Pacific Community
Communauté du Pacifique

INTERNATIONAL COURT OF JUSTICE

Request for an Advisory Opinion on Obligations of States in respect of Climate Change

Expert Report for the Government of the Kingdom of Tonga prepared by the Pacific Community (SPC)

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Acknowledgements

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I. INTRODUCTION AND EXPERTISE

The Pacific Community (SPC) supports Pacific countries and territories with scientific and technical solutions to address the region's greatest challenge, climate change. SPC is one of the Pacific region's scientific and technical intergovernmental organisations working alongside its Pacific Island country and territory (PICT) members[1] to understand and develop effective solutions to the challenges they face. In this case, SPC's core technical abilities to provide the objective science behind observed impacts of the adverse effects of climate change experienced by Tonga will further substantiate its state submission.

SPC's mandate and work programme addresses the many facets of climate change and its impacts on the region, including but not limited to, marine ecosystems, fisheries,[2] coastal hazards, and human rights protections.[3] Additionally, SPC is the regional lead for the implementation of many climate change mitigation and adaptation programmes, including on sea level rise as well as loss and damage, and it sustainably manages Pacific maritime zones, ecosystems, and resources from 'ridge to reef' for current and future generations.[4] Its expertise in global and regional analyses of the impacts of climate change on the marine environment led to its inclusion in the advisory opinion proceedings at the International Tribunal for the Law of the Sea in Case No. 31.[5]

SPC is also a consultative and advisory body to participating governments in matters affecting the economic and social development of its members within its scope, and the welfare and advancement of their peoples.[6] SPC sustainably manages social and environmental risks and impacts of all its activities in an inclusive manner, with a people-centred approach to maximise whole-of-society benefits. SPC is committed to openness and transparency, maintaining the highest ethical standards, and, as such, the statements contained in this report are factually correct and materially complete.

II. METHODOLOGY

Tonga requested this expert report to include the full scope of climate-related losses and damages experienced, including environmental, human health, socio-economic, and cultural impacts. From this request, several of SPC's largest and most relevant divisions provided the necessary science to put

[1] SPC has 27 members, including 22 PICTs: American Samoa, Cook Islands, Federated States of Micronesia, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Nauru, New Caledonia, Niue, Northern Mariana Islands, Palau, Papua New Guinea, Pitcairn Islands, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu and Wallis and Futuna.

[2] Note that, under the United Nations Convention on the Law of the Sea (UNCLOS), fishing is singled out among the legitimate uses of the sea that are negatively affected by pollution ('pollution of the marine environment means the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities), UNCLOS, 10 December 1982, 1833 United Nations Treaties Series (U.N.T.S.) 397 (entered into force 1 November 1994) at Article 1(1)(4).

[3] Article IV, §§ 6-10, of the Canberra Agreement establishing the South Pacific Commission (U.N.T.S., vol. 97, p. 227).

[4] For the full range of SPC's implementation for mitigation and adaptation programming, *see* Pacific Community Strategic Plan 2022–2031 (available at: https://purl.org/spc/digilib/doc/uzzya).

[5] *See* Request for an Advisory Opinion submitted by the Commission of Small Island States on Climate Change and International Law (Request for an Advisory Opinion submitted to the Tribunal).

[6] See note 3 at para. 6.

together this report, compiled by an international lawyer with a scientific background to ensure proper competencies.[7]

The science captured in this expert report builds upon the best available science, including the Sixth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC).[8] It covers climate impacts that have already been observed as well as those currently occurring, like cyclones and other natural disasters, extreme weather events, marine environment degradation, and others.

It concludes that (i) PICTs like Tonga are highly vulnerable to the impacts of anthropogenic climate change, (ii) Tonga has already experienced significant harm as a result of anthropogenic climate change, and (iii) future losses and damages are bound to occur, with the extent of future harm depending on actions taken to avert, minimise, and address such losses and damages.

III. CLIMATE CHANGE–RELATED IMPACTS

Small island developing states, due to their geographical circumstances and level of development, are specially affected and particularly vulnerable to the adverse effects of climate change. For Tonga, these well-documented harms include, but are not limited to, extreme weather events (heat drought, precipitation, etc.); sea-level rise, shoreline change, and coastal inundation (waves); extreme weather events; ocean warming, acidification, and deoxygenation; water security; food security; displacement; and cultural loss.[9] These impacts are described under the progression of time and corresponding increased temperature projections, and where possible, the climate impacts likely to occur at 2.8°C—the level of warming projected to occur if nationally determined contributions (NDCs) submitted under the Paris Agreement are fully implemented.[10]

Tonga is extremely vulnerable to the adverse effects of climate change because of its geographical, geological, and socio-economic features. Tonga is also sensitive to severe natural events (volcanic eruption, seismic activity, etc.) which are likely to become worse with the ongoing climate crisis. Of particular concern are climate change impacts of increasing sea-level rise and associated coastal inundation and erosion; increasing intensity of extreme weather events such as tropical cyclones; and sea surface temperature effects on coral reefs.

Sea-level rise

Climate change–induced sea level rise is an existential threat to archipelagos such as Tonga, which include high volcanic islands, elevated limestone islands, and low-lying atolls. Tonga consists of 176 islands, of which 36 are inhabited, with approximately 85% of the population living in rural areas. The sea-level rise near Tonga as measured by satellite altimeters has been over 6 millimetres (mm) per year since 1993, which is double the global average of 3.2 ± 0.4 mm per year, with even higher estimates in

[7] SPC's relevant divisions include Human Rights and Social Development (HRSD), Geoscience Energy and Maritime (GEM), Fisheries, Aquaculture and Marine Ecosystems (FAME), Land Resources Division (LRD), and Climate Change and Environmentally Sustainability (CCES) programme.

[8] Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2022: Impacts, Adaptation, and Vulnerability*. Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, 2022 (available at: https://report.ipcc.ch/ar6/wg2/IPCC_AR6_WGII_FullReport.pdf).

[9] *See mainly*, McGree, Simon, Grant Smith, Elise Chandler, Nicholas Herold, Zulfikar Begg, Yuriy Kuleshov, Philip Malsale and Mathilde Rittman, SPC. *Climate Change in the Pacific 2022: Historical and recent variability, extremes and change.* Chapter 14 'Tonga'; and Gillett, Robert and Fong, Merelesita 2023. Fisheries in the economies of Pacific Island countries and territories (Benefish Study 4). Noumea, New Caledonia: Pacific Community. 704 p. https://purl.org/spc/digilib/doc/ppizh. SPC also received further data from experts at the Secretariat of the Pacific Regional Environment Programme (SPREP) in consultation with the Government of Tonga.

