Agriculture and Food Production Vulnerability Assessment

A companion to the

GCF Baseline Survey for Climate Resiliency Among Farming Households in the Federated States of Micronesia SAP020

Prepared by Rutgers University Center for Agriculture Food Ecosystems (RUCAFE), Rutgers School of Environmental and Biological Sciences, 2024

Foreword:

The Federated States of Micronesia (FSM) is one of the most highly vulnerable Small Island Developing States (SIDS) in the Pacific. Climate hazards are projected to severely threaten FSM communities' food security - primarily because of crop loss, degraded arable land, price/supply shocks, and forced migration from low lying outer island communities.

This Agriculture and Food System Vulnerability Assessment has been compiled as a companion to the Green Climate Fund's Climate Resiliency among Farming Households in the Federated States of Micronesia (GSFSAP020) baseline survey prepared by the Rutgers University food system science team.

For the purposes of the GSFSAP020 baseline survey and this Vulnerability Assessment, a farming household is defined as any FSM household that produced/procured/harvested/raised their own food by agriculture, agroforestry, fishing, aquaculture, poultry and/or livestock.

The GCFSAP020 is part of a national effort to focus on increasing the resilience of FSM's most vulnerable communities to climate change-induced food insecurity. Planned measures include introducing sustainable agricultural practices and developing climate-resilient agriculture value chains that support place based, culturally relevant and community led food system development and local capacity .

The Agriculture and Food System Vulnerability Assessment was compiled using data from the GSFSAP020 baseline survey of more than 600 subsistence farmers across the FSM as well as critical climate change data from the Third National Communication to the UNFCCC 2023 that was prepared in part by this Rutgers food system science team.

Other key reports that contributed to this Assessment include:

Federated States of Micronesia's Integrated Agriculture Census 2016
FSM's Second National Contribution to the UNFCCC 2015
Federated States of Micronesia Agricultural Policy 2012-2016
Policy Measures to Increase Local Food Supply and Improve Food Security in the Federated States of Micronesia. Food and Agricultural Organization of the United Nations. 2014
Federated States of Micronesia Aquaculture Management and Development Plan 2019-2023.
FSM Voluntary National Review 2020
FSM 2023 Action Plan
Pohnpei State Food Security Policy and Food Production Master Plan 2023

All other resources that contributed to this document are listed in the concluding references.

Finanpes Farms grows food for Kosrae markets
Photo Credit: Micah Seidel, Rutgers University

Agriculture and Food System Vulnerability Assessment Core Team

Rutgers, The State University of New Jersey:

Dena K. Seidel, Cultural Anthropologist & Food Systems Researcher, Department of Plant Biology
James E. Simon, Distinguished Professor of Plant Biology, Director, Center for Agricultural Food Ecosystems (RUCAFE)
Ramu Govindasamy, Economist, Professor, and Chair, Department of Agricultural, Food and Resource Economics
Oscar Schofield, Distinguished Professor of Marine and Coastal Sciences
Michael Balick, Indigenous Foods of Micronesia, Director and Philecology Curator, Institute of Economic Botany, New York Botanical Garden
Surendran Arumugan, Data analysis and Econometrics
James Shope, Extension Specialist in Climate Services
Tori Rosen, Graduate Student, Department of Plant Biology

FSM Collaborators:

Willie Kostka, Executive Director, Micronesia Conservation Trust (MCT)
Mark Kostka, FSM R&D, Green Climate Fund-FSM Food Security Project Manager
JoLynne G. Mori, Tamara Greenstone Alefaio, Winfred Mudong, Bertha Reyuw of MCT

Chuuk:

Tim Mondale, Director, State of Chuuk, Department of Agriculture
Mary Rose Nakayama, Chuuk Women's Council (CWC)
Shinobu Courtney Stinnett-Benito, Acting President, Chuuk Women's Council (CWC)
Grace Poll-Serious, President Chuuk Women's Council (CWC)

Kosrae:

Andy George, Executive Director, Kosrae Conservation and Safety Organization
Heidi Floyd, ODA State of Kosrae Administrator, Mixon Jonas, Extension agent

Pohnpei:

Hubert K. Yamada, Director, Department of Resources and Development, Pohnpei State Government
Mr. Engly Ioanis, College of Micronesia (COM)
Eugene Joseph, Executive Director, Conservation Society of Pohnpei (CSP)
Francisca Sohl Obispo, Terrestrial Program Manager, Conservation Society of Pohnpei (CSP)
Shawn Walters, Pohnpei State, Dept of R&D

Yap:

Mr. Constantine Yowbalaw (Lead Researcher and Project Coordinator)
Michael Wiencek (Lead Logistics and Finance), Yap Catholic High School (YCHS)
Mercedes Tiningmow, Food Security and Livelihoods Coordinator

Table of Contents

Abbreviations

ACIAR = The Australian Centre for International Agricultural Research
ADB = Asian Development Bank
AFTA = ASEAN Free Trade Area
BAU = Business-As-Usual
CBD = Convention on Biological Diversity
CDC = Center for Disease Control
CePaCT = The Center for Pacific Crops and Trees
CITI = Collaborative Institutional Training Initiative
CMIP(1-6) = Coupled Model Intercomparison Project (Phases 1-6)
COFA = Compact of Free Association
COM = College of Micronesia
COPD = Chronic Obstructive Pulmonary Disease
CRA = Climate Resilient Agriculture
CRE = Land Grant Cooperative Research and Extension
CRI = Climate Risk Index
CSA = Climate-Smart Agriculture
CSIRO = Commonwealth Scientific and Industrial Research Organisation
CSP = Conservation Society of Pohnpei, Pohnpei
CWC = Chuuk Women's Council, Chuuk
DCO = Disaster Coordinating Office, Chuuk State
DOA = Department of Agriculture, Chuuk State
EEZ = Exclusive Economic Zone
ENSO = El Niño-Southern Oscillation
ESCAP = Economic and Social Commission for Asia and the Pacific
FAO = Food and Agriculture Organization of the United Nations
FEMA = Federal Emergency Management Agency
FSM = Federated States of Micronesia
GCF = Green Climate Fund
GCM = Global Climate Models
GDP = Gross Domestic Product
GHG = GreenHouse Gases
GSFSAP020 = Green Climate Fund's Climate Resiliency among Farming Households in FMS
H = high (emission scenario)
HIES = Household Income, Consumption and Expenditure Survey
IAC = Integrated Agriculture Census
IAS = Invasive Alien Species
IDA = Initial Damage Assessment
IDP = Infrastructure Development Plan
IMF = International Monetary Fund
IOM = International Organization for Migration
IPCC = Intergovernmental Panel on Climate Change
IPLCs = Indigenous Peoples and Local Communities
IPM = Integrated Pest Management
ISI HDPE = Indian Standards Institute High-Density Polyethylene
ITCZ = Inter-Tropical Convergence Zone
IUCN = International Union for Conservation of Nature
JDA = Joint Damage Assessment
KCSO = Kosrae Conservation and Safety Organization, Kosrae State

L = Low (emission scenario)
MCT = Micronesia Conservation Trust
MPA = Marine Protected Area
NBSAP = National Biodiversity Strategies and Action Plans
NCDs = Non Communicable Diseases
ND-GAIN = Notre Dame Global Adaptation Initiative
NGO = Non-governmental organization
NOAA = National Oceanic and Atmospheric Administration
NRCS = Natural Resources Conservation Service
NYBG = New York Botanical Garden
OA = Ocean Acidification
OEEM = Office of Environment and Emergency Management
OFDA = Office of U.S. Foreign Disaster Assistance
PACCSAP = Pacific-Australia Climate Change Science Adaptation Planning
PAN = Protected Areas Network
PCCDP = Pacific Climate Change Data Portal
PDO = Pacific Decadal Oscillation
PGOOS = Pacific Global Ocean Observing System
PICs = Pacific Island Countries
PSLGM = Pacific Sea Level and Geodetic Monitoring Project
PVC = Polyvinyl Chloride
R&D = Research and Development
RCP = Representative Concentration Pathway
RU = Rutgers University
RUCAFE = Rutgers University Center for Agriculture Food Ecosystems
RUSLE = Revised Universal Soil Loss Equation
SDG = Sustainable Development Goal
SIDS = Small Island Developing States
SLM = Sustainable Land Management
SNC = Second National Communication
SOE = State of Environment
SPC = Secretariat of Pacific Community
SPREP = South Pacific Regional Environment Programme
SSC = Species Survival Commission
SSPs = Shared Socioeconomic Pathways
SST = Sea Surface Temperature
TC = Tropical Cyclone
TK = Traditional Knowledge
TNC = Third National Communication to the UNFCCC
TTPI = Trust Territory of the Pacific Islands
UNDP = United Nations Development Programme
UNFCCC = United Nations Framework Convention on Climate Change
USAID = United States Agency for International Development
USD = United States dollars
USDA = United States Department of Agriculture
UV = Ultra Violet (light)
WFP = World Food Programme
WMP = Water Management Plan
WPM = West Pacific Monsoon
YCHS = Yap Catholic High School, Yap
ZECC = Zero Energy Cool Chambers

Introduction: FSM Agriculture and Food Production Vulnerability

The Federated States of Micronesia (FSM) is an island nation in the north Pacific that is extremely vulnerable to climate change. FSM is home to 110K people speaking 17 distinct languages across 607 islands spread across a longitudinal distance of almost 2,700 km (1,678 mi2) and within an Exclusive Economic Zone (EEZ)[1] that covers roughly 2.9 million km2 (1.15 million mi2) of ocean waters. The people of FSM—inclusive of Indigenous Peoples and local communities (IPLCs)—are culturally diverse and inhabit 65 islands across four independently governed states—Yap, Chuuk, Pohnpei and Kosrae. Because of the FSM's wide variety of ecosystems and geology, the people of the FSM experience a wide range of climate change impacts.

The FSM is particularly vulnerable to suffering serious threats to its already vulnerable food system that is currently dependent on subsistence farming and fishing. According to the Notre Dame Global Adaptation Initiative (ND-GAIN)[2] in 2020 the FSM was the 12th most vulnerable country to climate change and the 123rd in terms of climate change readiness in the world (FSM scored 0.58 on the vulnerability scale and 0.35 on the readiness scale).

The geographic remoteness of the islands, limited infrastructure, dependence on foreign aid, and small landmass, which constrains any scalable development for export, exacerbates the nation's vulnerability. The FSM's population is already suffering from negative impacts associated with climate change, which will increasingly compromise food security as land, freshwater and marine resources are increasingly threatened.

The nation is already experiencing a higher incidence of flooding from sea level rise and changes in weather patterns. Such changes significantly impact local food production and access to potable water. Rising average temperature has also significantly impacted important marine and agricultural species, negatively affecting yield and production. Projections on climate change indicate that impacts in the Pacific will directly affect FSM communities, burdening their health, incomes and subsistence. For these reasons, it is vital to assess the key risks and factors associated with a changing climate and its impact on the FSM, and to gather baseline data for staple crops in the FSM (e.g., taro, yam, breadfruit, banana and coconut); marine species that possess the potential for local aquaculture development and other foods; modeling climate change impacts such as salinization, increasing temperature, saltwater intrusion/inundation, etc., on future crop yields.

The people of FSM require action to ensure their food security in the coming decades through crop loss, loss of arable land, catastrophic weather patterns, price/supply shocks, and forced migration of outlying communities. Since 2011, the Federated States of Micronesia (FSM)'s long-term development goals have included enhancing the resilience of the nation's agriculture sector to strengthen food security for the people of FSM (Agriculture Policy 2012-2016).

Achieving national food security, safety and nutritional health is one of the priority goals outlined in the

[1] An Exclusive Economic Zone is a sea zone prescribed by the United Nations Convention on the Law of the Sea (UNCLOS) over which a state has special rights regarding the exploration and use of marine resources, including energy production from water and wind.

[2] See https://gain.nd.edu/our-work/country-index/.

FSM National Agriculture Policy (2012-2016) and FSM's Strategic Development Plan 2004-2023. These reports identified agriculture as one of the priority economic sectors to prepare the nation for long- term food security. In addition, FSM's 2016 Integrated Agriculture Census concluded that approximately 40% of the land in the nation is used for agricultural purposes (10% Kosrae, 40% Pohnpei, 70% Chuuk, 47% Yap) and over 90% of FSM households have access to land that be used for agriculture.

The most severe challenge to the food system in FSM is the increase in frequency and impact of extreme weather events which reduce the amount of arable land suitable for farming as well as reduce crop yields. FSM's islands are particularly vulnerable because the anticipated sea level rise will threaten fertile coastal plains as saltwater intrudes into previously fertile land.

