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PACIFIC MARINE CLIMATE CHANGE REPORT CARD
*Science Review 2018*: *pp* 189-200

# Effects of Climate Change on 1.5° Temperature Rise Relevant to the Pacific Islands

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**EXECUTIVE SUMMARY**

This report synthesizes the emerging evidence of climate impacts at different temperature thresholds for Pacific islands. All evidence points to vast differences in impacts in a 1.5˚C world, compared to the +3˚C world to which our current policies and climate change pledges are leading us. For Pacific islands and marine and coastal ecosystems in the region, these differences cannot be overstated; even a 0.5˚C difference (between 1.5˚C and 2˚C) may mean that critical tipping points are crossed. Some of the most critical impacts for marine and coastal ecosystems and communities in the region include:

- At 2˚C global sea levels could increase by approximately 50cm by 2100 (5.5mm p/a), compared to 40cm under a 1.5˚C scenario (4mm p/a). As polar ice dynamics are better reflected in projections it is evident that sea level rise (SLR) of 1m+ by 2100 is a real risk, especially given we are currently heading towards a +3˚C world.
- Warming exceeding 1.5°C is expected to greatly increase the probability of reaching critical tipping points for the Greenland and Antarctic ice sheets, with the former facing irreversible decline most likely around 1.6°C of warming. This would lead to multi-metre SLR for centuries and millennia ahead. This is consistent with recent projections of SLR which illustrate that above 2˚C of warming the impacts of Antarctic ice melt become increasingly apparent by the end of the current century.
- The frequency of tropical cyclones is expected to decrease, while the intensity of these storms is projected to increase with global temperature. Research indicates a greater increase in monthly sea-surface temperature (SST) for the months of the main Pacific cyclone season under a 2˚C scenario compared to 1.5˚C. SSTs are an important driver for the formulation of intense cyclones in the region.
- At 2˚C virtually all coral reefs in the region may be lost (98% loss) with severe implications for biodiversity and island communities, economies and cultures. Reef degradation at 1.5˚C is still catastrophic (90%) but significant reef ecosystems could remain.
- Ocean acidification will impact upon reefs, fisheries and biodiversity with knock-on impacts for communities and economies. Only by limiting warming to 1.5°C can ocean acidification be halted and the worst impacts avoided.
- Deoxygenation of the ocean will increase with a rise in global temperatures. Under warming scenarios exceeding 4°C, ocean oxygen levels in coastal seas could reduce by more than 40%. At 1.5°C this reduction would be limited to less than 10% and, critically, may allow for stabilization and eventual recovery of oxygen levels.

Impacts at different temperature thresholds must be set in the context of the full range of pressures already placed upon ocean and coastal systems.

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# Introduction

A key outcome of the 2015 Paris Agreement was the objective of "holding the increase in the global average temperature to well below 2˚C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5˚C" (UNFCCC, 2015). This objective has triggered a variety of research which seeks to fill gaps in our knowledge regarding these two temperature limits and the implications in terms of impacts. It also led to the initiation of the IPCC Special Report on 1.5˚C which is due to be published in 2018.

The much-publicised 1.5˚C limit refers to a global mean temperature increase in relation to pre-industrial levels, averaged over a period of at least 20 years. Thus, it is possible that in an individual year average global temperature will reach 1.5˚C above preindustrial levels before we exceed this threshold in the longer term.

Before examining specific impacts within the Pacific region, it is worth noting that emerging evidence points to substantial differences in impacts between a 1.5˚C and 2˚C warming and the implications for dangerous anthropogenic interference with the climate system (Schleussner, 2016). These differences are likely to be even greater should we continue on a 'business as usual' pathway, which is currently projected to lead us to an increase of well over 3˚C based on analysis of both current policies and mitigation commitments to date (Climate Action Tracker, 2017). Research highlights that, in some cases, the additional 0.5˚C increase may push natural systems such as coral reefs beyond critical tipping points, while for heat-related extremes it takes the planet beyond the upper limit of present-day natural variability moving us into what could be considered a new climate regime (Schleussner, 2016).

Ocean systems are highly vulnerable to climate change and research underscores the importance of limiting warming to below 1.5°C in order to limit adverse impacts. Above this warming level there is a risk of fundamentally affecting ocean systems and undermining any other attempts to protect them (Climate Analytics, 2017). A study of abrupt transitions of regional climate indicates that such changes in ocean systems occur more often for warming of less than 2°C, whereas over land they occur more often for warming greater than 2°C (Drijfhout *et al*., 2015), suggesting oceans may be more easily tipped towards abrupt change. The same study also found that approximately two-thirds of critical thresholds in ocean systems identified in climate models may be crossed under a 2°C warming - compared to about one-third under 1.5°C. This, and other evidence, indicates that limiting warming to a maximum of 1.5˚C above preindustrial levels is crucial, however it should be noted that even this level of warming will lead to considerable loss and damage within coastal and ocean systems.

It is important to note that the differences in oceanic and coastal impacts at different temperature thresholds must be set in the context of the full range of pressures already placed upon ocean and coastal systems including: pollution and marine waste; eutrophication; resource over-exploitation and overfishing; invasive species; damage to key ecosystems; and coastal development. These multiple stressors can combine to weaken ecosystems (Roberts, 2012) thus exacerbating the impacts of climate change.

Exactly if and when specific global temperature thresholds are reached depends on the societal decisions we make in the near future and the global emissions pathways followed. Pathways deemed to be consistent with maintaining temperatures below 1.5˚C commonly include the need for large scale application of negative emissions approaches and the presumption that greenhouse gas (GHG) emissions will peak around 2020. Present day global warming is nearly 1˚C above pre-industrial levels compared to the 1860-1880 average (ECI Global Warming Index, 2017) and based on a review of policies we are heading for a 3.4˚C world by 2100 (Climate Action Tracker, 2017), thus considerable efforts are needed to ratchet ambitions. More positively, maintaining global average temperatures below 1.5˚C is considered technically feasible. Furthermore, a recent study also highlighted that there may be three times more 'room' within the carbon budget than was previously estimated (Millar *et al*., 2017). If correct, very aggressive emissions reductions would still be required immediately, however it would provide further evidence to support the premise that limiting warming to 1.5˚C remains possible.

