 70 sites in New Zealand for up to 25 years (see http://geodata.govt.nz/geonetwork_memp). Time series established demonstrate a wide variety of trends and cycles, and it is difficult to draw overall conclusions. For example, Mahurangi Harbour, which has a predominantly rural catchment, has demonstrated a declining trend in species sensitive to increased sediment loading (Halliday et al., 2013), whereas Manukau Harbour, adjacent to New Zealand's largest city, has demonstrated no declining trends that might indicate that the habitat is becoming degraded (Greenfield et al., 2013). New Zealand is developing a Marine Environmental Monitoring Programme to coordinate and report on the diverse monitoring being conducted.

In temperate regions of the eastern South Pacific Ocean, rocky intertidal communities are dominated by mussel beds, corticated algae and herbivorous gastropods in shallow regions and kelps, crustose algae, chitons and fissurellids in deeper regions (Broitman et al., 2001). Carnivorous gastropods and crustaceans also dominate communities. Latitudinal gradients occur in some species; mussel and crustose algae densities decrease with decreasing latitudes, whereas ephemeral algae increase with decreasing latitudes (Broitman et al., 2001). Further south, recent inventory studies conducted in the relatively easily accessible areas of the Chilean fjord region have documented that over 30 per cent of the sampled specimens represent new species; 10 per cent of these are in benthic communities (Häussermann and Försterra, 2009). Many of the species documented exhibited unexpected distribution patterns: for example, species thought to be limited to the Peruvian faunal province were discovered far to the south; others, presumed to be subantarctic, were present in northern Chilean fjords, and deep water species were found in shallow depths of the fjords (e.g., Försterra et al., 2005). The species richness of several benthic taxa has been observed to decrease with increasing latitude and then increase again south of 40-45˚S. This is possibly associated either with an increase in the presence of Antarctic fauna or an increase in habitat with the broadening of the continental shelf south of 40˚S (Escribano et al., 2003).

Temporal changes in the density and assemblage of benthic communities have been observed at two long-term sites in the Chilean fjord region. Within the Comau Fjord, mussel banks, meadows of sea whips, sea anemones, large calcified bryozoans and the rare gorgonian *Swiftia* n. sp. have reduced by at least 50 per cent and in some cases, completely disappeared. Associated decapod species have also experienced declines in abundance (Häussermann et al., 2013). Declines in biodiversity in this fjord are thought to be associated with increased mussel harvesting in the area, eutrophication, increased organic sedimentation and the extensive use of chemicals in aquaculture operations (Häussermann et al., 2013; Forsterra et al., 2014; Mayr et al., 2014).

Further detail on estuaries, mangroves, kelp forests, seagrass and corals can be found respectively, in chapters 44, 48, 47 and 42-43.

2.4 Fish and macro-invertebrates

Fish and macro-invertebrates occurring in coastal and shelf regions of the South Pacific Ocean range from highly resident species (e.g., cardinal fishes, Apogonidae; wrasses, Labridae), species that move relatively small distances, but utilize multiple habitats during their lifespan (e.g., penaeid prawns; yellowfin bream, *Acanthopagrus australis*), pelagic species that roam shelf waters extensively (e.g., Australian salmon or kahawai *Arripis* spp., white sharks, *Carcharodon carcharias*), to highly migratory pelagic species that utilize shelf regions periodically or seasonally (bigeye tuna, *Thunnus obesus*; southern bluefin tuna, *T. maccoyii*). A few species are anadromous (e.g., shorthead and pouch lampreys, Mordaciidae) and some are catadromous (e.g., barramundi, *Lates calcarifer*; short-finned eel, *Anguilla australis*).

Time series of indicators of populations are largely limited to species that are the focus of recreational/sport, subsistence and commercial fisheries and are subject to varying degrees of management (Bates et al., 2014). Subsistence fishing tends to be more important in rural areas throughout the South Pacific Ocean and is much larger than commercial fishing in these areas (Dalzell et al., 1996; Kulbicki et al., 1997). In the Pacific Islands region, where fish consumption in some countries is at least twice the level needed to supply 50 per cent of the recommended protein requirements, 60 – 90 per cent of fish consumed is caught by subsistence fishers (Bell et al., 2009). Across much of the rest of the South Pacific Ocean, and in the shelf areas of the Pacific Island region, commercial fishing is much larger than subsistence or recreational fishing.

Small-scale subsistence and commercial reef fisheries across the Pacific Island region and coastal commercial fisheries in Ecuador and northern Peru can catch up to 200 – 300 species (Dalzell et al., 1996; Heileman et al., 2009; FAO, 2010). The primary fish families important to Pacific Island communities are the Acanthuridae (surgeonfish), Scaridae (parrot fish), Lutjanidae (snapper), Lethrinidae (emperor fish) and Balistidae (triggerfish; Dalzell et al., 1996; Pratchett et al., 2011). A number of fish species are also commercially fished for the live reef food and the aquarium trade. Macroinvertebrates of importance include sea cucumbers (22 species are commercially caught across the region for the production of bêche-de-mer), trochus (*Trochus* spp.), green snail (*Turbo marmoratus*), giant clams (*Tridacna* spp.), cephalopods (primarily cuttlefish and octopus) and crustaceans (penaeid prawns, crabs, lobsters). Commercial pearl oyster aquaculture operations occur in the eastern (Melanesian) part of the Pacific Islands region; two-thirds of all production occurs in French Polynesia (Dalzell et al., 1996). Species of importance in the eastern South Pacific include silverside (*Odontesthes regia*), flathead grey mullet (*Mugil cephalus*), lorna drum (*Sciaena deliciosa*), Peruvian scallop (*Argopecten purpuratus*), and the cephalopods *Loligo gahi* and *Dosidicus gigas* (FAO, 2010).

Reef fish abundances are influenced by the extent and condition of coral cover, and can vary two- to ten-fold over time, largely in association with loss and subsequent recovery of coral reef habitat following storm events (Halford et al., 2004; Kulbicki et al., 2007; Wilson et al., 2008; Brewer et al., 2009). Macro-carnivores, micro-herbivores and plankton feeders show some of the highest variability (Kulbicki, 1997).

A large-scale assessment of coral reef fish and invertebrate communities in 17 Pacific Island countries and territories found that across 63 sites, less than one-third of the sites had resources that were in good condition; most were in average/low or poor condition (Pinca et al., 2009). Herbivores and smaller fish were more abundant in reefs of below average condition, whereas reefs in good condition had higher biomasses of carnivores and greater numbers of larger fish (Pinca et al., 2009). More recently an assessment of the status of reef fish assemblages on fished reefs estimated that reef fish assemblages around Papua New Guinea were at a point indicating fisheries collapse (Mac Neil et al., 2015). Declines have also been observed in sea cucumber species, giant clam and *Trochus* spp. Sea cucumber fisheries in Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga and Vanuatu have been closed due to overfishing (Purcell et al., 2013). Some species of giant clam have been declared extinct in a number of countries and all giant clam species are now listed under Appendix II of the Convention of International Trade in Endangered Species[1] (CITES), which covers species that may become threatened if their trade is not effectively regulated (Pinca et al., 2009). Formal monitoring and regulation of coastal fishery resources is largely lacking throughout the region, particularly for subsistence fisheries resources (Dalzell et al., 1996; Gillett, 2010). Landings that are reported are considered to be underestimates; reconstructed catches from coral fisheries in American Samoa have been estimated to be 17-fold greater than those officially reported (Zeller et al., 2006).

Large components of tropical reef systems along eastern Australia are managed as part of the multiple use Great Barrier Reef Marine Park, some of which is open to commercial, recreational and traditional fishing for a range of fish (for food and the live aquarium trade), crustaceans (penaeid prawns, crabs, lobsters), sea cucumbers, trochus, beach or sand worms and live coral. Monitoring of 214 fish populations in the Great Barrier Reef Marine Park since the 1990s indicate high inter-annual variability (Figure 7); population declines are associated with a declining coral cover, particularly in southern parts of the park, where coastal development is greatest (GBRMPA, 2014). Overall abundance and size of commercially caught species have declined when compared to historical abundance and size; the fishery for black teatfish sea cucumber (*Holothuria whitmaei*) was closed in 1999 (GBRMPA, 2014). Illegal fishing is known to occur in areas closed to fishing and is likely to have contributed to overall declines in fish populations. Recreational fishing catches throughout the marine park are largely unmonitored; however, in 2010 an estimated 700,000 recreational fishers throughout Queensland caught over 13 million fish, approximately half of which were returned to the water (Taylor et al., 2012). Recreational catches appear to have been declining over the last decade.

Temperate fish and macro-invertebrates are also affected by the physical and biological attributes of temperate habitats (De Martini and Roberts, 1990; Curley et al., 2003; Anderson and Millar, 2004). Spatial variability in assemblages has been associated with type of reef habitat (e.g., urchin barren, kelp forest, sponge habitat), benthic topography and depth (Williams and Bax, 2001; Curley et al., 2003; Hill et al., 2014). Long-term changes in temperate fish assemblages have been observed in

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[1] United Nations, *Treaty Series,* vol. 993, No. 14537.

eastern Australia, associated with fishing, introduced alien species and ongoing changes to the marine environment as a result of climate change and coastal development (Last et al., 2011; State of the Environment Committee, 2011; Bates et al., 2014).

Coastal waters of the tropical eastern Pacific are some of the least explored in the region (Cruz et al., 2003; Zapata and Robertson, 2007); approximately 70 per cent of fish are endemic to the region. The unique oceanographic conditions and heterogeneity of the coastal regions of Chile have resulted in high levels of endemism in many invertebrate groups (Griffiths et al., 2009; Miloslavich et al., 2011). Endemism is also high in the waters of small oceanic islands in the eastern South Pacific Ocean; approximately 77 per cent of the fish at Easter Island, 73 per cent at Salas y Gómez, 72 per cent at Desventuradas and 99 per cent at the Juan Fernández Archipelago are endemic (National Geographic/Oceana/Armada de Chile, 2011, Friedlander et al., 2013; National Geographic/Oceana, 2013). Most of the oceanic islands of the eastern South Pacific are thought to have relatively healthy biomasses of fish and macro-invertebrates, with the exception of Easter Island, where fisheries have been operating for over 800 years (Hunt and Lipo 2011). Within the last three decades, a dramatic decrease in the marine resources of Easter Island has been observed; this is largely associated with overexploitation, increasing tourist numbers with associated increases in demand for resources, illegal industrial fishing and lack of surveillance and enforcement procedures (Gaymer et al., 2013).