These climate change impacts will make it increasingly difficult for FSM to produce enough food to meet its populations' needs. Close to 100% of the nearly 35 inhabited outer islands in FSM lie within the 2-meter zone of potential sea level rise and within a 5- meter zone of storm surge. Due to saltwater inundation, many of these outer island communities have had to abandon their taro patches, a key food security crop (Keim, 2010, FSM, 2015). It is anticipated that the high volcanic islands of the FSM will need to prepare for population increase in the form of climate change refugees from low-lying islands, while at the same time, enhancing and adapting their own food production systems. Aside from direct crop damage from inundation and erosion, increasing soil salinity is the greatest threat to crop productivity on the atolls of the FSM. Saltwater intrusion from coastal erosion, sea level rise, and extreme events are critical risks for food security and agricultural production. The 2016 Integrated Agriculture Census highlighted that at least 60% of households with land for agriculture have experienced some loss from weather, diseases, pests, or other reasons with weather damage reported as resulting in ten percent (6,903 acres) or more land parcels with crop losses.

The majority of FSM residents are subsistence farmers/fishers who live in a wide variety of ecosystems across the vast nation. FSM's local food producers practice agroforestry, agriculture, fishing, aquaculture and animal husbandry and poultry farming. Thus, understanding the nation's food production challenges in the face of climate change requires first understanding the nation's climate change threats to FSM's diverse environments and ecosystems.

This assessment first takes a wide view of the nation's overall environmental challenges due to climate change. Yet, as food security will require the resilience of the national indigenous farmers/fishers food producers, we will then learn what the local farmers are experiencing and what they say they need in order to be able to continue producing food in the wake of a wide range of climate threats.

Aquaculture Pilot Project, Pohnpei State. Photo Credit: Micah Seidel, Rutgers University

Geological Profile and Natural Resources

The islands of the Federated States of Micronesia are home to some of the world's greatest biodiversity, with a wide range of endemic species and a great deal of geographic variety, from high volcanic islands to small islets and low-lying coral atolls. Pohnpei Island, home to a rich and diverse tropical rainforest, is one of the wettest places on Earth, with an average annual recorded rainfall of 4,775 mm (188.0 in). Each of the FSM's four states centers around one or more high volcanic islands where the largest populations reside, and all but Kosrae State include numerous outer island atolls. The FSM's total land area is small, approximately 701 km^2 (271 square miles), with a total lagoon area of 7,192 km^2 (2,777 square miles). Because of the FSM's wide variety of ecosystems and geology, the people of the FSM experience a wide range of climate change impacts.

Climate change represents a significant threat throughout the FSM but especially to the physical environment of the low-lying outer island coral atoll communities with mean elevation of only 1-2 meters above sea level. Natural hazards, such as typhoons, frequent heavy rains, flooding along with threats of storm surges, rising sea levels, and droughts are increasingly causing damage to the FSM's natural environment, infrastructure, and to the livelihoods of the Micronesian people.

The FSM's high biodiversity, combined with unique topographic and geographic features, results in a variety of ecosystems and associated services. The FSM's terrestrial and marine biodiversity and ecosystem services support the nation's economy and development of the country as well as the long-term persistence of culture and customs in the country. These natural services are inclusive of water retention (via its forest and watersheds); shoreline protection (coral reefs, mangrove forest); livelihoods (fisheries); and tourism/eco-tourism (beaches, mangroves, biodiversity, aesthetics). The protection, conservation and sustainable use of ecosystems and associated biodiversity is of paramount importance for the nation's sustainable development, which includes maintaining healthy and abundant biodiversity as well as well-functioning ecosystems that are crucial to the FSM climate change mitigation and adaptation strategies (CBD 6th National report 2020).

Terrestrial ecosystems

The FSM states show wide-ranging ecosystem diversities, including forest type and composition associated with diverse climate, soil type and island topography. Forest characteristics differ between high islands and outlying islands, with the latter presenting a smaller forest community diversity (SOE, 2019). The rich plant diversity found in the country is associated with the high forest cover, estimated to be nearly 82% of the total land mass area (CBD 6th National report 2020; IAC, 2016).

The forests of the FSM vary from east to west due to differences in climate, geology, topography and geographical isolation. As a result, forest type varies from state to state. The dominant vegetation types are mixed broadleaf forest, swamp, mangrove, savanna, and agroforests. The largest forest, around 330 km^2 (127 sq mi), is found within Pohnpei, while Yap contains the smallest forest with almost 70 km^2 (27 sq mi; NBSAP, 2018). FSM forests and mangroves are particularly important to subsistence economies. They provide a series of services such as firewood, building material and other wood products that are used for handicrafts, carving and making canoes. While resources and activities in the forest are generally accessed and managed by men, mangrove areas are equally used by men and women for fishing, firewood and recreational activities (IAC 2016).

Cross-cutting threats to the FSM's forest systems are climate change, invasive alien species (IAS), wildfires and deforestation due to unsustainable use associated with monocropping or development (FAP 2020, SOE 2019).

In 2006, 46% of the forested lands in the FSM were classified as highly drought resilient, while the remaining 54% was medium (51%) to low (3%) drought resilient (SOE, 2019). Nearly 600 alien species, the majority being terrestrial plant species, are considered to be invasive or potentially invasive (IUCN SSC, 2015), which, along with the climate change impacts, is increasing food insecurity throughout the country. Of the 130 Areas of Biodiversity Significance identified in the FSM at the beginning of this millennium, IAS were assessed as being a major threat at 9% of such sites. Currently there are no nationwide studies assessing the effects of climate change on the spread of IAS in the FSM, although synergistic effects are largely known. Forest habitat fragmentation and loss in the high islands is also associated with road construction, causing spread of fast- growing invasive vines.

Freshwater and Marine Ecosystems

Approximately 60% of water resources in the FSM exist as surface water in the form of small, intermittent streams that drain catchment areas of limited aerial extent (Johnston 2011). The remaining 40% exist as groundwater in small, dispersed zones of sedimentary deposits, weathered volcanics and schists.

The FSM has a range of marine habitats and species from nearshore coral reefs to seagrasses and mangroves. These are key to the FSM population, which relies heavily on marine resources for income and livelihoods. It is estimated that the FSM coral reefs provide an annual value of $16 million through tourism and recreation, while more than 70% of households engage in fishing activities (CBD 6th National report 2020). Coral reefs are valuable ecosystems. They are essential in the formation and protection of beaches, provide a habitat for a variety of species, and play an important role in economic activities. Three main types of coral reefs surround the FSM islands: fringing reefs, barrier reefs and atolls. The FSM coral reefs are estimated at 14,517 km^2 (5,605 sq mi).

The FSM is a tropical coral ecoregion, containing some of the largest coral atoll complexes in the world, characterized by two terrestrial and one marine ecoregion. The terrestrial ecoregions are comprised of Yap, Chuuk, Pohnpei and Kosrae ecoregion (NBSAP 2018).

Biodiversity

In the FSM, terrestrial and marine biodiversity and ecosystem services support the economy of the country and social well-being. Ecosystem services and biodiversity are vital to food and water security, coastal protection and the long-term persistence of culture and customs in the country. The FSM is at the forefront of climate change, which is posing a concrete threat to biodiversity, by accelerating habitat fragmentation and loss, which exacerbates the deterioration of fragile ecosystems (i.e., coral reefs, mangroves, native forests). Concurrently, ecosystems resources and services are being undermined by unsustainable use and practices and spread of invasive alien species. Impacts on agriculture, fisheries, forestry, and degrading land from climate change have been reported throughout the FSM (NBSAP, 2018; CBD 5th National report 2014). The protection, conservation and sustainable use of ecosystems, and associated biodiversity, is of paramount importance for maintaining well- functioning ecosystems that are crucial to the FSM climate change mitigation and adaptation strategies (CBD 6th National report 2020).

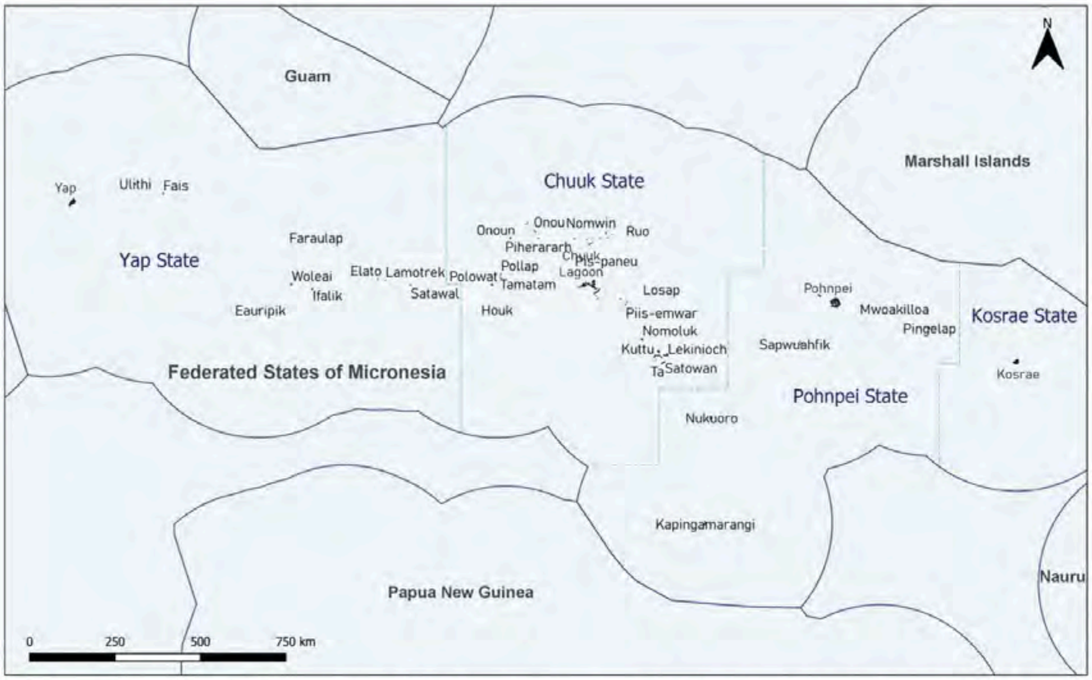
Geological Characters of each state in the FSM

Yap State consists of the main island Yap where four islands are connected by a coral reef and have geology of volcanic origin characterized by gentle topography with an elevation of 175 m (574 ft) above sea level, and substantial swampy lowlands. The state's landmass is a total of 102.9 km^2. Yap state also includes several outlying coral islands and atolls of which nineteen (19) are inhabited.

Chuuk State has a total landmass of approximately 127 km^2 and includes seven major volcanic island groups within a large 93 km^2 lagoon enclosed by a string of islets on a barrier reef, and a group of 14 inhabited outlying atolls and low islands located outside Chuuk Lagoon. Geographically the state of Chuuk is divided into 5 regions: Northern Namoneas, Southern Namoneas, Faichuk, Mortlocks and Northwest islands. The highest elevation in Chuuk is Mt. Uinipot on Tol Island at 443 m (1,453 ft).

Pohnpei State has a total land area of approximately 371 km^2 and is made up of one large volcanic island and six (6) inhabited coral atolls (Mwoakilloa, Pingelap, Kapingamarangi, Nukuoro, Sapwuafik and Oroluk). Pohnpei high volcanic island is the largest in the FSM (345 km^2) and has the highest peak elevation, Nahnalaud, at 734m (2,408 ft) above sea level.

Kosrae State, farthest east, is geologically the youngest high volcanic island with a steep topography and a total landmass of approximately 111 km^2. The island is surrounded by coral reefs and has around 10.3 km^2 of land suitable for agriculture and 64.5 km^2 of forested land located on the steep mountains. The majority of the island coastline is experiencing chronic erosion. The highest elevation in Kosrae is Mt. Finkol at 635 m (2,083 ft). Kosrae is the only FSM state without outer islands.



Data Source: SPREP

Data source: FSM Integrated Agriculture Census 2016

FSM Land Mass	FSM	Yap	Chuuk	Pohnpei	Kosrae
Land Area (km^2)[a]	701	102.9	127	371	111.3
Forest Area (km^2)[b]	580.6	69.5	73.4	330.5	107.2
Forest Area as percent of total land[b,d]	0.82	0.67	0.57	0.89	0.96
Agriculture land as percent of total land[c]	0.4	0.47	0.70*	0.40	0.10
Agroforest with IAS presence (percent)[d]	0.86	0.09	1	0.85	0.99

FSM National Aquaculture Center, Kosrae State
Photo Credit: Micah Seidel, Rutgers University

FSM History and Traditional Food System Knowledge

The people of the FSM have a strong relationship with their land and ocean. The islands of the FSM were first settled more than 4,000 years ago in decentralized, chieftain-based communities. Today, each of the four states exhibits its own distinct culture, traditions, social organization and language(s), but they all continue to share recognition and respect for the traditional extended family and clan systems and ritual exchanges that include locally produced and prepared foods.