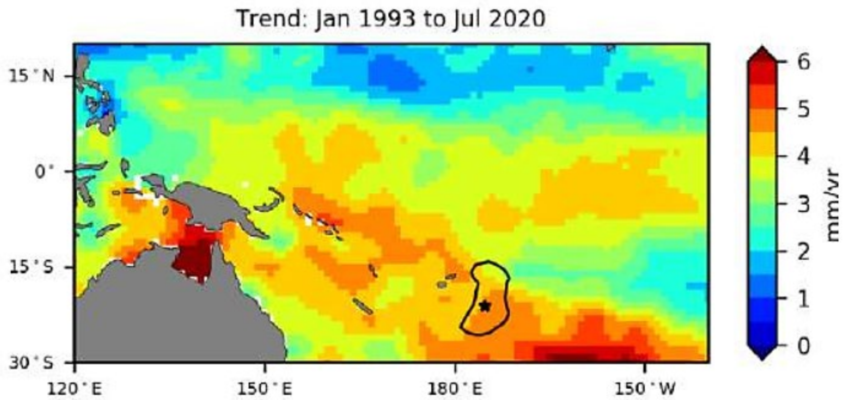
[10] Additional information on historical climate trends for Tonga can be found in the Pacific Climate Change Data Portal, available at http://www.bom.gov.au/climate/pccsp.

the south (see Table 1).[11] For Nuku'alofa, the trend is even higher at 6.6 mm per year, significantly higher than altimetry trends shown in Figure 1. This difference is largely attributed to subsidence (land sinking) occurring at Nuku'alofa.[12]

Table 1. Decadal increments for projections of sea level rise in metres (m) for Tonga relative to the 1995–2014 mean sea level.[13]

Year	*Low* SSP1-2.6	*Intermediate* SSP2-4.5	*High* SSP3-7.0	*Very High* SSP5-8.5	*Very High - Low* SSP5-8.5 H+
1995–2014	0.00	0.00	0.00	0.00	0.00
2020	0.07 (0.05–0.10)	0.07 (0.04–0.10)	0.07 (0.04–0.10)	0.07 (0.05–0.10)	0.08 (0.05–0.11)
2030	0.14 (0.10–0.18)	0.13 (0.10–0.17)	0.13 (0.09–0.18)	0.14 (0.11–0.19)	0.15 (0.10–0.22)
2040	0.19 (0.14–0.25)	0.20 (0.15–0.25)	0.20 (0.15–0.27)	0.22 (0.17–0.28)	0.22 (0.16–0.35)
2050	0.26 (0.20–0.34)	0.28 (0.22–0.36)	0.29 (0.23–0.38)	0.31 (0.24–0.40)	0.32 (0.24–0.51)
2060	0.33 (0.25–0.43)	0.35 (0.28–0.46)	0.38 (0.30–0.49)	0.41 (0.33–0.53)	0.43 (0.32–0.71)
2070	0.40 (0.31–0.53)	0.44 (0.35–0.58)	0.49 (0.38–0.63)	0.53 (0.41–0.69)	0.56 (0.41–0.96)
2080	0.46 (0.35–0.62)	0.54 (0.42–0.71)	0.60 (0.47–0.79)	0.66 (0.52–0.87)	0.72 (0.52–1.25)
2090	0.53 (0.40–0.72)	0.63 (0.49–0.84)	0.73 (0.57–0.96)	0.81 (0.64–1.07)	0.90 (0.64–1.59)
2100	0.60 (0.44–0.83)	0.73 (0.54–0.99)	0.88 (0.66–1.17)	0.97 (0.76–1.29)	1.11 (0.76–1.93)
2110	0.69 (0.49–0.96)	0.83 (0.59–1.15)	0.99 (0.69–1.35)	1.10 (0.80–1.50)	1.31 (0.80–2.28)
2120	0.76 (0.53–1.06)	0.93 (0.66–1.29)	1.13 (0.79–1.54)	1.25 (0.91–1.71)	1.55 (0.91–2.60)
2130	0.82 (0.57–1.16)	1.02 (0.72–1.43)	1.26 (0.88–1.73)	1.39 (1.01–1.92)	1.81 (1.01–3.38)
2140	0.89 (0.61–1.26)	1.11 (0.78–1.57)	1.40 (0.97–1.92)	1.53 (1.11–2.12)	2.09 (1.11–4.46)
2150	0.95 (0.65–1.36)	1.21 (0.84–1.70)	1.53 (1.06–2.11)	1.66 (1.20–2.32)	2.41 (1.20–5.63)

Figure 1. Satellite altimetry annual trend for the Pacific from 1993 to 2020 with Tonga's exclusive economic zone (EEZ) highlighted in black.[14]



Pacific Island countries are experiencing sea-level change that exceeds that of global rates, particularly for Tonga, which is subject to seismic activity. Consistent with the AR6 assessment, rates for Tonga are high, dominated by rapid short-term changes during seismic events followed by a period of readjustment.[15] The highest sea levels typically occur in the months of December to April. Additionally,

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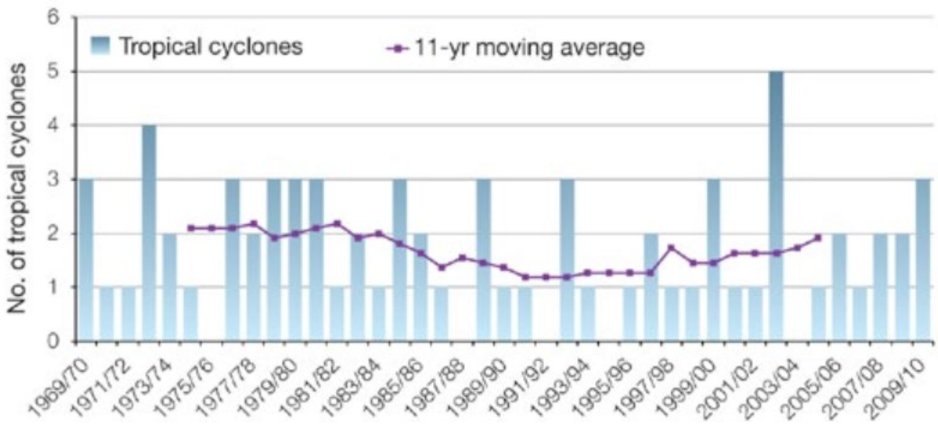
[11] McGree et al., *Climate Change in the Pacific 2022.* Chapter 14 'Tonga'.
[12] Brown, N. J., Lal, A., Thomas, B., McClusky, S., Dawson, J., Hu, G., and Jia, M. 2020. Vertical motion of Pacific Island tide gauges: combined analysis from GNSS and levelling. Record 2020/03. Geoscience Australia, Canberra. http://dx.doi.org/10.11636/Record.2020.003.
[13] Graphic taken from *Pacific Regional Infrastructure Facility (PRIF) (2021): Guidance for managing Sea Level Rise Infrastructure Risk in Pacific Island Countries*, 2021. Projections based on IPCC (2021) sourced from AR6 and interpolated to nearest decade and adjusted for the upper bound of the most *likely* vertical land movement defined by Fox-Kemper et al. (2021).
[14] Figure from McGree et al., *Climate Change in the Pacific 2022.* Chapter 14.8.2 'Trends', 182. The star symbol indicates the location of the Nuku'alofa tide-gauge.

[15] *PRIF*, 47.

the top ten sea-level events on record occurred from December to March and at least half of these were associated with tropical cyclones, indicating the importance of weather events in contributing to sea-level extremes (see Graph 1).

