Climate Change in the Federated States of Micronesia

PIRCA | 2023

Indicators & Considerations for Key Sectors

Report for the Pacific Islands Regional Climate Assessment (PIRCA)

EAST-WEST CENTER

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PACIFIC ISLANDS REGIONAL CLIMATE ASSESSMENT

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The Pacific Research on Island Solutions for Adaptation (Pacific RISA) program provided oversight of this PIRCA report. A regional research partnership between Arizona State University, the University of Hawai'i, and the East-West Center, the Pacific RISA is one of 12 National Oceanic and Atmospheric Administration (NOAA) Climate Adaptation Partnerships (CAP). The CAP program network conducts applied research and engagement to expand regional capacity to adapt to climate impacts in the U.S. This work is supported by funding from NOAA.

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Ahnd Atoll, Pohnpei, Federated States of Micronesia. Courtesy of Jez O'Hare

About PIRCA and this Report

Climate Change in the Federated States of Micronesia: Indicators and Considerations for Key Sectors is a report developed by the Pacific Islands Regional Climate Assessment (PIRCA). It is one in a series of reports aimed at assessing the state of knowledge about climate change indicators, impacts, and adaptive capacity of the US-Affiliated Pacific Islands (USAPI) and the Hawaiian archipelago. PIRCA is a collaborative effort engaging federal, state, and local government agencies, non-governmental organizations, academia, businesses, and community groups to inform and prioritize their activities in the face of a changing climate.

The initial phase of PIRCA activities was conducted during June—October 2019 and included meetings and workshops in American Sāmoa, the Republic of Palau, the Commonwealth of the Northern Mariana Islands (CNMI), and Guam. The draft PIRCA report for the Federated States of Micronesia (FSM) was developed and refined through virtual engagement with experts from the PIRCA network in April 2022—March 2023. The material presented in this report is based largely on published research and insights from participants in PIRCA activities. Workshop participants and reviewers independent of the PIRCA workshops who made contributions are recognized as Technical Contributors.

The Pacific RISA program has primary oversight of the 2020—2023 PIRCA, with funding from the US National Oceanic and Atmospheric Administration (NOAA) and support from the East-West Center. Key partners and supporters are NOAA's National Centers for Environmental Information (NCEI), the Department of the Interior's Pacific Islands Climate Adaptation Science Center (PI-CASC), and the US Global Change Research Program (USGCRP).

This series represents the latest assessment in a sustained process of information exchange among scientists, businesses, governments, and communities in the Pacific Islands region that began with the 2012 PIRCA, which produced *Climate Change and Pacific Islands: Indicators and Impacts* (Island Press). We anticipate that in conjunction with other collaborative regional assessment efforts, the PIRCA reports will provide guidance for decision-makers seeking to better understand how climate variability and change impact the Pacific Islands region and its peoples.

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Aboard a traditional Yapese sailing canoe.
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Key Issues for Managers and Policymakers

Increasing air temperatures — Hot days have increased, while the frequency of cool nights has decreased in the Federated States of Micronesia (FSM). Air temperatures will continue to rise under all future warming scenarios.

More extreme rainfall and more intense typhoons — Heavy rainfall events are projected to become more frequent and intense in the FSM, increasing the risk of flooding. Tropical cyclone intensity is also projected to increase, thus higher wind speeds, heavier rainfall, and higher storm surge will be more likely during typhoons.

Sea level rise — Despite natural variability, sea level is rising in the FSM and will exacerbate coastal flooding, storm surge, and coastal erosion.

Infrastructure near coastal areas — Infrastructure design that accommodates or withstands sea level rise, ocean surges, wave action, and tidal flooding is critical for sustainability long-term. Rebuilding or repairing houses and infrastructure near the coast is expensive for communities and governments, and preparedness can avoid costs and lessen this burden.

Severe challenges for atolls — The FSM's numerous low-lying atolls face growing challenges due to climate change. People living on atolls are exposed to increasing coastal inundation and erosion, extreme events, the compound effects of sea level rise on limited freshwater resources, and loss of ecosystem services. Continued habitability of atolls entails significant adaptation responses, especially under higher emissions scenarios.

Traditional knowledge and cultural resources — Collaboration among state agencies (such as Historic Preservation Offices), non-governmental organizations (NGOs), and local community members with traditional knowledge and skills can help maintain cultural values, preserve traditional medicine, bolster food security, and enhance cultural resilience in each state.

Threats to human health — Hotter temperatures and changing rainfall patterns can increase mosquitoes in the environment and lead to more vector-borne disease. Extreme weather events, such as heat waves and typhoons, increase illness, impact infrastructure, and disrupt access to care. Adaptation actions at multiple levels—from individual health to healthcare facilities and public infrastructure—are needed to prepare for and manage health risks in a changing climate.

Migration — Currently, climate-related migration in the FSM is rare. The main drivers for internal and external migration are: employment, education, and healthcare. Increased internal migration and urbanization driven by climate change impacts would put additional stress on limited housing, land, food, water, and other resources. Migration, both at the international level and between islands and states, can be used by families as a climate adaptation strategy. Citizens who migrated out of the FSM for healthcare, education, or better economic opportunities assist their families in the FSM through remittances and non-monetary gifts.

Food security — Preparing for changes in food security can enhance safety and health for communities. Integrating traditional food systems and agroforestry knowledge with modern, "climate smart" interventions reduces the risk of lower agricultural yield while bolstering livelihoods. Fisheries distribution and catch are also expected to experience change. Monitoring these trends, expanding sustainable aquaculture, and reducing pressures to coastal ecosystems are some strategies for adapting to such changes.

Ecosystems and biodiversity — Coastal and nearshore ecosystems, including mangroves and coral reefs, help protect islands and provide other services and resources but are in decline. Combining economic empowerment and biodiversity conservation, such as community-managed forest and marine areas, can deliver nature-based solutions.

Changes in fresh water — Changes to both the quality and quantity of fresh water will require updating water storage capacity and increasing water access. Monitoring the El Niño—Southern Oscillation and having plans in place for drought and heavy rainfall can help communities to prepare for and avoid impacts such as water contamination, landslides, and food shortages.

Equity considerations — Social, economic, and geographic factors shape people's exposure to extreme weather and climate impacts. Some groups—including children, the elderly, rural and remote communities, and individuals with disabilities—are at greater risk, in part because they are often excluded from planning processes.

Economic sustainability — Changes to fisheries distribution and catch may lower national revenue from fishing license fees and cause loss of household income for fishing families. Climate impacts can also cause shocks in supply chains and agricultural productivity, both of which also drive up prices.

Climate finance — Significant expansion of climate finance is needed to meet the scale of challenges facing the FSM and increase adaptation capacity locally. Better coordination between climate funds and the FSM National Government, and streamlining grant application, reporting, and management processes, could increase access to funds and align their use with national and state priorities.

Climate Change in the FSM: Indicators and Considerations for Key Sectors

Report for the Pacific Islands Regional Climate Assessment (PIRCA)

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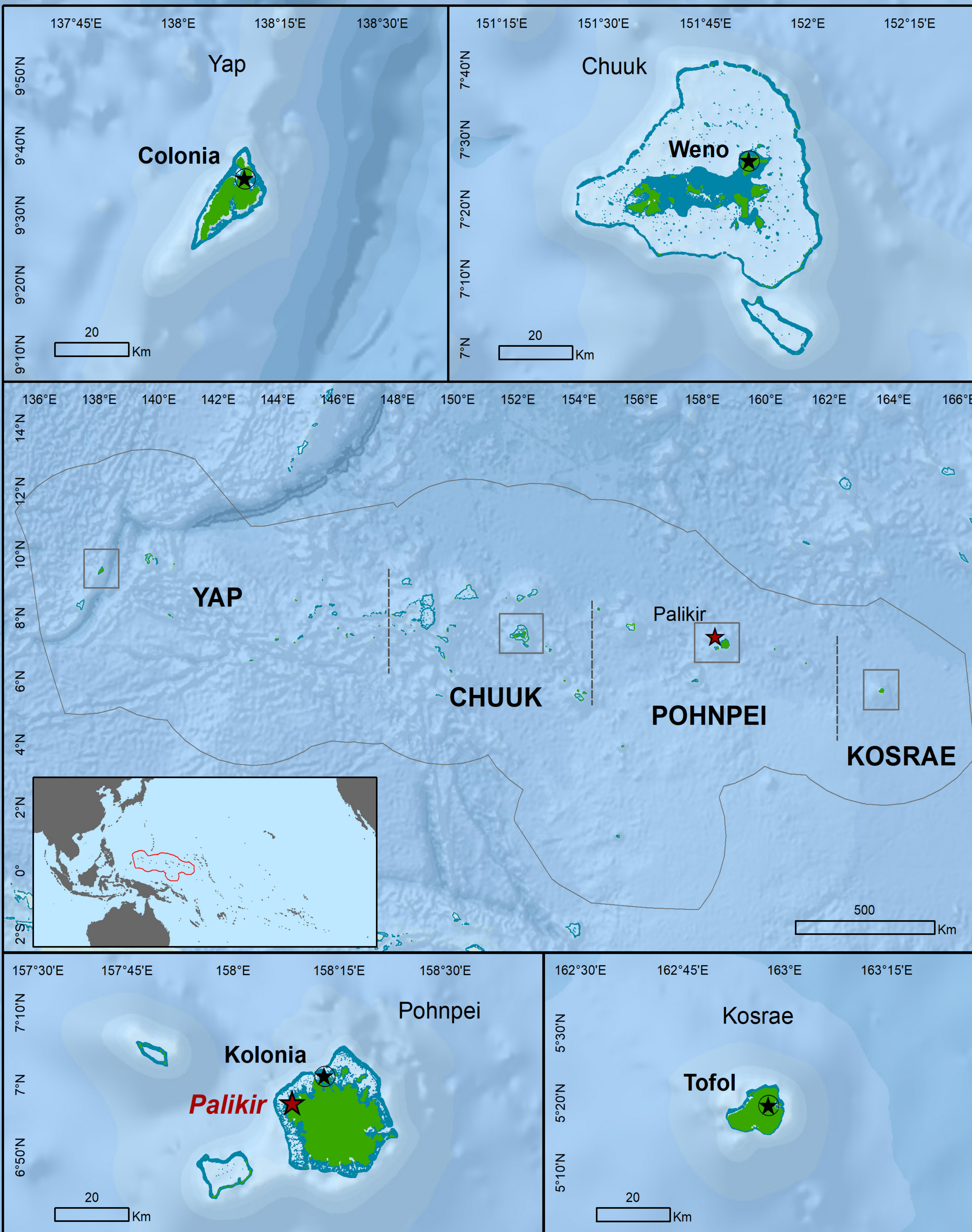


Original map by Laura Brewington

Inside this Report

Combinations of large healthy coral species covering the reef in Kosrae.
Photo: istock.com/KathyMendes

Global Climate Change: Causes and Indicators

The causes of climate change

Scientists have researched the physical science of climate change for almost two centuries. Carbon dioxide, methane, and other greenhouse gases that naturally occur in the atmosphere capture the heat from the Sun's energy that radiates from Earth's surface, preventing some of the heat from escaping to space (USGCRP 2018, Ch. 1: Overview). Known as the "greenhouse effect," this process keeps Earth habitable for life. However, humans have emitted an increasing amount of greenhouse gases into the atmosphere since the late 1800s by burning fossil fuels (such as oil, gas, and coal) and, to a lesser extent, through changes in land-use and global deforestation. As a result, the greenhouse effect has intensified and driven an increase in global surface temperatures and other widespread changes in climate. These changes and the rate at which they are happening are unprecedented in the history of modern civilization[1] (IPCC 2021, A.1; USGCRP 2018, Ch. 1: Overview; USGCRP 2017, Ch. 2: Physical Drivers of Climate Change).

Although natural climate cycles and other factors affect temperatures and weather patterns at regional scales, especially in the short term, the long-term warming trend in global average temperature documented over the last century cannot be explained by natural factors alone (IPCC 2021, A.1.3; USGCRP 2018, Ch. 2, Key Message 1). Human activities, especially emissions of greenhouse gases, are the only factors that can account for the amount of warming observed over the last century (IPCC 2021, A.1; USGCRP 2018, Ch. 2, KM 1). The largest contributor to human-caused warming is carbon dioxide (IPCC 2021, Box SPM.1).

[1] Human influence has warmed the climate at a rate unprecedented in at least the last 2,000 years (See IPCC 2021, A.1).

How is climate changing?

Long-term scientific observations show a warming trend in the climate system and the effects of increasing greenhouse gas concentrations in the atmosphere. The factors observed to be changing are known as **indicators** of change. Data collected from around the globe show, for example:

- Globally, annual average temperatures over land and oceans increased over the past century;
- For the Pacific Islands region, seven of the eight warmest years on record have occurred since 2007, with the warmest year being 2020 (Marra et al. 2022);
- Seas are rising, warming, and becoming more acidic;
- Some ocean species are moving poleward as waters warm;
- Sea ice is decreasing and glaciers, ice caps, and snow cover are shrinking.

These and many other changes are well documented and are clear signs of a warming world (IPCC 2021, A.3; USGCRP 2018, Ch. 1: Overview, Fig. 1.2, and Ch. 2, KM 3–7; also see USGCRP Indicators and EPA Indicators websites).

▸ **Global Climate Change:** Causes and Indicators

As in all regions of the world, the climate of the Pacific Islands is changing. The top panel of Figure 1 summarizes changes observed by scientists using several key indicators. The impacts of climate change (Fig. 1, lower panel) are being felt in the Pacific Islands and are projected to intensify in the future (Keener et al. 2018).

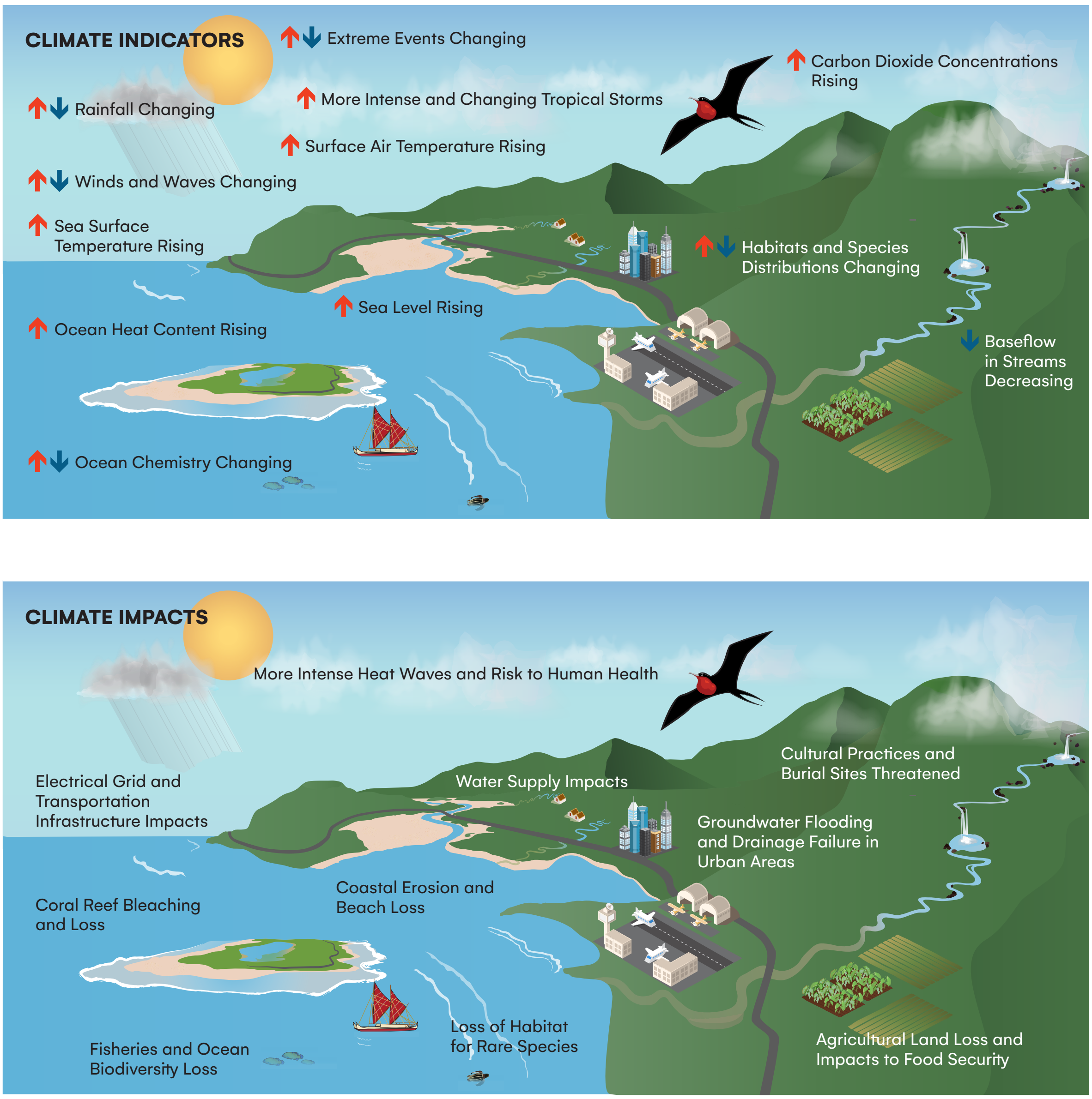


Figure 1. Observed changes in key climate indicators in the Pacific Islands (top)—such as carbon dioxide concentration, sea surface temperatures, and species distributions—result in (bottom) impacts to multiple sectors and communities, including built infrastructure, natural ecosystems, and human health. In the top panel, red arrows signify an indicator is increasing, while blue arrows show the indicator is decreasing. Red and blue arrows appear together when an indicator is changing and the direction of change varies. Source: Keener et al. 2018.

Future changes

Greenhouse gas emissions from human activities will continue to affect the climate over this century and beyond; however, efforts to cut emissions of certain gases can help to reduce the rate of global temperature increases over the next few decades (IPCC 2022, C.2; USGCRP 2018, Ch. 2, KM 2). Limiting human-caused global warming to a particular level requires cutting carbon dioxide emissions to as close to zero as possible ("net zero"), plus strong reductions in other greenhouse gas emissions (IPCC 2021).