The FSM's traditional cultural systems evolved over thousands of years with social mechanisms to insure the sustainable use of limited resources on small islands. The FSM's diverse and complex traditional knowledge (TK) developed as generation upon generation passed on skills for sustainably cohabiting within the many unique island ecosystems that are found throughout the nation. The social fabric of the FSM's people was built upon traditional knowledge and cultural norms that provided a framework for sustainable harvesting of food and resources from the forests, the reefs and the ocean. The Carolinian islands of Yap and Chuuk are home to peoples who have continuously practiced way-finding, a traditional non-instrument ocean navigation that includes a deep understanding of the stars, wind, ocean currents, weather, and migratory birds. Many of the FSM's farming and fishing families still live by their local, traditional knowledge.

The FSM's people and their traditional practices have been impacted over centuries. Beginning in the 16th century, Spain claimed islands throughout this Pacific Region as part of its colonial empire, naming the islands the Caroline Islands, after King Charles II. After the Spanish-American War, Spain sold the Caroline Islands to Germany in 1899 and the Germans then passed their control to the Japanese through the 1919 Treaty of Versailles. Following World War II, the islands became part of the UN Trust Territory of the Pacific Islands (TTPI), administered by the U.S. On May 10, 1979, the TTPI districts of Chuuk, Yap, Pohnpei, and Pohnpei's then sub- island, Kosrae ratified a new Governmental Constitution. On November 3, 1986, the Federated States of Micronesia signed the Compact of Free Association (COFA) and became a newly sovereign nation. The COFA was amended in 2004 and on-going compact negotiations are scheduled to conclude in the first half of 2023.

In addition to the threat of environmental change, the FSM is also vulnerable to rapid cultural change. The country's wide geographic dispersal and limited amount of land make the local people extremely at risk to climate hazards. The FSM increasingly faces severe climate impacts such as sea-level rise, coastal erosion, coral bleaching, rising temperatures, changing rainfall patterns, and extreme weather events. Demands for rapid economic development have also fostered degradation of islands ecosystems as pollution, overfishing, and unsustainable development exacerbate the country's vulnerability to climate hazards.

FSM's traditional agriculture systems are based on biotic diversity and the practice of polyculture (e.g., such as agroforestry) rather than larger-scale monoculture. This historic approach has sustainably supported subsistence livelihoods, community obligations, and food security over generations while also preserving the soil and forests. Properly managed, these home garden/agroforestry systems can be highly productive while also contributing important environmental services such as soil stabilization, carbon sequestration, clean water and air.

On small islands and low atolls, marine food sources extracted through local harvesting are often used for household sustenance and production since agriculture and freshwater resources are limited. Subsistence fishing, both reef and open ocean line fishing, is practiced by many families and is critically important to the food security of FSM's outer island communities. Coastal fishing is conducted for family subsistence as well as sale to local markets with some catch shipped to relatives in Guam, Saipan and Hawaii (FAO 2023). FSM's people remain committed to the traditional agrarian lifestyle which provides a generational pattern of sustainability.

The Importance of Agroforestry in FSM

Per the USDA definition, agroforestry is the intentional integration of trees and shrubs into crop and animal farming systems to create environmental, economic, and social benefits. Terrestrial ecosystems produce the largest local inputs to the macro- economic fabric of society from a variety of local staple crops. FSM's forests are not only essential to communal and rural survival – more than 80% of the FSM population lives in rural areas – they are also a foundation to the nation's economy and systems of exchange.

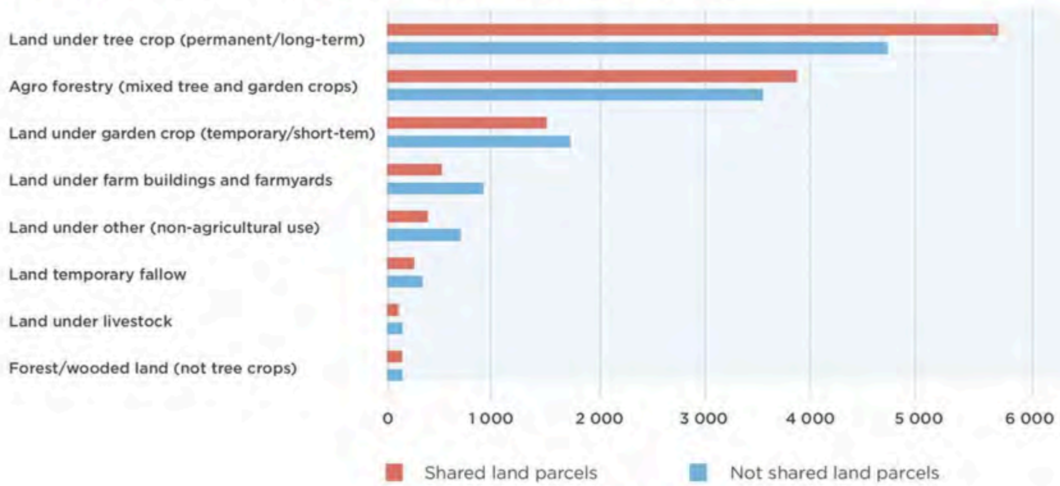
Yap		Chuuk	
Rural	Urban	Rural	Urban
10,537 (93%)	840 (7%)	34,804 (71%)	13,850 (29%)

Pohnpei		Kosrae	
Rural	Urban	Rural	Urban
30,122 (83%)	6,074 (17%)	4,456 (67%)	2,160 (33%)

Source: FSM Division of Statistics, 2010 Census

Thirty five percent of FSM land mass is devoted to agroforests playing a significant role in the cultural exchange, social fabric and economy of the country.
In 2016, the majority of farmed land was still identified as land under tree crop or agro forestry.

Number parcels of shared and not shared land by main use: 2016



Source: FSM 2016 Integrated Agriculture Census

Land that is not shared is more often used for garden crops, farm buildings and non-agricultural purposes, while shared land is more likely to be agroforestry or tree crops.

Over 74 percent of households reported that the main purpose of the use of the land was only for home consumption.

FSM’s tropical forests are some of the most biodiverse in the world. The practice of traditional agroforestry integrates annual or perennial crops to create a sustainable farming system. Such a practice preserves and can improve soil fertility and protect crops from extreme weather. Traditional agroforestry can also contribute to the conservation of FSM’s forests and biodiversity. A 1991 survey of 54 randomly selected FSM farms documented 161 species (102 trees, shrubs, and crops and 59 uncultivated herbaceous plants). The number of tree, shrub, and crop species per farm ranged from 16 to 37, with an average of 26 species.

The Importance of Reef and Ocean Fishing

Marine ecosystems play an even larger role in the livelihoods of the people of FSM. Near shore and offshore fisheries bring in tens of millions of dollars annually supporting micro and macro economic networks throughout the states. The primary source of local revenue at the national level is through the sale of tuna fishing licenses.

When it comes to food, the near shore marine areas – mangroves, reefs, estuaries, lagoons as well as the open ocean are critical to the nation's food security. Nearly 55% of all households engage in fishing activities on a regular (monthly) basis.

Fishing weir Yap State, Photo credit William Jeffrey

Chart FSM 2016 IAC

Fishing and other activities

	NUMBER	PERCENTAGE OF ALL HOUSEHOLDS
Number of households involved in fishing	8 508	54.7
Number of households catching:		
Coastal fish (reef fish)	6 799	
Octopus / squid	4 348	
Oceanic fish (tuna and oceanic pelagic fish)	3 059	
Crab	3 008	
Lobster	2 850	
Turtle	2 210	
Estimated average number of fishing trips per month by fishing households	19	
Number of households involved in aquaculture	499	3.2

FSM's Farmers/Fishers and 2016 Integrated Agriculture Census

In 2016, the FSM Integrated Agriculture Census (IAC) 2016 reported on 87,357 people in 15,545 households across the nation. The results showed that agriculture activities remain crucial to the livelihood of FSM households. The occupation and industry data shows 36 percent of the workforce were skilled agricultural forestry and fisheries workers. The vast majority were unskilled subsistence farmers. Subsistence agriculture remains a primary activity with 92 percent of those working in agricultural occupations being unpaid, compared to just under 60 percent of all those participating in the labor force. Overall, the population age and sex distribution in the 2016 IAC shows the impact of migration and birth rate changes, as well as possible undercount.

The below graphs compares to the 2013/14 HIES8 report (estimated 103 382 people) and the Census 2010 (102 839 people) to the FSM Agriculture Census of 2016.

Total population by age and sex: 2010, 2013 and 2016

AGE	CENSUS 2010			HIES 2013			IAC 2016		
	TOTAL	MALES	FEMALES	TOTAL	MALES	FEMALES	TOTAL	MALES	FEMALES
Total	**102 839**	**52 192**	**50 647**	**103 382**	**51 441**	**51 941**	**87 357**	**44 085**	**43 272**
0–14 years	36 697	18 797	17 900	34 753	17 522	17 230	28 308	14 551	13 756
15–29 years	28 997	14 987	14 010	28 982	14 671	14 312	24 073	12 366	11 707
30–45 years	18 121	9 044	9 077	18 576	9 148	9 429	16 338	8 154	8 184
45–59 years	13 427	6 819	6 608	14 168	6 908	7 261	12 065	5 932	6 131
60–74 years	4 410	2 093	2 317	5 464	2 633	2 832	5 519	2 703	2 815
75 years and over	1 187	452	735	1 437	560	878	1 054	377	677

Paid and unpaid labor force and skilled agricultural, forestry and fishery worker: 2016

	TOTAL	PAID	UNPAID	% UNPAID
Total labor force	33 353	13 534	19 819	59.4
• Skilled agricultural, forestry and fishery workers	12 153	955	11 198	92.1
• Percent skilled agricultural, forestry and fishery workers	36.4	7.1	56.5	
Males in the labor force	19 488	8 396	11 092	56.9
• Skilled agricultural, forestry and fishery workers	9 577	689	8 888	92.8
• Percent skilled agricultural, forestry and fishery workers	49.1	8.2	80.1	
Females in the labor force	13 865	5 138	8 728	62.9
• Skilled agricultural, forestry and fishery workers	2 576	267	2 310	89.7
• Percent skilled agricultural, forestry and fishery workers	18.6	5.2	26.5	

Source: FSM 2016 Integrated Agriculture Census

10

Of the 14,031 households represented in the 2016 Census, a full 100% had access to land available for agriculture. Of those surveyed, 74% of those surveyed farmed the land for home consumption.

FSM's 2016 Integrated Agriculture Census concluded that approximately 40% of the land in the nation is used for agricultural purposes (10% Kosrae, 40% Pohnpei, 70% Chuuk, 47% Yap) and over 90% of FSM households have access to land that can be used for agriculture. Much of the land is used for agroforestry and tree crops.