Graph 1. Number of tropical cyclones passing within 400 km of Nuku'alofa per season.[16]



Shoreline change and coastal inundation (waves)

King tides, which typically occur a few times a year, are generally considered a proxy for the extent of permanent exposure to sea-level variation. For Tonga, the land and infrastructure near the coastal margin are highly susceptible to the impacts of sea-level rise and will feel its impacts earlier than other PICTs.[17] In 2015, the eastern areas of Tongatapu Island were already identified as harmed and vulnerable to coastal erosion and inundation, with several villages in need of extra protections. The Trialling Coastal Protection Measures in Eastern Tongatapu project used different engineering methods to protect coastal areas, including through construction of offshore breakwaters, beach replenishment, and coastal planting. These measures served to protect nearly 4000 people living in the adjacent coastal area from storms and storm surges.[18]

Tonga experiences a semidiurnal tidal cycle, meaning two high and two low tides per day. The highest predicted tides of the year typically occur during the wet season months of December to February. Projected climate change and sea-level rise also affects the groundwater via saltwater intrusion and loss of land from coastal erosion or flooding associated with climate extremes.[19] Extreme wave analysis completed for Nuku'alofa was done by defining a severe height threshold and fitting what is known as a generalized Pareto distribution (GPD)—a two-parameter distribution that is often used to model the tail of a distribution beyond a certain threshold; it is particularly useful to show that an individual extreme event (such as a severe wave) can be quantified by an observable measure (such as sustained wave height over intervals). The optimum threshold selected was 2.95 m. In the 42-year wave hindcast, 169 wave events reached or exceeded this threshold, averaging four waves per year.[20] The GPD was

[16] Figure adapted from McGree et al., *Climate Change in the Pacific 2022.* Chapter 14.6.1 'Tropical cyclones', 179. The 11-year average is presented as a purple line and considers all years.
[17] *PRIF*, 49.
[18] Kingdom of Tonga, Voluntary National Review (VNR) 2019 at 49, available at https://sustainabledevelopment.un.org/content/documents/23588Kingdom_of_Tonga_Voluntary_National_Review_2019_Report_web.pdf.
[19] Pacific Adaptation to Climate Change, Kingdom of Tonga Report of In-country Consultations, para. 62, p. 21, available at https://www.sprep.org/attachments/Climate_Change/PACC_Report_of_in-country_consultations_Tonga.pdf.
[20] Extreme wave analysis is a useful tool but is not always accurate because the analysis is sensitive to the data available, the type of distribution used, and the threshold to which it is fitted. For example, the analysis does not accurately account for tropical cyclone waves that reach greater heights and over shorter intervals.

fitted to the largest wave height reached during each of these events (Table 2). Modelling such as this is useful for designing coastal infrastructure and hazard planning.

Table 2. Summary of the results from extreme wave analysis in Nuku'alofa of wave events that have occurred since 1979.[21]

Large wave height (90th percentile)	1.90 m
Severe wave height (99th percentile)	2.97 m
1-year ARI wave height	4.46 m
10-year ARI wave height	8.80 m
20-year ARI wave height	10.76 m
50-year ARI wave height	14.02 m
100-year ARI wave height	17.11 m

Extreme weather events

On average, Nuku'alofa experiences 17 tropical cyclones per decade (recall Graph 1 and see also Graph 2), with the majority occurring between November and April—Tonga's wet season. The high interannual variability in the tropical cyclone numbers makes it difficult to identify long-term trends in frequency.[22] Nevertheless, global evidence shows that the economic damage caused by cyclones is long-lasting and cumulative.[23] For example, Tropical Cyclone Gita, a Category 5 cyclone that hit Tonga in February 2018, caused widespread damage to basic public infrastructure, livelihoods, and living facilities, many of which are still under reconstruction and recovery to this day.[24]

Communities in Tonga also face varying and increasing threats from natural disasters and climate change, including an increase in the strength and frequency of tropical cyclones.[25] Ha'apai and Tongatapu both experienced multiple Category 4 (and above) cyclones within the past ten years, with increasing impacts from storm surges.[26] These direct impacts to communities not only damage infrastructure and increase risks to safety, and to human life, but also weaken the health of marine habitats and marine resources, threatening the food security and subsistence of families living in coastal areas, reducing their resilience.

For example, Special Management Areas (SMAs) are part of a community-based fishery programme in Tonga, where designated communities are granted legal rights to manage their coastal fishery resources. Findings from the household survey conducted in SMA communities from February to March 2021 were collected and evaluated for socio-economic impacts and community perception of SMAs. In total, 275 household surveys were conducted that provide insights into community-focused, socio-economic impacts of climate change (see Table 3). This data also shows community perception of climate change impacts, how often they occur, and the degree to which they feel prepared to handle climate-related

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[21] Table from McGree et al., *Climate Change in the Pacific 2022*, Chapter 14.1.1 'Current Climate', 216.
[22] McGree et al., *Climate Change in the Pacific 2022*, Chapter 14.9.3 'Extreme waves', 184.
[23] United Nations Capital Development Fund (2020), Economic impacts of natural hazards on vulnerable populations in Tonga, available at https://www.uncdf.org/article/6318/climate-risk-insurance-literature-reviews, 5.
[24] Voluntary National Review, 49.
[25] Tropical cyclone data and historical tracks starting from the 1969/1970 season are available from the Southern Hemisphere Tropical Cyclone (SHTC) Data Portal, http://www.bom.gov.au/cyclone/tropical-cyclone-knowledge-centre/history/tracks/.
[26] Household survey of Special Management Area communities in Tonga: Assessment for the monitoring and evaluation of the SMA programme, 2, available at https://purl.org/spc/digilib/doc/zj35s.

hazards. It shows that these harms are occurring now, are observable, and that the loss and damage communities feel have long-lasting consequences.

Table 3. Households that have experienced natural and climate-related hazards and the coping ability of the household.[27]

Climate-related hazard	No. of households that have experienced impacts in last five years	No. of # households with little or no ability to cope	Percentage of households that have experienced hazards
Cyclones	187	118	63
Drought	149	86	58
Changes in rainy/dry season	133	81	61
Coastal erosion	101	74	73
Saltwater intrusion	82	67	82
Sea level rise	84	64	76
Flooding	78	57	73
Coral bleaching	56	46	82
Increased sea surface temperature	44	29	66

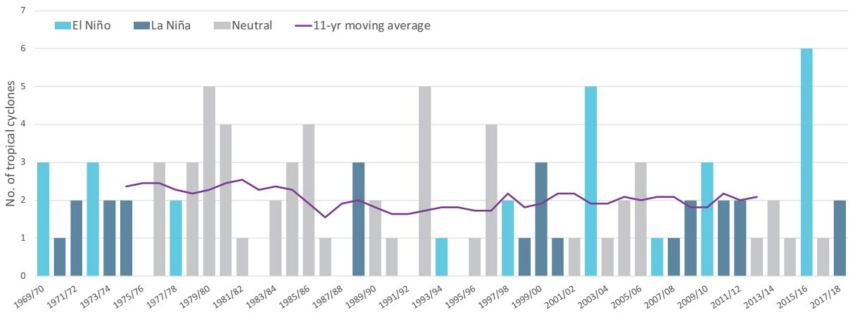
Tropical cyclones usually affect Tonga during the southern hemisphere tropical cyclone season, which is from November to April, but they also occasionally occur outside the tropical cyclone season. The Southern Hemisphere Tropical Cyclone archive indicates that between the 1969/1970 and 2017/2018 seasons, 101 tropical cyclones passed within Tonga's EEZ (refer to Graph 1).[28] This represents an average of 21 cyclones per decade. Tropical cyclones were most frequent in neutral years (23 cyclones per decade, shaded in grey), followed by El Niño years (20 per decade, shaded in light blue), and least frequent in La Niña years (17 cyclones per decade, shaded in dark blue).[29] Gross domestic product loss due to the frequency and intensity of cyclones occurring will certainly increase and adversely affect vulnerable aspects of nature and community into the future.

