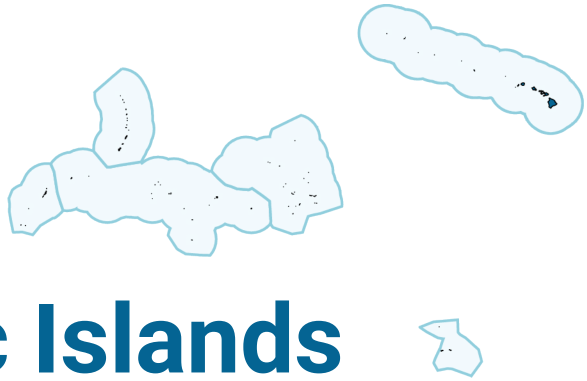
Fifth National Climate Assessment: Chapter 30

Hawaiʻi and US-Affiliated Pacific Islands



Chapter 30. Hawaiʻi and US-Affiliated Pacific Islands

Authors and Contributors

Federal Coordinating Lead Author

Mari-Vaughn V. Johnson, US Geological Survey, Pacific Islands Climate Adaptation Science Center

Chapter Lead Author

Abby G. Frazier, Clark University, Graduate School of Geography

Chapter Authors

Lucas Berio Fortini, US Geological Survey, Pacific Island Ecosystems Research Center

Christian P. Giardina, USDA Forest Service, Institute of Pacific Islands Forestry

Zena N. Grecni, Arizona State University, Pacific Research on Island Solutions for Adaptation (RISA)

Haunani H. Kane, Arizona State University

Victoria W. Keener, Arizona State University, Pacific Research on Island Solutions for Adaptation (RISA)

Romina King, University of Guam, Pacific Islands Climate Adaptation Science Center

Richard A. MacKenzie, USDA Forest Service, Institute of Pacific Islands Forestry

Malia Nobrega-Olivera, University of Hawaiʻi at Mānoa, Hawaiʻinuiākea School of Hawaiian Knowledge

Kirsten L. L Oleson, University of Hawaiʻi at Mānoa, Department of Natural Resources and Environmental Management

Christopher K. Shuler, University of Hawaiʻi, Water Resources Research Center

Ann K. Singeo, Ebiil Society

Curt D. Storlazzi, US Geological Survey, Pacific Coastal and Marine Science Center

Richard J. Wallsgrove, University of Hawaiʻi at Mānoa, William S. Richardson School of Law

Phoebe A. Woodworth-Jefcoats, NOAA Fisheries, Pacific Islands Fisheries Science Center

Technical Contributors

Malia K. H. Akutagawa, University of Hawaiʻi at Mānoa, Hawaiʻinuiākea School of Hawaiian Knowledge

Rosanna A. Alegado, University of Hawaiʻi at Mānoa

Kristen C. Alkins, US Geological Survey, Pacific Coastal and Marine Science Center

Marie Auyong, NOAA Office for Coastal Management

John I. Borja, University of Guam, Pacific Islands Climate Adaptation Science Center

Laura Brewington, Arizona State University

Jeff Burgett, US Fish and Wildlife Service

Janice E. Castro, NOAA Office for Coastal Management

Sandra P. Chang, University of Hawaiʻi at Mānoa

Patrick L. Colin, Coral Reef Research Foundation

Catherine A. Courtney, Tetra Tech Inc.

Laxmikant Dhage, University of Hawaiʻi at Mānoa

Diana Felton, Hawaiʻi Department of Health

Patricia Fifita, Oregon State University

L. Kealoha Fox, Institute for Climate and Peace

Kathleen S. Friday, USDA Forest Service

Scott J. Glenn, Hawaiʻi State Energy Office

Rodney L. Itaki, Pohnpei Department of Health & Social Services

L. Alex Kahl, NOAA Fisheries, Pacific Islands Regional Office

Heather Kerkering, US Geological Survey, Pacific Islands Climate Adaptation Science Center

Elizabeth Kiefer, University of Hawaiʻi, John A. Burns School of Medicine

Kelli A. Kokame, University of Hawaiʻi at Mānoa, John A. Burns School of Medicine

Natalie Kurashima, Kamehameha Schools

Dennis A. LaPointe, US Geological Survey, Pacific Island Ecosystems Research Center

Scott Laursen, Pacific Islands Climate Adaptation Science Center

Carlotta A. Leon Guerrero, Office of the Governor of Guam

Roseo Marquez, Micronesia Conservation Trust

Stephen E. Miller, US Fish and Wildlife Service, Pacific Islands Office

Tomoaki Miura, University of Hawaiʻi at Mānoa

Kanoe Morishige, NOAA Papahānaumokuākea Marine National Monument

Michael Parke, NOAA Pacific Islands Fisheries Science Center

Elliott W. Parsons, University of Hawaiʻi at Mānoa, Sea Grant College Program

Kalani Quiocho Jr., NOAA National Ocean Service, Office of National Marine Sanctuaries

Laurie J. Raymundo, University of Guam Marine Laboratory

Nicole Read, Duke University

Bradley M. Romine, University of Hawaiʻi at Mānoa, Pacific Islands Climate Adaptation Science Center

Clay Trauernicht, University of Hawaiʻi at Mānoa, Department of Natural Resources and Environmental Management

Yinphan Tsang, University of Hawaiʻi at Mānoa, Department of Natural Resources and Environmental Management

Colette C.C. Wabnitz, University of British Columbia, Institute for the Oceans and Fisheries

Matthew J. Widlansky, University of Hawaiʻi at Mānoa, School of Ocean and Earth Science and Technology

Myeong-Ho Chris Yeo, University of Guam, Water and Environmental Research Institute

Review Editor

Carolyn V. Balk, Federal Emergency Management Agency

Cover Art

James Keul

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Introduction

Moananuiākea, Hawaiian for the Pacific Ocean, connects a diverse group of island peoples who share reciprocal and spiritual relationships with the lands, waters, natural resources, and cultures of the region. Indigenous Knowledge systems derived from thousands of years of stewardship and underlying observations have sustained Pacific Islanders, as evidenced in the cultural practices of seafaring,[1] canoe building, agroforestry (a farming system that includes trees),[2,3,4,5] harvesting fish and other marine life,[6,7,8] traditional medicine,[9] and managing water.[10]

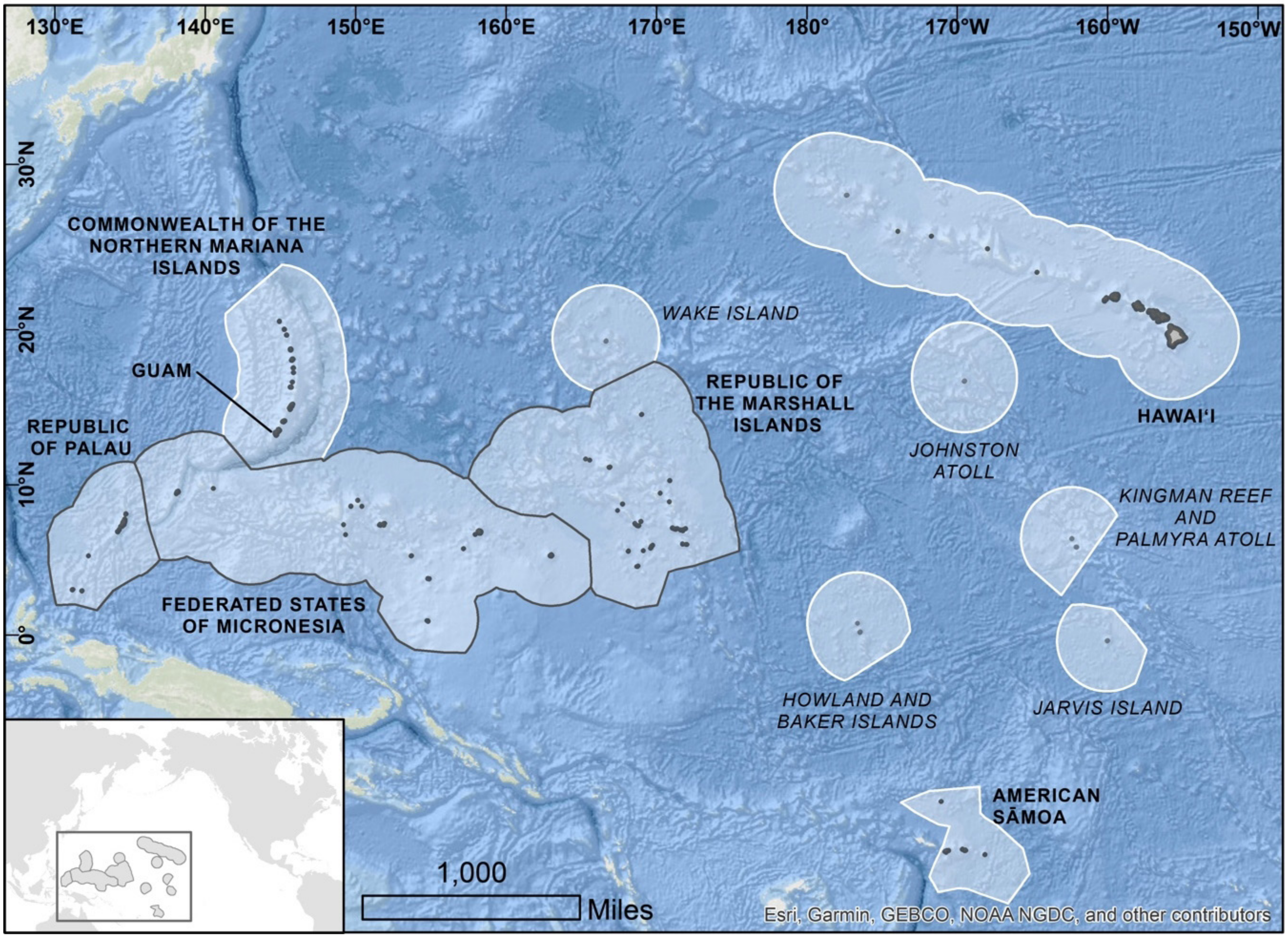
The Pacific Islands region is defined here as Hawaiʻi and the US-Affiliated Pacific Islands (USAPI). The USAPI comprises the Commonwealth of the Northern Mariana Islands (CNMI); the unincorporated territories of American Sāmoa, Guam, and the Pacific Remote Islands (PRI); and the Freely Associated States (FAS): the Federated States of Micronesia (FSM), the Republic of the Marshall Islands (RMI), and the Republic of Palau. The region spans a vast geography and encompasses over 2,000 islands, ranging from small low-lying atolls to large volcanic islands, with the highest peak rising to 13,803 feet (Figures 30.1, 30.2). Marine and terrestrial biodiversity and species endemism are exceptionally high. These islands (excluding FAS) total only 14,060 square miles in land area but define nearly half (47.2%) of the entire US exclusive economic zone (EEZ). The islands also support more than two dozen defense installations key to US security, including the headquarters for the US Indo-Pacific Command. As a consequence of colonization, the lands, waters, and peoples of the Pacific Islands were significantly involved in World War II,[11] resulting in widespread environmental devastation, displacement of Indigenous Peoples, and nuclear weapons testing.[12,13,14]

The 1.9 million people who call the region home are predominantly (more than 77%) Pacific Islanders, many of whom are Indigenous Peoples (CHamoru, Chuukese, Kosraean, Marshallese, Native Hawaiian, Palauan, Pohnpeian, Samoan, Yapese, and others)—who speak more than 20 Indigenous languages[15]—and members of diverse communities of Asian heritage. Population is declining on all islands (except Hawaiʻi) and is increasingly urban.[16,17,18,19,20,21,22] Important economic sectors include tourism, agriculture, and fishing, with government assistance, foreign direct investment, and remittances as major sources of capital. Average per capita income ranges from a high of 124% above the US average in Hawaiʻi to 4%–20% in the FAS.[22,23,24] Governance arrangements across the islands vary, but all share histories of colonization that contribute to structural inequities and vulnerabilities that exacerbate the social and economic impacts of climate change (Box 30.1).[14,25]

Box 30.1. Historical Under-Resourcing Results in Continuing Data Inequities for the Pacific Islands Region and US Caribbean

The Pacific Islands region and the US Caribbean continue to face similar climate change–related challenges (Ch. 23; see Keener et al. 2018[26]), including geographic isolation and reliance on imports, critical dependence on local natural resources (fresh water, fisheries), and vulnerabilities to drought, sea level rise (SLR), and natural disasters. Missing data in both regions is representative of ongoing exclusion in data collection efforts and perpetuates historical social injustices that are reinforced by colonial and postcolonial governance systems (KM 31.2). In the Pacific Islands, this has resulted in sparse and discontinuous climate data records, the absence of coastal flood hazard modeling and detailed SLR exposure mapping for most islands, a lack of downscaled future climate projections in most locations (App. 3), insufficient information about groundwater and surface water resources, and limited data on ecosystem response.[15,27,28,29,30] Similar gaps are apparent in socioeconomic and health data: for example, on migration and health outcomes, including morbidity and mortality related to extreme weather events; food supply chain vulnerabilities; and resource-dependent livelihoods.[31,32,33,34] Indigenous Knowledge systems and stewardship are foundational in responding to climate change, but generations of knowledge have been undervalued, suppressed, and ignored by Western science and were only recently recognized as valid knowledge sources at the federal level.[35,36,37] This lack of climate-relevant data is evident throughout NCA5. Filling these data gaps could better enable data-driven decision-making and improve climate services in the region.

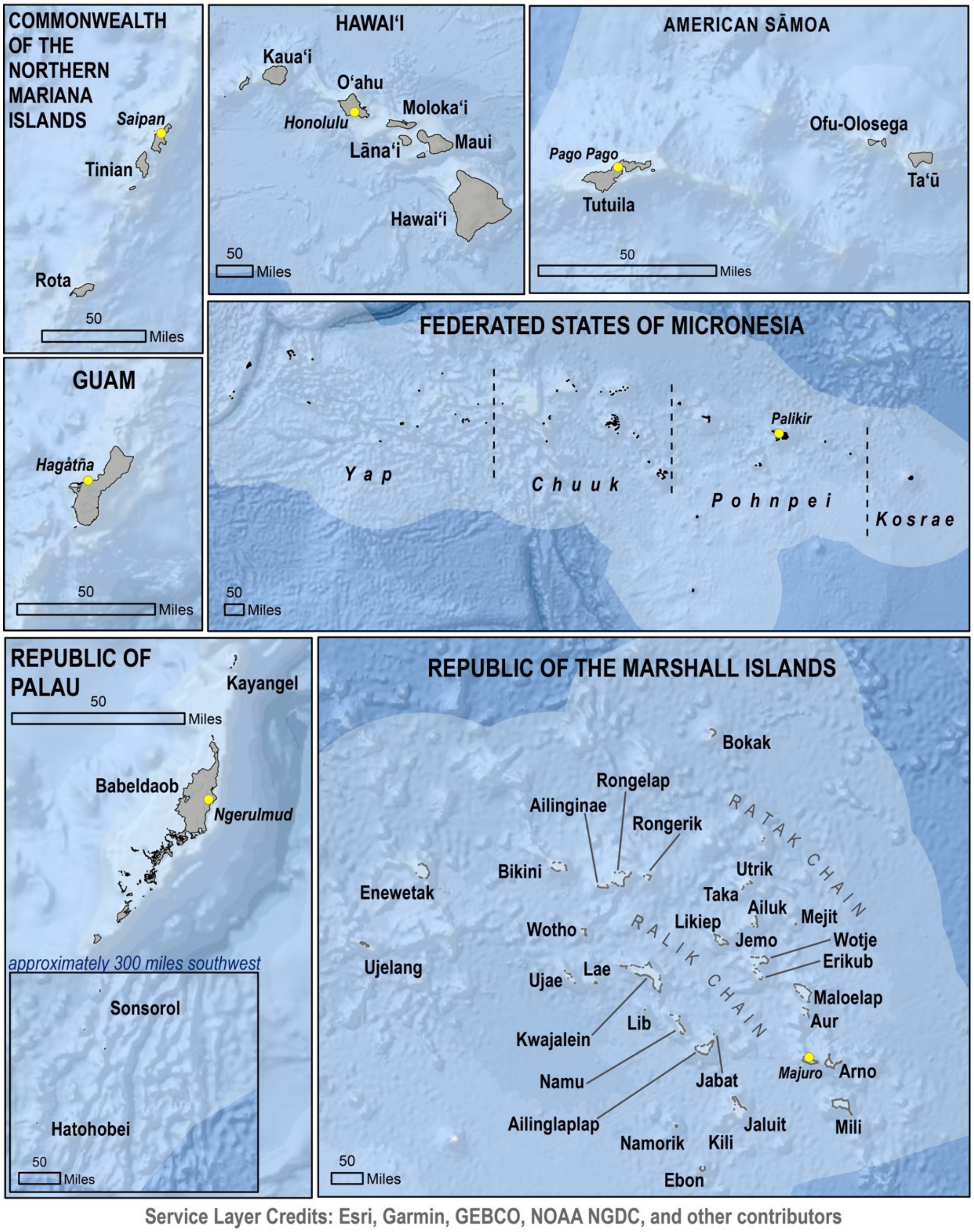
Hawai‘i and the US-Affiliated Pacific Islands



Hawai‘i and the US-Affiliated Pacific Islands span a vast geography.