## Sea level rise (SLR)

### *Global SLR*

Anthropogenic climate change is raising sea levels globally, resulting from a combination of thermal expansion and ice melt on land, including long term melting of polar ice sheets. This has major consequences for coastal communities and ecosystems, especially in the Pacific. Sea level rise combines with other climate change impacts (such as increased storm intensity) and natural variability within atmospheric and ocean systems to exacerbate losses and damage. This is especially true for low-lying Pacific atolls where an increase in sea level of just a few centimetres significantly increases the damage caused by storm surge and king tides, leading to repeated, damaging coastal inundation. It is important to note that even with stabilisation at 1.5˚C it is virtually certain that sea levels will continue to rise up to and beyond 2100 (Church *et al*. 2013), although action to reduce emissions can slow rates of increase by the end of the century. In the context of the 1.5˚C and 2˚C it is both the rate of sea level rise and our ability to stabilise sea levels at levels which avoid catastrophic impacts that are at stake.

It is estimated that at 2˚C global sea levels would increase by 10cm more than for 1.5˚C by 2100 (equating 50cm and 40cm increases by 2100). Correspondingly, the rate of sea level rise is also greater at a higher temperature with 5.5mm p/a estimate under 2˚C compared to 4mm p/a if warming is limited to 1.5˚C (Schleussner, 2016). These differences have implications for hazard occurrence; under a warming scenario of 2˚C by 2100, we can expect one in fifty-year coastal flood events to be occurring every year (Climate Analytics, 2017). Research examining the difference between 2˚C and 1.5˚C scenarios in terms of mean local sea level found a stark difference; under median projections, lands currently home to 5 million people (including 60,000 in Small Island Developing States (SIDS)) will be spared from being permanently submerged by local mean sea levels by 2150 if temperatures can be stabilized at 1.5˚C (Rasmussen *et al*., 2018).

Warming exceeding 1.5°C is expected to greatly increase the probability of reaching critical tipping points for the Greenland and Antarctic ice sheets (Climate Analytics, 2017) with the Greenland ice sheet facing irreversible decline most likely around 1.6°C of warming (Hare *et al*., 2016). While there is some uncertainty regarding tipping points, it is evident that only limiting warming to below 1.5°C will keep sea-level rise under 1m and that warming above this level risks multi-meter sea-level rise over centuries to come. Modelling techniques are increasingly able to account for polar ice dynamics (AMAP, 2017; Nauels *et al*., 2017; DeConto and Pollard, 2016). These studies highlight that SLR is likely to be at the upper end or even well beyond IPCC estimates and the aforementioned tipping points also become apparent. Figure 1 highlights that for 2˚C and below, SLR projections by 2100 are virtually identical whether Antarctic ice melt is considered or not, but moving beyond this temperature threshold (based on 'no climate action') the risk of rapid sea level rise becomes evident. It is clear that current mitigation policies will lead to a world well beyond 3˚C by 2100, thus potentially committing ourselves to SLR of a metre or more by the turn of the next century and to multi-metre SLR beyond.

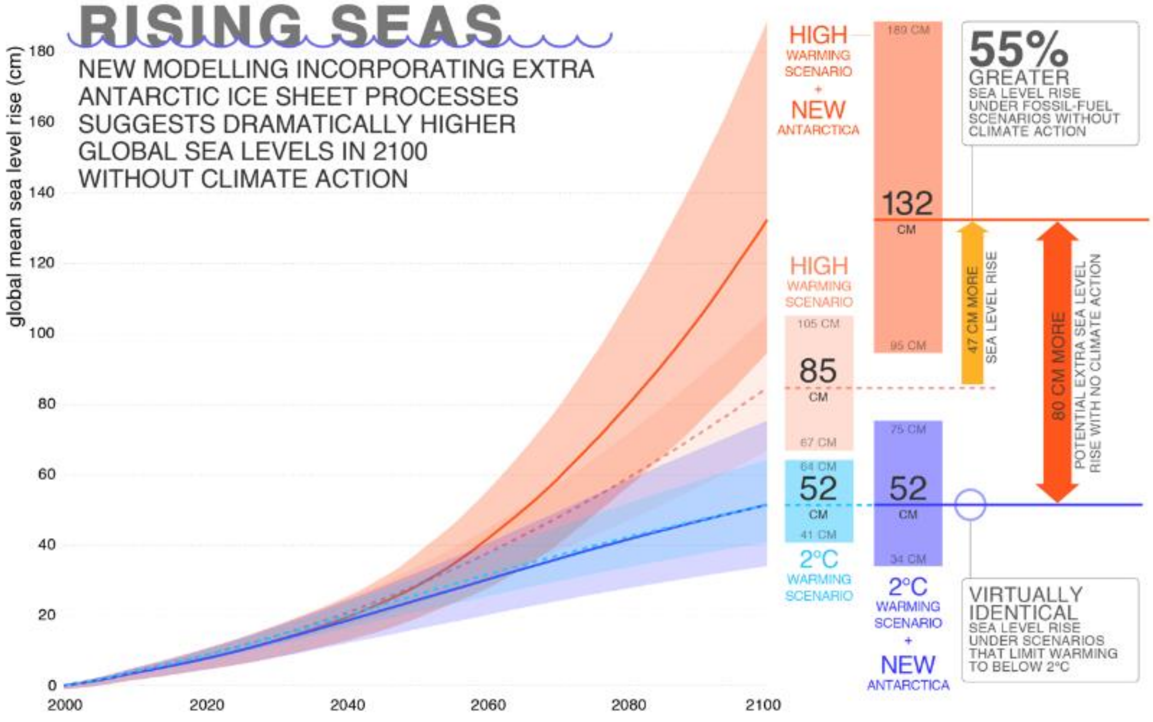


**Figure 1.** Projections of 2100 global mean sea level rise (based on Nauels *et al*., 2017).

Future global sea level rise will not be evenly distributed. In calculating local sea level (LSL) projections, Kopp *et al* (2014) highlight that spatial variability of future sea level influenced by a range of climatic and non-climatic factors meaning higher rates of increase in some regions and coastal areas than others. In addition to such longer-term variability in LSL, sea levels in the Pacific vary over shorter time periods due to tides, winds, storms and cyclical climatic conditions such as the El Niño Southern Oscillation (ENSO).

When considering the risks and damage levels associated with SLR, extreme sea levels (ESLs) play a vital role. ESLs combine height of the astronomical tide and storm surge (i.e. the storm tide) and mean sea level. This is especially important for low-lying Pacific atolls where a relatively small increase can be critical. A recent study highlighted that the effects of global mean surface temperature stabilization at 1.5˚C, 2˚C, 2.5˚C on ESLs varies greatly by region and by historical return period. The evidence is clear that that it is beneficial to maintain global temperatures to 1.5˚C and below (compared to 2˚C or 2.5˚C) in terms of the frequency of extreme ESL events, however the extent of these benefits varies (Rasmussen *et al*., 2018).