Interannual variability in the number of tropical cyclones in the EEZ is large, ranging from zero in some seasons to six in 2015/2016 and five in 1979/1980, 1992/1993, and 2002/2003 (see Graph 2 and Map 1). High interannual variability and the small number of tropical cyclones occurring in the EEZ make reliable identification of long-term trends challenging.[30] However, extensive data does exist for the loss and damages caused by previous extreme weather events that have had lasting impacts on Tonga. For example, severe Tropical Cyclone Gita damaged over 4000 homes and destroyed over 800, causing the evacuations of over 4500 people and left more than 80% of homes without power. The economic damages alone were estimated at US$164 million, equivalent to 38% of Tonga's total gross domestic

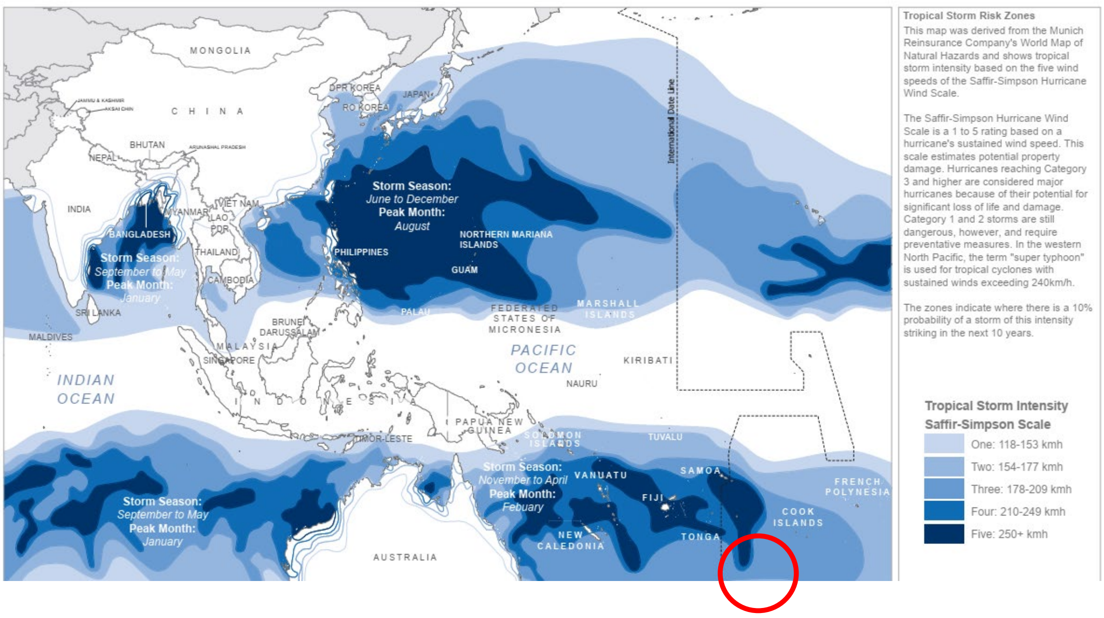
[27] Table from the Household survey of Special Management Area communities in Tonga, note 26, 24.
[28] McGree et al. *Climate Change in the Pacific 2022.* Chapter 14.6 'Tropical cyclones', 179.
[29] *Ibid*., Chapter 14.6.1 'Seasonal cycle'.
[30] Records of tropical cyclones exist from the late 1800s in some countries in the Southwest Pacific, but trends in tropical cyclones have only been presented from 1981/1982. Satellite-based observations began in the Southwest Pacific in the early 1970s, but consistent coverage and reliable intensity estimates have only been available since the early 1980s. Confidence in tropical cyclone trends is moderate as the definition of a tropical cyclone has changed, and satellite observation methods have continued to improve over the last 40 years. Tropical cyclone data and historical tracks starting from the 1969/1970 season are available from the SHTC Data Portal http://www.bom.gov.au/cyclone/history/tracks/index.shtml.

product (GDP).[31] Dealing with the damage of even a single cyclone—whether labelled as severe or not—puts a lot of strain on small island developing states like Tonga. Additionally, after severe storms, governments are often still recovering when other storms hit. This cycle makes even the smallest storms feel severe as people are still rebuilding homes, fixing power, and recovering from previous damages—particularly in Tonga where they have had to deal with volcanic eruptions as well as cyclones. This cycle can be endless and difficult to manage when GDPs are consistently redirected towards disaster relief.

Graph 2. Number of tropical cyclones passing within Tonga's EEZ per season as defined by El Niño–Southern Oscillation (ENSO) status.[32]



Map 1. Tropical storm risk for Tonga showing it sits in the highest intensity pathway for the Southern Pacific.[33]



[31] Australian Department of Foreign Affairs and Trade, Crisis Hub, *Tropical Cyclone Gita*, 19 June 2018 (accessed 4 February 2024) available at: https://www.dfat.gov.au/crisis-hub/cyclone-gita.
[32] A light blue line indicates an El Niño year, dark blue a La Niña year, and grey a neutral ENSO year. The 11-year moving average is presented as the purple line and considers all years.
[33] Map from the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), *Asia-Pacific: Tropical Storm Risk,* available at: https://reliefweb.int/map/world/asia-pacific-regional-hazard-map-tropical-storm-risk.

Ocean warming, acidification, and deoxygenation

Monthly average ocean temperature, as measured by the Nuku'alofa tide-gauge, ranges from 23°C in August to 27.5°C in the months of February/March.[34] However, there are individual months in January to March that can reach as high as almost 30°C (see Figure 2). Hourly temperatures can be up to 3°C higher or lower than these monthly averages, although 50% of hourly observations fall within 1.5°C of the average. Altogether, the sea surface temperature (SST), as per satellite observations, is increasing by 0.27°C per decade (Figure 3).

