Key climate change effects on the coastal and marine environment around the Pacific UK Overseas Territories

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EXECUTIVE SUMMARY

- Climate-driven changes in the central south Pacific Ocean will cause widespread warming of ocean waters, altered circulation, increased stratification of the water column and limited nutrient supply to the surface, decreasing dissolved oxygen, ocean acidification and rising sea levels. These changes will impact marine and terrestrial ecosystems and the communities they support.
- Ultimately, important sectors, such as fisheries and tourism, will be affected by these changes, as will food and water security and essential services, such as energy, transport of goods and coastal protection.
- Coral reefs are unlikely to experience significant heat stress, but should they be impacted by changes in sea temperature, including cold water intrusion, their recovery appears challenging due to the islands' isolation and therefore the low supply of healthy coral larvae from other reef systems. By the end of the century, even under low-emissions scenarios, acidification conditions in the seawater around the Pitcairn Islands are likely to become marginal for coral calcification.
- Increasing Sea Surface Temperature (SST), ocean acidification and related changes to oxygen concentrations and stratification are expected to affect the health of coral reefs that support coastal fisheries in the Pitcairn Islands, and reduce productivity. Pelagic tuna fisheries are also expected to be affected by climate change with a slight increase in biomass for all tuna species projected for this part of the central south Pacific Ocean.
- Rising sea levels, storm surges, severe storm events and heavy rains will impact infrastructure networks on Pitcairn Island and the safe transport of goods via shipping to the island. Integrating climate-change considerations into existing and new infrastructure is essential for building resilience to future climate change impacts.

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- Downscaled projections for the Pitcairn Islands (at a relevant scale) will be particularly important for SST, since it is postulated that coral reefs and marine species may be buffered from regional increasing SST due to circulation patterns. This dynamic needs to be examined further to determine if it is in fact occurring or likely to occur, and therefore improve understanding on the potential impacts of increasing SST on marine ecosystems.

DESCRIPTION OF OVERSEAS TERRITORIES IN THE REGION

The UK Overseas Territory of the Pitcairn Islands, located in the south-eastern edge of the tropical Pacific in the central south Pacific Ocean, consists of a chain of four small islands – Pitcairn, Oeno, Henderson and Ducie. The Pitcairn Islands have a collective land area of 49 km^2 (Irving and Dawson, 2012) along the Foundation Seamount chain and only Pitcairn Island is inhabited. The islands run west north-west to east south-east through the central South Pacific and have an Exclusive Economic Zone (EEZ) of 841,910 km^2, with only 0.0001% of its land area (Lincoln *et al.*, 2021). The Pitcairn Islands can therefore be considered a ‘large ocean state’.

The ocean climate and oceanography of the region significantly influences the natural resources of the Pitcairn Islands and the small population of about 50 people (2017 Government Census) that depend on them for food, income and development.

The oceanic habitats of the Pitcairn Islands EEZ lie within the South Pacific Subtropical Gyre and are low in nutrients (Le Borgne *et al.*, 2011) due to the rotation of the gyre that deepens the vertical structure of the water column, making the surface waters nutrient poor.

Pitcairn Island is volcanic, Henderson Island is formed from a raised coral reef, and Oeno and Ducie islands are low coral atolls (Bell *et al.*, 2018; Spencer 1995). Henderson Island – a UNESCO World Heritage site – is the best example in the Pacific of a large raised atoll and is an important breeding site for seabirds. Oeno Island is also an important seabird site, supporting the world’s second largest colony of Murphy's petrels. The coastline of Pitcairn Island is rocky, steep and exposed to large ocean swells (Bell *et al.*, 2018). Biodiversity around the islands is high and the area is considered to be one of the least impacted in the Pacific (Friedlander *et al.*, 2014). The Pitcairn Islands Marine Protected Area was designated in September 2016 and covers the whole EEZ. It is a no-take marine protected area (MPA), with artisanal fishing to the 12-mile limit around all four islands permitted for islanders.

MAIN CLIMATE CHANGE DRIVERS

Anthropogenic climate change is projected to impact the central south Pacific Ocean environment through widespread warming of ocean waters, altered circulation (e.g. strengthening of the South Pacific Gyre), increased stratification of the water column that limits vertical supply of nutrients to the surface, decreasing concentrations of dissolved oxygen, decreasing aragonite saturation state (ocean acidification) and rising sea levels (Cravatte *et al.*, 2009; Durack and Wijffels, 2010; Ganachaud *et al.*, 2011; Heron *et al.*, 2016; Lough *et al.*, 2018). These changes to the ocean climate will impact species, ecosystems, food webs and dependent communities in the Pitcairn Islands. Although corals have been found to grow at unusual depths, sheltered from warming sea temperatures, there is high risk of future ocean acidification compromising coral calcification. The isolation of Pitcairn corals is a challenge to recruitment due to the low supply of coral larvae that could support recovery. Sea-level rise is projected to double by the end of the 21st Century and it is unclear whether the island shorelines can adapt. Ultimately, important sectors, such as fisheries and tourism, will be affected by these changes, as will food and water security and essential services, such as energy, shipping, coastal protection and community access to natural resources.

While climate change is a key driver of change for the central south Pacific Ocean and the Pitcairn Islands, impacts from other human pressures can magnify the effect or be exacerbated by climate change. For example, marine plastic litter at Henderson Island is already compromising nesting beaches for seabirds and marine turtles[1] and as climate change pressures emerge related to coastal inundation and temperature increases, the impacts on nesting success will accelerate.

PRIORITY 1: IMPACTS ON CORAL REEFS AND ASSOCIATED COMMUNITIES

WHAT HAS HAPPENED

The impacts of climate change on coral reefs are associated with changes in physical drivers (ocean circulation, sea temperature, acidification, sea-level rise and extreme weather events), which affect the biology and ecology reef organisms. The impacts of climate change are relatively well known and are mostly negative (e.g. Johnson *et al.*, 2020; Dutra *et al.*, 2018, 2021). Changes in these climate drivers affect species and reef habitats directly (e.g. through coral bleaching, storm damage) and indirectly via changes in growth, reproduction and phenology.