Globally, the largest uncertainty in projecting future climate conditions is future greenhouse gas emissions, which could vary widely depending on the actions that human society takes in the coming years (USGCRP 2018, Ch. 2, KM 2). Climate models representing our understanding of historical and current climate conditions are often used to project how our world will change under future conditions. To understand how different levels of greenhouse gas emissions could lead to different climate outcomes, scientists use plausible future scenarios—known as Representative Concentration Pathways (RCPs)—to project temperature change and associated impacts. In this summary, the "high scenario" (RCP8.5) represents a future where reliance on fossil fuels and greenhouse gas emissions continue to increase throughout this century. The "low scenario" (RCP4.5) is based on reducing greenhouse gas emissions (about 85% lower emissions than the high scenario by the end of the 21st century). The "very low scenario" (RCP2.6) represents a scenario of substantial greenhouse gas reductions and net-negative emissions by 2100. Under this scenario, it is likely that global warming will be kept below 2°C (IPCC 2014).

Current greenhouse gas emissions far outpace lower emissions pathways and are currently tracking higher than the high scenario (RCP8.5). Human activities have caused approximately 2.0°F (1.1°C) of warming above pre-industrial levels (IPCC 2021, A.1). Limiting global warming to 1.5°C, while physically possible, would require immediate, deep, and sustained emissions reductions across all sectors, including energy, agriculture, cities, transportation, and industry (IPCC 2022, C.3).

This report summarizes the observed changes and future projections in key climate indicators in the Federated States of Micronesia (FSM). Later sections describe climate-related issues affecting communities, families, and households; extreme weather and climate change risks and considerations for managers and decision-makers; and information and research needs. The findings are drawn from published literature on climate science, climate-related risks in the Pacific Islands, and risk management approaches.

Indicators of Climate Change in the FSM

This discussion of indicators of climate change in the FSM builds on previous work that includes the *Pacific Islands Climate Change Monitor* (Marra et al. 2022), *State of Environmental Conditions in Hawaii and the U.S. Affiliated Pacific Islands under a Changing Climate: 2017* (Marra and Kruk 2017), work of the Australian Bureau of Meteorology (BOM) and Commonwealth Scientific and Industrial Research Organization (CSIRO) (Australian BOM and CSIRO 2011, 2014; CSIRO and SPREP 2021; McGree et al. 2022), and work of the Intergovernmental Panel on Climate Change (IPCC). Indicators were derived through a series of formal and informal discussions with a variety of stakeholders in the public and private sectors, and members of the scientific community. Criteria for their selection included regional and local relevance, and an established relationship to climate variability and change (Marra and Kruk 2017).

Air temperature

Indicator	How has it changed?	Projected future change
Average air temperature	↑	↑
Hot days	↑	↑
Cool nights	↓	↓

Surface air temperature factors into many realms of decision-making, from public health to utilities and building construction. Also, **average air temperature** is a key indicator of climate change. Temperatures in the FSM have warmed less than the global average. Since pre-industrial times, the average temperature has increased (Fig. 2), by 1.4°F (0.8°C) in eastern FSM—including Kosrae, Pohnpei, and the eastern islands of Chuuk (east of the 150°meridian), and by 1.6°F (0.9°C) in western FSM—including all of Yap and the western islands of Chuuk (CSIRO and SPREP 2021).

Fig.2

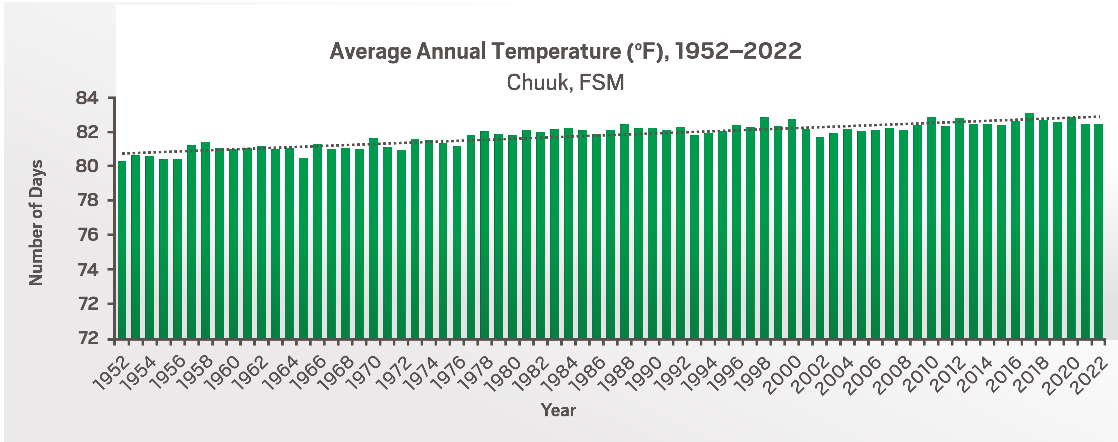


Figure 2. The annual average air temperature from 1952 to 2022 at Chuuk International Airport increased at a rate of 0.03ºF per year (black, dotted line). Original figure by Paula Moehlenkamp, using data from the NOAA GHCN–Daily database for station FMW00040505 (NOAA 2023).

The number of **hot days** has increased across the FSM. The number of days per year with a daily maximum temperature of 91°F (33°C) or above has increased at the Pohnpei International Airport weather station (Fig. 3., NOAA et al. 2023). Days with a maximum temperature of 90°F (32°C) or above have increased at the Chuuk and Yap weather stations since data collection began in the 1950s (Fig. 4–5; NOAA 2023; Marra et al. 2022).

As the climate has warmed, the number of **cool nights** has decreased in the FSM (Marra et al. 2022). At Chuuk International Airport, the number of cool nights, with a daily minimum temperature below 74°F (23°C), has decreased (Fig. 6). Weno (Chuuk) experienced an average of 69 cool nights per year in the first decade that records were kept (1952–1961). In the last decade, the number of cool nights decreased to an average of four nights per year (NOAA 2023).

▶ **Indicators of Climate Change** in the FSM

Fig.3

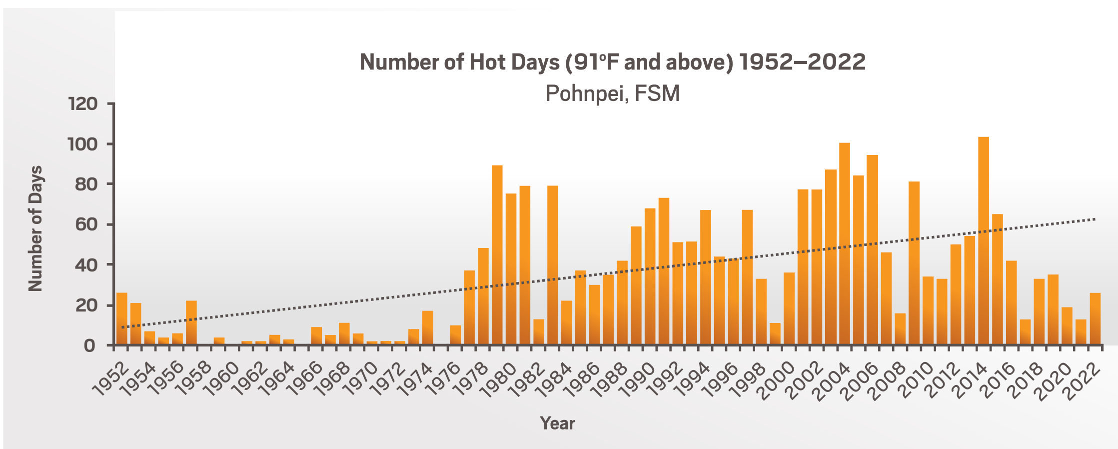


Figure 3. The annual number of days with maximum temperature of 91ºF (33ºC) or hotter from 1952 to 2022 at Pohnpei International Airport. The trendline (black, dotted line) shows an increase in hot days on average. Original figure by Paula Moehlenkamp, using data from the NOAA GHCN–Daily database for station FMW00040504 (NOAA 2023).

Fig.4

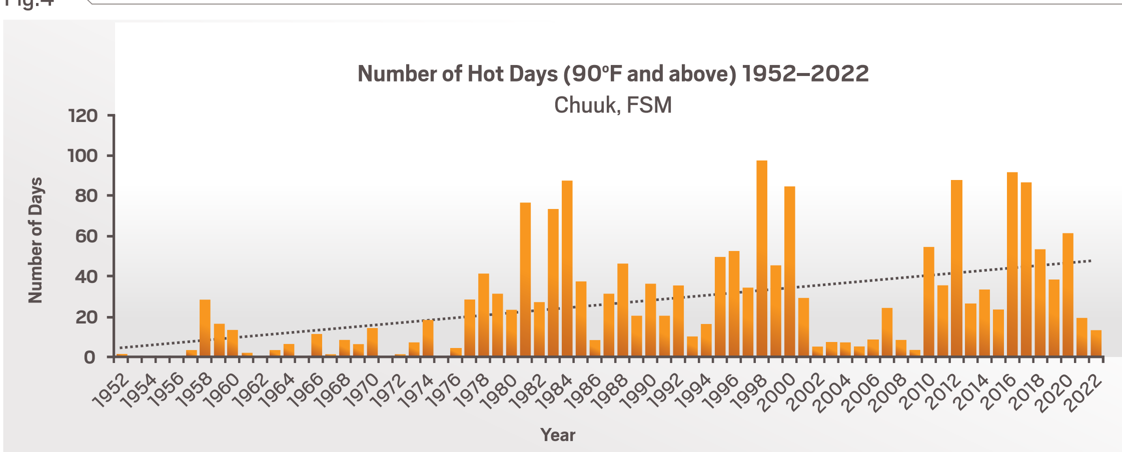


Figure 4. The annual number of days with maximum temperature of 90ºF (32ºC) or hotter from 1952 to 2022 at Chuuk International Airport. The trendline (black, dotted line) shows an increase in hot days on average. Original figure by Paula Moehlenkamp, using data from the NOAA GHCN–Daily database for station FMW00040505 (NOAA 2023).

Fig.5

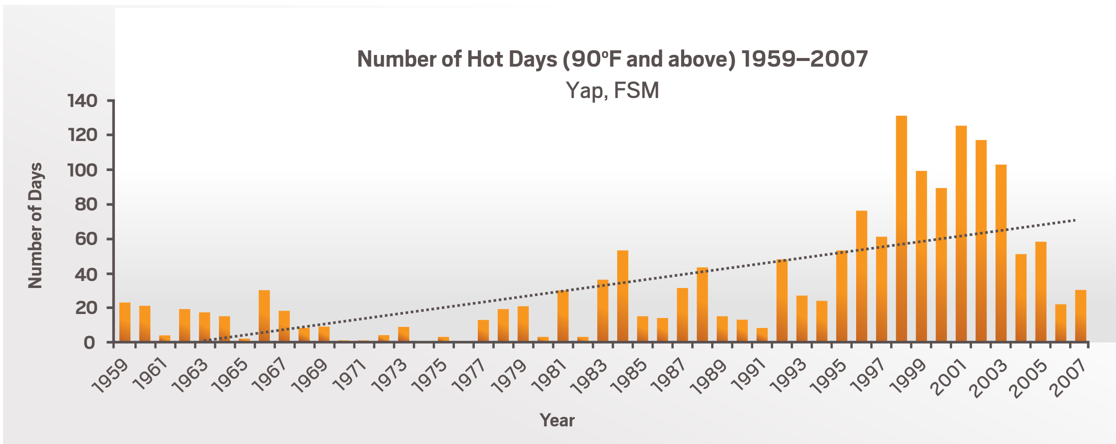


Figure 5. The annual number of days with maximum temperature of 90ºF (32ºC) or hotter from 1959 to 2007 at Yap International Airport. The trendline (black, dotted line) shows an increase in hot days on average. Original figure by Paula Moehlenkamp, using data from the NOAA GHCN–Daily database for station FMW00040308 (NOAA 2023).

Fig.6

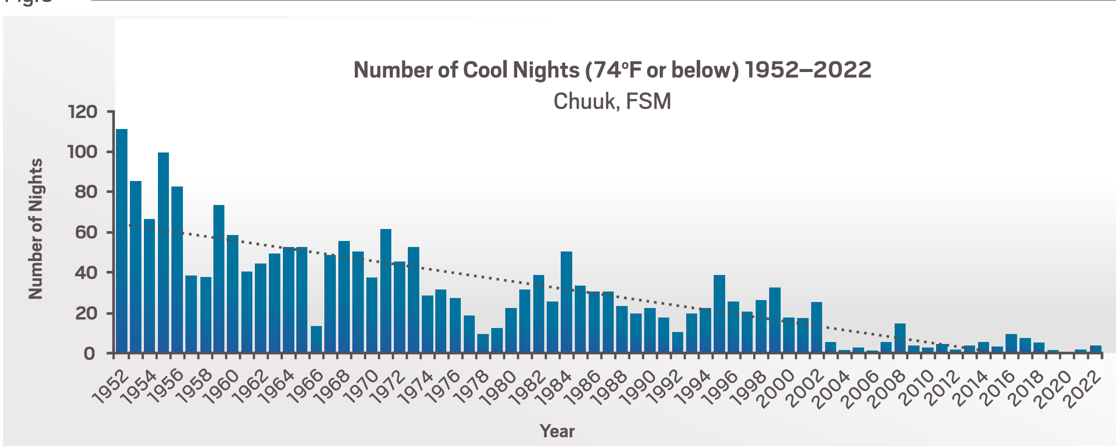


Figure 6. The annual number of cool nights with a minimum temperature of 74ºF (23ºC) or below from 1952 to 2022 at Chuuk International Airport. The trendline (black, dotted line) shows a decrease in the number of cool nights on average. Original figure by Paula Moehlenkamp, using data from the NOAA GHCN–Daily database for station FMW00040505 (NOAA 2023).

Surface air temperatures are expected to continue to increase. In the FSM, change in average annual air temperature is expected to total about 1.3°F (0.7°C) by 2030, compared to the 1986–2005 average. The range of possible future temperature change beyond 2030 depends greatly on the amount of future emissions. For instance, by 2090, an increase of 1.4°F (0.8°C) is expected under the very low emissions scenario (RCP2.6) while a 5.4°F (3.0°C) increase is projected under the high scenario (RCP8.5) (Australian BOM and CSIRO 2014). With 1.5°C global warming, air temperature in the FSM would increase by 1.3°F (0.7°C). If average global warming reaches 3.0°C, average air temperature in the FSM is expected to increase by 3.4°F (1.9°C) (CSIRO and SPREP 2021).

Rainfall and streamflow

Indicator	How has it changed?	Projected future change
Annual total rainfall	No change	?
Heavy rainfall	No change	↑
Consecutive dry days	No change	?
Streamflow	?	?

On high islands and atolls, rainfall is the primary source of fresh water, making it essential to communities and ecosystems. Rainfall patterns across the FSM are strongly linked to the monsoons of the western North Pacific and the El Niño–Southern Oscillation (ENSO). El Niño events can bring severe drought, with significant impacts on agriculture, ecosystems, and communities. During the El Niño drought of 1983, the Kolonia weather station on Pohnpei received just 12% of its normal precipitation in the period from January through June (Polhemus 2017). Yap and Chuuk received only about 30% of normal rainfall during that same period in 1983. No rain data were available for the atolls of FSM, but they also experienced the drought (Polhemus 2017).

On Kosrae and Pohnpei, the driest months of the year are January and February, and April and May are generally the wettest (McGree et al. 2022). Chuuk and Yap generally experience less rainfall for a period of a few months (approximately January to March for Chuuk and February to April for Yap), and rainfall amounts vary little the rest of the year. The few drier months are also slightly warmer on average. Historically, annual total rainfall has been higher in eastern states of Pohnpei (160 inches, or 4064 mm, annually) and Kosrae (180 inches or 4572 mm) than in Chuuk (140 inches or 3556 mm) or Yap (120 inches or 3048 mm) (Lander and Khosrowpanah 2004). Rainfall also varies with elevation, with the highest areas on Pohnpei receiving approximately double the rainfall along the coast, where measurements are taken (Lander and Khosrowpanah 2004).

Any long-term changes in **annual total rainfall** are difficult to detect because of the high variability in rainfall amounts from year to year and scarcity of data. Only Pohnpei, Chuuk, and Yap main islands have stations where daily long-term rainfall data have been collected and are suitable for climate studies. No change in annual total rainfall on average is evident in Pohnpei since

1950 and Yap since 1952, despite year-to-year variability (Australian BOM and CSIRO 2014). In Pohnpei, seasonal total rainfall in May–October shows a decreasing trend (McGree et al. 2022).

Models show a range of possible future changes in annual rainfall for the FSM (Dhage and Widlansky 2022), from little change to an increase in total annual rainfall (CSIRO and SPREP 2021). The range of possible change in rainfall is greater with the higher global warming levels projected for later in the 21st century (CSIRO and SPREP 2021). Any changes in the Intertropical Convergence Zone (ITCZ), a prominent climate feature in the FSM region, will affect future rainfall. Current models show the ITCZ intensifying and shifting equatorward with global warming (Mamalakis et al. 2021; Dhage and Widlansky 2022).

The average number of **heavy rainfall days** per year show no significant change for Pohnpei, Chuuk, and Yap since 1951 (Fig. 7–9, Marra et al. 2022). The frequency and intensity of heavy rainfall events are projected to increase in the western tropical Pacific (high confidence with 2°C warming and greater) (IPCC 2021). In Kosrae, Pohnpei, and eastern Chuuk, a 1-in-20-year rainfall event would become a 1-in-7-year event under the low scenario (RCP4.5) and a 1-in-6-year under the high scenario (RCP8.5) by 2090. In western Chuuk and Yap, a 1-in-20-year event would become a 1-in-8-year event under the low scenario and a 1-in-4-year event under the high scenario (Australian BOM and CSIRO 2014). Increased heavy rainfall events will likely result in increased runoff and increased potential for flooding in some locations.