Figure 30.1. The map shows the geographic breadth of the state of Hawai’i and the US-Affiliated Pacific Islands (USAPI). The USAPI comprises the US territories of American Sāmoa, Guam, and the Pacific Remote Islands (Baker Island, Howland Island, Jarvis Island, Johnston Atoll, Kingman Reef, Palmyra Atoll, and Wake Island); the Commonwealth of the Northern Mariana Islands; and the Freely Associated States: the Federated States of Micronesia, the Republic of the Marshall Islands, and the Republic of Palau. The exclusive economic zones around each jurisdiction are shown. Figure credit: University of Guam, Clark University, NOAA NCEI, and CISESS NC. Sources: Esri, Garmin, GEBCO, NOAA NGDC, and other contributors. Map image is the intellectual property of Esri and is used herein under license. Copyright © 2020 Esri and its licensors. All rights reserved.

Detailed View of Hawai‘i and the US-Affiliated Pacific Islands



The Pacific Islands region contains a diversity of high and low islands.

Figure 30.2. These detailed maps show the inhabited Pacific Islands region with islands and capital cities labeled. Shown are American Sāmoa; the Commonwealth of the Northern Mariana Islands; the Federated States of Micronesia (with its four states labeled: Yap, Chuuk, Pohnpei, and Kosrae); Guam; Hawai‘i; the Republic of the Marshall Islands; and the Republic of Palau. Figure credit: Clark University, Arizona State University, University of Guam, NOAA NCEI, and CISESS NC. Sources: Esri, Garmin, GEBCO, NOAA NGDC, and other contributors. Map image is the intellectual property of Esri and is used herein under license. Copyright © 2020 Esri and its licensors. All rights reserved.

Climate Variability and Change

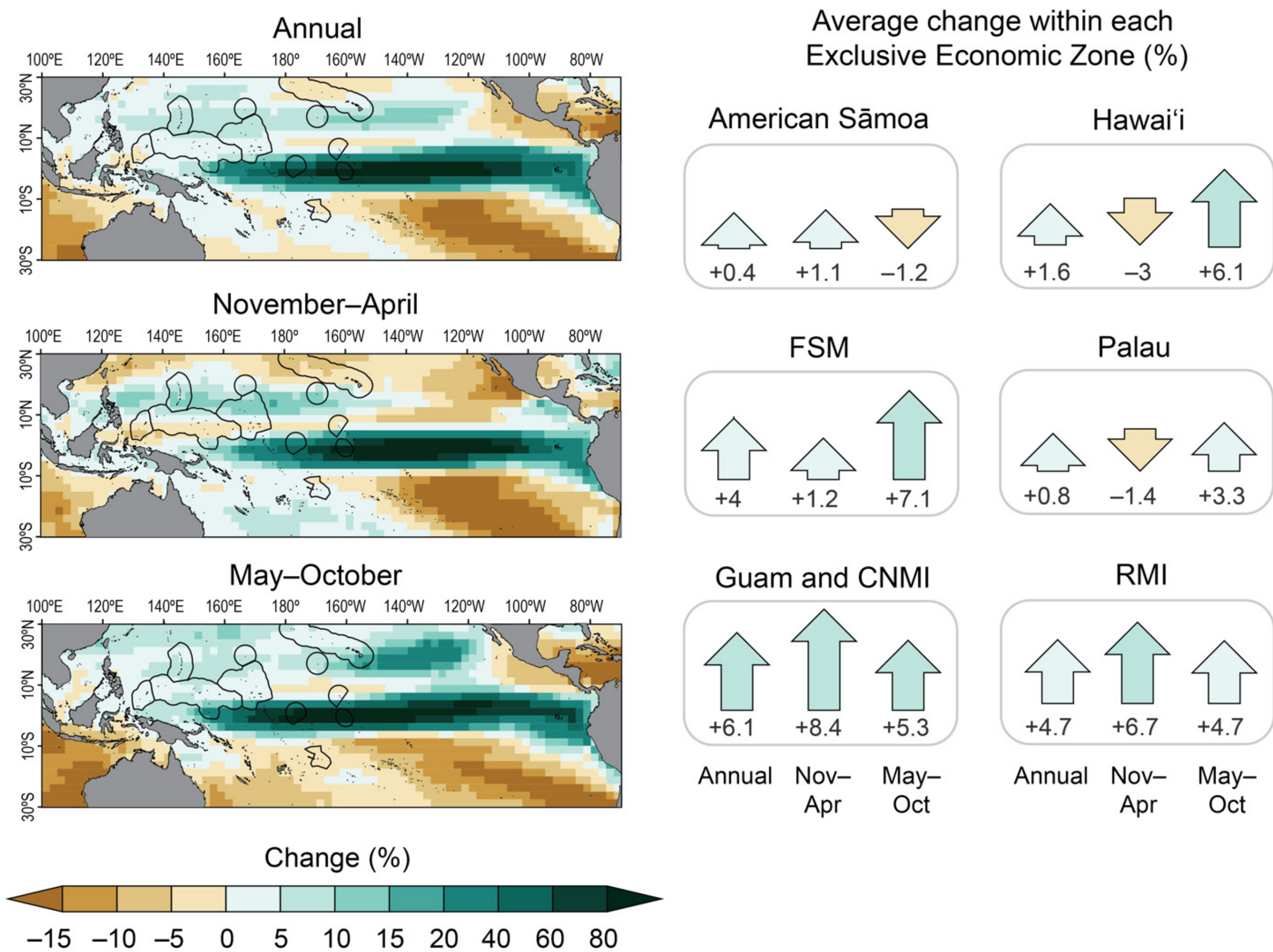
The El Niño–Southern Oscillation (ENSO) and Pacific Decadal Oscillation (KMs 2.1, 3.3) are dominant sources of climate variability in the Pacific Islands region, affecting rainfall, air and ocean temperature, sea surface height, and trade winds (Box 27.1 in Keener et al. 2018[38]).[30,39,40,41] ENSO and other sources of climate variability interact with climate change to reduce or amplify trends and their impacts on decadal and shorter timescales. Natural variability in sea level and tides, for example, affects tidal flooding experienced at various Pacific Island locations.[42,43,44]

Between 1951 and 2020, annual average air temperatures across the Pacific Islands region increased 2°F (1°C).[45,46] End-of-century projections indicate up to 4.5°F (2.5°C) higher temperatures at high elevations (above 9,800 feet) for an intermediate scenario (RCP4.5) and up to 9°F (5°C) under a very high scenario (RCP8.5).[47] Historical precipitation trends are variable across the region, with some islands seeing long-term drying and increases in drought frequency, severity, and duration (KM 4.1).[48,49,50] The magnitude and direction of projected precipitation changes are currently highly uncertain (Figure 30.3); some areas are projected to experience drying (e.g., leeward [western] areas of Hawai‘i;[51] KM 2.1), while increases in precipitation are expected for others (e.g., American Sāmoa).[52]

Although the findings are uncertain and geographically diverse, current analyses indicate that the frequency of tropical cyclones is expected to decrease,[53] but associated wind speeds, rainfall rates, and storm surge heights are projected to increase across the entire region (KM 2.2).[53,54,55,56,57]

The rate of increase in regional sea surface temperatures (SSTs) has exceeded global rates, while ocean acidification (declining ocean pH)[58] in the region has reached levels not seen over the past 30 years.[59] These region-wide changes are projected to continue over the remainder of this century,[60] with dire consequences for coral reef ecosystems (KM 10.1).[61,62] Relative sea level rise (SLR) rates vary across the Pacific region,[63] with the highest SLR rates observed in the western Pacific.[64] With warming above 3.6°F (2°C), SLR projections of 3.5 to 7.5 feet by 2100 are increasingly possible (Figure 30.4; KM 9.1).[65]

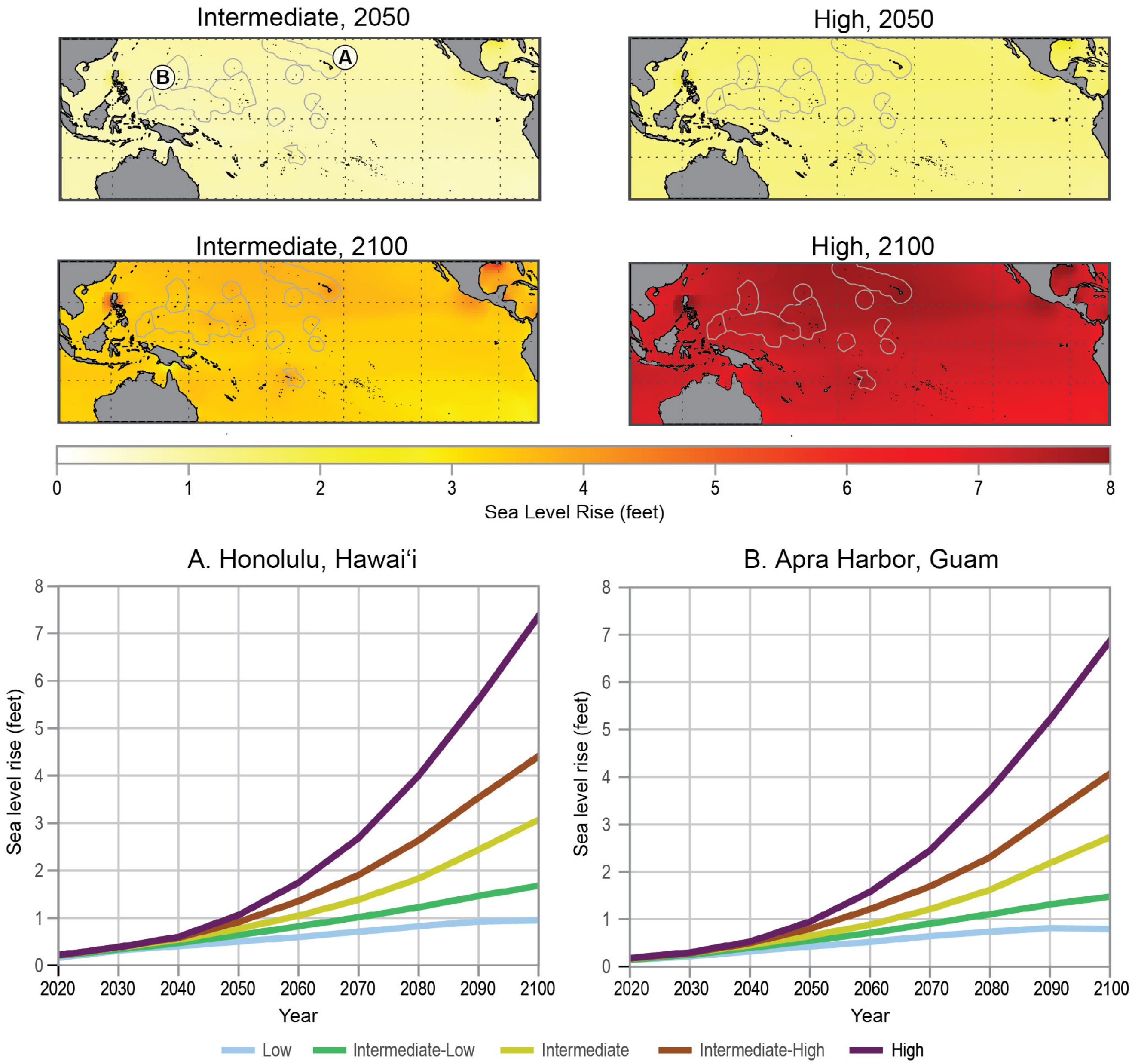
Projected Changes in Rainfall at 3°C (5.4°F) of Global Warming (Relative to 1985–2014)



Rainfall is projected to increase across most of the region with 3°C (5.4°F) of global warming.

Figure 30.3. The figure shows projected percent change in annual and seasonal rainfall by 2100 across the Pacific Islands region under a global warming level of 3°C (5.4°F) relative to 1985–2014. Large increases in future rainfall are seen for the Commonwealth of the Northern Mariana Islands (CNMI), the Federated States of Micronesia (FSM), Guam, and the Republic of the Marshall Islands (RMI), while almost no change is projected for American Sāmoa. Hawai'i and Palau are projected to see decreases in November–April rainfall and increases in May–October rainfall. Adapted from Dhage and Widlansky 2022[66] [CC BY 4.0].

Regional Sea Level Rise Projections



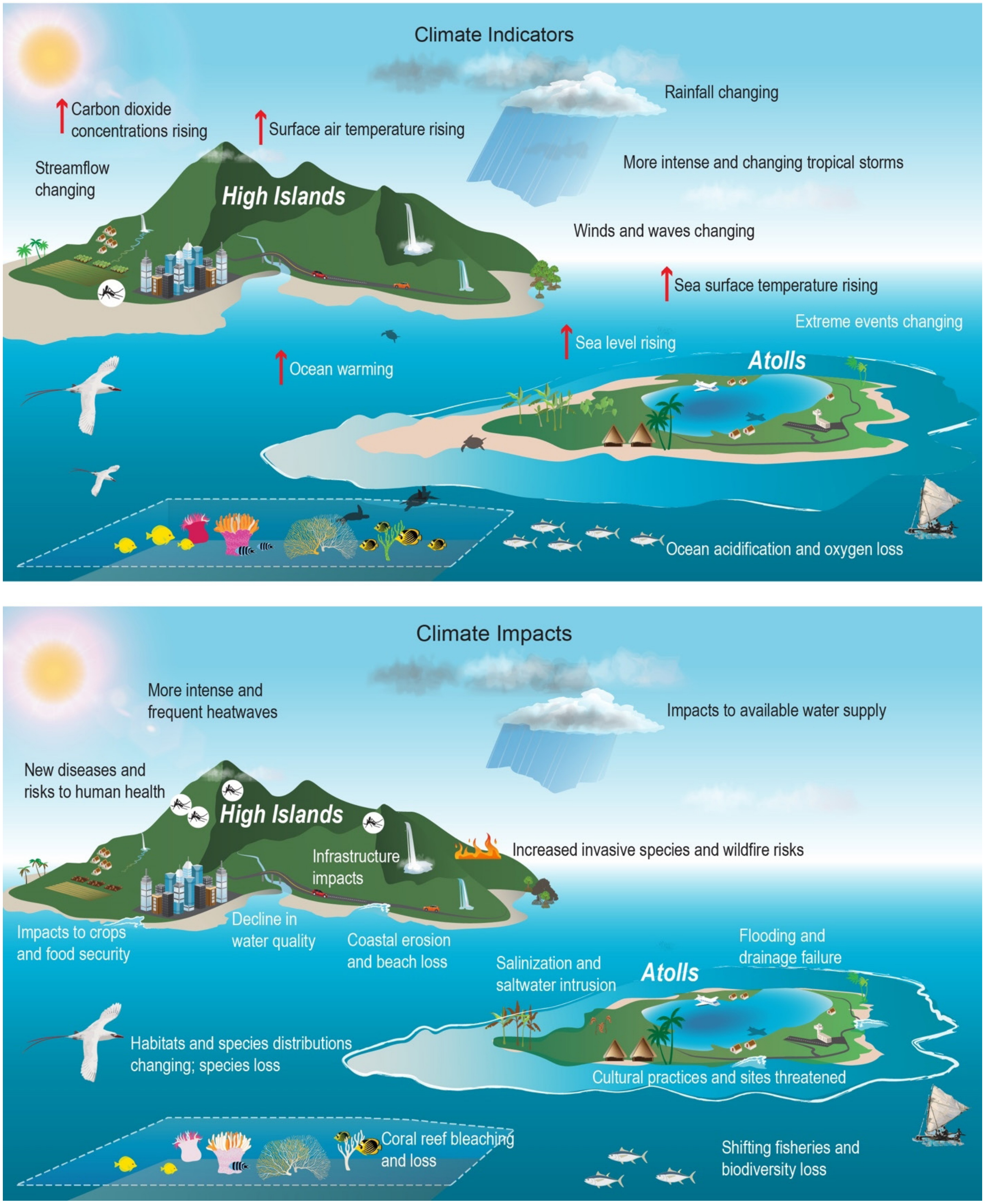
Future sea levels strongly depend on the scenario, and rates will vary across the region.