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[1] https://interactives.stuff.co.nz/2019/07/henderson-island-rubbish-plastic-ocean-waste/chapter1/

Trends in climate change in the Pacific Ocean are linked to global emissions, although changes are spatially variable, and some differ in magnitude and rate to global trends (Seager *et al.*, 2019). For example, the Pacific Ocean is becoming warmer, but some areas (western Pacific warm pool) are warming at different rates (Seager *et al.*, 2019). The Pacific Ocean is also becoming more acidic (Barros *et al.*, 2015; IPCC, 2019; Johnson *et al.*, 2016), sea level is rising (Dean and Houston, 2013; IPCC, 2019), and tropical cyclones are becoming more intense (Elsner *et al.*, 2008) with more severe cyclones occurring more frequently (IPCC, 2019). More acidic seawater, rising sea level and increasing frequency and intensity of extreme weather events are impacting coral reefs and are expected to continue to drive their decline in the future if efforts to reduce local impacts and curb global greenhouse gas emissions are not implemented (Abelson, 2019; Gattuso *et al.*, 2015).

Sea Surface Temperature

Sea Surface Temperatures (SST) in the Pacific Ocean are strongly influenced by interannual variation associated with the two phases of the El Niño Southern Oscillations (ENSO) – El Niño and La Niña (Stuecker *et al.*, 2017) and the western Pacific warm pool. The Pitcairn Islands are located to the south-east of the western Pacific ‘warm pool’ and therefore the influence of its movement is less than for nations closer to the equator (Capotondi *et al.*, 2020). On average, SST in the Pacific Ocean increased by 0.31 °C between 1950 and 2009 (IPCC, 2014), with SST observations from monitoring sites in the Pitcairn Islands recording three relative marine heatwaves, with peaks in 1995, 2006 and 2017. These marine heatwaves occurred principally around Oeno, Pitcairn and Henderson islands, and to a lesser extent around Ducie Island (Lincoln *et al.*, 2021). Cold-water intrusions have also been recorded in 1972 and 2016 and can cause a similar stress response in corals (Dawson and Zhang, 2020).

SST plays an integral role in the growth of corals and therefore reef structures by influencing their skeletal density, extension and calcification rate. Anthropogenic induced ocean warming is negatively impacting coral reefs through loss of coral colonies impacted by heat-stress bleaching (Kleypass *et al.*, 2015, Raymundo *et al.*, 2019), increasing bio-erosion (Chaves-Fonnegra *et al.*, 2017), reduced coral calcification rates (Nurse *et al.*, 2014) and potential reductions in coral reproduction (Keith *et al.*, 2016).

Coral bleaching is a stress response in marine invertebrates with symbiotic algae (zooxanthellae) including hard and soft corals, giant clams, and anemones. While the full mechanism remains unresolved, studies hypothesise that the influence of combined variables such as peak hot temperatures, light exposure, the duration of cool temperatures, and temperature bimodality, are responsible for heat stress bleaching events (McClanahan *et al.*, 2019). Bleaching conditions are often associated with hot, calm and clear conditions (or marine heatwaves) when SST peaks, where wind-driven mixing and cooling is limited, and light exposure is high. Cold-water intrusion and how it drives coral bleaching is less well understood, although it is also a thermal stress response.

Marine heatwaves impact coral species differently because responses depend on the genetics of both the coral host and symbiont, and their ability to cope with warmer waters (Hoadley *et al.*, 2015). Bleaching can affect corals directly by causing mortality after prolonged exposure to marine heatwaves, or indirectly via sub-lethal effects on growth and reproduction, influencing feeding behaviour, and increasing the incidence of diseases (Bonesso *et al.*, 2017; Langlais *et al.*, 2017; Maynard *et al.*, 2015). Higher ocean temperatures have been causing widespread coral bleaching and mass mortality worldwide, including on reefs in the tropical Pacific region in 2016-17 (Dutra *et al.*, 2021; Raymundo *et al.*, 2019; Townhill *et al.*, 2020). Coral cover and bleaching data are scarce for Pitcairn Islands (but see Irving *et al.*, 2019; Friedlander *et al.*, 2014) but local evidence suggests low impacts due to thermal stress and confidence in the data is medium due to the paucity of data and limited monitoring.

Ocean acidification

The oceans are absorbing 25–30% of the additional atmospheric CO_2 which is causing acidification of ocean waters and negatively affecting calcification by corals and shellfish (IPCC, 2019). The pH baseline for surface waters in the equatorial Pacific between 1997–2011 is lower and more variable than the pH measured in other open-ocean regions, with a declining trend at a rate of 0.0018 to 0.0026 units per year. Global climate model ensembles estimate mean surface water pH around the Pitcairn Islands at 8.12 between 1956 and 2005 (Lenton *et al.*, 2018), but highly variable due to ENSO, where ocean acidification progresses more rapidly due to strong upwelling of CO_2 rich deep water (Sutton *et al.*, 2014).

Ocean acidification is changing seawater chemistry and influencing the availability of carbonate ions – the undissolved pure minerals of calcium carbonate (aragonite and calcite) – in surface waters. The increased acidity of seawater reduces the saturation state of aragonite, the mineral that calcifying organisms, such as corals, plankton and shellfish use to build calcium carbonate skeletons. This change in aragonite saturation impairs calcification, accelerating the dissolution of coral skeletons thus weakening skeletons and triggering stress-response mechanisms. This stress-response affects the rate of tissue repair, feeding, reproduction, growth and early life-stage survival of corals (Enochs *et al.*, 2015; Fabricius *et al.*, 2015; Fabricius *et al.*, 2017). It is likely that the response of corals to more acidic waters in the Pacific Ocean are not yet outside natural variability and local conditions and stressors (e.g. circulation patterns and pollution) may influence or exacerbate any response (Barros *et al.*, 2015) .

