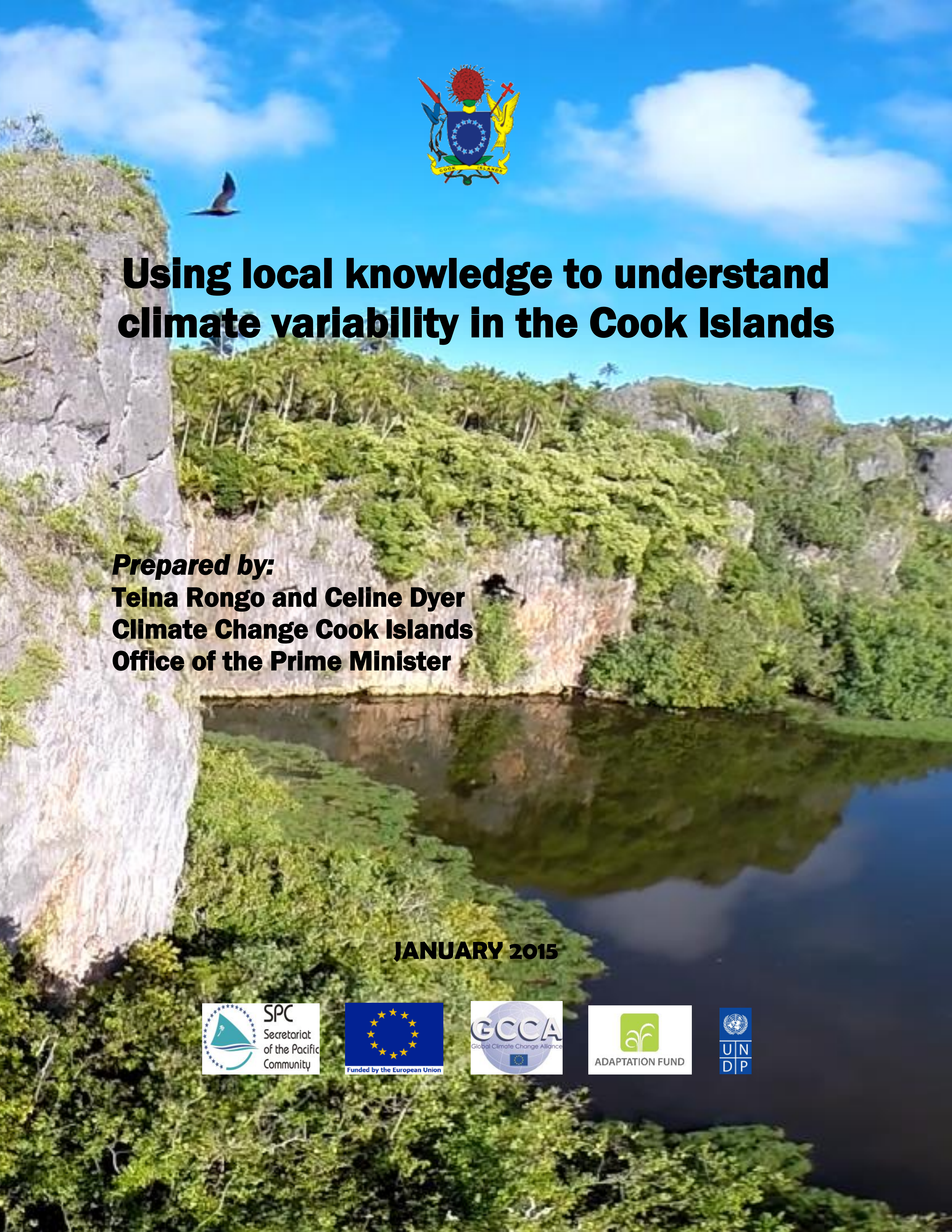

Using local knowledge to understand climate variability in the Cook Islands

Prepared by:

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Climate Change Cook Islands
Office of the Prime Minister

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Front cover photo: Lake Tiriara, Mangaia; taken by Teina Rongo in 2014.
Back cover photo: Surgeonfish *Acanthurus guttatus* on the fore reef of Vaimaanga, Rarotonga; taken by Teina Rongo in 2009.

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EXECUTIVE SUMMARY

Climate change has been the topic of much research in the last few decades, however information on its impacts — particularly on remote small island nations — remain scant. Yet, through centuries of observation of their natural environment, Pacific islanders hold a wealth of knowledge of the sky, land, and sea. Sadly, with a shift towards a more western lifestyle on some of these islands in recent decades, this local knowledge is at risk of being lost because it is not passed down to younger generations; recognizing this, Climate Change Cook Islands of the Office of the Prime Minister conducted a questionnaire survey on most of the Cook Islands from January to April 2014. The aim of the survey was to collect information on changes in various biological and physical systems over people's lifetimes to understand climate variability in this region.

Causal factors for some changes recorded seem complex and difficult to explain with the limited information available. Nevertheless, a large number of changes seemingly coincided with hydroclimatic shifts associated with the well-documented phase shift of the Interdecadal Pacific Oscillation/Pacific Decadal Oscillation (IPO/PDO) in 1976/77 that affected rainfall distribution in the region; this shift coincided largely with the loss or the decline of many important floral and faunal species on the islands in both the terrestrial and marine environment. We note that the recent shift in the IPO/PDO to the negative phase would bring less rainfall to the northern group, and therefore certain measures need to be taken to minimize the adverse impacts (e.g., water shortages) this shift may have on island communities there.

It was difficult to link observed changes recorded in this survey to the effects of anthropogenic-driven climate change. However, some changes recorded may support the well-documented global sea level rise, such as the loss of salt crystals on reef flats and shorter low tide durations. The latter has negative repercussions on the livelihood of residents, especially in the outer islands of the southern group, because it limits people's access to marine resources as most subsistence fishing is carried out during low tide. Rougher sea conditions and stronger ocean currents that have been observed by fishers may explain the decline in the *ika tauira* (new recruits of reef fishes) throughout the Cook Islands in recent years, which is a concern with regards to food security and reef health in general. The decline in pelagic fish stocks noted throughout the Cook Islands is also concerning, and managers need to take these observations seriously considering the lack of historical information on these fisheries in the Cook Islands, and the interest of the Government to increase offshore commercial pelagic fishing activities in the future.

Indeed, the information collected in this survey justifies the need for a more comprehensive survey to be carried out throughout the Cook Islands. The loss and the decline of species noted in this survey is of interest; we need to understand the extent of climate-driven changes in the Cook Islands, particularly in regard to its impact on biodiversity. We note that the information collected in this survey will be useful in developing strategies for infrastructure and resource management, and could provide the basis for future research in the Cook Islands.

1. INTRODUCTION

Both naturally-occurring climate cycles as well as man's potential influence on the Earth's weather is an issue that has come to the forefront on a global scale in recent decades. In small Pacific island nations, the impacts of climate change are reported to be widespread, affecting food security, economic development, and increasing the risk of island communities to natural disasters. While much of our knowledge of the impacts in the Pacific are largely generalized based on studies conducted on a few islands in this region as well as model predictions provided by the Intergovernmental Panel of Climate Change, impacts remain poorly understood particularly on remote islands where resources are limited for consistent monitoring and reporting on this issue.

Through centuries of observation of their natural environment, Pacific islanders have acquired a wealth of local knowledge of the sky, land, and sea. Local knowledge offers valuable insight that complements scientific data essential for verifying climate models, can assist in evaluating climate change scenarios developed by scientists at much broader spatial and temporal scales, and can assist in the design of mitigation and adaptation measures to address climate change. Thus, documenting local knowledge about climate change has gained popularity in the literature (e.g., Martello, 2008; King et al., 2008; Choudhary et al., 2011). In the Cook Islands (Figure 1), elders in the community are primarily the keepers of local knowledge. However, the shift towards a more westernized lifestyle far more desirable today has resulted in Cook Islanders relying less on their environment, and the transfer of this knowledge to younger generations has been compromised.

Recognizing the importance of documenting local knowledge regarding observed environmental changes before this information is lost, Climate Change Cook Islands (CCCI), a division of the Office of the Prime Minister, began collecting this information in the *pa enua* (outer islands) in both the southern and northern Cook Islands as well as the main island of Rarotonga in the southern group.

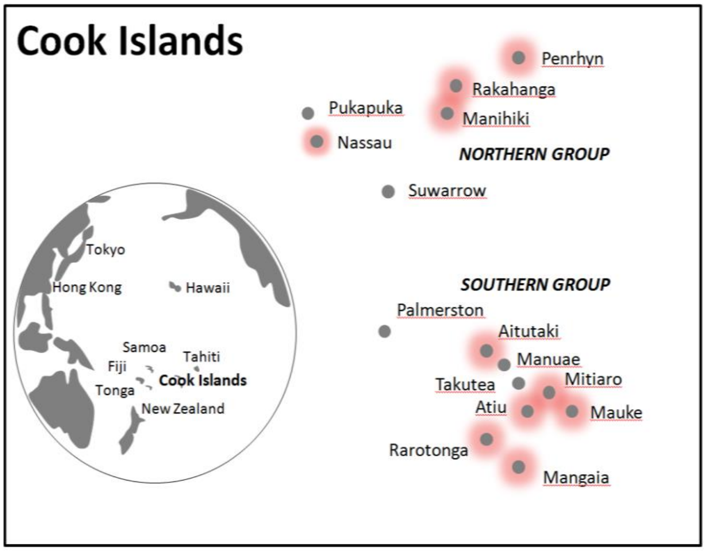


Figure 1. *Left*: map of the Pacific region with the Cook Islands indicated (bold). *Right*: map of the Cook Islands indicating the northern and southern group, with the islands surveyed highlighted in red.

1.1. INFLUENCE OF THE SPCZ IN THE COOK ISLANDS

The South Pacific Convergence Zone (SPCZ) is an important climatic feature not only in the Cook Islands, but also for the tropical southwest Pacific because it determines the long-term distribution of rainfall in this region. On average for the Cook Islands, the SPCZ lies to the west and south of the northern group, but north of the southern group stretching in a northwest to southeast orientation (Figure 2). During the wet season (November to April), the SPCZ is active, bringing unsettled weather and rain over the Cook Islands. However, during the dry season (May to October), the SPCZ is weak and roughly lies to the north of the southern group bringing dry southeast trades winds over the group.

A slight displacement in the SPCZ location can cause drastic changes to hydroclimatic conditions and the frequency of extreme weather events in the region, and therefore understanding its behaviour has broad scientific and economic implications. The SPCZ position varies from its mean location with the El Niño Southern Oscillation (ENSO), moving a few degrees northward during moderate El Niño events and southward during La Niña events (Vincent, 1994; Folland et al., 2002; Vincent et al., 2011). During strong El Niño events, however, the SPCZ could undergo an extreme swing up to 10 degrees of latitude toward the Equator (Cai et al., 2012), bringing severe weather impacts to vulnerable small island nations in the region.

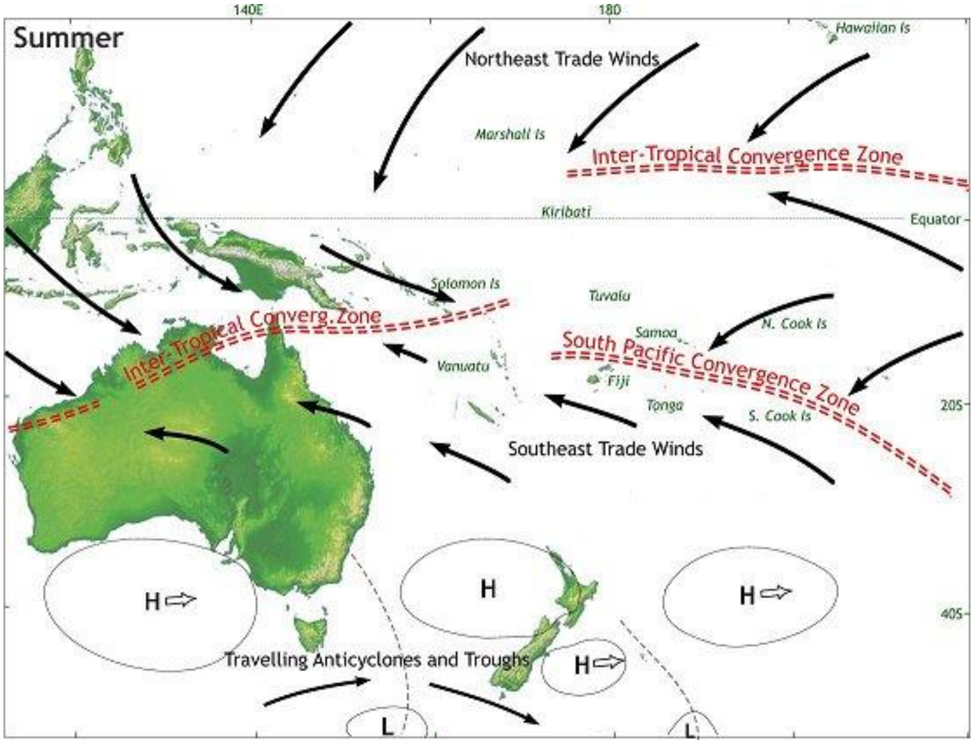


Figure 2. The location of the South Pacific Convergence Zone (SPCZ) over the southern Cook Islands group during summer months. Map taken from: http://blog.metservice.com/2012/10/convergence-lines/

1.1.1. Pacific Decadal Variability

At the decadal scale, Pacific-wide variability in climate that results in abrupt ‘shifts’ in climate patterns can persist for decades. The Interdecadal Pacific Oscillation (IPO; Latif et al*.,* 1997; Folland et al., 1998; Zhang et al*.,* 1997) and the Pacific Decadal Oscillation (PDO; Mantua et al*.,* 1997) have been used interchangeably in the literature to describe these decadal oscillations, because they are highly correlated and equivalent in describing Pacific-wide variations in ocean climate (Power et al., 1999; Verdon & Franks, 2006); in this report, we used both IPO and PDO interchangeably as well to describe interdecadal climate variability in the Cook Islands region. At the inter-annual scale, the El Niño Southern Oscillation (ENSO), which has a similar effect as the decadal oscillations mentioned above but is more intense, operates at approximately two to seven years before phase shifts compared with the IPO and PDO that undergo phase shifts approximately every 15 – 30 years.

Although the link between ENSO and PDO remains ambiguous, Verdon & Franks (2006) suggested a coupling effect in which El Niño events tend to be frequent during the positive PDO phase, and La Niña events frequent during the negative PDO phase. During the negative IPO/PDO phase and La Niña years, the southern Cook Islands experience warm and wet conditions, while the northern Cook Islands experience the opposite (Figure 3). On the contrary, the positive IPO/PDO phase and El Niño years tend to bring cool and dry conditions to the southern group, and warm and wet conditions to the northern group (see Figure 3).