Figure 2. Annual temperatures measured at the Nuku'alofa tide-gauge.[35]

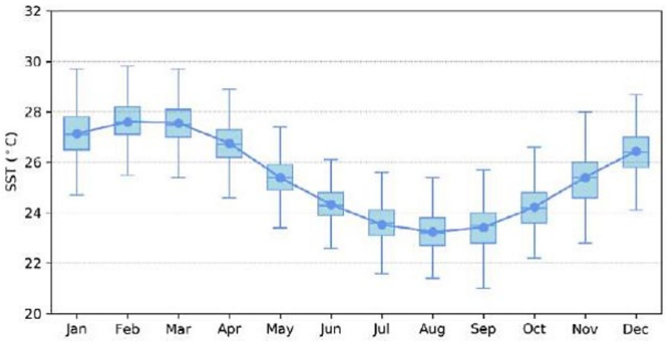
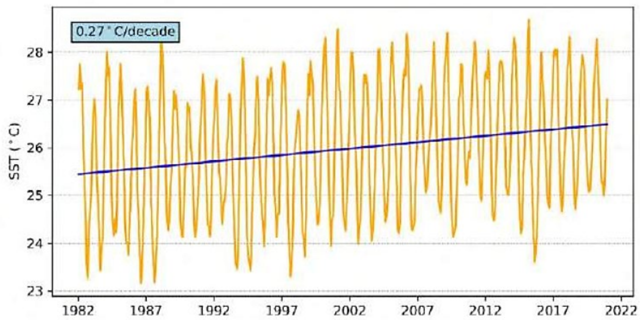


Figure 3. Sea surface temperature from satellite observations averaged across Tonga's EEZ.[36]



The long-term averages are expected to result in sustained increases in SST and ocean acidification (see Table 4). Under climate change, variations due to the ENSO will have a major influence on the abundance of tuna in Tonga's EEZ. The projected changes to the key features of the tropical Pacific Ocean surrounding Tonga relative to the long-term averages are expected to result in increases to SST, sea level, and ocean acidification (see Table 4). Changes to ocean currents and reductions in nutrient supply are also expected to occur.[37]

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[34] Tide-gauge data were sourced from the Nuku'alofa tide-gauge station, which dates back to 1988 at hourly intervals.
[35] Figure from McGree et al., *Climate Change in the Pacific 2022*, 14.7.1 'Sea surface temperature', 180. Blue dots show the monthly average and shaded boxes show the middle 50% of hourly observations. Lines show the top and bottom 25% of hourly observations.
[36] *Ibid*. The orange line depicts the averages, and the blue line indicates the linear regression trend (average temperature rise since 1982).
[37] Bell J.D., Johnson J.E., Ganachaud A.S., Gehrke P.C., Hobday A.J., Hoegh-Guldberg O., Le Borgne R., Lehodey P., Lough J.M., Pickering T., Pratchett M.S., Waycott M. 2011. *Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change: Summary for Pacific Island Countries and Territories*. Chapter 2.19. Secretariat of the Pacific Community, Noumea, New Caledonia (2017). https://purl.org/spc/digilib/doc/tns8k.

Table 4. Projected changes to key ocean features surrounding Tonga over time.[38]

Ocean feature	1980–1999 average	Projected change			
		B1 2035	A2 2035	B1 2100*	A2 2100
Sea surface temperature (°C)	25.9[a]	+0.6 to +0.8	+0.7 to +0.8	+1.2 to +1.6	+2.2 to +2.7
Sea level (cm)	+6 since 1960				
IPCC **		+8	+8	+18 to +38	+23 to +51
Empirical models ***		+20 to +30	+20 to +30	+70 to +110	+90 to +140
Ocean pH (units)	8.08	-0.1	-0.1	-0.2	-0.3
Currents	Increase in South Pacific gyre	Continued increase in strength of South Pacific gyre			
Nutrient supply	Decreased slightly	Decrease due to increased stratification and shallower mixed layer			< -20%

* Approximates A2 in 2050; ** projections from the IPCC-AR4; *** projections from recent empirical models {Chapter 3, Section 3.3.8}; a = average for EEZ derived from the HadISST dataset.

Food security: Coastal fisheries

In Tonga, coastal fisheries annual catch was estimated to be 6500 tonnes, worth US$17.5 million. The projected change to coastal fisheries catch reflects the very high reliance on demersal fish—or fish that live and feed on or near the bottom of seas and occupy the ocean floors. Additionally, existing coastal fish habitats in Tonga are vulnerable to climate change impacts. Tonga has more than 5800 km^2 of coral reefs that support many important fisheries species as well as mangrove and seagrass. Climate change is expected to add to the existing local threats to coral reefs, mangroves, seagrasses and intertidal flats, resulting in declines in the quality and area of all habitats. According to projections (A2—conservative estimates), by 2050, the progressive declines in productivity in demersal fish and intertidal/subtidal invertebrates are due to both direct effects (e.g., increased SST) and indirect effects (e.g., changes to fish habitats) of climate change (see Table 5).

Table 5. Projected changes to coastal fish habitat.[39]

Habitat feature[a]	Projected change (%)		
	B1/A2 2035	B1 2100*	A2 2100
Coral cover[b]	-25 to -65	-50 to -75	> -90
Mangrove area	-30	-70	-80
Seagrass area	-5 to -10	-5 to -20	-10 to -20

* Approximates A2 in 2050; a = no estimates in reduction of intertidal flats available; b = assumes there is strong management of coral reefs.

[38] Table from *Ibid*. 239. Updates to AR6 expected later this year.
[39] *Ibid*. 242.

Tonga's fishing industry is a key sector for economic growth, so protecting it from the adverse effects of climate change is critical to sustainability. Coastal communities continue to rely on subsistence fishing. Both inshore and offshore fishing are in fair and stable condition. However, climate change in Tonga poses a severe threat to coastal fisheries and aquaculture sectors, in turn affecting food and nutrition security, local livelihoods and the national economy. More severe extreme weather events, rising sea levels, increasing water temperature, and ocean acidification, are expected to have profoundly negative effects on the status and distribution of coastal habitats, and the fish and invertebrates they support. As a result, the productivity of coastal fisheries and aquaculture will decline**.**

Coastal fisheries in Tonga are already impacted by climate variability and change. Recent sea temperature increases around Tonga's coastal waters have caused widespread coral bleaching and increased algal blooms.[40] The variability of fishing yields and fish stocks has already increased as a consequence of extreme climatic events. When rain falls intensively over a short period, increased overland flow and runoffs smother and poison intertidal and subtidal areas, affecting ecosystem health, fisheries productivity, and threatening important food sources.[41] In fact, an assessment of the vulnerability of reef-dependent communities to the effects of ocean acidification on food security and livelihoods from fishing, aquaculture and tourism found that communities in Tonga were among the most vulnerable in the Pacific.[42]

Food security: Pelagic fisheries

Tuna is greatly impacted by climate change for a range of reasons. Shifts in biogeographical distribution indicate a loss of suitability of habitats due to changes in the biophysical environment such as increases in water temperature and a decrease in oxygen concentration. Since tuna are migratory species, they are widely distributed throughout the world's ocean for feeding and spawning purposes; however, the largest portion of the world's tuna catch—upwards of 80%—is found within the western central Pacific Ocean (WCPO). More importantly, the largest portion of this catch is taken within EEZs of PICTs in WCPO, including Tonga.[43] Of this, the most economically important tuna species for Tonga are albacore (*Thunnus alalunga*), bigeye (*Thunnus obesus*), skipjack (*Katsuwonus pelamis*), and yellowfin (*Thunnus albacares*), which account for over 95% of all Tonga's tuna fisheries annual catch.[44]