Population

	NUMBER OF PEOPLE			NUMBER OF HOUSEHOLDS		
	TOTAL	MALES	FEMALES	TOTAL	HAS LAND USED FOR AGRICULTURE	DOES NOT HAVE LAND FOR AGRICULTURE
FSM total	**87 357**	**44 085**	**43 272**	**15 545**	**14 031**	**1 514**
Yap	11 037	5 338	5 699	2 279	2 138	141
Chuuk	39 350	20 284	19 066	6 223	5 743	480
Pohnpei	31 159	15 470	15 689	6 006	5 260	746
Kosrae	5 811	2 993	2 818	1 037	890	147

Source: FSM Integrated Agriculture Census 2016

Agriculture

	NUMBER	PERCENT OF HOUSEHOLDS WITH LAND AVAILABLE FOR AGRICULTURE
Number of households with access to land for agriculture	14 031	100.0
Number *parcels* of land operated only by single household:	12 019	
Own free-hold land	7 293	
Leases free-hold land	419	
Customary land	3 818	
Leased customary land	223	
Leased government land	192	
Other	74	
Number of households with unshared land parcels	9 850	70.2
Number of households with shared land parcels	9 626	68.6
Median size of total land holding	0.2 acres[1]	
Household with land available for agriculture – *Main purpose*	14 031	100.0
Only for home consumption	10 444	74.4
Mainly for home consumption but occasionally sell	3 365	24.0
Mainly for sale but occasionally consume	211	1.5
Only for sale	11	0.1
Number of people involved in agricultural activities		
Total (aged 15 and over)	21 818	
Males	14 100	
Females	7 718	

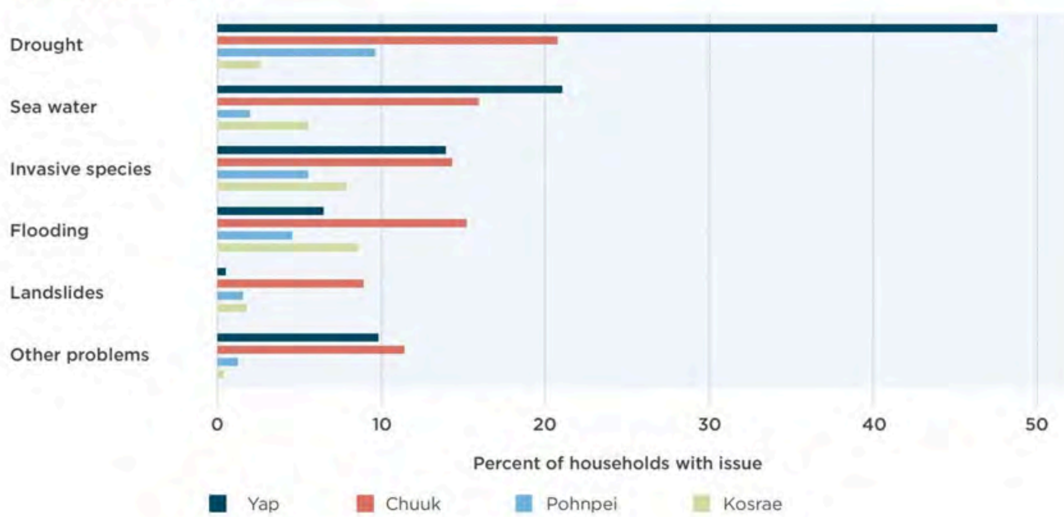
Coconuts, bananas and breadfruit were listed as the primary crops. The greatest barriers to agriculture were identified as production inputs and financing. In 2016, drought was identified as the most significant threat to local crops.

	NUMBER	PERCENT OF HOUSEHOLDS WITH LAND AVAILABLE FOR AGRICULTURE
Top crops by number of households reporting growing:		
Coconut	13 301	94.8
Banana	13 118	93.5
Breadfruit	12 906	92.0
Lime/lemon	8 250	58.8
Swamp taro	7 561	53.9
Papaya	7 535	53.7
Mango	7 486	53.4
Betelnut	6 816	48.6
Land taro	6 666	47.5
Pineapple	5 623	40.1
Yam	5 073	36.2
Tapioca	4 989	35.6
Sakau (Kava)	3 382	24.1

		PERCENTAGE OF ALL HOUSEHOLDS
Barriers to agriculture		
Lack of production inputs	9 700	62
Lack of source of finance	6 262	40
No land available	5 192	33
Lack of management skills	4 612	30
Difficulty getting to the land	3 996	26
Lack of market to see produce	2 763	18
Lack of new tech & infrastructure	1 675	11
No barrier	4 727	30

FSM 2016 IAC

GRAPH 3.2
Damage to land: 2016



Source: FSM 2016 Integrated Agriculture Census

FSM’s Environmental Vulnerability to a Rapidly Changing Climate

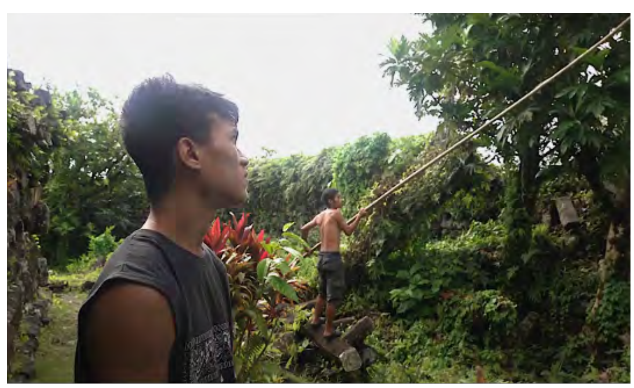
FSM is also home to some of the most biodiverse terrestrial and marine ecosystems in the world. FSM is currently threatened by sea level rise, altered rainfall, rising temperatures, and increased storm frequency/intensity all of which directly impacts local food production. FSM’s indigenous population has become dependent on imported, unhealthy processed foods and non-communicable, diet related diseases are their greatest health threat. Thus, developing a sustainable, local food system in this rapidly changing climate has become a national priority.

Climate change poses a significant threat to FSM’s low-lying outer island coral atoll communities with mean elevation of only 1-2 meters above sea level. Natural hazards, such as typhoons, frequent heavy rains, flooding along with threats of storm surges, rising sea levels, and droughts are increasingly causing damage to the FSM’s natural environment, infrastructure, and to the livelihoods of the Micronesian people.8

The FSM’s terrestrial and marine biodiversity and varied ecosystems support the nation’s economy and development of the country as well as the long-term persistence of culture and customs in the country. These natural services are inclusive of water retention (via its forest and watersheds); shoreline protection (coral reefs, mangrove forest); livelihoods (fisheries); and tourism/eco-tourism (beaches, mangroves, biodiversity, aesthetics). The protection, conservation and sustainable use of ecosystems and associated biodiversity is of paramount importance for the nation’s sustainable development, which includes maintaining healthy and abundant biodiversity as well as well-functioning ecosystems that are crucial to the FSM climate change mitigation and adaptation strategies (FSM R&D CBD 6th National report 2020).

Projections on climate change indicate that impacts in the Pacific will directly affect the FSM communities, becoming a threat to the health, incomes and subsistence of FSM residents. For instance, under a high emission scenario (RCP 8.5-BAU), the Asian Development Bank (ADB) estimated over a 20% decline of Skipjack tuna catches for the west Pacific, due to migration of tuna to cooler waters (ADB 2013). Similarly, changes in the climate will have repercussions for agriculture, agroforestry and a wide range of marine food sources. Agriculture yield is expected to be reduced due to more severe droughts and the burden of health costs will increase due to increased incidence of respiratory disorders, mosquito and water borne (e.g., dengue or conjunctivitis) diseases. In January 2024, Pohnpei State declared a state of emergency due to the El Nino inspired drought.

Another significant threat to food security is the FSM is the anticipated continued decline of coral reef cover. Climate change is estimated to cause up to a 70% loss of coral cover, reducing the ability of this ecosystem to keep pace with projected sea level rise of approximately 10 inches by 2050 and up or more than 35 inches by the end of the century (Australian Bureau of Meteorology and CSIRO 2014). This important decline in coral cover will affect coastal protection and fishery catches for reef fishermen and will also come with elevated costs for already vulnerable communities.



Agroforestry, Pohpnei State
Photo Credit: Dena Seidel, Rutgers University

Changes in FSM's Weather Patterns

FSM residents and their local food systems are particularly vulnerable to the combined effects of sea level rise, changes in rainfall and large-scale ocean-atmosphere oscillations (El Niño–Southern Oscillation [ENSO]), increasing tropical cyclone intensity, and ocean warming and acidification. Most of the nation's population, infrastructure and cultural sites are located within 500 m and 1 km of the coastline and therefore particularly vulnerable to climate-induced impacts (Kumar et.al 2020, Andrew et.al. 2019). Almost all of the FSM's outer island atolls lie within the 2-meter zone of potential sea level rise, and all lie within a 5-meter zone of storm surge. This poses a significant disaster risk to most public and private buildings, homes and infrastructures. The FSM's extensive coastline is prone to climate- induced coastal erosion, spring tides, and species loss / coral bleaching. The high dependence of the population on fisheries and agriculture for subsistence is another factor shaping the vulnerability of the FSM, since both sectors are particularly susceptible to climate change and the FSM population is highly dependent on marine biodiversity as a protein source. Natural hazards have affected the population and natural resources over the years, also contributing to human displacement, both internal (to urban centers) and external (to other countries), affecting the overall social capacity of the FSM. The reliance on economic assistance under the Compact of Free Association (COFA) and the impact of the Sars-Cov-2 pandemic on the national economy further exacerbates the FSM's vulnerability.

Small island developing states like the FSM are internationally recognized as very much at risk due to climate change and are often described as being at the frontline of climate change (Corneloup and Moi, 2014; Schleussner C-F and Kumar M, 2018, Walsh and Stancioff 2018). The recognized threat of climate change and the strong passionate advocacy of the small island developing states, through the Alliance of Small Island States, has been critical to influencing the United Nations Framework Convention for Climate Change attempting to hold the line on the projected temperature increase to 1.5° C (Betzold 2010, Ourbank and Magnan 2018, Thomas et al. 2020). While these efforts continue, current trends in global temperature will exceed the 1.5° C benchmark within the next seven to eight years with worst cases on the highest emissions scenarios suggesting a possible 3.0° C by the end of the century. Therefore, while impassioned advocacy is required by all to still try to avoid this benchmark, a strong focus must also focus on strategies to increase FSM resilience in the face of expected change.

Long-term temperature data over the last 70 years have documented a general warming trend across the FSM (0.10-0.15° C per decade) with variations across the island states and some indications of an accelerating trend since 1980s. Coincident with the rising temperatures, long term trends suggest a decline in annual rainfall (FSM 2015), however the trends are not yet statistically significant (Australian Bureau of Meteorology and CSIRO, 2014) resolving the climate induced signals from natural variability is difficult but long-term trends suggest that the FSM should develop long term plans to address the ocean vulnerabilities with expected long-term change. Beyond the large-scale changes in the atmosphere and ocean reflecting human-induced climate change there is additionally regional/local forcing reflecting human activity. Therefore, a holistic strategy is required with a recognition that the environmental changes will be expressed in a myriad of forms and the impacts will be differentially expressed on the outer islands and larger island communities. Specific issues to consider are provided below which we separate global trends driven by climate change to those that could be influenced from global-regional-local influences.

FSM's Current Climate Change Impacts Local Food Production

With a majority of FSM residents practicing some form of subsistence food production, whether on land or sea, understanding the dynamic impacts of climate change on all aspects of FSM's environment is a necessary step toward establishing plans and policies that protect local food producers and mitigate the threats they face from a rapidly changing climate.

This section provides a description of the climatic scenario for the FSM including its past and present climate as well as projections for the future and is derived from the Pacific- Australia Climate Change Science Adaptation Planning (PACCSAP) reports (Australian Bureau of Meteorology and CSIRO 2011, 2014) and the Australia Bureau of Meteorology and CSIRO, and the Pacific Climate Change Data Portal (PCCDP[3]). Additionally, most recent changes in average climate were derived from the "Next Generation Climate Projections for the Western Tropical Pacific."(CSIRO and SPREP, 2021) Sea level data for the FSM were obtained from different data sets and reports. Data and figures on mean monthly sea level for Pohnpei (2001-2020) is obtained from PCCDP, Lindsey (2020) and the World Bank Climate change knowledge portal[4].

When considering paths for current and future local food production, observed trends and analysis of air temperature, rainfall, extreme events (including tropical cyclones), sea- surface temperature, ocean acidification, mean and extreme sea levels are presented and projections for air and sea-surface temperature, rainfall, sea level, ocean acidification and extreme events for the next century are provided and must be considered.

The FSM has a tropical climate that is strongly influenced by northeast trades that prevail from December through April. The country has two seasons, a dry season that occurs from November to April and a wet season from May to October, when the Inter-Tropical Convergence Zone (ITCZ) is strongest and furthers North (Australian Bureau of Meteorology and CSIRO, 2014). In western FSM (Yap and Chuuk), the West Pacific Monsoon (WPM) affects rainfall patterns, bringing additional rain during the wet season (FSM SNC, 2015[5]). Rainfall is generally high on the volcanic islands of Pohnpei, Kosrae and Chuuk, with mean annual rainfall reaching 466.8cm (183.8 inches) on Pohnpei main island for the latest 30 years (NOAA NCEI, 2021[6]). The FSM western states of Chuuk and Yap are affected by WPM climatic patterns bringing storms and typhoons with excessive rainfall more frequently than the eastern states of Pohnpei and Kosrae. The states of Yap and Chuuk are also affected by drought spells associated with the warm and cold phases of the El Niño–Southern Oscillation (ENSO); more frequent periods of drought can be experienced by the most western state of Yap (Australian Bureau of Meteorology and CSIRO, 2014).

---

3 The PCCDP was developed through the Pacific Climate Change Science Program (PCCSP; 2009-2011) and Adaptation Planning Programs 2009-2014, with further improvements/updates undertaken by the Climate and Oceans Support Program in the Pacific 2018-2022 (http://www.bom.gov.au/climate/pccsp/). PCCDP provides site-specific historical climate information and trends for the Pacific Islands.

