Climate change impacts on corals

in the UK Overseas Territories of BIOT and the Pitcairn Islands

Marine Management Organisation

Centre for Environment Fisheries & Aquaculture Science

UK Government

BIOT

The British Indian Ocean Territory (BIOT) consists of five atolls of low-lying islands, including the largest atoll in the world, Great Chagos Bank, and a number of submerged atolls and banks. Diego Garcia is the only inhabited island.

The BIOT Marine Protected Area (MPA) was designated in 2010. It covers the entire maritime zone and coastal waters, an approximate area of 640,000 km^2. The marine environment is rich and diverse, attracting sea birds, sharks, cetaceans and sea turtles and with extensive seagrass and coral reef habitats. It includes the endangered Chagos brain coral (*Ctenella chagius*), an endemic massive coral unique to BIOT.

BIOT reefs have suffered extensive bleaching and mortality, and they remain vulnerable to current and future climate change and other pressures, including:

Bleaching

The heavy mortality has been caused by recurrent marine heatwaves since the 1970s. Reefs have not yet recovered from the most severe bleaching in 2016 and 2017, with increasingly severe events expected. Deeper fore-reefs may act as refuges, but those colonies are likely to be more sensitive to temperature change. Limiting other pressures will not guarantee resilience to future bleaching.

Ocean acidification

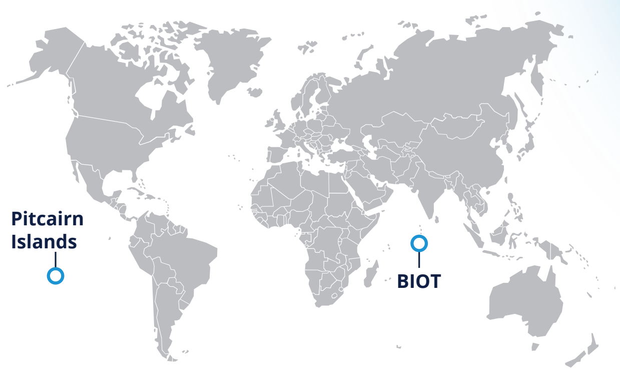
There has been a low impact of ocean acidification on coral reefs so far, but when combined with future bleaching the risk of decalcification and erosion will increase. Under high emissions scenarios, BIOT is projected to become less suitable for corals by the end of the century.

Changes in sea level and extreme weather events

In BIOT, sea level is rising twice as fast as the global average. Extreme sea levels appear related to El Niño or La Niña events. When combined with bleaching and acidification sea level rise will reduce the effectiveness of reefs to perform as breakwaters. BIOT has experienced considerable shoreline erosion, which suggests loss of breakwater effects from protective fringing reefs.

Other human pressures

Rats have caused a crash of seabird populations, disrupting guano nutrient flows to the detriment of some reef organisms including sponges and corals. Around Diego Garcia, small scale fishing is allowed to residents but illegal, unreported and unregulated (IUU) fishing is also known to occur, and there are concerns of pollution and anchor damage within the lagoon.



PITCAIRN ISLANDS

The Pitcairn Islands (Pitcairn, Oeno, Henderson, and Ducie) comprise a volcanic outcrop of four small islands in the Southern Pacific Ocean. Pitcairn is the only inhabited island.

The Pitcairn Islands MPA was established in 2016 and covers 841,910 km^2. The marine environment is less varied in terms of species richness than BIOT, due to its isolation, and includes fewer endemics. Coral reefs are abundant, particularly around Ducie Island, are found at deeper waters than usual due to exceptional water clarity, and are dominated by massive resistant species as well as the more sensitive cauliflower and soft fire corals.

While the location of the Pitcairn Islands has provided a relative shelter from the effects of warming, these sensitive corals are vulnerable to expected future climate impacts and other pressures:

Bleaching

No evidence of past bleaching has been found, and no change in average sea surface temperature (SST) has been detected. Low levels of thermal stress are expected in the future. The South Pacific Circulation Gyre may slow down future warming, and the deeper reefs may be relatively sheltered from future climate change. However, these corals may be more sensitive if stress occurs, and their isolation may challenge their recovery. Monitoring is needed to ensure any future bleaching is recorded.