In relation to food security, fewer than 10% of Tonga's farmers and fishers are commercial producers, meaning that most of Tonga's fisheries are still based on traditional/subsistence fishing systems.[45] Fish is identified as the primary food source for Tongans, and fresh fish consumption in Tonga is one of the highest in the Pacific (80% nationally, 87% for coastal communities).[46] Thus, fishing is critical to household food security in Tonga, not only through subsistence production and income generation

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[40] Food and Agriculture Organization of the United Nations, Joint National Action Plan on Climate Change Adaptation and Disaster Risk Management (JNAP), 2; Tonga Fisheries Sector Plan 2016-2024, available from https://www.fao.org/faolex/results/details/en/c/LEX-FAOC170089/
[41] *Ibid*., 2.
[42] Johnson, Johanna, Johann Bell, and Alex Sen Gupta. (2016) Pacific Islands ocean acidification vulnerability assessment. SPREP, Apia, Samoa, 40.
[43] Vaihola, S., Kininmonth, S., 'Climate Change Potential Impacts on the Tuna Fisheries in the Exclusive Economic Zones of Tonga', *Diversity* 2023, 15(7), 844: 10 July 2023 (accessed 11 February 2024) available at https://www.mdpi.com/1424-2818/15/7/844.
[44] All species data and extracted predictor variables are available in Vaihola, Siosaia (2023), Tonga tuna, Dryad, Dataset available at https://datadryad.org/stash/dataset/doi:10.5061/dryad.nk98sf7xs
[45] Tonga Strategic Development Framework (2015-2025), available at https://policy.asiapacificenergy.org/sites/default/files/TSDF%20II.pdf
[46] Karen E. Charlton, Joanna Russell, Emma Gorman, Quentin Hanich, Aurélie Delisle, Brooke Campbell, and Johann Bell, Fish, food security and health in Pacific Island countries and territories: a systematic literature review. BMC Public Health. 2016,16:285. https://doi.org/10.1186/s12889-016-2953-9.

(which allows food purchases), but also for communities that have limited opportunity to engage in other agricultural or economic sectors to produce food and/or income.

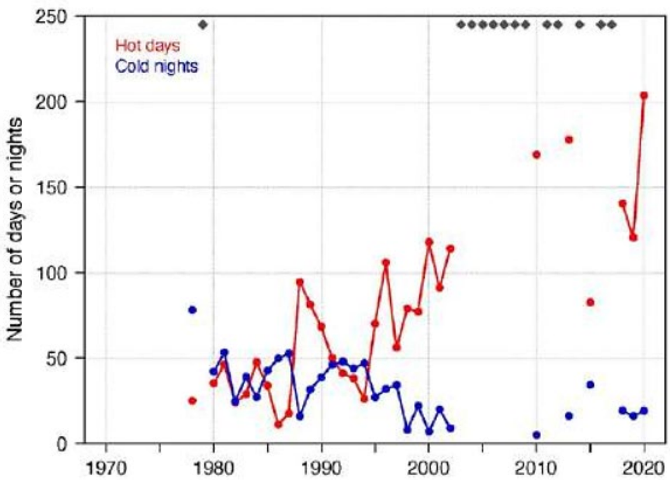
Variabilities in climate, such as global warming and the ENSO, threaten global fisheries production and have negative climate change–related impacts such as increasing regional temperature, changing weather patterns, rising sea levels, ocean acidification, cycling nutrient loads in ocean circulations, increasing stratification of water columns, and changing precipitation patterns. Under these extreme circumstances, environmental stress on primary producers, including changes in tuna spatial and temporal distribution and abundance is acute, resulting in decreased tuna catch over time. Within this context, climate change has serious negative impacts on pelagic fisheries (tuna catch in open ocean) and consequently economic outcomes for Tonga and other PICTs.[47]

Temperature rise

Air temperatures in Tonga are driven by surrounding ocean temperatures. Average annual and seasonal temperatures have increased significantly at Nuku'alofa. Daily minimum temperatures are increasing faster than daily maximum temperatures and November–April temperatures are increasing faster than May–October temperatures.[48] In other words, there has been warming across all months at Nuku'alofa for both maximum and minimum air temperatures between the 1991–2020 and 1961–1990 climatology periods.

Numerous gaps exist in the daily temperature record for Nuku'alofa, which prevents the robust calculation of trends in temperature extremes. Nevertheless, Figure 4 shows that several years since 2010 experienced more than three times as many hot days than at the beginning of the record. This is consistent with the increases in average temperatures and trends in temperature extremes in neighbouring PICTs.

Figure 4. Annual number of hot days and cold nights in Nuku'alofa.[49]



Drought and water security

Tonga relies heavily on groundwater and rainfall as its primary source of freshwater. Droughts caused by the intensification of ENSO events pose significant challenges to Tonga's freshwater supply. With limited rainfall, the replenishment of groundwater slows, making overuse of this vital resource

[47] Note that analysis of the tuna longline fisheries data was double verified by government officials and considered a true representation of catch data in Tonga. SST, sea surface salinity, and sea surface current data were also used as variables within this data set.
[48] McGree et al., Climate Change in the Pacific 2022, Tonga, 14.5.1 'Air temperature', 178.
[49] *Ibid*. Diamonds indicate years with insufficient data for one or both variables.

unsustainable. When extended and severe droughts become more frequent, water scarcity becomes a pressing concern. The 2022 Hunga Tonga–Hunga Ha‘apai eruption also affected clean drinking water supplies and caused water restrictions resulting from volcanic ash.

The Tonga Meteorological Services declared a drought for the islands of Tongatapu and ‘Eua, with alerts for Niuafo‘ou and Niuatoputapu, and warnings for Ha‘apai and Vava‘u just in November of last year.[50] Findings suggest that 90% of the population in remote islands in the Niuas group (Ha‘apai, Vava‘u, etc.) depend on rainwater for drinking,[51] making water security a dire issue for this island group.