Extreme weather events

Tropical cyclones are part of the natural dynamics of Pacific Islands, and the impacts from extreme weather events include physical damage to corals through wave action and associated flood events which bring sediment and nutrient runoff onto coral reefs (Veitayaki and Holland, 2018), further stressing corals and impeding recovery (Guillemot *et al.*, 2010). In the tropical Pacific Ocean, cyclones are becoming stronger (IPCC, 2019) and the proportion of intense tropical cyclones (category 4-5) versus weaker cyclones (category 1-2) has increased substantially in the last 40 years (Holland and Bruyere, 2014). Deep-ocean swells from extra-tropical cyclones frequently reach Pacific islands and these are more likely to impact the Pitcairn Islands, but no assessment on these impacts has been conducted for the region to date.

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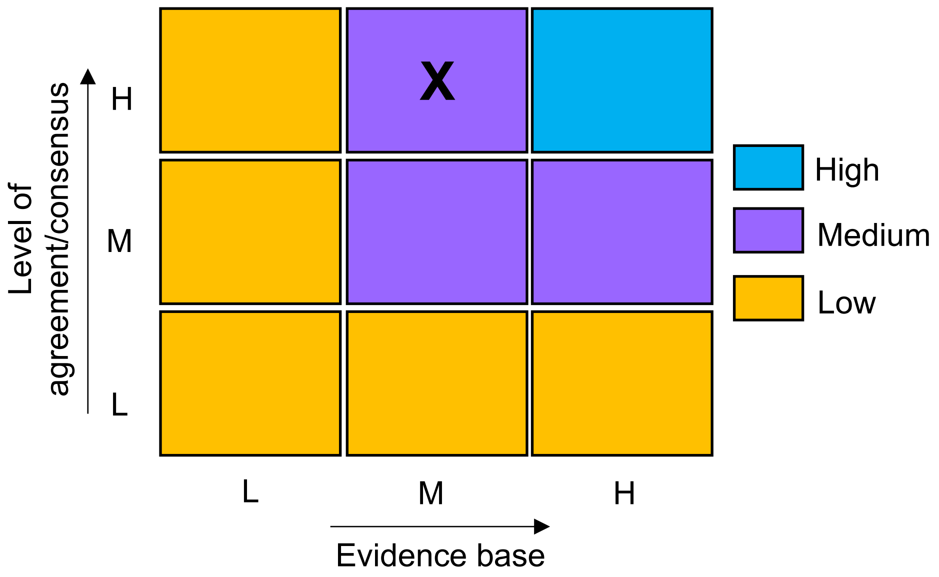

Confidence in the data is medium due to the paucity of data and limited monitoring. However global and regional observations provide useful insight on the response of reefs and their associated communities.

WHAT MIGHT HAPPEN

Sea Surface Temperature

SST is projected to increase by >3°C by 2100 in the Pacific region (Asch *et al.*, 2018), producing cascading effects on sea level, dissolved oxygen levels, net primary productivity and pH (IPCC, 2019). Higher SSTs are predicted under all future carbon emissions scenarios. This has the potential to increase the extent, frequency and severity of coral bleaching events (van Hooidonk *et al.*, 2016). The corals from the Pitcairn Islands extend into deeper, cooler waters south of the western Pacific warm pool (Irving and Dawson, 2013) and, as a result, low heat-stress is expected for the rest of the 21st Century (Friedlander *et al.*, 2014), although adequate assessments of future coral reef condition are not possible due to the paucity of data. However, there are records of coral mortality caused by cold water intrusions in Ducie Island in the 1970s (Irving and Dawson, 2013; Rehder and Randall, 1975). Further evidence suggests that these rare ocean intrusions cause cold-water stress to corals and resulted in bleaching and mortality at reefs around Ducie Island in

2016 (Dawson and Zhang, 2020). It appears that corals around the Pitcairn Islands are less at risk from heat-stress bleaching than their Pacific neighbours such as French Polynesia, but instead cold-water stress may potentially lead to declines in coral reef condition.

Ocean acidification

Ocean acidification is expected to increase in the future under all carbon emissions scenarios (IPCC, 2019). Variability in coral reef responses in the Pacific Ocean due to local conditions and species composition is likely to be substantial (Chan and Connolly, 2013). This, along with lack of evidence of contracting geographical range of calcifying species towards the equator (Hughes *et al.*, 2017), contributes to the low confidence on the effects of ocean acidification on corals. However, a decline in pH would result in marginal calcification conditions throughout most of the Pacific region and threaten corals and other calcifying organisms. Ocean acidification levels projected by 2100 may also influence critical behaviours of coral reef fish (Clark *et al.*, 2020).

Sea level rise

Despite the negative effects of coastal inundation associated with Sea Level Rise (SLR) on Pacific island nations (Nurse *et al.*, 2014), there may be some opportunities for corals in the Pitcairn Islands. Corals in Pitcairn grow deeper in clear waters and are relatively protected from warmers waters, and in principle, coastal inundation would provide extra ‘space’ because corals grow vertically. However, coral growth depends on other factors, such as reproductive capacity and larval dispersal, which is linked to temperature, pH and water circulation. The extra ‘space’ could allow corals to expand into current intertidal areas and colonise new inundated areas – provided that suitable substrate is available (Saunders *et al.*, 2016; van Woesik *et al.*, 2015) – thus increasing live coral cover. While Pitcairn corals grow in deep water, the current rate of SLR is accelerating (Nerem *et al.*, 2018) and there is a risk that corals will not be able to ‘keep pace’ with SLR and ‘drown’ as occurred elsewhere in the early Holocene Epoch (Stute *et al.*, 1995).