Ocean acidification

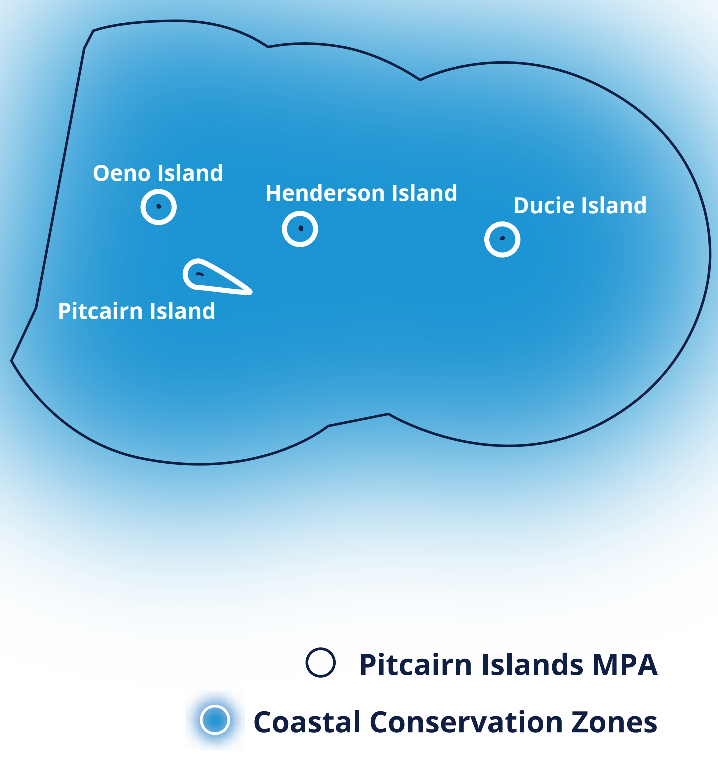
Saturation state of calcium carbonate-based minerals is reaching the point where coral skeletons weaken and growth slows down. Low pH is changing the composition of colonies, favouring algal cover and encouraging bioerosion. Even under low emissions scenarios, saturation of calcium carbonate based minerals and pH levels are unlikely to support net coral calcification in this island group by the end of century.

Changes in sea level and extreme weather events

Sea level has risen faster here than the global average, although island margins appear to have adjusted, however, as sea level rise accelerates it is unclear whether these islands will persist. Corals have suffered damage from waves around Henderson and cold water intrusions at Ducie. Heavy rainfall on Pitcairn has caused sedimentation and turbidity although strong prevailing currents seem to mitigate this risk.

Other human pressures

There are concerns around overfishing, and Henderson Island has some of the highest levels of plastic pollution on the planet. Cruise ships and sediment runoff are causing damage to the seabed and the corals. Crown of thorns starfish may be present around Pitcairn. There are also rats on Henderson Island, which reduce numbers of seabirds with potential negative effects on surrounding reefs through the loss of guano nutrients, as it has been observed in BIOT.



Sea temperature change

BIOT

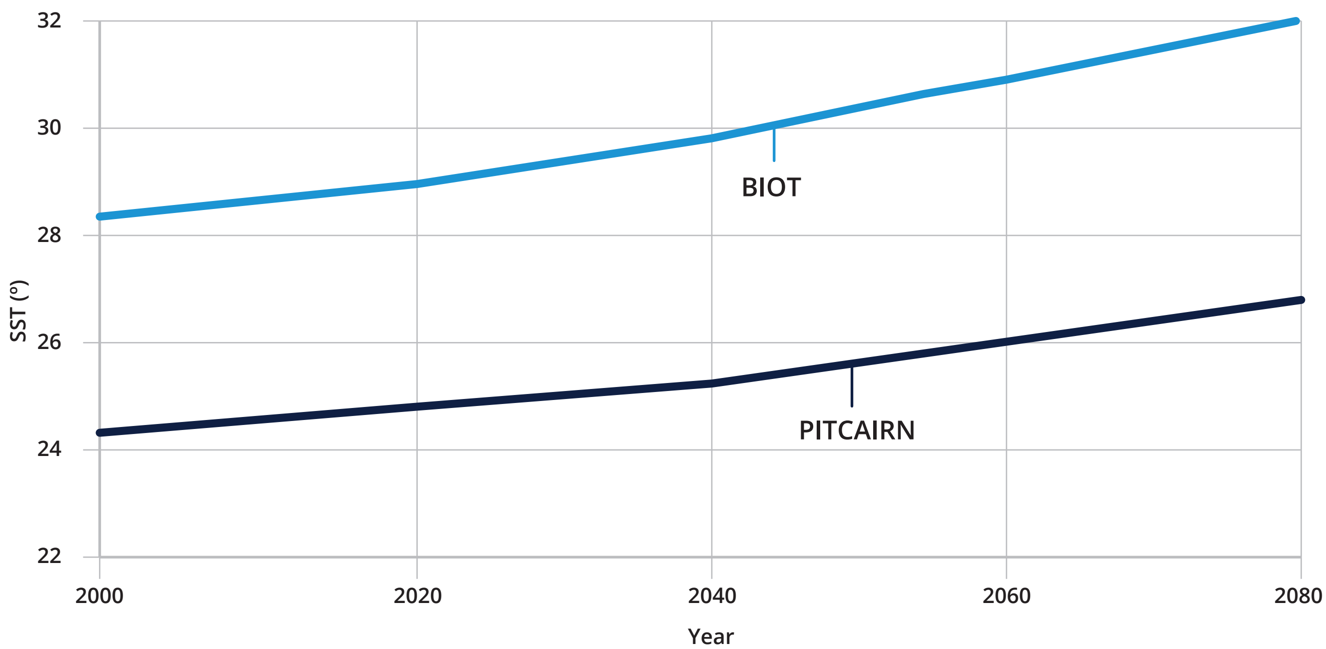
In the tropical Indian Ocean, average sea surface temperature (SST) increased by more than 0.6°C between 1950 and 2009. In BIOT, severe marine heatwaves have been detected over the last two decades, with elevated temperatures persisting for several weeks. Warming was more acute in shallow lagoons compared to ocean-facing reefs where subsurface waves of cooler water help attenuate the warming effect. Bleaching and mortality of corals are generally linked to seasonal temperature increases of 2°C above normal.