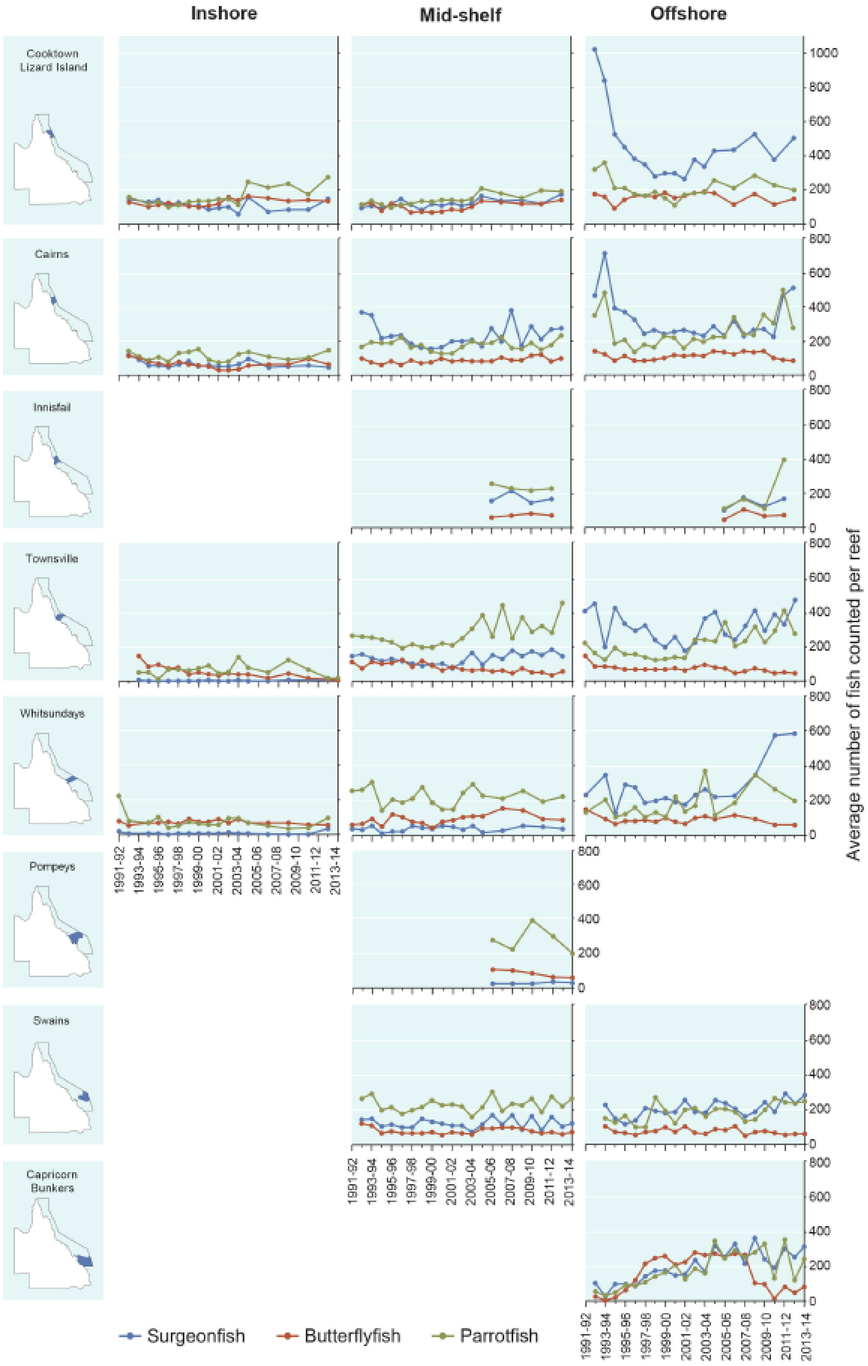

Figure 7. Time series of the abundance of some coral reef fish species in the Great Barrier Reef Marine Park 1991 – 2003. Taken from Great Barrier Reef Marine Park Authority (2014) and adapted from Australian Institute of Marine Science Long-term Monitoring Program (2008 and 2014).

Shallow reef habitats of the Galápagos archipelago are reported to have undergone major transformation as a result of the severe 1982/1983 El Niño warming event, resulting in local and regional decline in biodiversity, including a number of identified extinctions (Edgar et al., 2010). Artisanal fishing for lobster and fish species is thought to have magnified the impacts of the El Niño event; the grouper *Mycteroperca olfax* is characterized as functionally extinct in the central Galápagos region (Ruttenberg, 2001; Okey et al., 2004). Commercial fishing within the Galápagos Islands reserve has been largely banned from the area, except for artisanal fishing, which has been allowed in the reserve since 1994. The region has been subject to extensive illegal fishing for sharks, sea cucumber and a range of fish in the region and a lack of controls on or enforcement of management measures for artisanal fishing and a lack of credible assessment of stocks have resulted in over-exploitation (Hearn, 2008; Castrejón et al., 2013).

Coastal regions of Ecuador and northern Peru have been the site of extensive shrimp (penaeid prawn) mariculture operations since the 1960s. The establishment of these operations has been responsible for extensive reduction in mangrove forests and associated fish and invertebrate populations (Bailey, 1988; Primavera, 1997).

A diverse range of fish and macro-invertebrate species are targeted by fisheries in the coastal waters of Chile, including molluscs, gastropods, echinoderms, cephalopods and fish. Fisheries catches in general were low prior to the 1980s, reflecting low levels of effort and predominantly local consumption of catches. During the 1980s, export markets grew and catches increased substantially. Catches of many invertebrate species subsequently declined and have remained at low levels since (Thiel et al., 2007). Many species targeted by coastal fisheries demonstrate fluctuations in abundances linked to El Niño/Southern Oscillation (ENSO) (e.g., Wolff, 1987).

A wide range of fish and macro-invertebrate species are the focus of commercial and recreational fisheries in Australia and New Zealand; most coastal and shelf stocks are considered to be sustainably fished (e.g., MPI, 2013; Andre et al., 2014). For example, of 93 stocks managed at the national level in Australia, 77 (83 per cent) were considered as not subject to overfishing, four were considered to be subject to overfishing and 12 were considered as uncertain (Woodhams et al., 2013). In New Zealand, 99 of 114 (87 per cent) were considered as not subject to overfishing. The proportion of assessed stocks experiencing overfishing declined from 25 per cent in 2009 to 13 per cent in 2013 (MPI, 2013). Inshore stocks are the least assessed in New Zealand waters, particularly inshore fish species. Species of ongoing concern tend to be long-lived, slow-maturing species which have been subject to a number of decades of fishing, such as southern bluefin tuna, orange roughy (*Hoplostethus atlanticus*) and school shark (*Galeorhinus galeous*). Species that are caught in lesser amounts and non-targeted species are not routinely assessed and as a result the status of populations is largely unknown (Woodhams et al., 2013; MPI, 2013). In Australian waters, the grey nurse shark (*Carcharias taurus*) is listed as critically endangered, the white shark (*Carcharadon carcharias*), black rockcod (*Epinephelus daemelii*), and the whale shark (*Rhincodon typus*) are listed as vulnerable, and orange roughy, gemfish (*Rexea solandri*), southern bluefin tuna and several shark species, including school shark, have been listed as conservation-dependent under the Environment Protection and Biodiversity Conservation Act 1999.

Recreational fisheries are subject to variable levels of assessment and monitoring and most are regulated only via size and bag limits. In some areas (e.g., New South Wales, Australia) and for some species recreational fishing licenses are required. In Australia, recreational catches of many highly sought-after species are thought to be larger than commercial catches (State of the Environment Committee, 2011). Catches of snapper (*Chrysophrys auratus*), which comprise New Zealand's largest recreational fishery from the north-east coast of the North Island, were 3,750 t in 2011/12, similar to commercial landings (Hartill et al., 2013). The first reliable and comprehensive assessment of recreational harvest across all stocks in New Zealand was completed in 2013 (Hartill et al., 2013). Populations of commercially exploited fish and macro-invertebrates in the temperate coastal regions of New Zealand are considered mainly to be in good condition (Mace et al., 2014).

Offshore fisheries resources in tropical, sub-tropical and temperate shelf regions of the western and central South Pacific Ocean largely consist of commercial operations targeting tuna and billfish species, as well as a number of other large pelagic species, such as mahi mahi (*Coryphaena hippurus*), rainbow runner (*Elegatis bipinnulata*), wahoo (*Acanthocybium solandri*) and Spanish mackerel (*Scomberomorus commerson*), and small pelagic species, such as flying fish, pilchards and sardines. Several shark species are either directly targeted or caught as by-catch. Across the Pacific Island region, pelagic fish species are estimated to contribute on average up to 28 per cent of coastal fisheries production (range 10 – 70 per cent; Pratchett et al., 2011). This proportion is likely to increase as increasing populations lead to further exploitation of pelagic species by coastal populations (Bell et al., 2009).

All of the tuna and billfish species, that comprise the majority of commercial catches in the Western and Central Pacific Fisheries Commission (WCPFC) area, except bigeye tuna, are not considered to be in an overfished state, although recent catches of skipjack tuna (*Katsuwonus pelamis*) and yellowfin tuna (*T. albacares*) are at levels that marginally exceed maximum sustainable yield and catches of swordfish (*Xiphias gladius*) are at levels that exceed maximum sustainable yield (Hoyle et al., 2012; Davies et al., 2013; Davies et al., 2014; Rice et al., 2014). In the Inter-American Tropical Tuna Commission (IATTC) area in the eastern Pacific Ocean, all of the main tuna and billfish species are not considered to be in an overfished state, although some uncertainty exists as to whether current catches of skipjack tuna are at levels that exceed maximum sustainable yield (IATTC, 2012; IATTC, 2014). Catches of species other than the main tuna and billfish species that comprise the majority of commercial catches are largely unmonitored and so the status of populations and ongoing sustainability of resources is unknown. Recent assessments of shark species caught in substantial numbers throughout the WCPFC and IATTC areas have indicated that fishing mortalities are well above those considered to be sustainable (e.g., Rice and Harley, 2013; IATTC, 2013). Current catches of most small pelagic species throughout the Pacific Island region are considered to be sustainable (Blaber, 1990; Pratchett et al., 2011).