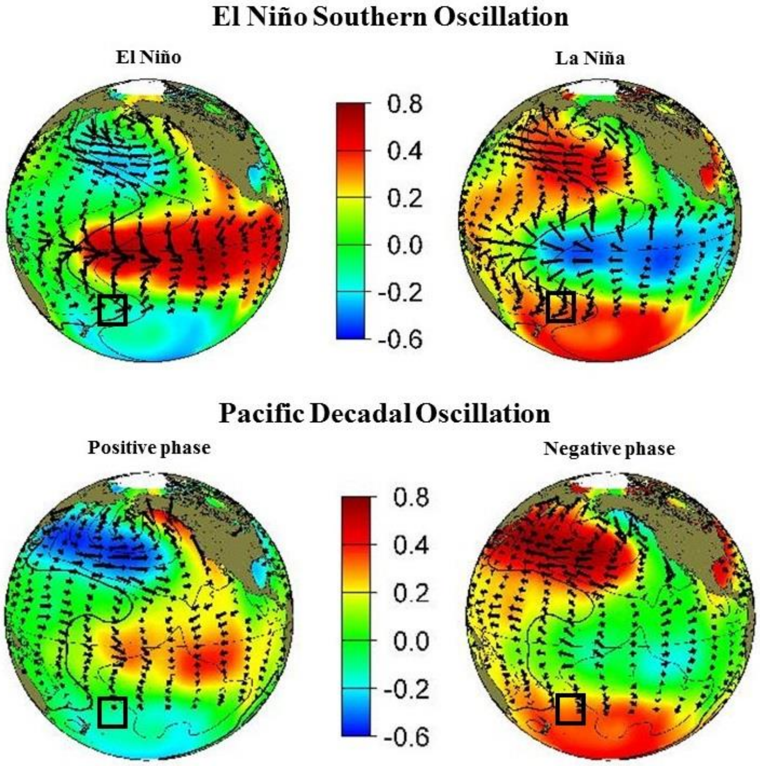


Figure 3. Sea surface temperature anomalies in the Pacific with regards to the El Niño Southern Oscillation and the Pacific Decadal Oscillation. The black box indicates the southern Cook Islands region. Figure modified from http://jisao.washington.edu/.

Although the influence of decadal cycles on Pacific-wide climate remains unclear, Linsley et al. (2000) showed using coral core data that decadal oscillations had the strongest signal on Rarotonga over the last 300 years (see also Rongo and van Woesik, 2011). For example, since the 1940s up until the late 2000s, the PDO has gone through one full cycle of a negative and positive phase, with the shift occurring in 1976/77 (Figure 4), affecting the distribution of rainfall to regions influenced by the SPCZ; in recent years, the PDO has shifted back into the negative phase. Historically, several abrupt changes in rainfall associated with decadal phase shifts within the last 450 years have been more intense than the change noted in the 1976/77 shift (Partin et al., 2013), indicating how variable the intensity of these shifts can be.

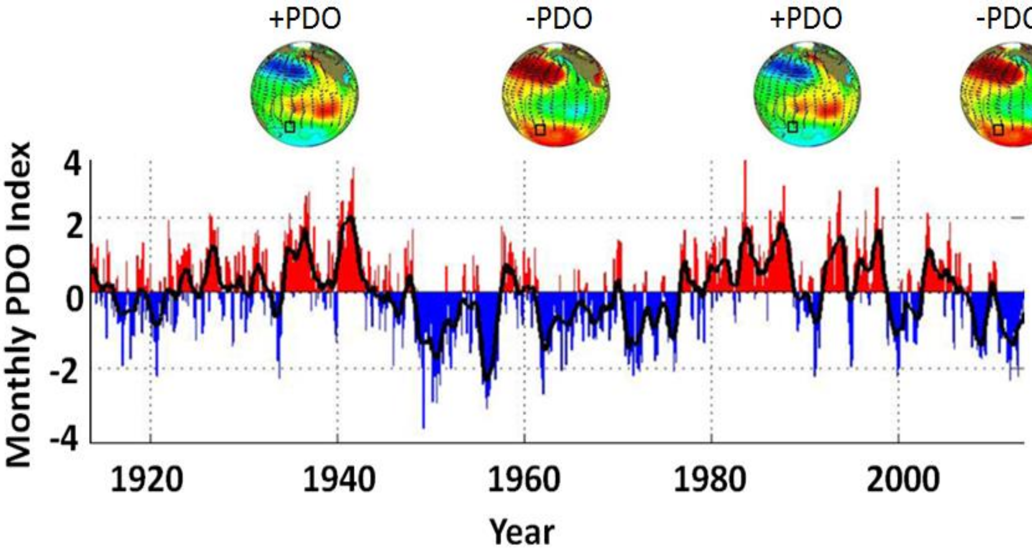


Figure 4. Monthly values for the Pacific Decadal Oscillation (PDO) from 1910 to 2013 (modified from http://jisao.washington.edu/pdo/). Boxed areas in globes indicate the southern Cook Islands region, with red regions indicating higher sea surface temperature anomalies. The red region on the PDO index graph indicates positive values, while the blue region indicates negative values.

While the focus of research on the influence of decadal climate variability in regions of small island nations has been essentially on the distribution of rainfall (Deser et al., 2004; van Loon et al., 2007; Matthews, 2012; Partin et al., 2013), others have shown that this variability can influence fisheries in regions. For example, Alaskan salmon production in the northeast Pacific Ocean dramatically declined during the negative phase of the PDO, but increased after the 1976/77 shift to the positive phase (Hare & Francis, 1995; Mantua et al., 1997). Similarly, recruitment of yellowfin tuna in the eastern Pacific Ocean declined during the negative phase of the PDO and increased during the positive phase (Maunder & Watters, 2001). In the southern Cook Islands, it was suggested that this 1976/77 shift influenced the increased incidence of ciguatera poisoning noted in the 1980s onwards (Rongo et al., 2009a; Rongo and van Woesik, 2013).

1.2. PRIMARY OBJECTIVES

The objectives of this survey were:

1. To quantify the level of awareness of Cook Islands communities on the issue of climate change.
2. To collect information on changes within the environment (i.e., physical and biological systems) that people have observed within their lifetime to examine decadal variability in climate in this region, with focus on the well-documented decadal climate shifts around 1976/77.
3. To distinguish observed changes influenced by the effects of anthropogenic-driven climate change and natural climate variability, and local activities (e.g., poor land use practices and overfishing).

1.3. MATERIALS AND METHODS

A team from Climate Change Cook Islands (CCCI) of the Office of the Prime Minister visited and surveyed six islands in the southern Cook Islands (Mangaia, Mitiaro, Atiu, Aitutaki, Mauke, and Rarotonga). In collaboration with the Marine Park consultation project, a member of the team also surveyed three islands in the northern Cook Islands (Rakahanga, Manihiki, and Penrhyn) (see Figure 1). The team interviewed around 200 individuals, focusing primarily on senior citizens aged 60 years and older, but some young adults and local experts in various fields were also interviewed. The target population included fishermen, planters, traditional healers, and arts & crafts individuals who utilize natural materials.

Generally, information gathered were people's personal experience of their natural environment, particularly their perception of changes in the resources they used or observed over time. Literature review of relevant information was also conducted. The team were also interested in determining the extent of knowledge on climate change of people in the Cook Islands, and interviewees assigned their own level of understanding by ranking their level between 0 (not aware) and 10 (very aware) (see *Appendix A* for questionnaire survey employed). The team did not provide any climate-related information prior to surveys to ensure that responses were not influenced.

1.3.1. Data analysis

All information from the questionnaire surveys were compiled into the following indicator categories: 1) terrestrial and freshwater (i.e., flora & fauna), 2) marine (i.e., reef fish, pelagic fish, and invertebrates), and 3) other. Subsequently, indicators were separated into three categories based on the potential driver of these changes pre- and post-1976/77 phase shift: 1) rainfall, 2) climate change impacts, and 3) other (i.e., those that could not be explained with the available information). Indicators were only considered in the results if independently mentioned by two or more individuals interviewed.

Rainfall data were obtained from the Cook Islands Meteorological Office for the island of Penrhyn to represent the northern group, and from Rarotonga to represent the southern group. Monthly rainfall data were grouped *a prior* into two periods corresponding to the pre- and post-1976/77 shift. Subsequently, Kruskal-Wallis analysis for comparative statistics was performed for the two periods; tests were significant at $p < 0.05$. For Rarotonga, the periods were 1947 – 1977 that corresponded with a predominantly negative IPO/PDO phase, and 1978 – 2013 that corresponded with a predominantly positive IPO/PDO phase. Because rainfall data for Penrhyn were missing for some months, the negative IPO/PDO phase was taken from 1951 – 1977, and the positive IPO/PDO phase from 1978 – 2011 where data were complete. Statistical analysis and graphical representation of results were performed using STATISTICA 12.

2. RESULTS

2.1. CLIMATE CHANGE AWARENESS

All residents from all islands surveyed indicated they've heard of climate change, and around 94% indicated the need for more climate change awareness programs, particularly in the *pa enua*. Around 40% of residents interviewed ranked their level of awareness on climate changes issues as 5 out of 10, with the majority ranking themselves below 5. Subsequent to the surveys conducted, the CCCI team presented climate change information to residents of the islands using local examples taken from the interviews (Figure 5).

Figure 5. A member of the Climate Change Cook Islands team, conducting climate change awareness on the island of Mauke in 2014. Photo by Eruera Nia.

2.2. RAINFALL PATTERNS ASSOCIATED WITH THE 1976/77 SHIFT

The negative phase of the IPO/PDO from 1947 to 1977 (see Figure 4) was a wet period in the southern group, with the opposite conditions experienced in the northern group. For example, wetlands in islands of the southern group (e.g., Mangaia and Rarotonga) were filled with running water and teaming with fishes between the 1940s to the early 1980s (Figure 6 *left*), while in Nassau and Pukapuka in the northern group, drought conditions were frequent during this period (T. Neiao and C. Dyer respectively, pers. comm.). On the contrary, the shift in 1976/77 dried up most wetland areas in the southern group including Mangaia (Figure 6 *right*), leading to a host of floral and faunal changes (discussed in *Section 3.2.* of this report).

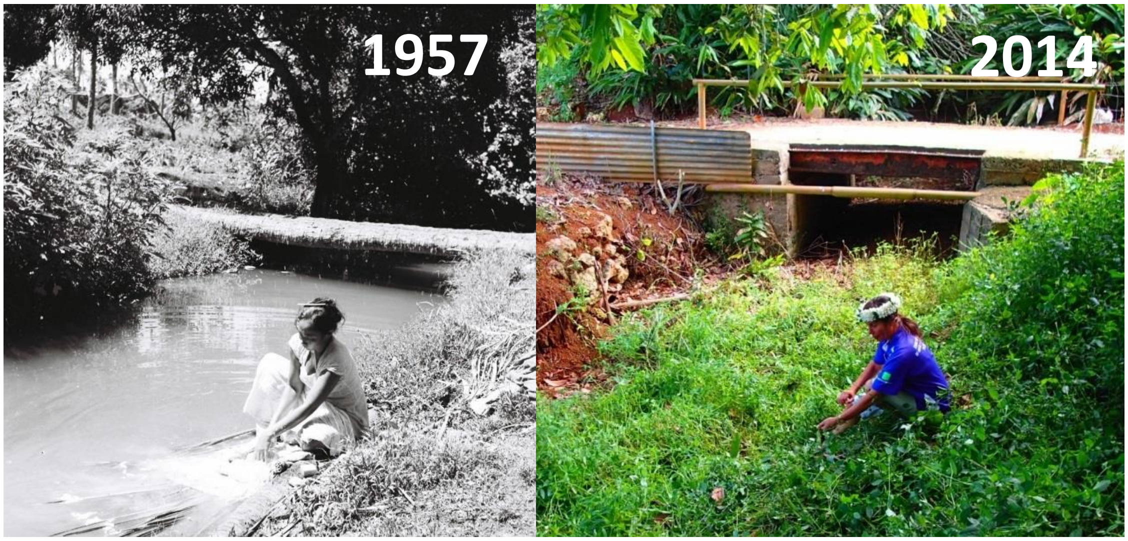
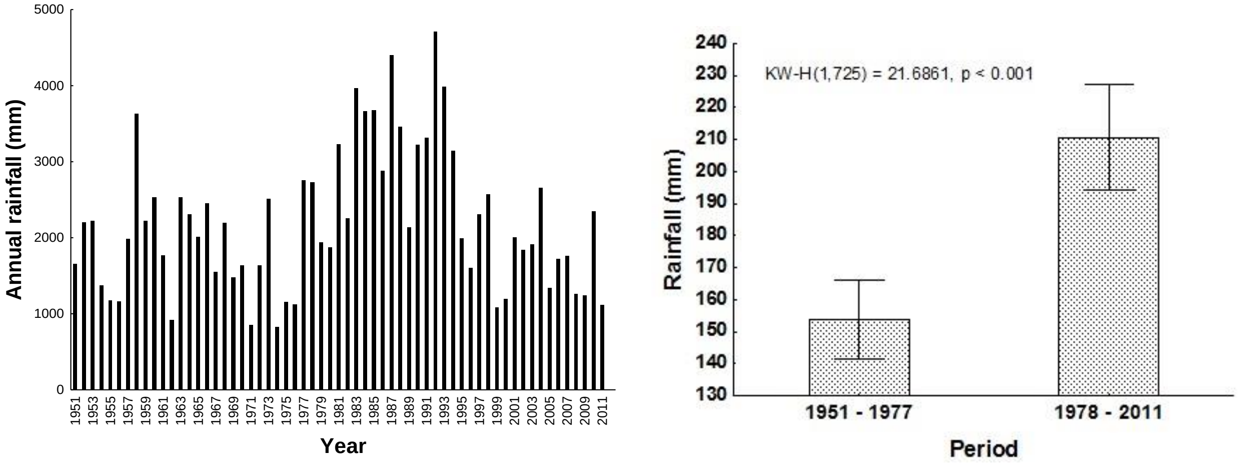


Figure 6. *Left*: photo taken in Mangaia stream in 1957, a period predominantly in the wet conditions of the negative phase of the IPO/PDO. Photo by Don Marshall, provided by the Mangaia Heritage Society. *Right*: photo of the same location taken in 2014, during a period still transitioning out of the dry conditions of the positive phase of the IPO/PDO. Photo by Teina Rongo.

Annual rainfall data from Penrhyn and Rarotonga clearly demonstrated the contrasting effect of changes in rainfall patterns associated with the pre- and post-1976/77 shift in the IPO/PDO between the northern and southern group. The post-1976/77 period showed significantly more rainfall ($p < 0.001$) for Penrhyn compared with the pre-1976/77 period (Figure 7). Although no statistical difference ($p = 0.088$) was noted between the two periods for Rarotonga, indeed the trend indicated less rain during the post-1976/77 period, which was contrary to conditions experienced in Penrhyn (see Figure 7).