Fig.7

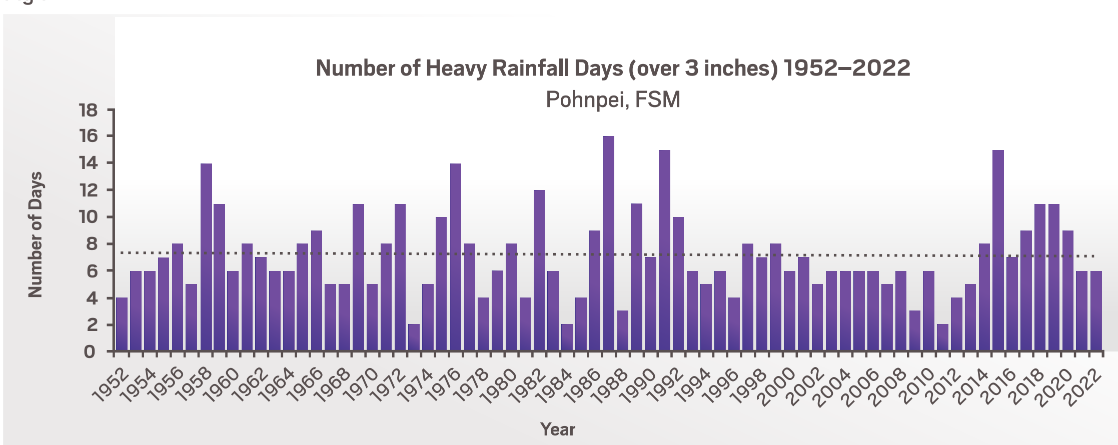


Figure 7. The annual number of days with heavy rainfall (over 3 inches in a day) from 1952 to 2022 at the Pohnpei International Airport showed no statistically significant change (dashed back trend line). Original figure by Paula Moehlenkamp, using data from the NOAA GHCN–Daily database for station FMW00040504 (NOAA 2023; Menne et al. 2012).

Indicators of Climate Change in the FSM

Fig.8

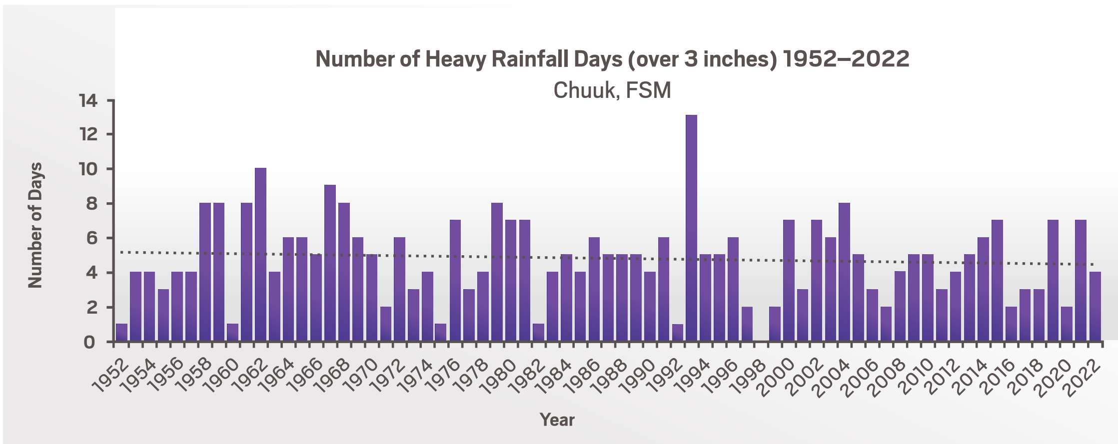


Figure 8. The annual number of days with heavy rainfall (over 3 inches in a day) from 1952 to 2022 at the Chuuk International Airport showed no statistically significant change. Original figure by Paula Moehlenkamp, using data from the NOAA GHCN–Daily database for station FMW00040505 (NOAA 2023).

Fig.9

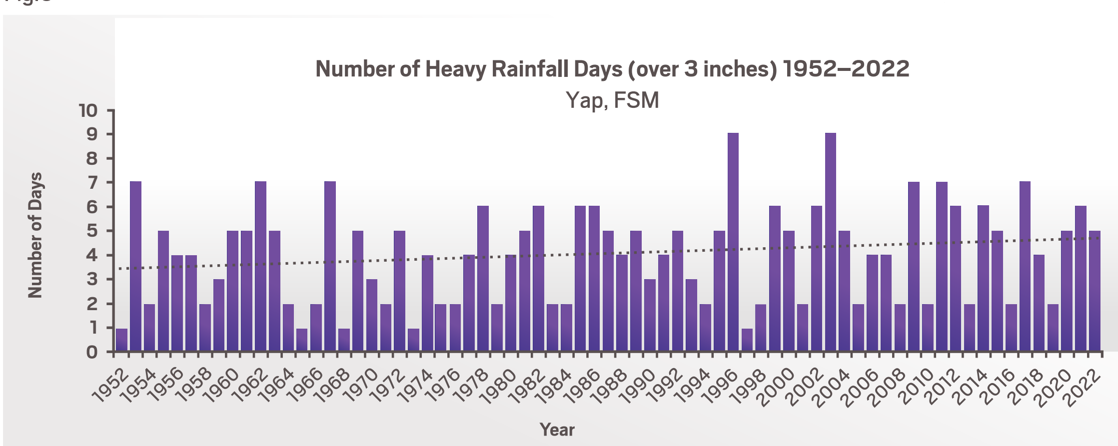


Figure 9. The annual number of days with heavy rainfall (over 3 inches in a day) from 1952 to 2022 at the Yap International Airport showed no statistically significant change. Original figure by Paula Moehlenkamp, using data from the NOAA GHCN–Daily database for station FMW00040308 (NOAA 2023).

Consecutive dry days are an indicator of the length of dry periods without rainfall, measuring the longest period in a year during which less than 0.04 inches (1 mm) of rain is received each day. The number of annual consecutive dry days has remained approximately constant in each of the States of the FSM since 1951 (Marra et al. 2022; McGree et al. 2022). Data indicates that drought conditions have increased on Pohnpei since 1952, in line with the decrease in May to October rainfall (McGree et al. 2022).

Streamflow data for the FSM were collected beginning at the end of World War II and then ceased in the 1990s due to a lack of funding. Streams are susceptible to drought because rainfall accounts for a large proportion of total streamflow. Especially low water retention in streams characterizes the geology of Yap, and streambeds are dry for an average of 10 weeks each year (Polhemus 2017). During the 1983 drought, streamflow was only 5–6% of the normal rate on Yap. Streamflow was similarly low in streams across the FSM during the drought (Polhemus 2017).

Tropical cyclones and storms

Indicator	How has it changed?	Projected future change
Tropical cyclone intensity	No change	↑
Tropical cyclone frequency	No change	?

Typhoons, tropical storms, and tropical depressions (referred to collectively as tropical cyclones) can bring intense winds, torrential rainfall, high waves, and storm surges to islands near their path. The effects of a tropical cyclone can cause severe impacts on lives and property. The western North Pacific is the most active tropical cyclone basin in the world. Generally, typhoons generate around Kosrae and move west to Chuuk and Yap where they intensify. An increased risk of tropical cyclones striking eastern Micronesia (including Kosrae and Pohnpei) is experienced during medium-to-strong El Niño events when storm development shifts eastward (PEAC Center 2015a).

In the western North Pacific region—roughly the area of the North Pacific between 120°E and 180° including the FSM—there was no notable increase or decrease in the intensity or frequency of tropical cyclones during 1981 to present (Marra et al. 2022; McGree et al. 2022). There were nearly an equal number of seasons with above- and below-normal numbers of named tropical cyclones in the western North Pacific (Marra et al. 2022).

There is scientific consensus that **tropical cyclone intensity** (strength) is likely to increase in a warmer world (IPCC 2021; USGCRP 2017; Knutson et al. 2020). Globally, the future expected changes in tropical cyclones include increased wind speeds and rainfall rates (Knutson et al. 2020; IPCC 2021), and higher storm surge potential with sea level rise (IPCC 2021). For the western North Pacific basin, which includes the FSM, tropical cyclone rain rates and wind speeds are projected to increase in the future with global warming (Knutson et al. 2020). The overall outlook is for stronger storms in the future.

The **frequency of tropical cyclones** is projected to decrease globally by the late 21st century (Knutson et al. 2020; Ranasinghe et al. 2021), however, the projected decrease in frequency is less robust for the western North Pacific (Knutson et al. 2020). The future of tropical cyclones in the FSM still carries uncertainties (Knutson et al. 2020). The area where tropical cyclones reach peak intensity in the western North Pacific is expected to continue to move north (poleward), possibly affecting tropical cyclone frequency (Kossin et al. 2016). Projections also indicate an increase in the number of tropical cyclones during El Niño and a decrease during La Niña events by the end of the 21st century (Chand et al. 2017).

Sea level

Indicator	How has it changed?	Projected future change
Sea level	↑	↑
High water frequency	↑	↑

Sea level rise poses many challenges to communities and infrastructure because it brings more frequent and extreme coastal erosion, coastal flooding, and saltwater intrusion into coastal aquifers. For the FSM, rising sea levels pose a threat to the long-term habitability of some low-lying islands, particularly on outer islands where transportation ports and infrastructure are vulnerable, or on the coasts of high islands, where most people live.

The local sea levels experienced in the FSM vary significantly over time—sea level is high at times and lower during other periods. Sea level fluctuates due to seasonal cycles of ocean temperature, and on shorter time spans due to abrupt changes in winds and atmospheric pressure (such as storm surges). Large phenomena, such as ENSO, also affect sea level on seasonal to interannual timescales. In the months of October through December during a developing La Niña, the FSM typically experiences higher-than-average sea levels (McGree et al. 2022).

Globally, sea level is rising. Although large variations make it difficult to determine the long-term trend, measurements of sea level in the FSM indicate **average sea level** is increasing. Fine-scaled estimates of sea level rise from 1993 to 2019 are derived from satellite altimetry observations. Over this recent period, sea level in the FSM is estimated to have risen between 0.12 and 0.18 inches (3 and 4.5 mm) per year (McGree et al. 2022). Trends are highest around Kosrae and in the southeast (0.16 to 0.18 inches per year) (McGree et al. 2022).

Relatively small changes in average sea level can have large effects on the tidal flood frequency and coastal erosion. **High water days** (also called "tidal flooding") affect the FSM when exceptionally high tides combine with waves or high sea level events. During a recent tidal flooding event in December 2021, multiple FSM states experienced coastal flooding. Substantial damage to infrastructure, crops, and water supply were reported, particularly in Chuuk. The figures below show the number of hours each year that sea levels were high, with the potential to cause flooding, at Pohnpei (Fig. 10, for 2002 to 2022) and Yap (Fig. 11, for 1970 to 2022).

Fig.10

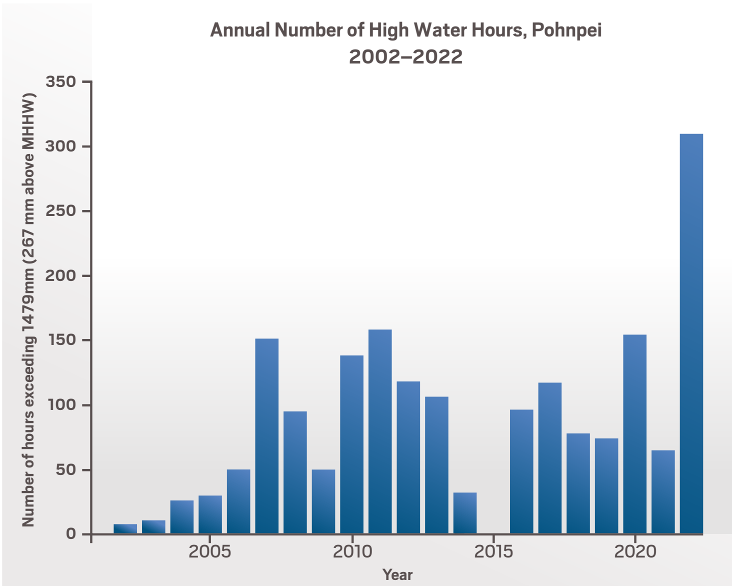


Figure 10. The number of high water hours per year at Pohnpei, FSM, from 2002 to 2022. The high water threshold (1479 mm) is defined as the Mean Higher High Water level plus one-third of the difference between that and the Mean Lower Low Water level at the tide gauge (water levels above the daily average highest tide plus a factor of the typical tidal amplitude). Original figure by Matthew Widlansky, with data from the University of Hawai'i Sea Level Center Station Explorer (https://uhslc.soest.hawaii.edu/stations/?stn=001#datums).

Fig.11

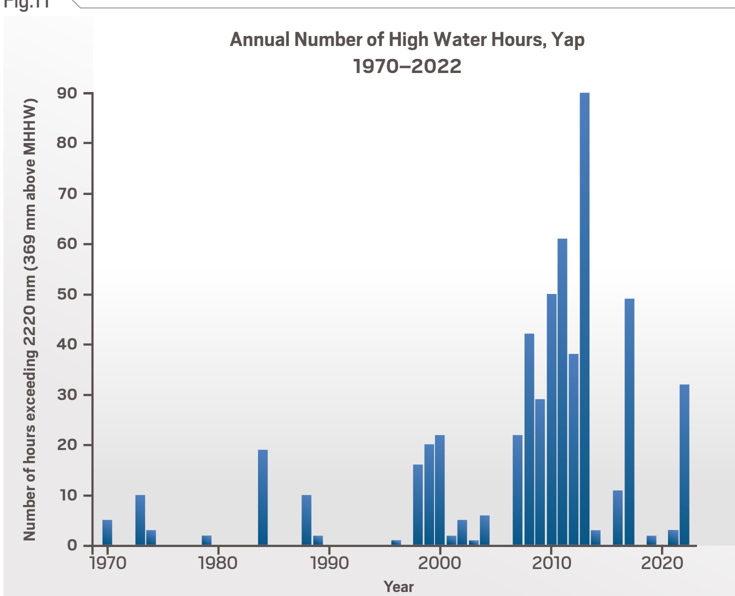


Figure 11. The number of high water hours per year at Yap, FSM, from 1970 to 2022. The high water threshold (2220 mm) is defined as the Mean Higher High Water level plus one-third of the difference between that and the Mean Lower Low Water level at the tide gauge (water levels above the daily average highest tide plus a factor of the typical tidal amplitude). Original figure by Matthew Widlansky, with data from the University of Hawai'i Sea Level Center Station Explorer (https://uhslc.soest.hawaii.edu/stations/?stn=008#datums).

It is *virtually certain* that sea level will continue to rise globally over the 21st century, including in the FSM. Relative to the year 2000, Global Mean Sea Level (GMSL) is projected to rise 0.5 to 1.4 feet (0.15 to 0.43 m) by 2050 and 1.0 to 6.6 feet (0.3 to 2.0 m) by 2100 (Sweet et al. 2022). The median GMSL rise projection for 2100 in a world where temperatures are 2.0°C above 1850–1900 levels is about 1.6 feet (0.5 m) (*likely* range of 1.3 to 2.3 feet). If temperatures reach 4.0°C on average in 2100, the median projected GMSL rise is 2.3 feet (0.7 m) (*likely* range of 2 to 3 feet) (Sweet et al. 2022). The potentially large contributions of ice sheet melt to long-term sea level rise are less well understood and could lead to sea level rise at the high end of

IPCC ranges (IPCC 2021, B.5.3). Sea level will continue to rise after 2100, for centuries to millennia, and remain elevated for thousands of years (IPCC 2021, B.5.3).

In the FSM and other tropical Pacific Island nations, which are far away from the gravitational attraction of the sources of melting land ice, sea level rise is expected to be slightly higher than the global average (Sweet et al. 2017; Church et al. 2006, see Table 1). For example, if GMSL rises 1.6 feet by 2100 (the Intermediate-Low Scenario by 2100), the FSM would expect to see 2 feet of sea level rise.

Sea level rise will cause coastal flooding to become more frequent and severe. Future increasing sea level variability associated with more extreme El Niño and La Niña events could further exacerbate flooding (Widlansky et al. 2015).

Sea Level Rise Scenarios

Sea level rise scenarios represent possible future sea level changes in response to global warming and increasing greenhouse gas emissions. These scenarios are used to communicate how much sea level rise could occur under certain conditions, and by when. Figure 12 is a chart showing several scenarios of global sea level rise through 2150 (in feet and meters). Table 1 shows those same global scenarios compared with scenarios for the Pacific Islands possible by 2050 and 2100 relative to a 2000 baseline.

Fig.12

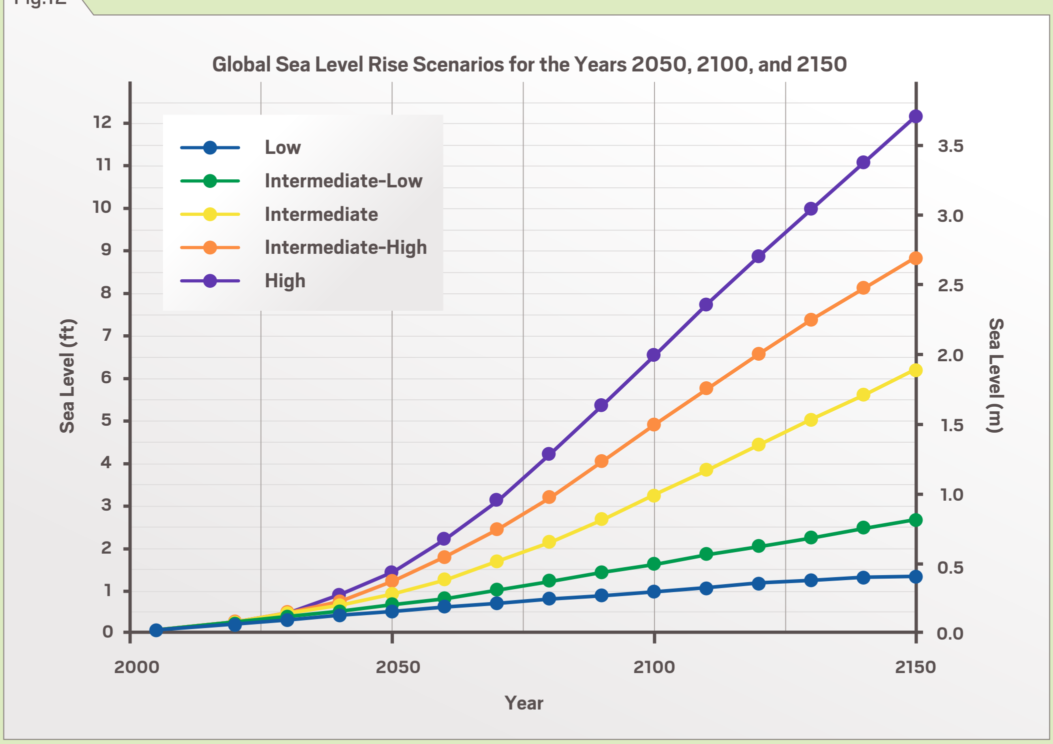


Figure 12. Global sea level rise scenarios from the 2022 Sea Level Rise Technical Report (Sweet et al. 2022), including projected sea level rise for the years 2050, 2100, and 2150. All values are referenced to a baseline of year 2000.