*SRL in the Pacific*

Observations show that climate change has increased the average sea level in the Pacific by about 15 cm in the last 100 years, with most estimates indicating an accelerated rate of change in recent decades. Climate change will continue to increase sea levels, but the exact rate of increase is likely to vary across the Pacific (as is already the case) and will depend on a range of factors including rates of thermal expansion and polar ice melt.

Current estimates suggest an increase of between 20–60 cm by 2100 in the western Pacific (PACCSAP, 2014a). Given the sensitivity of many Pacific nations to relatively small increases in SLR, failure to limit global temperatures to 1.5˚C will have huge economic, social and environmental implications. Kopp *et al* (2014) indicate that static-equilibrium effects (differences in the Earth’s gravitational field and crustal height) lead to a tendency for greater-than-global SLR in the central and western Pacific Ocean.

**Ocean temperatures**

Sea surface temperatures (SSTs) have increased during the 20th century and continue to rise. From 1901 to 2015 temperature rose at an average rate of 0.07°C per decade globally. Sea surface temperature has been notably higher during the past three decades than at any other time since reliable observations began in 1880 (EPA, 2017) with the observed warming most pronounced at higher latitudes. The Pacific has been warming at a rate of 0.05°C per decade over the period 1950-2016; thus at a slightly slower rate than the Indian and Atlantic Oceans.

Sea surface temperatures are an important variable due to their potential impact on the productivity in the upper layers of the oceans and on atmospheric conditions. Temperatures near the surface of the ocean are influenced by heat from the atmosphere but also by the rate of upwelling and mixing of layers which are critical to the distribution of heat within oceans. The Pacific SSTs are also affected by natural factors such as the Interdecadal Pacific Oscillation (IPO) which facilitates mixing within the water column.

In most regions, including in the Pacific, the average SST will continue to rise due to climate change. One of the most damaging impacts on increased ocean temperatures is the increasing propensity for coral bleaching and there is strong evidence that corals are sensitive to temperature thresholds (as illustrated later in this report). Ocean temperatures are naturally variable, and for coral reefs, peaks in SST are as significant as changes to the mean. This is illustrated by past coral beaching events which correspond with relatively short-term increases in ocean temperature. Elevated SST is also an important source of energy for the development of tropical cyclones.

**Deoxygenation**

Climate change is causing both ocean warming and increased stratification of the upper ocean, leading to deoxygenation of the ocean (Keeling *et al*., 2010). This, in turn, is likely to have implications for ocean productivity and marine habitat. Under warming scenarios exceeding 4°C, ocean oxygen levels in coastal seas could reduce by more than 40%. In contrast, limiting warming to below 1.5°C would limit this decrease to less than 10% and may allow for stabilization and eventual recovery of oxygen levels (Climate Analytics 2017) (Figure 2).

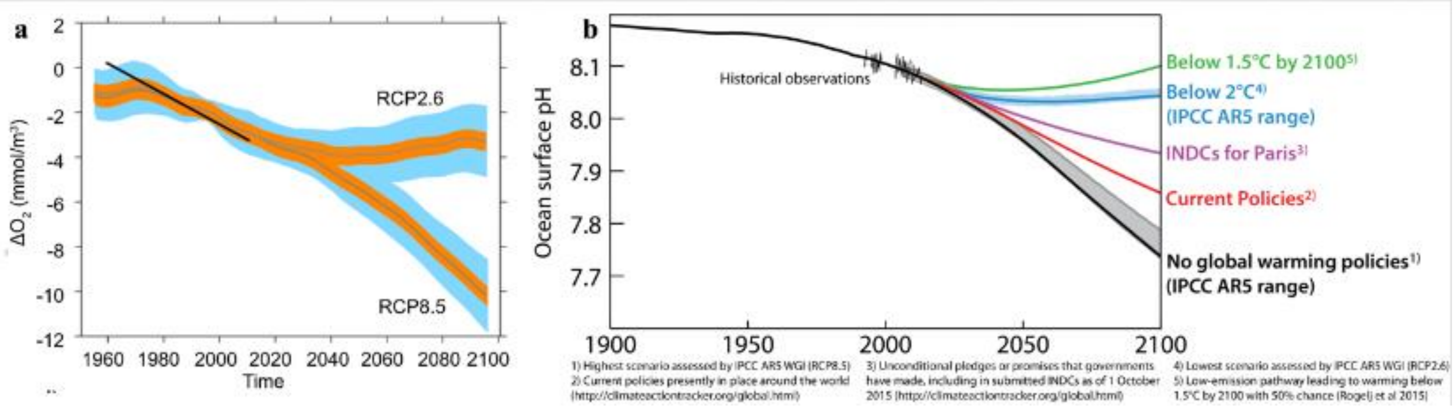


**Figure 2.** Panel a: Global deoxygenation under IPCC scenarios for high emissions (RCP8.5) about a 4˚C global warming and in a hold below 2˚C scenario (RCP2.6). Whilst the latter 2˚C scenario stabilizes deoxygenation but does not appear to initiate full recovery, a 1.5˚C pathway appears likely to lead to initiation of recovery. Panel b: Observed and projected ocean surface pH for different warming scenarios. (From Climate Analytics 2017). Key: Black – highest scenario assessed by IPCC AR5 WGI (RCP8.5); Red – Current policies in place around the world (http://climateactiontracker.org/global.html); Purple – Unconditional pledges or promises that governments have made, including in submitted NDCs as of 1 October 2015; Blue – Lowest scenario assessed by IPCC AR5 WGI (RCP2.6); Green – Low-emission pathway leading to warming below 1.5˚C by 2100 with 50% chance (Rogelj *et al*. 2015).

Research shows that deoxygenation rates are regionally variable; impacts are already discernible in some parts of the world and are likely to be evident across large regions of the oceans between 2030 and 2040, however other areas may not experience detectable loss of oxygen due to climate change even by 2100 (Long et. al., 2016). The same study suggests that the eastern Pacific region may experience discernible changes in oxygen levels in the 2030s and 2040s while impacts in the west of the region (Melanesia) will not be evident until much later in the century or even into the 2100s.

## Ocean acidification

The current rate and magnitude of ocean acidification is at least 10 times faster than any event within the last 65 million years (Pörtner *et al*., 2014). It is clear that greater emissions will increase the rate and level of ocean acidification, which in turn will have adverse impacts on ocean life by inhibiting the development of the many marine organisms that produce calcium carbonate shells or skeletons. The impacts of ocean acidification will be magnified by the vital role such organisms can play within food webs, nutrient cycling and in habitat creation (e.g. coral reefs). Anthropogenic $CO_2$ emissions could result in ocean pH levels being lower than at any time in the last 300 million years (Climate Analytics, 2017). There is little or no information available on ocean acidification for specific temperature scenarios in the Pacific region. However, global climate projections suggest that if we follow the current emissions trajectory, by mid-century, acidification will result in coral reefs in the western tropical Pacific dissolving faster than they are built (PACCSAP, 2014b).