Penrhyn



Rarotonga

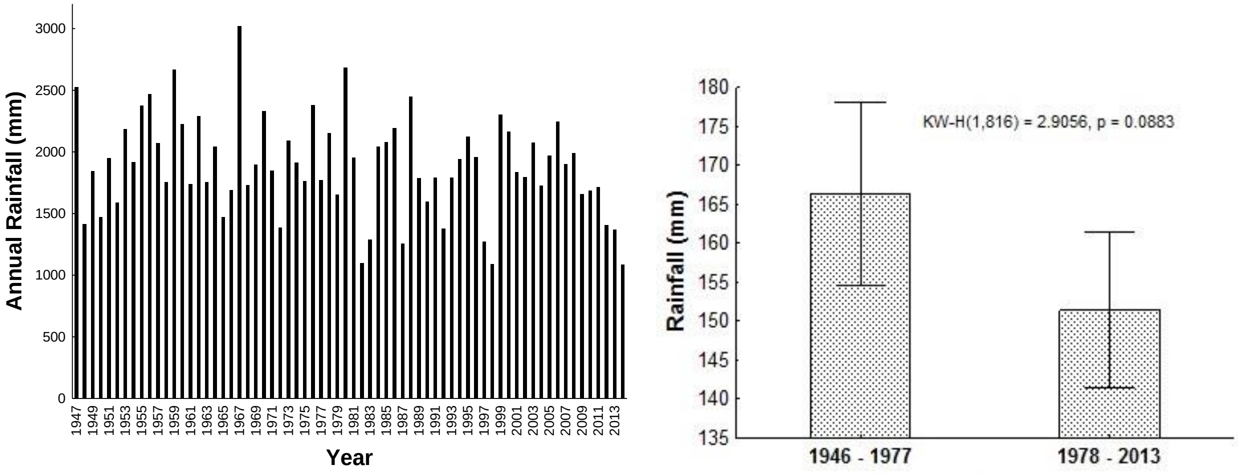


Figure 7. *Top left*: total annual rainfall data for Penrhyn in the northern Cook Islands from 1951 – 2011. *Top right:* Kruskal-Wallis analysis of Penrhyn's monthly rainfall data for the two periods, with $p < 0.05$ indicating significant difference. *Bottom left*: total annual rainfall data for Rarotonga in the southern Cook Islands from 1947 – 2013. *Bottom right:* Kruskal-Wallis analysis of Rarotonga's monthly rainfall data for the two periods, with $p > 0.05$ indicating no significant difference.

2.3. INDICATORS

Physical and biological changes within the environment as observed by those interviewed were considered 'indicators' in this survey. In the marine environment, changes to these indicators included: 1) the increase, decline, or loss of some pelagic species, algae, and target reef species, and 2) changes in ocean currents, sea level trends, and sediment dynamics. In the terrestrial environment, changes included: 1) multiple and offseason fruiting of some important fruit trees, 2) the increase, decline, or loss of some plants, insects, and birds, and 3) shifts in rainfall patterns. Important indicators were tabulated below (Table 1, 2, and 3).

2.3.1. Indicators associated with rainfall

Table 1 shows indicators that may be related to hydroclimatic changes associated with the 1976/77 shift in decadal oscillation from the negative phase (1947 – 1977) to the positive phase (1978 – 2013). The majority of indicators showed a decline from pre- to post-1976/77 (18 out of 28), while five showed an increase. Five of the indicators have not been observed in recent years, where three of them were identified as important food fish for residents.

2.3.2. Indicators associated with climate change impacts

Table 2 shows indicators that may be related to anthropogenic-driven climate change. The loss of salt crystals, shorter low tide durations, rougher sea conditions, and sediment build-up in lagoons are changes that were noted by residents. Coral bleaching, coralline algae disease, and the decline in coral cover in lagoon areas have also been noted in recent years for some of the islands. On the island of Manihiki where pearl farming is conducted, farmers are noticing problems with oysters; shells are thinner and deformities in the pearls have become common in recent years.

2.3.3. Other indicators

Table 3 shows indicators that were considered 'others' in this survey because linkages could not be clearly identified. The majority of these changes showed a decrease in recent years (23 out of 27). The *kuku* (winged mussel; *Modiolus auriculatus*), a common invertebrate on the reef flats of Rarotonga, has seemingly disappeared. The increase in pine (*Pinus radiata*) and Acacia trees (*Acacia auriculiformis*) on a few of the islands were the result of an introduction made in the 1980s to control soil erosion on previously citrus- and pineapple-farmed lands.

Table 1. Changes in indicators likely associated with hydroclimatic shifts related to decadal oscillations. Indicators that have decreased after the shift from negative IPO/PDO (1947 – 1977) to positive IPO/PDO (1977 – 2013) are marked with a down arrow (↓), indicators that have increased are marked with an up arrow (↑), and indicators that are no longer observed are marked with a zero (0). Indicators with no arrows have an unknown previous status. Islands where indicator was noted were abbreviated: Mangaia (Mng), Mitiaro (Mit), Atiu (Ati), Aitutaki (Ait), Mauke (Mau), Rarotonga (Rar), Rakahanga (Rak), Manihiki (Mani), and Nassau (Nas).

Common name	Scientific name	Māori name	(-)PDO 1947 -1977	(+)PDO 1978 - 2013	Island	Comments
Terrestrial/Freshwater						
Whitebait	Likely *Eleotris* spp.	*Īnanga*	↑	0	Rar	Whitebaiting was only recorded in Rarotonga; in the past, these were harvested from several stream mouths around the island (e.g., Avatiu, Avarua, Titikaveka and Avana) particularly after flood events. These are no longer observed today
Dusky sleeper	*Eleotris fusca*	*Kokopu*	↑	↓	Mng, Ati, Mau, Rar	Common throughout streams and taro swamp areas before the 1980s; began declining in the 1980s after frequent drought events. The *kokopu* is believed to be the adult of whitebait
Western gambusia	*Gambusia affinis*	*Ika namu*	↑	↓	Rar	Common throughout streams and taro swamp areas, considered an important predator of mosquito larvae; began declining in the 1980s after frequent drought events
Tilapia	*Oreochromis mossambicus*	*Tirāpia*	↑	↓	Mng, Ati, Mau, Rar	Introduced to all the islands, and were common in taro swamp areas in the southern group; began declining in the 1980s after frequent drought events
Freshwater eel	*Anguilla* spp.	*Tuna vai*	↑	↓	Mng, Ati, Mau, Rar	Common throughout streams and taro swamps before the 1980s; began declining in the 1980s after frequent drought events
Dragonfly	Several species of dragonfly	*Karakarā vai*	↑	↓	Mng, Mit, Ati, Ait, Mau, Rar	Common in wetland areas throughout the southern group, but has noticeably declined in the 1980s; considered an important predator of mosquito larvae and sandflies
No-see-'em biting-midge	*Culicoides belkini*	*Manumanu kakati*	↓	↑	Mit, Ait	Some suggested that sandflies are more a problem now than before; Mitiaro, Manuae, and Aitutaki are the only islands where this insect is a problem
Grey duck	*Anas superciliosa*	*Mokorā rere-vao*	↑	↓	Mng, Ati, Mau, Rar,	Common in wetland areas of the southern Cook Islands and were consumed on some islands; began declining in the 1980s
Spotless crake	*Porzana tabuensis*	*Kuramo`o*	↑	↓	Mit, Ati, Mau, Rar	Mitiaro have seen a significant decline in this species over time; these have not been spotted on other islands in recent years
Yellow necklace shell	*Orobophana pacifica*	*Pūpū*	↑	↓	Mng, Mit, Ati, Mau, Rar	This species are now harder to find on Mangaia because of frequent drought events after the 1980s; Mangaia is perhaps the only island that makes *pūpū ei* in the Cook Islands today
Lindernia	*Lindernia crustacea*	*Tūtae tōrea*	↑	↓	Mng, Rar	Medicinal plants that grow along the banks of taro swamp areas; harder to find today because most taro swamp areas have dried up due to the frequent drought events after the 1980s
Small-flower nightshade	*Solanum americanum*	*Poroporo puaka*	↑	↓	Mng, Ati, Mau, Rar	Used to be a common shrub on taro patches, but have declined in recent decades
Grass	Grass of various genera	*Matie*	↓	↑	Rak, Mani, Nas	People in Manihiki and Rakahanga are complaining that weeds have increased because they are cutting lawns today when in the past this was not something they did
Coastal sludge-weed	*Nostoc* spp.	*Remuremu enua*	↓	↑	Rak, Mani, Nas	This plant has become common in the northern Cook Islands within the last few decades
Breadfruit (local variety)	*Artocarpus altilis*	*Kuru enua*	↓	↑	Mng, Mit, Ati, Ait, Mau	Some suggest they are fruiting more today
Breadfruit (Tahitian variety)	*Artocarpus altilis*	*Kuru Taiti*			Mng, Mit, Ati, Ait, Mau	This variety fruits year-round

Pacific lychee	*Pometia pinnata*	*Tava*	↓	↑	Mit, Mau	Fruiting two or more times annually, but are more diseased today
Mango	*Mangifera indica*	*Vī*	↓	↑	Mng, Ati, Ait, Mau, Rar	Fruiting up to four times annually in the southern group in recent years; most blame climate change for this change
Marine						
Hatchet seahare	*Dolabella auricularia*	*Nga`u*	↑	0	Mng, Rar	According to elders, the *nga`u* was a reserve food that was only harvested when other fishing methods were unsuccessful, particularly on Rarotonga; these were common prior to the 1980s; their decline may be linked to the decline in *Lygnbya* beds
Giant seahare	*Aplysia dactylomela*	*Tuatai*	↑	0	Mng, Rar	This species is rarely consumed by locals; began declining after the 1980s after frequent drought events and possibly the loss of *Lyngbya* beds
Lined seahare	*Stylocheilus striatus*	*Patito*	↑	↓	Mng, Mit, Ait, Rar, Rak	Seasonal snail that are considered a delicacy on Rarotonga; harvested around September and October especially in the Ngatangiia area; began declining after the 1980s; some suggested that the loss of *Lynbya* beds led to their decline
Serrated swimming crab	*Scylla serrata*	*Tātarā roa*	↑	↓	Ait, Rar	Used to be fished near stream outlets around Rarotonga, especially around the Avarua/Avatiu and Avana stream mouths
Sargassum	*Sargassum* spp.	*Remu `ūmoemoe*	↑	0	Mng, Mit, Ati, Rar	This *remu* is common in tide pools and lagoon habitats that are relatively sheltered; the loss of this species also resulted in the loss of the parrotfish*`ūmoemoe* that seek food and shelter among this *remu*
Tangled-hair seaweed	*Lyngbya spp*	*Remu inaina*	↑	↓	Mng, Rar	Some suggested that the decline and infrequent blooms of this species in recent years is due to rougher conditions experienced in recent years as well; rough conditions easily dislodge *Lyngbya* from the reef substrate
Sea grapes	*Caulerpa racemosa*	*Remu kai*	↑	↓	Mng, Mit, Ati, Ait, Mau, Rar	Aitutaki is the only island today where *remu* is harvested and exported, especially to Rarotonga; before the 1980s, *remu* was harvested on most islands in the southern group
Sponge seaweed	*Hydroclathrus clathrus*	*E`ena*	↑	↓	Mng, Rar	On Managaia this seaweed is sometimes harvested for making desert similar to the dish *poke*. But it is also use as bait for catching *ume* (*Naso unicornis*).
Seagrass parrotfish	*Leptoscarus vaigiensis*	*`Umoemoe*	↑	0	Mng, Mit, Ati, Mau, Rar	The loss of this food fish coincided with the loss of the algae *Sargassum* in the 1980s
Scribble rabbitfish	*Siganus spinus*	*Maemae*	↑	↓	Mng, Ati, Mau, Rar	A common fish well into the 1980s and arguably one of the favorite food fish in the southern group; this species has been rarely observed in recent years
Forktail rabbitfish	*Siganus argenteus*	*Mōrava*	↑	↓	Mng, Ati, Mau, Rar	Large juvenile recruits of this important food fish were once one of the most common *ika tauira* on islands in the southern group; in the last 20 years, recruits and adults of this species are no longer common
Rudderfish	*Kyphosus* spp.	*Pipi*	↑	↓	Mng, Mit, Mau, Rar	This species has experienced heavy fishing pressure in recent years because it is considered 'low risk' for ciguatera poisoning
Fringelip mullet	*Crenimugil crenilabis*	*Kanae*	↑	↓	Mng, Ati, Ait, Rar	In the last two decade, this food fish has seen a decline on four of the islands; in Rarotonga, this species is considered 'high risk' for ciguatera poisoning
Ciguatera poisoning	Ciguatera poisoning	*Ika ta`ero*	↓	↑	Mng, Mit, Ati, Ait, Mau, Rar	Ciguatera has been problematic in the southern group for the last 30 years; however, cases have declined in recent years

Table 2. Changes in indicators that may be related to climate change. Indicators that have decreased after the shift from negative IPO/PDO (1947 – 1977) to positive IPO/PDO (1977 – 2013) are marked with a down arrow (↓), and indicators that have increased are marked with an up arrow (↑). Indicators with no arrows have an unknown previous status. Island names were abbreviated: Mangaia (Mng), Mitiaro (Mit), Atiu (Ati), Aitutaki (Ait), Man (Manuae), Mauke (Mau), Rarotonga (Rar), Rakahanga (Rak), Manihiki (Mani), and Nassau (Nas).

Common name	**Scientific name**	**Māori name**	**(-)PDO 1947 -1977**	**(+)PDO 1978 - 2013**	**Island**	**Comments**
Salt crystals on reef flat areas			↑	↓	Mng, Mit, Rak	Used for flavoring and preserving food, especially in the *pa enua*; rarely observed today; a combination of global sea level rise and noted rougher sea conditions in recent years may have caused the decline in salt crystallization on reef flat areas during low tide.
Tidal duration			↑	↓	Mng, Mit, Ati, Ait, Mau, Rar, Rak, Mani	Residents are suggesting that low tides are shorter and extreme low tides have been infrequent in recent years. Low tides are important as most subsistence fishers rely on this tide in the *pa enua*.
Sediment transport			↓	↑	Ait, Rar, Rak, Mani	Residents of Aitutaki and Rarotonga complained that their lagoons are getting shallow; movements of sediments were notable with sand banks eroding in some locations, and new banks forming in other locations; frequent storm surges and the observed rougher sea conditions in recent years are likely contributors to this change.
Coral bleaching			↓	↑	Ait, Rar, Man	Coral bleaching has been notable in the last 20 years; events tend to be associated with extreme low tides or high regional sea surface temperature anomalies where corals in lagoon areas tend to bleach the most.
Coral disease					Ait, Man	Coralline algae disease was noted on Aitutaki in the 1990s and also in 2013. In 2013, coral disease was reported on the fore reef of Manuae. Whether disease was present prior to these records is unknown.
Coral cover			↑	↓	Mng, Mit, Ati, Ait, Mau, Rar, Rak, Mani	Recovery of corals from a recent *taramea* outbreak has been slow in Rarotonga and Aitutaki; observed loss of corals are noticeable only for lagoon habitats because people interact more with the lagoon when fishing.
Branching coral types	*Branching species*		↑	↓	Mng, Mit, Ati, Ait, Mau, Rar, Rak, Mani	Branching corals have seen a decline, and small encrusting and massive to sub-massive growth forms are more abundant today.
Black-lipped pearl oyster deformities	*Pinctada margaritifera*	*Parau*	↓	↑	Rak, Mani	Deformities in both the shell and the pearl have been noted in Manihiki.
Sea conditions			↓	↑	Mng, Mit, Ati, Ait, Mau, Rar, Rak, Mani	Rougher ocean conditions have become more frequent in recent years. Some suggest that the prevailing winds, which can dictate the calm exposure of islands for reef flat fishing, are erratic and rarely blow consistently from one direction for longer periods like they use to.
Ocean currents			↓	↑	Mng, Mit, Ati, Ait, Mau, Rar, Rak, Mani	All islands are suggesting that ocean currents are getting stronger, and more rough sea conditions have been experienced in recent years.

Table 3. Other changes of flora and fauna that were noted during the survey; those that have decreased after the shift from negative IPO/PDO (1947 – 1977) to positive IPO/PDO (1977 – 2013) are marked with a down arrow (↓), and indicators that have increased were marked with an up arrow (↑). Islands where changes were recorded were abbreviated as follows: Mangaia (Mng), Mitiaro (Mit), Atiu (Ati), Aitutaki (Ait), Mauke (Mau), Rarotonga (Rar), Rakahanga (Rak), and Manihiki (Mani), Nassau (Nas).