Scenario	2050		2100	
	Pacific Islands	Global	Pacific Islands	Global
Low	0.62	0.49	1.3	1.0
Intermediate - Low	0.79	0.66	2.0	1.6
Intermediate	0.95	0.92	3.6	3.3
Intermediate - High	1.25	1.21	5.6	4.9
High	1.51	1.41	7.5	6.6

Table 1. Global mean sea level and Pacific Islands regional sea level scenarios (in feet), for 2050 and 2100 relative to a 2000 baseline. Median values are shown. Adapted from Sweet et al. 2022.

The rate of GMSL rise is closely related to the magnitude of global warming. Table 2 shows the probability of exceeding each global sea level rise scenario at specific levels of global warming by 2100.

Global Mean Surface Air Temperature 2081–2100	1.5ºC	2.0ºC	3.0ºC	4.0ºC
Low (1.0 feet GMSL rise in 2100)	92%	98%	>92%	>99%
Intermediate - Low (1.6 feet in 2100)	37%	50%	82%	97%
Intermediate (3.3 feet in 2100)	<1%	2%	5%	10%
Intermediate - High (4.9 feet in 2100)	<1%	<1%	<1%	1%
High (6.6 feet in 2100)	<1%	<1%	<1%	<1%

Table 2. Probabilities of exceeding global mean sea level scenarios by 2100 under IPCC warming level-based scenarios. Global mean surface air temperature anomalies are projected for years 2081–2100 relative to 1850–1900 climatology. Adapted from Sweet et al. 2022.

Ocean changes

Indicator	How has it changed?	Projected future change
Sea surface temperature	↑	↑
Frequency of heat stress on coral	↑	↑
Ocean acidification	↑	↑

Human-caused greenhouse gas emissions have resulted in changes in the chemical composition, temperature, and circulation of oceans, which have ramifications for marine ecosystems. Changes in **sea surface temperature**—the temperature of water at the ocean's surface—can dramatically alter conditions for marine organisms. Sea surface temperature has increased globally since 1880. Across the FSM, average sea surface temperatures have increased by 0.45°F (0.25°C) per decade on average since 1982 (Fig. 13; McGree et al. 2022; Marra et al. 2022).

Fig.13

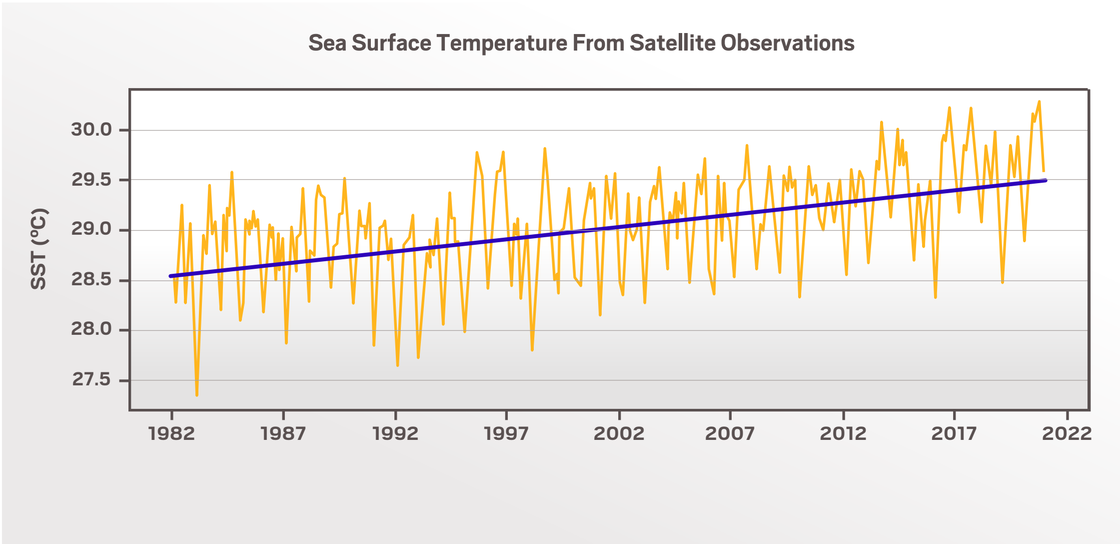


Figure 13. Sea surface temperature from satellite observations averaged across the FSM EEZ, denoted by the orange line. The blue line shows the increasing trend. Figure from McGree et al. 2022.

The **frequency of heat stress**, which is responsible for coral reef bleaching, is on the rise in the FSM. The number of days per year that coral reefs are exposed to accumulated heat stress, as categorized by the NOAA Coral Reef Watch, has risen from 24 days per year (in 1982–91) to 38 days per year in the eastern FSM (Kosrae, Pohnpei, and Chuuk). In Yap State and Palau, corals were exposed to heat stress 13 days per year in 1982–91. The occurrence has risen to 33 days per year (in 2007–16), a 155% increase (Marra and Kruk 2017). Intense heat stress was experienced in 2016–2017 in eastern FSM during the third global bleaching event, which resulted in extensive coral bleaching and reef degradation (Rowley et al. 2019). In 2016, 85% of coral areas monitored were exposed to conditions associated with widespread bleaching and significant coral mortality. In Yap, only two years have had widespread, severe bleaching conditions: up to 12 days in 1998 and for three days in 2010 (Marra and Kruk 2017).

Under a high warming scenario, most coral reefs in the FSM are expected to annually experience conditions known to cause severe bleaching by about 2040 (van Hooidonk et al. 2016). Bleached corals typically do not reproduce in a year that they bleach and are more prone to disease and death in the future if they do recover.

While ocean water has a basic pH, data show that **ocean acidification**, caused by the ocean's uptake of carbon dioxide from the atmosphere, has slowly increased in the waters of the West Pacific (Kuchinke et al. 2014). This increase threatens coral reefs by making it harder for corals to build healthy skeletons. To this point, high temperatures have been far more damaging to coral reefs, but ocean chemistry will continue to change, and under the high scenario, all coral reefs are projected to exist under increasingly acidified conditions that will impede their ability to grow by the end of the century (Australian BOM and CSIRO 2014).

Managing Climate Risks in the Face of Uncertainty

Climate change impacts are often difficult to predict, leading to uncertainties in the timing, magnitude, or type of impacts. Resource managers respond with various risk management approaches that can be used to plan for uncertainty. Risk management typically involves identifying, evaluating, and prioritizing current and future climate-related risks and vulnerabilities (even those with uncertainties that are difficult to characterize with confidence), and assigning effort and resources to actions that reduce those risks (USGCRP 2018, Ch. 28, KM 3). Future economic and social conditions are considered alongside climate risks. Often, risk management allows for monitoring and adjusting strategies to risks and vulnerabilities as they evolve. Addressing equity, economics, and social well-being are important parts of effective climate risk management efforts (Fatorić and Seekamp 2017).

Two such approaches that can be used either separately or together are: (i) **scenario planning**, which involves the creation of several potential scenarios that might develop in the future, based upon a set of variables or projections; and (ii) **adaptive management**, in which resource managers monitor, evaluate, and adapt management practices to changing environmental conditions, such as rising sea levels and temperatures. Scenarios are used to assess risks over a range of plausible futures that include socioeconomic and other trends in addition to climate. Adaptive management approaches can benefit from technical analysis of hazards, such as critical infrastructure vulnerability assessment.

Comprehensive risk management helps to avoid adaptation actions that address only one climate stressor, such as sea level rise, while ignoring other current or future climate impacts. **Maladaptation** arises when actions intended to address climate risks result in increased vulnerability. For example, if a city builds new infrastructure designed to minimize the impacts from sea level rise and the sea level rise turns out to be higher than expected, the infrastructure can contribute to flooding if stormwater and sewer systems are unable to handle the rising water. To avoid maladaptation, policymakers and managers need to consider a range of future scenarios and projected impacts over the lifetime of a project and communicate across sectors when designing solutions.

What Do Extreme Weather and Climate Change Mean for the FSM's Families, Households, and Populations?

Globally, more intense extreme weather events, flooding, disease transmission, and ecosystem degradation all threaten the health and well-being of families and communities (USGCRP 2018, Summary of Findings). Additionally, climate-related risks to energy, food production, and the global economy are projected to cause large shifts in prices and availability of goods and lead to price shocks and food insecurity (USGCRP 2018, Ch. 16, KM 1 and 3). The subsistence economy is therefore crucial for communities, especially those with limited access to imports.

Social, economic, and geographic factors shape people's exposure to climate-related impacts and their ability to respond. Those at greater risk from extreme weather and climate change include children, older adults, low-income communities, outer island communities, and those experiencing discrimination, in part because they are often excluded from climate adaptation planning processes (USGCRP 2018, Ch. 14, Ch. 15, Ch. 28). An individual's awareness of hazards affects the ability to respond, underlining the importance of early warning and hazard communication. For example, during Typhoon Chata'an in 2002, children under 15 years old and those who were unaware of hazardous landslides were at a higher risk of landslide-related mortality in Chuuk compared to average annual rates (Sanchez et al. 2009).

Specific groups are likely to be disproportionately affected by climate change, including:

- Children, who have a higher rate of heat stroke and heat-related illness than adults, are at greater risk from increasing hot days (USGCRP 2016; EPA 2016).
- Older adults and persons with disabilities are at greater risk during extreme events such as storms, which cause power outages or require evacuation. Emergency response plans specifically accommodating these groups can lessen the risks (Government of the FSM 2013; USGCRP 2016; EPA 2016).
- Women, who have varying roles and degrees of involvement in certain activities, such as cultivation, harvest, and preparation of food, which differ significantly across states (FSM Department of Resources and Development 2018). Women are often community caregivers and involved in childcare, health, and education. Because of this role, they may be at higher risk during disasters and other climate events, as they may prioritize staying at home or protecting family members above their own safety.
- People who work outdoors, such as tourism and construction workers, fishers, farmers, and other outdoor laborers, who are exposed to the effects of heat and extreme weather (USGCRP 2016; Schulte and Chun 2009).
- Populations living in or adjacent to low-lying areas (World Bank Group 2021a), whose infrastructure is more susceptible to wave action, especially in areas without intact natural systems such as mangroves and coral reefs.
- Those living on outer islands or in remote communities with limited access to health facilities, markets, and other vital services.
- Those whose livelihoods depend on ecosystem services. For example, in the outer islands of Yap, Pohnpei, and Chuuk, farming communities rely on low-lying atoll taro patches and local fisheries for food.
- Other disadvantaged groups, including asylum seekers, socially isolated people, and those suffering from disease or mental health problems (Micronesia Red Cross Society 2021).

Global action to significantly cut greenhouse gas emissions can reduce climate-related risks and increase opportunities for all populations in the long term. For example, health-related impacts and costs across the United States are projected to be 50% lower under a lower warming scenario (RCP4.5) than a higher scenario (RCP8.5) (USGCRP 2018).

Globally, climate change is increasing migration. About one third of FSM-born people live outside of the FSM (Hezel 2013). Groups may use internal and external migration as a climate adaptation strategy. For example, residents of low-lying atolls may relocate in response to sea level rise (Government of the FSM 2013). Saltwater inundation damages freshwater wells and taro patches, which prompts some citizens to migrate to main islands with higher elevations (Pam and Henry 2012). Internal migration related to climate change poses additional challenges for each state with limited land, food, and water resources and increasing population density (Dema 2012; Permanent Mission of the FSM to the UN 2009). In addition, some have voiced concerns about the impacts of relocation to other islands or countries, such as the risk of cultural and identity loss and disconnection from their lands (Pam and Henry 2012).

Equitable Climate Finance

Large, multilateral funds are becoming increasingly available for climate adaptation. While allocating resources is necessary to avoid the worst impacts of climate change, greater accessibility and equity in their dispersal must be achieved to ensure the funds' effectiveness.

Climate finance mechanisms, and other public and private sources, require significant coordination and management, putting additional strain on small island communities that have limited human and technical capacity. Restructuring financing opportunities with a focus on building institutional capacity can help local governments prepare to manage and fairly allocate resources. Other interventions that funders could consider include:

- aligning reporting requirements with local capacity and cultural norms;
- harmonizing requirements across multilateral climate funds and donors;
- ensuring funding is available for permanent staff positions to enable government ownership as well as long-term sustainability;
- streamlining the application process;
- ensuring advertisements and eligibility are accessible and fair;
- and, more actively supporting national government strategic planning, coordination, consultation, and monitoring.

The Green Climate Fund is piloting direct access, whereby funding is accessible to national and sub-national governments and regional, public, and private entities themselves. This approach could be scaled up to enable Pacific Island regional and national institutions to have a more direct role in coordinating climate finance flows.

Finally, the gap between global finance toward mitigation versus adaptation still remains large. No fund exists to specifically address the unique needs of Small Island Developing States (SIDS) or their climate change losses and damages.

What Do Extreme Weather and Climate Change Mean for the FSM's Key Sectors?

The PIRCA suggests the following considerations for managers working in key sectors based on an up-to-date review of published literature on climate science, climate-related risks in the Pacific Islands, and risk management approaches.

If you are involved in fisheries or managing ocean resources...

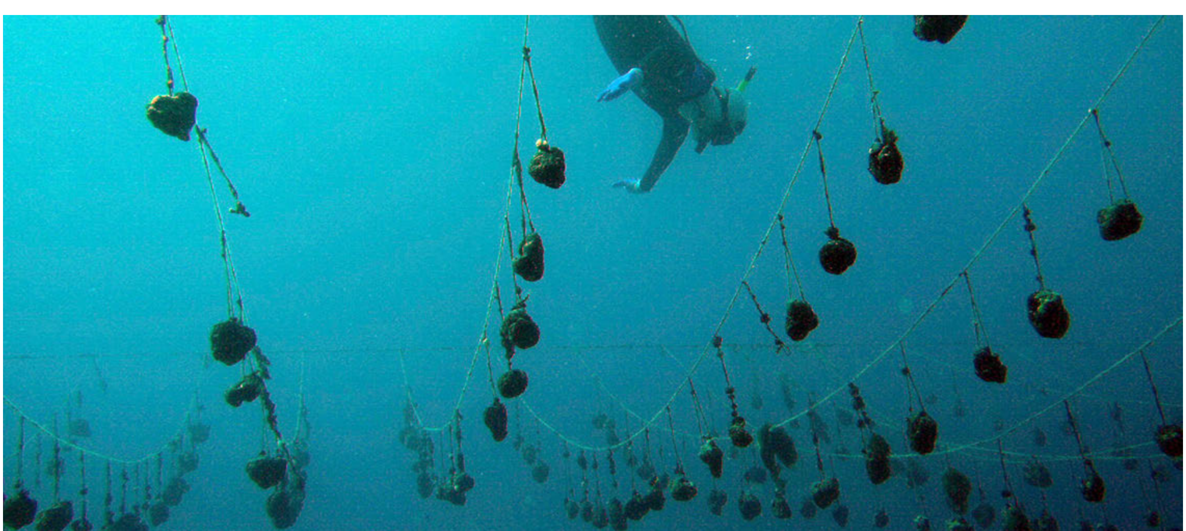
- ***Prepare for and monitor changes in fisheries distribution and catch.*** Fish are an important natural resource in the FSM. Fish account for 80% of animal protein in rural areas (Bell et al. 2009), and over 70% of FSM households engage in some fishing activities (FSM Office of SBOC 2012). Continuing under a high global warming scenario, a 20–50% decrease in coral reef fish abundance is projected by 2050 for the broad Pacific Islands region (Bell et al. 2011; Asch et al. 2018). A large proportion of coral reef fisheries in Micronesia support a regional demand for food fish (Cuetos-Bueno and Houk 2018), and long-term trends point towards unsustainability (Rhodes et al. 2015). Foreign corporations mostly operate pelagic purse and long-line fisheries, while local communities are the main users of nearshore reef fisheries (Primo 1996).

- ***Consider economic and livelihood strategies for resilience to changes in household income and food security.*** Tuna is an important resource for local subsistence, employment, and government revenue. Between 2015 and 2018, access fees from distant-water fishing nations operating in the FSM's exclusive economic zone (EEZ) averaged $68 million per year (Ruaia et al. 2020) and contributed an average of 48% of the FSM's (non-grant) government revenue (Ruaia et al. 2020; Bell et al. 2021). Significant changes to transboundary fisheries distribution are expected to occur by 2040 (Palacios-Abrantes et al. 2022; Blasiak et al. 2017). Recent modeling indicates that under a high global warming scenario (RCP8.5), the purse seine tuna catch from FSM's EEZ is expected to decrease by 13% and government revenue by 6% by 2050 due to eastward redistribution of skipjack, yellowfin, and bigeye tuna (Bell et al. 2021). A large impact on household income and food security is possible from changes in nearshore and pelagic fisheries (Hodgson et al. 2022). Despite these changes, fishing communities in Yap and Pohnpei exhibit high levels of livelihood flexibility and perceived agency regarding climate change adaptation (Wongbusurakum et al. 2021). Monitoring research on projected changes to coastal fish production and tuna distribution could help communities and the national economy prepare and plan accordingly.