SST will continue to rise over the 21st Century in the Indian Ocean, with a significant risk to corals. Under a medium emissions scenario, SST is projected to rise by approximately 1°C by 2050 in the BIOT region, and by 1.5°C by the end of this century. Under a high emission scenario, SST will rise by 2°C by 2050 and by at least 4°C by the end of this century, which is enough to cause widespread mortality across the corals in BIOT every year. There will continue to be some natural interannual variation in SST in the Indian Ocean, driven by the Indian Ocean Dipole and by extension the El Niño/Southern Oscillation (ENSO).

PITCAIRN ISLANDS

Since 1950, SST has risen by more than 0.4°C in the warmest months in the western Pacific Ocean. It is difficult to establish to what extent this warming is due to climate change however, due to the effect of the Pacific Decadal Oscillation and ENSO. In addition, the Pacific warm pool extends towards Pitcairn during El Niño years, and has increased in area since the 1980s, raising SSTs further. Records from the Pitcairn Islands show three distinct ocean heat events that peaked in 1995, 2006 and 2017, principally affecting Oeno, Pitcairn and Henderson.

Further SST rise in the Pacific is projected over the 21st Century and the equatorial Pacific warm pool will expand further across the western tropical Pacific. High natural variability means projections are not yet consistent or confident, but they suggest that under a medium emissions scenario, SST around Pitcairn could rise 0.5°C by 2050, and 0.9 °C by 2099. Under a high emissions scenario, SST will rise by 2°C by 2050 and by just under 4°C by the end of this century, enough to cause mortality to a significant proportion of the corals in the Pitcairn Islands every year.



Projection of future average SST for Pitcairn and BIOT, showing predicted warming temperatures under high emissions scenario.

[Adapted from: Sellar, A.A., et al. (2019). UKESM1: Description and evaluation of the UK Earth System Model. Journal of Advances in Modeling Earth Systems 11, 4513– 4558.]

Impacts from bleaching

BIOT

Until 1997, coral cover in the archipelago was 50–70%, with diverse colonies in lagoons, reef crests and reef slopes. A series of warming events in the late 1990s resulted in extensive coral bleaching and mortality. Only 12% of the reef survived, mostly thermally resistant branching corals, while more sensitive forms of table, branching and massive corals declined significantly. Colonies have partly recovered from this, and other bleaching events that followed, although not to the extent that existed before 1998. Between 2015 and 2016, two severe ocean heat events impacted BIOT from which colonies have not yet recovered, partly because of low spawning. Only 10% of the pre-1998 BIOT reef now remains and the composition has changed. Some species have been lost such as brain corals and bird's nest coral, and others, like the endangered Chagos brain coral unique to BIOT, have greatly declined.

Apart from Diego Garcia, BIOT atolls do not endure the human pressures found elsewhere. Reef fish include herbivorous fish that graze on the seaweed that could otherwise smother the coral, and shark numbers appear to be slowly recovering. Whilst this should allow BIOT reefs some resilience to climate change, it is not clear whether coral colonies will persist in a warming ocean. The deep corals of the cooler fore-reef slopes may escape future bleaching, but the extensive reef flats, and shallow back-reefs are likely to experience severe thermal stress again in the future. Their survival will greatly depend on how colonies evolve in the coming decades, to be dominated by corals that are tolerant or sensitive to temperature change.

Past sea warming events have already caused substantial coral bleaching and mortality around BIOT, particularly in shallow reefs

PITCAIRN ISLANDS

Based on the limited marine data available for the Pitcairn Islands, SST has not changed significantly, and no bleaching events are recorded. An expedition in 2012 found high coral cover (56%) in Ducie Island, compared to Oeno, Henderson and Pitcairn (28, 24 and 5% respectively). Reefs showed low diversity, dominated by heat-resistant branching corals, and more sensitive cauliflower and soft fire corals. There are, however, records of mass coral mortality in Ducie caused by a cold water intrusion in 1970.

The future risk of exposure to thermal stress for Pitcairn corals is relatively low compared to other reef areas globally. The minimal pressure from human activities should also allow these corals better chances of overcoming climate impacts. However, the [inferred] lack of previous exposure to bleaching could also mean a heightened sensitivity for these corals. Their isolation and lack of surplus of coral larvae from other reef areas, would challenge the recovery of the corals, should they suffer major mortality over the coming century. The Pitcairn Islands are on the edge of the southern limit for optimal reef growth, with Ducie being the most southerly atoll in the world. Water temperature will likely remain suitable for reef growth, particularly in the deeper, cooler and well flushed fore-reefs, while the risk of thermal stress and bleaching may be slightly higher for the shallower reef flats and lagoons. These reefs have yet to be further explored however, to better understand the risk of exposure to future bleaching.