When specific ecosystems such as coral reefs are examined, it is evident that ocean acidification combines with other climatic (e.g. sea surface temperatures) and non-climatic drivers (e.g. pollution or invasive species) to decrease resilience and magnify damage. Evidence from the Eastern Tropical Pacific highlights the reduced resilience of coral reefs when increases in temperature and lower pH combine (Manzello et al., 2017). Interactions between climate-related stressors (e.g. SST and pH) and non-climate stressors (e.g. eutrophication) may play an important role in the localised impact of ocean acidification. Corals are capable of regulating pH at the point of calcification (within certain limits) however, their ability to do so in environments that are already stressed due to elevated temperatures and high nutrient levels may be hampered, increasing the likelihood and extent of permanent coral degradation. It appears clear that only by limiting warming to 1.5°C can ocean acidification be halted and that in a 2˚C world there is little chance of coral reef survival (Hare et al., 2016) due to the effects of temperature-induced bleaching and ocean acidification.

## Tropical cyclones

Our understanding of the impacts of climate change on tropical cyclone activity in the Pacific is hampered by a range of factors including the single event nature of these storms, influences of natural variability such as the El Niño Southern Oscillation and the limited nature of observational records (Thomas *et al*., 2017). Looking at the global picture, a synthesis of literature on global warming and hurricanes by NOAA (NOAA, 2017) highlights:

- Fewer tropical cyclones globally in a warmer late-twenty-first-century climate
- An increase in average cyclone intensity
- Increase in the number and occurrence days of very intense category 4 and 5 storms in most basins
- Increases in tropical cyclone precipitation rates.

A number of underlying factors which influence the intensity and impact of tropical cyclones need to be considered under the 1.5˚C and 2˚C scenarios. Firstly, as described earlier in this report, SLR will exacerbate coastal flooding associated with tropical cyclone events in the Pacific. Secondly, as the atmosphere warms, it can carry more moisture. Extreme precipitation events have been found to scale with the moisture carrying capacity and such events are projected to intensify by about 6% per °C of warming (Kharin *et al*., 2013), thus there is greater likelihood of cyclones bringing destructive heavy rainfall of the type experienced during hurricane Harvey in the USA in 2017. Thirdly, sea surface temperatures will be greater in a 2˚C scenario, and are associated with high intensity tropical cyclones as was illustrated during the devastating Caribbean hurricane season in 2017.

Figure 3 (Thomas *et al*., 2017) shows the probability density of tropical cyclone formation against SST in the formation region by cyclone category in the South Pacific basin. While this is not an analysis of future cyclone formation, Figure 3 shows a substantial increase in the frequency of the most devastating tropical cyclones at 1.5°C of global warming and even more so at 2°C of global warming. This is in line with other findings in the literature. For example, for warming of about 2.5°C by the end of the century, occurrence probabilities of Category 4 or 5 cyclones are found to increase substantially (Knutson *et al*., 2015) up to nearly double across all major basins relative to the recent past (Bacmeister *et al*., 2016).

## Coastal ecosystems

### Tropical coral reefs

Tropical coral reefs play a central role in the ecology, economies and cultures of many Pacific islands. As is outlined above, reef ecosystems are impacted by a variety of climate and non-climate-related factors. In particular, increased sea temperatures are leading to more regular coral beaching events (see Figure 4) while ocean acidification is expected to hinder, and eventually prevent, coral growth. In a 2˚C world there will be almost total loss of reefs in the region and even in a 1.5˚C world, reef systems would be at extreme risk, albeit with some window for ecosystem adaptation remaining. By examining the fraction of coral reef cells at risk of long-term degradation (defined as experiencing at least one bleaching event every five years), it has been suggested that under 1.5˚C conditions there will be a 90% reduction in coral reefs by 2050 whereas losses in a 2˚C world are almost total (98%) (Hare *et al*., 2016). Coral bleaching events are associated with El Niño events therefore it is worth noting that extreme El Niño frequency is expected to increase by approximately 130% in a 1.5˚C world compared to around 190% in a 2˚C world. There is currently ongoing research in the region into reef resilience which points towards certain species and ecosystems exhibiting greater ability to recover from bleaching events than was expected, although the overall prognosis for coral reefs remains bleak if emissions do not decrease dramatically.

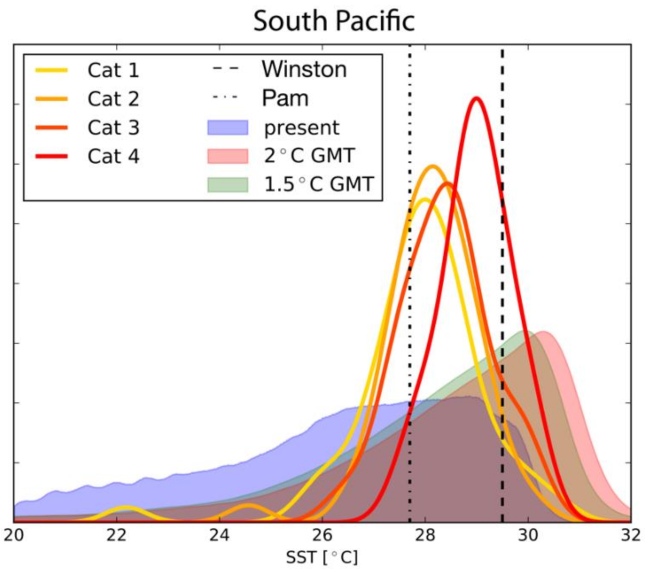


**Figure 3.** Probability density of tropical cyclone formation against sea surface temperatures. The shaded areas show monthly SST distributions for the months of the main cyclone season including all grid cells of the main development region (Present i.e. period 1986-2005 = blue; projections for 2°C global warming = red and; 1.5°C global warming = green). Black lines show recent tropical cyclones Winston and Pam.