Pelagic fisheries in the eastern South Pacific have been responsible for approximately 10 – 20 per cent of the world landings over the last 50 years (Chavez, 2008; Fréon et al., 2008) and are dominated by the anchoveta fishery, which primarily targets anchovy (*Engraulis ringens*) and sardine (*Sardinops sagax*). Jack mackerel (*Trachurus murphy*), chub mackerel (*Scomber japonicus*) and, in the southern Peru-Chile region, a herring-like sardine (*Strangomera bentincki*) also sustain important pelagic fisheries. Fisheries across the region also target the common hake (*Merluccius gayi*), swordfish, tunas, cephalopods, primarily *D. gigas,* and a number of crustaceans. The Chilean fjord region is an important region for catches of gadiform fishes, such as Patagonian grenadier (*Macruronus magellanicus*) and the southern hake (*Merluccius australis*; FAO, 2011). Variability in the population size and distributions of anchovies and sardines in the waters of the eastern South Pacific Ocean and linkages with environmental variability have been well documented (e.g., Arntz and Tarazona, 1990; Ayón et al., 2004; Bertrand et al., 2004; Cubillos et al., 2007) and are now recognised to be associated with short-term dynamics associated with ENSO and longer-term dynamics associated with decadal climate variability (Alheit and Nuiquen, 2004; Fréon et al., 2008). The two northern anchovy stocks appear to not be overfished, whereas the southern stock is considered to be depleted and estimated to be at around 8 per cent of virgin stock biomass (Fish Source, www.fishsource.com, accessed 17 August 2014). Currently no recovery plan is in place for this fishery. Fisheries for sardine are based on four stocks: northern, central and southern Peru and northern Chile. Stocks between Peru and Chile are assessed independently and management measures are not co-ordinated between the two countries.

For many other species subject to commercial catches, information on important biological parameters (larval ecology, spawning, movements) is lacking and consequently, little is known about the effects of inter-annual variability in oceanographic conditions on their population dynamics (Thiel et al., 2007). Artisanal fishing, which comprises a significant proportion of the total fishing effort in the region, is largely unreported and is unregulated across the region. Most fisheries throughout the region, other than those mentioned above, are considered to be over-exploited (De Young, 2007).

Further detail on sharks and other elasmobranchs and tuna and billfish can be found in chapters 40 and 41.

2.5 Other Biota

The South Pacific Ocean contains a diverse assemblage of marine mammals, seabirds and marine reptiles, most of which have been subject to some level of direct and indirect harvesting (SPREP, 2012). The region contains the northernmost populations of penguins and fur seals, both of which breed on the Galápagos Islands, breeding populations of six of the seven species of sea turtles and populations of the only sirenian in the family Dugonidae. Although harvesting of many of these species has been either banned or limited in many countries across the region and protection measures have been put in place for some species in some countries, many species interact with commercial fishing operations (e.g., Table 1) and for some, this is a substantial source of mortality (Waugh et al., 2012; Reeves et al., 2013; Richard and

Abraham, 2013; Wallace et al., 2013; Lewison et al., 2014). Populations of species throughout the region demonstrate varying trends as a result.

Overall, global populations of sea turtles are considered to have declined (Wallace et al., 2011) with those that occur in the South Pacific Ocean demonstrating varying trends. Two distinct genetic stocks of green turtles (*Chelonia mydas*) occur within the Great Barrier Reef Marine Park which experience different pressures and demonstrate differing population trajectories. The southern stock has demonstrated a consistent increase in population size, whereas the northern stock may be in the early stage of decline (GRMPA, 2014). The loggerhead turtle (*Caretta caretta*) population is increasing after substantial decline, whereas the hawksbill turtle (*Eretmochelys imbricata*) population has declined and the flatback turtle (*Natator depressus*) population has remained stable (GRMPA, 2014). Little is known of the current population status of leatherback turtles (*Dermochelys coriacea*), which are known to nest in Papua New Guinea, the Solomon Islands and Vanuatu in the western South Pacific Ocean, but regionally they are considered to be in decline (Dutton et al., 2007). In the eastern Pacific Ocean, leatherback, green and hawksbill turtles nest along the coast in Ecuador, with vagrant nesting sites occurring in Peru. Large numbers are caught in small-scale fisheries off the coasts of Ecuador and Peru (Alfaro-Shigueto et al., 2011).

Table 1. Fisheries interactions with species of conservation concern 2006 – 2012. Reproduced from Great Barrier Reef Marine Park Authority (2014) using data from Queensland Department of Agriculture, Fisheries and Forestry (2013).

SPECIES	**COMMERCIAL FISHERY GEAR TYPE**			
	Otter trawl	**Net**	**Line**	**Pot**
Green sawfish	•			
Narrow sawfish	•	•		
Leafy seadragon	•			
Unspecified seahorse	•			
Unspecified seasnake	•	•	•	
Estuarine crocodile		•		
Unspecified crocodile		•		•
Flatback turtle	•			
Green turtle	•	•		
Hawksbill turtle	•	•		
Loggerhead turtle	•	•		
Unspecified marine turtle	•	•	•	
Seabird: gannets and boobies	•			

Dugong		•		
Offshore bottlenose dolphin		•	•	
Humpback whale		•	•	
Minke whale			•	

International protection and management of saltwater crocodile populations in Australia and Papua New Guinea after periods of commercial harvesting have resulted in increases in populations to pre-exploitation levels (Thorbjarnarson, 1999; Tisdell and Swarna Nantha, 2005). Few data on the population abundances of sea snake species are available, despite substantial numbers being caught in fishing operations (e.g., Milton 2001; Wassenberg et al., 2001). What data have been collected indicate population declines (Goiran and Shine, 2013).

Most large cetaceans occurring in coastal and shelf regions throughout the South Pacific Ocean are seasonal visitors, spending large periods of time in offshore regions (e.g., Birtles et al., 2002; Hucke-Gaete et al., 2004; Olavarría et al., 2007). Of those species that historically have been subject to widespread commercial harvesting, some populations have been documented to be increasing, while the status of others in the South Pacific Ocean region is still uncertain (e.g., Baker and Clapham, 2004; Branch et al., 2007; Magera et al., 2013). Smaller coastal cetacean species, although largely lacking in population data, are considered to demonstrate varying trends: some are relatively stable and others are decreasing (e.g., Gerrodette and Forcada, 2005; Parra et al., 2006; Currey et al., 2009). Dugong (*Dugong dugon*) populations across the western South Pacific are considered to be declining, although estimates of abundance are lacking for most countries (Marsh et al., 1995; Marsh et al., 1999; Marsh et al., 2002). Fisheries for the species throughout the region are considered to be unsustainable (Marsh et al., 1997; Garrigue et al., 2008). Most pinniped populations, although substantially reduced due to commercial exploitation during the 1800s, are considered in some areas to be increasing at varying rates in temperate regions, whereas in others they may be decreasing (e.g., Kirkwood et al., 2010; Robertson and Chilvers, 2011). Seabirds throughout the region demonstrate varying trends; most species that forage in offshore regions are considered to be decreasing (e.g., Majluf et al. 2002; Baker and Wise, 2005).

Further details on marine mammals, marine reptiles and seabirds can be found in chapters 37-39.

3. Major pressures

3.1 Climate change and oceanographic drivers

Changes to ocean environments occurring as a result of long-term changes to the global climate are likely to be highly variable across the South Pacific Ocean. Ocean temperatures have risen across most of the South Pacific Ocean over the last century and are expected to continue to rise into the future (IPCC 2014). Inter-comparison of climate models used to explore future changes to the global climate under emission scenarios (see Taylor et al., 2012) has identified numerous biases in ocean parameters, both within and across models. These biases are particularly evident in the tropical Pacific Ocean and are associated with difficulties in simulating sea-surface temperatures, precipitation and salinity (Sen Gupta et al., 2009; Ganachaud et al., 2011). Use of a multi-model mean derived from models used in inter-comparisons considerably reduces these biases, although certain regions still retain sizeable biases, indicating systematic biases across models (Sen Gupta et al., 2009). In particular, the eastern tropical Pacific cold tongue is placed too far west and the South Pacific Convergence Zone is too elongated towards the east, resulting in biases in precipitation and ocean surface salinity, which has implications for projections of climate relating to a number of Pacific Islands. Along the Chilean shelf edge, problems with the representation of local atmospheric processes and upwelling lead to biases in cloud formation and radiative heat transfer, with flow-on impacts on ocean salinity (Randall et al., 2007; Sen Gupta et al., 2009; Brown et al., 2013Ganachaud et al. 2013). The resolution at which most climate models are run does not take into account processes occurring in the near-coastal ocean, so pressures and associated projections derived from climate models are extrapolated from observations made offshore (Rhein et al., 2013). This is particularly problematic for projections relating to islands in the South Pacific Ocean and also for mesoscale and submesoscale processes that are important for delivering nutrients to the photic zone (Ganachaud et al., 2011). Bearing in mind the biases and the resolutions of current models, a summary of observed and projected changes to the South Pacific Ocean are presented here.

Projections of surface temperatures are robust at a large scale and suggest a warming rate of the surface ocean during the 21st century that is approximately seven times that observed in the 20th century (Sen Gupta et al., 2015). Within the South Pacific Ocean, the western tropical Pacific Ocean is projected to warm and the region associated with the EAC and its extensions is projected to undergo enhanced warming (Cravatte et al., 2009; Ganachaud et al. 2013.). Intensification of south-easterly trade winds in the eastern South Pacific Ocean region will result in weakened warming (Sen Gupta et al., 2015).

Observations of surface salinity within the subtropical gyre in the South Pacific Ocean have demonstrated an increasing trend, particularly in the east, whereas in the equatorial WWP, surface waters have freshened (Durak and Wijffels, 2010). Model projections suggest an increase in rainfall across tropical latitudes in association with increased evaporation and enhanced convection, which will have implications for ocean salinity in these regions. The area of the WWP in the tropical western Pacific Ocean is projected to continue to freshen and the area of relatively fresher water is projected to move east (Cravatte et al., 2009; Ganachaud et al. 2013). At mid-latitudes, rainfall is projected to decrease, particularly over the central and eastern Pacific Ocean, which will result in increasing surface salinity (Ganachaud et al., 2011).