Coral reefs and biodiversity

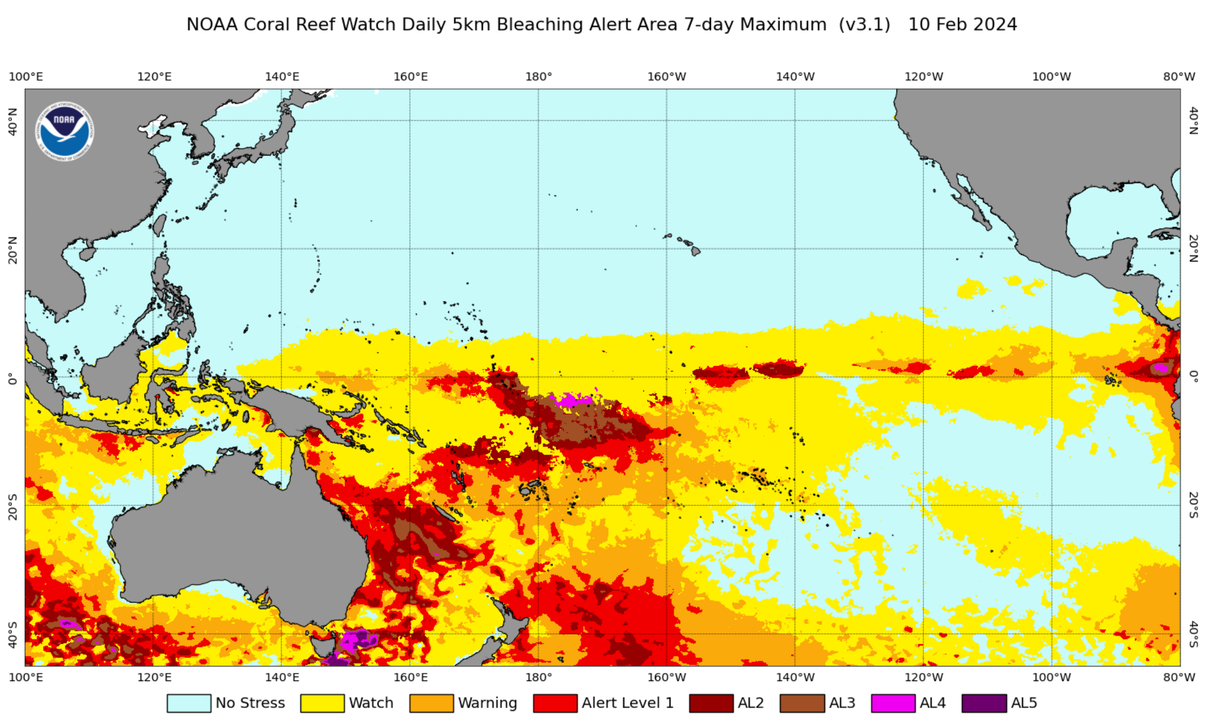
As with many other South Pacific nations, coral reefs in Tonga are increasingly threatened. In the past decade alone, five severe tropical cyclones (Category 4–5) have affected Tonga (Wilma 2011, Evan 2012, Ian 2014, Winston 2015 and Gita 2018), and coral bleaching events were reported in 2012, 2014 and 2016 (personal communication, Vava‘u Environmental Protection Association [VEPA]). Concerns about overfishing and destructive fishing practices have also been raised for decades, with multiple management strategies employed with varying degrees of success.[52]

Coral reef resources are very important to Tonga for income and food security. The coral reefs for each of the islands are impacted as follows:

- Vava‘u – the reefs of Vava‘u are generally sheltered, narrow fringing reefs below limestone cliffs and adjacent to deep (60–100 m) water. Most reefs are likely to have very little current flow and are sheltered from the open ocean and prevailing weather conditions. Reefs in Vava‘u might therefore be more susceptible to impacts from both coral bleaching and local pollution. When reefs are subjected to heatwaves, coral bleaching in more open areas could be limited by flushing from cool oceanic waters, while the geography of Vava‘u would limit flushing and result in pockets of warm water persisting for much longer. Likewise, pollutants from local sources are unlikely to wash away readily given the topography of the islands and instead might persist at greater concentrations. However, limited data are available on current regimes around Vava‘u to investigate this hypothesis.[53]
- Ha‘apai – Many of the sites in northern Ha‘apai are sheltered from the east by the main islands and therefore could also trap pockets of warm water, exacerbating bleaching at a local scale. Conversely, the reefs of Southern Ha‘apai are much more exposed, which might therefore promote flushing by prevailing winds, waves and currents.[54]
- Tongatapu – The reefs in Tongatapu were overall in better condition than anticipated. Coral cover within the main bay was higher than assessed elsewhere, and reef fish richness and density were moderate. These results could be due to the cooler waters in Tongatapu, which might buffer against the large bleaching events which appear to have impacted Vava‘u and northern Ha‘apai (Figure 5).[55]

[50] Kingdom of Tonga, Meteorological Services 2023, https://met.gov.to/.
[51] Kingdom of Tonga, Voluntary National Review 2019, available at https://purl.org/spc/digilib/doc/ffz9t.
[52] Smallhorn-West Patrick, Sophie Gordon, Karen Stone, Daniella Ceccarelli, Siola‘a Malimali, Tu’ikolongahau Halafihi, et al., (2020*), Biophysical and anthropogenic influences on the status of Tonga’s coral reefs and reef fish fishery*. PLoS ONE 15(11). doi:10.1371/journal.pone.0241146
[53] *Ibid*.
[54] *Ibid*.
[55] *Ibid*.

Figure 5. Coral Reef Watch 5 km Bleaching Alert Area



Impacts on marine mammals (particularly humpback whales and turtles)

Tonga's EEZ has a total area of about 700,000 km². There have been 38 species identified as pelagic fish found in both deep sea and coastal zones. Also recorded were 12 species of whales and six species of marine turtles. Humpback whales and bottlenose whales are considered endangered and together with hawksbill turtles are all protected under Tongan legislation.[56]

One of Tonga's most precious marine mammals is the humpback whale: the waters surrounding Tonga are an important mating, birthing and nursing area for a population of around 2000 humpback whales. Each austral winter the whales migrate to the warm waters around Tonga, which is one of the most important overwintering areas for humpback whales in Oceania.[57] Humpback whale populations are still recovering since whaling was banned in the southern hemisphere in 1966 and the species is listed as Least Concern on the IUCN Red List.[58] Vava'u in particular is a humpback whale hotspot and whale watching and swimming with whales has become an important component of Tonga's tourist industry, contributing an estimated US$700,000 to the economy in 2002.[59]

Global warming is predicted to impact habitat suitability in a great part of current breeding grounds in Oceania (including Tonga), based on shifting isotherms toward higher latitudes. Studies suggests that a great part of the currently occupied breeding sites in Oceania might become unsuitably warm for humpback whales by the end of the 21st century. The thermal tolerance displayed by humpback whales

[56] Tonga State of Environment Report 2018, 89, available at https://tonga-data.sprep.org/dataset/tonga-state-environment-report-2018.
[57] Constantine, Rochelle, Jennifer A. Jackson, Debbie Steel, C. Scott Baker, Lyndon Brooks, Daniel Burns, Phillip Clapham et al., "Abundance of humpback whales in Oceania using photo-identification and microsatellite genotyping." Marine Ecology Progress Series 453 (2012): 249-261, available at https://www.int-res.com/articles/meps2012/453/m453p249.pdf.
[58] Cooke, J. G. "Megaptera novaeangliae." The IUCN Red List of Threatened Species (2018). https://www.iucnredlist.org/species/13006/50362794
[59] See note 56, 117.

in Oceania, combined with flexible patterns of habitat use and the great extent of available suitable habitats, suggests an adaptive capacity of these subpopulations on their breeding grounds. In response to global warming, humpback whales risk relocating to areas where other threats are currently unidentified and deserve investigation.[60]