A man fishes in front of mangroves in Kosrae. Photo by Richard A. MacKenzie.

- ***Plan for a decline in coral reef health.*** In addition to providing food and cultural significance, it is estimated that the FSM's coral reefs provide more than $16 million of annual revenue through recreation and tourism (The Nature Conservancy 2021). However, continued ocean warming and acidification are projected to cause a decrease in coral cover (van Hooidonk et al. 2016; Bell et al. 2011, 2013). Increases in the frequency and severity of marine heatwaves will result in coral bleaching and mortality (Smale et al. 2019). Sediment and nutrient run-off from land-based activities cause pollution and lower water quality, which also contribute to reef degradation (Richmond et al. 2007; Bell et al. 2011). Nutrient-dense water in nearshore habitats may also result in greater occupation of reefs by the invasive crown-of-thorns starfish (*Acanthaster planci*), often referred to as COTs. For these reasons, inner reefs closer to major ports or urban centers are particularly vulnerable to decline (Houk et al. 2012). Finally, interactions between large oceanographic processes, such as the El Niño–Southern Oscillation and Pacific Decadal Oscillation, can produce compounding disturbances such as elevated sea surface temperatures and increased *A. planci* abundances (Houk et al. 2020).

- ***Reduce local stressors to support adaptive management in marine ecosystems.*** Local stressors, such as fishing pressure and land-based pollution, are known to influence coral reef health (Houk et al. 2015). Integrating land-based management with strategies to conserve marine resources can help to protect coral reefs from land-based pollution (Richmond et al. 2007). Reduced fishing pressure, fishery diversification, predator and herbivore conservation, and community-owned fishery management are all strategies that can bolster livelihoods, increase coral reef resilience, and support recovery from climate impacts (McLean et al. 2016; Houk et al. 2015; Bell et al. 2011, 2013). Marine Protected Areas (MPAs) were found to be successful in some contexts, particularly when there is community ownership. One study in Yap found that community-oriented decision-making and management tools implemented in tandem with social and cultural structures can offer increased



Sponge farming at Marine and Environmental Institute of Pohnpei (MERIP) in Pohnpei state, FSM. Photo by MERIP.

social and ecological resilience (Johnson et al. 2020). Further, conservation areas can be an opportunity for outreach and, in turn, for the community to be involved in resilience planning. In addition, sustainable, small-scale aquaculture and mariculture can be used as an alternative livelihood that reduces pressure on marine systems (Ellis et al. 2017). One example of this is the work of the Marine and Environmental Research Institute of Pohnpei (MERIP) with coastal communities to develop small-scale mariculture activities adjacent to community-based Marine Protected Areas. MERIP works with five MPAs in Pohnpei and farms coral, giant clams, and sponges for export globally (Ellis et al. 2017; FSM Department of Resources and Development 2018).

- ***Monitor marine resources and changes in coral reefs.*** Monitoring reef health is useful because results can be applied to inform current practices or regulations within designated conservation areas. For example, satellite imagery can help predict COTs outbreaks, informing removal programs that protect species of hard coral (Houk et al. 2007). In Yap, monitoring marine food web recovery after reintroduction of customary management led to more effective community enforcement. In Pohnpei, a monitoring program led to developing catch limits and adjusting marine conservation area boundaries (Montambault et al. 2015). International partnerships such as the Global Environmental Facility Coral Reef Targeted Research Programme, Coral Reef Triangle Initiative, and Micronesia Challenge Initiative can also assist in training and securing project funding. The FSM has a Protected Areas Network National Guiding Policy Framework for the existing network, which aligns with the Micronesia Challenge goals.

If you work in agriculture, agroforestry, and food security...

- ***Plan for climate impacts such as changes in temperature, rainfall, and sea level that reduce agricultural yield.*** Food crops are principally grown for sustenance and cultural uses and include bananas, breadfruit, taro, yams, sweet potatoes, and coconuts. In addition to climate stressors, these crops also face pests, invasive alien species, disease, wildfire, clearing and development, and soil infertility. The 1997–1998 El Niño drought significantly reduced yields of staple crops; food shortages occurred, particularly on atolls, and tree crops (coconut, breadfruit, etc.) took up to five years to recover from the drought (Fletcher and Richmond 2010). Climate change may also trigger outbreaks of pests such as mealybugs, scale insects, and whiteflies. To prevent and control outbreaks, quarantine, sanitation, and biological control for some pests are recommended. Anecdotal evidence points to a shift in the dry and wet seasons, which caused an increase in crop disease as well as decreased crop productivity. Early warning systems help communities prepare for drought-related changes in agricultural yield.

Figure 14. The College of Micronesia–FSM Cooperative Research and Extension Program is testing climate-smart agricultural practices. Women in the program utilize agroforestry practices for soil enrichment (top left). Other participants apply: integrated soil management for staple crops production (upper right); micro-gardening utilizing locally available resources, as demonstrated by vertical gardening using repurposed shipping pallets (two photos at lower left) and container gardening (lower middle); small plot intensive (SPIN) farming to increase yields and income (lower right). Photos by Murukesan Krishnapillai, College of Micronesia–FSM.

- ***Monitor and encourage research on climate smart agriculture.*** Future agriculture can benefit from evaluating adaptable varieties of both traditional and introduced crops such as taro, cassava, and sweet potato, leaving communities less vulnerable to rising temperature, sea level rise, and rainfall variations. Agricultural interventions to maximize crop productivity can build on traditional knowledge and use new science-based approaches at the same time. Other practices that build resilience to climate change impacts include water conservation and management, soil management, and livelihood enhancement. For example, some women's groups are using agroforestry practices for soil enrichment and accessing higher quality soils deeper in the forest. Small plot intensive farming, micro-gardening, agroforestry, and integrated soil management strategies are some alternative crop production methods that also show promise (Krishnapillai 2018). The College of Micronesia–FSM Cooperative Research and Extension Program tests these climate smart methods with communities in Yap, with the aim of improving livelihoods, food security, and ecological function (see Fig. 14; Krishnapillai 2017).

- ***Atoll communities experience climate challenges and migration; sustainable food production may help them to adapt.*** Climate variability and extreme events have brought unprecedented challenges to remote atoll communities in recent decades, especially in the State of Yap. Atoll communities face

Figure 15. Degraded lands at the site of Gargey Village were transformed with a combination of soil health and land management measures and climate resilient agriculture. At the upper left, a satellite image shows the settlement area in 2003 with exposed, degraded soil evident. In the aerial photo on the upper right, taken in 2007, the community of about 1,000 migrants had begun to settle and land management interventions had started. In 2022, pictured at bottom, residents' interventions increased land cover in Gargey Village by more than 50%, with the planting of 42 varieties of native trees and food crops. Photos courtesy of Murukesan Krishnapillai, College of Micronesia–FSM.

destructive storm surges, saltwater inundation, coastal erosion, and periodic droughts, as once-vibrant traditional agriculture can no longer sustain staple crop production. Climate stressors threaten food security and can drive internal migration, in which communities move from less viable areas to build new lives elsewhere. For example, Yap Island has experienced an influx of internal migrants from atolls. On Yap Island, atoll communities occupy four settlements on lands dominated by degraded volcanic soils (Krishnapillai 2017). To enhance the adaptive capacity of migrants, the Cooperative Research and Extension program of the College of Micronesia–FSM provides outreach, technical assistance, and extension education that resulted in increased food security and livelihood opportunities (Birkmann et al. 2022, Box 8.2). Crop production and native tree plantings have transformed Gargey Village settlement (see Figure 15). This example illustrates the ability of targeted efforts and funding to increase the resilience of communities displaced by climate variability and change.

- ***Prepare for decreased food security and increased prices.*** About 95% of households in the FSM are engaged in agricultural activity (FSM Office of SBOC 2012). However, reliance on agroforestry and associated traditional knowledge has recently diminished with an increased reliance on imported food (Chuuk State Government 2017). Food imports increased from $17 million in 2000 to $43 million in 2009 (FSM Department of Resources and Development 2021a). In addition to the loss of some traditional agricultural practices, food security is further threatened by shocks and stresses affecting food import prices and availability. Access to land is at risk from sea level rise and impacts of soil salinity.

Displaced atoll communities living on Yap Main Island display their garden produce grown as part of the Climate Adaptive Agriculture Resilience (CAAR) Project. Photo by Murukesan Krishnapillai, College of Micronesia–FSM.

- ***Consider opportunities to reduce loss of traditional knowledge and management practices to increase resilience.*** Communities in the FSM have managed and conserved natural resources for centuries. In Yap, for example, taro patches and tree gardens—called agroforests—provide a stable food system that uses natural processes without heavily impacting the watershed or surrounding ecology (Falanruw 1993). Food production in the FSM is highly integrated with natural systems; large areas are diverse ecosystems with a mixture of "wild" forest and agriculture (Lopez 2020). Agroforests occupy a significant area in all four states (FSM Department of Resources and Development 2018). Agroforestry is also deeply culturally significant and loss of agricultural land or practices impacts traditions and customs (Falanruw and Ruegorong 2015). Moreover, in some areas, the soil is no longer fertile because Indigenous practices for soil enrichment have ceased. In Kosrae, ka tree (*Terminalia carolinensis*) and taro cultivation were practiced for centuries, often together, in coastal freshwater wetlands. When ka trees are allowed to regenerate, the system may contribute to the continued presence of ka trees. A household survey found that 70% of those interviewed favored conservation measures for ka forests (Conroy et al. 2011). In addition to its critical role in food supply, traditional agroforestry may promote the conservation of forest species biodiversity (Falanruw et al. 2019).

If you manage ecosystems or biodiversity...

- ***Prepare for changes in rainfall and sea level that threaten terrestrial ecosystems.*** Biodiversity in the FSM is rich and abundant with a high number of endemic species—those found only in the FSM or on a single island (FSM Department of Resources and Development 2018). In Pohnpei, for example, 34% of the recorded plant species and 16% of bird species are endemic (Pohnpei State Government 2016). Island species are vulnerable to climate change for a number of reasons including small geographic range and limited genetic variation. In response to climate impacts such as changes in rainfall patterns and salt water inundation, some species will likely experience distribution shifts, while those that are unable to adapt may face extinction. Climate change combined with land-use change and biological invasions is predicted to have a large impact on the Polynesia–Micronesia Hotspot, a region characterized by high biodiversity that includes the FSM (Conservation International and SPREP 2007, Bellard et al. 2014). Other anthro-pogenic stressors such as mining, logging, pollution, deforestation, and development exacerbate the impacts of climate change (Taylor and Kumar 2016).

- ***Sustainable use of biodiversity can be coupled with economic empowerment and ecosystem-based adaptation.*** Some examples include the Awak Farmers Association, which makes biodegradable plates out of the abundant betel nut palm as an alternative to plastic that generates local income; and the Green Banana Paper Company in Kosrae that creates local jobs by transforming banana stems into paper products (FSM Department of Resources and Development 2018). Meanwhile, the Yela Ka Forest on Kosrae Island is the largest intact ka tree forest in the world and a priority area for invasive species management in the National Invasive Species and Strategy Action Plan. It provides fresh water, food, and medicine to nearby communities. In 2014, 87 acres of the forest were protected through a conservation easement between the landowners, the Kosrae Island Resources Management Authority (KIRMA), and the Micronesia Conservation Trust (MCT). The easement is seen as an opportunity to encourage biodiversity preservation while providing an economic incentive to adjacent populations. As of 2021, the easement has provided more than $111,600 to local families (Micronesia Conservation Trust 2021; FSM Department of Resources and Development 2015).

Dr. Tholman Alik in the Yela Ka Forest in Kosrae state, FSM. Photo by Nick Hall.

If you manage water resources or utilities…

- ***Monitor and prepare for changes to quality and quantity of fresh water.*** The public water supply in the FSM is inconsistent and of limited availability, with about 60% coming from small streams and requiring treatment before use, and the remaining 40% sourced from groundwater. Many outer islands do not have adequate water storage capacity, making residents vulnerable to drought (Yap State Government 2016). Individual rainfall catchments are commonly needed to meet demand, particularly on low-lying atoll islands (Haga et al. 2012; World Bank Group 2021a). Some rivers are polluted as not all residents are served by waste collection services and must dispose of waste on their own, with illegal dumping into rivers often a preferred method. Piggeries near streams can be a major source of bacterial contamination (Fukumoto et al. 2016). With climate change, the increased frequency and intensity of heavy rainfall can lead to high sediment loads impacting water quality. Sea level rise poses the additional threat of saltwater intrusion into the groundwater supply (Mulalap 2013; Fletcher and Richmond 2010).

- ***Identify opportunities to manage water supply uncertainty and variability.*** There is a wealth of traditional knowledge centered around freshwater systems in the FSM that can aid efforts to manage watersheds and provide safe, clean water (Chuuk State Government 2017). Watershed protection could be coordinated through a watershed management plan. A National and State Water Development Plan could help to integrate climate change effects into the prioritization and planning for water infrastructure. Monitoring progress in desalination technology could also prove useful, as it would allow for stable water supply. Water utility managers can also incorporate climate change into new infrastructure design, such as treatment plants, as well as disaster management strategies to ensure outer islands have access to water during emergencies.

- ***Monitor the El Niño–Southern Oscillation (ENSO) and its effects on rainfall and water availability.*** Rainfall patterns can vary greatly from year to year in Micronesia as a result of ENSO. The climatic response to El Niño produces a period of above normal precipitation, often delivered in heavy rainfall events, followed by a period of drought (Fig. 16). During an El Niño year, rainfall starts declining as early as August in Yap and Chuuk and as early as October in Pohnpei and Kosrae. Dry conditions continue through the first half of the next year (PEAC Center 2015a,b). Rainfall across the FSM can be as much as 50–60% below normal through April in the year following the onset of El Niño (PEAC Center 2015a,b). Drought impacts can last through June or longer. A strong El Niño can cause severe drought leading to water and food shortages, fire, and landslides when rain does return. Water levels at the reservoir in Yap can be very low in May and June with strong El Niño; in some years water can only be used for essential purposes to reduce consumption. Seasonal forecasts can help water managers prepare for potential water shortages during drought and plan maintenance and upgrades. In some areas, such as Yap, main water tanks and treatment plants are urgently in need of renewal.

Fig.16

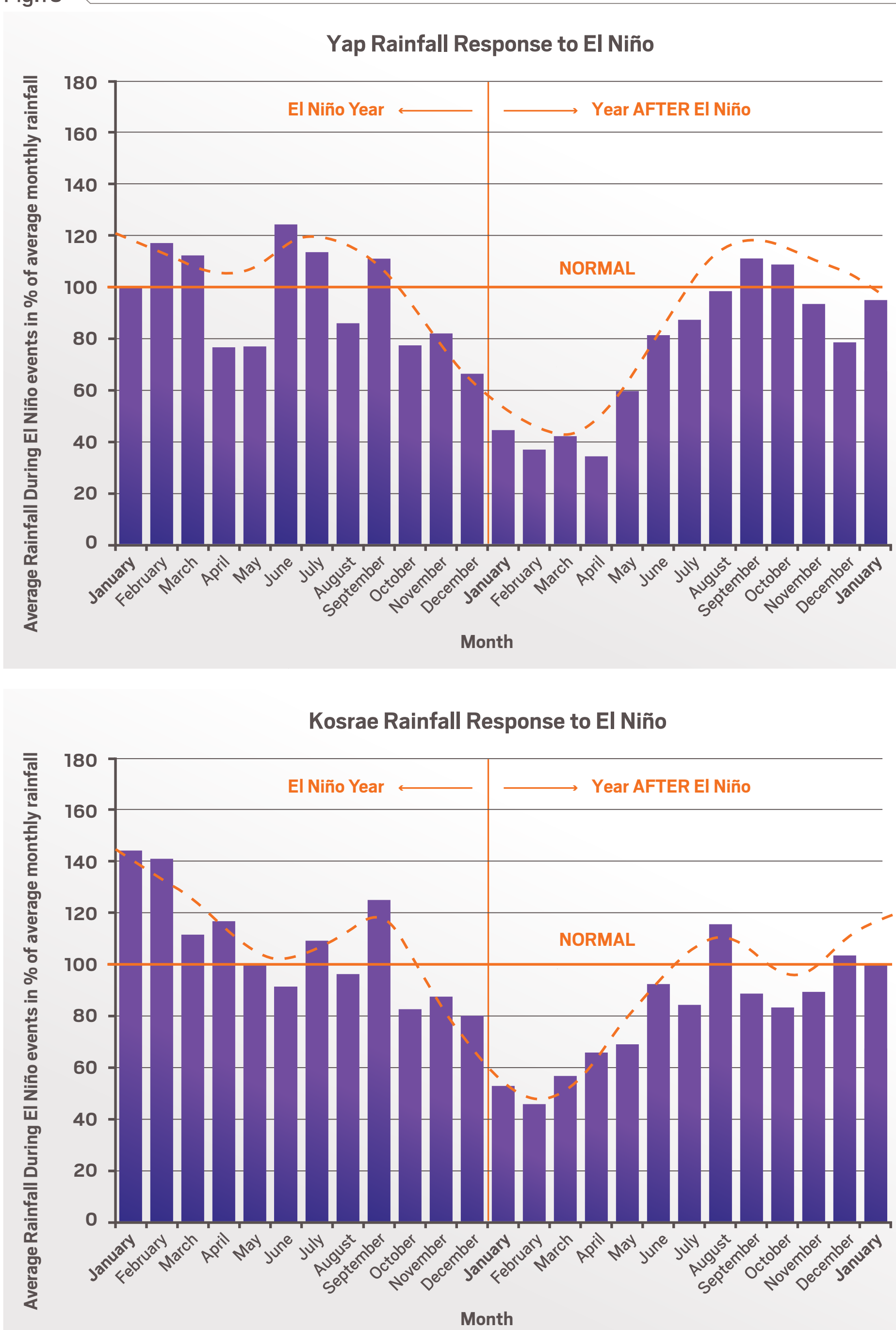


Figure 16. Average rainfall in Yap (top) and Kosrae (bottom) during El Niño events, shown as a percentage of average monthly rainfall. The red horizontal line in each chart indicates the normal level of annual rainfall. Source: PEAC Center 2015a,b.