Changes in wind stress forcing over the past two decades has resulted in changes in circulation in the South Pacific Ocean (Rhein et al., 2013). The southern limb of the South Pacific subtropical gyre and the subtropical cells have intensified in response to intensification of Southern Hemisphere westerlies. In addition, the gyre and cells have moved poleward (Roemmich et al., 2007; Rhein et al., 2013). This has also resulted in a southward expansion of the EAC into the Tasman Sea (Ridgway, 2007; Hill et al., 2008). These wind-driven changes are most likely due to inter-annual to decadal variability (i.e., intensification of the Southern Annular Mode); time series are currently not substantial enough to determine longer-term trends (Ganachaud et al., 2011; Rhein et al., 2013). Interactions between large scale oceanographic and atmospheric processes and island topography are expected to have local effects on the waters surrounding islands in the South Pacific Ocean; however, local projections of confidence are scarce (Ganachaud et al., 2011).

The combined effect of changes to surface temperature and salinity will result in changes to the stability of the water column and the level of stratification. The level of stratification of the water column affects the potential for vertical exchange of ocean properties, such as oxygen or nutrients, which has flow-on effects for primary productivity (Ganachaud et al. 2011; 2013). Surface warming of the tropical South Pacific, in combination with freshening in the WWP, have resulted in an increase in stratification over the upper 200 m (Cravatte et al., 2009). Stratification is projected to continue being most pronounced in the WWP and the South Pacific Convergence Zone (Ganachaud et al., 2011; 2013). In conjunction, the annual maximum depth of the mixed layer is projected to shoal across most of the tropical South Pacific Ocean (Ganachaud et al. 2013). Although the mixed layer depth is expected to shoal, in the eastern South Pacific Ocean this is not expected to affect primary production. This is because nitrate concentrations due to upwelling processes are still likely to exceed levels at which the supply of iron currently limits phytoplankton growth (Le Borgne et al., 2011). Within the western South Pacific Ocean, use of high-resolution ocean models has suggested that projected increased mixing due to changes in currents (which are not fully resolved in lower-resolution models), will result in increased subsurface primary production. This is expected to result in close to no change in overall net primary production throughout the region (Matear et al., 2015).

Oxygen concentrations in the tropical South Pacific Ocean thermocline have decreased over the past 50 years in association with changes in oxygen solubility (resulting from warming), ventilation and circulation. This has resulted in a major westward expansion of oxygen minimum waters in the eastern Pacific Ocean (Stramma et al., 2008). Recent observations for the period 1976–2000 have shown that dissolved oxygen concentrations have declined at a faster rate in the coastal ocean than in the open ocean and have also occurred at a faster rate than in the period 1951 – 1975 (Gilbert et al., 2010). Projected changes to surface temperatures and stratification are likely to result in a decreased transfer of oxygen from the atmosphere, resulting in lower concentration of oxygen in waters above the thermocline across the tropics (Ganachaud et al., 2011). Existing oxygen minimum waters in the eastern South Pacific Ocean are projected to intensify (Ganachaud et al., 2011), although uncertainty in model projections limits projections associated with the evolution of oxygen concentrations in and around oxygen minimum zones (Ciais et al., 2013). Outside the tropics, trends in oxygen concentrations are less obvious (Keeling et al., 2010), but it is expected that warming of the ocean will result in declines in dissolved oxygen in the ocean interior (Rhein et al., 2013). In coastal regions, because hypoxia is largely driven by eutrophication and is therefore controlled by the flow of nutrients from terrestrial origins, any increase in nutrient run-off associated with increasing agriculture or industrialization of coastal regions will also result in increasing coastal water deoxygenation (Rabalais et al., 2010; Ciais et al., 2013; see also section 3.2).

Observations of carbon concentration in the ocean demonstrate considerable variability associated with seasonal, interannual (associated with ENSO) and decadal (associated with the Pacific Decadal Oscillation) changes in wind and circulation (Rhein et al., 2013). Taking into account this variability, trends in surface ocean carbon dioxide have increased, resulting in a decrease in surface pH. This decrease varies regionally: the subtropical South Pacific Ocean demonstrates the smallest reduction in pH (Rhein et al., 2013). Continued increased storage of carbon dioxide in the ocean will result in further decreases in the pH of the ocean; surface ocean pH is projected to decrease by 0.06 – 0.32 depending on the emission scenario used in projections (Ciais et al., 2013). Generally, projected changes to pH are greatest at the ocean surface; surface waters are projected to become seasonally corrosive to aragonite at higher latitudes in one to three decades. In the subtropics, however, the greatest changes to pH are projected to occur at 200 – 300 m where lower carbonate buffering capacity results in lower pH, although carbon dioxide concentration might be similar to that at the surface (Orr, 2011). The horizon separating shallower waters supersaturated with aragonite from deeper under-saturated waters will shoal, resulting in a decline in the global volume of ocean with supersaturated waters (Steinacher et al., 2009). In areas of freshwater input (e.g., around river mouths), reduction in pH and the aragonite saturation state will be exacerbated (Ciais et al., 2013). Overall, projected decreases in pH will be greater at higher latitudes than at lower latitudes (Le Borgne et al., 2011).

Taking into account inter-annual fluctuations associated with ENSO, time series of global sea level measurements demonstrate that mean sea level has risen at a rate of 1.7 mm yr^{-1} over the last century in association with ocean warming and redistribution of water between continents, ice sheets and the ocean (Church and White, 2011; Church et al., 2013). This rate has increased over the last two decades (to a mean rate of 3.2 mm yr^{-1}), but it is unclear whether or not this reflects decadal variability or an increase in the long-term trend (Church et al., 2013). In the western Pacific Ocean, sea level has risen up to three times the rate of global sea level over the last two decades, largely in association with intensified trade winds which may be related to the Pacific Decadal Oscillation (Merrifield et al., 2012). Increases in mean sea level have resulted in an increase in sea-level extremes. Short-term drivers of sea level (e.g., tides) are not projected to change substantially, whereas longer-term drivers (e.g., ice melt, thermal expansion of the ocean) are projected to continue. Over the next century the rate of global mean sea-level rise is expected to increase to 4.4 – 7.4 mm yr^{-1} depending on the emission scenario used, noting that the rate of regional sea level rise can differ from the global average by more than 100 per cent as a result of climate variability (Church et al., 2013). In the South Pacific Ocean, coastlines are projected to experience an increase in sea level from approximately 0.3 m to over 0.8 m by 2100 depending on the emission scenario used and noting that projections of land-ice melt have large uncertainties. These uncertainties result in considerable variability in projected patterns of sea-level change between climate models (Church et al., 2013).

At present little evidence exists of any trend or long-term change in tropical or extra-tropical storm frequency or intensity in the South Pacific Ocean (Rhein et al., 2013). Increases in observed sea-level extremes have primarily been associated with an increase in mean sea level rather than the level of storminess (Church et al., 2013; Rhein et al., 2013). Across the South Pacific Ocean, the monsoon area is projected to expand over the central and eastern tropical Pacific and the strength of monsoon systems is projected to increase. Monsoon seasons are also likely to lengthen and so precipitation throughout tropical regions is projected to increase (Christensen et al., 2013). However, because the South Pacific Convergence Zone is projected to move to the northeast, precipitation over many South Pacific islands is projected to decrease. Projections of tropical cyclones suggest that although the global frequency of cyclones is likely to remain the same, their intensity is likely to increase and a poleward shift in storm tracks is likely, particularly in the Southern Hemisphere. Regional projections are not yet well quantified; many climate models fail to simulate observed temporal and spatial variations in tropical cyclone frequency (Walsh et al., 2012). As a result, projections of the frequency and intensity of cyclones at the level of ocean basins are highly uncertain and confidence in projections is low (Christensen et al., 2013).

The potential impacts of changes to the physical and chemical structure of the South Pacific Ocean and on the biodiversity of the region will depend on the capacity of organisms to adapt to these changes over the time scales at which they are occurring. As waters warm, some species are expected to alter their distribution and already evidence exists that some species have extended their distributions poleward in line with warming trends in the South Pacific Ocean (Sorte et al., 2010; Last et al., 2011). The introduction of new species into regions via expansion of their distribution has the potential to alter marine communities and it is likely that at least some marine communities will undergo major changes to their community structure (Hughes et al., 2003). Conversely, other species may demonstrate range contraction as range edges become thermally unsuitable and the time scales at which changes are occurring exceed the adaptive ability of species (e.g., Smale and Wernberg, 2013). For example, it is likely that the latitudinal and bathymetric range of kelp communities will become restricted. Although other species might replace these climatically sensitive species, reductions in kelp production will have important consequences for the communities that rely on them and other near-shore habitats that depend on the export of kelp detritus (Harley et al., 2006).

Bleaching events as a result of thermal stress induced by higher ocean temperatures, in combination with a reduced ability of corals to calcify due to ocean acidification, are expected to result in steep declines in coral cover across the South Pacific Ocean over the next decades, even under good management (Figure 8; Hughes et al., 2003; Bell et al., 2013). Already evidence exists that corals within the Great Barrier Reef are calcifying at lower rates than those prior to 1990 (De’ath et al., 2009). This will have flow-on effects for benthic organisms and fish and macro-invertebrate populations associated with reef communities. The differing abilities of coral species to migrate in response to climate change and their genetic ability to adapt to warmer waters will, however, result in changes to community structure beyond the immediate effect of selective mortality caused by severe bleaching (Hughes et al., 2003).

Altered temperatures may decouple population processes of taxonomic groups that are reliant on the population processes of (and) other group(s). For example, the breeding processes of many marine species are timed to coincide with peaks in forage-species populations, whose timing is often driven by temperature. If the timing of the two is altered so that they no longer match, this will likely affect population recruitment (e.g., Philippart et al., 2003).