Figure 6: Humpback whales breeding grounds in the Pacific region (including Vava'u, Tonga)[61]

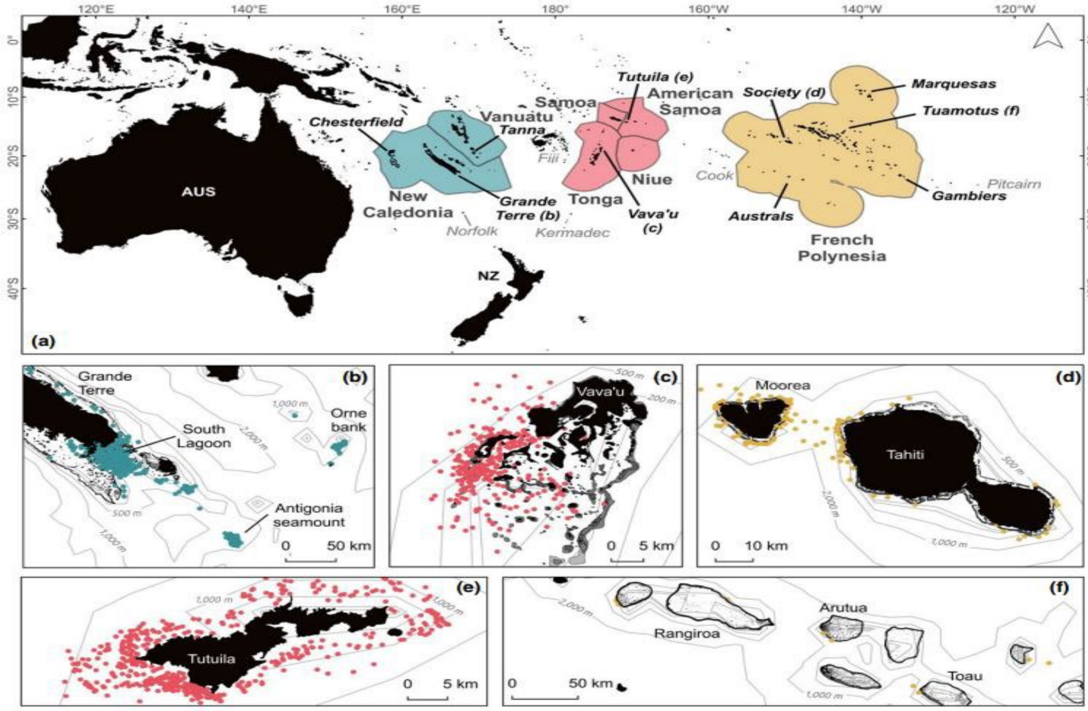


FIGURE 1 Humpback whale breeding grounds and study sites of Oceania. (a) Overview of Oceania with EEZs included in the study represented by colored polygons (from left to right: western, central, and eastern regions). Country names are shown in bold, localities are shown in italics. Other panels zoom in on specific study sites, with land in black, reefs in gray, and presence locations in color: (b) the southern New Caledonia area; (c) Vava'u archipelago in Tonga; (d) Tahiti and Moorea Islands in the Society archipelago of French Polynesia; (e) Tutuila island in American Samoa; (f) Rangiroa atoll in the Tuamotu archipelago of French Polynesia. Isobaths are represented with gray lines [Colour figure can be viewed at wileyonlinelibrary.com]

Turtles are also of particular importance. Turtles live throughout Tonga but the island groups of Ha'apai and Vava'u support the largest populations.[62] All marine turtles recorded from Tonga are listed as threatened on the IUCN Red List.[63]

Climate change affects species and ecosystems around the globe. The impacts of rising temperature are particularly pertinent in species with temperature-dependent sex determination (TSD), where the sex of an individual is determined by incubation temperature during embryonic development. In sea turtles, the proportion of female hatchlings increases with the incubation temperature. With average global temperature predicted to increase by 2.6°C by 2100, many sea turtle populations are in danger of high egg mortality and female-only offspring production. Furthermore, extreme incubation temperatures not only produce female-only hatchlings but also cause high mortality of developing clutches. With rising

[60] Derville, Solène, Leigh G. Torres, Renee Albertson, Olive Andrews, C. Scott Baker, Pamela Carzon et al., Whales in warming water: Assessing breeding habitat diversity and adaptability in Oceania's changing climate, (2018), available at https://library.sprep.org/sites/default/files/2021-07/whales-warning-habitat-diversity.pdf, 10.
[61] Derville et al., Whales in warming water, 4.
[62] Atherton, J. N., S.A. McKenna, and A. Wheatley, 2014. Rapid Biodiversity Assessment of the Vava'u Archipelago, Kingdom of Tonga, https://evols.library.manoa.hawaii.edu/bitstreams/ccc5c85c-3ec0-4687-91ce-c19722c98e43/download
[63] Jensen, Michael P., Camryn D. Allen, Tomoharu Eguchi, Ian P. Bell, Erin L. LaCasella, William A. Hilton, et al., Environmental Warming and Feminization of One of the Largest Sea Turtle Populations in the World, (2018), https://doi.org/10.1016/j.cub.2017.11.057.

global temperatures and most sea turtle populations naturally producing offspring above the pivotal temperature, it is clear that climate change poses a serious threat to the persistence of these populations.

Economic and cultural impacts

Tonga's economy is highly dependent on climate-sensitive sectors like agriculture, fisheries, and tourism, with a limited resource base that is sensitive to external shocks. Vulnerability to extreme weather events not only damages infrastructure, but it also contributes to a population's health challenges. One example of relocation is the original Nui'ui Hospital on Lifuka, located about 18 m from the coastline with an elevation of five m. The hospital was damaged by Tropical Cyclone Ian in 2014 and a new hospital was built inland 1907 m from the coastline at an elevation of 61 m. Renamed the Princess Fusipala Hospital, it serves the population of Lifuka and Foa Islands, approximately 6470 people.

Additionally, the Hunga Tonga–Hunga Ha'apai volcanic eruption and subsequent tsunami waves of 15 January 2022 resulted in the displacement of about 2390 people and 564 households based on data collected to date. About 54.41% of affected households were located in Tongatapu, 30.54% in Ha'apai Islands, and 15.05% in 'Eua.

IV. CONCLUSION

Climate change is causing significant harm to Pacific Island countries, with archipelagic nations such as Tonga being injured and/or specially affected by the adverse effects of climate change. This harm is seen in increasing sea-level rise and ocean temperatures, ocean acidification, coastal erosion, extreme weather events, prolonged drought, and other impacts.[64] Projections indicate that these impacts are bound to intensify with climate change. The extent to which this existential threat materialises will heavily depend on actions taken to curb anthropogenic greenhouse gas emissions—the vast majority of which are generated outside its borders—as well as measures to adapt to climate change and respond to the loss and damage it causes.

[64] *See* SPC, written submission to the Tribunal for the Law of the Sea, 16 June 2023, available at https://www.itlos.org/fileadmin/itlos/documents/cases/31/written_statements/2/C31-WS-2-5-SPC.pdf.