Figure 30.4. Sea level rise (SLR) projections for different scenarios are as follows: Low (1 foot of global SLR by 2100), Intermediate-Low (1.5 feet), Intermediate (3 feet), Intermediate-High (5 feet), and High (6.5 feet). (**top four panels**) Maps display regional variations in projected SLR by 2050 (top row) and 2100 (center row) in the Pacific under Intermediate (left) and High (right) scenarios. In general, sea levels are relatively higher in the northern and western Pacific than in the southern and eastern Pacific. Although patterns vary spatially due to various processes such as thermal expansion and subsidence, the greatest sources of variability are time and the scenario. (**bottom two panels**) SLR scenarios are shown for 2020–2100 at Honolulu, Hawai'i (A), and Apra Harbor, Guam (B; locations noted in the upper-left panel). For information regarding the likelihood of these scenarios under possible future warming levels, see Appendix 3. Figure credit: US Geological Survey, University of Guam, Arizona State University, and NASA Jet Propulsion Laboratory.

Increasingly Severe Climate Impacts Are Causing Cascading Impacts for People

All Pacific Island communities are experiencing climate change impacts and, in some cases, facing existential risks (Figure 30.5). Sea level rise is compromising critical infrastructure and threatens to displace populations on low-lying atolls, forcing migration and disrupting social relationships (KMs 9.1, 9.2, 9.3). The vast majority of ports, airports, primary roads, power plants, and water treatment plants are located a few feet above sea level. Ports bring in 80%–100% of all consumer goods (including food and medical supplies) and 100% of fuel,[67] placing the islands at the end of long supply chains and making them extremely susceptible to disruptions (Ch. 23). Climate change increasingly affects the lands and waters of the region crucial for sustaining primary economic and cultural livelihoods, including tourism, agriculture, fishing, forestry, and artisan practices (KMs 10.2, 18.1, 19.1, 23.2). These effects exacerbate structural inequities (KMs 20.1, 31.2).[68,69] Climate change poses risks to the region's rich biodiversity, including many threatened and endangered species, that supports functioning ecosystems and cultural practices (KMs 8.2, 16.1). Table 30.1 illustrates examples of impacts across the region for each of the chapter's Key Messages related to water and food, human health, the built environment, ecosystems, and cultural and historical resources.

Climate Change Indicators and Impacts in the Pacific Islands



Monitoring key indicators of climate change is essential for understanding impacts and informing adaptation efforts.

Figure 30.5. Changes in climate, as measured through key indicators (**top panel**), including sea surface temperature, sea level, and tropical cyclone intensity, result in impacts and risks (**lower panel**) for Pacific Island environments and communities, both on high volcanic islands and atolls. Improved monitoring of indicators is essential for tracking the pace and extent of climate change. Understanding of the connections between indicators and impacts is expanding, which supports adaptation efforts. Adapted from Keener et al. 2018,[26] which was adapted from Keener et al. 2012.[15]

Table 30.1. Illustrative Climate Change–Related Impacts Across the Pacific Islands Region

Examples of historical, ongoing, and projected climate change impacts are given for each jurisdiction. Sea level rise is abbreviated as SLR.

Jurisdiction	KM 30.1: Water and Food	KM 30.2: Human Health	KM 30.3: Built Environment	KM 30.4: Ecosystems	KM 30.5: Cultural and Historical Resources
American Sāmoa	Increased extreme precipitation events degrade drinking water quality by stressing the water systems' filtration capacity (KM 4.2).[70,71]	Hot weather worsens chronic health conditions, including heart disease and diabetes, already at emergency levels (KM 15.1).[72]	Climate change threatens fisheries and impacts economic infrastructure, including canneries.[73]	Climate change promotes invasive species spread in native rainforests, home to rare and culturally important plants.[29]	Coastal flooding affects villages that contain burials of relatives and ancestors.[74]
Commonwealth of the Northern Mariana Islands (CNMI)	Access to safe drinking water is threatened as climate change exacerbates ongoing challenges of disposal of military, industrial, and municipal waste.[27]	Super Typhoon Yutu in 2018 negatively impacted mental health and healthcare providers.[75]	Two successive typhoons (2015 and 2018) damaged or destroyed significant portions of the built environment.[27]	Climate change aids species invasions, which threaten the high biodiversity in wetlands and forests, including endemic birds, threatened reptiles, and two species of bats.[27,76]	Coastal historical and cultural sites are exposed to SLR.[27]
Federated States of Micronesia (FSM)	Warmer temperatures and saltwater intrusion are projected to increase disease in staple crops such as taro, bananas, and breadfruit.[77]	Changes to marine and coastal habitats threaten artisanal fisheries, a key protein source.[78,79,80,81,82,83]	In FSM, 59% of infrastructure (89% of population) is within 0.3 miles (0.6 km) of the coast and vulnerable to coastal climate impacts.[84,85]	Highly valued mangrove forests in Pohnpei will be threatened by SLR.[86]	Coastal men's houses *(faluw)* are exposed to SLR and can benefit from historical adaptation measures.[87]
Guam	Northern Guam Lens Aquifer is at risk from hotter weather, drought, and possible increases in demand.[28,88]	In 2018–2019, compound extreme events (flash flooding followed by drought and wildfire) negatively impacted human health (safety, pathogens, and respiratory issues).[28]	Stronger tropical cyclones around Guam will increase the potential for severe damage to the built environment.[53]	Increased frequency of coral bleaching[89] and increased risk of wildfires are expected.[28]	Many cultural and historical resources located along the coast will be impacted by 3 feet of SLR.[90]
Hawaiʻi	Increasing drought is reducing available water supplies.[49]	Hot weather causes heat-related illness and increases hospitalizations (KM 15.1).[91]	3.2 feet of SLR would cause $23.1 billion in economic loss (in 2022 dollars).[92]	Warming at higher elevations will expand transmission of avian malaria, causing declines in endemic bird populations.[93,94]	Strong winds, large storm waves, SLR, and changes in groundwater impact fishponds throughout Hawaiʻi.[95,96,97]

Jurisdiction	KM 30.1: Water and Food	KM 30.2: Human Health	KM 30.3: Built Environment	KM 30.4: Ecosystems	KM 30.5: Cultural and Historical Resources
Pacific Remote Islands (PRI)	Decreasing precipitation and salinization from SLR are reducing freshwater availability.[98]	The possibility of disappearing islands contributes to distress due to loss of identity and relationship with place (solastalgia).[99]	US military installations and low-lying islets are at risk from SLR, which may impact exclusive economic zones.[98]	The 2014–2016 El Niño bleached over 90% of monitored reefs in Palmyra Atoll.[100]	Sea level rise threatens remote islands and megafauna connected to the Native Hawaiian culture and creation story.[101,102]
Republic of the Marshall Islands (RMI)	During the 2015–2016 extreme El Niño drought, the northern atolls established freshwater "filling stations" for water access.[103]	Sea level rise threatens health infrastructure,[104] and migration harms mental health.[105]	Highly urbanized atolls may not be able to adapt to future SLR, leading to land loss and potential uninhabitability.[98,106,107,108]	Tuna catch within the exclusive economic zone is projected to decline by 10%–40% by 2050 relative to the early 2000s under a very high scenario (RCP8.5).[109]	Graves in the Jenrōk neighborhood on Majuro were lost to coastal erosion.[110]
Republic of Palau	Climate change affects the timing of when crops are traditionally planted, which impacts food security.[111]	Mental health challenges arise from degradation of places and ecosystems essential to ocean-centered culture and livelihoods (Box 30.3; KM 15.1).[112]	Migration to and development in Koror's coastal zone exposes more people to SLR; king tides already flood urban areas.[113]	The strong 2015–2016 El Niño reduced the jellyfish population in Palau's Jellyfish Lake.[113]	High tides and SLR submerged and damaged Kukau el Bad, a historic healing ritual site in Ollei, Ngarchelong.[113]

Mitigation and Adaptation Through Indigenous Knowledge Systems, Collective Action, and Planning

Effective climate mitigation and adaptation measures for Pacific Islanders and Indigenous Peoples are grounded in local ecological knowledge, which promotes intergenerational and holistic stewardship approaches,[114,115] and best available Western science (KM 18.3). Indigenous ways of knowing can revitalize resilient practices and confront environmental injustices (KMs 16.3, 31.2).[14] Examples of Indigenous Knowledge–informed adaptation include agroforestry, wetland taro agriculture, fishponds, and fisheries rules such as rest periods.[116,117,118,119] Mangrove and seagrass conservation and regenerative agriculture demonstrate high potential for carbon sequestration (KM 30.4).[120,121,122]

Collective action in the region is codified in pursuit of the Sustainable Development Goals (SDGs) through the Local2030 Islands Network and Micronesia Challenge (Box 30.2; KM 20.2). Climate literacy may help spur collective action and build social capacity to address climate-driven changes (KM 32.5). Climate change–focused education and outreach programming in the Pacific Islands region is diverse and extends across federal, state, and county levels, nongovernmental organizations, and Indigenous-serving organizations (e.g., Bolden et al. 2018;[123] Frungillo et al. 2022;[124] HWMO 2021;[125] Longman et al. 2022;[126] USGS 2021[127]). Native Hawaiian and Pacific Islander epistemologies are woven into many programs (KM 16.2).[128,129]

Box 30.2. Sustainable Development Goals and Collective Action

Many Pacific Island states have adopted the 17 United Nations Sustainable Development Goals (SDGs)[130] as part of a place-based path toward climate resilience (KM 17.4). The Local2030 Islands Network is forming regional communities of practice around energy, data, tourism, and other topics of interest and is piloting SDG dashboards in Guam, Hawaiʻi, and Palau (KM 18.4). In Hawaiʻi, a scorecard provides annual progress summaries on SDGs for 2030.[131] Across sectors, Hawaiʻi has progressed toward meeting 6 of 36 local SDG metrics as of 2021 and is actively measuring progress in 17 more. While strong progress was made in measuring relevant goals, additional data and efforts are needed to meet more SDGs. Hawaiʻi Green Growth and Guam Green Growth[132] are diverse public–private partnerships formed to develop measurable economic, social, and environmental adaptations toward sustainability (Box 18.3). FSM's more formal commitment to the SDGs is evident in their national Strategic Development Plan 2004–2023.[133]

The Micronesia Challenge is a commitment by the Commonwealth of the Northern Mariana Islands, the Federated States of Micronesia, Guam, Palau, and the Republic of the Marshall Islands to conserve at least 20% of their terrestrial resources and 30% of their nearshore marine resources. With a regional endowment fund of approximately $23.1 million (in 2022 dollars)[134] providing a sustainable funding stream, the Micronesia Challenge has established over 150 protected areas throughout Micronesia, conserving biodiversity, protecting the environment, securing livelihoods and cultural practices, and enabling these islands to become more resilient to climate change.

Key Message 30.1

Climate Change Impairs Access to Healthy Food and Water

Access to clean, fresh water and healthy food is expected to be increasingly impaired by climate change (*very high confidence*). On low-lying atolls, sea level rise has caused saltwater contamination of fresh water (*high confidence*). Regionally, food and water availability will be further negatively impacted by increasing temperatures, altered rainfall patterns, increased flooding and pollution, and degradation of nearshore fisheries (*very high confidence*). Adaptation actions such as traditional farming, fishing, and land-management practices can help build more resilient water and food systems (*very high confidence*).

Changing Climate Threatens Freshwater Resources

Dependable and safe freshwater resources and associated services in tropical islands are particularly vulnerable to rising temperatures (KM 4.1), altered rainfall patterns (Figure 30.3), runoff intensity and flooding, reduced groundwater recharge, and SLR (Figure 30.4; KM 4.2). Depletion of island aquifers compounds the potential for saltwater intrusion from SLR.[98,135,136] The availability of surface water for irrigation, drinking water, and hydropower is affected by increasing frequency and severity of flooding and by reductions in stream baseflow;[137] water contamination through increased *Staphylococcus sp.*, *Leptospira* (a waterborne pathogenic bacteria), fecal coliform bacteria, and suspended sediment (KM 15.1);[138,139,140,141] and extreme drought (KM 2.2).[103] In response to these changes, adaptation-focused restoration techniques are being applied, including revegetating with native species, reducing impervious surfaces, and redundant water distribution systems. Climate-induced land-cover change can have significant control over groundwater recharge, indicating that land-use adaptation is viable for managing impacts on water resources (KM 6.1).[142,143] Flood frequency is projected to increase across the region,[70] while drought frequency is projected to vary across the region (KMs 2.2, 4.1).[27,28,29,113]

Changes Undermine the Sustainability of Water Supplies

Pacific Islands potable water supplies depend heavily on accessing clean groundwater or rain catchments, while other needs, such as irrigation, are often met with surface water resources. Groundwater recharge is affected by annual or longer-scale climate processes, while surface water supplies are more sensitive to shorter-term climatic influences.[144,145,146,147,148] Although few studies assess regional changes in drought, evidence is clear that Hawaiʻi has experienced a drying trend since the 1950s and in La Niña years.[149,150] On atolls and low-lying islands, freshwater aquifers typically occur as very thin lenses and are highly sensitive to groundwater extraction and SLR-driven saltwater intrusion.[135,136] Shifting rainfall patterns and runoff conditions are affecting the availability of surface water to meet growing demands.[103] Climate change has elevated region-wide efforts to protect and conserve freshwater resources. Communities that rely heavily on rain-fed catchments and surface water are acutely susceptible to short-term and, in particular, long-term drought and the resulting reductions in streamflow.[103]

Salinization and Pollutants Deteriorate Water Quality

Increased intensity of extreme rainfall events, coupled with SLR, is projected to exacerbate freshwater contamination risks.[151] Past and ongoing disposal of military, industrial, agricultural, and municipal waste contaminates island water supplies.[35,152] Although SLR-driven mobilization of subsurface contaminants has received little study in the Pacific Islands, evidence of diverse groundwater contaminants in the region[153] and their mobilization[154,155] raises concerns for low-lying island aquifers (KM 4.2). Salt is a critical freshwater contaminant; wave-driven overwash[135,136,156] and SLR-induced rise of the freshwater–saltwater transition zone[157,158,159,160] cause salinization and saltwater intrusion.