Common name	Scientific name	Māori name	(-)PDO 1947 -1977	(+)PDO 1978 - 2013	Island	Comments
Marine reef fish						
Marbled grouper	*Epinephelus polyphekadion*	*`Hāpuku*	↑	↓	Mng, Mau, Pen, Rak, Mani	This important food fish aggregates in the lagoon before heading out to passages to spawn; this species has noticeably declined in Penrhyn and especially in Manihiki over the years.
Yellowfin goatfish	*Mulloidichthys vanicolensis*	*Takua*	↑	↓	Mng, Ati, Mau, Rar	This species is an important food fish in *Ngaputoru* and has been known to recruit in large numbers, but has declined in recent years.
Yellowstripe goatfish	*Mulloidichthys flavolineatus*	*Kōma*	↑	↓	Mng, Mit, Ati, Ait, Mau, Nas	This species is an important food fish in most of the southern islands and tends to recruit in large numbers once annually, but has declined in recent years; this species has been implicated in some fatal cases of ciguatera poisoning in Rarotonga.
Convict surgeonfish	*Acanthurus triostegus*	*Manini*	↑	↓	Mng, Ait, Mau, Nas	One of the most common herbivorous fish on reefs, but has certainly seen a decline over the years.
Goatfish	*Parupeneus* spp.	*Ka`uru*	↑	↓	Ati, Mau, Rar	This species does not recruit like the other two goatfish species (i.e., *koma* and *takua*), but certainly has seen a decline in recent years.
Mackerel scad	*Decapterus macarellus*	*Kōperu*	↑	↓	Mng, Ati, Rar, Rak, Mani, Nas	An important bait fish for tuna that has seen a decline in recent decades.
Barracuda	*Sphyraena barracuda*	*Ono*	↑	↓	Mng, Mit, Ati, Ait, Mau, Rar	Not consumed in the southern Cook Islands because considered 'high risk' for ciguatera poisoning.
Seasonal fish recruitments	Various species	*Ika tauira*	↑	↓	Mng, Mit, Ati, Ait, Mau, Rar, Rak, Mani, Nas	Large recruitment of various reef fish species that used to be very common on all islands, especially during the end of the wet season (February - April); no longer common.
Porcupinefish	*Diodon hystrix*	*Tōtara*	↓	↑	Mit, Rar	This species has seen an increase especially in Rarotonga within the last 15 years.
Pelagic fish						
Reef sharks	*Carcharhinus spp*	*Mangō akau*	↑	↓	Mng, Mit, Ati, Ait, Mau, Rar, Rak, Mani	There has been a noticeable decline in all reef sharks throughout the Cook Islands, particularly in the southern group.
Bigeye scad	*Selar crumenophthalmus*	*`Ature*	↑	↓	Mng, Mit, Ati, Ait, Mau, Rar, Rak, Mani, Nas	*`Ature* runs have become infrequent on all the islands.
Skipjack tuna	*Katsuwonus pelamis*	*`Au`opu*	↑	↓	Mng, Mit, Ati, Ait, Mau, Rar, Rak, Mani	These have seen a considerable decline in recent years.
Yellowfin tuna	*Thunnus albacares*	*`A`ai*	↑	↓	Mng, Mit, Ati, Ait, Mau, Rar, Rak, Mani	Both numbers and sizes have seen a considerable decline in recent years.
Oceanic sharks	Few species	*Mangō moana*	↓	↑	Mit, Ati, Ait, Mau	Population of oceanic sharks noted to have increased on some islands in the southern group within the last few years.

Invertebrates						
Brown pencil urchin	*Heterocentrotus mammillatus*	*`Atuke*	↑	↓	Mng, Mau, Rar	Favorite food urchin whose population has dropped in the last 20 years.
Rose-mouthed turban	*Astralium* spp.	*Karikao*	↑	↓	Mit, Ait, Mau, Rar	This was a common species on reef crest areas and was sometimes consumed by people; today, this species is hardly seen on the reef.
Giant clam	*Tridacna maxima*	*Pā`ua*	↑	↓	Mng, Mit, Ati, Ait, Mau, Rar, Rak, Mani	This species started declining on all the islands in the 1980s; perhaps Manuae is the only island remaining with a healthy population of *pa`ua*, but are also experiencing a decline as well according to fishers who harvest on Manuae.
Rough turban	*Turbo setosus*	*Ariri*	↑	↓	Mng, Mit, Ati, Ait, Mau, Rar, Nas	Some suggest that the decline in this species is the result of the *Trochus* introduction whose habitat overlaps the *ariri's* habitat to some extent.
Star-shaped limpet	*Scutellastra flexuosa*	*Mapi`i*	↑	↓	Mng, Mit, Ati, Mau, Rar	Intertidal invertebrate that are sometimes eaten have notably declined in the last 20 years.
Longspined urchin	*Echinometra diadema*	*Vana*	↓	↑	Mng, Mit, Ati, Ait, Rar	According to residents, *vana* densities have increased in recent years to levels never seen before in the past.
Winged mussel	*Modiolus auriculatus*	*Kuku*	↑	0	Mng, Rar	*Kuku* beds used to be very common on reef flats around Raroronga, but have essentially disappeared in these areas.
Other						
Sea birds		*Rau manu*	↑	↓	Mng, Mit, Ati, Ait, Mau, Rar, Rak, Mani	*Rau manu* are large flocks of a variety of sea birds that fishers use to locate schools of tuna; like tuna stocks, these birds have also noticeably declined.
Atiu swiftlet	*Aerodramus sawtelli*	*Kōpeka*	↑	↓	Atiu	Some suggested that decades ago, the numbers of *kōpeka* observed in the *makatea* of Atiu resemble swarms of butterflies.
Pine tree	*Pinus radiate*	*Paina*	0	↑	Mit, Ait, Mau, Rar	These were introduced to four southern islands for the purpose of controlling erosion, especially after the collapse of the citrus- and pineapple-farming industry, which left the land exposed to the elements. In addition, pine trees were chosen for the purpose of potentially using this species for building. While their introduction coincided with the drought period associated with the decadal shift in climate cycles, there is a strong belief on the islands of Mangaia and Atiu that water shortages experienced on these islands in the last two decades are largely the result of this introduction.
Acacia	*Acacia auriculiformis*	*Akatia*	0	↑	Mit, Ait, Mau, Rar	These were introduced to four islands in the south after the collapse of citrus and pineapple farming to combat erosion; these have spread prolifically, mainly on Atiu and Mangaia.
Pacific Banyan (Dye Fig)	*Ficus prolix* (*Ficus tintoria*)	*Ava* (*Mati*)	↑	↓	Atiu, Mng, Rar	These species are used for various arts and crafts purposes (e.g., for making *tapa* and artificial flowers for decorating church hats) and also for herbal remedies. However, in recent decades, people are noticing a decline in their numbers. Some suggest that they are outcompeted by the introduced pine and Acacia trees, especially on Atiu and Mangaia.

3. DISCUSSION

3.1. CLIMATE CHANGE AWARENESS

Climate change is an issue that all residents surveyed have encountered. Yet, their understanding of climate change varied substantially from 0 to 10, with the majority ranking themselves below 5. Given that most had limited knowledge on the science of climate change and its potential effect on their island, there was a tendency for people to put the blame on climate change for any unexplained variations observed. The assessment used in this survey was subjective and ineffective in determining an individual's true awareness of climate change issues. Perhaps an appropriate assessment would be to subject individuals to a series of standardized questions and assign a level accordingly.

Certainly there is a general consensus, particularly from those in the *pa enua*, of the need for more climate change awareness campaigns. Effectively, we found that these campaigns must be conducted in the local Māori language using local examples; future campaigns could use examples recorded in this survey that were specific to each island. According to residents of the *pa enua,* past awareness campaigns on climate change were conducted by English-speaking individuals. Because climate change information can often be technical, understanding the concepts presented in English has been difficult for *pa enua* residents. We found that when people were better informed about the impacts of climate change to their island, they become more receptive to ideas that could potentially affect their livelihood, such as limiting their access to marine resources through the establishment of *ra`ui* (as a well-managed marine protected area would not only increase the resilience of marine ecosystems to climate change impacts, but also lead to more sustainable fisheries) and employing better land use practices.

3.2. CHANGES ASSOCIATED WITH RAINFALL DISTRIBUTION

The survey results confirmed that hydroclimatic conditions before and after the 1976/77 IPO/PDO phase shift were clearly important drivers to changes noted in the flora and fauna in the Cook Islands. These changes were largely associated with the shift from predominantly wet to dry conditions in the southern group, and from dry to wet conditions in the northern group. Because our questionnaire survey focused on changes at the decadal scale with the 1980s provided as a reference point in time, people essentially compared conditions prior to the 1980s with conditions in recent years; at this time scale, people were able to clearly recollect increases, declines, or complete loss of resources and other physical changes within their environment.

For the most part, terrestrial and marine floral and faunal changes within the Cook Islands showed a decline in the abundance of species, while some species are no longer observed. For the southern Cook Islands, wetter conditions are expected with the recent phase shift to the negative IPO/PDO phase. It will be interesting to note whether or not the abundance of species that have declined will return to the levels noted in the previous negative IPO/PDO phase from 1947 – 1977, considering conditions have changed since (i.e., land use and the impacts of global climate change).

3.2.1. Terrestrial floral and faunal changes in the southern Cook Islands

There were several climate indicators compiled in this survey that were seemingly linked to the predominant drought conditions over the last 30 years in the southern group (see Table 1). Most floral and faunal populations showed a decline over this period. For example, dragonfly populations (Figure 8), found most abundant around wetland areas because their larvae are aquatic, have declined on all islands. Interestingly, some Mitiaro residents have suggested that the decline in dragonfly populations may explain the increase of their sand fly prey, which has seemingly become more problematic over the last few decades. Dragonflies are also important predators of mosquitoes; their decline could potentially have some implications on human health as increased mosquito populations can increase the likelihood for transmission of vector-borne diseases (e.g., dengue fever).

Figure 8. *Left*: the aquatic larvae of a dragonfly. Photo by Konini Rongo. *Right*: adult dragonfly which are commonly found in taro swamp areas in the Cook Islands. Photo by Teina Rongo.

Drought conditions over the last 30 years likely caused the loss of some freshwater fish species on islands in the southern group as well. For example in Rarotonga, the *kokopu* (dusky sleeper; *Electris fusca*), *tirāpia* (tilapia; *Oreocromis mossambicus*), and *ika namu* (Western gambusia; *Gambusia affinis*) used to be common in the taro swamp areas when water was plentiful (see Table 1). Some middle-aged individuals recollect the fun activity of fishing for *tirāpia* in these swamps; this activity would be difficult for individuals under 30 years of age to imagine considering these areas would have been dry throughout most of their lives. Some of these fish species such as *ika namu* are also important predators of mosquito larvae.

In Mitiaro, Mauke, and also Rarotonga, the *kurāmo`o* (spotless crake; *Porzana tabuensis*; Figure 9) — a bird that used to be common in taro swamp areas — has become rare. People in Mitiaro remember how this bird was commonly seen crossing the road running through the tall grass field adjacent to *Te Roto Nui* lake in the middle of the island. Today, the water level has dropped substantially according to residents and the surrounding swamp areas have gotten drier. Perhaps a reduction in the habitable area for the *kurāmo`o* due to drought conditions in the past decades may explain the decline in their population. Cats are known to kill the fledglings of some bird species in the Cook Islands and this could have also contributed to the decline of the *kurāmo`o,* especially when this bird is known to spend most of its time foraging on the ground. Another bird that was noted to have declined is the *mokora rere-vao* (grey duck; *Anas superciliosa*); this duck species used to be common in wetland areas of Mauke, Mangaia, and Atiu.

Figure 9. *Left*: *Kurāmo`o* (spotless crake; *Porzana tabuensis*), a bird that used to be common in taro swamp areas. Photo taken from: http://polynesiandiversity.wordpress.com/category/6-inselnislands/pitcairn-islands/. *Right*: *Mokora rere-vao* (grey duck; *Anas superciliosa*), a bird that has also seen a decline in water body areas in the southern Cook Islands. Photo taken from: http://cookislands.bishopmuseum.org/MM/TX-150Wq3/5BD027_Anas-supe_Aust1_GM2_2006_TX.jpg

Population of the *pūpū* (golden shell; *Orobophana pacifica*) (Figure 10 *left*), which rely on moderately wet conditions to survive, have also declined on islands that collect this snail for making necklaces (Figure 10 *right*). Normally, *pūpū* are easier to collect after rainy periods because they would come out of their hiding places. Mangaia is perhaps the only island where *pūpū* necklaces are still made. However, necklace makers have observed a drastic decline in *pūpū* numbers over the last two decades, even after a heavy downpour. Similarly, in Rarotonga where *pūpū* used to be common in the 1960s to the 1970s, a decline has also been noted in the last few decades. Generally, these were found along rocky shorelines particularly along the eastern to southeastern exposure of Rarotonga, including the *motu* (islets) in Ngatangiia (T. Joseph, pers. comm.). Although drier conditions of the 1980s to the 2000s are the likely cause of this decline, the loss of habitat from development along this coast of Rarotonga may have also contributed.

Figure 10. *Left: pūpū* (golden shell; *Orobophana pacifica*) in Mangaia, where populations have notably declined over the last few decades. Photo by Mitchell Tutangata. *Right: ei pūpū*, or golden shell necklace, worn in the Cook Islands. Photo by Teina Rongo.

Some plants, particularly those that grow around taro swamp areas, have also declined in the southern Cook Islands. The *tutae tōrea* (Lindernia; *Lindernia crustacea*; Figure 11), a plant used by traditional healers in Mangaia as an important ingredient in their herbal remedies, are harder to find in recent times because the taro swamp areas where they normally grow have dried up. Similarly, the *poroporo puaka* (small-flower nightshade; *Solanum americanum*), which grows around wetland areas where the fruits are sometimes consumed, is also harder to find today.

Figure 11: *Tutae tōrea* (Lindernia; *Lindernia crustacea*), a medicinal plant that normally grows in taro swamp areas of Mangaia, have been harder to find because of frequent drought events in the 1980s to recent years. Photo by Mitchell Tutangata.

3.2.1.1. Changes in fruiting trees

Climate change has been suggested to affect seed crops through changes in crop phenology, reproduction, flowering, pollen viability, pollination/fertilization, length of seed-filling duration, seed setting, seed size, seed dormancy, seed yield, and ultimately seed quality (Kjøhl et al., 2011). Consequently, several studies have indicated that climate change will cause a decline in crop yield globally (e.g., Singh et al., 2013). In the southern Cook Islands, there were strong indications that fruiting of important food trees have now gone outside their normal season. Normally fruit are available during the summer months with one fruiting season annually, but in recent years this has extended into the winter months with multiple fruiting in a year becoming common among some fruit trees. For example, *vi* (mango; *Mangifera indica*; Figure 14) in the southern group are normally available between the months of December and March for Rarotonga, and around October to December for Aitutaki, with one fruiting per year. Today, the availability of *vi* has extended into July, with trees often bearing fruit twice and sometimes up to four times per season. Reduced rainfall has been suggested to increase off-season fruiting (Rajan, 2012). Frequent drought periods in recent years for the southern group may explain the multiple fruiting in mangoes within a season. Fruiting may also vary depending on the variety. For example, *vi oka* is known to be one of the most productive varieties, which tend to do well during wet years (M. Purea, pers. comm). Frequent drought events in recent years appear to have hampered fruiting of the *vi oka*, but this conjecture needs more examination.