- ***Research energy systems that decrease vulnerability.*** The FSM has an electrification rate (percent of the population with electricity access) of 75% as of 2016. The dispersed island geography requires multiple independent grids, creating a high cost for utilities (CFE–DM 2019). Moreover, the FSM relies heavily on imported petroleum and diesel, which are vulnerable to price fluctuations. Currently, renewable sources account for only 4.3% of the FSM's energy production. There is potential to expand this share, particularly with solar and wind, which is expected to provide cost-saving benefits in the long term (NREL 2015). The FSM state energy master plans call for collectively reaching 100% electricity access nationally by 2027, with 66% from renewable sources. The plans recommend investment in new generation capacity and maintenance of the existing generation and distribution network (Castalia Limited 2018). The FSM already has experience with renewable electricity generation. A 2009 solar electrification project on Ulithi Atoll in Yap included two solar microgrids. Another project provides affordable, sustainable electricity on Yap's outer islands through off-grid solar PV systems (European Commission 2012). To electrify Yap's outer islands, preference is given to mini-grid projects to facilitate easier maintenance, affordability, and sustainability. Solar Mama is a project with the Chuuk Women's Council that trains women to maintain and operate solar panels.

- ***Measures to protect electrical, water, and other infrastructure can improve reliability, resilience, and energy and water security.*** Possible measures include reinforcing assets that are vulnerable to wind damage, adding greater storage capacity for water collected in drought prone areas, creating microgrids capable of isolating for local self sufficiency during wider outages, and relocating certain assets upslope and away from coastal threats (USGCRP 2018, Ch. 14). For example, Yap Renewable Development Project constructed a wind farm capable of withstanding typhoons, which is expected to generate about 11% of the electrical supply required for Yap, and a new solar farm is planned (ADB 2018).

Mangrove Forests of the FSM

Just two decades ago, the goods and services that the FSM's mangrove forests provide were not very well known. Mangrove forests grow over large expanses of tidal wetlands on individual islands and can stretch hundreds of meters inland from open water. On Kosrae, mangroves occupy 14% of total land area and two-thirds of the shoreline, which is common among FSM's islands. A combination of high rainfall, nutrients, few tropical cyclones, and limited developmental pressures result in large trees, continuous regeneration, and ecological relationships with everything from microbes to crabs to fish. FSM's mangroves protect human communities from wind and waves, trap sediments, sequester nutrients in their soils, and protect seagrasses and coral reefs. They also facilitate uptake of atmospheric carbon dioxide, a greenhouse gas. Mangroves are able to respond to sea level rise by building elevation with trapped sediments and root productivity, and have adjusted to various rates of sea level rise in the past by maintaining their elevation relative to sea level (Ellison and Stoddart 1991; Woodroffe 1995; McKee et al. 2007; Woodroffe et al. 2016).

Understanding how mangroves continue to respond to increasing rates of sea level rise, and other stresses, such as drought, can increase our ability to more effectively manage them (Drexler and Ewel 2001). Mangrove forests with the greatest distance between forest floor and highest tide, or that can migrate inland, should be prioritized for conservation (Rogers et al. 2019; Ellison et al. 2022) so that they can continue to provide FSM with goods and services. Management strategies are needed for mangrove forests that do not keep up with sea level rise. On Pohnpei, modeling indicates mangroves will

Kosrae State Forester Maxon Nithan holds a mangrove crab (*Scylla serrata*) collected from the Utwe River Basin. The harvest of these crabs strongly contributes to the economy of individual islands and provides an important local food source. Photo by Ken W. Krauss, US Geological Survey.

respond to moderate rates of accelerated sea level rise by adjusting species distributions (Buffington et al. 2021b). Thus, mangrove persistence is a real possibility with climate change, as long as these ecosystems are allowed to respond naturally. The value provided by mangroves to offshore fisheries, biodiversity protection, and artisanal inshore fisheries such as mangrove crab, combined with being a source of firewood and construction material, make the FSM's mangrove forests a critical resource for food security and protection as climate variability causes new stresses in individual years. In recognition of this, traditional knowledge and respect for the mangrove resource is ingrained in the cultural history of the FSM.

If you are a coastal resources manager...

- ***Protect the ecological integrity of mangrove forests.*** Sea level rise and more intense heavy rainfall events will produce flooding and damaging erosion in coastal areas. Mangrove forests mitigate the effects of rising sea levels by reducing wave energy, lessening erosion, and retaining sediment. Seawalls and other structures that replace mangroves in some places are intended to reduce erosion, yet have actually worsened it (Krauss et al. 2010). The harvest of even a few trees can result in peat collapse, negatively impacting the forest floor elevation and increasing the forest's vulnerability to rising sea level (Krauss et al. 2010). Protecting and restoring natural shorelines and ecosystems as alternatives to hard structures can improve the resilience of coastal communities (Narayan et al. 2016; Mycoo et al. 2022). Healthy ecosystems are known to provide cost savings from avoided flood damages (Arkema et al. 2013). Furthermore, conserving intact mangroves and restoring degraded forests enables them to continue to support livelihoods (Donato et al. 2012). Fringe mangroves may be the most resilient to sea level rise (Sasmito et al. 2016; Ellison et al. 2022) and conservation efforts could be focused there (Krauss et al. 2010).

- ***Consider cultural heritage and traditional knowledge in coastal adaptation measures.*** Traditionally, communities had temporary structures along shorelines and built residences inland. Currently, approximately 89% of the FSM's population lives within one kilometer of the coast, and buildings and infrastructure are vulnerable to coastal climate impacts (Andrew et al. 2019). Pacific Islanders have used adaptations such as exchange networks, "cyclone foods," and coastal stonework for millennia (Nunn et al. 2017a). Deeply rooted social norms and values are likely to support resilience and adaptation to climate change, as they have during events when resource availability has been stressed, such as during World War II (Perkins and Krause 2018). Each island will have a different capacity based on its geological, ecological, socioeconomic, and cultural context (Perkins and Krause 2018). Local communities in Yap, for example, have resource management, social structure, and land tenure systems that promote resilience and bolster adaptive capacity (Perkins and Krause 2018). Traditional leaders often implement new policies quicker than a legislative process (Victor et al. 2006), but traditional governance is limited by ongoing colonial dynamics (Bordner et al. 2020).

- ***Prepare for increased flooding and storm surge to affect coastal infrastructure.*** Coastal infrastructure is particularly vulnerable to climate impacts due to the concentration of populations and development in low elevation and coastal areas (Taylor 2021). In the FSM, 71% of built infrastructure is within 500 meters of the coastline, including critical facilities such as seaports, airports, and five out of seven medical facilities (Taylor 2021). The FSM is also far from major trading centers and has the additional cost of linking goods and services among islands (Taylor 2021). Road infrastructure is vulnerable to extreme rainfall, elevated temperatures, higher sea levels, and storm surge (Regmi and Hanaoka 2011). Insufficient water drainage can also be an issue in some areas, such as on Pohnpei, and can restrict transportation and access across the island (Pohnpei State Government 2016). The Dekehtik Causeway in Kolonia, Pohnpei, is a crucial transportation link between the airport and seaport, but is increasingly affected by king tides and sea level rise. “Climate proofing” interventions such as raising roads may help to extend the life of coastal development (Fletcher and Richmond 2010). One such project, Priority Road Improvements and Management Enhancements (PRIME), a World Bank-funded initiative under former President David Panuelo’s Pave the Nation program, aims to provide a climate resilient road network across the FSM (Staff, Pacific Island Times, 2021).

- ***Prepare for rising sea level and increased localized impacts.*** Sea level rise is projected to accelerate (see “Indicators of Climate Change in the FSM,” page 20). Exposure of communities and infrastructure varies across islands and locations, and is shoreline specific, with evidence of land accretion in some places and disappearance in others, underscoring the highly localized impacts (Nunn et al. 2017b; Sengupta et al. 2021). Sea level rise and variability has already resulted in coastal erosion, shoreline inundation, and saltwater intrusion, leading to significant losses in crops and freshwater sources (Keim 2010; Fletcher and Richmond 2010). For example, in 2007 saltwater inundation destroyed 90% of the taro crops in Chuuk, up to 100% on some islands in Pohnpei, and 90% in Falalop, Ulithi in Yap State (Hezel 2009). Coastal flooding, including from extreme tides, causes residents to evacuate, putting additional stress on limited available land area (Mulalap 2013). At least half of the mangroves on Kosrae and Pohnpei are not keeping up with current rates of sea level rise (Krauss et al. 2010; Lovelock et al. 2015). Sea level rise effects are currently most extreme on leeward reef edge islands and their fringing mangroves (Krauss et al. 2010).
- ***Consider measures to promote natural barriers that can protect the coastline.*** Three types of coral reefs present in the FSM all provide protection, as do mangroves, seagrasses, and intertidal flats (Fletcher and Richmond 2010; Victor et al. 2006; Krauss et al. 2010), as long as they keep pace with rates of sea level rise. Loss or degradation of these prevalent ecosystems can put coastal communities at additional risk (Kosrae State Government 2016; Woltz et al. 2022). Threats to coral reefs include thermal anomalies, COTs, and land use change that affects water quality. Conservation efforts are needed to protect nearshore reefs in order to help them keep pace with sea level rise (van Woesik and Cacciapaglia 2019).

Climate change, sea level rise, and erosion

A number of coastal development practices in the FSM can worsen coastal hazards including erosion, seawater inundation, and flooding. Those practices include: sand, gravel, and coral rubble removal; reef flat dredging; stream outlet repositioning; building seawalls; land reclamation in flood-prone areas; and road development over mangroves. Climate change exacerbates these hazards (Kosrae State Government 2016). As beachfront is lost, some burial grounds and family homes along the coastline are at risk from erosion and inundation or may even be lost to the sea (Monnereau and Abraham 2013a).

Coastal burial area subject to erosion in Kosrae. Photo by Carlos Cianchini, courtesy of Iris Monnereau.

In Chuuk, the low-lying outer islands contend with erosion and some residents are choosing to move inland. Coastal hazards and erosion are priorities for action in the 2017 Chuuk Joint State Action Plan for Disaster Risk Management and Climate Change. Pohnpei's outer islands also experience severe erosion, mainly where mangroves have been cleared (Nunn et al. 2017b). Pohnpei's Urban and Community Forestry program, Kosrae Island Resource Management Authority, and FSM's Ridge to Reef program all use mangrove rehabilitation and conservation projects to stabilize shorelines. In a 2013 study, 87% of households interviewed in Kosrae indicated they experienced adverse effects from coastal erosion, and of those, 80% said their household economy was affected, mostly from loss and damage to crops, trees, and housing. Although half of respondents reported taking adaptation measures such as building seawalls (29%), landfilling (29%), planting trees along the coastline (15%), and elevating houses (11%), most (92%) said those measures were insufficient (Monnereau and Abraham 2013a).

Strategies can be employed to make coastal areas more resilient to climate impacts. Climate proofing existing infrastructure is a strategy that shows promise. The goal of the Pacific Adaptation to Climate Change (PACC) project is to complete the circumferential road around Kosrae island to provide access to the remote village of Walung and upgrade sections of already-built road to withstand sea level rise, high tides, and heavy rains. The PACC program re-designed road sections that crossed mangrove areas to support ecosystem connectivity under sea level projections. However, this type of intervention can also lead to ecosystem degradation. KIRMA and USFS are now working to restore mangroves in the area, which have been opened up to harvest. Despite some issues, the PACC project helped to mainstream climate risk management into development policy and planning, including supporting the Climate Change Act in Kosrae in 2011 and the revision of a shoreline management plan (SPREP 2015). The plan outlines key strategies to reduce coastal hazards including erosion and protect communities and infrastructure. An Adaptation Fund project is simultaneously working to construct an inland road connecting Malem and Utwe, and a recently approved World Bank project aims to improve the climate resilience of the FSM's primary and secondary road networks to deliver safer road connections to schools, clinics, and communities. Other ways to manage coastal erosion include relocating development to inland or uphill areas, protecting the ecological integrity of mangrove forests, maintaining coastal defenses already in place, and including climate impacts in policies (Ramsay and Webb 2021; Monnereau and Abraham 2013b; SPREP 2015; Gombos et al. 2014; Fletcher and Richmond 2010).

If you work in public health...

- ***Prepare for extreme weather events that challenge health care delivery and worsen health outcomes.*** Globally, tropical cyclones are becoming more intense, with higher wind speeds, greater rainfall amounts, and higher storm surge. Although the future outlook for tropical cyclones in the FSM is still uncertain, projections indicate that strong typhoons will be more likely to occur in the future as ocean temperatures warm (Ranasinghe et al. 2021). Flooding—from both marine inundation and heavy rainfall—are likely to be more frequent and intense in the future. The impacts on human health can continue long after a weather-related disaster when people face challenges such as inability to obtain medications, disrupted transportation networks, no access to emergency services or health care, lack of electricity to run medical equipment, and shortage of trained medical professionals (Mitchell et al. 2014; Kishore et al. 2018). Infectious disease outbreaks can increase after disasters, but prevention and control measures are shown to help (Kouadio et al. 2014). Adaptation actions at multiple levels—from individual health to healthcare facilities and public infrastructure—are needed to prepare for and manage health risks in a changing climate (USGCRP 2018, Ch. 14, KM3).

- ***Future sea level rise is expected to impact some medical facilities, and health infrastructure may need to be retrofitted, redesigned, or relocated to ensure continued operation.*** Although there are no vulnerability analyses of FSM's medical infrastructure to climate change and sea level rise, some medical facilities are located close to the shoreline (Taylor 2021), which suggests some facilities may be exposed to sea level rise impacts. Outer island emergency referrals and lack of investment in road infrastructure to state hospitals are major issues in the FSM. Currently, no dedicated medical evacuation plans are in place.

- ***Prepare for more frequent hot weather and heat waves that are expected to increase heat-related illness and death.*** Some groups are at higher risk of becoming ill or dying due to extreme heat, including people with chronic illnesses, older adults, and children (Sarofim et al. 2016). In the FSM, the leading causes of death are non-communicable diseases (NCD), including heart disease, diabetes, cancer, and hypertension (Ichiho et al. 2013a–d). In Pohnpei State, for instance, more than half of the population (56.7%) is at high risk for NCD. The diabetes prevalence is 37% for women and 26% for men (Ichiho et al. 2013c). Heat exposure can worsen the outcomes for people with these conditions. For example, prolonged exposure to extreme temperatures can increase hospitalizations for cardiovascular, kidney, and respiratory disorders (Sarofim et al. 2016). Rising temperatures also challenge the management of NCD because exercise is difficult to do safely in hot weather. Education and awareness activities about the effects of climate change and health at the community level are currently limited.

- ***Monitor research on the climate's effects on diseases.*** Future warming and rainfall changes will likely increase the suitable habitat for pathogens and vectors, thereby increasing the risk of outbreaks of dengue fever, malaria, diarrhea, salmonellosis, and other diseases (Mora et al. 2018; Trtanj et al. 2016). In the Pacific, influenza-like illnesses, diarrheal diseases, and febrile illnesses were identified as potentially sensitive to climate change (McIver et al. 2016). Rainfall is observed to correlate with outbreaks of leptospirosis, which is a frequent cause of febrile illness typically involving joint aches and pain and is associated with dogs, pigs, and rats (Colt et al. 2014). Outbreaks often occur one to two weeks after heavy rainfall. Likewise, the frequency of dengue and lymphatic filariasis, two endemic, mosquito-borne infections, is also related to rainfall (McIver et al. 2015). Dengue fever has markedly increased in prevalence in the FSM in recent times and cases often go unreported. The small atoll islands of the FSM have a high concentration of lymphatic filariasis (Pretrick et al. 2017). In addition to mass drug administration to eliminate lymphatic filariasis, controlling mosquito breeding sites is a proven preventive strategy. Kosrae has experienced periodic dengue outbreaks in the past. The sporadic outbreaks were most likely related to the vector population's rise and fall. However, until 2013, no reliable data existed on the dengue vector population in Kosrae (Noda et al. 2013). Understanding the correlation of local mosquito populations with rainfall can be used to enhance the environmental management of dengue. Community-level adaptation measures can limit human vulnerability to disease (Beard et al. 2016; Radke et al. 2012).

- ***Disease surveillance can aid the assessment of trends and serve as an early warning system.*** Ongoing surveillance of febrile syndromes and integration with weather monitoring systems can effectively detect potential early signals of an outbreak. Preliminary analysis of syndromic surveillance data from Pohnpei State hospital show that diarrheal illness and influenza-like illnesses account for more than 90% of infectious disease syndromes across all age groups (Itaki and Hadley 2021). The highest frequency is in children aged 0–10 years. Correlation of infectious disease syndromes with rainfall data suggests that influenza-like illnesses are negatively correlated with rainfall and febrile illnesses are positively related to rainfall (Itaki and Hadley 2021). Combining syndromic surveillance trends with meteorological variables can provide evidence to inform policy development, health promotion, and health service planning. Such approaches will strengthen health systems to be more responsive, resilient, and adaptable to climate change.

- ***New diseases may emerge, carrying the risk of outbreaks or pandemics that interact with the impacts of climate hazards.*** New diseases have arrived in Micronesia in recent times. Zika appeared for the first time in Micronesia in 2007 when Yap experienced a widespread outbreak (Duffy et al. 2009). Climate change–related habitat shifts can bring different species closer together, increasing risk for disease transmission (Zang et al. 2021). Furthermore, climate-related extreme events can affect the response to disease outbreaks, adding challenges for the public to limit disease spread and for the health sector to provide needed prevention and care (Salas et al. 2021). For example, the novel coronavirus (COVID-19) pandemic had large social and economic impacts on FSM's populations. The disruption of access to schools and health facilities during the COVID-19 pandemic put populations at increased risk in the face of climate-induced hazards (Phillips et al. 2020). Pandemic preparedness could be included in climate preparedness efforts, as other pandemics are likely in the future.