Changes in the frequency, severity, and duration of drought, associated fires, and flooding all interact to exacerbate sediment loading to streams.[103,161] Given the short ridge-to-reef distances in the region, sensitive nearshore coral ecosystems and fisheries are directly impacted by increased sediment and pollutant loads to streams,[162] compromising biodiversity, subsistence practices, and economies (KM 9.2).[162,163,164]

Food Systems Disrupted

Climate change will increasingly impact food production, transport, processing, packaging, storage, retail, consumption, and waste for Pacific Island communities (KMs 11.2, 13.1). The aforementioned challenges will disrupt imports reliant on fragile supply chains and reduce viability of local agriculture and fisheries, thus reducing access to nutritious foods.[31,165,166,167,168,169] Fisheries are the principal protein sources for many Pacific Islanders, with locally grown staple food crops such as bananas, taro, breadfruit, and sweet potato supplying critical calories and nutrients.[170,171,172] However, Pacific Island communities have increasingly relied on imported foods, which come with complex and sometimes hidden environmental, financial, social, cultural, and nutritional costs (KM 30.2).[173,174] COVID-19 and previous disasters exposed the fragility of global supply chains (Focus on Risks to Supply Chains) and emphasized the need to bolster local food production capacity to increase resilience.[166,167,175,176]

Declining Fisheries

The global capacity of coral reefs to supply fish has declined by half since the 1950s, a change that climate stressors have exacerbated (KM 9.2)[62,177,178,179,180] through coral bleaching, acidification, SLR (Figure 30.4), terrestrial sediment, and contaminants (Box 30.3).[78,79,181,182] Small-scale coral reef fisheries supply Pacific Island communities with a substantial portion (in some cases 50% to 90%) of their dietary protein and important micronutrients.[82,172,177,183,184,185,186] Warming waters, acidification, and deoxygenation redistribute open-ocean fish stocks, and fisheries catch within regional EEZs is projected to decline by up to 40% by 2050 relative to the early 2000s under a very high scenario (RCP8.5; KM 10.1).[109] Fishing fleets are ill-equipped to adapt to this deficit (KM 10.2).[81,187] Warming, extreme events, acidification, and SLR may also compromise efforts to expand mariculture (marine farming), through damage to aquaculture systems,[188] decreased species richness,[189] and decreased local access to nearshore and open-ocean species.[190,191,192]

Box 30.3. Changing Fisheries: Local Knowledge from Palau

Indigenous practitioners are often the first to observe and respond to changes in the environment (KM 16.3). For hundreds of years, fishers in Palau have gathered at seagrass meadows on the sixth day after a new moon during late-afternoon low tide to catch rabbit fish using cast nets (Figure 30.6). Since 2021, fishers have been unable to participate in this age-old tradition.[193] The normal low tide no longer occurs, and ocean levels remain too high for rabbit fish aggregation. It is unclear whether these changes can be attributed to SLR, human impacts (e.g., overfishing), or natural variability. If this change persists, loss of this fishery would threaten the fishers' livelihood and resilience as ocean people (KM 10.2). Integrating place-based and complementary knowledge systems into assessments can help ensure sustainable management under future climate change.[194,195]

Traditional Cast Net Fishing

Species loss threatens the traditions, livelihoods, and resilience of Pacific Islanders.

Figure 30.6. Traditional Palauan cast net fishing remains important for local food security. Photo credit: © Reid Endress

Agriculture

Crop production in the USAPI has generally kept up with population growth over the past 20 years.[165,173] Although local agriculture provides a fraction of nutritional needs in the region,[165] it remains a critical food source, complementing imported foods, serving as an emergency food source, providing culturally important items, and supplementing household income and government revenue.[196,197]

Climate change is projected to impact island food systems through a variety of different mechanisms (KMs 11.1, 23.3).[77] Warmer nighttime temperatures and saltwater intrusion, especially in FSM and RMI, are projected to increase damage from disease on staple crops such as taro, bananas, and breadfruit.[77,198] Cash crops are also *likely* to be affected, with higher temperatures and increased plant pathogens decreasing coffee yields, increased flooding depressing sugar yields, and higher winds damaging coconut palms, bananas, and breadfruit.[191] In Hawai'i, droughts have become longer and more severe and are the principal cause of crop loss.[49]

Adaptation Strategies to Improve Local Food System Resilience

Strategies are being developed and implemented across the region to revitalize healthier traditional food systems, resulting in more just access to food (KM 11.2).[117,118,165,199] Subsistence-based food system practices such as agroforestry and fishing have sustained Pacific Island peoples for millennia and have aided in recoveries from natural disasters such as typhoons, earthquakes, volcanic eruptions, and tsunamis.[119,171,200,201] Restoring Indigenous agroecology practices can support conservation, food security, and broader sociocultural objectives in the face of shifting precipitation and SLR (e.g., Bremer et al. 2018;[202] Winter et al. 2020[203]). Community food-sharing networks that empowered the most overburdened to overcome economic and social hardship during the COVID-19 pandemic offer a model for resilient food systems in the face of climate change.[175,204,205] Promising fisheries adaptations include establishing networks of marine protected areas to preserve coastal resources, safeguarding fish habitats from pollution runoff, and restoring traditional fishpond mariculture (KM 10.3; e.g., Bell et al. 2013;[73] McLeod et al. 2019;[119] Farmery et al. 2022[116]).

Box 30.4. Food Security and Traditional Knowledge

For thousands of years, Pacific Islanders have relied on traditional food systems that now face threats from climate change. Traditional agroforestry and aquaculture investments are critical to strengthen food security and reduce reliance on food imports.[4,5,206] The Melai Mai Breadfruit Project was initiated in 2016 to increase food security in typhoon-devastated outer islands of Yap, FSM.[207] Importing diverse breadfruit varieties to extend the harvest length increased food production and sustainability. Other examples include programs working to identify saltwater-tolerant taro species (Figure 30.7) in Palau and distribute them to the community.[111,208]

Key Agricultural Plants: Giant Swamp Taro

Programs aimed at supporting traditional crops help strengthen food security.

Figure 30.7. Several varieties of giant swamp taro are salt tolerant, making them valuable for adapting to saltwater intrusion. Photo credit: © Ann Singeo, Ebiil Society Inc.

Key Message 30.2

Climate Change Undermines Human Health, but Community Strength Boosts Resilience

Climate change undermines the place-based foundations of human health and well-being in the Pacific Islands (*high confidence*). Climate shocks and stressors compromise healthcare services (*medium confidence*) and worsen long-standing social and economic inequities in both mental and physical health (*high confidence*), and these negative impacts are expected to increase in the future (*very high confidence*). Adaptation efforts that build upon existing community strengths and center local and Indigenous Knowledge systems have great potential to boost resilience (*high confidence*).

Climate change can degrade societal foundations of health and well-being, including access to shelter, nutritious food, clean water, and cultural and social relationships (KM 15.1). Prominent international frameworks and Pacific Island Indigenous conceptualizations of health and well-being recognize that the health of people is closely connected to the health of nonhuman beings, to the shared environment, and to place (Figure 16.3).[209,210,211,212]

Indigenous communities of the Pacific Islands have actively responded to climate-related and other health risks, as well as external economic shocks (Box 30.3; KM 16.3).[119,205] However, colonization and economic disparities have resulted in disproportionately high rates of morbidity and mortality for Native Hawaiian and Indigenous Pacific Island peoples (KM 15.2).[213] Moreover, Pacific Island populations experienced severe economic shocks during the COVID-19 pandemic (KM 30.3),[214] which interacted with existing societal and non-climate stressors that worsen health inequities (KM 18.2).

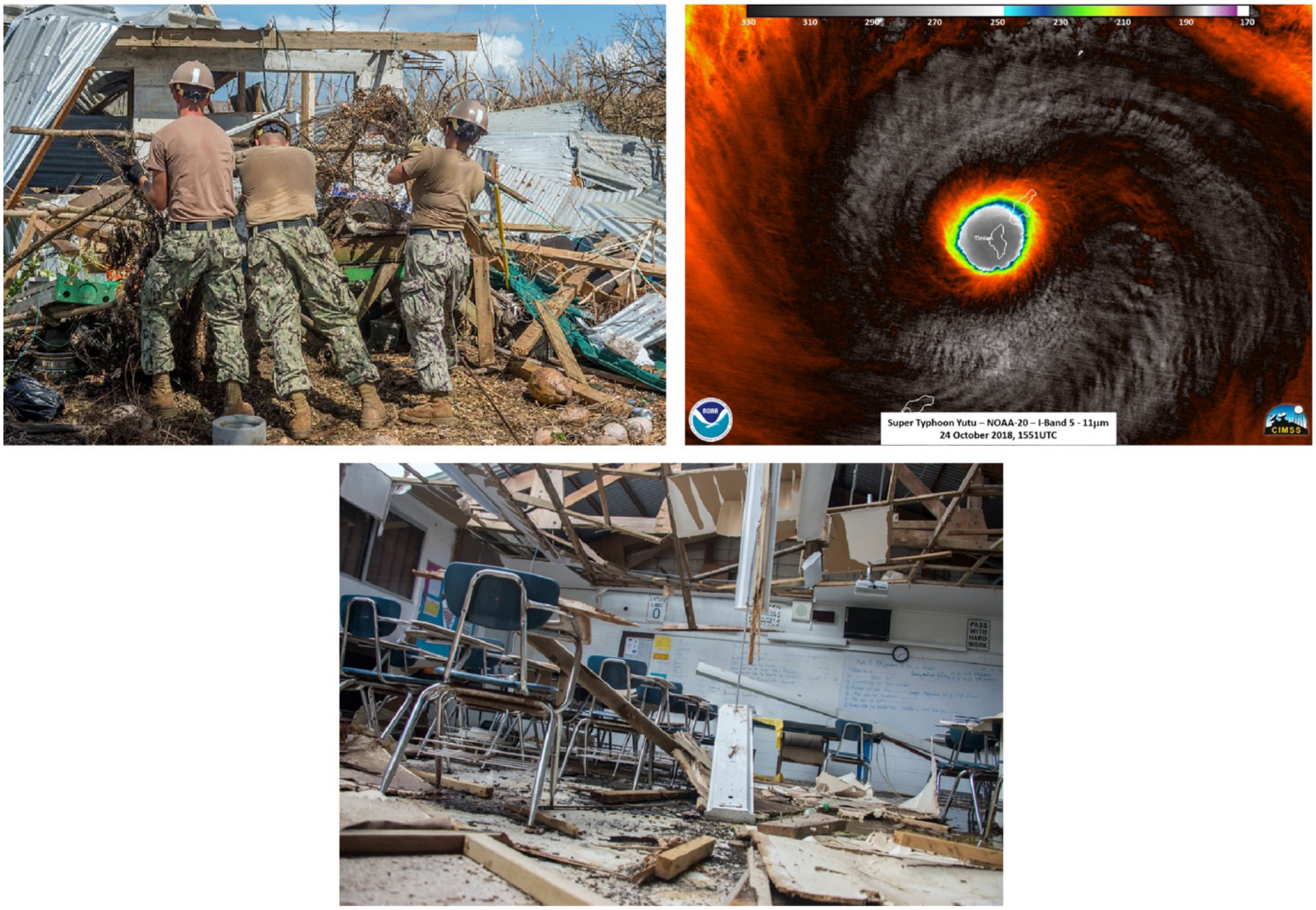
The Health Impacts of Extreme Events

Tropical cyclone intensity,[53,215,216] drought frequency,[150,217] and flood potential (KMs 30.3, 2.2)[70,98,218,219] are expected to increase and continue to aggravate social and geographic inequities (KMs 2.2, 4.2, 10.1, 16.1, 17.4).[53,98] Extreme weather impacts health in ways that persist beyond the initial disaster,[220,221] including increases in food- and waterborne pathogens, loss of access to medications and emergency services, loss of electricity needed for medical equipment and medical facilities, and disruptions to transportation networks, all of which increase illnesses and deaths (KM 15.1).[222] Healthcare facilities in the Pacific Islands are located primarily on coastlines, making them especially susceptible to tropical cyclones and SLR-driven flooding (KM 9.2),[104,223] with limited space and resources for relocation (KM 30.3).

The built environment is especially affected by extreme weather because of high costs of building materials, supply shortages, delays in code updates, and physical isolation (Figure 30.8; KM 30.3).[224] Given the limited emergency infrastructure and evacuation options, extreme weather events create high risks for the mental and physical health of island populations, with individuals with low-income, older adults, children, and persons with disabilities at disproportionately higher risk (Box 15.1).[26,225,226,227]

Drought poses health challenges, particularly for rural island populations. A 2013 drought in the northern atolls of RMI caused crop failures and unsafe and insufficient water supplies, which led to nutritional deficits and increased prevalence of infectious diseases, especially in children.[103,228] Severe wildfires, which occur primarily during droughts,[229,230,231] directly threaten health and safety and can create respiratory hazards (KM 14.2).[232]

Damage from Typhoon Yutu



Extreme events acutely affect Pacific Island communities and their built environment.

Figure 30.8. In 2018 Super Typhoon Yutu struck the Commonwealth of the Northern Mariana Islands and damaged or destroyed a significant portion of the islands' buildings and critical infrastructure, leaving a sizable population temporarily unhoused. The experience underscored how events such as cyclones, flooding, and droughts combine with societal factors to acutely affect human health and safety. Images show US Naval personnel clearing debris at a Tinian family's home destroyed by Super Typhoon Yutu (**top left**); a satellite infrared image of Super Typhoon Yutu (**top right**); and a classroom in Hopwood Middle School on Saipan after the storm (**bottom**). Image credits: (top left) Matthew R. White, US Navy; (top right) NOAA/UWM-CIMSS, William Straka III; (bottom) Grace Simoneau, FEMA.

Health-Associated Impacts from Migration

Under a very high scenario (RCP8.5), human migration will increase due to SLR-driven inundation and salinization, displacing people, even entire populations, from low-lying atolls and low-elevation areas of high islands, with enormous implications for health and well-being (KMs 15.1, 17.1, 20.3).[98,105] Migrants often have difficulty navigating foreign healthcare systems[233] and face other barriers to accessing healthcare, including ineligibility for federal programs.[234] An improved understanding of the experiences and health outcomes of people who migrate, within or away from the USAPI, could inform better policy.

Mental Health Consequences and Climate Grief

Climate change directly and indirectly affects the mental health of Pacific Islanders.[235,236,237] On some islands globally, local climate stressors (such as floods, droughts, and SLR) are linked with negative mental health outcomes such as sadness, distress, and anger (KM 15.1).[238,239,240] Across the Pacific region, studies show that rural populations, socioeconomically disadvantaged groups, and people with disabilities experience more severe mental health consequences from various climate impacts (KM 15.2).[105,239,240,241,242]

Research is limited on the mental health impacts of climate-induced migration. Instability caused by voluntary and involuntary migration is expected to be a continuing source of anxiety,[99] although evidence indicates that social cohesion and reducing disparities can counter negative impacts.[105,243] Some data show that distress from thinking about climate stressors can be comparable to that from experiencing direct impacts.[239] Additionally, because Indigenous People in the Pacific are strongly connected to place, and place is central to conceptions of cultural identity, sudden ecological devastation or gradual change to the environment can create considerable stress (KMs 10.1, 15.1, 15.2, 23.1, 29.1).[99]

Mental health services related to climate change show effectiveness when they are designed to serve Pacific Islander populations in a culturally centered way and include diverse ways of knowing.[235,243,244] Finally, the lack of studies on mental health and climate change in Hawai‘i and the USAPI indicates that additional research may provide a more nuanced understanding of local implications.