4 World Bank Climate change knowledge portal; last accessed July 15, 2021 at: https://climateknowledgeportal.worldbank.org/country/federated-states- micronesia

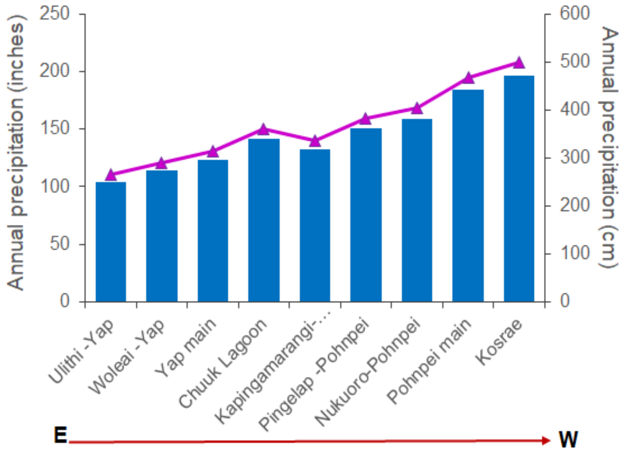
5 Federated States of Micronesia. (2015). Second National Communication under the UN Framework Convention on Climate Change. Retrieved from: https://unfccc.int/resource/docs/natc/fsmnc2.pdf (Accessed: June 2021)

6 NOAA National Centers for Environmental Information (NCEI): most recent standard climatological period (1991-2020) for precipitation data was derived from the U.S. Climate Normals Quick Access tool, last accessed on 26 December 2021 at https://www.ncei.noaa.gov/access/us- climate- normals/#dataset=normals-annualseasonal&timeframe=30&location=FM

The ITCZ plays a significant role in influencing climate in the FSM and recent studies suggest a range of possible future changes in annual and seasonal rainfall largely determined by the intensification or weakening of the ITCZ (CSIRO and SPREP, 2021).

Air Temperature in the FSM

The FSM experiences little seasonal variation in mean air temperatures across the year (less than 1.5° C / 2.7° F between the average hottest and coolest months), which is driven mainly by sea surface temperatures around the islands. In general, across the island groups, the mean annual temperature averages 27.1° C (80.8°F) over the period 1901–2019, with interannual variability determining cooler years and warmer years (CSIRO and SPREP, 2021). However, annual mean air temperatures have increased (~0.5 - 1˚C) across the FSM since 1951 (Australian Bureau of Meteorology and CSIRO, 2014), showing a warmer trend over the 1850-2020 period with years since 2000 warmer than the pre-industrial climate average (CSIRO and SPREP, 2021).

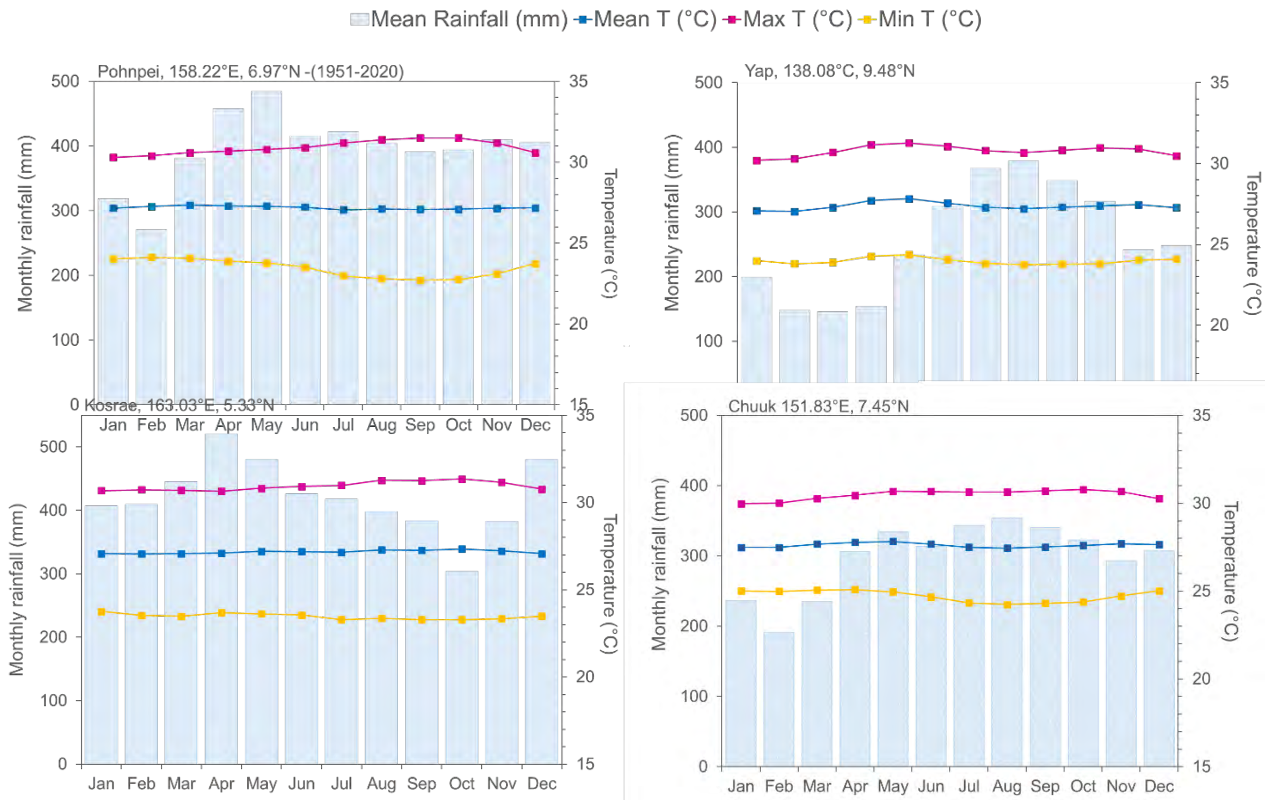


Mean annual rainfall normals in eastern and western FSM. Blue bars: annual rainfall in inches; purple line: annual rainfall in cm. Source: NOAA NCEI

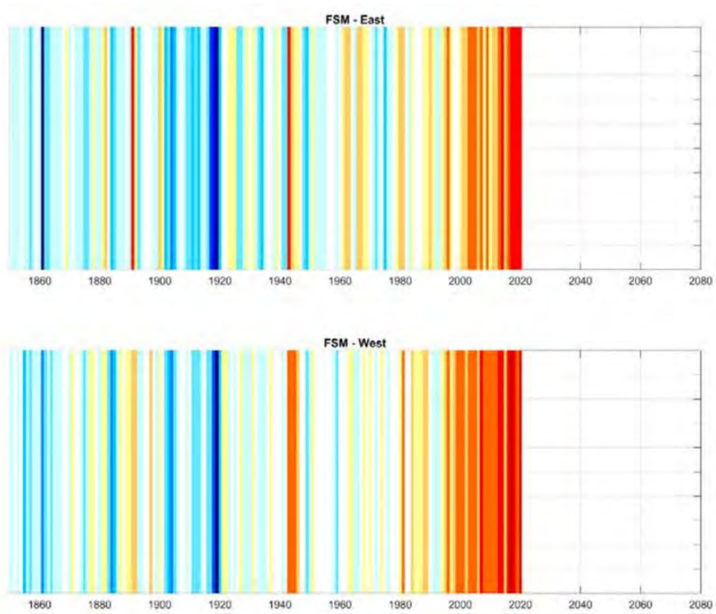
The warming trend for the FSM is clear, but its magnitude is less than that observed for the global average. The average temperature by around 0.8 ˚C (1.4°F) in eastern FSM increased and by about 0.9 ˚C (1.6°F) in western FSM (CSIRO and SPREP, 2021).

Extreme temperatures in Pohnpei are consistent with the increasing global trends. Annual mean temperatures at Pohnpei show an increase, while at Yap, little variation was observed up to 2010. However, mean annual temperatures increased sharply at Yap during the 2015 ENSO event, which continued to impact global temperatures at the beginning of 2016. Indeed, 2016, tied to strong El Niño conditions, was the warmest year on record since 1850, overcoming the previous record (set in 2015) by 0.2°C (0.36°F; NOAA, 2016).

Annual maximum temperatures have increased in the FSM over the period 1951-2020. Maximum temperatures have increased at a rate of +0.26 ºC (0.47°F) per decade at Chuuk and at a rate of +0.12°C (0.22°F) per decade at Pohnpei and Yap, with Yap maximum temperatures increasing at a rate of +0.18˚C (0.32°F) per decade during the dry season (November–April). Maximum annual air temperature trends in Pohnpei and Yap are significantly increasing (Australian Bureau of Meteorology and CSIRO, 2014).

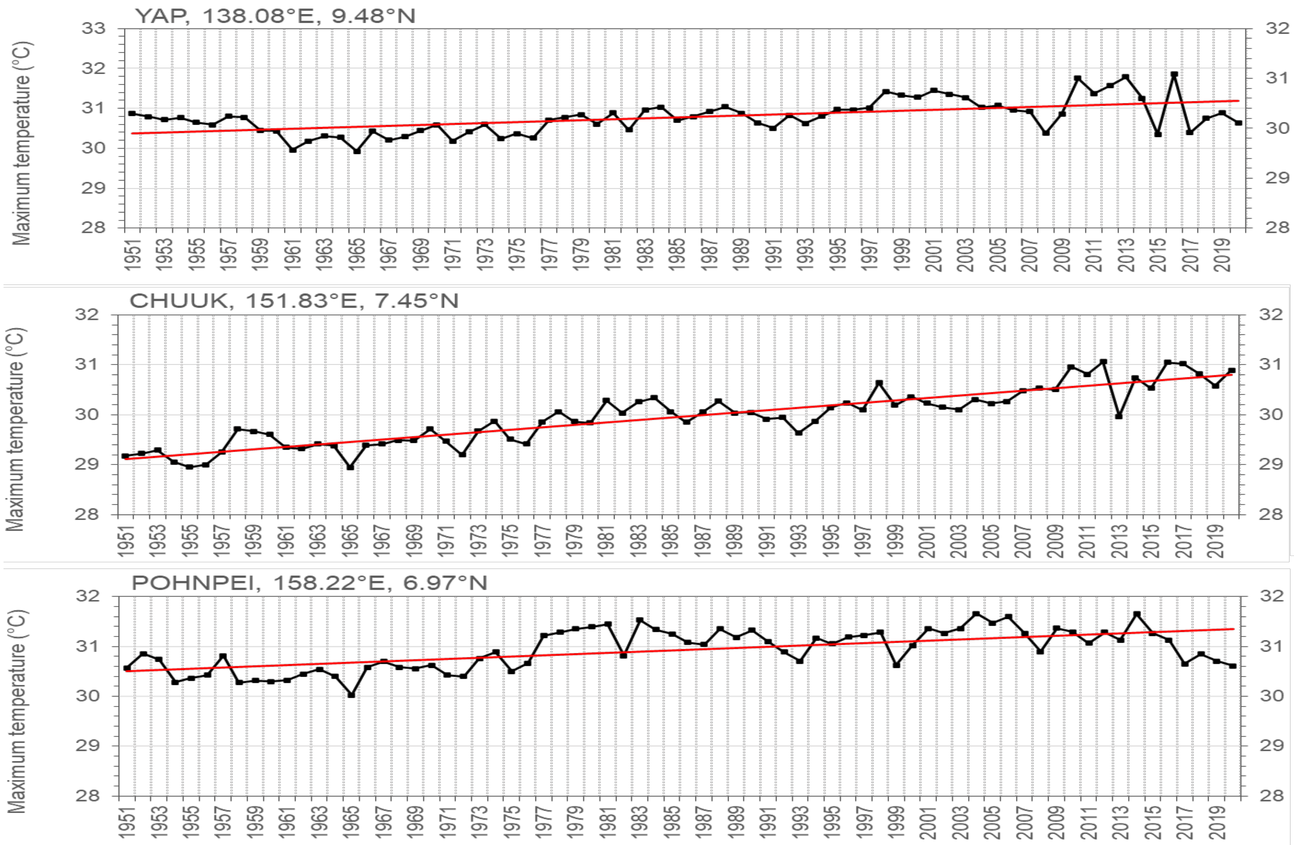


Mean annual rainfall, monthly maximum, minimum and mean air temperatures at Pohnpei, Yap, Kosrae and Chuuk over the period 1951-2020 (source: Pacific Climate Change Data Portal; http://www.bom.gov.au/climate/pccsp/).