- ***Traditional food systems promote food security and nutrition in FSM households.*** In addition to greater potential for food- and water-borne disease, climate change increases challenges to nutrition and food security. Climate change is likely to drive up the prices of imported foods (USGCRP 2018, Ch. 16 and 17). Increasing storm intensities threaten food supply by disrupting food production, processing, and transport infrastructure (such as ports and harbors in the FSM and internationally). Projected declines in coral reef and coastal ecosystems will impact subsistence fishing and market fisheries. Similarly, subsistence agriculture and agroforestry will be challenged (see section on agriculture and agroforestry). Sufficient, nutritious food is essential to supporting human health, and interventions can help. Increased production and consumption of local foods (such as banana, giant swamp taro, and local vegetables) improves diet, decreases the NCD burden, and increases food security (Englberger et al. 2010; 2011).

- ***Climate change has consequences for mental health.*** Climate change directly and indirectly affects mental health. In some places, local climate stressors are shown to increase sadness, distress, and anger (O'Brien et al. 2014; Asugeni et al. 2015; Gibson et al. 2019). In the Pacific Islands, ecological devastation can add stress for Indigenous people because conceptions of identity and wellbeing are strongly tied to place. Rural populations, people with disabilities, and socioeconomically disadvantaged populations may be at greater risk of experiencing mental health impacts of extreme weather and climate change (O'Brien et al. 2014; Speldewinde et al. 2009; Gibson et al. 2019). If populations are displaced due to sea level rise–driven inundation or other climate impacts, the resulting migration is likely to be a source of anxiety (Albrecht et al. 2007) and have lasting consequences for mental health, although there are no such assessments in the FSM to date.

If you work in disaster management or disaster risk reduction...

- ***Prepare for hotter days, critical water shortages, and wildfires, particularly in Chuuk and Yap.*** An increase in hot days and a decrease in cool weather, along with an increase in extreme rainfall, is projected across the FSM (Australian BOM and CSIRO 2014). The probability of heatwaves is also predicted to steadily increase (World Bank Group 2021a). Chuuk and Yap are prone to wildfire during the drier season of December to June, and particularly vulnerable to fire during times of drought (Polhemus 2017; Figure 17). In contrast, wildfires are rare in Kosrae and Pohnpei because of their wetter climates. Fires make way for the spread of invasive *Pennisetum* grass, which exacerbates the fire risk because it is more prone to burn than the forests that had previously covered the land (FSM Government 2021; Polhemus 2017). Seasonal heavy rainfall increases the prevalence of this grass, making extensive fires more likely. Yap has a comprehensive fire reduction and control strategy, potentially accounting

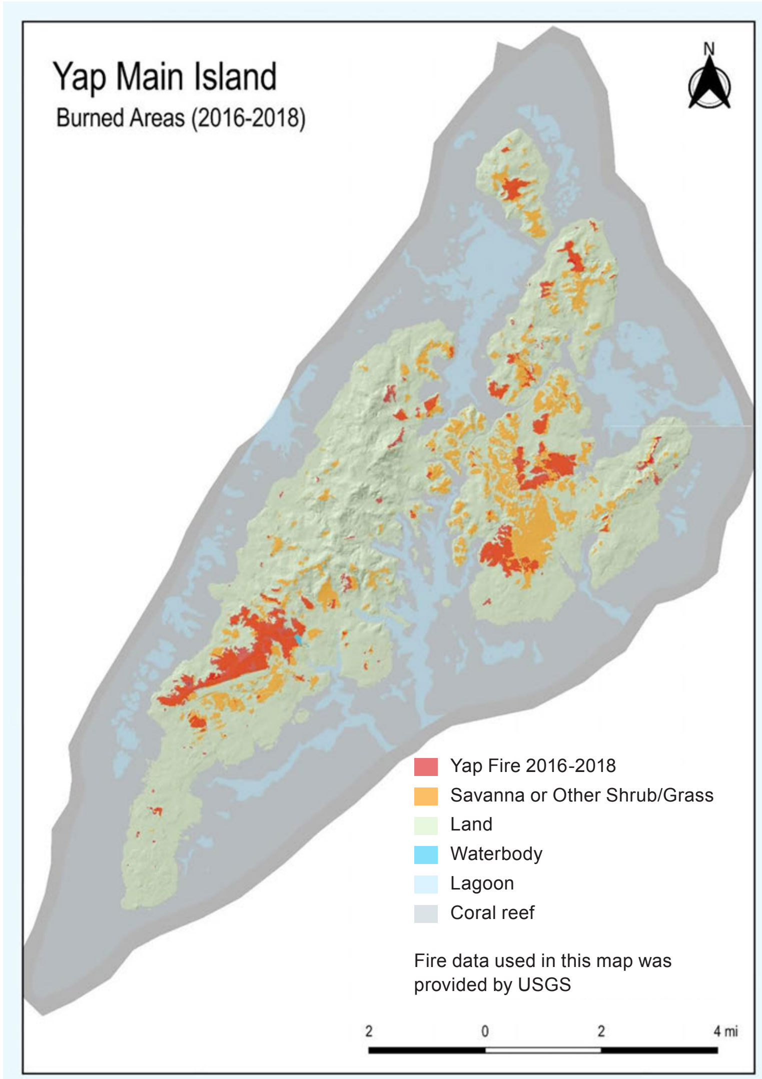


Figure 17. Map of burned areas from 2016 to 2018 based on USGS survey data in Yap Main Island, FSM (From FSM Department of Resources and Development's Forest Action Plan 2020–2030, 2020, p 228).

for the lower incidence of fire during the 2015–2016 drought than the 1982–1983 drought (FSM Department of Resources and Development 2021b; Polhemus 2017). Chuuk and Yap are the most at-risk states for drought and critical shortages of water (CFE–DM 2019).

- ***Plan for more intense tropical cyclones.*** The FSM is in the Typhoon Belt, and the western states are particularly impacted by the West Pacific Monsoon (Chuuk State Government 2017). Yap alone is affected by 3–5 typhoons every year (Yap State Government 2016). In 2015, Typhoon Maysak wiped out 90% of key agricultural crops such as banana, breadfruit, and taro in Chuuk and Yap, affecting 29,000 people and causing $8.5 million in damages (World Bank Group 2021b). Typhoons and storms can also bring devastating secondary effects. Typhoon Chata'an in 2002 and the resulting heavy rainfall triggered landslides in Chuuk, killing 43 people (Sanchez et al. 2009). It also destroyed 231 structures and buried roads, crops, and entire watersheds (Harp et al. 2009). Typhoon intensity—measured through wind speeds, rainfall rates, and storm surge heights and extent—is projected to increase in the western North Pacific, including the FSM, with global warming (IPCC 2021). There is still some uncertainty in typhoon and storm projections, so monitoring the latest scientific research can be useful to plan ahead (Pohnpei State Government 2016).

- ***Other disasters, particularly earthquakes and tsunamis, can coincide with climate change events and other stressors, increasing the overall threat and impact.*** The FSM is also within the Pacific "Ring of Fire." Yap State experienced earthquakes in recent years and is vulnerable to tsunamis because it is low lying and islands are separated by significant distances. To date, however, no tsunami has been recorded to cause significant damage (Yap State Government 2016). When combined with other disasters, climate impacts can multiply the threat and risk levels to communities. For example, after a tsunami struck American Samoa in 2009 and destroyed coastal infrastructure, the community experienced an increase in dehydration, heat-related illnesses, and barriers to receiving medical care (Choudhary et al. 2012). Accounting for the interactions of non-climate and climate hazards when developing pre-disaster mitigation plans can enable responses to adequately address multiple challenges during a disaster.

- ***Consider strategies to reduce risk from disasters in the context of climate change.*** The FSM is vulnerable to a variety of natural hazards, including typhoons, landslides, storm and tidal inundation, flooding, drought, fire, and earthquakes. However, risk levels vary significantly across states. Some communities are more vulnerable as a result of factors such as lack of health facilities or inner road networks that allow access to higher ground (Micronesia Red Cross Society 2021). States and communities can take actions to reduce vulnerability. Improving awareness and knowledge of natural warning signs, communication between and within islands, community preparedness, and targeted disaster education can all improve resilience (Sanchez et al. 2009). In some areas, landslide hazard assessment and mapping could be helpful (Harp et al. 2009). Preserving ecological integrity can also mitigate risk, as environmental degradation and urbanization increases exposure to hazards (CFE–DM 2019). Traditional methods that support disaster preparedness, such as offsetting food variability with fermentation of breadfruit, can be effective as well (Kosrae State Government 2016).

- ***Consider climate change and disasters in development and infrastructure projects.*** Including disaster risk reduction in development projects, especially for critical infrastructure such as hospitals, can prepare coastal areas for climate shifts (Taylor 2021). For example, shipping ports in the FSM aren't usually congested but they do have limited equipment. A bottleneck during a disaster would put the island at additional risk (CFE–DM 2019).

If you are a cultural or historical resources steward…

- ***Sharing traditional knowledge can help future generations.*** Traditions and customs are essential to the livelihoods of people in the FSM. During climate-related hardships, traditional practices such as fishing and agriculture become vital for survival. While disasters caused by typhoons, monsoons, and droughts are not new to the FSM, the frequency and intensity of occurrences of some phenomena are changing in the islands. The people of the FSM endured various hardships throughout history, some related to climate change. The elders retell the lessons and experiences of struggling to survive when resources become scarce (usually evident in the aftermath of a typhoon, for instance) to the younger generation (Perkins and Krause 2018). Oral history or storytelling is one of the many unique characteristics of cultural heritage that was and is still prevalent in the FSM.

- ***Reinforcing traditional construction methods or structures can maintain cultural values in the community.*** Oral history can teach newer generations the knowledge, skills, techniques, and strategies needed to survive climate-related disasters as their ancestors did. In Yap State, stonework construction strategies are one of the traditional, historical methods people use as adaptive responses to changes in sea level (Perkins and Krause 2018). However, the evolving effects of sea level rise continue to challenge this traditional strategy. Traditional men's houses, or faluw, serve significant cultural purposes. Sometimes, they must be rebuilt in different locations or abandoned due to permanent damage caused by ocean waves. Typically, faluw were built near the sea for easier access for Yapese men when they disembarked from their canoes or motor boats. Because of their location near the sea, the traditional houses are exposed to wave erosion and strong swells during high tides. This recurring phenomenon has compelled people to use non-traditional methods, such as cemented platforms elevated 1.5 m above the high tide to reinforce the foundations of the traditional houses (Nunn et al. 2017a). Other times, the houses are built at locations that are more inland.

- ***Preserving traditional foods and agriculture can bolster food security.*** In addition to cultural houses, sea level rise affects traditional food production. Like the few abandoned faluw, people forsook taro gardens or taro patches near the coastlines as the sea level rose in historic times. However, indigenous people used adaptations, such as stone-lined enclosures, taro plantings raised above coastal groundwater tables, and replanted mangroves, to respond to sea level rise (Nunn et al. 2017a). Based on these historical experiences, similar adaptations can be used today to ensure local food supply and help communities to buffer global supply chain disruptions.

An oceanside faluw in Yap. Photo by CLM Photography.

- ***Managing native trees and plants can increase traditional medicine and uses.*** Most people living in atolls or the outer islands in the FSM have limited access to modern medicine prescribed in state hospitals or private clinics, usually located only in the main islands of each respective state. The alternative healing method is traditional medicine. Essentials of traditional medicine come in many forms, such as trees, herbs, and other native plants. About 76% of plants in the FSM are found nowhere else in the world. Likewise, the traditional knowledge of their uses exists only in communities of the FSM (Balick et al. 2019). Climate change threatens native plants and trees—vital pillars for maintaining the FSM's cultures. It is common knowledge that intense storms or typhoons wreak havoc on communities. However, more knowledge is needed about how natural disasters impact traditional medicine. In 2004, Typhoon Sudal destroyed or damaged many trees and plants that served cultural medicinal purposes in Yap. In the wake of the typhoon, surviving large trees were cut as materials for housing restoration or commercial use, which decreased the supply of traditional local medicines (Falanruw 2015). As most trees take many years to reach maturity, the sustainable management of forest resources is crucial for preserving traditional medicine.

If you work in economic development or tourism...

- ***Expect economic disruptions, increased costs, and climate-related risks to local businesses.*** Climate changes—both gradual and abrupt—disrupt the flow of goods and services that form the backbone of economies (Houser et al. 2015). Climate change is expected to increasingly affect trade and economies internationally beyond the FSM, affecting prices and availability of goods. Import and export price fluctuations and unanticipated impacts on supply chains and customers can disrupt local businesses (Smith et al. 2018). To reduce risk, businesses can proactively research and prepare for the impacts of climate change on their customers, employees, communities, supply chain, and business model (Goldstein et al. 2019). Some financial institutions are requiring demonstrated climate adaptation plans to secure financing for new development.

- ***Climate change may increase current migration trends, with implications for the labor force and national economy.*** Migration from the FSM to Guam, the CNMI, Hawaiʻi, and other US locations has greatly increased since 1980 (Hezel 2013). It is estimated that one-third of FSM-born people live outside of the FSM (Hezel 2013). Climate change may motivate more people to migrate. Factors such as human health impacts and sea level rise–driven inundation that degrades water supplies, lands, and resources relied upon for subsistence or livelihoods can increase migration (Krzesni and Brewington 2022). Availability of labor (especially wage labor), already chronically short in the FSM, would likely further decrease if migration flows increase. Remittances from those living abroad are a significant source of income for the FSM, but the total amount appears to have decreased between 2006 and 2012 (Hezel 2013). This suggests more out migration will not necessarily increase remittance income.

- ***Prepare for coral reefs and nearshore ecosystems to support fewer recreational and tourism activities.*** Although the number of tourists visiting the FSM has decreased and is relatively small, coral reefs generate approximately $16 million per year in on-reef and reef-adjacent tourism for the FSM (The Nature Conservancy 2021). In the next few decades, more frequent coral bleaching events and ocean acidification will combine with other stressors, with likely declines in coral reef cover. Tourism activities that do not rely on the reef may help to buffer the economy and tourism-reliant businesses against the impacts.

- ***Research and monitor innovative insurance mechanisms.*** The risks posed by climate change, for example to coral reefs, are often too great for companies, individuals, and local governments to cover on their own. Countries with greater insurance across sectors experience better GDP growth after weather-related catastrophes (Melecky and Raddatz 2011). There are an array of options to manage climate-related risks, including weather-indexed insurance products and risk transfer-for-adaptation programs. Some cities and states buy catastrophe bonds or parametric insurance policies. For example, the government of Quintana Roo, Mexico, purchased a parametric policy that would provide up to $3.8 million to repair tropical cyclone damage to their coral reef (Gonzalez 2019). This kind of policy provides a fast payout to quickly address impacts from a triggering event. The government could consider similar mechanisms for protecting the FSM's significant ecological resources.

If you are an educator or education decision-maker...

- ***Consider improving classroom buildings conducive to learning and sheltering, and account for climate change in infrastructure development and maintenance.*** Hot weather is not uncommon in the islands and projected to increase over time due to climate change. While heat is often associated with health issues, it can also impact students' learning. The impacts may be worse in classrooms that lack cooling systems such as AC units, ceiling/wall fans, or vents for natural breezes. Furthermore, classrooms can provide safe shelter for people living near the coastline affected by strong storms, heavy rainfall, flooding and/or ocean surges. In these instances, people may seek shelter in schools located at higher elevations and away from the sea. That schools are used as shelters further highlights the importance of bolstering their integrity given the increased future risk of storm surge and sea level rise. The National Infrastructure Development Plan sets aside funding for infrastructure and identifies failure of water and power supplies, poor maintenance, a shortage of supplies, and a lack of facilities, as some of the main issues that additional funding

Ohmine Elementary School students performing a skit during the CADRE Pilot Program Closing Ceremony in Pohnpei State, FSM. Photo courtesy of IOM.

could address for schools (Pohnpei State Government 2016). After Typhoon Maysak in 2015, some schools closed for over a year due to damaged sanitation systems (CFE–DM 2019). Severe drought in 2016 led to temporary school closures in Pohnpei due to water scarcity.

- ***Consider enhancing human resources in climate change–related areas.*** Human resources capacity is one of the challenges in implementing needed projects in the FSM (Davies et al. 2019). Hence, some projects may warrant specialized skill sets and knowledge to enhance resilience of the community to climate change. Training and educational opportunities in climate-related areas such as environmental management and sustainability, infrastructure design and maintenance, and urban and regional planning can strengthen the human resources capacity in the FSM. Further, ensuring these opportunities exist locally will increase the technical capacity available in-country. The College of Micronesia Land Grant Program, for example, provides education and technical assistance to FSM communities and currently works on six “critical issues”: 1) lack of local food production and food security; 2) sustainable aquaculture development; 3) youth and family issues in the communities; 4) climate change challenges; 5) food and waterborne illnesses; and 6) childhood obesity.
- ***Including climate change in school curricula can ensure students are aware of the effects of climate change and adaptation strategies.*** The International Organization for Migration (IOM) worked with the FSM to include disaster education through the Climate Adaptation, Disaster Risk Reduction and Education (CADRE) program. It also offered emergency training and first aid instruction (CFE–DM 2019). Educational materials exist for increasing knowledge about water supply, sanitation, and health in Micronesia. Use of this and other climate adaptation–focused curricula could be expanded in public education.

Needs for Research and Information

This assessment identified the following research and information needs that, if met, could enhance and support responses to extreme weather and climate change.

- ***Maps of inundation risk and vulnerability*** – Localized sea level research, projections, and mapping can provide communities with information useful for planning (Gesch et al. 2020). Such information can be used to develop an inundation timeline to inform state and national plans, and specifically to form a National Adaptation Plan (Davies et al. 2019; Fletcher and Richmond 2010). Passive inundation models alone (the so-called "bathtub" approach) underestimate the total land area exposed to flooding. Vulnerability mapping that includes wave action, multiple SLR stresses, and dynamic responses of coastal ecosystems (such as the Wetland Accretion Rate Model of Ecosystem Resilience; Buffington et al. 2021a) can provide useful models of future inundation. Sea level rise poses threats to food and water security, and the FSM's low lying atolls are particularly exposed to such impacts. Effective community-level resilience measures rely on detailed, island-scale sea level rise information.