Figure 14. *Vi* (mango; *Mangifera indica*) in Rarotonga, which in recent years have begun to fruit twice annually. Photo by Teina Rongo.

Similarly, breadfruit trees (*kuru*) on some islands in the southern group are fruiting more frequent than normal in a season. Although some interviewed argued that multiple fruiting in a season is normal for the introduced *kuru taiti* (Tahitian breadfruit; *Artocarpus altilis*; Figure 15 *left*), some indicated that the local variety (Figure 15 *right*) are also fruiting more frequent than normal. Like *vi*, the *tava* (Pacific lychee; *Pometia pinnata*; Figure 16) that normally fruit during the summer months have now extended their fruiting period into winter months, fruiting two or more times a season. Although offseason fruiting may be influenced by reduced rainfall in recent years, the rise in global temperatures associated with climate change may also have an influence. Given the recent shift into a warmer period associated with the negative IPO/PDO phase for the southern Cook Islands, it may be difficult to determine the contribution of natural climate cycles and anthropogenic-driven climate change to fruiting. In addition, whether multiple fruiting during a season compromises the quality of the seeds in the Cook Islands is not known. If we are unable to grow our fruit trees from seeds, then other methods will have to be considered.

Figure 15. The introduced Tahitian variety of breadfruit (*kuru Taiti; left*) and the local variety (*kuru enua; right*) are important starches for some islands in the *pa enua*. The local variety is normally seasonal while the Tahitian variety fruits multiple times throughout the year. Photos by Teina Rongo.

Figure 16. *Tava* (Pacific lychee; *Pometia pinnata*), a common fruit tree in Mauke and Mitiaro. Photo from: http://cookislands.bishopmuseum.org/showarticle.asp?id=25

3.2.2. Terrestrial floral and faunal changes in the northern Cook Islands

The northern Cook Islands experienced drought conditions between the 1950s and the 1970s, contrary to the wet conditions experienced in the southern Cook Islands during the same period. It was noted that drought periods can last up to 6 months at a time, and were more frequent in Nassau and Rakahanga during this period. However, after the 1980s, wet conditions prevailed and changes in some flora were notable. For instance, the cover of grass and other weeds have increased in the last few decades in Manihiki and Rakahanga, noted especially by residents who complained about the lawn they now have to cut; in the past the land was brighter because the gravel was more exposed and weed cover was less.

Wet conditions in the northern Cook Islands were also indicated by the growth of the terrestrial cyanobacteria *Nostoc* spp., as these were uncommon in the past (Figure 12). In support, the lushness of vegetation in the northern group was also evident in the fronds of coconut palms. For example, arts & crafts individuals indicated that *kikau* (coconut frond) brooms made from fronds in Rakahanga in the northern group tend to be longer (Figure 13 *left*) than those sourced in the southern group (Figure 13 *middle*). In fact, *kikau* brooms imported to Rarotonga from the northern islands (Figure 13 *right*) are immediately purchased because of this reason.

Figure 12. Cyanobacteria *Nostoc* spp. growing along road sides of Manihiki and Rakahanga, which became common in the last few decades in the northern islands from wetter conditions.

Figure 13. *Left*: lush coconut trees of Rakahanga indicating abundant rainfall. Photos by Teina Rongo. *Middle*: yellow coconut fronds in Mangaia, which is typical growth of coconut trees in most southern islands in the drier conditions over the last few decades. Photo by Eruera Nia. *Right: kikau* (coconut frond) brooms imported from Rakahanga in the northern group. Photo by Jackalyn Rongo.

3.2.3. Changes in target marine resources

Marine resources are the bulk of the diet of people in the *pa enua*, therefore residents are very aware of any changes occurring with these resources and the marine environment in general. For the most part, noted changes have had adverse effects to the residents of individual islands. Changes in pulse recruitment of juvenile reef fish, or *ika tauira* (Figure 17), is perhaps an important one because of the critical role this plays in the replenishment of fish stocks on reefs. In the southern group, *ika tauira* usually occurs around February to April. However, these large recruitment events are becoming infrequent when compared with those observed a few decades ago. For example, *pipiriri,* a juvenile *mōrava* (*Siganus argenteus*; Figure 17 *insert*), has not been observed in the last decade or so on the island of Rarotonga and Mangaia.

Figure 17. Pulse recruitment of several reef fishes were common on all islands in the Cook Islands. Photo by Teina Rongo. *Insert*: the *mōrava* (*Siganus argenteus*) have become noticeably rare on many of the islands in the southern Cook Islands. Photo taken from: http://farm8.static.flickr.com/7514/15657384435_55effbeaaf_m.jpg

Seemingly, declines in target species are linked to the decadal-long hydroclimatic shifts as well. Low rainfall in the last few decades may have changed the chemistry of near-shore waters to conditions unfavorable to marine flora that supported these target species. In contrast, wet conditions between the 1940s and the 1980s in the southern group, associated with the last negative IPO/PDO phase, may have provided the ideal conditions for species that thrive in low salinity waters. For example, *Sargassum* species (Figure 18) are generally found in near-shore areas where terrestrial runoff is frequent (McCook, 1996), and prior to the 1980s this algae was common throughout the southern group. However, the 1976/77 shift to more drought conditions may explain the decline of *Sargassum*. The increase in rough conditions that have been observed in recent years may have also contributed to their loss, considering that these algae are found in sheltered areas such as tide pools on reef flats and in the lagoon of Rarotonga.

Figure 18. *Sargassum* beds on the reef flat of Mangaia. Photo taken by Teina Rongo.

Consequently, this notable decline of *Sargassum* was also suggested by subsistence fishers to have caused the loss of `*ūmoemoe* (*Leptoscarus vaigiensis*; Figure 19), a type of parrotfish that was once an important food fish in the southern Cook Islands. Generally, `*ūmoemoe* can be caught by hand in *Sargassum* mats during the day at low tide or with a hand spear at night using a kerosene lantern. Although this species is native to the southern Cook Islands and its distribution is widespread in the Pacific, there are no known threats to this species. However, habitat destruction and loss of coral reefs may influence their establishment. Because they are known to inhabit sea grass and heavily algal-dominated reefs, freshwater effluent may be important. For example, they are mainly found on the larger islands in the southern group (i.e., Rarotonga, Mangaia, Mauke, Atiu, and Mitiaro), but seem to be absent in the northern group. Whether the drought period in the last 30 years contributed to their decline is unknown. However, it will be of interest to find out whether the recent shift of the IPO/PDO that should bring more rain to the southern group will increase `*ūmoemoe* populations, considering that no observed reports have been made in recent years.

Figure 19. `*Ūmoemoe* (*Leptoscarus vaigiensis*) is a type of parrotfish that used to be fished on the reef flats of islands in the southern Cook Islands. This fish is normally found in dense mats of *Sargassum* algae. Photo taken from Randall, 2005.

The decline of the *patito* (seahare; *Stylocheilus striatus*; Figure 20 *insert*) on the island of Rarotonga in the last 20 years or so also coincided with reduced rainfall during the same period. In the past, large recruitment of *patito* was common in the Ngatangiia lagoon during the months of September to October. During these recruitment events, women from around the island would flock to Ngatangiia to harvest the *patito* as it is a delicacy on Rarotonga. Typically, *patito* recruitment coincides with large blooms of the *remu `ina`ina* (cyanobacteria; *Lyngbya* spp; Figure 20), which the *patito* feed on. However, observations of both species have been infrequent in the last few decades for reasons unknown.

With less rain in the 1980s onwards, it is expected that runoff nutrient into the lagoon would have decreased and ocean salinity near the coast would have increased. Furthermore, given that coastal developments in the area where the *patito* are normally harvested have increased, this would have certainly changed the composition of nutrients flowing into the lagoon; subsequently, this would have also changed algal species composition in the lagoon. In this context, we suggest that these changes would have contributed to the decline in the *remu `ina`ina,* and consequently the decline of *patito* as well. However, this conjecture is difficult to confirm given that long-term monitoring of lagoon waters around Rarotonga only begun in the early 2000s. Alternatively, some elders in Ngatangiia suggested that rougher sea conditions in recent years contributed to the decline of the *remu `ina`ina*, considering that the *remu `ina`ina* grow better in sheltered lagoon areas.

Figure 20. Cyanobacteria *Lyngbya* spp. that host *patito* (insert; photo by Gustav Pauly), which used to grow in abundance in the lagoon of Ngatangiia. Photo by Robert van Woesik.

Interestingly, *kanae* (mullet; *Crenimugil crenilabis*; Figure 21) populations were suggested to have also declined, especially on Mangaia, Atiu, Aitutaki, and Rarotonga. While low salinity conditions associated with consistent freshwater input into estuary areas play an important role in the rearing and development of larval and juvenile *kanae*, frequent drought periods in recent years have likely contributed to their decline.

Figure 21. *Kanae* (mullet; *Crenimugil crenilabis*), a food fish whose populations have declined in recent years. Photo from: http://www.fishbase.org/images/species/Vaseh_u1.jpg

The decline in *remu kai* (sea grapes; *Caulerpa racemosa*; Figure 22) in Mitiaro and Rarotonga could also be linked to this 1976/77 hydroclimatic shift. According to the people of Mitiaro, diving for *remu kai* in the past was an activity carried out by young women particularly around the harbour area. Today, *remu kai* are hardly observed and if they are found, strands are shorter than what was normally collected. Some suggested that the development of the Mitiaro Harbour may have contributed to this decline. Alternatively, the increase in *remu kai* noted in Rakahanga in the northern group after the 1976/77 shift may be linked to the subsequent increase in rainfall.

Figure 22. *Remu kai* (sea grapes; *Caulerpa racemosa*), an edible seaweed commonly harvested for consumption, but have become less common in recent years. Photo from: http://biogeodb.stri.si.edu/bioinformatics/dfmfiles/files/c/31012/31012.jpg

3.2.3.1. Loss of whitebait

Whitebait is a collective term used for freshwater juvenile fishes (Figure 23) that often school along the coast, particularly around estuaries where there is freshwater effluent. In the Cook Islands, whitebait was only reported in Rarotonga where these were caught in large schools at stream mouths at several locations around the island (e.g., Avatiu, Titikaveka, Takuvaine, Avana). According to elders, whitebait was an important food source for some villages on Rarotonga, and was prepared in many different ways (e.g., mixed in pancakes or wrapped in banana leaves and placed in the *umu;* earth oven).

In Rarotonga, whitebait is believed to be the juvenile of the *kokopu* (dusky sleeper; *Eleotris.* spp), a fish noted to have drastically declined in the last few decades. For example, whitebait disappeared in Avatiu village towards the end of the 1970s; some elders claim that the construction of the Avatiu Harbor which redirected the flow of the Avatiu stream from the west to the east (its present day location) may have contributed to its loss. Nevertheless, this fishery completely disappeared from Rarotonga around the same period. The hydroclimatic shift around 1976/77 that resulted in less rainfall for Rarotonga and the southern group – thus less water running down streams – is likely the cause of the whitebait fishery collapse, considering that freshwater effluent is critical for whitebait species.

Figure 23. Whitebait in New Zealand, which consists of several native freshwater fish species of *kokopu*. http://www.stuff.co.nz/national/blogs/in-our-nature/7393261/Why-our-whitebait-are-at-risk

3.2.4. Ciguatera poisoning

Ciguatera poisoning, a type of seafood intoxication in humans that result from the consumption of reef fishes that have inadvertently ingested toxic microscopic algae (ciguatoxic dinoflagellates), has become problematic in the southern Cook Islands in the last few decades. A recent study suggested that ciguatera poisoning in the southern Cook Islands was linked to decadal climate oscillations (Rongo and van Woesik, 2011), through cyclone frequency associated with the different phases (Rongo and van Woesik, 2013). For example, the shift to the positive phase of the PDO in 1976/77 increased the frequency of El Niño events (e.g., Verdon and Franks, 2006), which for this region increased the frequency of cyclones (de Scally, 2008), particularly in the 1980s onwards. Cyclones disturb large areas on reefs, creating space for ciguatoxic dinoflagellates to establish (e.g., Kohler and Kohler, 1992; Bagnis et al., 1992), which ultimately leads to increased incidence of ciguatera poisoning (see Rongo and van Woesik, 2013).

Congruently, other reef disturbances were also prevalent in the southern Cook Islands during this period after the 1976/77 shift. For example, it was reported that coral bleaching events increased during this period as a result of extreme low tides and calm conditions associated with El Niño events (see *Section 3.3.4.*). Clearly, the frequency of reef disturbances in the last 20 years has increased, which corresponded with increased cases of ciguatera poisoning in Rarotonga when compared with the period prior to the 1980s (where only a few cases of ciguatera poisoning were recorded; Rongo & van Woesik, 2011) (Figure 24). In addition to disturbances, some have suggested that high salinity (i.e., low rainfall) conditions are favourable for ciguatoxic dinoflagellates to proliferate (see Anderson and Lobel, 1987). Perhaps this period of increased reef disturbances and low rainfall provided the ideal conditions for ciguatera poisoning to occur in the southern Cook Islands.

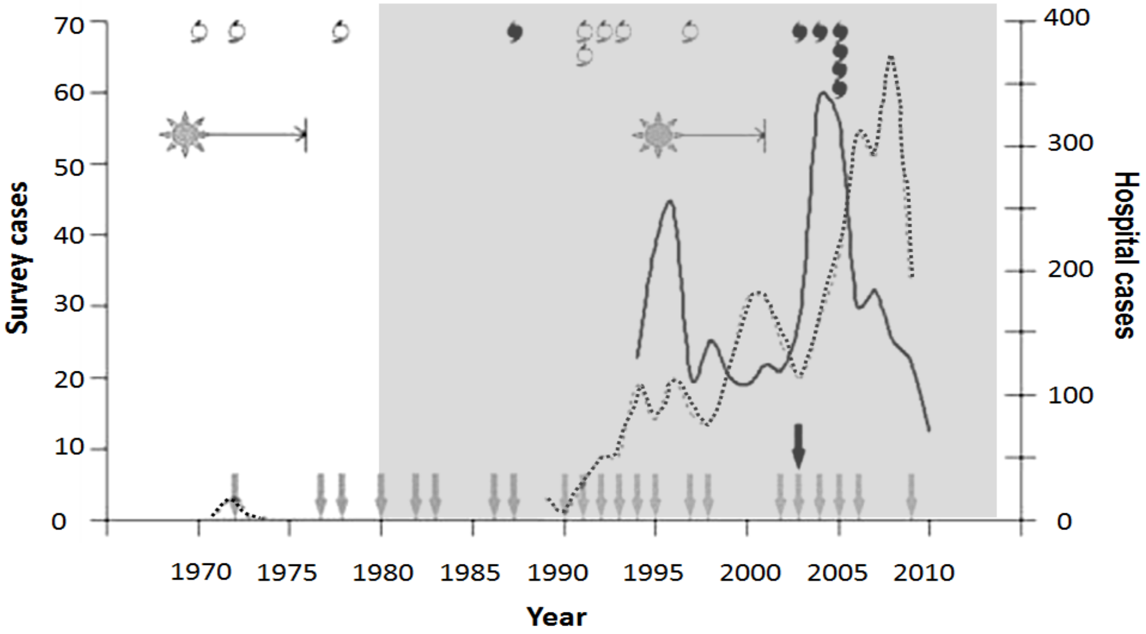


Figure 24. Cases of ciguatera poisoning from Rarotonga's hospital data (solid line) and a questionnaire survey (dashed line). Shaded regions indicate the ciguatera problem period (1988–2010). Sun-shapes and horizontal arrows indicate periods of two major *Acanthaster planci* outbreaks: 1969–1976 (Devaney and Randall, 1973; Dahl, 1980), and 1995/96–2001 (Lyon, 2003; Rongo et al., 2006). Also shown are the years of Category 3 or less cyclones (open) (1970, 1972, 1978, 1991, 1992, 1993, 1997) and Categories 4 and 5 cyclones (black) (1987, 2003, 2004, 2005) impacted Rarotonga (Baldi et al., 2009). Grey arrows indicate El Niño years taken from the National Oceanic and Atmospheric Administration Climate Prediction Center (1972, 1977, 1978, 1980, 1982–1983, 1986–1987, 1990–1995, 1997–1998, 2002–2006, 2009). Black arrow marks a major harmful algal bloom referred to as the Titikaveka Irritant Syndrome in 2003. Figure modified from Rongo & van Woesik, 2011.