Stripe pattern (from Hawkins 2018) indicates a clear change in temperature records since 1850 for east and west FSM. Cooler than average temperatures (blue stripes) are replaced by warmer than average temperatures (red stripes), especially since 2000 (Graphs sourced from CSIRO and SPREP, 2021).

For the state of Pohnpei, trends in increasing “warm days” and “warm nights” are statistically significant. In Yap, a significant increase of maximum air temperature is observed, albeit extreme minimum temperature shows an opposite trend. The inconsistency observed for mean and extreme global warming trends is “likely due to remaining inhomogeneities in the data record” (Australian Bureau of Meteorology and CSIRO, 2014). The decrease in the occurrence of cool nights may be correlated to the increasing Sea Surface Temperatures (SST) that may add to the local moisture content and help sustain elevated nighttime temperatures (Marra et al., 2017). Overall, in the FSM, the number of hot days has increased since 1950, while in the last decade the number of cool nights has decreased to an average of 59 nights per year (Grecni et al, 2022).



Trends in annual maximum air temperature for Yap, Chuuk and Pohnpei (source PACCSAP and the relevant FSM meteorological service; Pacific Climate Change Data Portal, last accessed July 10, 2021, http://www.bom.gov.au/climate/pccsp/).

Annual air temperature at Pohnpei and Yap over the period 1952-2011. Values for trends significant at the 5% level are shown in boldface; 95% confidence intervals are shown in parenthesis (Australian Bureau of Meteorology and CSIRO, 2014).

TEMPERATURE	Pohnpei	Yap
Warm Days (days/decade)	**7.86** (+3.65, 11.70)	**12.23** (+4.60, +19.80)
Warm Nights (days/decade)	**5.12** (+1.22, +9.05)	**-16.68** (-21.57, -10.24)
Cool Days (days/decade)	**-3.98** (-5.53, -2.52)	**-8.50** (-13.66, -2.67
Cool Nights (days/decade)	-2.73 (-8.21, +3.68)	**+8.70** (+3.71, +14.90)

Warm Days: Number of days with maximum temperature greater than the 90th percentile for the base period 1971–2000
Warm Nights: Number of days with minimum temperature greater than the 90th percentile for the base period 1971–2000
Cool Days: Number of days with maximum temperature less than the 10th percentile for the base period 1971–2000
Cool Nights: Number of days with minimum temperature less than the 10th percentile for the base period 1971–2000

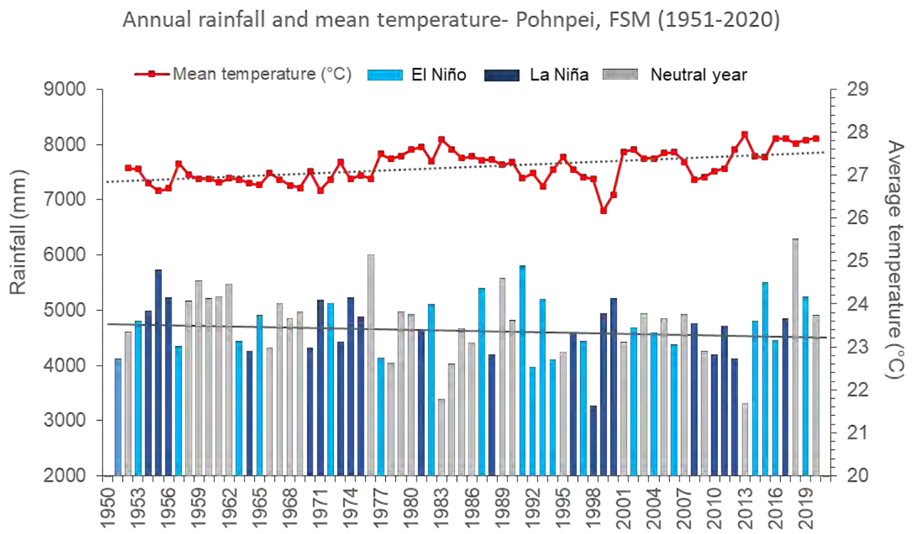
Rainfall in the FSM

FSMs traditional agroforestry and terrestrial food production has long been dependent on predictable rainfall but due to climate change, rain patterns have become erratic and varied. Annual total rainfall in the region shows large interannual variability partly related to the ENSO, and no significant trends for the FSM since 1960 (Australia Bureau of Meteorology and CSIRO, 2014). Similarly, there is no significant change in annual rainfall between the pre-industrial baseline of 1850-1900 to the more recent baselines (CSIRO and SPREP, 2021). At Pohnpei, there has been a statistically significant (at 5%) declining trend in May–October rainfall since 1950. This may imply that the mean location of the ITCZ is shifting away from Pohnpei and/or that rainfall associated with the ITCZ is changing in the intensity (Australian Bureau of Meteorology and CSIRO, 2014). There have also been statistically significant negative trends in annual "very wet day" rainfall at Pohnpei and annual "consecutive dry days" at Yap since 1950 and 1952 respectively.

The average number of heavy rainfall days per year shows a non-significant increase for Pohnpei and Yap, and no change for Kosrae since 1951 (Marra et al, 2021). Declining trends in annual rainfall of -45.5mm (1.8 in) per decade were observed for Pohnpei, -17.4mm (0.7 in) per decade for Chuuk and -0.87mm (0.03 in) per decade for Yap, since 1950.

Time series of mean annual air temperature (degree Celsius) and total rainfall (mm) in Pohnpei, Yap, and Chuuk from 1951 to 2020. Light blue, dark blue and gray bars denote El Niño, La Niña and neutral years respectively. (Source: PACCSAP Program and the Yap, Chuuk, and Pohnpei meteorological services; data source: Pacific Climate Change

Data Portal, http://www.bom.gov.au/climate/pccsp/.)



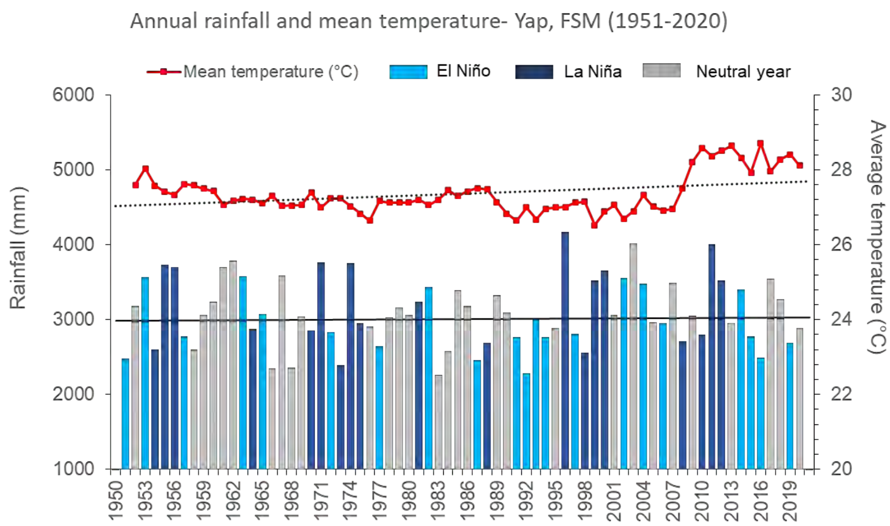
Average annual rainfall and temperature Pohnpei:

Rainfall least squares linear trend of -45.55 mm/decade (solid black trend line);

Average annual rainfall 4727 mm (186in);

Temperature least squares linear trend of

+0.13°C/decade (0.23°F/decade).

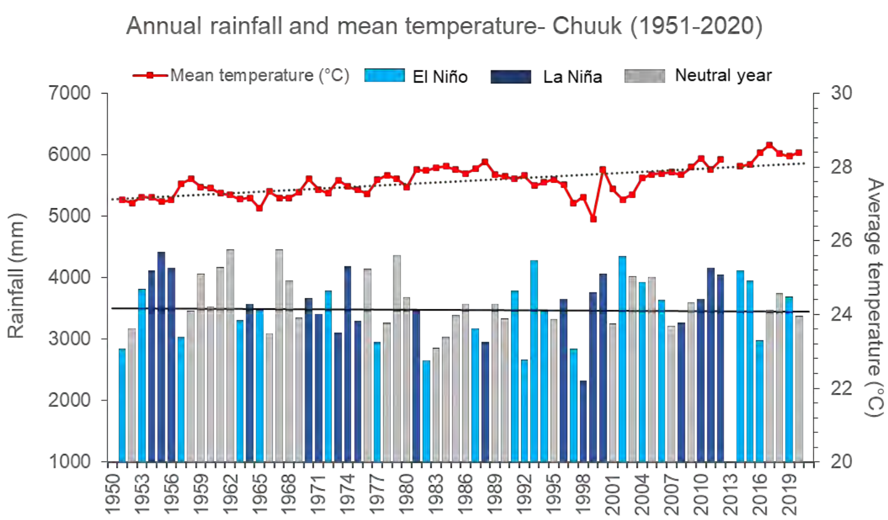


Average annual rainfall and temperature Yap:

Rainfall least squares linear trend of -0.87 mm/decade (solid black trend line);
Average annual rainfall 3098 mm (122in);

Temperature least squares linear trend of

+0.17°C/decade (0.3°F/ decade).



Average annual rainfall and temperature Chuuk:

Rainfall least squares linear trend of -17.38 mm/decade (solid black trend line);
Average annual rainfall 3579 mm (140.9in);

Temperature least squares linear trend of +0.19°C

/decade (0.34 °F/ decade)

Interannual rainfall variability, associated with ENSO events, was observed for Pohnpei since 1950 and Yap since 1952 (Leong et al., 2014). A decline of 15% in annual rainfall has been observed in the eastern-most islands of FSM, although a slight increase in precipitation, related to ENSO variability, is observed for the western-most islands. In a typical El Niño, dryness and drought are common in the FSM.

Annual trends in rainfall extremes in Pohnpei and Yap over the period 1952-2011. Values for trends significant at the 5% level are shown in blue bold face; 95% confidence intervals are shown in parenthesis (Australian Bureau of Meteorology and CSIRO, 2014).

RAINFALL		Pohnpei	Yap
Rain Days ≥ 1 mm	(days/decade)	-0.21 (-2.79, +2.48)	-1.01 (-4.20, +1.82)
Very Wet Day rainfall	(inches/decade)	-2.63 (-5.15, -0.12)	+0.22 (-1.39, +1.97)
	(mm/decade)	-66.88 (-130.81, -3.05)	+5.55 (-35.30, +49.95)
Consecutive Dry Days		0.00 (-0.43, +0.20)	-0.37 (-0.77, 0.00)

Rain Days ≥ 1mm: Annual count of days where rainfall is greater or equal to 1mm (0.039 inches)

Very Wet Day rainfall: Amount of rain in a year where daily rainfall is greater than the 95th percentile for the reference period 1971– 2000.

Consecutive Dry Days: Maximum number of consecutive days in a year with rainfall less than 1mm (0.039 inches)

Sea Level in the FSM

FSM coastal communities have been experiencing an increase in salt water inundation of their taro patches and other food crops threatening their subsistence food production. The FSM is immediately and directly impacted by the rising global temperatures which is increasing sea level driven by several processes that include the melting of ice in polar oceans and terrestrial regions, the subsidence of land masses, and the thermal expansion of the ocean associated with warming temperatures. Over the last century, the global mean sea level rise has been 1.05 mm/year however since the 1980s these sea level rise rates appear to be increasing (Meirer et al. 2002). Sea level rise will impact all of the FSM; however, the impacts will be magnified on the outer islands and atolls that are closer to sea level than the volcanic main islands. The rising sea level potentially will overwhelm lowest outer lying islands and atolls, but the timing of this is difficult to predict given current model forecast capabilities to provide the specific guidance of the shelter in place to evacuate. It would be critical that the FSM be able to access embedded higher resolution regional modeling assessments within current Global Climate Models (GCM). Beyond the land loss associated with the sea level rise, there will be other impacts including enhanced storm surge, king tides, and saltwater intrusion into groundwater. These combined impacts will be felt most acutely by the outer island and atoll communities and over the long term will affect the overall habitability to support communities.