Increase in Vector-Borne Disease

Outbreaks of mosquito-borne diseases such as dengue, chikungunya, and Zika are increasing in frequency, extent, and duration across the region.[245,246] Changes in rainfall (Figure 30.3) and temperature, combined with environmental and demographic changes, are anticipated to exacerbate this trend.[34,247] Resources for vector control and managing outbreaks are limited on small tropical islands, and outbreaks sometimes overwhelm health systems.[245,247] Health officials in FSM, RMI, and Palau are developing predictive modeling to create a dengue early warning system.[248] Similar to how chikungunya and Zika recently emerged and expanded in the Pacific, other vector-borne diseases may emerge in the future.[249]

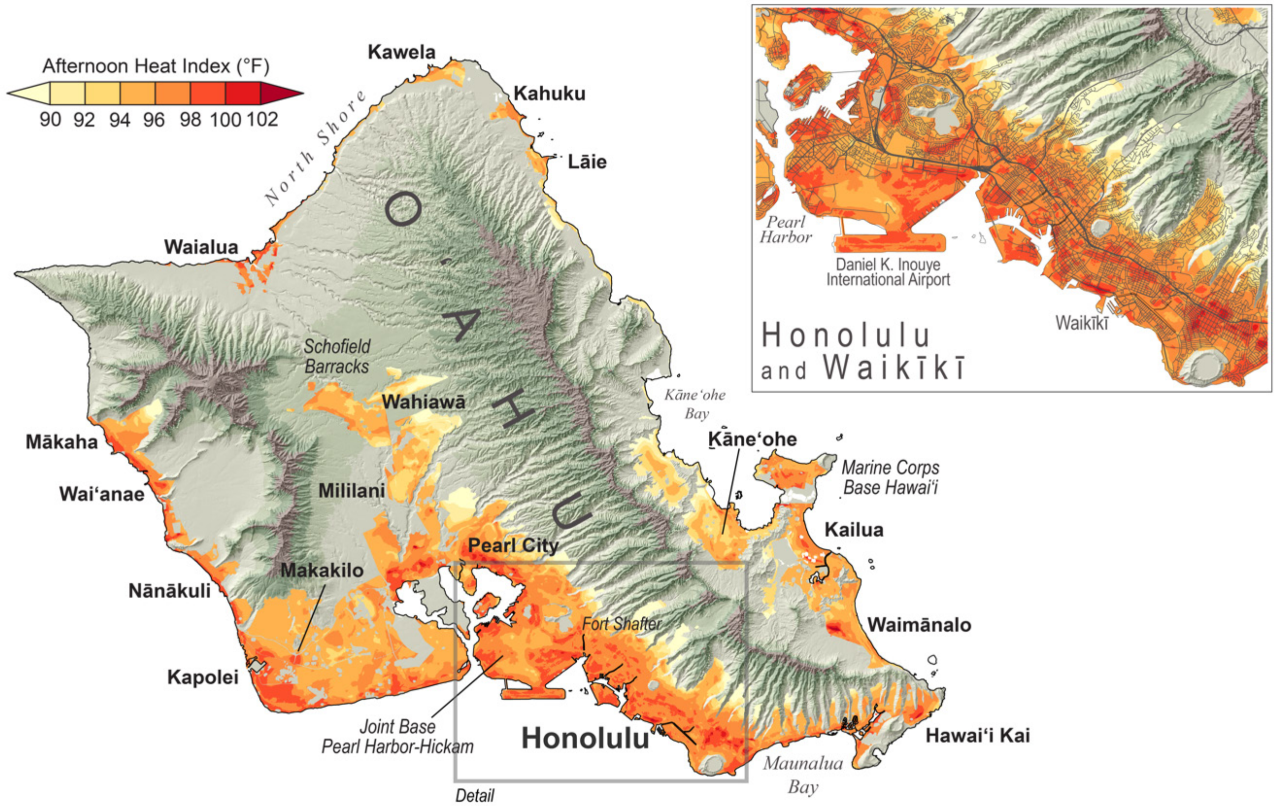
High Temperatures and Heat-Related Illness and Death

As in much of the US (Figure 2.11), the number of hot days has increased across the Pacific Islands; 2020 was the region's hottest year on record.[27,28,29,45,113] A community heat assessment in O‘ahu, Hawai‘i, in August 2019 found many neighborhoods with record-high afternoon heat indices between 100°F (38°C) and 107°F (42°C) (Figure 30.9).[250,251]

Climate change–driven hot weather causes heat-related illness and increases hospitalizations and deaths; 82% of heat-related deaths in Honolulu are already attributable to climate change (KM 15.1).[252] Those more likely to experience heat-related illness include young children, older adults, outdoor workers, economically burdened and disadvantaged people with little access to cooling or healthcare (KM 15.1), military personnel whose duties require heavy gear and vigorous activity, and non-acclimated visitors.[91] Shock events interact with heat: for example, after the 2009 tsunami in American Sāmoa, dehydration, heat stress illnesses, and barriers to receiving medical care increased.[253]

Imported low-quality foods have replaced local, nutritious, traditional diets (KM 30.1), resulting in some of world's highest prevalence of noncommunicable diseases (NCDs).[165,190,199,254,255] Heat worsens health outcomes for people with NCDs such as heart disease, cancer, stroke, and diabetes[256] and creates challenges for the management of obesity and other diseases because exercise is more difficult to do safely. Overweight and obesity in young children are at a higher prevalence in American Sāmoa, CNMI, and Guam than globally.[257]

Oʻahu Community Heat Assessment (August 31, 2019)



High temperatures are responsible for heat-related illnesses, hospitalizations, and death.

Figure 30.9. This community heat assessment map shows the afternoon heat index and "hotspots" for the island of Oʻahu, Hawaiʻi. The inset is urban Honolulu. Data were collected by community volunteers and the City and County of Honolulu on August 31, 2019. On this day, the high temperature tied the hottest-ever recorded for Honolulu. Multiple neighborhoods on Oʻahu experienced afternoon heat indices above 100°F (38°C), with a maximum recorded heat index of 107.3°F (42°C). Climate change is increasing the frequency, intensity, and duration of heat extremes, putting individuals and communities at risk. Figure credit: Arizona State University, University of Hawaiʻi at Mānoa, NOAA NCEI, and CISESS NC.

Social Adaptive Capacity and Community Resilience

The ability of individuals, communities, and institutions to endure stress and adapt to change determines health impacts of climate change. Recent examples demonstrating the importance of social capital (such as community networks, equitable access to education [KM 15.3], sharing, and relationships) in disaster response include community initiatives addressing flooding on the island of Kauaʻi[258] and drought in RMI.[259] Traditional Knowledge and coping strategies can enhance adaptive capacity and disaster response in some contexts.[260,261,262,263] The resilience of organizations, including health-related institutions and disaster response systems, depends on the ability of organizations to form relationships and communicate with one another, participation by traditional leaders and faith organizations, and effective planning by disaster management agencies (KMs 16.2, 20.2).[227,264,265,266,267] Prioritizing social and mental health initiatives in the health sector would aid in responding to the psychological issues that emerge with disasters and climate change.[268]

Key Message 30.3

Rising Sea Levels Threaten Infrastructure and Local Economies and Exacerbate Existing Inequities

Climate change, particularly sea level rise (SLR), will continue to negatively impact the built environment (*very likely*, *high confidence*) and will harm numerous sectors of the islands' economies (*very likely*, *high confidence*). SLR intensifies loss of territory and exclusive economic zones, particularly in low islands (*high confidence*). Climate-driven changes will exacerbate existing social challenges by disrupting livelihoods (*likely*, *medium confidence*). Adaptation to climate change and recovery from disasters is logistically challenging and disproportionately more expensive in the islands (*high confidence*). Government and community groups have developed innovative ways to reduce emissions and improve resilience by moving toward renewable energy and green infrastructure, nature-based urban planning, forward-looking building codes, and sustainable and equitable economic growth, guided by Western science and Traditional Knowledge.

Built Environment

The built environment refers to all human-made structures, including buildings, transportation infrastructure (ports, airports, roads, and bridges), military installations, and distribution systems for food, water, wastewater, communications, and power (electrical, oil, and gas). For this region, it includes traditional structures such as burial grounds, fishponds, and taro terraces (KM 30.5). These structures are critical to connecting people and providing access to goods and services, yet their location within a few feet of sea level renders them particularly vulnerable to SLR (Figure 30.4) and natural disasters (KM 9.2). For example, 98% of RMI's and 80% of Palau's built infrastructure is located within approximately 1,600 feet of their coastlines.[85]

Impacts to Infrastructure

Sea level rise will increasingly impact coastal infrastructure through increased magnitude and duration of storm wave–induced flooding (KMs 2.2, 9.1),[98,219,269] rising high tides,[270] and increased coastal erosion (Figure 30.10).[271] In Hawai'i, 3.2 feet of SLR above 2000 levels, which could occur as soon as 2100 under the Intermediate SLR scenario or 2070 under the High scenario (for information on the likelihood of these scenarios, see Appendix 3; Figure 30.4),[65] would affect 550 cultural sites, 38 miles (6%) of major coastal roads, 6,500 structures, and 25,800 acres of land, potentially displacing 20,000 residents and incurring $23.1 billion (in 2022 dollars) in economic loss.[92] Approximately 3 feet of SLR is projected to affect at least 58% of Guam's built environment[90] and most atolls in FSM and RMI.[98] Highly urbanized atolls may not be able to adapt to future SLR (KMs 9.2, 12.2),[106,107] leading to land loss and potential uninhabitability.[98,108] Elevated SSTs can increase bleaching and degradation of coral reefs, which are some islands' primary natural defenses (Figure 30.11; KM 30.4) against coastal flooding.[272] Lastly, increased flooding and erosion due to SLR and stronger future cyclones threaten US military bases in the region, potentially destabilizing regional security and the ability of the Department of Defense to respond to natural disasters (KM 17.1).[53]

Coastal Flooding Events

Sea level rise is increasingly impacting infrastructure and communities.

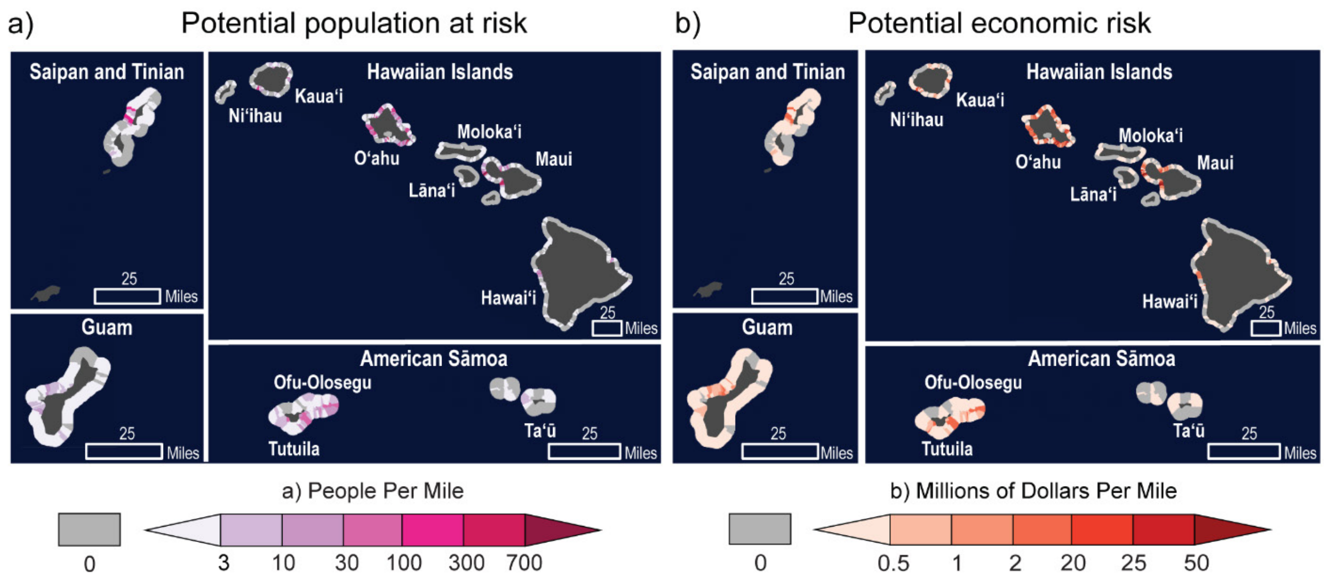
Figure 30.10. Rising sea levels are increasing the frequency and magnitude of coastal flooding events. (**top left**) Cars travel through king tide flooding on Oʻahu, Hawaiʻi, in August 2019. (**top right**) High tide inundates a low-lying coastal area in Majuro, Marshall Islands, in February 2020. (**bottom left**) A residence on Oʻahu, Hawaiʻi, has collapsed due to coastal erosion during a large wave event in February 2022. (**bottom right**) American Sāmoa experienced flooding around homes in May 2021. Photo credits: (top left) Maya Walton via © Hawaiʻi Sea Grant King Tides Project, 2019 [CC BY 4.0]; (top right) Max Sudnovsky via © Hawaiʻi Sea Grant King Tides Project, 2020 [CC BY 4.0]; (bottom left) © Shellie Habel; (bottom right) Kelley Anderson Tagarino via © Hawaiʻi Sea Grant King Tides Project, 2021 [CC BY 4.0].

Adapting the Built Environment

Protecting coastal infrastructure on small islands is costly and requires strong governance and thoughtful urban planning.[273] Hawaiʻi has enacted forward-looking state and county policies, including increased minimum setbacks for coastal development,[274,275,276] setbacks incorporating science-based erosion rates and long-planning horizons that account for future SLR,[275,277,278,279] a first-in-the-Nation mandate to disclose SLR hazards prior to real estate transactions,[280] a requirement for state agencies to assess and plan for SLR impacts,[281] and a mandate that environmental impact assessments consider SLR and other climate factors.[282] While evaluating a balance between public and private property interests (KM 30.5), Hawaiʻi is also assessing the feasibility of relocating some coastal developments,[283] prohibiting most coastal hardening,[274] and helping to preserve public beach access.[283]

Nature-based solutions such as coral reef restoration[284,285] have been proposed at the federal (DARPA Reefense Program),[286] state (e.g., State of Hawai'i 2021[287]), and territorial[288] levels. Such solutions are potentially cost effective for protecting coastal infrastructure[289] and habitats, sustaining ecosystem services such as fisheries (KM 30.1), and supporting tourism and recreation.[290]

Annual Risk Reduction Benefits Provided by Coral Reefs



Coral reef degradation could affect thousands of people and cause millions of dollars in damages.

Figure 30.11. The maps show coastal flood protection that the top-most 3.28 feet (1 m) of coral reefs provide annually in American Sāmoa; Guam; Saipan and Tinian (Commonwealth of the Northern Mariana Islands); and Hawai'i. The maps display (**a**) the number of people per mile at risk and (**b**) the potential economic losses (in millions of dollars per mile) from direct building damages and indirect economic disruption from flooding. Adapted from Storlazzi et al. 2019.[291]

Livelihoods and Economy

Demographics and Migration

Compared to Hawai'i, the USAPI have smaller populations and smaller land masses, as well as fewer financial resources, making adaptation more challenging. During 2010–2020, populations increased in Hawai'i and decreased in American Sāmoa, CNMI, Guam, and Palau.[16,17,18,19,20,21] Pacific Islanders are moving from rural to more urban areas that sometimes lack resources and infrastructure to accommodate influxes of people.[273,292] Migration is a traditional strategy for coping with resource scarcity in Micronesia—for example, a family member often migrates to an urban area for employment, sending money home to support family needs.[293] In 2020, these external remittances accounted for 5.7% of FSM's GDP, 0.08% of Palau's GDP, and 12.7% of RMI's GDP.[294,295,296] As livelihoods in climate-sensitive sectors are impacted by climate change, the amount of money migrants send to relatives will be affected. Climate change may displace populations,[297] but the extent to which climate change drives migration is not well established because migration is an inherent part of Pacific Island cultures.[298] However, some evidence points to a strong correlation between climate impacts on ecosystem services (e.g., food and water provision, protection against floods and storms) and people's propensity to migrate.[299]

Economy

The costs of adapting to, mitigating, and suffering the consequences of climate change are projected to increase over time, amounting to between 3% and 13% (under the 450ppm and SRES [Special Report on Emission Scenarios] A1FI scenarios, respectively) of Pacific Island regional GDP by 2100 (KM 19.1).[300] Relative to Hawaiʻi and larger countries, USAPI economies have smaller total GDPs and GDP-per-capita and higher dependence on fisheries and agriculture—climate-sensitive industries representing a large portion of GDP.[301] They also are more dependent on remittances, federal aid, and foreign aid (KM 17.1).[302,303]

Tourism is a major economic engine in the Pacific.[304] Before COVID-19, tourism accounted for over 80% of total exports for Palau and less than 20% for RMI[305] and approximately 25% of total GDP in Hawaiʻi. Climate change impacts tourism-based jobs and revenue. Damages to the built environment, especially coastal infrastructure, deterioration of natural assets, and expanding vector-borne disease occurrence could reduce tourism.[300]

Fishing is a critical economic sector in many Pacific Islands.[178,306] Tuna license revenues represent a significant source of government income for the FAS but are expected to decline due to projected changes in fish availability in the EEZs (KMs 10.1, 10.2),[79,80,81,83,306] with ramifications for local canneries in American Sāmoa and the FAS. Changing coastlines and potential land loss from SLR may result in changed maritime entitlements via changes in the size and shape of the respective EEZs,[306] affecting not just fisheries but also marine mineral rights. Climate-related marine and coastal habitat impacts threaten artisanal fisheries, a critical source of food and income for many households (KMs 30.1, 10.1, 10.2).[78,82,178,184]