The impact of ciguatera poisoning may also explain the decline of some fish species such as barracuda, red snapper, and reef sharks (Figure 25) in the last two decades noted in the southern group. Ciguatoxins have been reported to have adverse effects on reef fishes that become intoxicated by reducing the survival of fish larvae (Lewis 1992; Landsberg 1995; Edmunds et al. 1999; Ajuzie 2008). Ciguatoxins tend to bioaccumulate in high concentrations in top predators especially reef sharks, making them susceptible to its effects. Considering that in the last decade, ciguatera poisoning has been on the decline in the southern group, perhaps reef shark populations may rebound if indeed ciguatera poisoning was affecting them. Regardless, given the importance of reef sharks in maintaining balance in reef ecosystems, there is a need to understand why reef shark populations have declined in the southern Cook Islands in the past two decades or so.

Figure 25. *Mangō pāpera* (grey reef shark; *Carcharhinus amblyrhynchos*), one of the few species of reef sharks in the Cook Islands whose populations have noticeably declined in the last few decades. Photo by David Hannan.

Within the last 20 years or so, reef sharks have not been on the menu because of the fear of ciguatera poisoning, however their populations have not noticeably increased. The contribution of overfishing by foreign fishing vessels to their population decline is unlikely given that reef sharks stay close to the coast, and these vessels are not allowed to fish within 24 nautical miles of islands, particularly in the southern group. Interestingly, pelagic fishers on the islands of Mauke, Mitaro, and Aitutaki have been complaining recently about shark populations increasing and becoming a nuisance because they take the catch with their expensive lures. However, the sharks noted by fishermen were large — almost the entire length of their canoes (discussed in *Section 3.4.3.2*) — suggesting they are pelagic species that should be unaffected by ciguatera poisoning; their increase may suggest a shift in hunting grounds, possibly a result of a loss of their normal pelagic food sources.

3.3. CLIMATE CHANGE IMPACTS

Indeed, examples of climate change impacts in the marine environment have been reported extensively in the literature. Some of these impacts have contributed to the degradation of coral reef ecosystems worldwide. These included the loss of corals through bleaching events associated with elevated ocean temperatures, coral diseases, cyclones, and the slow onset of ocean acidification. Also, these impacts are expected to increase considering the Intergovernmental Panel on Climate Change's projections in the next 50 to 100 years. Because our marine environment is a major attraction for tourism, a degraded reef would also have detrimental impacts to the Cook Islands economy. A degraded reef would also increase the incidence of ciguatera poisoning, which renders reef fishes unusable to local communities (Lehane & Lewis, 2000; see *Section 3.2.4.*). In this report, we propose that changes appearing to be consistent throughout the Cook Islands are certainly not attributed to local impacts on individual islands, but are driven by regional and global climate effects. While there is a large body of literature regarding the impacts of climate change to marine ecosystems, very little of these studies come from remote parts of the Pacific and much of our understanding of these areas are largely drawn from models derived from a few studies.

3.3.1. Sea level rise

Sea level rise is a consequence of climate change, and low-lying atolls in the Pacific region such as the Marshall Islands are predicted to be under water within this century. Mean sea level trends across the Pacific vary significantly (e.g., Australian Bureau of Meteorological & CSIRO, 2011). In Rarotonga, where sea level trends have been monitored by the National Oceanic and Atmospheric Administration since 1991, sea level has risen by around 3.8 mm per year based on data from 1993 to 2003. This rise is similar to the global average of 3.2 mm, but lower than those recorded in the western Pacific such as Palau at 9 mm, Marshall Islands at 7 mm, and Niue at 5 mm (see Australian Bureau of Meteorological & CSIRO, 2011). Yet, we have little information available regarding the impacts of sea level rise in the *pa enua.* Obvious indicators of sea level rise is the advancement of the sea towards land noted on Aitutaki, Rarotonga, Rakahanga, Penrhyn, and Manihiki (Figure 32), which is causing coastal erosion.

Figure 32. Inundation of coastal areas noted on Manihiki. Photos by Rangi Johnson.

Other indicators of sea level rise noted in Rakahanga and Mitiaro were the loss of salt crystals that used to form on reef flat areas during extreme low tides. In the past, these salt crystals were important for seasoning food and especially for preserving sun-dried fish in these islands, considering the infrequent visits by supply ships that bring salt. Interestingly, it was also suggested that the duration of low tides are shorter than 'normal'. While much of the fishing in the *pa enua* are carried out on the reef flat during low tide (e.g., *tākiri pātuki* [bamboo rod fishing for cods; Figure 33] and gleaning for snails and other invertebrates), a shorter low tide would limit people's access to these resources. In support, local fishers on Mauke and Mangaia have suggested that extreme low tide events referred locally as *tai tu`a* are no longer common. During the *tai tu`a,* the reef crest is exposed, which essentially prevents any water exchange between the reef flat and ocean. As a result, reef fishes can be trapped in tide pools and for Mauke and Mangaia, the *tai tu`a* presents an opportunities for easy fishing. With this information, we note that the impact of sea level rise span beyond just the well-being of our coasts, but also impinge on issues relating to food security.

Figure 33. *Takiri pātuki* (bamboo rod fishing for cods) on the reef flat of Rarotonga. Photo by Teina Rongo.

3.3.2. Oceanographic changes

Deep sea fishers on all islands in the southern group and also on Manihiki and Rakahanga in the northern group are indicating that currents are getting stronger and unpredictable. This change is problematic particularly for deep sea fishing methods like 'drop-stone' used for catching *`a`ai* (yellowfin tuna) and *mangā* (snake mackerel). According to some fishers, strong currents would prevent the hook and line from reaching the target species because the current would push the line towards the surface. In addition, stronger currents experienced in the *pa enua* perhaps contributed to the noted shift towards surface trolling for pelagic species using powered boats. On some islands, an outboard motor is attached to the traditional *vaka* to cater for trolling as well (Figure 34). Consequently, this shift in fishing method can be costly for those in the *pa enua,* considering the price and availability of fuel.

Figure 34. A Mangaian outrigger canoe fitted with an outboard motor to enable trolling activities. Photo by Mitchell Tutangata.

A major change noted for both the northern and southern groups is the apparent build-up of sand in the lagoon and foreshore areas due to increased sediment transport. Such changes can have both positive and negative impacts. For example, sand build-up along the coast of Avarua Harbour on Rarotonga has increased the aesthetic appearance of the area and provided easier access to the water by paddlers who frequently use this site to launch their outrigger canoes. On the contrary, it was indicated that sand build-up in Rakahanga between *motu* Te Kainga (small islet) and the main island likely caused the reduction of ocean and lagoon water exchange; according to residents the state of the lagoon is worse today than before. Poor circulation in the Rakahanga lagoon may have contributed to hypoxic conditions reported in 1997 and also in 2008, where mass die-off of marine life in the lagoon occurred (N. Takai, pers. comm.). Sand build-up was also observed on Manihiki, where sand banks are closing the opening between islets, limiting ocean and lagoon water exchange in these areas (Figure 35). On some islands, increased sediment transport was blamed for the decline of some fisheries. For example, subsistence fishers in Rarotonga, Aitutaki, and Mangaia are attributing the decline in octopus catch to high sedimentation in the lagoon; sand has filled the burrowing holes of octopus that fishers usually revisit on their fishing trips. On Rarotonga, some suggested that the loss of *kuku* (winged mussels) beds in the lagoon were also the result of high sedimentation.

Figure 35. Newly formed sand banks between some *motu* (islets) in Manihiki on the southern exposure are reducing ocean and lagoon water exchange in the area. To the right of the sand bank is the reef flat on the ocean side, and to the left is the lagoon.

Drivers of sand build-up in lagoons and foreshore areas mentioned above may be attributed to several factors, including changes in ocean currents and human activities. For example, foreshore development, harbor improvements, seawall construction, and dredging of lagoon areas can free sediments to be transported. Also, given that reefs on some islands in the Cook Islands have been degraded by *taramea* outbreaks, coral bleaching, and increased bioerosion (e.g., grazing by urchins), the production of sand may be accelerated. Alternatively, sand build-up has been suggested as the result of reefs keeping up with sea level rise. For example, a study by Webb & Kench (2010) found that out of 27 atoll islands in the central Pacific, 23 islands have gained more land areas along the coast; they suggested this may indicate that reefs are able to keep up with sea level rise.

Consequently, the increased frequency of cyclones in the last few decades may have exacerbated the transport of sediment on islands. Residents have observed sand banks frequently appearing and disappearing in recent years. Interestingly, a recent study has shown a more pronounced strengthening of the Pacific trade winds since the IPO shifted into the negative phase (England et al., 2014). Such changes will certainly influence sediment transport in our region that may also explain some of the changes noted above (i.e., stronger currents, rougher sea conditions). It is also likely that the strengthening of the trade winds in combination with sea level rise may also explain the observed shorter low tide duration and the loss of salt crystals on reef flats (see *Section 3.3.1*).

3.3.3. Ocean acidification

The ocean absorbs around 30% of carbon dioxide (CO_2) released into the atmosphere. Consequently, with more CO_2 going into the atmosphere, more is taken up by the ocean. With more CO_2, the ocean will become more acidic, decreasing the availability of carbonate ions needed by calcifying organisms like corals, clams, and crustaceans (e.g., crabs and lobsters) to make their skeleton (Kleypas et al., 1999; Hoegh-Guldberg et al., 2007; Veron, 2011). Although there is limited information available on the impact of ocean acidification on coastal ecosystems to date, studies have shown that increased CO_2 in the ocean – especially at levels projected for the middle and the end of this century – can reduce fertilization and settlement success of reef-building corals (Albright et al., 2010), which is problematic for small island nations considering the goods and services these ecosystems provide. Although we are unsure of the effects of ocean acidification in the Cook Islands, perhaps we are already witnessing some of its impacts. For example, Rarotonga's long-term coral reef monitoring is suggesting that reef recovery has been slow compared with previous recovery events (Rongo et al., 2009b). On the island of Manihiki in the northern group, pearl farmers are noticing that oyster shells are getting thinner and deformities in harvested pearls are becoming common (K. Kora, pers. comm.). With some important food clams, especially the *pa`ua* (*Tridacna maxima*), their numbers have substantially declined throughout the Cook Islands. Understanding the impact of ocean acidification through research will be critical because it has greater economic and food security implications, given that limited carbonate ions in the ocean will certainly have adverse effects on coral reefs and the goods and services this important ecosystem provides.

3.3.4. Coral bleaching

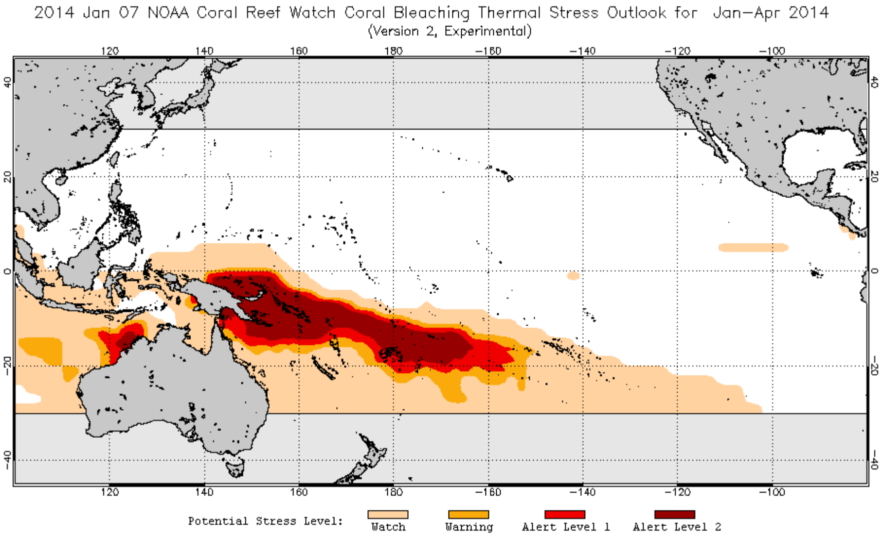
Coral bleaching is the response of corals to elevated temperatures and to high levels of irradiance (Glynn, 1993; Goreau & Hayes, 1995; Brown, 1997; Nakamura & van Woesik, 2001). According to some researchers, the intensity and frequency of coral bleaching is expected to increase because of climate change (e.g., Hoegh-Guldberg, 1999). In the Cook Islands, coral bleaching has only been reported in Rarotonga, Manuae, and Aitutaki in the last few decades (Goreau & Hayes, 1995, Rongo et al., 2005; Rongo and van Woesik, 2013). First anecdotal reports of bleaching were from Aitutaki in 1987, due to an extreme low tide event and stagnant conditions in lagoon areas (Goreau & Hayes, 1995). Subsequent bleaching events were reported in 1991 and 1994 from Aitutaki and Rarotonga, which resulted in a massive die-off of corals in the lagoon and on the fore reef (Goreau & Hayes, 1995). Because corals on Aitutaki and Rarotonga (where monitoring has been conducted intermittently) have been depauperate for the last ten years – following a *taramea* (crown-of-thorns starfish; *Acanthaster planci*) outbreak that killed off over 70% of corals particularly on the fore reef between the 1990s and 2000s – it has been difficult to monitor bleaching events.

Indeed, coral bleaching has certainly been more apparent on at least Aitutaki and Rarotonga in the last 20 years. Interestingly, some fishers have also noticed that branching corals are becoming less common and encrusting and small massive type corals appear to dominate today. This observation is consistent with Loya et al. (2001), who suggested that increased bleaching events will shift coral communities from the branching types (faster growth rate) to more massive types (slower growth rate). Considering that climate change is causing sea level to rise, corals communities that are slow-growing may not be able to keep up with such changes.