Extreme weather events

The observed increase in the proportion of Category 4–5 tropical cyclones may not continue at the same rate, although an increase in the proportion of intense cyclones is expected (IPCC, 2019). Following an initial increase in intense cyclone proportions, a saturation level will be reached, beyond which any further global warming will have little effect (Holland and Bruyere, 2014). The increase in the proportion of intense tropical cyclones will affect the deep ocean swells reaching the Pitcairn Islands, with potential negative effects on corals due to physical destruction.

The combination of climate change impacts on coral reefs, including increasing SST, more-intense storms and weather events and ocean acidification, are expected to affect the health of coral reefs in Pitcairn Islands, with coral cover projected to decline by up to 50% by 2100 (Bell *et al.*, 2011).

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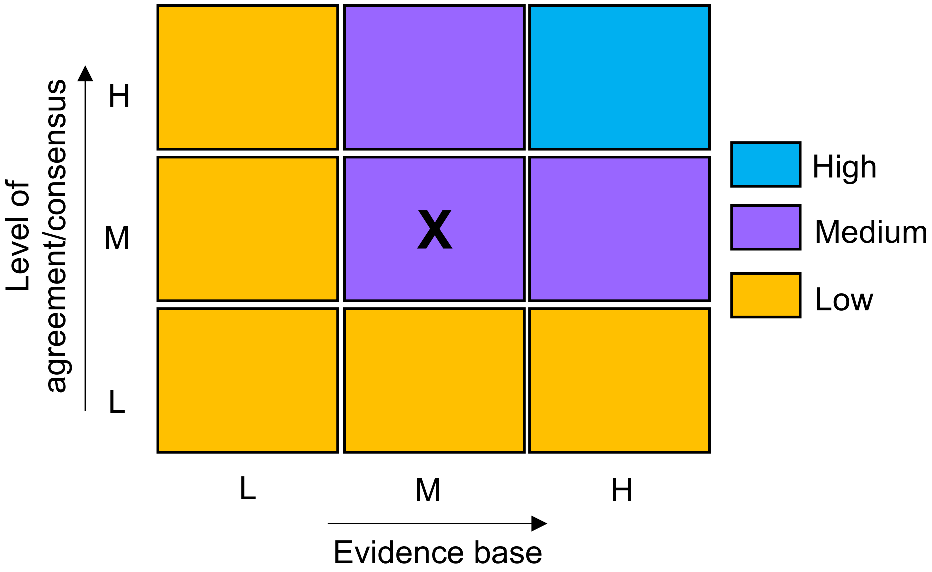


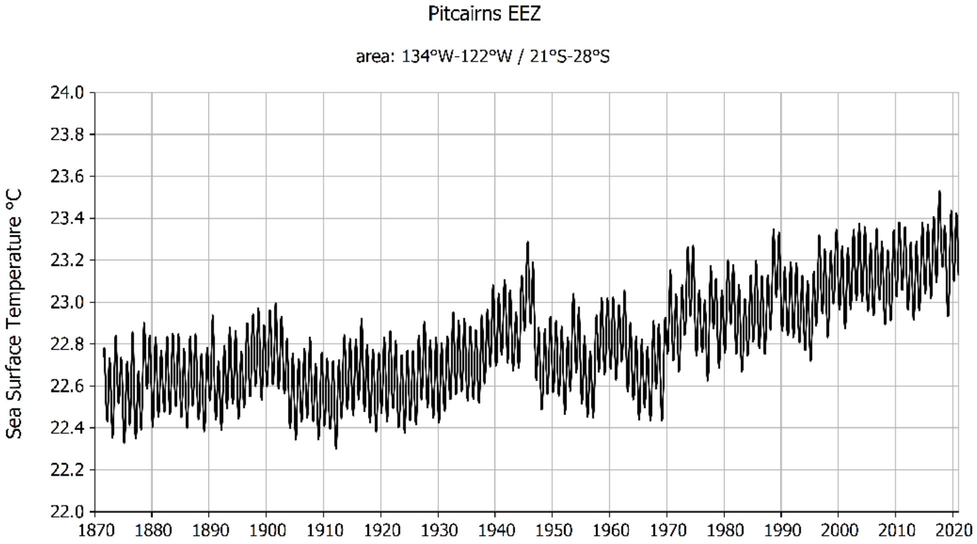
Assessments of future reef condition are not possible due to the paucity of data. Projections are also hampered by a lack of evidence on geographical range shifts of calcifying species.

PRIORITY 2: IMPACTS ON FISHERIES RESOURCES – COASTAL AND OCEANIC

WHAT HAS HAPPENED

A total 438 species of marine fishes are recorded from Pitcairn Islands EEZ (Randall 1999). The islands slope sharply to great depths, with very narrow, shallow, and, therefore, limited areas available for slope and shelf coastal fishing (Zeller, 2013). The Pitcairn Islands have 48 km^2 of coral reef habitat that supports coastal fisheries species (Bell *et al.*, 2011). There are no mangrove or seagrass habitats (Bell *et al.*, 2011). The coastal fisheries of Pitcairn Islands are made up mainly of three components: demersal fish (bottom-dwelling fish associated with the coast and coral reef habitats), nearshore pelagic fish, and invertebrates gleaned from intertidal and subtidal areas. Overall, catches for the subsistence and artisanal sectors have varied between 4 and 12 tonnes per year since the in 1950s (Coghlan *et al.*, 2017), and since the MPA was declared in 2016, only subsistence fishing is permitted in coastal conservation zones. Demersal fish are estimated to make up > 80% of the total catch. Surveys for deep-water species have not detected quantities sufficient for commercial operations (Sharples, 1994; Langley and Adams, 2005). The maximum sustainable yield of deep-water snapper (all species) was estimated to be between 1.1 and 3.3 tonnes per year (Langley and Adams, 2005).