Estimated Economic Costs of Climate Change

The estimated economic impacts of climate change will vary by sector. Coastal hazards have a disproportionately large impact on small islands' GDPs.[307] Specifically, the projected increased duration and magnitude of storm wave–induced flooding[98,219,269] and increased coastal erosion[271] can damage infrastructure underpinning the local economy. Degradation of coral reefs due to a rise in SSTs[272] could incur coastal damages costing approximately $1.2 billion (in 2022 dollars) annually to the economies of Hawaiʻi and the US Pacific territories.[218]

In American Sāmoa and Guam, coastal flooding and erosion are projected to disproportionately harm at-risk individuals, including minority and low-income populations and those younger than 16 or older than 65 (groups defined by the 2010 US Census data).[218] High-risk coastal properties (i.e., those located in hazard-erosion areas of updated FEMA Flood Insurance Rate Maps) will be difficult to insure.[308] Increased coastal flooding events and drought are expected to negatively impact agricultural revenues (KM 30.1). For example, between 2008 and 2016, Hawaiʻi lost approximately $53.5 million (in 2022 dollars) in cattle production due to the most severe drought on record, and federal crop insurance programs paid $11.2 million (in 2022 dollars) to farmers for drought losses during 1996–2018, mainly for macadamia nuts and coffee.[49]

Adapting Livelihoods and Economies

As a percentage of GDP, the costs of climate change adaptation are significantly higher for small islands than for larger countries.[300,309] Islands' geographic isolation, reliance on imported goods, and vulnerable infrastructure can increase adaptation and disaster recovery costs (see Figure 30.8).[224] Hawaiʻi and the USAPI have adopted the United Nations Sustainable Development Goals (Box 30.2)[130] to increase resilience by creating more equitable approaches to adaptation and mitigation. Financing costly climate adaptation is a shared international challenge for the FAS (KM 17.4).[300,301] Unlike American Sāmoa, CNMI, Guam, and Hawaiʻi, the sovereign FAS are eligible for foreign direct investment and receive substantial funding from the Green Climate Fund,[310] the Asian Development Bank,[311,312] the US Government via the Compact of Free Association,[310,313] and other nations (KMs 19.2, 19.3).[314] Because credit agencies are increasingly considering vulnerability to climate change as a factor in their ratings, however, Palau's and RMI's credit ratings may decrease, with negative impacts on their abilities to borrow external funds, attract foreign investment, or access below-market-rate financing to accelerate development.[315]

Decarbonization, Sequestration, and Resilience

Although many Pacific Islands emit minimal greenhouse gases, they are striving to reduce emissions and sequester carbon while addressing ecosystem resilience needs.[119] For example, Guam and Hawaiʻi established 100% renewable portfolio standards for the electricity sector, to be achieved by no later than 2045.[316,317] Hawaiʻi established a net-negative emissions target by 2045 and created a sequestration task force[282] charged with establishing baselines and benchmarks, recommending policies including mitigation, and developing strategies for sustainable agriculture. This work led to a carbon pricing evaluation.[318] Similarly, RMI pledged emissions reductions of 45% below 2010 levels by 2030 and carbon neutrality by 2050.[319] Palau recently committed to 100% energy generation from renewable sources by 2032.[320] Opportunities exist for ecosystem-based, place-based adaptation and mitigation informed by Indigenous Knowledge systems (KMs 30.1, 30.5).[321,322,323]

With limited land areas, each island in the region is carefully evaluating options for transitioning to renewable energy. In 2016, American Sāmoa's island of Taʻū transitioned its energy supply from 100% diesel to 100% solar with battery backup.[324] In Hawaiʻi, rapid growth of rooftop solar generation—combined with centralized solar, battery storage, wind power, and pumped hydropower storage—is enabling a transition away from an oil-predominant grid.[325] The potential for success is high: Kauaʻi's grid achieved a 69.5% renewable portfolio standard in 2021, and the island is occasionally 100% renewably powered during midday hours; it is projected to achieve a 90% renewable portfolio by 2026.[326,327] Hawaiʻi's Act 100[328] required a community-based renewable energy program; power utilities and communities in the region are now developing mechanisms to enable shared ownership of renewable infrastructure.[329]

Key Message 30.4

Responses to Rising Threats May Help Safeguard Tropical Ecosystems and Biodiversity

The structure and composition of Pacific Island coastal and marine ecological communities are directly threatened by rising ocean temperatures, ocean acidification, and sea level rise (*very likely*, *high confidence*). Increasingly severe droughts and warming are increasing fire risk (*high confidence*) and will have broad negative impacts on native plants and wildlife, including an increased risk of forest bird extinctions (*very likely*, *high confidence*). Adaptation strategies improve the resilience of ecosystems, including ecosystem protection, ecological restoration, invasive species prevention and control, and investments in fire prevention (*medium confidence*).

Marine and Coastal Ecosystems

Pacific Island marine environments serve as the foundation for local food systems and cultures (Figure 30.12). Rising ocean temperatures, declining dissolved oxygen concentrations, and marine heatwaves are projected to impact the structure and composition of marine ecosystems (Figure 30.5; Ch. 8; KM 10.1).[330] Global marine food web models project biomass declines of 10% to 40% across the region throughout this century, with greater declines projected for large predators.[331] Finally, marine species within the region's EEZs are projected to shift beyond historical ranges as early as 2030—sooner than much of the globe.[83]

Coastal and oceanic environments supply direct goods and services such as fish, recreation and tourism areas, regulating services such as coastal protection and carbon storage, and means for trade and transportation—collectively valued at over $3.1 trillion per year (in 2022 dollars; KM 23.2).[332] Rising SSTs and marine heatwaves continue to be the most pressing climate change impacts facing Pacific reefs,[333,334] leading to more frequent and severe bleaching events with less recovery time.[61,62,335,336] Bleaching-induced mortality has reduced coral cover and decreased available habitat for reef-associated species.[62,334] Increased SSTs will negatively affect some animal species distributions,[337,338,339] and rising ocean and sand temperatures lead to a higher ratio of female sea turtles observed around the Pacific, threatening the viability of sea turtle populations.[340] Increased air temperatures and reduced precipitation are *likely* to have negative effects on coastal vegetation[341] and coastal pond communities,[342] adversely affecting coral reefs, seagrasses, and mangroves via altered sediment and pollutant delivery to coasts.[343] Increased ocean acidity[344] and increased nutrient runoff from the land[345] negatively impact corals, shellfish, and associated fisheries (KM 30.1). Although these systems generally have limited capacity to adapt to large climatic changes, regional strategies are being developed to reduce impacts.[337,338,346]

Box 30.5. Blue Carbon Ecosystems

USAPI mangroves and seagrasses are among the world's most productive blue carbon ecosystems (BCEs—ocean and coastal ecosystems that capture carbon; Focus on Blue Carbon),[347] storing over 30% of total island carbon despite their small area.[120] Guam, the Republic of the Marshall Islands, the Federated States of Micronesia, and Palau plan to use BCE carbon to offset emissions while also protecting coastal infrastructure.[285,348,349] BCEs also provide food, fiber, fuel, and income to Pacific Islanders.[350] Mangroves are non-native to Hawai'i and threaten shorebird habitat, coastal access, and cultural sites and services.[351] However, evidence suggests that these non-native species can provide some ecosystem benefits, for example, by significantly increasing coastal sediment accumulation[352] and carbon capture rates.[353] Mangrove loss in Micronesia is projected to start by 2080 under Intermediate SLR scenarios (Figure 30.4).[86] The conservation and restoration of BCEs and their associated reef systems provide cost-effective solutions for protecting coastal communities and increasing other benefits (KM 8.3).[289]

Sea level rise will cause more frequent and extensive flooding of coastal ecosystems, impacting plants[354,355] and animals,[356] especially on low-lying atolls such as those in the Northwestern Hawaiian Islands, PRI, RMI, and FSM. In some cases, flooding is *likely* to increase erosion rates, reducing the elevation of mangroves, vegetated dunes, and beaches. Development exacerbates these drivers by exposing soils, creating impervious surfaces, and impeding inland migration of coastal ecosystems, limiting their adaptive capacity.[357]

Characteristic Ecosystems of the Pacific Islands

Pacific Island marine environments provide the foundation for local food systems and cultures.

Figure 30.12. Pacific Islands offer a diversity of ecosystems that include mangroves (**top left**), limestone forests (**bottom left**), tropical alpine habitats (**top center**), dry forests (**bottom center**), coral reefs (**top right**), and cloud forests (**bottom right**). Photo credits: (top left) Richard Mackenzie, USDA Forest Service; (top center) © Paul Krushelnycky, University of Hawai'i; (top right) © Underwater Earth / XL Catlin Seaview Survey / Christophe Bailhache; (bottom left) Christian Giardina, USDA Forest Service; (bottom center) Hawai'i Department of Land and Natural Resources; (bottom right) Lucas Fortini, USGS.

High Island Ecosystems

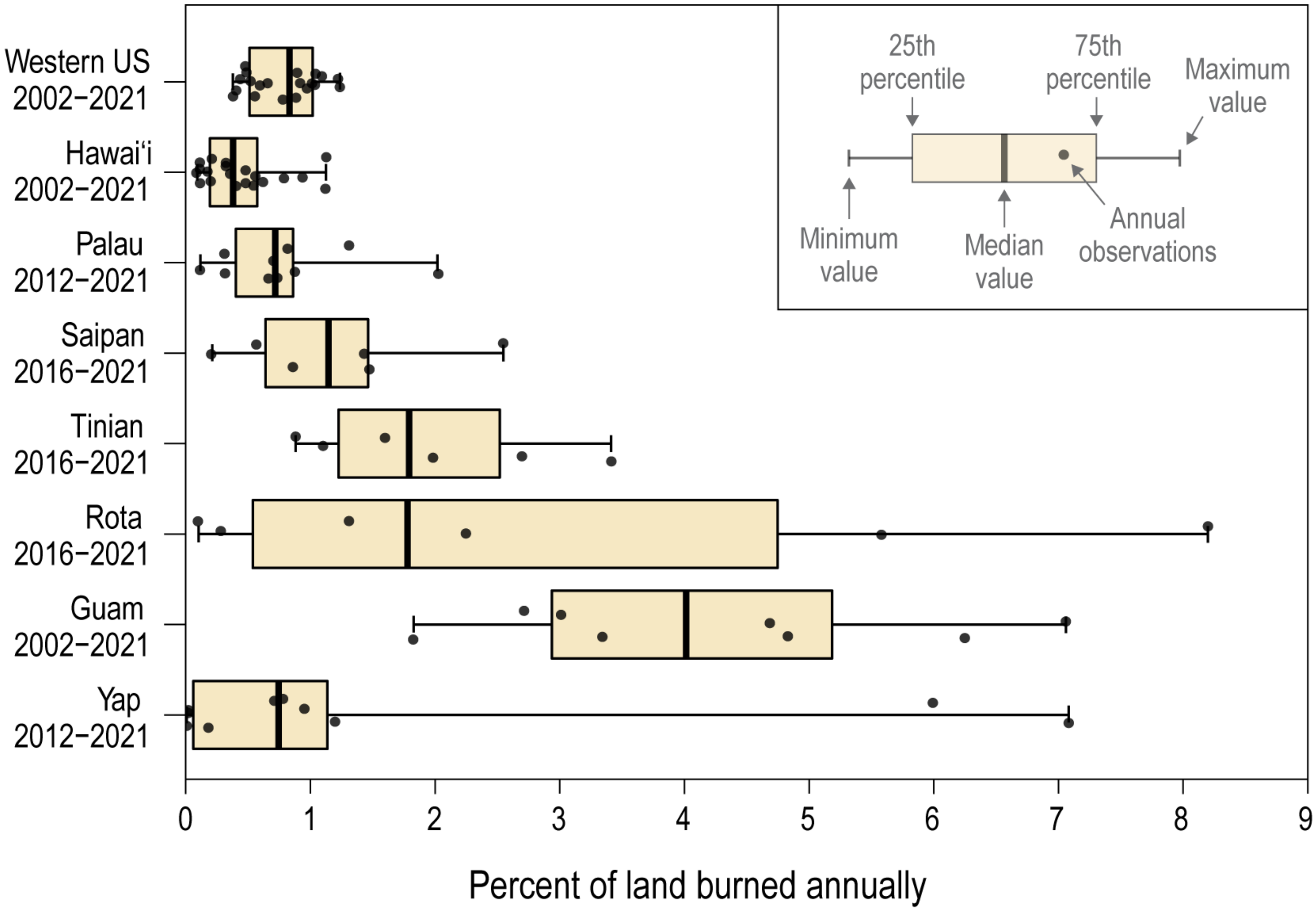
Terrestrial ecosystems of high islands (i.e., islands characterized by volcanic origin and consequently more diverse topography) have evolved in isolation from continental areas, resulting in unique and diverse fauna and flora with a high proportion of native species naturally occurring only on these islands (Figure 30.12). However, the combination of invasive plants and animals and diseases; habitat destruction; and intensifying fire regimes and ecological drought has resulted in severe range contractions and native species extinctions.[93,358,359,360,361,362,363]

In Hawaiʻi, past droughts and rainfall variability had landscape-level impacts on vegetation[364,365] and cascading ecological effects.[366] Long-term climatic shifts are *likely* to accelerate range contraction and extinction rates,[93,367] but responses will vary by species, including differences in drought tolerance across populations.[368,369,370,371]

Rainfall changes (Figure 30.3) will affect island aquatic ecosystems. In Hawaiʻi, declines in dry-season streamflow will result in more intermittent streams[137] and loss of habitat connectivity and conservation value.[372] Decreased streamflow will also negatively impact stream organisms by reducing fitness and increasing disease and habitat for invasive fish and mosquitoes.[373,374,375]

Across the region, climatic shifts are expected to impact native ecosystems via interactions with fire (e.g., Trauernicht 2019;[376] Nugent et al. 2020[377]). Wildland fires already burn a higher proportion of total land area in the Pacific Islands than in the continental US (Figure 30.13)[229,378] and are strongly linked to El Niño events.[49,103] While limited future climate projections indicate increasing fire probabilities,[376] the future of fire in the region is highly sensitive to management and policy decisions, since ignitions are largely caused by humans (e.g., Dendy et al. 2022;[229] Trauernicht et al. 2015[378]). Education and outreach will continue to play a critical role in wildfire mitigation (e.g., HWMO 2021[125]).

Wildfire Area Burned in the Pacific Islands Compared to the Western US



Wildfires burn large percentages of land in Pacific Islands compared to the western US.

Figure 30.13. The annual percentage of total land area burned for seven Pacific Islands is equivalent to or greater than the percent area burned for western US states. Years examined are noted for each location. Figure credit: USDA Forest Service, USGS, NOAA NCEI, and CISESS NC.

Interactions between invasive species and climate change in isolated Pacific Islands are complex (KM 8.2),[379,380,381,382,383] with climate change most often exacerbating invasion.[384,385,386,387] Invasive species may aggravate local water stress, for instance, by using more water resources than native plants[148,380,388,389] or by causing less rainfall to reach the forest floor, as in the case of strawberry guava invasion.[148,390] Similarly, fire-prone invasive vegetation is likely to further increase future climate-driven fire risk.[376] With the steep increase in the number of naturalized species on Pacific Islands,[391] these climate and invasion interactions will become increasingly important for managers to address.[392] Critical region-wide investments are being made to prevent the introduction of potentially invasive species and diseases,[393] given that climate change can alter pathways for species introductions.[394,395,396]

Responding to Rising Threats

Regional efforts increasingly focus on restoration management that enhances climate resilience.[397,398,399,400,401] Besides boosting adaptive capacity,[402] ecosystem restoration efforts may provide multiple benefits to islands, including hydrological (KM 8.3)[140,148,161,401,403,404] and sociocultural benefits,[404,405] as well as carbon sequestration[406] and sediment retention.[407] Hawai'i and the USAPI have established both marine and terrestrial protected areas (Box 30.2),[119,134,408,409] which elsewhere have successfully supported ecosystem resilience under climate change (e.g., Gaüzère et al. 2016;[410] Lawler and Hepinstall-Cymerman 2010;[411] Roberts et al 2017;[412] Virkkala et al. 2014[413]).