Although previous bleaching events in Rarotonga in 1998, 2006, and 2009, were associated with extreme low tides (Rongo and van Woesik., 2013) (Figure 26), sometimes bleaching events are due to regional ocean warming (Figure 27). For example, during the CCCI team's visit to Aitutaki in April 2014, there was an extensive bleaching event that affected coral communities in the lagoon and reef flat areas (Figure 28). This bleaching event was even evident from the plane, especially on the reef crest zone where numerous large coral colonies extend over a vast area. Interestingly, revisiting the same site five months later, bleached corals on the reef crest appear to have made a full recovery (see Figure 28), giving hope for the future of coral reefs in the face of climate change. Corals on the reef crest area seem resilient to elevated temperatures, tolerant to solar irradiance, and may be spared from *taramea* infestations as high wave action in this habitat would dislodge *taramea* from corals. Therefore, this habitat may play an important role as refugia for coral reefs and should be protected.

Figure 26. Coral bleaching from an extreme low tide event in Avarua, Rarotonga in 2009. Photo by Teina Rongo.

Figure 27. Sea surface temperature anomaly for the Pacific region indicating areas of potential bleaching activities. Black circle area indicates the southern Cook Islands. Taken from: http://coralreefwatch.noaa.gov/satellite/bleachingoutlook/



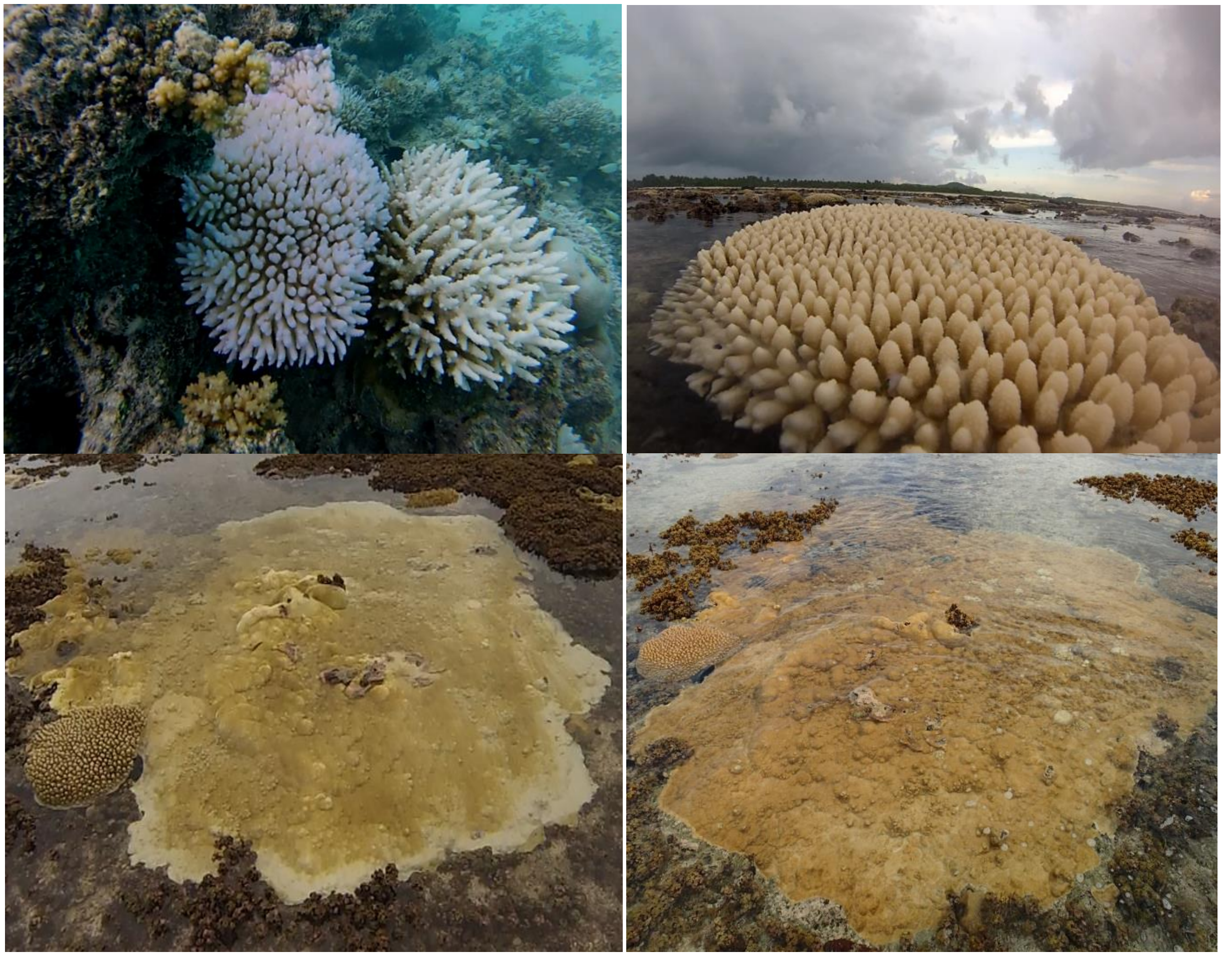


Figure 28. Corals in the Aitutaki lagoon and reef crest area east of the Aitutaki runway. *Top left*: bleached colonies of *Acropora* spp. in the lagoon (taken in April 2014). *Top right*: bleached colony of *Acropora humilis* on the reef crest (taken in April 2014). *Bottom left*: partially bleached colony of *Acropora palmerae* on the reef crest (taken in April 2014), and the same colony (*bottom right*) showing full recovery five months later (taken in September 2014). Photos by Teina Rongo.

3.3.5. Changes in reef health

Information on the health of coral reefs in the Cook Islands are limited, especially on the more remote islands in both the northern and southern islands. Rarotonga and Aitutaki are the only islands where several reef surveys have been conducted intermittently by the National Environment Service, the Ministry of Marine Resources, and independent researchers. Generally, these surveys are conducted on fore reef habitats around the island, where several sites are identified to give some estimate reef health. The surveys examined coral communities, fish communities, algal communities, and other invertebrate communities (e.g., urchin, sea cucumbers, and clams). Often percent coral cover has been used as indicators of reef health; higher cover indicates good reef health while lower cover indicates poor reef health.

The fore reefs of Rarotonga have experienced several disturbances over the last few decades. Perhaps the most important disturbance was *taramea* outbreaks that decimated coral cover. In the 1970s, Devaney & Randall (1973) reported the first known *taramea* outbreak on Rarotonga, Aitutaki, and Penrhyn, which coincided with a Pacific-wide outbreak (Sapp, 1999). The second *taramea* outbreak was recorded in the 1990s for Rarotonga and Aitutaki. Between 1995 and 2001, the *taramea* outbreak on Rarotonga reduced coral cover from around 30% recorded in 1994 (Miller et al., 1994) to around 5% in 2003 (Lyon, 2003), and to < 5% recorded in 2006 following five Category 4 & 5 cyclones (Rongo et al., 2006) that impacted Rarotonga in 2005 (Figure 29). By 2009 and 2011 (Rongo et al., 2009b; Rongo and van Woesik, 2013), coral reefs around Rarotonga showed signs of recovery, and coral cover increased to approximately 17% in 2014 (Rongo et al., in prep.; see Figure 29).

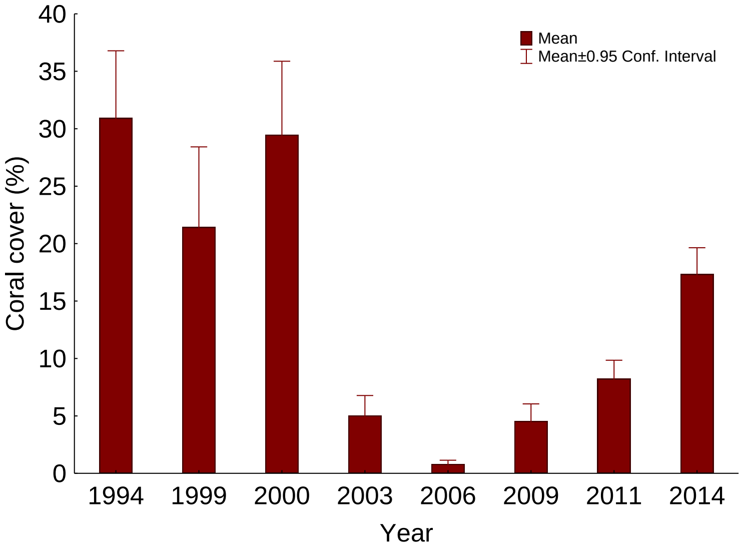


Figure 29. Mean percent coral cover from several sites around Rarotonga. Data taken from surveys conducted by the National Environment Service (Miller et al., 1994; Lyon, 2000; 2003; Rongo et al., 2006; 2009), Ministry of Marine Resources (Ponia et al., 1999), independent researchers (Rongo and van Woesik, 2013), and Climate Change Cook Islands (Rongo et al., in prep.).

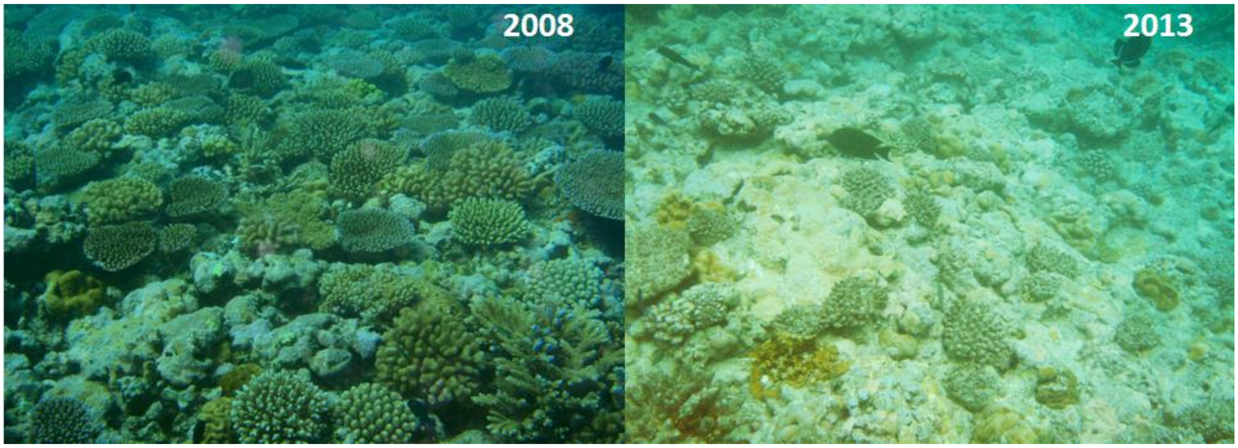


Figure 30. Aitutaki fore reef coral community before and after a *taramea* (crown-of-thorns starfish; *Acanthaster planci*) outbreak.

In Manuae, extensive areas of coral on the fore reef were destroyed by what appeared to be a yellow-band disease (Rongo et al., 2013). This was the first time a disease of this extent was recorded in the Cook Islands. Because Manuae is located about 100 km southeast of Aitutaki, Rongo et al. (2013) suggested that this disease could be the result of the poor water quality and reef condition on Aitutaki that may be influencing the neighboring island of Manuae. Alternatively, elevated temperatures as a result of global climate change have been suggested to favor bacteria growth that would increase the prevalence of coral disease globally (e.g., Kushmaro et al, 1998; Toren et al, 1998). Although climate change is the likely culprit for coral disease on Manuae, given that the island is uninhabited, it is important that this problem is investigated through research, to determine the extent of coral disease in the Cook Islands and what we can do to manage this.

Figure 31. *Left*: Coral disease noted on the fore reef of Manuae in the southern group that resembled a yellow-band disease. *Right*: Large area of corals that were killed off by the disease and overgrown by turf algae. An extensive area on the north to the northeastern exposure of the island was affected by this disease. Both photos are of an *Astreopora* coral species. Photos taken from Rongo et al., 2013.

3.4. OTHER CHANGES

3.4.1. Changes associated with air temperature variations

Along with drought conditions experienced in the southern Cook Islands particularly for much of the 1980s and the 1990s, this was also a cooler period. Interestingly, there were anecdotal reports of hail storms occurring in Mangaia and to a lesser extent Rarotonga. For example, a hail storm on Mangaia in 2003 caused extensive damage to taro plantations on the island (T. Tangatavavia, pers. comm.). This particular hail storm lasted about 10 minutes, producing golf ball-sized pieces that turned the area white and melted after 20 minutes or so. This cooler period associated with the positive phase of the IPO/PDO also had an effect on the crops and vegetation on Mangaia. In particular, apple trees introduced to the island during this cooler period bore fruits with sizes comparable to those imported from New Zealand. On the contrary, mango trees on Mangaia never bore fruit during this period.

In recent years, residents of Mangaia have noticed the opposite effect happening; apple trees are no longer fruiting while mangoes trees are now fruiting for the first time. While warm conditions that was expected for the southern group because of the recent shift to the negative phase of the IPO/PDO in the latter 2000s may be contributing to changes mentioned above, this may also support the poleward warming associated with anthropogenic-driven climate change. In the context of climate change, Mangaia – being the southernmost island in the Cook Islands where conditions are naturally cooler in comparison with the other islands – could very well be experiencing conditions that are now ideal for mangoes and not apples.

3.4.2. Terrestrial environment

3.4.2.1. Introduced trees

Some increases noted in various plant species were due to introduction. For example, coconut and mango trees have increased in Rarotonga because more have been planted and introduced respectively. The introduction of the pine (*Pinus radiata;* Figure 36) and acacia (*Acasia auriculiformis*) trees in the 1980s (following the collapse of the citrus and subsequently the pineapple farming) not only for the purpose of controlling erosion but also for potential commercial uses, have now become the most dominant canopies on Atiu, Mangaia, and to a lesser extent Mauke. In addition, the introduction of these trees has been blamed for the water shortages experienced on these islands. Though the contribution of pines to groundwater extraction through evapotranspiration is not known for these islands, a recent study by Fan et al. (2014) in subtropical Australia showed that pine trees extracted twice the amount of water when compared with native trees. Considering that pine trees on these islands are largely growing in catchment areas, suggest a likely contribution to groundwater extraction. However, we suggest that the frequent drought conditions associated with the positive IPO/PDO phase present a more compelling argument. We note that the introduction of pine and Acasia trees coincided with the 1976/77 shift to a drier period for the southern group. Therefore any future plans to remove these trees must take into consideration the recent shift in the IPO/PDO to a presumably wetter period for the southern group, given the erosion problems of the 1970s to the 1980s that was observed on Mangaia and Atiu.

Figure 36. Pine trees (*Pinus radiata*; background in Mangaia) and acasia (*Acasia auriculiformis*; insert from Atiu) are the most dominant canopy on Mangaia and Atiu. Photo by Eruera Nia.

3.4.3. Marine environment

3.4.3.1. Changes in pelagic fisheries

Overfishing represents the greatest threat to marine fish stocks globally (Hutchings and Reynolds, 2004; Jackson et al., 2001; Pauly et al., 2002), and management of fish stocks has been the focus of marine resource managers today. Indeed, there seem to be a disparity between regional fisheries data and those collected in this survey. On one hand, fisheries data suggest that the status of tuna stocks (with the exception of big-eye tuna) remain healthy. In contrast, conservationists have suggested a decline in all pelagic fish stock over time. Because much of our knowledge on pelagic fish stocks in the Cook Islands come from the fishing companies themselves, it is important that information from each island is forth-coming as well because it may help us understand the influence of commercial fishing efforts and other factors (i.e., climatic regimes) on the availability of these resources to local fishers. The Ministry of Marine Resources recently began recording information on artisanal fishing for almost all the islands, yet the issue remains in that we have limited historical records of this type available to understand the trends of pelagic fish stocks over time.