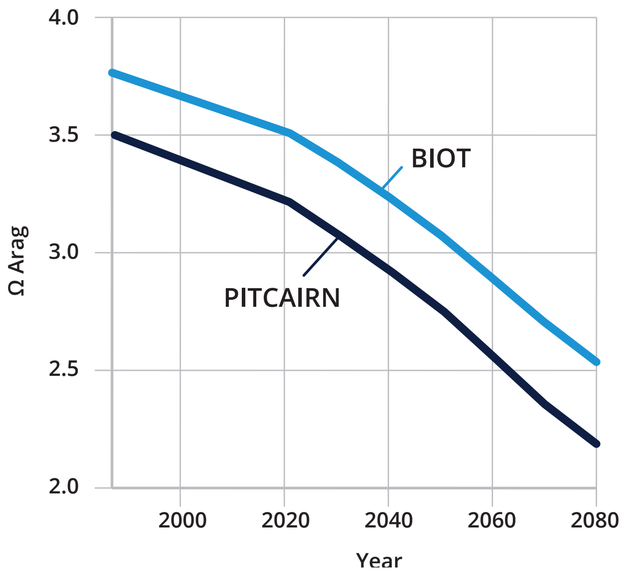
Corals may persist longer around the Pitcairn Islands, especially in the deep fore-reefs of Pitcairn Island itself, despite warming seas

Ocean acidification

BIOT

The biogeochemistry of the Indian Ocean is highly variable and influenced by the seasonal monsoon and other oceanic circulation systems. This includes ocean acidification, the decrease in pH of seawater. Trends of pH levels in the Indian Ocean are largely understudied, particularly around the BIOT region, although the Global Ocean Acidification Observing Network (GOA-ON) is currently developing monitoring stations in the western Indian Ocean. Surface pH appears low compared to other ocean basins and is declining more rapidly. The mean surface water pH around BIOT has previously been estimated to be approximately 8.09. The saturation state of calcium carbonate-based minerals such as aragonite is currently around 3.5.

Global models project an average decrease of 0.08 pH units in BIOT waters by the end of this century under a low emissions scenario, or 0.27 units under a high emissions scenario. This indicates a faster rate of acidification than the global average. Aragonite saturation levels on the other hand are projected to decrease although more slowly, remaining higher than other regions. These discrepancies between projections of future ocean acidification at ocean-basin and regional scales in the Indian Ocean, highlight a need for further research.



Projection of future average sea surface aragonite saturation state for Pitcairn and BIOT, showing the predicted decline in saturation under a high emissions scenario. Aragonite is a calcium carbonate-based mineral, which makes the skeleton of corals. [Adapted from: Sellar, A.A., et al. (2019). UKESM1: Description and evaluation of the UK Earth System Model. Journal of Advances in Modeling Earth Systems 11, 4513– 4558.]

PITCAIRN ISLANDS

No long-term time-series for pH exist for the equatorial region of the Pacific Ocean, although there are plans to improve data resolution across the Pacific. Surface pH has been previously estimated to range between 7.91–8.12, which is lower than other open-ocean regions, and it may be declining faster. There are indications that saturation state of calcium carbonate-based minerals in surface waters of the Pacific is declining and aproaching 3.2 for the Pitcairn Islands. During non-El Niño periods, ocean acidification has been observed to progress more rapidly due to the upwelling of deep, CO2-rich water. Around the Pitcairn Islands, mean surface water pH has been estimated to be near 8.12.

Under a high emission scenario, it has been estimated that average surface pH around the Pitcairn Islands will decrease by 0.27 pH units by the end of this century. The confidence in these projections however is only relative, due to high variability and interannual fluctuations.

Ocean acidification effects

BIOT

To date, there are few studies on the impacts of ocean acidification on Indian Ocean reefs compared to bleaching, and therefore there is heavy reliance on estimations from global scale models. The saturation state of aragonite in the BIOT region suggests potentially healthy, calcifying reefs. However, the effect of bleaching has caused coral loss and there is an increased risk of further loss into the future, with bleached corals more fragile and vulnerable to breakage and erosion.

Some models suggest BIOT will become less suitable for coral calcification, because of the combined effect of sea temperature warming and ocean acidification.

BIOT will become less suitable for corals due to future ocean acidification and warming sea surface waters

PITCAIRN ISLANDS

The South Pacific is nearing the point where coral calcification weakens and growth slows down, but direct links between observed pH changes and physiological impacts on corals are lacking. Responses of corals to local acidification conditions are likely to be affected by processes such as circulation patterns and pollution. While there are no studies of ocean acidification from the Pitcairn Islands, there is evidence of shifts in reef-forming coral species, encroachment of algae and increased bioerosion of reefs by boring organisms elsewhere in the Pacific, threatening ecosystem function. Acidification affects skeletal density, rather than growth. An attempt to disentangle the effects of temperature and ocean acidification found that, in the tropical Pacific Ocean, acidification alone was responsible for a 13% decline in the skeletal density of massive corals since 1950.