### Mangrove ecosystems

Mangroves provide a range of ecosystem services including as a habitat for fisheries, especially juveniles of commercial fish species, coastal protection from inundation and storms, and carbon sequestration. Mangrove forests have the capacity to keep pace with sea-level rise and to avoid inundation (Lovelock *et al*., 2015). If sediment accretion rate keeps pace with relative sea-level rise then suitable inundation conditions can be maintained; if lower, then mangrove

**Figure 4.** An illustrative example of coral reef mortality in American Samoa 2014-2016. Photograph by R. Vevers, XL Catlin Seaview Survey | Coral Reef Watch.

systems are expected to migrate landward or be reduced in their extent (Shearman 2009). In the Pacific, both human development and topography can prevent the inland migration of mangroves. On densely populated atolls there is often little undeveloped land while in the western Pacific, significant mangrove ecosystems occur adjacent to steep terrain of islands (Bell *et al*., 2013). The resilience of mangroves under 1.5˚C and 2.0˚C scenarios in the Pacific is hard to determine as local conditions, including SLR, erosion rates and sentiment availability are influential factors. Increased rates of SLR projected under a 2˚C+ scenario will place mangrove systems under greater pressure as fewer systems will be able to accumulate sediment at a rate which can match SLR. Small Island Developing States such as those in the Pacific are highly vulnerable to small increases in SLR and it will be physically and economically difficult to allow the landward retreat of mangroves (Gilman, 2006). There is growing evidence of the adverse impacts of marine heat waves on mangrove forests evidenced by a heatwave event in Australia in 2016 which contributed to extensive die-back. The impacts of marine heat waves are currently poorly understood as are potential future changes in the frequency of such events in the Pacific.

### Seagrass

Seagrass is a highly valued ecosystem providing a range of services including food and habitat for fish (including commercial fisheries) and large marine mammals, nutrient recycling and sediment stabilization and they are 35 times more efficient at sequestering carbon than rainforests (Macreadie, 2014). The Indian Ocean and western Pacific exhibit the greatest diversity of seagrasses globally with up to 14 species growing together (Smithsonian Ocean Portal, 2017). Seagrass beds are being destroyed by a range of factors including dredging and invasive species. While increased levels of $CO_2$ could theoretically boost growth of seagrasses in the Pacific, higher temperatures, increased turbidity, sedimentation and nutrient loads associated with greater rainfall, and more intense tropical cyclones, are expected to have negative effects on seagrasses in the region (Bell *et al*., 2013). As many of these impacts are indirect consequences of climate change it is difficult to determine direct impacts for specific future temperature scenarios. Tropical seagrass meadows near coral reefs could offset local effects of ocean acidification, because they can increase the pH of surrounding water up to 0.38 units (Unsworth *et al*., 2012). The effect depends on seagrass density, the water depth, the degree of mixing, and the water turnover rate. In shallow water reef environments, the ability of coral to be hardened or calcified can be 18% greater (Unsworth *et al*., 2012). Guanell *et al*. (2016) further illustrate how when combined, corals, seagrasses, and mangroves supply more protective services than any individual habitat or any combination of two habitats. For example, all three ecosystems play different and interacting roles in coastal protection. This may have implications for future adaptation responses, highlighting the need for integrated solutions.

### Ocean productivity and fisheries

Ocean productivity will be affected by the climate impacts outlined above, including deoxygenation, ocean acidification, temperature increases and damage to coastal and marine ecosystems. There is strong evidence that most, if not all, of these impacts will be significantly greater at 2˚C compared to 1.5˚C, and as global temperatures increase the risk of non-linear changes in impacts grows; thresholds may be passed and positive feedbacks triggered.

A 2016 study of global marine fisheries highlighted the significant benefits of achieving the 1.5°C objective outlined in the Paris Agreement (Cheung *et al*., 2016). It found that potential catches will decrease by more than 3 million metric tonnes per °C of warming and that species turnover is more than halved when warming is lowered from 3.5° to 1.5°C above preindustrial levels. Of relevance to the Pacific is this finding that if warming can be limited to 1.5˚C the greatest reduction in risk is achieved in the Indo-Pacific and Arctic regions. A study of the responses of tropical Pacific fisheries and aquaculture to climate change found that there will be both winners and losers, with potential increases in tuna productivity in the eastern Pacific while coral reef fisheries could decrease by 20% by 2050 (Bell *et al*., 2013).

# Conclusions

Evidence points to substantial differences in impacts between 1.5˚C and 2˚C warming and the implications for dangerous anthropogenic interference with the climate system. The difference of 0.5˚C is likely to be critical for many coastal communities and ecosystems which are already sensitive to changes in sea level and ocean temperature. Furthermore, it significantly increases the chances of critical tipping points being passed which would fundamentally affect coastal and marine organisms and ecosystem services in the Pacific. These differences are illustrated in Figure 5.

# Knowledge Gaps

Contemporary models are not sufficiently downscaled to produce useful projections that support local adaptation. For example, typical global climate model grid cell size is 50-100 $km^2$, and the total land area of Nauru and Tuvalu is 21 and 26 $km^2$, respectively. Even for SIDS with larger total land area, this is usually composed of many small islands and granularity in model outputs prevents any localised predictions to be made.

There is low agreement on how large scale climate drivers, such as ENSO, will be affected by climate change (Hoegh-Guldberg *et al*., 2014), and this is particularly pertinent for the Pacific SIDS as it will limit the capacity to predict changes to the position of the South Pacific Convergence Zone (SPCZ), and the impact that this will have on rainfall, droughts, wave climate and cyclogenesis.

Some SIDS, such as Kiribati, are spread over large distances, meaning that there is great heterogeneity of habitat and pressure on one country. It is important to address this complexity in projections and adaptation methods as local factors may affect the efficacy of measures that have successfully applied elsewhere (Nurse *et al*., 2014).

A recent review on the topic of tropical cyclone formation and climate change, published since the production of the IPCC AR5, highlights that there is still little agreement between different models on how regional cyclogenesis will be affected (Walsh *et al*., 2016).