- ***Comprehensive digital elevation models (DEMs) for all islands in the FSM*** – It is almost impossible to conduct reliable modeling and infrastructure and habitat migration planning without reliable absolute elevation data relative to mean sea level. A comprehensive aerial-based light detection and ranging (LIDAR) survey needs to be commissioned for all of the FSM, and processed into digital elevation models to match to infrastructure, homes and development, and terrestrial, intertidal, and sub-tidal habitat (to the degree possible at the time of survey) (Government of the FSM 2015). LIDAR imagery is critically needed to accurately assess exposure to sea level rise and storm surge. This is especially important for low-lying atolls (Government of the FSM 2015).

- ***Defining appropriate and effective Nature-based Solutions (NbS) to climate change in the FSM*** – Use of what has recently been defined as NbS approaches is currently being implemented in climate adaptation policy and action around the world. However, the science of NbS lags significantly. Most expectation for what NbS approaches might provide versus costs of implementation is being driven by what natural ecosystems (coral, mangrove, seagrass, shoreline forest strands) provide currently. Specific NbS approaches need to be rated by cost vs. ability to self sustain vs. actual benefit provided (for example, limiting greenhouse gas emissions, wave suppression, carbon sequestration) to the FSM and, more generally, to Pacific Islands. Furthermore, national assessments need to include how connected habitats, such as mangroves and coral reefs, provide synergistic value as both natural systems and incorporation into NbS approaches (with emergent value), which might also include economic accounting/valuation of environmental services (FSM Department of Resources and Development Government 2018).

- ***Documentation and sharing of traditional Micronesian knowledge of climate change and disaster management systems, food systems, and healing practices*** (Yap State Government 2016) – Practices used for many generations will continue to be important sources of resilience to extreme weather and climate events. For example, techniques for storing breadfruit and other foods are important in times of crisis. Research and trials are needed to understand ways to adapt some of these practices to new stressors such as sea level rise and intensified drought. Documenting traditions helps to ensure their accessibility and continued practice. One way to document traditional Micronesia knowledge could be a techniques manual. This knowledge is held and owned by Indigenous people of the islands and, thus, must be documented by them and only with the prior informed consent and permission of knowledge-holders.

- ***Research supporting food security*** – Furthering the research already underway on "climate smart" farming and agroforestry methods and resilient cultivars, in combination with an expansion of the cultivation of Indigenous food and historical food security practices, can increase the resiliency of the FSM's food systems. For example, Indigenous knowledge combined with contemporary science for improved gardening, aquaculture, and food storage and processing is already being experimented with in the FSM (Krishnapillai 2017). Increasing local food security can boost health outcomes and lower rates of non-communicable diseases (Englberger et al. 2010).

- ***Quality controls and expanded coverage in climate data*** – The FSM Government cited inadequate meteorological capability, an absence of climatologists, and lack of adequate baseline information to measure change and assess impacts in the FSM as a root cause of constraints to implement climate change policies. Expanding meteorological and climatological monitoring capabilities can help to provide baseline information and measure change. For example, there is a need to increase the number and distribution of rain gauge stations across the FSM. When developing better monitoring, it is recommended that observation and application systems are user friendly for local communities. In addition, an assessment of women in climatology and the broader field of environmental STEM research could help identify and fill gaps in technical expertise.

- ***Enhanced early warning systems and hazard communication, specifically for children and people with disabilities*** – Priorities for enhancing disaster communication and response were identified in the FSM states' Joint State Action Plans (JSAPs) and still need to be implemented. Most JSAPs will expire soon and updates to their assessments and recommendations are needed, which involve cross department collaboration. Enhanced information about local climate change risks and support needed for adaptation can form the basis for the JSAP updates.

- ***Integrated assessment of international partnerships and financial instruments to aid adaptation efforts*** – Given that enhanced technical capacity is needed to build adequate adaptation measures (Monnereau and Abraham 2013b), identifying partners to provide training and technical assistance can improve the effectiveness of international finance. Also needed is research that reveals how regional and international agreements that address climate change and shifting ocean resources, such as the Nauru Agreement, can be leveraged in support of climate adaptation (Bell et al. 2021; Sumby et al. 2021).

- ***Socio-economic data and information to support vulnerability and adaptation assessments*** – Information on changing demographic and economic patterns and trends can inform and help to target adaptation measures. Such studies might include studies on gender mainstreaming in relation to climate change, and studies on climate change and social cohesion.

▸ **Needs for Research and Information**

- ***Ethnographic/qualitative research*** – Ethnographic and qualitative research methods can be applied to assess: cultural consequences of human migration; safety net provided by cultural heritage; overall impact of US financial assistance on migration; and impact of climate on migration, particularly in the outer islands of the FSM (Perkins and Krause 2018). Gathering human mobility data can enable decision makers to better understand reasons for movement (education, jobs, healthcare). In the FSM, increased migration from outer, low-lying islands is a long-term management challenge. The adoption of national policy on how to integrate the value of human security in addressing climate change mobility may help to guide state-level policy and governance around internal migration.
- ***Research defining coastal wetland migration corridors to assist with selecting areas to protect for future SLR-driven habitat shifts*** – Inundation vulnerability mapping (a priority noted above) should include coastal wetland adjustment, plant species shifts, and migration opportunity. A national assessment of sea level rise vulnerability of coastal wetlands for the FSM was initiated by the US Geological Survey and USDA Forest Service, beginning first with Pohnpei and Kosrae (Buffington et al. 2021b). Research efforts need to expand to Chuuk and Yap to complete an FSM-national approach to support mangrove habitat migration, and associated atolls also need to be added. An attempt to evaluate impacts of sea level rise on food security and biodiversity in Yap (Ruegorong et al. 2016) was hampered by a lack of more precise data on land elevation needed to produce DEM models linked with vegetation type maps.
- ***An assessment of freshwater resources across the FSM*** – Insight into surface water and groundwater (freshwater lens aquifer) systems can assist water managers to enhance water sustainability. Understanding the spatial variation in well fields, pumping activities, and salinity levels can help to adapt water infrastructure to sea level rise. Island-specific water resource assessments are needed to determine when and where conservation measures or storage and recharge solutions may be appropriate.
- ***Research and, potentially, a pilot study on the co-benefits of community conservation*** – Community conservation areas are established within states, however, research is needed to understand the additional benefits beyond the communities involved in conservation and within and adjacent to conservation areas. In other words, how do the benefits extend beyond the community?

FSM Sources of Climate Data and Projections

Interagency Sea Level Rise Scenario Tool: https://sealevel.nasa.gov/task-force-scenario-tool/

NOAA Coral Reef Watch: https://coralreef-watch.noaa.gov/satellite/index.php

NOAA Digital Coast Sea Level Change Curve Calculator (plot for Chuuk): https://coast.noaa.gov/digitalcoast/tools/curve.html

NOAA Quarterly Climate Impacts and Outlook for the Pacific Region: https://www.drought.gov/drought/climate-outlook/Pacific%20Region

Pacific Climate Change Data Portal: http://www.bom.gov.au/climate/pccsp/

University of Hawaiʻi Sea Level Center Experimental Seasonal Sea Level Forecasts (available for Pohnpei and Chuuk): https://uhslc.soest.hawaii.edu/sea-level-forecasts/

University of Hawaiʻi Sea Level Center CMIP6 Atlas: https://uhslc.soest.hawaii.edu/cmip6_atlas/

Traceable Accounts

The findings in this report are based on an assessment of the peer-reviewed scientific literature, complemented by other sources (including grey literature and personal communication). These Traceable Accounts document the quality of supporting evidence and main sources of uncertainty, drawing on guidance by the IPCC and USGCRP (2018) to evaluate the conclusions reported in the "Indicators of Climate Change in the FSM" section in terms of:

- **Confidence** in the validity of a finding based on the type, quantity, quality, and consistency of evidence; the skill, range, and consistency of model projections; and the degree of agreement in literature; and
- **Likelihood,** based on statistical measures of uncertainty or on expert judgment as reported in literature.

Traceable Accounts

Indicator	How has it changed?	Source	Data Range	Projected future change	Source
Hot days	↑	NOAA Global Historical Climatological Network–Daily (GHCN–Daily), Stations: FMW00040504, Pohnpei Weather Service Office, Airport; FMW00040505, Chuuk Weather Service Office, Airport; FMW00040308, Yap Weather Service Office, Airport	Pohnpei and Chuuk: 1952–2021; Yap: 1959–2007	↑	Australian BOM and CSIRO 2014 (CMIP5)
Cold nights	↓	GHCN–Daily, FMW00040505, Chuuk Weather Service Office, Airport	1952–2021	↓	Australian BOM and CSIRO 2014 (CMIP5)
Average air temperature	↑	GHCN–Daily, FMW00040505, Chuuk Weather Service Office, Airport	1952–2021	↑	Australian BOM and CSIRO 2014 (CMIP5)
Total annual rainfall	No change	Australian BOM and CSIRO 2014	Pohnpei: 1950–2011 Yap: 1952–2011	?	CSIRO and SPREP 2021
Heavy rainfall days	No change	GHCN–Daily, FMW00040504, Pohnpei Weather Service Office, Airport; FMW00040505, Chuuk Weather Service Office, Airport; FMW00040308, Yap Weather Service Office, Airport; Marra et al. 2022	1952–2021	↑	IPCC 2021
Consecutive dry days	No change	Marra et al. 2022; Australian BOM and CSIRO 2014	1952–2021	?	No analysis available
Streamflow	?	No analysis available; Polhemus 2017		?	No analysis available
Tropical cyclone intensity	No change	Marra and Kruk 2017; Marra et al. 2022	1980–2021	↑	IPCC 2021; USGCRP 2017; Knutson et al. 2020; Widlansky et al. 2019
Tropical cyclone frequency	No change	IPCC 2021; Kossin et al. 2020; Ranasinghe et al. 2021	1980–2021	?	Knutson et al. 2020

Indicator	How has it changed?	Source	Data Range	Projected future change	Source
Sea level	↑	McGree et al. 2022; NOAA 2022a,b; Marra et al. 2022	1993–2021 (McGree et al. 2022; Marra et al. 2022); 1978–2016 (NOAA 2022a)	↑	Sweet et al. 2022; IPCC 2021; also see Interagency Sea Level Rise Scenario Tool, based on Sweet et al. 2022
High water frequency	↑	Marra et al. 2022 (Minor Flood Frequency); University of Hawai'i Sea Level Center	1980–2020	↑	Sweet et al. 2022; Mycoo et al. 2022; also see NASA Flooding Days Projection Tool (UHSLC 2022), Location: Apra Harbor, Guam
Sea surface temperature	↑	NOAA OI SST V2 High Resolution Dataset (NOAA NCEI 2022); Reynolds et al. 2007; Huang et al. 2021	1982–2021	↑	Dhage and Widlansky 2022; Fox-Kemper et al. 2021; Australian BOM and CSIRO 2014
Frequency of heat stress	↑	NOAA Coral Reef Watch 2018 (Liu et al. 2014)—Daily Global 5 km Satellite Coral Bleaching Heat Stress Monitoring	1985–2021	↑	van Hooidonk et al. 2016; Hoegh-Guldberg et al. 2017; Fox-Kemper et al. 2021, Box 9.2
Ocean acidification	↑	Hawaii Ocean Time-series (HOT) (SOEST 2020; Clayton and Byrne 1993)	1988–2020	↑	Fox-Kemper et al. 2021; Australian BOM and CSIRO 2014

▸ **Traceable Accounts**

Temperature – The daily air temperature records at Pohnpei International Airport, Chuuk International Airport, and Yap International Airport each extend from 1952–2021. The daily air temperature record at Kosrae International Airport extends from 1955–2021, however, the record contains numerous years for which significant data is missing, limiting its usefulness in climatological studies.

The minimum temperature record at the Pohnpei Weather Service Office Station (FMW00040504) showed inhomogeneities that remained after a homogeneity adjustment. The minimum temperature data were excluded due to low confidence in the dataset.

At the Chuuk Weather Service Office Airport Station (FMW00040505), breakpoints were found in the minimum temperature dataset, likely due to equipment issues or changes. Therefore, the daily minimum temperature values were statistically homogenized to account for these inconsistencies.

At the Yap Island Weather Service Office Station (FMW00040308) major inconsistencies were found in the daily maximum temperature data for 1952–1958 and 2008–2021. Breakpoints were found and data in those inconsistent periods were excluded. The minimum temperature record showed inhomogeneities that remained after data homogenization and, therefore, the minimum temperature data were excluded here due to low confidence in the dataset.

In 2014, the Australian government used general circulation model (GCM) simulations from the international Coupled Model Intercomparison Project Phase 5 (CMIP5) to project future climate conditions in the FSM, yielding projections for eastern FSM—including Kosrae, Pohnpei, and the eastern islands of Chuuk (east of the 150°meridian)—and western FSM, including western Chuuk islands and all islands of Yap (Australian BOM and CSIRO 2014). These future air temperature increases are reported in the "Indicators of Climate Change in the FSM." There is *very high confidence* that air temperatures will rise but *medium confidence* in the projected amount of average temperature change.

Rainfall and streamflow – Airport stations are most reliable because data is transmitted hourly via satellite (Marra and Kruk 2017). See Marra and Kruk for the location of selected Pacific region precipitation measurement sites (Marra and Kruk 2017, their Fig. 3.4).

There is *high confidence* that the frequency and intensity of extreme rainfall events will increase under lower (RCP4.5) and higher (RCP8.5) scenarios because: (a) a warmer atmosphere can hold more moisture so there is greater potential for extreme rainfall (IPCC 2021); and (b) increases in extreme rainfall in the Pacific are projected in all available climate models. However, there is *low confidence* in the magnitude of these changes (Australian BOM and CSIRO 2014).

Tropical cyclones – The future is less certain for tropical cyclones than some other elements of climate. The environmental conditions to produce a cyclone are at timescales much shorter than global climate model simulations; for example, the state of ENSO has a significant impact on tropical cyclone activity. How future changes in ENSO variability may impact regional TC activity is an emerging research area (Chand et al. 2017).

There is still a range of local- and regional-scale projections of tropical cyclone activity for the western North Pacific region (CSIRO and SPREP 2021). There is *low-to-medium confidence* in a projected global decrease in tropical cyclone frequency. Results from current available studies of tropical cyclone frequency for the western North Pacific vary; thus, the future outlook for tropical cyclone frequency in the FSM remains unclear (Kossin et al. 2020). There is no consensus on projected tropical cyclone tracks (Kossin et al. 2020), with some studies indicating a continued poleward (northward) shift in the region where cyclones reach maximum intensity (Kossin et al. 2016).

There is much greater agreement among high-resolution models on an increase in global average tropical cyclone intensity (surface winds and rainfall rates) (Knutson et al. 2020). Increases in intensity are projected for the western North Pacific, the basin containing the FSM, with wind speeds likely to increase (median 5% for 2°C warming; range: -1% to 12%) and rainfall rates expected to increase 5% to 33% with 2°C global warming (Knutson et al. 2020). There is *high confidence* sea level rise will increase TC-related storm surge events (Sweet et al. 2022; Knutson et al. 2020).

Sea level – Available data show that average sea level in the FSM is increasing. Sea level trend estimates for the FSM derived from satellite altimetry observations are reported and visualized in McGree et al. (2022, page 42). Regional sea level data were obtained from CSIRO satellite altimetry with correction for seasonal signals, inverse barometer effect, and glacial isostatic adjustment (as described in Church and White 2011). Global mean sea level has risen at an average rate of 3.4 mm/year since satellite altimetry observations began in 1993 (Thompson et al. 2022).

In addition to satellite altimetry, long-term sea level data records exist for Pohnpei (1969–present), Chuuk (1947–1991, 2022–2023), Yap (1969–2023), and Kapingamarangi (1978–2023) (UHSLC 2023). Additional tide gauges would be useful to validate satellite altimetry data across the FSM EEZ.

Ocean changes – The NOAA OISST V2 is a sea surface temperature product based on satellite and *in-situ* data available from NOAA, produced weekly on a 1-degree grid (NOAA NCEI 2022). The FSM experienced an average increase in ocean surface temperatures of between 0.1°C and 0.2°C per decade since 1982 (Marra et al. 2022). Average sea surface temperature is *virtually certain* to continue to increase globally (Fox-Kemper et al. 2021). For the FSM, there is *very high confidence* in this warming trend (Australian BOM and CSIRO 2014).

The third global bleaching event caused more reefs in the Pacific to be exposed to heat stress than at any time previously. In Pohnpei and eastern FSM, thermal conditions in 2016–2017 resulted in extensive nearshore coral bleaching and reef degradation from cyanobacteria and algae (Rowley et al. 2019).

There is *very high confidence* in the increased risk of coral bleaching as the ocean warms but only *medium confidence* in the rate of sea surface temperature change for the western North Pacific (Australian BOM and CSIRO 2014). Conditions that are known to cause severe coral bleaching are predicted to occur annually by 2034 to 2046 in the FSM under RCP8.5 (van Hooidonk et al. 2016). Severe coral bleaching is defined by van Hooidonk et al. (2016) as "the annual exceedance of >8 Degree Heating Weeks accumulating during any 3-month period." The potential for corals to adapt to warming is not incorporated into these projections. A model by Storlazzi et al. (2020) indicates that internal tides could delay the onset of bleaching fewer than 10 years at certain locations, under lower future warming scenarios (such as RCP4.5 or lower).

The best available documentation of pH for the North Pacific is time series data collected at Station ALOHA, 100 km north of O‘ahu, Hawai‘i (SOEST 2020; Clayton and Byrne 1993). Between 1988 (when data collection began) and 2020, pH has shown a linear decrease of 0.051 pH units, which corresponds to an increase of 12% in acidity over that timeframe (Marra et al. 2022).

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The **four five-pointed white stars** represent the four states—Yap, Chuuk, Pohnpei, and Kosrae—and appear on the national flag of the Federated States of Micronesia. On the flag, the stars are centered on a blue background symbolizing the Pacific Ocean.

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