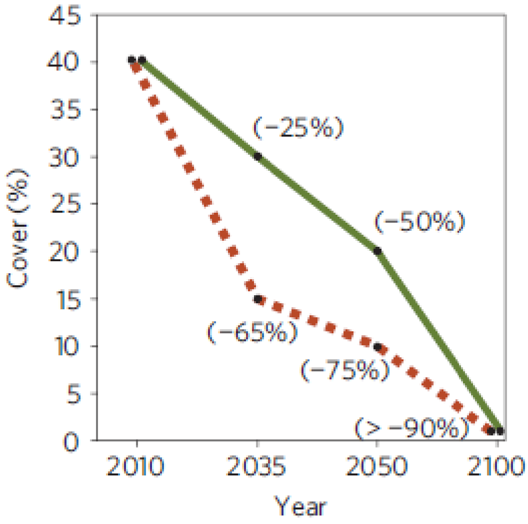

Figure 8. Projected changes in live coral cover across the Pacific Island region to 2100 based on projected changes in sea-surface temperature and aragonite saturation under the IPCC SRES A2 emissions scenario and current trends in coral decline of 1 – 2 per cent with strong (solid line) and weak (dashed line) management scenarios. Taken from Bell et al. (2013).

Because phytoplankton have differing sensitivities to carbon dioxide concentrations and utilise carbon in differing ways, changes in carbon dioxide concentrations will not only change the activity of individual phytoplankton species, but will also tend to favour some species over others. Increasing ocean carbon dioxide is therefore likely to result in shifts in phytoplankton community structure, which will in turn influence the community structure of higher trophic organisms reliant on phytoplankton for food (Hays et al., 2005). Furthermore, phytoplankton and zooplankton species that depend on current saturation levels of aragonite to build robust shells and skeletons (e.g., coccolithophorids, pteropod molluscs, gastropods) are expected to be most affected by ocean acidification. Reduced capacity to build shells and skeletons will make such organisms more fragile and vulnerable to predation and, in some cases, may result in the disappearance of these organisms from food webs (e.g., Coleman et al., 2014). This is likely to have unpredictable and cascading effects on marine food webs. Higher ocean carbon dioxide concentrations may have physiological impacts on a range of species, altering the metabolism and growth rates of some species and affecting the sensory systems of fish (Poloczanska et al., 2007; Munday et al., 2009; Munday et al., 2010; Appelhans et al., 2014).

Altered precipitation and increased storm intensity will affect the dynamics of coastal marine ecosystems through fluctuations in wave height and intensity, salinity, turbidity and nutrients. In regions where precipitation is expected to decrease, such as many Pacific Islands, these ecosystems will experience higher salinity environments, whereas those in regions where precipitation is expected to increase, such as eastern Australia, will experience fresher environments. Mangrove, seagrass and coral reef communities will be particularly prone to these changes (see Fabricus, 2005; Harley et al., 2006; Polaczanska et al., 2007).

3.2 Social and economic drivers

The South Pacific Ocean is a highly diverse region, featuring considerable variation in the social, economic, cultural and infrastructural composition of the countries and territories located within its bounds. Although climate change is considered to be one of the largest threats to marine environments over the long term, management of social and economic stressors on marine environments can be considered to be the most significant challenge over the short term (Bell et al., 2009; Center for Ocean Solutions, 2009; Brander et al., 2010). Coastal habitats have increasingly come under pressure as human populations grow. Pacific Island regions have been increasing at >3 per cent in the last two decades (Figure 9); urban areas are growing at twice the national growth rate (SPREP, 2012). The economic performance by countries throughout the South Pacific Ocean varies, and in some Pacific Island countries poor economic performance has resulted in *per capita* incomes stagnating (McIntyre, 2005). As a result of poor economic performance and growing inequalities, poverty is a growing problem in some countries. The majority of Pacific Island countries have relatively limited opportunities for development and are highly dependent on overseas development assistance (McIntyre 2005). Agriculture and fisheries are the mainstay of many of the economies of South Pacific Ocean countries, and support both subsistence livelihoods and commercial production. Logging and mining are significant in countries such as Australia, Chile, Ecuador, Fiji, Nauru, New Caledonia(France), Papua New Guinea, Peru and the Solomon Islands (Observatory of Economic Complexity, www.atlas.media.mit.edu, accessed 25 August 2014). Tourism is an important economic sector throughout the region and is growing in importance in the Pacific Islands (SPREP, 2012).

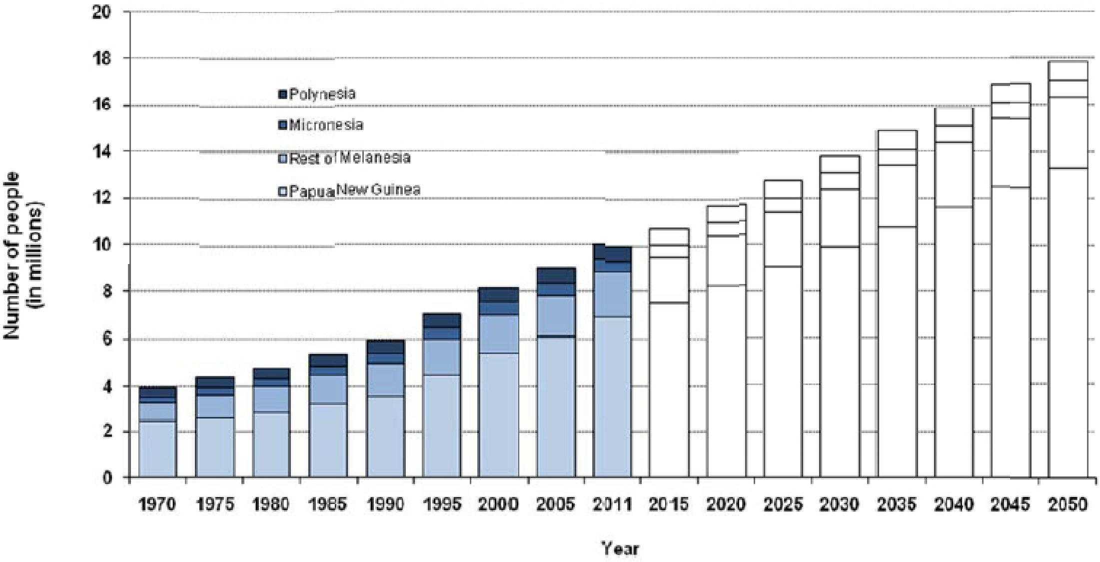

Figure 9. Observed and projected increase in Pacific Island populations. Taken from SPREP (2012).

Major pressures on coastal and shelf environments associated with social and economic drivers can be grouped into three broad categories: (i) habitat loss or conversion as a result of coastal development, destructive fisheries, deforestation and extraction of resources; (ii) habitat degradation as a result of various forms of pollution, increased salinization of estuarine areas and introduction of alien species; and (iii) overfishing and exploitation as a result of increasing demand at local, regional and global scales, poor fisheries management and a breakdown of traditional regulation systems (Table 2; UNEP, 2006a; UNEP, 2006b; Center for Ocean Solutions, 2009; UNEP, 2012). Many of these pressures have risen indirectly from larger changes to global populations, economies, industry and technologies.

Nearshore development associated with urbanization, growing populations and tourism replaces vegetated landscapes with hard surfaces and converts marine habitats into new land (e.g., Maragos, 1993; Table 2). Modification of shorelines alters currents and sediment delivery, often inducing erosion and receding beaches. Increased development is often also coupled with increasing land-based pollution (e.g., Ministry of Natural Resources and Environment, 2013; Table 2). The extent of land-use planning varies across the South Pacific Ocean, resulting in varying management of habitat conversion, construction activities and pollution. Many of the Pacific Islands are charting a new path from subsistence and traditional management systems to market-based economies (Center for Ocean Solutions, 2009). In many regions this has led to the slow breakdown of traditional land- and marine tenure systems, resulting in unregulated development and exploitation of coastal regions (Table 2; see also section 2.4 in regard to overexploitation of coastal fisheries). The unique natural environments of many islands in the South Pacific Ocean and the desire to experience these environments can end up contributing to the reason these environments are under threat. Unregulated coastal tourism development can result in the destruction of highly regarded environments (Table 2); the Galápagos Islands World Heritage Site was placed on the List of World

Heritage in Danger in 2007 largely as a result of unregulated tourism development and overexploitation of marine resources (see section 5.1).

Poor management of watersheds often leads to degradation of estuaries and coastal environments (Table 2). Agricultural and grazing practices that destroy natural riparian habitats can result in floods and burial of natural estuarine and coastal habitats under silt and enriched sediment (e.g., Fabricus, 2005). Interruption of natural water flow via extraction for agriculture or power restricts water and nutrient flow into estuarine environments, reducing flushing and dilution of pollution (fertilizers, pesticides, sewage, debris, chemicals, and stormwater run-off), causing siltation and, in extreme cases, closure of estuary mouths, and increasing the salinization and toxicity of estuary areas. Agricultural practices often result in excessive nutrient loading of estuarine and coastal environments, causing these areas to become eutrophied, resulting in algal blooms and dead zones. Land-based sedimentation, combined with nutrient inputs, is a major water-quality threat to many of the coastal environments of the western and central South Pacific (e.g., Maragos and Cook, 1995; Hughes et al., 2003; Orth et al., 2006; Center for Ocean Solutions, 2009; GBRMPA, 2014). Higher nutrient concentrations associated with run-off from coastal urbanized areas have been documented to drive shifts in phytoplankton community composition and abundance (Jacquet et al., 2006).

Port development, such as infilling, dredging, channelling, and installation of harbour works including seawalls and groins, often results in alterations to estuaries and embayments (Table 2). Alterations to soft bottom habitats in these areas often create conditions for new assemblages of species, and facilitate range expansions of invasive species (Ruiz and Crooks, 2001). Furthermore, the movement of ships and other transport vehicles into these areas from around the globe has enabled the spread of many marine species (Table 2). Introduction of invasive species facilitated by shipping (via fouling, boring, nestling into the hull, anchor chain, and ballast water) has been reported extensively across the South Pacific Ocean; alien species are reported from most countries and territories in the region (Carlton, 1987; Bax et al., 2003; Hewitt et al., 2004; Ministry of the Environment, 2004; Sakuma, 2004; Mourgues, 2005; Gabrie et al., 2007; Ministry of Environment Conservation and Meteorology, 2008; Ministry of Natural Resources and Environment, 2013). In the south-east region of Australia, invasive species such as starfish, sea urchins, plankton, algae, molluscs, crustaceans and worms have had major impacts on coastal marine environments. Port Phillip Bay, the site of the Port of Melbourne, has been described as one of the most invaded marine ecosystems in the Southern Hemisphere: more than 150 alien species are reported from the embayment (Bax et al., 2003). Another site of equal note is the Derwent River estuary in Tasmania (State of the Environment Committee, 2011). In New Zealand, invasive species have been detected in virtually all coastal habitat types (Hewitt et al., 2004).