ENSO strongly influences the oceanography of the Pacific Ocean and the distribution of its fisheries. However, the Pitcairn Islands EEZ is located in an area where ENSO has little to no impact on tuna habitat (Hare, 2020). Consequently, and unlike other nearby EEZs, the Pitcairn Islands do not experience redistribution of tuna into its EEZ associated with ENSO cycles. The current average SST in the EEZ is 23.2 °C, a rise of 0.4 °C since the 1970s, and there has been no definitive trend in primary production during the same period (Figure 1).



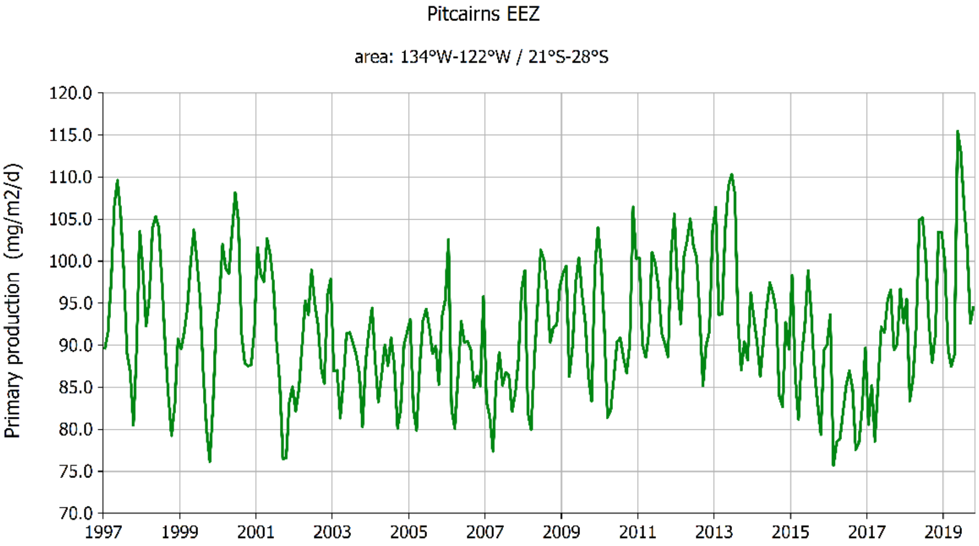


Figure 1. TOP: Mean sea surface temperature in the EEZ of Pitcairn Islands (Hadley Center HadISST dataset; www.metoffice.gov.uk/ hadobs/hadisst; Rayner et al., 2003), and BOTTOM: Mean primary production derived from ocean colour satellite data (CMEMS: OCEANCOLOUR_GLO_CHL_L4_REP_OBSERVATIONS_009_082)

Historically, commercial tuna fishing around the Pitcairn Islands EEZ was characterised by longline fishing fleets comprising vessels from Chinese Taipei, mainland China and Vanuatu, generally operating south of 20°S and targeting albacore tuna destined for canneries. Tuna catches in areas adjacent to the EEZ in 2019 included albacore (1431 Mt), bigeye (108 Mt), skipjack (5 Mt) and yellowfin (39 Mt). Surveys for skipjack using pole and line fishing gears did not detect sufficient skipjack populations to support commercial fishing operations (Argue and Kearney, 1982) and subsequent analyses of catches in the vicinity of the EEZ indicated that commercial operations would be marginal (Langley and Adams, 2005). Therefore, there has been little to no commercial fishing for tuna within the EEZ of Pitcairn Islands since 1993. In 2016, the government of the UK designated the world's largest no-take marine reserve in the Pitcairn Islands EEZ, essentially prohibiting commercial fishing.

Average national fish consumption in Pitcairn Islands is estimated to be 148 kg per person per year, well above the recommended levels for good nutrition (Bell *et al.*, 2011).

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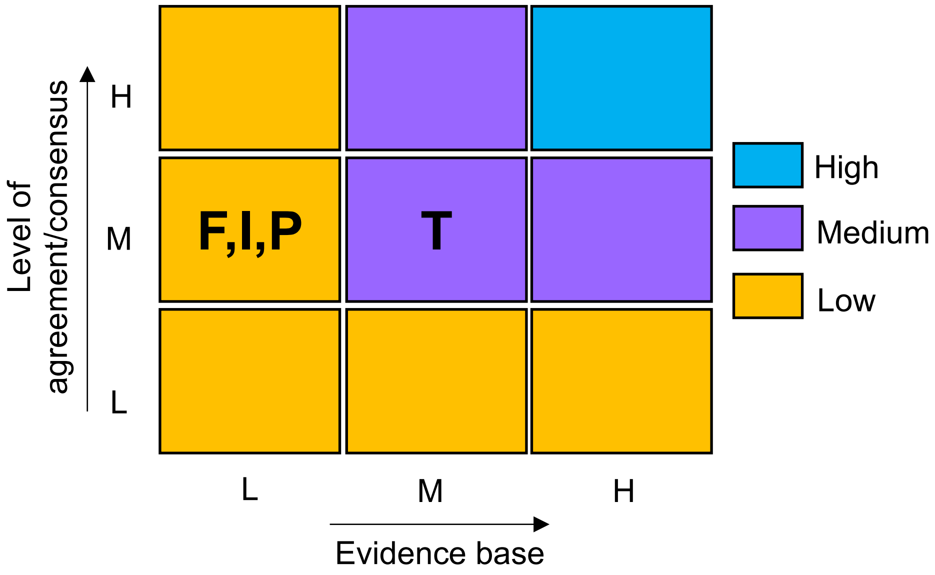

T = tuna, P=pelagic fish (not including tuna), F = demersal fish, I = invertebrates.

In general, the confidence is low due to a lack of long-term monitoring. This differs slightly when looking at the impacts of climate change on tuna where confidence is medium.