The urgency of conservation actions (Figure 30.14) is exemplified by the Hawaiian forest bird crisis. Forest bird populations are declining due to avian malaria spread driven by warming.[414,415] Managers are exploring options for safeguarding species near extinction,[416,417,418,419] including habitat restoration, avian malaria vector control,[420] and translocation.[421,422,423,424]

In addressing these myriad challenges, conservation efforts increasingly involve broader partnerships with educators (e.g., Bolden et al. 2018[123]) and Indigenous Knowledge holders, who play a vital role in conservation planning and implementation (KM 30.5; Ch. 16).[405,425,426,427,428]

The Climate Urgency of Pacific Island Conservation

Conservation efforts across the region help to restore ecosystem health and protect native species.

Figure 30.14. These images depict on-the-ground climate-related conservation actions across Pacific Island ecosystems: wildfire management in Hawai‘i Volcanoes National Park (**top left**); planting native species in Palau to restore watershed health (**bottom left**); installing protective fencing around native habitat in Hawai‘i (**bottom center**); conservation of native snails using captive populations to prevent extinction of vulnerable populations (**top right**); seabird translocations in the Northwestern Hawaiian Islands to safeguard against sea level rise (**center right**); and climate-resilient coral reef restoration experiments in Hawai‘i (**bottom right**). Photo credits: (top left) D. Benitiez, NPS; (top right) © Chris A. Johns; (center right) © Lindsay Young, Pacific Rim Conservation; (bottom left) © Ann Singeo, Ebiil Society Inc.; (bottom center) NPS; (bottom right) Hawai‘i Department of Land and Natural Resources.

Key Message 30.5

Indigenous Knowledge Systems Strengthen Island Resilience

Indigenous Peoples and their knowledge systems are central to the resilience of island communities amidst the changing climate (*high confidence*). Reciprocal and spiritual relationships among the lands, territories, waters, resources, and peoples are being strengthened and sustained as communities adapt and manage their resources collectively (*high confidence*). Indigenous Peoples are identifying and quantifying the potential loss and migration of critical resources and expanding the cultivation of traditional food crops on high islands (*high confidence*).

Reciprocal Relationships Between People and Place

Communities throughout Hawaiʻi and the USAPI demonstrate Indigenous cultural and community resilience grounded in Traditional Knowledge as they continue to adapt to global changes, just as their ancestors have for millennia (KM 18.3; Figure 16.3).[87] These adaptations and the collective resilience of Indigenous communities are strengthened and sustained through reciprocal exchanges between the peoples and the lands, territories, waters, and resources to which they are genealogically connected (Figure 30.15). Resilient communities are vital to the overall health and well-being of island peoples. To effectively advance the science of sustainability and manage resources amidst the changing climate, spiritual rituals and engagements are central to biocultural well-being—the collective well-being of landscapes, seascapes, and Indigenous communities (Box 30.6).[429] Through these rituals and engagements, island communities individually and collectively are able to connect to the place and all of its life-forms, cultivating reciprocal relations that enhance future resource abundance based on responsibility rather than ownership.[430]

Restoring and Caring for Hawaiian Limu (Seaweed)

The resilience of Pacific Island communities is strengthened by their connection to place and all of its life-forms.

Figure 30.15. *Limu* refers to ocean plants, including seaweed. The governor of Hawaiʻi designated 2022 as the Year of the Limu as a part of a statewide community effort to raise awareness about the importance of limu to Hawaiʻi's cultural identity and the health of the nearshore marine environment. The KUA Limu Hui (a seaweed practitioners group) shares traditional knowledge and practices related to limu gathering, use, and restoration. *Limu kala* (*Sargassum echinocarpum*; **left**) is incorporated into various food dishes, is used as bait for reef fish, and is an important component in Hawaiian forgiveness ceremonies. Limu such as *palahalaha* (*Ulva fasciata*; **right**) also play a critical role in intertidal ecosystems as they provide food and shelter for invertebrates and herbivores. Photo credits: © Haunani Kane.

Box 30.6. Local Cultural Resilience to Climate Change

Communities across the region are working to build local cultural resilience to climate change. In Hawaiʻi, community-based subsistence fishing[431] and forest[432] areas were established as place-based approaches to strengthen communities' ability to formally manage their natural resources through traditional and customary skills, practices, and social networks. Communities are cultivating reciprocal relationships as a shared responsibility[433] and including sacred relationships and ritual approaches to land and sea stewardship.[429] In Hawaiʻi, a common practice within the community is to ask for permission to physically and spiritually enter a sacred space, as this allows community members to introduce their genealogies to the lands and people, as well as express gratitude and respect for the land—the elder sibling—to sustain future generations.

Cultural and Historical Sites

Archaeological, cultural, and historical sites are representations of the living culture and ancestral knowledge of Indigenous and island peoples, and they serve as potential resources and models as communities seek to remediate increasing climate risks and impacts (Figure 30.16).[87,118,119,434] Indigenous communities are identifying and protecting cultural and historical sites, assessing climate impacts on natural resources, and creating restoration plans (KM 16.3).[435,436]

Archaeological sites and oral history document the culturally grounded and traditional resilience of island peoples to historical coastal change that resulted from extreme events and higher sea levels. Approximately 2,000–4,000 years ago across the equatorial Pacific, sea level was at least 3.3–6.6 feet higher than present, which directly influenced the timing of atoll formation and the initial migrations and settlement of island people.[437] Initial settlers of Majuro atoll, RMI, arrived within 100 years of island formation, when sea level was 3.3 feet higher than present, and they cultivated trees and shrubs into crop systems rather than waiting for natural vegetation succession.[438] On Yap, FSM, coastal stone-built structures are expressions of innovation, cultural identity, and pride that allowed islanders to occupy coastal areas under elevated sea level, and modern structures such as the coastal men's houses (*faluw*) and taro gardens document cultural resistance to rising waters.[87] On Guam, traditional CHamoru houses were elevated on limestone pillars (*latte*) along the coast, protecting them from coastal inundation.[439] Across higher islands like Sāmoa, settlement along narrow coastal plains occurred after nearly 1,000 years of sea level fall and subsequent natural development of habitable coastal environments.[437] The oral histories, stories, myths, storyboards (Palau), and songs/chants of Indigenous Peoples record their observations of the changing environments and lifestyles. The proverb *He pūkoʻa kani ʻāina* describes the natural evolution of a coral reef into an island and is also interpreted by Native Hawaiians to describe the resilience of a person who begins in a small way and gains steadily until she becomes firmly established.[440]

Climate Change Impacts on Cultural Sites

Cultural sites, representing the living culture and ancestral knowledge of Indigenous Peoples, are at increasing risk.

Figure 30.16. Sea level rise (SLR), strong winds, and large storm waves impact a fishpond in Kaloko-Honokōhau, Hawai'i (**left**). Kukau El Bad, a cultural site in Ngarchelong State, Palau, is inundated by salt water and continues to be threatened by SLR, storm surge, and erosion (**right**). Photo credits: (left) © Kimberly Crawford; (right) © Ann Singeo, Ebiil Society Inc.

Across the region, one approach to mediating climate impacts is to reinvigorate and restore food production across landscapes (KMs 11.1, 30.1; Box 30.4).[441] This is being accomplished through several pathways. At a policy level, work is being done to amend law in Hawai'i to add a "Traditional Lands" zone under the state's Land Use Commission that would streamline permit and building requirements[194] for eco-village-type living with mixed-use housing and other sustainable infrastructure such as commercial kitchen and food-processing facilities, as well as the use of traditional agriculture lands such as *lo'i kalo* (irrigated taro, agriculture), *loko i'a* (fishponds), and large expanses used to traditionally farm staple crops such as *'uala* (sweet potato).[442] Communities and cultural practitioners are working with scientists to identify areas where food production could be expanded under future climate scenarios (KM 12.4). For example, taro cultivation was modeled under future SLR scenarios[434] and sweet potato[442] and breadfruit under increasing temperature and rainfall scenarios,[118] showing the potential resilience of these traditional agricultural practices.

Indigenous Knowledge Systems and Values of Ecosystem Services

Indigenous island communities are also working to ensure that Traditional Knowledge is central to resilience strategies (KM 16.3). A growing body of Indigenous-led research describes how biocultural methods can successfully be incorporated into efforts focused on community-based subsistence,[431,432] relationships to place,[433] cultural–ecosystem service assessments,[443] and the protection of historical and cultural resources.[444] Biocultural approaches start with and build upon local cultural perspectives by encompassing values, knowledge, and needs and by recognizing reciprocal restoration between ecosystems and human well-being (KM 20.3).[195,443] The act of restoring ecosystem services contributes to cultural revitalization[433] by reaffirming connection to place, enhancing community relationships and social networks and the physical and mental well-being of Indigenous Peoples,[405] increasing local food production,[202] and diversifying the local economy[427]—all while distributing the abundance through reciprocal exchange.[431] In return, the renewal of culture promotes the restoration of ecological integrity through the creation and expansion of habitat for native species[434] and further supports recovery and resilience of ecosystems following future environmental disturbances (KM 8.3).[445] Equitable outcomes from climate research and planning are predicated on properly citing Indigenous elders and knowledge keepers,[446] enhancing Indigenous control of Indigenous data via data sovereignty, protecting intellectual property rights, and establishing free, prior, and informed consent (KMs 16.2, 20.2, 31.2).[447,448]

Traceable Accounts

Process Description

To build the author team, the federal coordinating lead author and the regional chapter lead author utilized the Fourth National Climate Assessment (NCA4) Key Messages and their assessment of new emerging issues to select key sectors of importance to the region. The lead authors compiled a comprehensive list of potential authors with expertise in those sectors. The regional chapter lead author then selected a total of 14 authors to join the team, representing a wide range of geographical and technical expertise (including physical and social scientists as well as cultural practitioners) and a diversity of career stages, affiliations (federal, academic, and private), and previous assessment experience.

The author team met weekly (virtually) to discuss chapter content and plan engagement activities. After brainstorming and agreeing on the five key topic areas for the chapter, authors identified which sections they would contribute to and met regularly in subgroups to discuss content. The team held a virtual public engagement workshop on January 24, 2022, to solicit public feedback on the chapter outline. In addition, the author team held five virtual technical meetings (one for each topic) where technical experts were invited to brainstorm and collect information to ensure the chapter covered the latest scientific results and most important topics in the region. The author team utilized interactive engagement tools to facilitate meetings, including collaborative writing exercises. Participants who contributed significantly to shaping chapter content were invited as technical contributors. Inputs from the workshop and technical meetings were synthesized by the author team and incorporated into the chapter draft.

Throughout this chapter, future projections of the physical environment come from general circulation models and earth system models from the fifth and sixth Coupled Model Intercomparison Projects (CMIP5[449] and CMIP6[450]).

Key Message 30.1

Climate Change Impairs Access to Healthy Food and Water

Description of Evidence Base

Global assessments support findings that coastal land loss attributable to sea level rise (SLR), increased precipitation, wave impacts, and increased aridity drive food and water insecurity on small islands.[89] Regional literature shows decreasing water quality and food production in both observed trends and modeled projections (KM 11.1).[77,135,147] However, these climate change manifestations are highly variable across different islands and within islands. Limited studies (e.g., Denton et al. 2014;[152] Felton 2021;[151] Ghazal et al. 2019;[144] Jarsjö et al. 2020;[154] Kibria et al. 2021;[155] Leta et al. 2017,[145] 2018;[146] Mair et al. 2019;[147] Strauch et al. 2014,[140] 2015,[451] 2018[141]) have quantified these effects on water resources and water quality throughout the large and diverse region. Although available studies and their results may be applicable to other, understudied islands, given the high diversity among islands, additional site-specific assessments in the Pacific Islands region would improve understanding of the impacts of climate change on water.

The importance of fisheries and agriculture for nutrition and livelihoods, and the nexus between food, trade, and malnutrition, come from a well-established evidence base,[31,32,165,175,191,199,255,452,453] although localized assessments dissecting socioeconomic–ecological dynamics remain limited.[166,199] Clear evidence shows that local agricultural and fisheries production is not keeping up with population, with outputs falling due to climate change.[31,452,454]

It is clear that fish, and particularly reef fish, are essential for regional nutrition and food security.[82,177,183] Evidence indicates that climate change is driving and will continue to drive changes to coral reefs and fisheries yields (along with pollution and overharvest).[78,81,113]

A broad literature base clearly establishes strong connections between drought and water security, sanitation, food productivity, and increased risk of wildfires.[191,217] Although few studies assess regional changes in drought,[49,50] Hawai'i has clearly experienced a drying trend,[48] particularly since the 1950s in La Niña years.[149,150]

It is generally agreed that reinvigorating local agricultural and marine food systems will be necessary, but not sufficient, for food security[116,175,190] and that investment in climate-resilient food supply chains is needed.[166,167,176]

Major Uncertainties and Research Gaps

Global and downscaled projections of rainfall exhibit large uncertainty in direction and magnitude of future change (e.g., Elison Timm et al. 2015;[51] Xue et al. 2020;[455] Zhang et al. 2016[57]). Island-specific downscaled projections of hydrometeorological extremes (drought, flooding, heavy precipitation) are not currently available for Hawai'i or the US-Affiliated Pacific Islands (USAPI). Understanding of future groundwater availability is limited by the lack of island-specific groundwater models for islands outside of the main Hawaiian Islands, some atolls in the Federated States of Micronesia, and Guam (e.g., Bailey et al. 2008;[456] Gingerich 2013;[457] Izuka et al. 2021[458]). Very little research exists regarding enhanced mobilization of subsurface contaminants from rising sea levels, despite the existence of many coastal contamination sites. Watershed management could be improved through better understanding of the current impacts of invasive plants (e.g., strawberry guava, *Psidium cattleianum*) on evapotranspiration and water cycling, and of how future climate change will modify such impacts.

Localized food supply chain vulnerability assessments are lacking (e.g., Dyer 2018[32]). Salt tolerance in many key agricultural plants is still not well understood (e.g., Palanivel and Shah 2021[198]), nor are the interactions between climate change and invasive agricultural pests. Reliable fish consumption information is not disaggregated by socioeconomic demographics nor by fish type, precluding analysis of nutrition (and risk from contaminants) by group. Barriers to and opportunities for reinvigorating local food systems are localized and require further analysis.

Description of Confidence and Likelihood

There is *very high confidence* that climate change will impair future access to clean and fresh water and healthy food. Broad global and regional literature support the finding that future water access will be compromised by reduced water availability, compromised water quality (KMs 2.2, 4.1),[26,103,138,139,140] and saltwater contamination, which has already been exacerbated by SLR, especially on atolls (*high confidence*).[98,135,136] The literature agrees that climate change will disrupt global food imports and supply chains through declines in nearshore and open-ocean fish stocks in the Pacific,[31,81,109,165,166,167,168,169,177,178,179] increased crop disease,[77,191] and drought.[49,103]

There is *very high confidence* that food and water availability will be negatively impacted by increasing temperatures, altered rainfall, flooding, pollution, and fisheries degradation. This confidence assessment is demonstrated by numerous peer-reviewed studies, robust global climate projections, and observations of changes to crop yields, fisheries, and freshwater ecosystems (e.g., Frazier et al. 2019;[103] Ghazal et al. 2019;[144] Leta et al. 2017,[145] 2018;[146] Mair et al. 2019;[147] Strauch et al. 2014,[140] 2015,[451] 2018[141]). Based on a broad evidence base including peer-reviewed literature and Indigenous Knowledge, there is *very high confidence* that adaptation actions such as traditional farming, fishing, and land management practices can help build more resilient water and food systems.[73,116,119,175,194,195,202,203,204,205]

Key Message 30.2

Climate Change Undermines Human Health, but Community Strength Boosts Resilience

Description of Evidence Base

Multiple assessments find an increasing trend in people affected or killed by climate-related disasters and extreme weather events worldwide.[220,221] While health infrastructure exposure to climate risk is well documented globally, few vulnerability assessments for islands, territories, and states in the Pacific (e.g., Greene and Skeele 2014[223]) have examined health infrastructure vulnerability. Just one study of medical facility vulnerability was found; it included an analysis of medical facility locations in 14 Pacific Island countries, including in FSM, the Republic of the Marshall Islands, and Palau.[104]

There is significant evidence in the international Pacific Islands region that the current and future projected impacts of climate change are negatively affecting peoples' mental health, although studies are lacking specifically in Hawai'i and the USAPI. Evidence also indicates that impacts are more severe for Indigenous Peoples because their central identity is tied to an ancestral place. Studies linking climate impacts directly to mental health outcomes point to strong differences in how mental health impacts are experienced among different populations.[105,239,240,241,242] There is general agreement on the benefits of tailoring mental health services for Pacific Islanders to the specific needs of the population, including different services for migrants who have voluntarily or non-voluntarily migrated.[237,243]

There is strong evidence of the high prevalence and impact on human health of vector-borne disease in the Pacific Islands. Recent data from 2014 to 2020 document 104 dengue, chikungunya, and Zika outbreaks across Pacific Island countries and areas.[246] Literature agrees that the viruses had unexpected virulence and epidemic potential[245,247] and that future climate-driven spread and emergence of vector-borne diseases the Pacific region is expected.[247,249]

Multiple lines of evidence demonstrate the impacts of high and extreme temperatures on human health.[220,459] Substantial and growing evidence supports the disproportionate and acute effects of heat on vulnerable populations.[220] However, analysis of the burden of heat-related illness and death among specific populations in Hawai'i and the Pacific Islands is lacking.