Coastal aquaculture operations, although bringing important socio-economic benefits to countries, can result in modification of coastlines and benthic habitats and pollution of coastal habitats (Table 2). Shrimp and salmonid aquaculture in the coastal regions of Ecuador, Peru and Chile contributes significantly to the economies of each country; Chile is one of the main producers of salmonids in the world (De Young, 2007). After lengthy periods of sustained growth, aquaculture operations in

Ecuador have resulted in the destruction of large tracts of mangrove forest and coastal wetlands (Bailey, 1988; Martinez-Porchas and Martinez-Cordova, 2012). Operations in Chile have caused significant loss of benthic biodiversity and local changes in the physical and chemical properties of sediments have occurred in areas with salmonid farms (Buschmann et al., 2006). Pulses in dinoflagellate densities have increased and it is suggested that escaped farmed fish may have an impact on native species, although their survival in the wild appears low. In addition, the abundance of omnivorous diving and carrion-feeding marine birds in areas of aquaculture operations has increased two - fivefold (Buschmann et al., 2006).

Table 2. Social and economic drivers of change in coastal and shelf ecosystems of the South Pacific Ocean. Modified from UNEP (2006b).

DIRECT DRIVERS	**INDIRECT DRIVERS**
Habitat loss or conversion	
Coastal development (ports, urbanization, tourism-related development, industrial development, civil engineering works)	Population growth; transport and energy demands; poor urban planning and industrial development policy; tourism demand; environmental refugees and internal migration
Destructive fishing practices (dynamite, cyanide, bottom trawling)	Shift to market economies; on-going demand for live food fish, aquarium species; increasing competition associated with diminishing resources
Coastal deforestation	Lack of alternative materials; increasing competition associated with diminishing resources; global commons perceptions
Mining (coral, sand, minerals, dredging)	Lack of alternative materials; global commons perceptions
Aquaculture-related habitat conversion	International demand for luxury items (including new markets); regional demand for food; demand for fishmeal in aquaculture and agriculture; decline in wild stocks or decreased access to fisheries (or inability to compete with larger-scale fisheries)
Habitat degradation	
Eutrophication from land-based sources (agricultural waste, sewage, fertilizers)	Population growth; urbanization; lack of infrastructure (stormwater, sewage systems); lack of sewage treatment; unregulated agricultural development and management; loss of natural catchments (wetlands, etc.)
Pollution: toxins and pathogens from land-based sources	Increasing pesticide and fertiliser use; lack of regulations associated with use; lack of awareness of impacts; unregulated industries

DIRECT DRIVERS	**INDIRECT DRIVERS**
Pollution: dumping and dredge spoil	Lack of alternative disposal methods; decreasing terrestrial options; increasing regulation and enforcement of terrestrial disposal; lack of awareness of impacts
Pollution: shipping-related	Increased ship-based trade; substandard shipping, pollution and violation of marine safety regulations; flags of convenience
Increased salinization of estuaries due to reduced freshwater flows	Increased and unregulated agricultural development; increased demand for electricity and water
Introduction of alien species	Lack of regulations on the discharge of ballast; increased aquaculture-related escapes; lack of agreements and policies on deliberate introductions
Overexploitation	
Directed take of low-value species at volumes exceeding sustainable levels	Population growth; demand for subsistence and markets; globalization of trade networks, increased demand for aquaculture feed, industrialization of fisheries; improved fishing technologies; poor management and enforcement; breakdown of traditional regulation systems; introduction/maintenance of subsidies
Directed take of high-value species for luxury markets at volumes exceeding sustainable levels	Demand for speciality foods, medicines, aquarium fish, globalization of trade networks, lack of awareness of or concern about impacts
Directed take of commercial species; decreasing availability for subsistence and artisanal use	Population growth, globalization of trade networks, industrialization of fisheries; improved fishing technologies; poor management and enforcement; breakdown of traditional social systems; introduction/maintenance of subsidies
Incidental take or by-catch	Poor management and enforcement; lack of awareness of or concern about impacts

4. Major ecosystem services

Coastal and shelf ecosystems provide a diverse range of services to marine and terrestrial environments and benefits to human society (Table 4). Globally, coastal and shelf marine habitats are estimated to provide over 14 trillion United States dollars' worth of ecosystem goods (e.g., food and raw materials) and services (e.g., disturbance regulation and nutrient cycling) per year (Costanza et al., 1997). Valuable natural resources, such as fisheries, oil, deep sea mineral deposits and pharmaceutical constituents, are abundant throughout coastal, shelf and offshore waters of the South Pacific Ocean. Inshore regions provide coastal protection and artisanal fisheries, aquaculture, and tourism provide significant income for local communities (SPREP, 2012). The natural environment of coastal and inshore regions is an integral part of the culture, tradition, history and way of life for many communities. These resources are therefore essential to the livelihoods of communities throughout the South Pacific Ocean, as well as being desirable for the global community. On-going use of coastal ecosystems and associated declines in the health of these ecosystems have flow-on effects on the benefits and ecosystem services these provide to the environment and to the communities that rely on them.

4.1 Services to ecosystem being lost

Loss of coastal ecosystem biodiversity has been identified as affecting three primary ecosystem services: provision of nursery habitats, filtering and detoxification services and maintenance of trophic stability (Worm et al., 2006). Estuaries, salt marshes, mangroves, lagoons, seagrass meadows and kelp forests serve as nurseries for many marine species, provide interconnectivity of habitats for the life stages of some species and provide essential food resources across multiple trophic levels (Figure 10; Robertson and Blaber, 1993; Dayton et al., 1998; Orth et al., 2006; UNEP, 2006b). Mangroves, seagrass meadows and coral reefs provide protective services for the coastline, binding sediments and dissipating wave action (Moberg and Folke, 1999). Mangroves, via their ability to trap water, control the chemistry of estuarine water and the flow rates of mangrove creeks, both of which are important for water-column biota survival and dispersal (Robertson and Blaber, 1993). Mangrove forests and seagrass meadows are both an atmospheric carbon dioxide sink and an essential source of oceanic carbon, providing an essential supply of organic matter in marine environments (Suchanek et al., 1985; Duarte et al., 2005; Duke et al., 2007). Coral reefs are nitrogen fixers in otherwise nutrient-poor environments (Sorokin, 1993) and the release of excess nitrogen by coral reef systems is important for the productivity of adjacent communities (Sorokin, 1990). Reduction of these communities imperils dependent fauna with their complex habitat linkages, and endangers physical benefits like the buffering of seagrass beds and coral reefs by mangroves against the impacts of river-borne siltation (Duke et al., 2007) and protection by coral reefs against the impacts of currents, waves and storms (Moberg and Folke, 1999).

Many coastal marine habitats contain species that regulate ecosystem processes and functions through grazing and predation (Moberg and Folke, 1999). These processes operate across all trophic levels and disruption at any one trophic level can have flow-on effects across other trophic levels. For example, reduction in herbivorous and predatory reef fish in coral reef communities, as a result of overfishing in the South Pacific Ocean, has been found to result in alterations to community structure.

Alterations include increases in coral-eating starfish densities, leading to a decline in reef-building corals and an increase in non-reef-building species, such as filamentous algae (Hughes et al., 2003; Dulvy et al., 2004). Once algae become abundant, coral recovery is suppressed unless herbivores return to reduce algal cover, and corals can then recruit. Recent research on coral communities in Fiji has demonstrated, however, that chemical cues emitted by algae in degraded reefs repulse coral recruits, resulting in coral juveniles actively avoiding recruiting to these areas (Dixson et al., 2014). Declines in coral cover have flow-on effects for ecosystem processes, such as reef building, primary and secondary production, which then in turn affect higher trophic levels, and reduce ecosystem functioning.

Table 4. Examples of the services coastal and shelf ecosystems provide. Taken from UNEP (2006b).

SERVICE	**ESTUARIES/ MARSHES**	**MANGROVES**	**LAGOONS/SALT PONDS**	**INTERTIDAL**	**KELP**	**ROCKY REEFS**	**SEAGRASS**	**CORAL REEFS**	**SHELVES**
Services to ecosystems									
Biodiversity	•	•	•	•	•	•	•	•	•
Biological regulation	•	•	•	•	•	•	•	•	
Hydrological balance	•		•						
Atmospheric and climate regulation	•	•	•	•	•	•	•	•	•
Biochemical	•	•	•	•	•	•	•	•	•
Nutrient cycling and fertility	•	•	•	•	•	•	•	•	•
Flood/storm protection	•	•	•	•	•	•	•	•	
Erosion control	•	•	•				•	•	
Services to humans									
Food	•	•	•	•	•	•	•	•	•
Fibre, timber, fuel	•	•	•						
Waste processing	•	•	•				•	•	
Atmospheric and climate regulation	•	•	•	•	•	•	•	•	•
Flood/storm protection	•	•	•	•	•	•	•	•	
Erosion control	•	•	•	•	•	•	•	•	

Culture and amenity	•	•	•	•	•	•	•	•	•
Recreational	•	•	•	•	•	•	•	•	•
Aesthetics	•	•	•	•	•	•	•	•	•
Education and research	•	•	•	•	•	•	•	•	•
Medicines, other resources	•	•	•		•			•	
Human disease control	•	•	•	•		•	•	•	

4.2 Services to humans being lost

Many of the development goals of Pacific Island countries and territories are intricately linked to marine ecosystems and the benefits provided by them. Nowhere else in the world do so many countries depend on marine resources, and in particular, fishery resources, for economic development, food security, government revenue and livelihoods (Bell et al., 2013). Loss of coral reef habitat will affect coral reef fisheries, the majority of which are already considered to be either fully or overexploited. Anticipated human population growth will place increasing pressures on these resources and it has been estimated that an additional 196,000 km^2 of coral reef habitat will be required to sustain current levels of fishing (Newton et al., 2007). Projections of further reductions in coral reefs as a result of climate change are more than likely to have flow-on effects on coral reef fisheries and, as a result, reliance on pelagic resources for protein is expected to increase throughout Pacific Island countries and territories (Bell et al., 2009). Increased reliance on pelagic resources will require careful management to ensure that the socio-economic benefits from these resources are maintained sustainably (Bell et al., 2013).