The distribution and the migration of pelagic fish species have been linked to multiple climate variability in the Pacific. In particular, ENSO strongly influences the longitudinal migration of skipjack tuna through the transport of warm water in the region (e.g., Lehodey et al. 1997), which therefore dictates the aggregation of macrozooplankton and micronekton that are their major food source. Based on catch data for skipjack tuna, catch rates were higher in the western Pacific during La Niña years while catch rates increased toward the east during El Niño years (see Bell et al., 2011 and references therein). For this reason, the availability of tuna in the Cook Islands is expected to fluctuate at an inter-annual time scale in response to ENSO. In addition, tuna availability can also be influenced by climate variability at the decadal scale. For example, Maunder & Watters (2001) have shown that the recruitment of yellow-fin tuna decreased during the negative phase of the PDO and increased during the positive phase in the eastern Pacific.

Although the distribution of tuna is likely influenced by climate variability in the Cook Islands, clearly there is an overall decline in all pelagic species throughout the Cook Islands based on the interviews conducted. In the northern group, elders shared stories of their catch 30 to 50 years ago; the size and quantity of their catch was bigger and more in comparison to what has been caught in recent years (Figure 37). For example, a fisherman in Rakahanga indicated that yellowfin tuna with heads too big to fit into a 200-litre drum were often caught using the drop-stone method (P. Ropati, pers. comm.), which is a story that would be seen as an exaggeration today. Yellowfin and skipjack tuna were abundant in the past, and time spent fishing was much shorter when compared with today. Furthermore, pelagic fishes were often caught close to land where at times the reef bottom was visible from a canoe (P. Toto, pers. comm.). However today, powered boats are used and fishing has become costly due to fuel usage, especially as fishers need to venture further away from land to fish.

Figure 37. Smaller yellowfin tuna are frequently caught throughout the Cook Islands in recent years when compared with the past. Photo taken by Teina Rongo from Manihiki in 2014.

Although we may be witnessing a decline in pelagic fish stocks in the Cook Islands due to shifts in climate phases that influence fish migration away from this region, we also need to consider that other contributing factors are likely, mainly overfishing. Based on the interviews from this survey, there was a general consensus that licensed foreign fishing vessels in the Cook Islands are the culprit for the decline in pelagic fish stocks. In the last 12 years, the number of foreign vessels licensed to fish within the Cook Islands' Exclusive Economic Zone has increased. To date, 70 vessels have been licensed to fish in the Cook Islands (40 of which are purse seiners), and this number is expected to rise due to the high demand of this fishery on a global scale.

3.4.3.2. Changes in shark populations

According to residents, reef shark populations in the southern group have seen a decline in the last 30 years. However, in recent years, fishermen in Mauke, Aitutaki, Atiu, and Mitiaro have noted an increase in unusually large sharks. Interestingly, some were not reef sharks but were oceanic sharks, and a satellite tag was seen on one of them in Mitiaro. Several fishers in Aitutaki complained of these large sharks attacking their catch and taking their expensive lures in the process. In Mauke, fishers noted that sightings of hammerheads and grey reef sharks have become more frequent in recent years. In Mitiaro, sharks longer than the traditional fishing canoes were reported; sharks have become a nuisance during *māroro* (flying fish) runs as they cause extensive damage to scoop nets.

There are several reasons that may explain the increase in shark sightings on these islands: 1) oceanic sharks are feeding near coastal areas because their food source in the open ocean may be depleted, 2) local fishers are encountering more sharks because they now have powered vessels allowing them to cover more area and venture further away from the islands, 3) improved fishing methods implemented by foreign commercial fishers (i.e., fishing deeper) have been effective to avoid sharks as by-catch, and 4) perhaps we are already seeing the result of the recently declared shark sanctuary (in 2012, the Cook Islands waters were declared a shark sanctuary by regulations under the Marine Resources Act [2005]; minimum fines of NZD $100,000 and maximum of NZD $250,000 per offence have been implemented to deter people from catching them).

There have been suggestions presented in the media and also in our survey to introduce shark culling to deal with this perceived increase in their numbers. Whether shark numbers are indeed increasing in the Cook Islands is a question that needs to be answered through research. Sharks play an important role in keeping our ocean's ecosystems in balance, and better information is needed before considering taking drastic management actions.

3.4.3.3. Changes in spawning and recruitment activities

Some have suggested that the frequency and the occurrence of spawning aggregation have declined among some important food fish. For example, *māroro tu* (flying fish aggregations; Figure 38) in the *ngaputoru* islands (Mauke, Atiu, and Mitiaro), which occur from around July to October, are not as frequent as in the past. For Atiu and Mauke, this is believed to have disappeared, and Mitiaro is the only island where large aggregations of *māroro* are still observed and traditionally fished by locals. According to fishers on Atiu, Mauke, and Mitiaro, the use of motorized boats may have contributed to the disappearance of the *māroro tu* on the islands except for Mitiaro, where motorized boats are prohibited for this event and canoes are used. However, it is difficult to confirm this as the main cause of the loss of the *māroro tu*, especially when fishing of *māroro* on Mauke and Atiu have declined though there are reports that *māroro tu* still occurs on these islands.

Figure 38. *Māroro* (flying fish; *Cheilopogon* spp.) is an important food fish in the Cook Islands. Photo by Teina Rongo.

In Manihiki, fishers are indicating that important food fishes that aggregate in large numbers for spawning have declined substantially. For example, the *paremo* (*Epinephalus merra*), *`hāpuku* (*Epinephalus polyphekadion*), and *tihitihi* (*Zanclus cornutus*) (Figure 39) that are normally caught around July to September, have now become very infrequent. In addition, large seasonal recruitment of the parrotfish *tōmore (Scarus* juvenile of perhaps *S. schlegeli*; see Figure 39*)* that are also important food fish on Manihiki are also recruiting much less in recent years. *`Hāpuku* has also seen a decline on the island of Penrhyn where spawning aggregations occur during the month of June to July. Although these species are caught before spawning and this practice has been passed down from generation to generation, changes on the islands such as the introduction of refrigeration, improved connectivity to other islands, and improved fishing methods likely contributed to the collapse of this fishery. However, considering that declines in the frequency of seasonal pulse recruitment of *ika tauira* in all reef fish species throughout the Cook Islands may suggest that overfishing may not be the only factor influencing this change. For example, rabbitfish (*mōrava* and *maemae*), surgeonfish (several species of *maito*), and goatfish (*kōma* and *takua*), the most common seasonal recruits in the southern group, have now declined substantially according to fishers.

It is not known why recruitment of reef fishes have declined throughout the Cook Islands, but several reasons could be argued. Perhaps reduced rainfall in the last few decades that supply nutrients into the marine environment has reduced the growth of the preferred food seaweed for some reef fishes. Alternatively, unpalatable types of seaweeds such as *Asparagopsis taxiformis* have seen an increase on the fore reefs of Rarotonga in the last few decades (Rongo & van Woesik, 2013). Also, stronger currents (as suggested by fishers) and the increased strength of trade winds (England et al., 2014) may also limit the recruitment of reef fishes. In support, it has been suggested that highly turbulent conditions can increase the mixing and dispersive properties of ocean flow, which can compromise the retention of marine larvae to local reefs (e.g., Sponaugle et al., 2002).

Figure 39. Important food fishes reported in the northern islands, whose spawning aggregations or large recruitment that occur from May to July have become infrequent in recent years. *Top left*: *paremo (Epinephalus merra)*, which aggregates for spawning. *Top right: tōmore* (*Scarus schlegeli*), which recruit in large schools. *Bottom left*: *hapuku* (*Epinephalus polyphekadion*), which aggregates for spawning. Photos from Randall (2005). *Bottom right*: *tihitihi* (*Zanclus cornutus*), which aggregates for spawning. Photo taken by Gustav Paulay.

3.4.3.4. Pa`ua

The *pa`ua* (giant clam; *Tridacna maxima;* Figure 40) is perhaps one of the most sought out invertebrates in the Cook Islands. In the 1970s to the 1980s in Aitutaki, large amounts of *pa`ua* that would fill several 200-litre drums would be harvested for visiting groups from neighboring islands to take back as gifts. Regularly, *pa`ua* was also making its way to families and friends in Rarotonga from Aitutaki for much of this period well into the 1990s. Similarly, *pa`ua* in the northern group was experiencing the same level of exploitation.

While the Ministry of Marine Resources and local island governments placed a ban on the exportation of *pa`ua* from Aitutaki in recent years, and also with some level of management for islands in the northern group, the current status of *pa`ua* according to our survey raises some concerns. For instance, Aitutaki, Manihiki, and Penrhyn have seen a dramatic decline in *pa`ua* numbers over the years. In Rakahanga and Pukapuka (through anecdotal reports), *pa`ua* today is hard to find. Although overfishing is the likely cause of this decline given that the only island with a healthy population is the uninhabited island of Manuae (Rongo et al., 2013; though visitors have noticed a decline in *pa`ua* here as well), the contribution of other factors cannot be ruled out. For example, impacts of climate change such as changes in ocean currents (e.g., Hobday et al., 2006), ocean acidification (e.g., Kleypas et al., 1999; Kleypas & Langdon, 2006; Hoegh-Guldberg et al., 2007), and elevated ocean temperature (e.g., Munday et al., 2008; Ruttenberg et al., 2005) can reduce connectivity, recruitment, and survival of marine populations respectively. In Rakahanga, poor flushing of the lagoon due to the buildup of sand in the main drainage passages on the island created unfavorable conditions (i.e., hypoxic condition) in the lagoon that resulted in the massive die-off of *pa`ua*, *parau*, and other invertebrates (N. Takai, pers.com). Thus, it is likely that a combination of factors may be operating here and research is needed to understand what contributions, if any, do climate change have on the decline of this important food resource.

Figure 40. High densities of *pa`ua* (*Tridacna maxima*) still observed on Manuae, whereas *pa`ua* density on most of the Cook Islands are very low. Photo taken by Teina Rongo in 2013.

4. SUMMARY

Indeed, local knowledge obtained from surveying island communities in the Cook Islands about changes in their environment was proven useful for validating climate science. The hydroclimatic shift in 1976/77 associated with the IPO/PDO was perhaps the most important driver of changes noted by island residents. Rainfall data for both the northern and southern group clearly indicated this decadal-long hydroclimatic shift, which had contrasting effects between the island groups. In addition, increased sediment transport, rougher ocean conditions, stronger ocean currents, and shorter low tide durations were all confirmation of the well-documented global sea level rise, and perhaps of the strengthening of the Pacific trade winds in recent decades associated with the shift in IPO/PDO reported in the literature.

Declines in the recruitment levels of marine fauna were noted throughout the Cook Islands. This is a concern with regards to food security because the replenishment of fish stocks will be compromised. In addition, the decline in pelagic fish stocks also noted throughout the Cook Islands is a concern, and managers need to take these observations seriously considering that we lack historical information on these fisheries, and offshore commercial pelagic fishing activities are expected to increase in the future for the Cook Islands.

Because some changes noted in this survey could not be explained with the limited information available, this clearly suggests the need for more research in this region to help elucidate changes that are climate-related and those that are human-induced as management differs accordingly. But most importantly, we have found that decadal-long climate shifts associated with the IPO/PDO are critical for infrastructure strategies and resource management planning. For example, considering the recent shift in the IPO/PDO where the northern group would experience less rainfall, certain measures need to be taken to minimize the adverse impacts (e.g., water shortages) this shift may have on island communities there.

It appeared that most of the information collected was restricted to resources that are of some value to residents, and other changes may not have been recorded as a result. Furthermore, more information could have been collected from the north if sufficient time was given to carry out the survey there. Indeed, information collected justifies the need for a more comprehensive survey to be carried out throughout the Cook Islands. The loss and the decline of species noted in this survey are of interest; we need to understand the extent of climate-driven changes in the Cook Islands particularly in regard to its impact on biodiversity. With regards to marine biodiversity, such information can be useful for effective management efforts that can be integrated into the newly declared Cook Islands Marine Park management plan.

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APPENDIX

Appendix A. Questionnaire survey used to record local knowledge in the Cook Islands on changes in the natural environment.

1. Have you heard of climate change?
2. Rank your understanding of climate change on a scale of 0 – 10 (10 being good).
3. Do you think that we are vulnerable to climate change impacts (e.g., cyclones, drought)?
4. Do you feel that outside assistance, such as financial support, is critical for us to cope with the impacts of climate change?
5. Is there a need to increase the awareness of climate change?
6. What seasonal resources on your island have you noticed have changed (e.g., fruiting season, spatial distribution) and how?
7. Do you know of any plant or animal on both land and sea that have declined or increased in abundance? If so, please indicate a time period when this happened.
    - Marine
    - Land
8. Have you noticed any climatic changes (e.g., rainfall, temperature) on your island?
    - Pre-1980s
    - Post-1980s
9. Have you noticed any oceanographic (e.g., currents) or tidal changes in the marine environment?
    - Pre-1980s
    - Post-1980s

GLOSSARY

Anthropogenic	refers to environmental pollution or pollutant produced by or the result of human activities.
ENSO	ENSO (El Niño Southern Oscillation) refers to the effects of a band of sea surface temperatures (SST), which are anomalously warm or cold for long periods of time that develops off the western coast of South America and causes climatic changes across the tropics and subtropics. The "Southern Oscillation" refers to variations in the temperature of the surface of the tropical eastern Pacific Ocean (warming and cooling known as *El Niño* and *La Niña*, respectively) and in air surface pressure in the tropical western Pacific.
El Niño	the warm phase of the El Niño Southern Oscillation that occurs every two to seven years.
La Niña	the cold phase of the El Niño Southern Oscillation that occurs every two to seven years.
IPO	Interdecadal Pacific Oscillation (IPO) displays similar sea surface temperature and sea level pressure patterns as ENSO, with phases shifts occurring every 15 – 30 years, affecting both the north and south Pacific.
PDO	Pacific Decadal Oscillation (PDO) is a pattern of Pacific climate variability similar to ENSO in character, but which varies over a much longer time scale. The PDO can remain in the same phase for 20 to 30 years, while ENSO phases typically only last 6 to 18 months.
Ciguatera poisoning	a type of sea food intoxication that results from the consumption of reef fishes that have inadvertently ingested ciguatoxin-producing dinofagellates.
Ciguatoxins	refers to a host of toxic compounds implicated in ciguatera poisonings.
Dinoflagellates	a group of mobile, microscopic algae that have the ability to also attach to reef surfaces. Most are marine plankton, but they are common in freshwater habitats as well. Toxin-producing dinoflagellates are the main culprit in ciguatera poisonings in many tropical countries.
Hydroclimatic shift	in this report, this refers to shifts in rainfall patterns at the decadal scale.
Ocean acidification	the term given to the chemical changes in the ocean as a result of carbon dioxide emissions. This change makes the ocean more acidic, thus reducing the availability of carbonate ions in the ocean which is needed by hard-shelled organisms like clams and corals to build their skeleton.
Bioaccumulate	refers to the accumulation of substances, such as pesticides or other organic chemicals, in organisms at a rate greater than that at which the substance is lost.
SPCZ	South Pacific Convergent Zone (SPCZ) is a band of low-level convergence, cloudiness, and precipitation extending from the Western Pacific Warm Pool at the maritime continent south-eastwards towards French Polynesia and as far as the southern Cook Islands (20°S 160°W).