By the end of the century, even under low emissions scenarios, sea surface aragonite saturation around Pitcairn will decline to just over 3, which is the limit for coral calcification below which no major reef systems are known to persist. Whilst in the short term the influence of the South Pacific Circulation Gyre may slow down some of these changes in the Pitcairn Islands region, under a high emissions scenario by 2050 the entire tropical Pacific will see a shift to sub-optimal calcifying conditions that is likely to cause a decline in coral calcification rate of about 10%. By the end of the century and under the same high emissions scenario, saturation states both in Pitcairn and most of the wider Pacific will be too low to support net coral calcification.

There is a high risk that future ocean acidification conditions will prevent coral calcification in the Pitcairn Islands by the end of the century

Sea level rise

BIOT

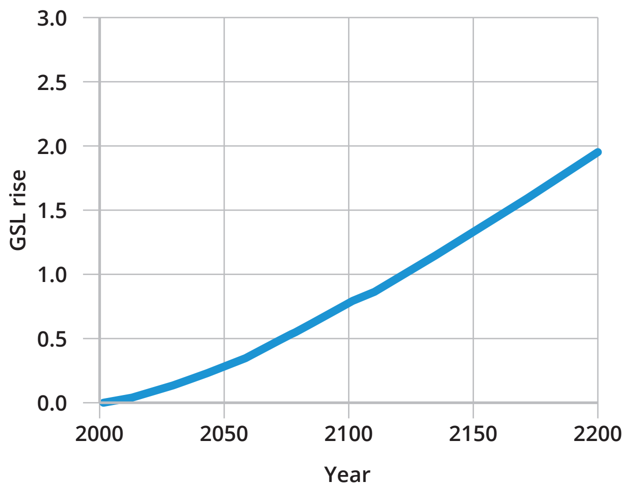
In Diego Garcia, sea level is rising more than 5 mm per year, and is accelerating faster than the oceanic average. Most land in BIOT is within 1 m of the high tide. Loss of land and mature soil is most apparent in the smaller islands, while in the horseshoe-shaped Diego Garcia there has been some accumulation of soft mud within the lagoon that has replaced, in terms of area, some of the erosion around the island. Shoreline defences exist and are reinforced regularly, but roads and military structures continue to suffer flooding from the sea every year. It is important for the persistence of these islands that the fringing reefs are able to grow upwards. Healthy reefs can keep up with current sea level rise, but due to bleaching and mortality shallow reefs are now suffering attrition, and the gap between the sea surface and the reef crest is widening.

In the Indian Ocean, there has been a further increase in the basin-mean sea level due to wind-driven mass redistribution combined with thermal expansion and salinity effects. This acts to augment environmental coastal stress, particularly on small low-lying islands, although there is considerable geographical variability. There are as yet no reliable downscaled projections of sea level rise for the BIOT region and therefore it is not possible to be confident about the potential impact on corals, and in particular fringing reefs.

PITCAIRN ISLANDS

Sea level rise across the Pacific Ocean varies depending on the influence of large-scale climate and ocean processes. Some of the rates reported in the western South Pacific are four times the global average (approximately 12 mm per year), and reflect short-term modulations by natural climate features such as ENSO. Lower or higher than average sea levels are induced during El Niño/La Niña events of the order of ±20 to 30 cm. Extreme sea levels have also been detected caused by a combination of tides and storms, along with long-term sea level rise. There are no tide gauges on the Pitcairn Islands, and therefore no accurate records of sea level.

At a basin-scale, future projections of sea level indicate that it will raise higher in the western Pacific than the global mean. The consequences will be particularly acute for small islands when combined with the impact of strong tropical cyclones and the potential loss of protective fringing reefs due to bleaching and ocean acidification. In the South Pacific and by end of century, sea level is expected to raise between 27–97 cm under a medium emissions scenario, and between 54–217 cm under a high emissions scenario. Future sea level rise for the Pitcairn Islands appears to be within the lower half of the range of values for the South Pacific, but such regional-scale projections are still uncertain.



Global sea level rise under a high emissions scenario, calculated based on a global set of local sea level projections.

[Adapted from: Kopp, R.E. et al. (2014). Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. Earths Future 2, 383–406.]

Impacts from sea level rise

BIOT

In the Indian Ocean, sea level rise is accelerating. BIOT is currently subject to considerable shoreline erosion, of up to 1 m horizontal attrition per year in several atolls, with signs of net erosion over the past 100–150 years on some islands. Coral mortality can also lead to changes in sand production, with further implications for beach nourishment and erosion.