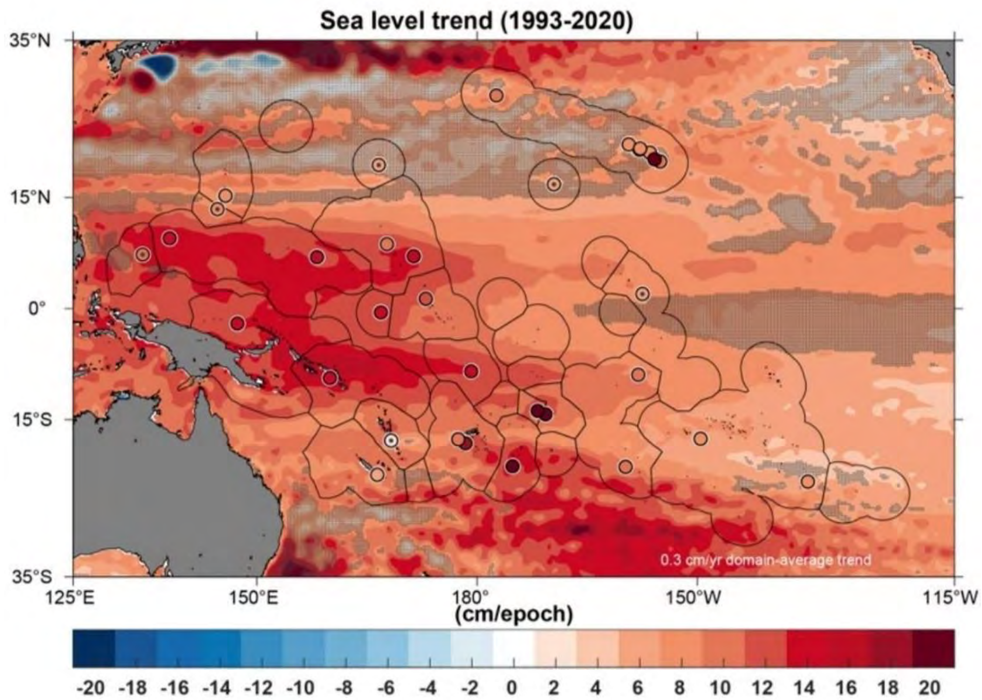
In the FSM, sea level varies due to seasonal and longer-term variations in winds, ocean temperature and sea- level pressure. In the western Pacific, sea level rising trends, since the start of satellite records in 1993, are doubled relative to the global rate, albeit interannual and multidecadal variation in sea level can be quite large. Satellite data indicates that in the FSM, sea level has risen by over 10mm (0.39 inches) per year since 1993. This is above the global average of 2.8–3.6 mm (0.11–0.14 inches) per year (Australia Bureau of Meteorology and CSIRO 2015[7]). This higher rate of sea level rise may be related to natural variations that take place on an interannual or decadal to multi-decadal time scales, generally attributed to changes in prevailing wind patterns associated with El Niño–Southern Oscillation (ENSO) as well as the Pacific Decadal Oscillation (PDO; Leong et al. 2014).

The occurrence of extreme tides is generally associated with changes in water levels due to ENSO, storms and rising sea level. Typically, these events in Pohnpei and Chuuk are observed during la Niña. Rising sea level above its normal value has caused coastal inundation, damaging infrastructures, soil, food and freshwater resources across the FSM. Drinking water sources are becoming more vulnerable, particularly in outlying atoll islands, and food availability is increasingly dependent on imports. After removal of the seasonal cycle, the FSM interannual variability in sea level is about 260mm (10 inches). As reported in the FSM SNC, Pohnpei experiences the highest monthly mean sea levels around March and its lowest around November and December.

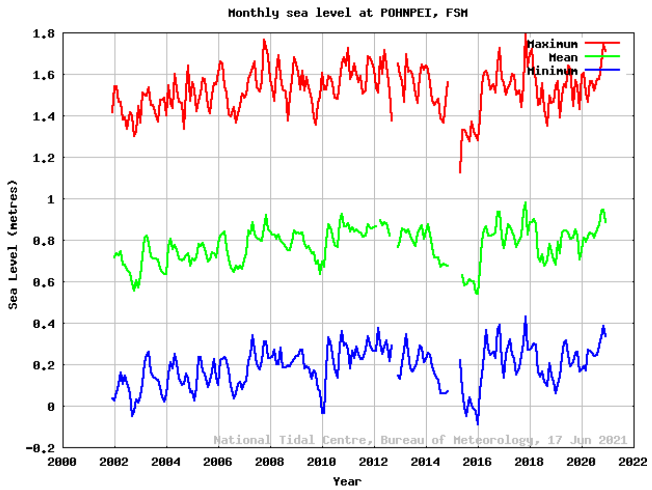
Nan Madol, Pohnpei State
Photo Credit: Dena Seidel, Rutgers University

---

7 Pacific-Australia Climate Change Science and Adaptation Planning Program partners (2015). Current and future climate of the Federated States of Micronesia. Retrieved from: https://www.pacificclimatechangescience.org/wp-content/uploads/2013/06/7_PACCSAP-FSM- 11pp_WEB.pdf



Sea level trends from satellite altimetry (colored contours) and from tide gauges (circles) less than interannual variability as determined by the standard deviation of sea level monthly anomalies since the beginning of the satellite record (1993-2020)



The record of monthly mean, minimum and maximum sea level at Pohnpei over the period PSLGM available at Pacific Climate Change Data Portal; http:// www.bom.gov.au/- oceanograp- hy/projects/spslcmp/data/month ly.sh tml#table

Records from the Pacific Sea Level and Geodetic Monitoring Project (PSLGM) indicate that mean sea level over the period 2001-2021 is 0.77 m (2.53ft), with a minimum of -0.091 m (-0.29 ft) on 11 January 2016, in conjunction with El Niño, and a maximum of 1.79 m (5.87 ft) on 6 November 2017, during La Niña. In the FSM, extreme low sea levels were recorded at the end of El Niño years (2001, 2010 and 2016), while high sea levels were observed in La Niña years (2002, 2011 and 2017).

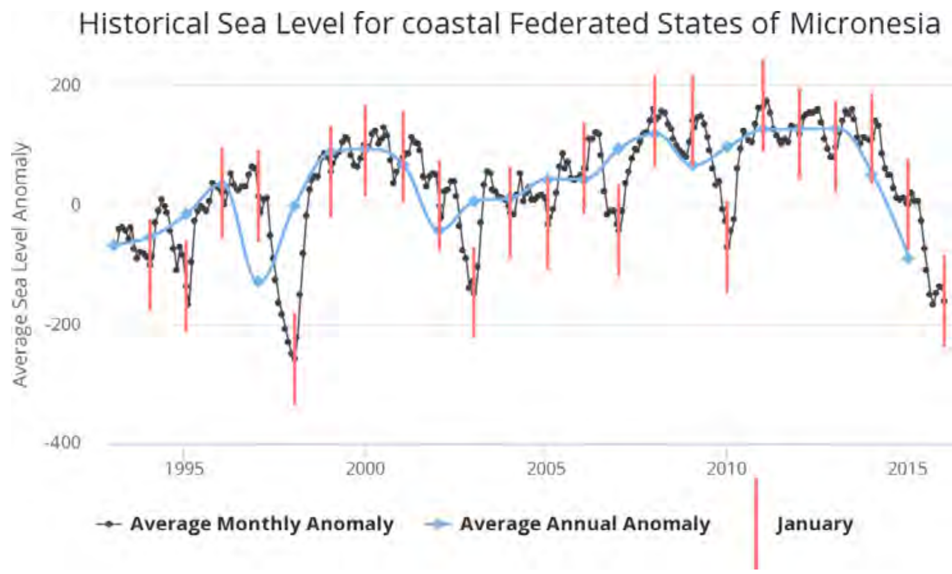


Figure 8 Observed sea-level anomalies (mm) relative to mean of 1993-2015 for the FSM (source: https://climateknowledgeportal.worldbank.org/country/federated-states-micronesia/impacts-sea-level-rise). The drop in 2015/16 corresponds to El Niño conditions

Climate Variability in the FSM: Interannual and Multi-Decadal

In the Micronesian region, interannual variability is a natural climate phenomenon, affecting rainfall patterns, sea level height and frequency in extreme weather events (i.e., typhoons, tropical storms). This natural climate variability is associated with major climatic drivers such as El Niño–Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO).

The El Niño–Southern Oscillation (ENSO[8] phenomenon is the dominant mode of year-to-year natural climate variability in the Micronesia region. During El Niño the trade winds weaken and may even change direction, while they strengthen during La Niña. The consequences of El Niño and La Niña phases in the FSM are drastic changes in precipitation, air and sea surface temperature, sea surface height, storminess, and wave size. ENSO extremes affect the interannual position and intensity of the intertropical convergence zone with effects on the seasonal rainfall patterns in the northwest Pacific region countries (Murphy et al 2014). Pohnpei, Yap, and Chuuk are usually drier in El Niño and wetter in La Niña phase than average. Over the past years another type of El Niño, referred to as El Niño Modoki, is observed producing below-normal SSTs in the eastern Pacific (Ashok et al. 2007,[9] Chand, 2020[10]), with some weak but significant

---

[8] Typically, El Niño years are associated with widespread warming of SST in the near equatorial Pacific east of the dateline between November and April, with greatest warming between December and March. Concurrently there is a weak cooling of SST in the far western Pacific. The opposite pattern (with cooling in the eastern and central equatorial Pacific) occurs during La Niña (Taylor et al, 2016.) The ENSO events are associated with neutral phases, with equatorial SSTs that are near the climatological averages. The effects of ENSO can be magnified when it is in phase with longer periodic cycles such as the Pacific Decadal Oscillation and the Interdecadal Pacific Oscillation.

[9] Ashok, K., S. K. Behera, S. A. Rao, H. Weng, and T. Yamagata, 2007: El Niño Modoki and its possible teleconnection. J. Geophys. Res., 112, C11007, doi:10.1029/2006JC003798

[10] Chand S. S., 2020: Climate Change Scenarios and Projections for the Pacific. In: Lalit Kumar (eds) Climate Change and Impacts in the Pacific, Springer Climate. Springer, Cham. https://doi.org/10.1007/978-3-030-32878-8_3

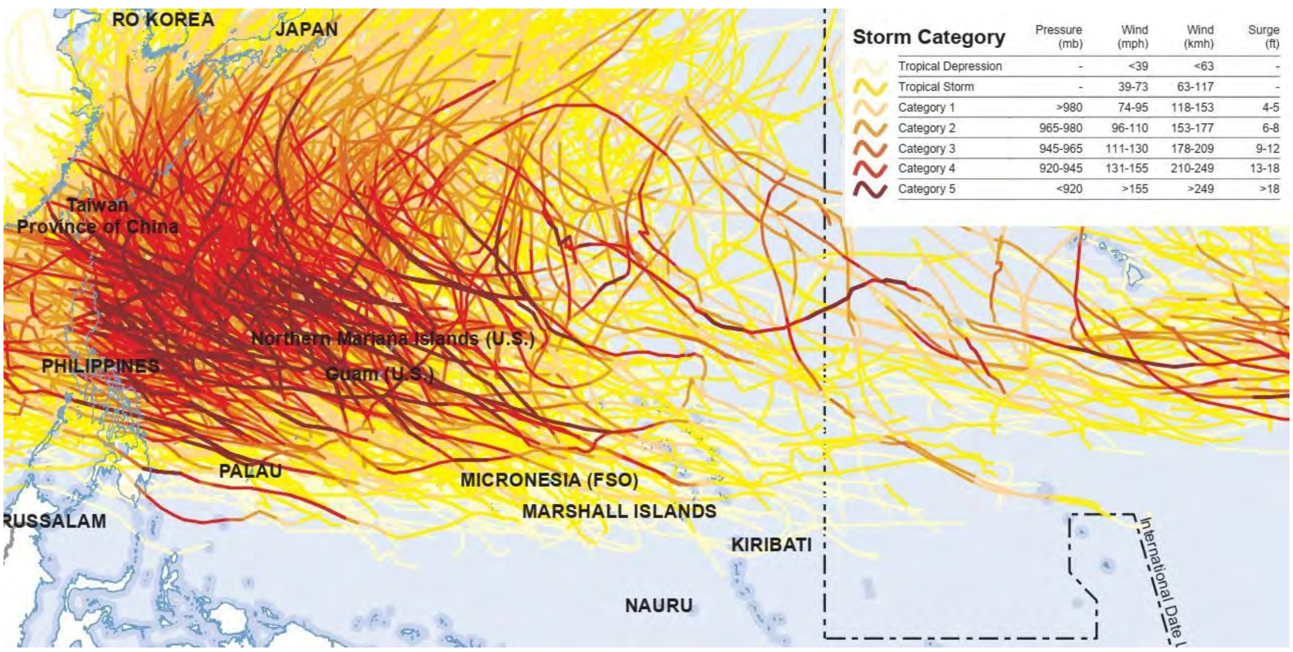
correlations on temperatures and a weak impact on Yap dry season rainfall (Australian Bureau of Meteorology and CSIRO, 2011).