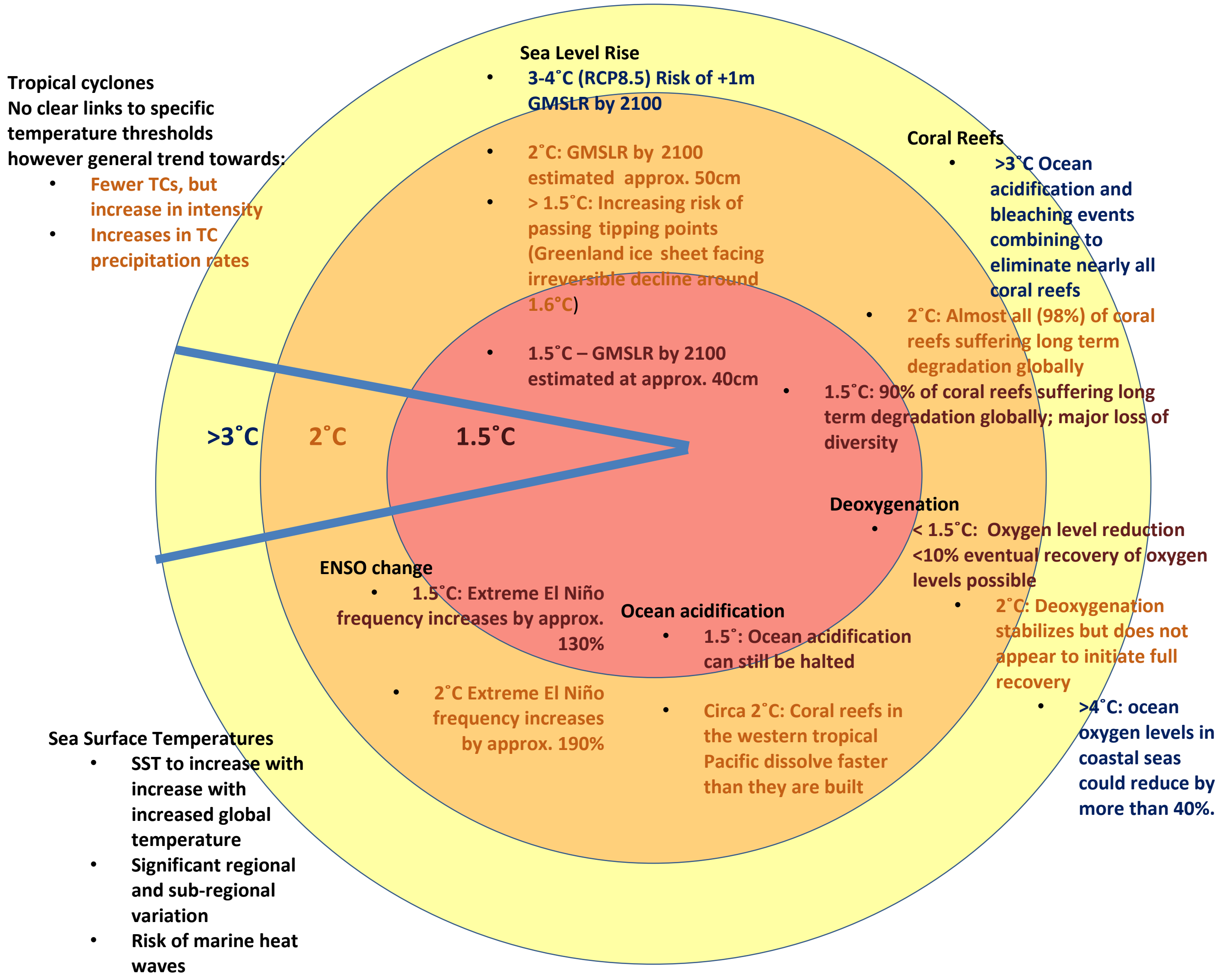
Potential impacts of climate change on blue carbon habitats, i.e. seagrasses and mangroves in the Pacific islands region, have been extensively reviewed, but there are still limited available data on the current location, health, and status of Pacific island blue carbon habitats (Ellison, 2018). These habitats are vital to the overall health of the ecosystem and present significant opportunities for adaptation and mitigation strategies (Nielsen *et al*., 2018; Sifleet *et al*., 2011; Temmerman *et al*., 2013); a better basic understanding would facilitate future work.

Comparisons regarding the difference between different warming scenarios have been undertaken at the global level and in some cases regional variations are also considered. However, there is generally limited information specifically focused upon the Pacific for 1.5˚C and 2˚C futures as biophysical impact projections in many cases have just become available in recent years. Key research gaps include:

1. **Limits to adaptation at 1.5°C and 2°C.** Adaptation to the impacts of climate change is of key importance for the Pacific. However, limits to adaptation will be reached for warming exceeding 1.5°C including in particular for ecosystem-based adaptation measures providing coastal protection.
2. **Loss and Damage arising from exceeding warming of 1.5°C.** Assessing the climate related Loss and Damage inflicted by exceeding 1.5°C is of key relevance. This includes impacts on ocean ecosystems such as coral reefs or fisheries as well as the human systems depending on it, but also impacts of sea level rise for loss of land, livelihoods and economic activity.
3. **Improving projections of regional sectorial impacts to inform adaptation**. This could include improved geophysical modelling (e.g. the need for improved tropical cyclone modelling), but also improved modelling of marine and coastal impacts on tourism, food security, fishing and aquaculture.
4. **The cumulative impact of interacting the pressures for different global temperature scenarios is poorly understood within the region.** Modelling of impacts largely focuses on biophysical changes and more work is needed to understand how these will play out in terms of interacting impacts. Where such research has been undertaken (for example the study of ocean acidification on stressed reef systems) it highlights how reducing other pressures may play a critical role in extending the limits of adaptation (see point 1).
5. **Mapping of seagrass beds.** Despite their potential to mitigate the impacts of ocean acidification, only a fraction of seagrass

meadows in the Pacific islands have been mapped, and their ecological significance is largely unknown by decision-makers and the general public. A concerted effort to map existing seagrass, communicate its importance, and to protect significant areas, especially close to coral reefs, is urgently required.

6. **Understanding future frequency and impact of marine heat waves**. Studies in Australia highlight the destructive potential of marine heatwaves on coastal ecosystems including coral reefs. Such phenomena are very poorly understood in the Pacific yet may have major and lasting impacts.



**Sea Level Rise**
- 3-4˚C (RCP8.5) Risk of +1m GMSLR by 2100
- 2˚C: GMSLR by 2100 estimated approx. 50cm
- > 1.5˚C: Increasing risk of passing tipping points (Greenland ice sheet facing irreversible decline around 1.6°C)
- 1.5˚C – GMSLR by 2100 estimated at approx. 40cm

**Tropical cyclones**
**No clear links to specific temperature thresholds however general trend towards:**
- Fewer TCs, but increase in intensity
- Increases in TC precipitation rates

**Coral Reefs**
- >3˚C Ocean acidification and bleaching events combining to eliminate nearly all coral reefs
- 2˚C: Almost all (98%) of coral reefs suffering long term degradation globally
- 1.5˚C: 90% of coral reefs suffering long term degradation globally; major loss of diversity

**Deoxygenation**
- < 1.5˚C: Oxygen level reduction <10% eventual recovery of oxygen levels possible
- 2˚C: Deoxygenation stabilizes but does not appear to initiate full recovery
- >4˚C: ocean oxygen levels in coastal seas could reduce by more than 40%.