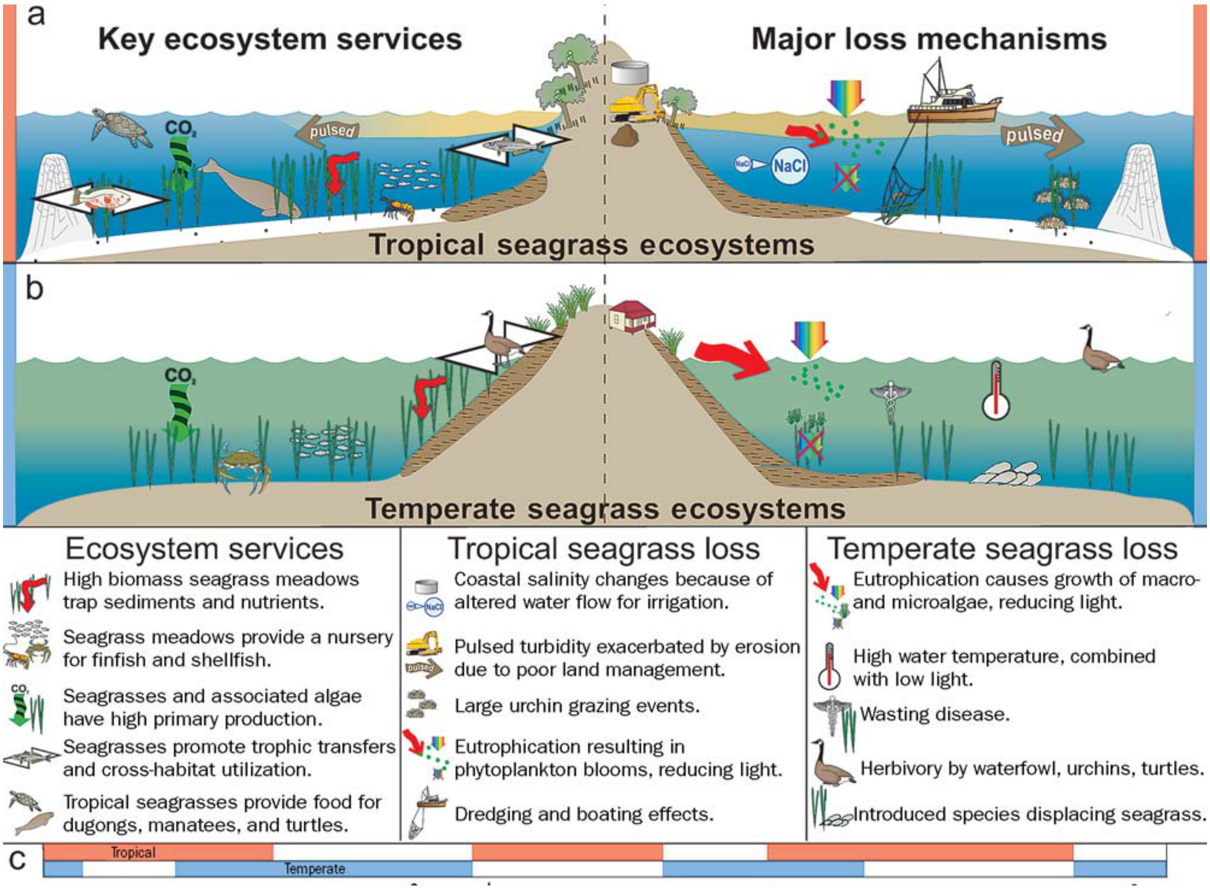

Figure 10. Conceptual depiction of major mechanisms of seagrass and related key ecosystem services loss for (a) tropical and (b) temperate seagrass ecosystems. Taken from Orth et al., 2006.

Many costal ecosystems provide communities with materials essential for construction and fuel. Mangroves provide timber, fibre and fuel, coral reefs provide lime and other building materials, and sand mining occurs in many coastal regions across the South Pacific Ocean. Shelf regions provide oil and gas and various other minerals. Over-exploitation and reduction of such finite resources will require identification of alternatives and adaptive strategies to ensure transfer to alternative economies. Logging has been identified as the most pressing issue facing the Solomon Islands: current rates are unsustainably high. Maintenance of unsustainably high rates of logging will result in serious impacts on the country's economy when the revenue stream collapses and on the population when building resources are no longer available and watersheds deteriorate (Ministry of Environment Conservation and Meteorology, 2008). Subsequent run-off of sediments from cleared areas will have further impacts on coastal reef environments and associated food resources. Construction of causeways on South Tarawa, Kiribati Islands, which block the migration pathways of several species of fish that are the focus of subsistence fisheries, has been associated with the collapse of their populations. Coastal erosion as a result of infrastructure development, overcrowding and overexploitation of the physical resources of the coastal zone of South Tarawa has resulted in the loss of houses, roads and agricultural land (Ministry of Environment, Lands and Agricultural Development, 2004).

5. Areas of special conservation significance and associated issues of the South Pacific

5.1 World Heritage Sites

Two of the largest World Heritage sites are in the South Pacific Ocean – the Phoenix Islands Protected Area and the Great Barrier Reef. Whereas the Phoenix Islands Protected Area is comprised of largely oceanic, deep water ecosystems, the Great Barrier Reef is entirely shelf-based. Other World Heritage sites located in the South Pacific Ocean with protected marine components include the Lord Howe Island Group in Australia, East Rennell in the Solomon Islands, the lagoons of New Caledonia and the Galápagos Islands in Ecuador.

The Great Barrier Reef is the world's largest coral reef system (34 million hectares), extending 2,000 kilometres along the eastern Australian coast. It comprises over 2,500 individual reefs and 900 islands. Declared in 1981, it was one of the first World Heritage sites. It is home to over 400 types of coral and is one of the richest areas in the world for animal biodiversity. The diversity of species and habitats, and their interconnectivity, make the Great Barrier Reef one of the richest and most complex natural ecosystems on earth. Key threats affecting the site include coastal development, development of ports and liquefied natural gas facilities, extreme weather events, grounding of ships, water quality and oil and gas (UNESCO, 2014a). The 2014 Great Barrier Reef Outlook Report (GBRMPA, 2014) concludes that: "Even with the recent management initiatives to reduce threats and improve resilience, the overall outlook for the Great Barrier Reef is poor, has worsened since 2009 and is expected to further deteriorate in the future." Serious declines in the condition of the Great Barrier Reef, including coral recruitment and reef building across large parts of the reef, have been observed and the report concludes that a 'business as usual' approach to managing the reef is not an option (GBRMPA, 2014; UNESCO 2014a).

The Phoenix Islands Protected Area (PIPA) was declared in 2010; at 40.8 million hectares, it is the world's largest World Heritage Site. It consists of eight oceanic coral atolls, most of which are uninhabited, two submerged reefs and fourteen identified seamounts. Its isolation and low population density have helped the area remain comparatively undisturbed and it provides important habitat for migratory and pelagic/planktonic species. It is an important breeding area for marine and seabird species and is considered a sentinel of the impacts of climate change on coral reef health (Anon., 2009). Key threats affecting the site include illegal fishing and overfishing by licensed and unlicensed vessels and degradation of seamounts. A phased zoning scheme has been proposed to ensure the site's long-term conservation. The first phase has been implemented by designating approximately 3.1 per cent of the total area of the site as a "no take" zone. As of 1 January 2015, the closure of the exclusive economic zone of the PIPA to fishing came into effect. Implementation of the second phase will involve increasing no-take areas to 25 per cent of the site and reducing offshore fishing effort for tunas. However, this implementation relies on the establishment of a trust fund which will only become operative once its capital reaches a level which will compensate the Kiribati government for losses in distant-water fishing nation license fees associated with the reduction in fishing effort. Currently, no timelines are set for reducing fishing effort (UNESCO, 2012).

The Lord Howe Island Group, declared a World Heritage site in 1982, spans 146,300 hectares and contains the world's most southerly true coral reef. The small land area within the site provides an important breeding ground for many seabirds and its marine system demonstrates a rare example of a transition zone between algal and coral reefs. Marine assemblages consist of cohabiting tropical and temperate species and endemism is high. Key threats affecting the site include invasive plants and animals, climate change, tourism and fishing (Anon., 2003).

The East Rennell World Heritage Site, declared in 1998, comprises the southern third of the world's largest raised coral atoll, Rennell Island, the southernmost island in the Solomon Islands, whose marine area extends three nautical miles to sea. Coastal waters around the island provide important habitat for migratory and pelagic/planktonic species and it is an important site for speciation processes, especially with respect to bird species. Key threats affecting the site include logging, invasive species, overexploitation of marine resources, climate change and management of the site. These threats have resulted in the site being placed on the List of World Heritage in Danger. A state-of-conservation assessment for the removal of the site from the List of World Heritage in Danger is currently underway (UNESCO 2014b).

The lagoons of New Caledonia were declared a World Heritage Site in 2008; at 1.57 million hectares, they comprise the third-largest reef system in the world. Reef systems within the site contain the most diverse concentration of reef structures in the world, ranging from barrier offshore reefs and coral islands to near-shore reticulate reefs. It contains intact ecosystems with top predators and a large diversity and abundance of large fish (Anon., 2008). Key threats affecting the site include mining, fishing and aquaculture, tourism and climate change. One of the main management issues for the site is a lack of capacity and resources for some of the existing co-management committees tasked with managing the site in enforcing fisheries and water-quality regulations and responding to incursions (UNESCO, 2011).

The Galápagos Islands were designated a World Heritage Site in 1978. They are renowned for their unique species and inspiration for the theory of evolution by natural selection proposed by Charles Darwin in the mid-1800s. The archipelago of 19 islands lies at the confluence of three ocean currents and is highly influenced by ENSO, generating one of the richest and most diverse marine ecosystems in the world. The direct dependence on the marine environment by much of the island's wildlife (e.g., seabirds, marine iguanas, sea lions) intricately links terrestrial and marine environments in the site. Lack of management of commercial, sport and illegal fishing, leading to overfishing of the marine environment, a lack of quarantine measures enabling alien species invasions, and unsustainable and uncontrolled tourism development contributed to the islands being placed on the List of World Heritage in Danger in 2007. Following strengthened quarantine, fishing and tourism management and governance of the islands, the site was removed from this list in

2010. Key threats affecting the site include changes in the identity, social cohesion and nature of the local population and community, illegal activities, tourism, visitors and recreation and the related infrastructure and management activities, systems and plans (UNESCO, 2014c).