In 2016, the warmest year on record, many reef areas suffered extensive bleaching and loss in the Indian Ocean, including BIOT. This may have impacted the reefs ability to keep up with sea level rise. Post-bleaching assessments have yet to be undertaken in BIOT, which are needed to confirm whether vertical reef accretion is keeping apace with sea level rise. By the end of this century, only a small proportion of reefs in BIOT and across the Indian Ocean, less than 3%, are projected to sustain vertical accretion at a rate matching sea level rise under a medium emissions scenario. Under a high emissions scenario that proportion is expected to be less than 1%.

BIOT islands are suffering erosion due to sea level rise and loss of protective fringe reefs

PITCAIRN ISLANDS

In the Pitcairn Islands, although sea level rise is expected to be greater than the global average according to data from other Pacific islands, it has not yet caused significant erosion or island "drowning". Island margins, particularly in Henderson, Ducie and Oeno, appear to be adjusting to seasonal erosion and accretion processes, even following extreme events and variations in sediment supply – often supplied by the coral reefs themselves.

However, it is unclear whether the islands will continue to persist as sea level rise accelerates over the coming century. Loss of diversity and changes on the structural complexity and skeletal density of the coral reefs that fringe and protect the islands are of particular concern.

As sea level rise accelerates, it is unclear whether the Pitcairn Islands will continue to adjust

Extreme weather events

BIOT

There are no routine wave measurements near BIOT, but information gathered from passing ships, satellites and numerical models show no evidence of changes in the wave and wind fields in this area. Storm tracks have shifted across the Indian Ocean but, because of its proximity to the equator, BIOT lies outside the cyclone belt and experiences few direct storm hits, although it is still exposed to the impact of deep ocean swells. Such long-distance waves, originated by extratropical cyclones generated in the Southern Ocean for example, are known to reach other islands causing flooding and damage.

For the Indian Ocean, while some climate models project waves becoming larger and shifting, most studies find negligible changes or even an attenuation of wave heights in the trade and monsoon wind regions. There are no downscaled projections for the BIOT region, but it is expected that the likelihood of tropical storms or cyclones reaching BIOT in the future will be even less than currently.

PITCAIRN ISLANDS

The link between tropical cyclone events and climate change is still unclear, particularly for the tropical Pacific basin. Storm activity across the Pacific is strongly correlated with natural short-term ENSO fluctuations, and there are no consistent trends in the number of very intense tropical cyclones across the basin. Because of the location of the Pitcairn Islands, a direct hit by tropical cyclones may be a lesser risk than the impact of long-distance ocean swells from remote low pressure systems. These ocean swells generated in mid and high latitudes frequently reach Pacific islands, especially during strong El Niño years.

Latest climate models show mean significant wave heights are increasing in the Pacific and Southern Oceans, apparently due to strengthening trade winds, but there is low confidence in these projections. A lack of wave height data makes it difficult to discern the influence of long term climate trends from short term changes due to natural variability. No reliable projections of future wave climate exist for the Pitcairn region.

Impacts from extreme weather events

BIOT

There is evidence of significant storm damage to BIOT coral reefs. Extreme seas generated by distant extratropical cyclones are also known to have caused significant damage in the Maldives 500 km away, breaking and displacing large reef boulders and killing many corals. Distant extratropical cyclonic activity therefore represents a latent, if minor, threat to BIOT coral reefs.

In BIOT, the reef crests that provide a breakwater effect are often only 25 m from the shoreline, meaning there is only a short distance over which waves can become attenuated before reaching the coast. If the reef crests are overtopped permanently, even at low tide, the immediate consideration is shoreline erosion and flooding of the islands, and salination of water tables. Extreme sea levels and waves in BIOT remain a high risk to coral reefs and to the islands themselves.

Protection and management actions could help improve climate resilience of corals in BIOT and Pitcairn, but their isolation is a further challenge due to the low supply of healthy coral larvae that could allow recovery

PITCAIRN ISLANDS

There is evidence of past storm and wave damage in the Pitcairn Islands. In the fore-reef around Henderson Island, bedrock is visible and appears encrusted by coralline algae, indicating scouring by strong wave action during storm events as coral debris from shallower waters is dragged into deeper water. Extensive areas of coral rubble are also found at depths of more than 30 m. In Ducie Island, signs of mass mortality have been found in lagoon corals, possibly killed by an influx of cold water from more southerly latitudes, together with evidence of land deforestation caused by waves. In 2012, a major rainfall event was experienced on Pitcairn Island, the worst since records began, that caused landslides and high sediment loads entering the near-shore marine environment. Runoff, turbidity and sedimentation caused some coral mortality, but the prevailing strong currents were likely to disperse and flush the sediment after a period of time. The low coral cover and proliferation of seaweeds in Pitcairn, compared to the other islands, has been partly attributed to runoff, but it is more likely that wave exposure and sand scouring prevent coral growth.

The extraordinary water clarity of the islands (up to 75 m depth at Ducie Island) allows coral to grow deeper than elsewhere in the Pacific reefs, which may offer protection from some of these impacts in the future.

Other human impacts

By limiting other pressures, marine management strategies can enhance the resilience of coral reefs to climate change impacts.