**ENSO change**
- 1.5˚C: Extreme El Niño frequency increases by approx. 130%
- 2˚C Extreme El Niño frequency increases by approx. 190%

**Ocean acidification**
- 1.5˚: Ocean acidification can still be halted
- Circa 2˚C: Coral reefs in the western tropical Pacific dissolve faster than they are built

**Sea Surface Temperatures**
- SST to increase with increase with increased global temperature
- Significant regional and sub-regional variation
- Risk of marine heat waves

Figure 5: An overview of possible climate change impacts on marine and coastal systems at different future global mean temperature.

# Social impacts and adaptation options

The difference of between 1.5˚C and 2˚C in terms of social impacts is likely to be highly significant given the exposure and relative sensitivity of many Pacific island communities. However, there are limited examples of where these impacts have been quantified and aligned to specific temperature thresholds. This partly reflects the cascading uncertainty associated with understanding how biophysical changes interact with the myriad of social and economic factors to shape vulnerability, and also due to limited sectoral and sub-national level impact modelling in the region. However, observed impacts, an understanding of the aforementioned biophysical impacts for different global temperature thresholds, and adaptation efforts to date enable social and economic impacts to be considered.

SLR is a huge concern in the Pacific with adverse impacts being experienced across the region. Low-lying atolls are particularly exposed to SLR impacts, for example, the Republic of Kiribati is made up of 33 scattered islands, 32 of which are low-lying atolls that rise to no more than 2-3 metres above sea level (Government of Kiribati, 2014). Such atolls already face loss of land due to coastal erosion and saline inundation which can damage agricultural land and pollute water sources. Such losses go beyond economic values and can lead to loss of traditional lands, cultural sites and navigation routes. Even on islands with higher evaluations such as Samoa, much of the population and infrastructure in located on the coast and thus is exposed to SLR-related impacts.

The medium and long-term implications of exceeding 1.5C for Pacific communities is stark; above this threshold there is a significant increase in the likelihood of exceeding tipping points which will make many low-lying islands uninhabitable, leading to mass, and permanent, migration.

**Impact of climate change on local ecosystems and marine productivity is likely to result in adverse social and economic effects.**
A vulnerability assessment of reef-dependent communities to ocean acidification impacts (Johnson *et al.*, 2016) found that high ratios of reef to land area, dependence of household incomes on coastal fisheries, and limited education as a key component of low adaptive capacity were all significant drivers of vulnerability. The study also examined dependence on reefs and their fisheries (for food security and livelihoods), aquaculture (for jobs), and tourism (for jobs and contribution to GDP). The following countries were most vulnerable (the most vulnerable listed first): Solomon Islands, Kiribati, Papua New Guinea (PNG), Federated States of Micronesia (FSM), Tonga, and Tuvalu.

Reduced marine productivity resulting from a range of climate change impacts, including increasing temperatures, ocean acidification and deoxygenation, has implications for biodiversity in the Pacific but also for human populations. It is estimated that approximately 70% of protein in the diet of Pacific islanders is derived from near-shore pelagic, and inshore reef and lagoon fisheries thus having potentially far reaching implications for food security and poverty (PACCSAP, 2014b). Pacific communities are increasingly dependent on expensive food imports and a loss of marine productivity would likely increase this situation. Furthermore, it would leave Pacific nations potentially exposed to food price shocks and incremental price increases exacerbated by climate change and global population growth. Climate-related damages to near-shore biodiversity is likely to have implications for the tourism and aquaculture sectors in the region (PACCSAP, 2014b). Potential reductions in productivity of commercial fisheries is not only a food security issue in the Pacific. It has been estimated that 7 out of 22 Pacific Island countries and territories received up to 40% of their tax income from fishing licences sold to other nations (Bell *et al.*, 2013).

**Adaptation and loss and damage**
The Pacific region is already having to address loss and damage, where climate change impacts exceed the limits of adaptation. In a 1.5˚C scenario these losses will be greater than today, however with planning and investment it will be possible for many Pacific island societies to adapt to the impacts of climate change in order to minimise these losses and to develop more resilient societies. Certain impacts would stabilize, and critical tipping points leading to ‘runaway climate change’ may be avoided. In a 2˚C world and above, these losses will be far greater and likely to rise sharply as climate change impacts reflect positive feedbacks in the climate system. In many nations, limits to adaptation would be reached, meaning ever greater losses and damage would be experienced. Where adaptation is possible, the costs would be likely to be much greater than in a 1.5˚C world.

# Citation

Please cite this document as:

Pringle, P. (2018) Effects of Climate Change on 1.5° Temperature Rise Relevant to the Pacific Islands. Pacific Marine Climate Change Report Card: Science Review 2018, pp 189-200.

# References

AMAP, 2017. Snow, Water, Ice and Permafrost. Summary for Policy-makers.

Bacmeister, J. T., Reed, K. A., Hannay, C., Lawrence, P., Bates, S., Truesdale, J. E., ... & Levy, M. (2016). Projected changes in tropical cyclone activity under future warming scenarios using a high-resolution climate model. *Climatic Change*, 1-14.

Bell, J. D., Ganachaud, A., Gehrke, P. C., Griffiths, S. P., Hobday, A. J., Hoegh-Guldberg, O., & Matear, R. J. (2013). Mixed responses of tropical Pacific fisheries and aquaculture to climate change. *Nature Climate Change*, *3*(6), 591-599.

Climate Action Tracker (2017). Briefing: *Improvement in warming outlook as India and China move ahead, but Paris Agreement gap still looms large*. http://climateactiontracker.org/assets/publications/briefing_papers/CAT_2017-11-15_Improvement-in-warming-outlook.pdf Date of access: 04/12/17.

Climate Analytics (2017) Because the Ocean: Achieving the Paris Agreement 1.5˚C temperature limit.

Cheung, W. W., Reygondeau, G., & Frölicher, T. L. (2016). Large benefits to marine fisheries of meeting the 1.5 C global warming target. *Science*, *354*(6319), 1591-1594.

Church, J. A., Clark, P. U., Cazenave, A., Gregory, J. M., Jevrejeva, S., Levermann, A., ... & Payne, A. J. (2013). *Sea level change*. PM Cambridge University Press.

DeConto, R.M. and Pollard, D., 2016. Contribution of Antarctica to past and future sea-level rise. *Nature*, *531*(7596), pp.591-597.