Social and community adaptive capacity has a long history and broad disciplinary foundations, with many studies specific to Pacific Island countries and territories highlighting the importance of social capital, cultural norms, Traditional and Indigenous Knowledge, and women's voices in successful adaptation and disaster response (e.g., Bryant-Tokolau 2018;[260] Cinner and Barnes 2019;[460] Cohen et al. 2016;[461] McNamara et al. 2020;[321] Nunn et al. 2020;[462] Warrick et al. 2017[463]).

The literature on necessary adaptations for Pacific Island public health systems is relatively underdeveloped compared to the global literature on the topic. For example, a study of Organization for Economic Co-operation and Development countries' national-level public health adaptation found a diverse array of adaptations related to cross-sectoral collaboration, vertical coordination, and national health adaptation planning.[264] Two studies focus on needed adaptations in the Pacific Islands,[227,265] while the World Health Organization[267] produced national climate change and health vulnerability assessments to guide health system adaptation plans.

Major Uncertainties and Research Gaps

Trends and changes in climate extremes in the USAPI represent a current research gap. Studies that account for compound or cascading extremes can best inform planning. Extreme event attribution studies for Pacific Islands and Hawai‘i would improve confidence and understanding of the role of climate change in driving societal impacts from extreme weather and climate events. The region lacks site-specific vulnerability assessments for critical health infrastructure. Dynamic inundation models that include wave-driven flooding and future scenario planning tools for coral reef–protected shorelines can improve understanding of health infrastructure vulnerability.

Few studies specifically investigate climate change impacts on mental health in Hawai‘i and the USAPI, which, given the evidence that effective interventions must be culturally appropriate and tailored, indicates a strong need for additional research. Few studies in the region specifically address the mental health impacts of climate-induced migration on displaced populations. New research can point to ways to build personal resilience to climate change among frontline workers and climate adaptation practitioners, a topic preliminary research has examined.[464]

Changes in climate are expected to exacerbate the increasing risk of vector-borne disease transmission throughout the region, and various species of invasive mosquitoes are already linked to outbreaks of Zika, chikungunya, and dengue. The ways in which climate change will affect disease emergence are complex and yet to be fully explored. Place-based surveillance to assess the association between climate factors and infections, as well as climate early warning systems for vector-borne disease, would help better understand and prevent epidemics.

Regional stakeholders have called for community-based approaches to research assessing climate change readiness. Such research may include assessments of community strengths and local knowledge, community-led pilot initiatives, and identification of priorities for climate resilience planning.[27]

Description of Confidence and Likelihood

There is *high confidence* that warming temperatures, impacts from tropical cyclones, food and freshwater insecurity, and flooding are already negatively impacting human health in the Pacific Islands region. This is based on agreement among multiple lines of evidence, including peer-reviewed publications and reports and national and regional government reports, that show increases in heat-related illness and vector-borne diseases, damage to critical infrastructure, and psychological stress. Documented impacts to critical electric, medical, and transit infrastructure provide evidence that healthcare services have been compromised, although formal assessments of regional healthcare infrastructure are lacking, resulting in an assignment of *medium confidence*. Data linking local climate impacts such as drought and flooding with negative direct and indirect health outcomes in different communities in the international Pacific Islands demonstrate that there is *high confidence* that these impacts have worsened existing health inequities in both physical and mental health across the region. Based on current scientific consensus, there is *very high confidence* that the drivers of the negative impacts of climate change, such as high temperatures and SLR, are expected to worsen in the future. Meta-studies show that examples of health and disaster adaptations and recovery that center Indigenous ways of knowing and social cohesion have had success in the region, and there is *high confidence* that expanding these activities will increase resilience.

Key Message 30.3

Rising Sea Levels Threaten Infrastructure and Local Economies and Exacerbate Existing Inequities

Description of Evidence Base

The finding that climate change, especially SLR, will continue to negatively impact buildings, infrastructure, and the built environment is based on future projections of SLR (App. 3) encompassed in a suite of scenarios that include physical and socioeconomic factors from Sweet et al. (2022).[65] Available literature agrees that wave-driven flooding and high sea level events and associated inundation will continue to increase in frequency and severity.[98,218,219,465] There is scientific consensus that tropical cyclone (TC) intensity is increasing globally with warming.[70,216] One study of TC changes shows a likelihood of fewer but possibly stronger storms (increasing maximum intensities) in the northwestern Pacific.[53]

Mycoo et al. (2022)[89] have extensively documented the impacts of SLR, heavy rain events, TCs, and storm surges on the coastal built environment and rural communities on small islands. The primary sources of economic data for Freely Associated States are the Asian Development Bank, the World Bank (2022b);[22] United Nations, and the CIA World Factbook economic impact (costs) studies. Population figures and trends for American Sāmoa, the Commonwealth of the Northern Mariana Islands, Guam, and Hawaiʻi are from the US Census.[19,20,21]

Major Uncertainties and Research Gaps

Wave run-up models incorporating Sweet et al. (2022)[65] SLR scenarios are not yet available. Needed for the development of wave run-up models are high resolution elevation and water depth data (topobathymetric information), which are currently lacking for many Pacific Islands.

The amount and timing of future SLR experienced across the region is a key area of remaining uncertainty. There is uncertainty in the physical processes—particularly marine ice sheet instability and marine ice cliff instability—that could lead to rapid ice mass loss over a period of several decades (KM 3.3).

There is uncertainty in the effectiveness of migration as a climate change adaptation strategy, as the outcomes are dependent on individual situations and there is limited evidence in the literature.[69,89,466,467,468,469,470,471] Anthropological and population geography literature (e.g., Connell and Brown 2005[293]) for Micronesia establishes that past and present migration was an adaptation strategy associated with resource scarcity and that, historically, migrants traveled for economic and educational reasons.[472] There is limited current empirical evidence of migration that includes historical records of disaster-driven displacement; projections of displacement are also not available.

There is a gap in the literature examining the linkages between climate change, transport, and tourism, as well as the impacts of ecological change and heat on tourism demand. Future economic losses and impacts to livelihoods due to climate change–driven invasive species distribution shifts are understudied. For example, recent coconut rhinoceros beetle (CRB) invasions in Guam and Hawaiʻi and impacts on coconut palms have led to economic losses and declines in aesthetic value and have threatened food security.[473] Increased invasion of CRB following strong tropical cyclones is apparent,[474,475] but the specific interactions between climate factors and invasions are not yet well studied. The invasive brown tree snake on Guam has caused billions of dollars in damage to infrastructure[476] and causes up to 200 electrical blackouts per year,[477] adding stress to Guam's electrical grid, which is already facing compound climate stressors; the economic costs of species invasions in a changing climate are likely underestimated.

More guidance is needed on how equity, inclusion, and justice can be embedded in decision-making across the diverse governance arrangements in the region.[478]

Research on nature-based solutions has improved considerably,[322,479,480] although there is limited research evaluating the benefits, economic efficiency, and long-term effectiveness of these solutions.[89,481,482] Recent literature has examined the effectiveness of protection services that mangroves provide, which has important implications for long-range adaptation planning on islands (e.g., Saintilan et al. 2020;[355] Sasmito et al. 2016;[483] Zeng et al. 2021[484]).

Description of Confidence and Likelihood

It is *very likely* and there is *high confidence* that SLR will continue to damage the coastal built environment in the Pacific Islands region. This is documented by multiple lines of evidence, including peer-reviewed literature, planning documents, models, and government reports analyzing flooding, erosion, and wave impacts on coastal infrastructure across the region.

It is *very likely* and there is *high confidence* that climate impacts, including SLR, drought, and storms, will impact key economic sectors, such as tourism and fisheries. These likelihood and confidence assignments are based on peer-reviewed literature, strategic planning documents, development bank reports, and government reports detailing the projected impacts on and understanding of the behavioral, logistical, and biological features of these economic sectors.

There is *high confidence* of the potential for loss of territory and maritime entitlements, particularly in low islands, based on models, reports from governments, international financial institutions, and international meetings.

It is *likely* and there is *medium confidence* that climate-driven changes will exacerbate existing social challenges, thereby disrupting livelihoods. Evidence related to livelihoods disruptions under future scenarios remains sparse and will vary across contexts, thus the assignment of *medium confidence*. *High confidence* in the higher costs of adaptation and disaster recovery in islands is based on various factors that characterize islands, including geographic isolation (e.g., ASCE 2020[224]), reliance on imported materials and labor, vulnerable infrastructure, and sensitive ecosystems.

Key Message 30.4

Responses to Rising Threats May Help Safeguard Tropical Ecosystems and Biodiversity

Description of Evidence Base

Based on consensus across the cited literature and the latest available climate projections, there is *high confidence* across all future scenarios that deteriorating climate conditions will continue to threaten regional ecosystems and biodiversity throughout the this century (e.g., Buffington et al. 2021;[86] Eakin et al. 2019;[61] Fortini et al. 2015;[93] Gove et al. 2022;[62] Jacobi and Warshauer 2017;[354] Kwiatkowski et al. 2020;[60] Liao et al. 2015;[94] Lotze et al. 2019;[331] Reynolds et al. 2015;[356] Palacios-Abrantes et al. 2022[83]).

Projections of how physical changes will affect ecosystems come from a range of approaches: ecosystem and food web modeling, statistical modeling, and extrapolations from change already observed. Despite the data inequities present across the region (Box 30.1), there are multiple observations documenting past and ongoing changes in marine and terrestrial ecosystems and their physical environments (e.g., Dendy et al. 2022;[229] Judge et al. 2021;[414] Raymundo et al. 2019[334]).

Major Uncertainties and Research Gaps

The adaptive capacity of organisms and ecosystems in the face of climate change remains uncertain. For example, there is uncertainty about the plankton community's response to climate change, which will influence the effect of climate change on higher-trophic-level organisms such as those targeted by subsistence, commercial, and recreational fisheries. Ecosystem response to simultaneous stressors and novel climate conditions is a complex subject area with high uncertainty. The effects of climate change on fish stocks outside the EEZs are underexplored.

While regional climate projections and historical climate analyses for Hawai'i have been developed, similar sets of studies for USAPI are much more limited, lowering our confidence in projected terrestrial impacts of climate in other US-affiliated jurisdictions (e.g., future wildfire probabilities).[376] This gap in available climate data and projections is paralleled in the Caribbean region (KM 23.2), indicating a broad uncertainty for the future of our Nation's island areas.

The impacts of extreme events on Pacific Island terrestrial ecosystems are still poorly studied given the limited data to characterize past and current events and project future shifts in intensity and frequency of such events. These uncertainties in extreme event impacts on island ecosystems are similar to those identified in the Caribbean chapter (see Traceable Account, KM 23.2), highlighting a common challenge faced by underserved island areas.

The societal response to regional climate impacts can have a large impact on surrounding ecosystems and is also a major area of uncertainty.

Description of Confidence and Likelihood

There is *high confidence* and it is *very likely* that the structure and composition of Pacific Island coastal and marine ecological communities are directly threatened by ocean changes. This assessment is based on similarities across climate scenarios through the mid-21st century, as well as on the degree to which climate conditions have already impacted regional ecosystems and biodiversity, and given species-specific climate and habitat tolerances.

Fire is already a substantial challenge to Pacific Islands (Figure 30.13),[229,378] with risks expected to rise under additional warming and drying (*high confidence*).[376] A wide body of literature links increasing droughts and temperatures to increased fire risk (Chs. 7, 8).

Regarding native plants, climatic shifts have already been shown to influence plant communities, from broad landscape shifts to individual species population trends (*very likely*, *high confidence*).[364,365,366,370] Future projections indicate continued and drastic effects.[93,367] Regarding forest birds and other wildlife, the link between forest bird declines in Hawai'i and warming is clear,[414,415] with underlying mechanisms well understood.[485,486] These declining trends are consistently projected to continue under additional warming (*very likely*, *high confidence*).[93,94]

There is *medium confidence* in the ability of certain adaptation strategies to improve the resilience of Pacific Island ecosystems. Ecological restoration efforts and invasive species prevention, eradication, and control enhance regional climate resilience and provide multiple benefits to islands (e.g., KM 8.3; Barbosa and Asner 2017;[398] Bremer et al. 2018;[202] Ferrario et al. 2014;[289] Wada et al. 2017[401]), including helping to reduce water stress and fire risk (e.g., KM 8.2; Dudley et al. 2020;[388] Fortini et al. 2021;[380] Strauch et al. 2017;[148] Trauernicht 2019[376]). However, due to the uncertainties in regional projections and climate and invasive species interactions, there is *medium confidence* in restoration and invasive species control efforts. The establishment and management of protected areas are also widely considered effective components of ecological adaptation strategies,[119] but large climatic shifts may reduce their effectiveness over time,[399] leading to *medium confidence* in their long-term effectiveness. Fire management strategies have been shown to be quite effective across the Pacific Islands region.[125] However, the effectiveness of these strategies under extreme fire conditions is expected to be reduced (e.g., atypically high wind and dry conditions), thus *medium confidence*.

Key Message 30.5

Indigenous Knowledge Systems Strengthen Island Resilience

Description of Evidence Base

There is no doubt that fostering reciprocal relationships between people, place, and cultural and historical sites across Hawai'i and the USAPI is central to the ongoing adaptation of island communities to the changing climate (e.g., Diver et al. 2019;[430] Nunn et al. 2017[87]). However, these types of relationships are usually documented in an oral rather than written format. For the most part, there is agreement that the culture of Indigenous Peoples influences their interpretation of the value of place and ecosystems and, subsequently, their resilience to climate change. The studies cited in this section use the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report CMIP5 results for temperature, rainfall, and SLR to assess impacts on traditional foods and cultural resources.[118,434,442]

Major Uncertainties and Research Gaps

Research that assesses the impacts of climate change (SLR, temperature, etc.) on cultural resources and historical sites is limited and largely focused on Hawai'i. Many of the studies that assess climate-related impacts to cultural resources were published prior to the release of the updated IPCC Sixth Assessment Report and NOAA's updated SLR projections. There is limited information on how climate change–driven shifts in the distributions of invasive plants and animals may disrupt cultural services and familial relationships (e.g., Brewington et al. 2023[359]).

Description of Confidence and Likelihood

Literature focused on community and place-based approaches to natural resource management supports that there is *high confidence* that Indigenous Peoples of the Pacific Islands, their knowledge systems, and their rituals are central to local climate resilience. Literature also supports that there is *high confidence* that reciprocal and spiritual relationships among people and place are being strengthened through adaptation and collective management of resources.

There is *high confidence* that the application of future climate scenarios has enabled the collective efforts of Indigenous researchers, stakeholders, and scientists to begin to identify and quantify the potential loss and migration of critical resources and expand the cultivation of traditional food crops on high islands. However, such assessments are limited in scope across Hawai'i and the USAPI, and as a result the impacts of climate change on cultural resources are still identified as a major gap in knowledge.

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