WHAT MIGHT HAPPEN

Impacts on the condition coral reef habitats that support coastal fisheries in Pitcairn Islands will have indirect effects on coastal fish and invertebrate species (Bell *et al.*, 2011; see Priority 1). A 20 to 50% reduction in production for demersal fisheries and 5% reduction in production of intertidal and subtidal invertebrates in Pitcairn Islands are projected due to both the direct effects (e.g. impact of increased SST on fish behaviour) and indirect effects (declines in fish habitats) of climate change (Bell *et al.*, 2011). The overall projected change to coastal fisheries catches reflects the relative reliance on demersal fish and the projected decrease in productivity of this component of the fishery. These effects however are not expected to have a noticeable impact on the fish available per person for food security. The large area of coral reefs relative to population size will continue to supply the fish needed in 2100, even if there is up to a 50% reduction in the productivity of demersal fish (Bell *et al.*, 2011; 2015). Additionally, the no-take MPA declared in 2016 only permits artisanal subsistence fishing by locals that is limited to shallow coastal reefs in the conservation zones, so these projected declines are unlikely to affect food availability.

Projected increasing SST and ocean acidification in the Pitcairn Islands’ EEZ will likely impact the pelagic ecosystem in the region. Earth-Climate model outputs have been used to project the future for key tuna species under IPCC emissions scenarios at the scale of the Pacific Ocean, using the Spatial Ecosystem and Population Dynamics Model (SEAPODYM). This model simulates the spatial dynamics of tuna under the effects of fishing and key environmental variables (temperature, primary production, oceanic currents and dissolved oxygen), and the predicted distributions of tuna prey in three vertical layers of the water column between the surface and a depth of ~1000 m. The current projections use an ensemble of bias-corrected atmospheric forcing variables from four different Earth System models to project changes in tuna biomass over the 21st Century (Senina *et al.*, 2018).

For the historical 2001–2010 period, the model simulation removed fishing pressure and estimated mean biomass to be approximately 31,300 tonnes (Table 1). Under a high emissions scenario (RCP8.5 or ‘business as usual’), the projections do not indicate substantial redistribution of albacore, bigeye, skipjack or yellowfin tuna into the EEZ of the Pitcairn Islands, with only a small increase in biomass for all species. Total tuna biomass was estimated to increase to approximately 38,800 tonnes in 2050. Changes in dissolved oxygen under future climate scenarios are uncertain, however, several climate models predict decreases in dissolved oxygen by 2050. The high sensitivity of albacore tuna to oxygen availability may result in albacore decreases in the Pitcairn Islands EEZ and immediate surrounds (Senina *et al.*, 2018). However, any potential increase in the biomass of tuna species could not be exploited in the Pitcairn Islands EZZ under the current MPA designation so the benefits will be primarily to pelagic ecosystems where tuna are high level predators and may spill-over into adjacent waters where commercial tuna fisheries operate.

Table 1. Change in tuna biomass (tonnes) in the Pitcairn Islands EEZ under IPCC high emissions scenario (RCP8.5) in the absence of fishing in the Pacific Ocean. Mean biomass change by area for the decades 2046-2055 (2050) relative to the 2001-2010 average.

	Tuna biomass (tonnes)				
No fishing pressure	**Albacore**	**Bigeye**	**Skipjack**	**Yellowfin**	**TOTAL**
Reference period (2001–2010)	12,400	9,400	2,000	7,400	31,300
Projected 2050 (RCP8.5)	13,600	10,400	3,300	11,500	38,800

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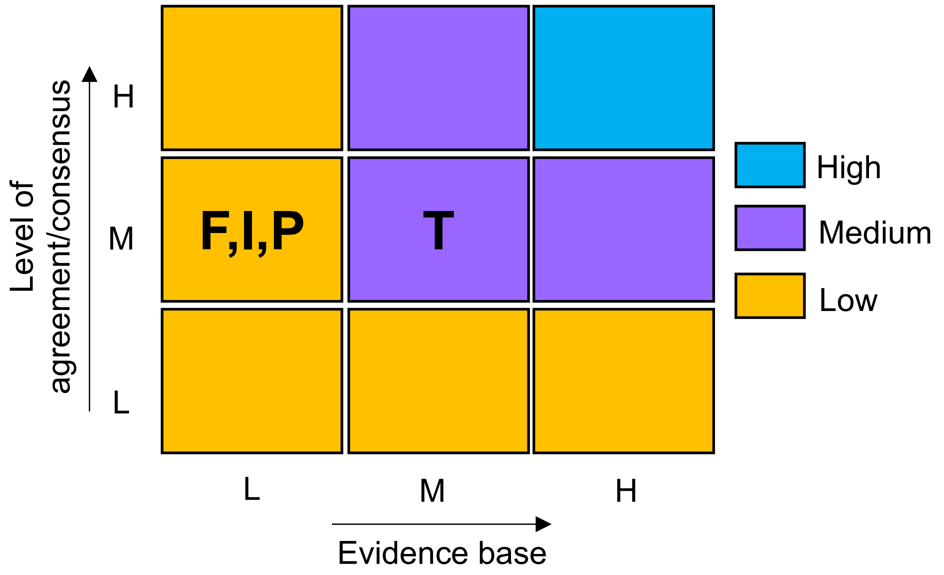

T = tuna, P=pelagic fish (not including tuna), F = demersal fish, I = invertebrates.

In general this is low, but differs slightly when looking at the impacts of climate change on tuna where confidence is medium due to wider regional studies.