5.2 Large Marine Ecosystems and Ecologically and Biologically Significant Areas

The South Pacific Ocean contains five Large Marine Ecosystems (LMEs), three along the eastern coastline of Australia (the north-east Australian shelf/Great Barrier Reef, the east-central Australian shelf and the south-east Australian shelf), one on the New Zealand shelf and one incorporating the Humboldt Current. The definition of these areas is based on four ecological criteria: (i) bathymetry; (ii) hydrography; (iii) productivity; and (iv) trophic relationships and definitions. These criteria provide a framework to focus on marine science, policy, law, economics and governance on a common strategy for assessing managing, recovering and sustaining marine resources and their environments (Sherman and Alexander, 1986). The approach uses five modules to measure and provide indicators of changing states within the ecosystem of each LME, including productivity, fish and fisheries, pollution and ecosystem health, socio-economics and governance. Because a lot of these factors have been discussed in previous sections of this chapter, details of each LME will not be provided again here.

The Strategic Plan for Biodiversity 2011-2020 developed under the Convention on Biological Diversity[2], provides a framework for reducing biodiversity loss and maintaining ecosystem services. It is centred around 20 targets, the Aichi Biodiversity Targets, organized under five strategic goals and the identification of marine areas in need of protection and within which the targets can be best focused known as Ecologically or Biologically Significant Marine Areas (EBSAs). Identification of these areas is based on seven scientific criteria, including (i) uniqueness or rarity; (ii) special importance for life-history stages of species; (ii) importance for threatened, endangered or declining species and/or habitats; (iv) vulnerability, fragility, sensitivity, or slow recovery; (v) biological productivity; (vi) biological diversity; and (vii) naturalness (Secades et al., 2014). To date, 26 EBSAs have been identified from the western South Pacific Ocean and 13 identified from the eastern South Pacific Ocean (Table 3).

Table 3. Ecologically and Biologically Significant Areas (EBSAs) identified by the Convention on Biological Diversity in the South Pacific Ocean.

1.	Phoenix Islands	14.	Vatu-i-ra/Lomaiciti	27	Equatorial high-productivity zone (east)
2.	Ua Puakaoa Seamounts	15.	South Tasman Sea	28	Galápagos archipelago and western extension
3.	Seamounts of	16.	Equatorial high-	29	Carnegie Ridge –

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[2] United Nations, *Treaty Series*, vol. 1760, No. 30619

	West Norfolk Ridge		productivity zone (west)		Equatorial Front
4.	Remetau Group: south-west Caroline Islands and northern New Guinea	17.	Central Louisville Seamount chain	30	Gulf of Guayaquil
5.	Kadavu and the southern Lau region	18.	Western South Pacific high aragonite saturation state zone	31	Humboldt Current upwelling system in Peru
6.	Kermadec-Tonga-Louisville junction	19.	Clipperton fracture zone petrel foraging areas	32	Permanent upwelling cores and important seabird areas of the Humboldt Current in Peru
7.	Monowai Seamount	20.	Northern Lord Howe Ridge petrel foraging area	33	Northern Chile Humboldt Current upwelling system
8.	New Britain Trench region	21.	Northern New Zealand/South Fiji basin	34	Central Chile Humboldt Current upwelling system
9.	New Hebrides Trench region	22.	Taveuni and Ringgold Islands	35	Southern Chile Humboldt Current upwelling system
10.	Rarotonga outer reef slopes	23.	Manihiki Plateau	36	Salas y Gómez and Nazca Ridge
11.	Samoan archipelago	24.	Niue Island and Beveridge Reef	37	Juan Fernandez Ridge seamounts
12.	Suwarrow National Park	25.	Palau southwest	38	West Wind Drift Convergence
13.	South of Tuvalu/Wallis and Futuna/north of Fiji Plateau	26.	Tongan archipelago	39	Grey petrel’s feeding area in the South East Pacific Rise

6. Factors for sustainability

The conservation and sustainable use of marine ecosystems is a goal articulated under a number of national and international policies and the development plans of countries in the South Pacific Ocean. It is becoming evident that the extent to which marine ecosystems can absorb recurring natural and anthropogenic perturbations and continue to regenerate without continued degradation will require improvements to current resource management (Hughes et al., 2005). Furthermore, current resource management and supporting marine policy will need to incorporate multi-scale ecological and social information in order to sustain delivery of ecosystem services and benefits. With this in mind, coastal and ocean managers confront a growing diversity of challenges in balancing environmental and socio-economic needs throughout the South Pacific Ocean.

6.1 Ecosystem-based management and integrated coastal zone management

Ecosystem-based management (EBM) approaches are broadly accepted as cornerstones to effective marine conservation and resource management (Levin et al., 2009). Ideally frameworks for EBM should consider multiple external influences, value ecosystem services, integrate natural and social science into decision-making, be adaptive, identify and strive to balance diverse environmental and socioeconomic objectives, and make trade-offs transparent. Integrated coastal zone management (ICZM) can be used within an EBM framework to address the ecological and human complexity of interconnected systems. Development of ICZM, in principle, should incorporate an integrated, adaptive approach for coastal management that addresses all aspects of the coastal and neighbouring ocean zone, including land–coastal interactions, climate change, geographical and political boundaries, in an effort to achieve long-term sustainable use and reduce conflicts. It requires the careful balancing of a wide range of ecological, social, cultural, governance, and economic concerns. Although some examples exist of the implementation of ICZM throughout the South Pacific Ocean (e.g., see National Resource Management Ministerial Council, 2006; Department of Conservation, 2010; section 6.2), for many countries, comprehensive coastal management remains a challenge.

Within the Pacific Islands region, a Framework for a Pacific Oceanscape has been developed and endorsed by 23 countries and territories within the region. This framework, finalised in 2012, draws on the Pacific Islands Regional Oceans Policy and has been designed to address six strategic priorities associated with marine resource conservation, habitat protection and fisheries management (Pratt and Govan, 2010). These priorities will be met via the development of terrestrial and marine protected areas, identification of risks and mitigation strategies for climate change and the provision of research and leadership capacity development throughout the region (Pratt and Govan, 2010).

Uptake of EBM approaches to resources and, in particular, to commercial fisheries has also been slow and although such an approach may have been adopted at a policy level, practical implementation is largely lacking (Garcia et al., 2003; Smith et al., 2007). Traditional management of fisheries, which is still conducted by most national and international management agencies throughout the South Pacific Ocean, concentrates on individual fish populations strictly in demographic terms, i.e., accounting for the input of individuals as population growth or immigration and the output in terms of natural and fishing mortality. Fish populations, however, are also affected by variability in external factors, such as predator and prey abundances and variability in their bio-physical environment. At the same time, changes in the abundance of populations will affect all the surrounding ecosystems of which fishes are part. Federal, state and territorial fisheries management agencies in Australia have adopted ecosystem-based fisheries management as the approach to future management (Smith et al., 2007). Tools to facilitate this approach have largely been developed and implemented for most Commonwealth fisheries and are in various stages of development for state and territory fisheries.

6.2 Marine management areas

The establishment of representative systems and networks of marine management areas is regarded internationally and nationally as one of the most effective mechanisms for protecting biodiversity and a tool for resource sustainability. Protected areas, including national parks, managed resource protected areas, locally managed marine areas, marine reserves, protected seascapes, and habitat management areas, occur in varying degrees in the coastal and offshore regions of countries and territories throughout the South Pacific Ocean (see also section 5.1). Co-ordinated networks of protected or managed areas providing for protection of ecosystems representative of regions are largely lacking, with the exception of Peru's Guano Islands, Islets and Capes National Reserve System (RNSIIPG), and enforcement is an issue for many marine management areas. Australia's National Representative System of Marine Protected Areas (NRSMPA) has been developed for Australian marine waters, but is currently under review and yet to be implemented. Community-based management areas throughout the Pacific Islands and territories have shown some level of success, largely because those that benefit from sustainable resource use are those directly involved in managing those resources. However, managers of community-based management areas are often not equipped to ensure that management is effective. Across many communities, knowledge about the long-term effects of current use of marine resources, sustainability issues, and the requirements for management, research, and monitoring is poor. The need to strengthen education has been identified by a number of countries. Frameworks for the identification and implementation of marine protected areas at regional scales are also being developed under the Convention on Biological Diversity[3] (see section 5.2) and the Framework for a Pacific Oceanscape (see section 6.1). Recent research has demonstrated that in areas where full protection of marine regions is untenable because of dependence of communities on marine resources, even simple forms of fisheries restrictions can have substantive positive effects on functional groups (MacNeil et al. 2015).

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[3] United Nations, *Treaty Series*, vol. 1760, No. 30619.

6.3 Integration of climate change adaptation and mitigation into marine policy, planning and management

Over the long term, one the largest threats to coastal and marine systems within the South Pacific Ocean is climate change. Responding to the environmental and socio-economic consequences of climate change in order to maintain ecosystem services requires coordinated and integrated efforts in incorporating adaptation and mitigation options into marine policy, planning and management. International efforts at coordinated adaptation and mitigation planning have occurred, largely through the United Nations Framework Convention on Climate Change, either via National Adaptation Programmes of Action (NAPAs) in the case of least developed countries, or National Communications for Annex I countries (see www.unfcc.int). At present, however, examples of the implementation of climate change adaptation actions are limited, even though acceptance is widespread of the need for adaptation and for significant investments in adaptation planning. Factors affecting implementation include local adaptive capacity, inabilities and inefficiencies in the application of existing resources, and limited institutional support and integration, particularly between and across governments (Christensen et al., 2007; Noble et al., 2014). In order to overcome this, adaptation assessments may need to link more directly to particular decisions and tailor information to local contexts to facilitate the decision-making process (Noble et al., 2014). Key components in the integration of adaptation and mitigation options should include (i) stakeholder participation in decision making; (ii) capacity development; (iii) communication, education and public awareness; (iv) development of alternative income-generating activities; (v) monitoring; (vi) addressing uncertainty and (vii) analysis of trade-offs (UNEP, 2006b). Without ensuring that adaptation options are integrated into coastal zone management, it is likely that ecosystem services will not be maintained into the future (Bell et al., 2013).

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