BIOT

Recreational fishing is allowed around Diego Garcia, but most catches are not recorded. Poaching and illegal, unreported and unregulated (IUU) fishing has caused sharp declines in some target species such as sharks.

Low levels of nutrients and some heavy metals have been found in the lagoon in Diego Garcia, although this is being closely monitored.

There are largely unchecked populations of black rats in BIOT, that have caused a catastrophic crash of the seabird populations of the islands, disrupting natural nutrient leaching from the guano, in detriment of the reefs.

In Diego Garcia, anchoring has caused damage to corals in the lagoon, with an estimate of two thirds of corals being lost. Yachts also moor off outer islands.

PITCAIRN ISLANDS

There are concerns of overfishing from the subsistence fishery by the local community allowed around Pitcairn Island, but it is unclear actually how many fish are caught.

Cruise ships that anchor off Pitcairn Island may be damaging the reefs.

Land sediment runoff is known to have caused some coral mortality.

Crown of thorns starfish, which are invading reefs across the Pacific, might be present around Pitcairn, but this is not currently monitored.

Henderson Island has some of the highest levels of ocean-borne plastic litter on the planet, which is collected from distant shores by the South Pacific Gyre and deposited on the island. Plastic is associated with coral diseases and it also causes physical damage to reefs and other marine life.

Invasive black rats on Henderson Island have already caused either extinction or decline of a number of endemic or endangered bird species, which can have a negative cascade effect disrupting the natural input of guano nutrients to the reefs.

Adaptation options

Reducing stressors

Marine management strategies can help limit other pressures and improve coral resilience. While their remote location might enable the reefs in these territories to survive longer into the future compared to other areas, as ocean warming intensifies, reefs will likely lose species and complexity.

Improved fisheries management as part of large MPAs can help improve the resilience of corals. For example, grazing by reef fish controls algae overgrowth, freeing up substrate for coral recruitment. Reducing non-climatic stressors will not prevent bleaching or mortality, but it may delay the onset of mass losses and allow time for global emission reduction and mitigation actions to have an effect.

Improving coastal water quality through a ridge-to-reef approach reduces pollution and disturbance impacts from land sources. Improving water quality conditions helps coral recover quicker and reduces susceptibility to crown of thorns outbreaks.

Invasive non-native species, even on land, can have catastrophic impacts on coral reef areas.

Pollution response plans and training will ensure that any incidents can be responded to and damage limited.

Anchoring damage to the seabed should be monitored regularly, so that further measures can be put in place if necessary.

Interventions

Coral planting, seeding and manipulation have had some local success in coral reefs elsewhere. Research is underway to breed species and strains of corals that are more heat tolerant. Engineering symbiotic bacteria or zooxanthellae to create heat resistant strains, is another possibility. It has also been proposed that it is possible to attenuate bleaching during heatwaves by using artificial shading. But most of these interventions involve complex decisions and are not without controversy as to their efficacy, and their implementation across large and remote areas such as the BIOT and Pitcairn Islands MPAs presents big challenges.

At present, reducing future global CO_2 emissions is the only feasible pathway to control future global warming and therefore effectively limit the risk to coral reefs, including those in BIOT and Pitcairn. To further promote the resilience and adaptation of the reefs in these territories, tangible and targeted management measures and regular monitoring can help in determining what, if any, active steps are feasible and need to be taken to promote resilience and limit impact. It will likely involve an array of interventions in order to improve their protection through MPA management, alleviate local pressures, and restore degraded and damaged reefs.

Current management measures

There are strict no-take regulations in both territories as part of their MPAs. Management plans now regulate the small scale local fishing activities allowed, and compliance and enforcement strategies ensure surveillance and prosecution of IUU fishing offences. There are currently several management actions being implemented on reducing the impact of human activities on corals. Further work is also considered on the eradication of rats on some of the islands.

Further options

Monitoring of reefs and other vulnerable benthic habitats would help identify impacts, and coverage could be maximised by coordinating this effort with data gathering from fisheries catches. Eradication of invasive species, also on land, could have positive feedback on corals. These territories could be considered as coral banks where corals and coral seeds could be harvested for replanting in other reefs.