PRIORITY 3: IMPACTS IN IMPORTS TO THE ISLAND AND THE SAFE MOVEMENT OF GOODS AT SEA

WHAT HAS HAPPENED

Pitcairn Island is the only inhabited island in the Pitcairn group, with a community that relies on imports for food and essential goods. Pitcairn Island relies almost entirely on budgetary support from the United Kingdom — totalling £3.48 million in 2016–17 and GB£3.01 million in 2017–18 (GB£1.00 = US$1.31). The per capita spending is GB£73,000 (DFID, 2021). In 2018, Pitcairn Island imported US$2.19M worth of goods, making it the number 221 trade destination in the world. During the last five reported years, the imports to Pitcairn Island reduced by US$1.28M from US$3.47M in 2013 to US$2.19M in 2018. The cause for this decline is uncertain, but will likely be a combination of an ageing and declining population and potentially reduced access due to weather. Pitcairn's import to export ratio is 1:1.76 (OEC, 2021). Pitcairn's exports are mainly goods from cottage industries, such as artwork and agricultural products such as honey, coffee and cocoa (OEC, 2021). The only way of accessing the island is by sea, but due to the difficult terrain, ships must moor offshore, with longboats operating between the ships and the harbours in suitable weather (Clegg, 2019).

All imports and exports are heavily dependent on weather as all have to transit Pitcairn's harbours. Up until recently there was only one harbour at Bounty Bay. However, with the increasing unpredictability of weather under a changing climate the importance of a second harbour was paramount as it would improve the resilience of the island by ensuring access to imports and allowing goods and visitors to land on the island. The second harbour (at Water Valley/Tedside) was completed in March 2019 (Rouault *et al.*, 2017) and allows longboats to land away from the prevailing weather, something that often restricted the transfer of cargo or visitors in the past.

The standard to which existing harbour and coastal infrastructure was built to is uncertain, and reports or confidence of the structural condition are limited. Medium-scale social infrastructure (schools, clinics, shelters, markets etc.) is generally not built to design standards that reflect escalating climate risks, and access to materials for maintenance and building may be affected by more extreme events (OECD, 2018).

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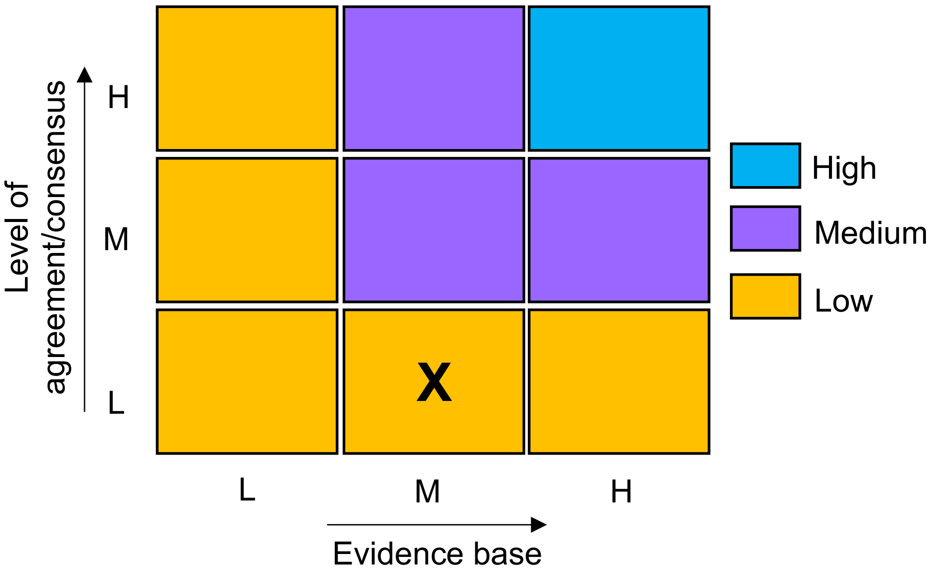


WHAT MIGHT HAPPEN

Pacific Island countries and territories, including Pitcairn Islands, are at the frontline of climate change, experiencing increasingly severe weather events and dramatic changes in weather patterns (IPCC, 2019). These changes bring escalating risks to the community, economy, livelihoods, and natural and social systems (OECD, 2018). Infrastructure networks on the Island (including the boat harbours, roads and other social infrastructure) will be affected by the physical impacts of climate variability and change. Previous extreme events have illustrated the extent of this potential exposure.

Rising sea levels, storm surge and severe storm events are all expected to reduce the integrity of coastal infrastructure and increase risk. Heavy rain will impact roads on the island, and may result in isolation of families or individuals, and reduce their access to goods and services, including critical food and medical care. With increasing extreme weather events due to changing climate, access will also likely restrict the safe transfer of cargo or visitors, even with the development of the second harbour. This will have economic and social implications and presents a high risk for the safety of transport shipping crews. Pitcairn Island is surrounded by high cliffs, with the sole habitation of Adamstown being approximately 80 m above sea level. A rise in sea level of 1 m during the next 100 years is therefore of concern mainly for infrastructure associated with the harbour and landing areas.

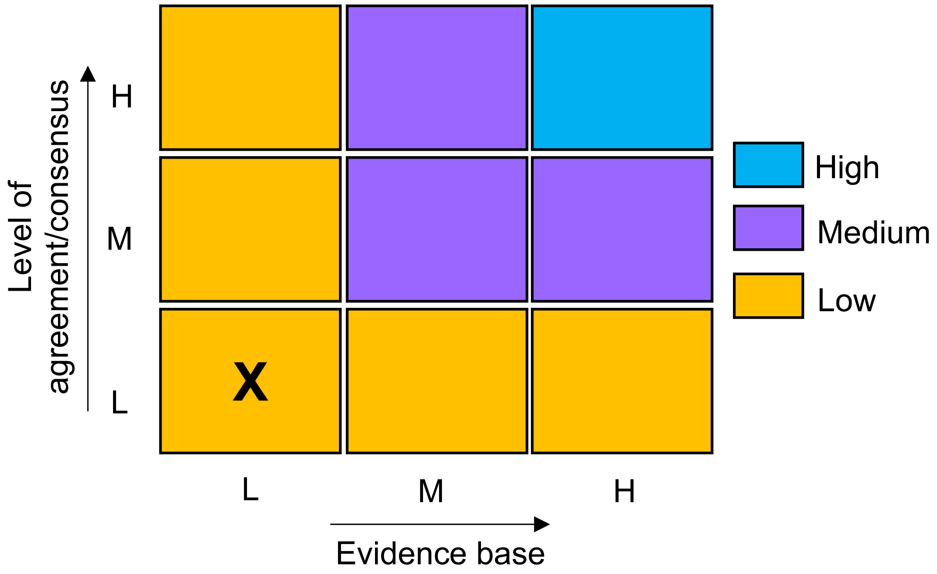
Integrating climate change considerations into existing and new infrastructure can play an essential role in building resilience to future climate change impacts (Hallegatte *et. al.*, 2018). New technologies are reducing the costs of resilient design and construction, while increasingly intense weather and disasters are increasing the costs of ‘business as usual’ construction and design. It is critically important that future investments in Pitcairn Island build resilient infrastructure.