Drijfhout, S., Bathiany, S., Beaulieu, C., Brovkin, V., Claussen, M., Huntingford, C. & Swingedouw, D. (2015). Catalogue of abrupt shifts in Intergovernmental Panel on Climate Change climate models. *Proceedings of the National Academy of Sciences*, *112*(43), E5777-E5786.

ECI Global Warming Index, http://www.globalwarmingindex.org/ Date of access: 30/11/17.

Gillett, R. Fisheries in the Economies of Pacific Island Countries and Territories (Pacific Studies Series, Asian Development Bank, 2009).

Government of Kiribati (2014) Kiribati Joint Implementation Plan for Climate Change and Disaster Risk Management (KJIP) 2014-2023.

Guannel G, Arkema K, Ruggiero P, Verutes G (2016) The Power of Three: Coral Reefs, Seagrasses and Mangroves Protect Coastal Regions and Increase Their Resilience. PLoS ONE 11(7): e0158094. doi:10.1371/journal.pone.0158094.

Hare, B., Roming, N., Schaeffer, M., & Schleussner, C. F. (2016). Implications of the 1.5 C limit in the Paris Agreement for climate policy and decarbonisation. *Climate Analytics.*

Johnson, J., Bell, J., and Gupta, A. (2016) Pacific islands ocean acidification vulnerability assessment. SPREP, Apia, Samoa.

Keeling, R. F., Körtzinger, A., & Gruber, N. (2009). Ocean deoxygenation in a warming world.

Kharin V V., Zwiers F W, Zhang X and Wehner M (2013) Changes in temperature and precipitation extremes in the CMIP5 ensemble Clim. Change 119 345–57.

Knutson T R, Sirutis J J, Zhao M, Tuleya R E, Bender M, Vecchi G A, Villarini G and Chavas D 2015 Global Projections of Intense Tropical Cyclone Activity for the Late Twenty-First Century from Dynamical Downscaling of CMIP5/RCP4.5 Scenarios J. Clim. 28 7203–24.

Kopp, R. E., R. M. Horton, C. M. Little, J. X. Mitrovica, M. Oppenheimer, D. J. Rasmussen, B. H. Strauss, and C. Tebaldi (2014), Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites, *Earth's Future*, *2*, 383–406, doi:10.1002/2014EF000239.

Long, M. C., Deutsch, C., & Ito, T. (2016). Finding forced trends in oceanic oxygen. *Global Biogeochemical Cycles*, *30*(2), 381-397.

Lovelock, C. E., Cahoon, D. R., Friess, D. A., Guntenspergen, G. R., Krauss, K. W., Reef, R., & Saintilan, N. (2015). The vulnerability of Indo-Pacific mangrove forests to sea-level rise. *Nature*, *526*(7574), 559-563.

Macreadie, P. I., Baird, M. E., Trevathan-Tackett, S. M., Larkum, A. W. D., & Ralph, P. J. (2014). Quantifying and modelling the carbon sequestration capacity of seagrass meadows–a critical assessment. *Marine pollution bulletin*, *83*(2), 430-439.

Manzello, D. P., Eakin, C. M., & Glynn, P. W. (2017). Effects of global warming and ocean acidification on carbonate budgets of eastern pacific coral reefs. In *Coral reefs of the eastern tropical Pacific* (pp. 517-533). Springer, Dordrecht.

Millar, R. J., Fuglestvedt, J. S., Friedlingstein, P., Rogelj, J., Grubb, M. J., Matthews, H. D., ... & Allen, M. R. (2017). Emission budgets and pathways consistent with limiting warming to 1.5 [thinsp][deg] C. *Nature Geoscience*, *10*(10), 741-747.

Nauels, A., Rogelj, J., Schleussner, C. F., Meinshausen, M., & Mengel, M. (2017). Linking sea level rise and socioeconomic indicators under the Shared Socioeconomic Pathways. *Environmental Research Letters*, *12*(11), 114002.

NOAA (2017) Global Warming and hurricanes: An Overview of Current Research Results

https://www.gfdl.noaa.gov/global-warming-and-hurricanes/ Date of Access: 30/11/17.

Pacific-Australia Climate Change Science and Adaptation Planning Program (PACCSAP) (2014a). Factsheet: Sea level rise in the western tropical Pacific.

Pacific-Australia Climate Change Science and Adaptation Planning Program (PACCSAP) (2014b). Factsheet: Ocean acidification in the western tropical Pacific.

Pörtner, H.-O., D.M. Karl, P.W. Boyd,W.W.L. Cheung, S.E. Lluch-Cota, Y. Nojiri, D.N. Schmidt, and P.O. Zavialov, 2014: Ocean systems. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 411-484.

Rasmussen, D. J., Bittermann, K., Buchanan, M. K., Kulp, S., Strauss, B. H., Kopp, R. B., & Oppenheimer, M. (2018). Extreme sea level implications of 1.5° C, 2.0° C, and 2.5° C temperature stabilization targets in the 21st and 22nd century. *Environmental Research Letters*.

Roberts, C. (2012). *The ocean of life: The fate of man and the sea*. Penguin.

Schleussner C-F, Lissner T, Fischer E, Wohland J, Perrette M, Golly A, Rogelj J, Childers K, Schewe J, Frieler K, Hare W and Schaeffer M (2016) Differential climate impacts for policy relevant limits to global warming: the case of 1.5°C and 2°C *Earth Syst. Dyn.* 7 327–51.

Shearman, P. L. (2010). Recent change in the extent of mangroves in the northern Gulf of Papua, Papua New Guinea. *Ambio*, *39*(2), 181-189.

Smithsonian Ocean Portal

http://ocean.si.edu/seagrass-and-seagrass-beds

Thomas, A., Pringle, P., Pfleiderer, P., Schleussner, C. (2017). Note on Tropical Cyclones: Impacts, the link to Climate Change and Adaptation, Climate Analytics.

UNFCCC (2017) Paris Agreement. Available at: http://unfccc.int/meetings/paris_nov_2015/items/9445.php Last Accessed on 05/12/17.

United States Environmental Protection Agency (EPA) (2017) Climate Change Indicators: Sea Surface Temperature. https://www.epa.gov/climate-indicators/climate-change-indicators-sea-surface-temperature Date of Access: 04/12/17.

Unsworth, R. K., Collier, C. J., Henderson, G. M., & McKenzie, L. J. (2012). Tropical seagrass meadows modify seawater carbon chemistry: implications for coral reefs impacted by ocean acidification. *Environmental Research Letters*, *7*(2), 024026.

Walsh, K. (2015). Fine resolution simulations of the effect of climate change on tropical cyclones in the South Pacific. Climate dynamics, 45(9-10), 2619-2631.