Research gaps

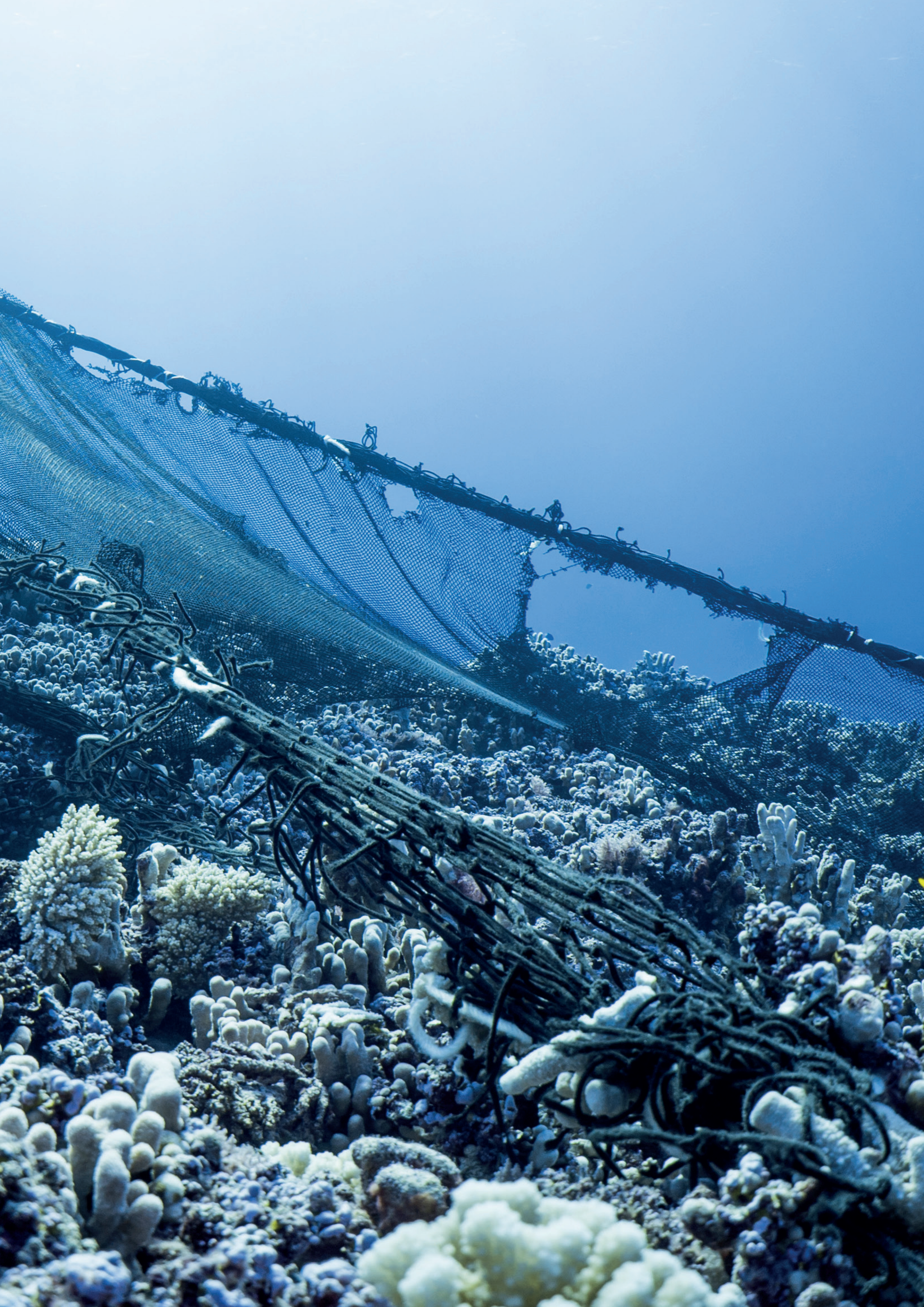
A coral vulnerability assessment of the coral reefs in BIOT and the Pitcairn Islands is an important first step.

This is underway and will help characterise the corals of BIOT and Pitcairn in terms of exposure and sensitivity to climate change or other risks across the MPAs, and inform what measures should be put in place, beyond reducing other human pressures. Coral areas resistant to bleaching should be further studied to better understand climate resilience and adaptation mechanisms and use the knowledge to improve the protection of reefs in other regions.

Emerging intervention techniques, such as planting, seeding and genetic engineering, require further research and discussion.

In addition, the following knowledge gaps and research needs in the Pitcairn Islands and BIOT are highlighted:

- **Monitoring of ocean acidification parameters, and understanding of ocean acidification effects on single coral species and on whole reef ecosystems.**
- **Sea level measurements in the Pitcairn Islands.**
- **Detailed habitat mapping of coral reefs and other benthic communities across these MPAs.**
- **Monitoring of the marine environment across the MPAs, including water quality indicators.**
- **Full implementation of fisheries management plans, including catch records.**
- **Further research of potential risk to corals from the combined impact of climate change and other pressures: fishing, marine plastics, anchoring, invasive non-native species and pollution.**
- **Further research of atoll coastal processes in response to sea level rise and reef erosion.**
- **Monitoring presence of invasive non-native species and coral diseases.**



A review was undertaken by the authors of this document, in order to compile the latest scientific information on current and future drivers of climate change in the marine and coastal environments of the UK Overseas Territories of the Pitcairn Islands and BIOT, to understand the risks to the coral reefs of these territories, as well as other important marine life.

This document is a summary of that review, to allow the information to be easily interpreted for the purposes of policy and decision making involved in the management and protection of the unique marine environment of these territories.

The review is available as a full report, and provides more detail on climate change drivers and impacts to the coral reefs in BIOT and Pitcairn Islands, along with further adaptation options and research priorities for these UK Overseas Territories.

An electronic copy of the report can be found here:
www.gov.uk/blue-belt-programme

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