New infrastructure assets should be prioritised, planned, designed, built and operated to account for the climate changes that may occur over their lifetimes (OECD, 2018). Existing infrastructure may need to be retrofitted, or managed differently, to account for climate change using climate-smart design principles. Simple solutions like where infrastructure is located may have significant benefits. Additional infrastructure, such as sea walls, may need to be constructed to address the physical impacts of climate change. This additional infrastructure can include traditional infrastructure, such as hard defences and other engineered solutions, as well as natural or soft infrastructure, such as wetlands and other nature-based solutions (see case study below).

Basic principles for strengthening climate resilience in Pitcairn Islands include:

- technically assessing the existing condition, and standard of infrastructure
- ensuring that all future infrastructure is built to standards that consider future climate scenarios and are climate and disaster resilient
- avoiding investment in infrastructure that is vulnerable, at risk of failure and likely to incur high maintenance costs
- maximising opportunity to serve multiple purposes including water capture, disaster centres etc.
- consulting with people and taking opportunities to ensure that infrastructure is robust enough to stand up to disasters and inclusive, building resilience in the community and for those who access it.

CONFIDENCE ASSESSMENT



REGIONAL NATURE-BASED SOLUTIONS: CASE STUDY

‘Nature-based solutions’ can be defined as *actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits*. They are underpinned by benefits that flow from healthy ecosystems and target major challenges like climate-change adaptation and mitigation, disaster risk reduction, food and water security, health and are critical to economic development (Cohen-Shacham, *et al.*, 2019).

A number of projects have been initiated in the Pitcairn Islands that are considered nature-based solutions, mainly in marine and coastal environments. For example, a Darwin initiative project (Dawson *et al.*, 2017) targeted the facilitation of informed sustainable marine resources decision-making by the Pitcairn Government by:

1. underpinning the decision-making with a strong scientific evidence base,
2. developing local capacity for fisheries and environmental assessments including fish catch data for recreational and subsistence fisheries (Duffy *et al.*, in press),
3. developing a Fisheries Management Plan within the coastal conservation zones, focused on management measures for the inshore subsistence fishery including gear restrictions and minimum landing sizes (Dawson and Irving, 2020; Irving *et al.*, 2019),
4. enhancing tourism opportunities, and
5. increasing awareness of Pitcairn Islands’ importance in meeting UK biodiversity targets.

These principles will continue to be implemented under the UK Blue Belt Programme (Lincoln *et al.*, 2021). All of these initiatives help to build the resilience of the Pitcairn Islands and people to environmental changes and have led to the strengthening of the Pitcairn Islands Marine Protected Area as well as an increased understanding of the importance of sustainable tourism to the economy.

The INTEGRE project (Rouault *et al.*, 2017) provided support to integrated coastal management in the Pitcairn Islands. An action plan was developed in close collaboration with the islanders, who are concerned about preserving their environment and heritage, as well as with the island council and the Natural Resource Division. The activities carried out with local stakeholders during the project were designed to:

- improve waste management,
- limit erosion,
- support better managed fisheries resources,
- control invasive species, and
- promote commercial development.

Again, these activities serve to build whole-of-territory resilience to environmental pressures.

NEXT STEPS

The climate change projections reported here are regional at best and there are no downscaled projections for the Pitcairn Islands (at a relevant scale). This will be particularly important for SST, since it is postulated that coral reefs and marine species in the Pitcairn Islands may be buffered from regional increasing SST due to circulation patterns. This dynamic needs to be examined further to determine if it is in fact occurring or likely to occur, and therefore improve understanding on the potential impacts of increasing SST on marine ecosystems.

While the Pitcairn Islands are a small state with limited monitoring and data collection, there will remain knowledge gaps regarding the implications of climate change for their natural resources and the people that depend on them. In particular, continuing recent efforts to collect fish catch data for recreational and subsistence fisheries (Duffy *et al.*, in press) and marine habitat monitoring (UK Blue Belt Programme), and application of these data to decision-making for sustainable fisheries and MPA management. Historical monitoring is sparce and carried out by CRIOBE from French Polynesia opportunistically (Chancerelle *et al.*, 2018), thus baseline data on coral cover, fish biomass and trends is limited. Regular monitoring would provide a baseline and help determine the extent of current impacts from non-climatic stressors that may be amenable to management and can be prioritised to build the resilience of the ecosystem to future threats. Marine habitat monitoring could also provide an early warning of impacts, such as coral bleaching, crown-of-thorns starfish outbreaks and coral diseases, to inform responsive management. Continuation of recent monitoring initiatives and inclusion of indicators for climate change impacts will be important for detecting change and informing management.

The implications of climate change for coastal infrastructure and security of shipping (imports and exports) also warrants further examination, with information on the location and condition of existing infrastructure, building standards that have been applied and future infrastructure plans required to determine the areas of greatest risk.

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