The effects of ENSO can be magnified when it is in phase with longer periodic cycles such as the Pacific Decadal Oscillation and the Interdecadal Pacific Oscillation (Keener et al. 2018).

The Pacific Decadal Oscillation (PDO) present pattern of variability, in the north Pacific Ocean, on decadal time scales (Chand, 2020), influencing the weather and climate of the region. As for ENSO, which on interannual time scales can influence sea level, differences in regional sea level on multi-decadal time scale across the Pacific Basin are associated with PDO climate variability.

Typhoons and Tropical Storms in the FSM

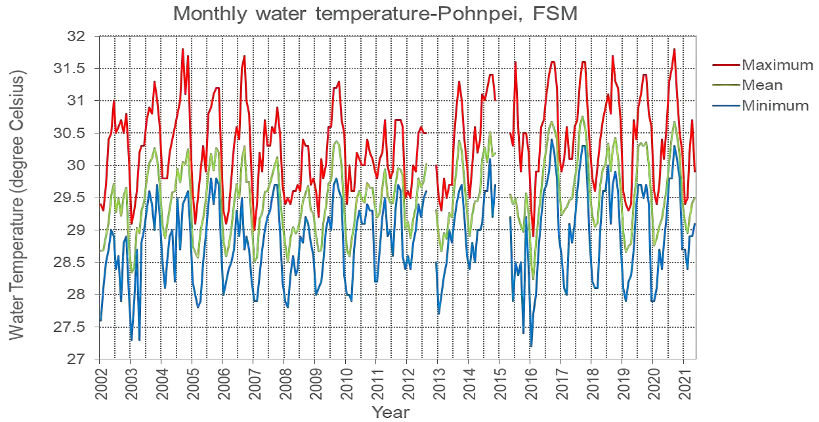
The western edge of the Micronesian Region is the most active tropical cyclone basin in the world, with tropical storms and typhoons that can occur annually, causing damage to infrastructure, flooding, and drainage complications. Typhoons affect the FSM mainly between June and November and are more common during El Niño years. The frequency of typhoons affecting the FSM varies from year to year ranging from 0 to 12 in a given year (NOAA 2015), with an average of seventy-one cyclones per decade that developed within or crossed FSM's EEZ between the 1977 and 2011 seasons (Australian Bureau of Meteorology and CSIRO, 2014). Thirty- seven of the 212 tropical cyclones (17%) that passed through the FSM's EEZ between the 1981 and 2011 became severe events, Category 3 or stronger (Australian Bureau of Meteorology and CSIRO, 2014).



Consolidated history of tropical storm paths over 50 years, 1968-2018, in the North Pacific region. The FSM lie in the path of many of the most destructive storms, which often reach their peak as they move north west from the FSM. (Source: UN Cartographic Section, UNISYS, NOAA; Map Ref: OCHA_ROAP_StormTracks_v8_190314).

Sea Surface Temperature (SST) in the FSM

Historical changes around the Federated States of Micronesia are consistent with the broad-scale sea-surface temperature trends for the wider Pacific region. Warming was relatively weak from the 1950s to the late 1980s. This was followed by a period of more rapid warming (approximately 0.11°C per decade and approximately 0.08°C per decade for 1970–present, in the eastern and western regions respectively). At these regional scales, natural variability plays a large role in determining the sea-surface temperature, making it difficult to identify long- term trends (Australian Bureau of Meteorology and CSIRO, 2011). Warmer than normal SSTs are determinants for coral reef bleaching and mortality. Large scale coral bleaching was observed during the last El Niño event (2015-2016), impacting coral reefs in most of the FSM islands and in some cases causing local mortality. Coral bleaching is becoming one of the major threats for coral reef persistence, which, driven by increasing SST, is likely to have harmful consequences on the subsistence and livelihoods of FSM communities.



Sea water maximum, mean and minimum temperature over the period 2002-2021 in Pohnpei

Summary of Current Climate Trends in the FSM

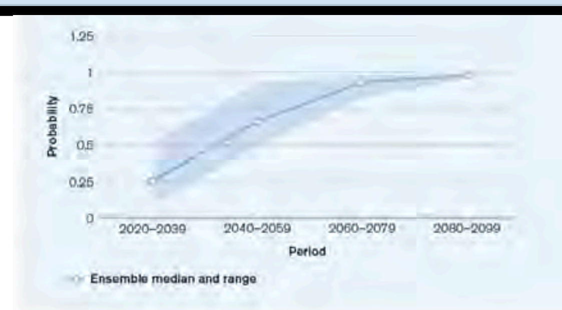
- Warming trends are evident with an increase by around 0.8˚ C (1.4°F) in eastern FSM and by about 0.9 ˚C (1.6°F) in western FSM since 1951.
- The number of hot days in the FSM has increased since 1950, while in the last decade the number of cool nights has decreased to an average of 59 nights per year.
- Annual total rainfall in the region shows large interannual variability partly related to the ENSO, and no significant trends for the FSM since 1960. At Pohnpei, there has been a significant declining trend in May–October rainfall since 1950. This may imply that the mean location of the ITCZ is shifting away from Pohnpei and/or that rainfall associated with the ITCZ is changing in the intensity
- Sea level has risen by over 10mm (0.39 inches) per year since 1993, which is above the global average of 2.8–3.6 mm (0.11–0.14 inches) per year.
- An average of seventy-one cyclones per decade developed within or crossed FSM's EEZ between the 1977 and 2011 seasons. Thirty-seven of the 212 tropical cyclones (17%) passing through the FSM's EEZ over the period 1981-2011 became severe events (Category 3 or stronger).
- Sea surface warming was relatively weak until late 1980s, showing a more rapid warming of approximately 0.11°C per decade and approximately 0.08°C per decade for 1970–present, in the eastern and western regions respectively.

Data Source: FSM Third National Contribution to the UNFCCC 2023

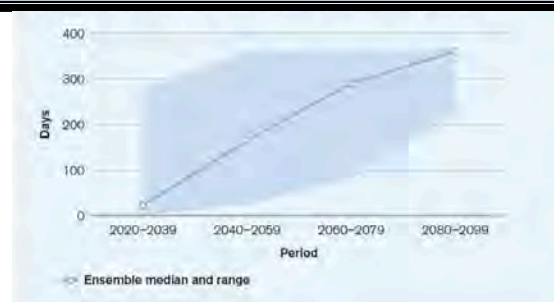
The Threat of Heat Waves to Food Production

Successive heat waves threaten the FSM islands and oceans ability to provide food. Heat waves are defined as 3 or more days when the daily temperature remains above the 95th percentile. Figure 5 shows the projected change in heat wave probability under RCP8.5 (compared to 1986–2005), highlighting the daily probability of a sudden heat wave in subsequent time periods. For FSM, this probability steadily increases in the long term. This is held within the global context in which probabilities are expected to increase. It should also be noted that the tropics are particularly vulnerable to heat wave probability because the day-to-day and month-to-month variabilities are small. (World Bank 2021)

Projected change in probability of Heat Waves in FSM under RCP8.5 (compared to 1986-2005)

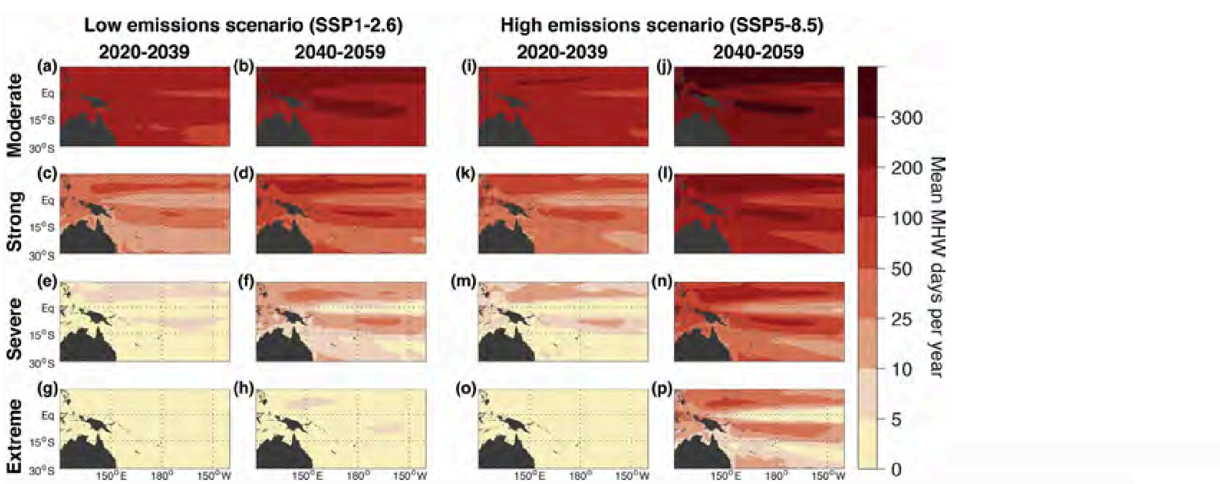


Projected change in the count of days in which climate conditions breach the Heat Index >35°C threshold, under RCP8.5



Heat waves impact local food production in myriad ways. The heat reduces soil water retention, preventing crop growth, which affects production and yield. Heat impacts workers and livestock who get dehydrated and tired which affects efficiency and associated production costs. Crops harvested in extreme heat tend to deteriorate faster.

Marine heatwaves can have devastating impacts on FSM pelagic fish and coastal marine species and habitats, often with negative effects to human communities, economies and livelihoods.



Holbrook et al. (2021)

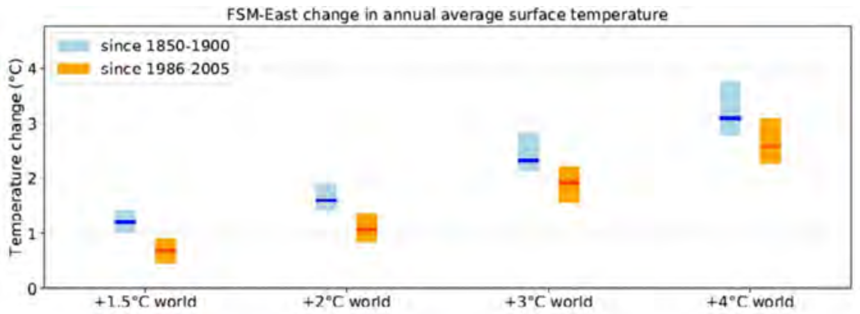
Volume 208, 2022, 103680, ISSN 0921-8181, https://doi.org/10.1016/j.gloplacha.2021.103680.

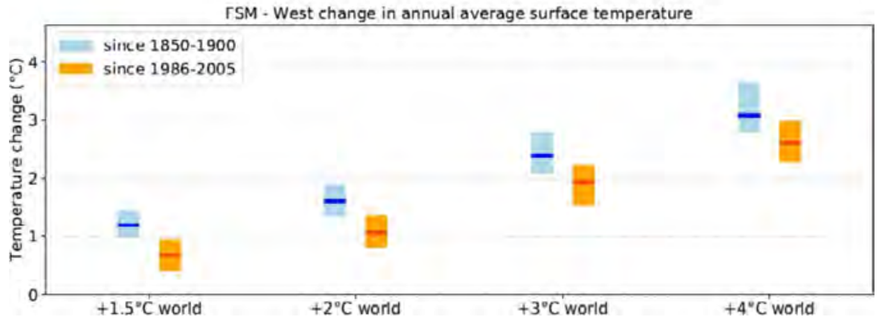
FSM Climate Projections to Prepare Future Food Production

Combating food insecurity through development of sustainable local food systems requires predicting future growing conditions. Climate models are therefore needed when preparing food production strategies. The below climate projections were derived from the Australian Bureau of Meteorology and CSIRO report[11] (2014) and from the CSIRO and SPREP (2021) "NextGen" technical report. Additional information was obtained from Marra et al. (2021) regional report and the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2021). Sea level projections for the western and eastern FSM were obtained from the Australian Bureau of Meteorology and CSIRO report (2014) as well as Marra et al. (2017, 2021).

Projections for the FSM indicate that:

Air temperatures over the next decade (by 2030) is expected to increase by about 0.7°C from the 1986-2005 baseline under all emission pathways and the increase will continue to the end of the century. By 2050 and 2070 temperature changes will vary depending on the greenhouse gases emission pathway. Under the very low emission scenario (RCP2.6) 0.8°C (1.4 °F) temperature change is expected by 2050 and 2070, and 0.4°C to 1.2°C by 2090, from the 1986-2005 period. Under the very high emission scenario (RCP8.5) temperature will change 1.4°C by 2050, 2.2°C by 2070 and 2.1°C to 4.0°C by 2090, relative to 1986-2005. For the FSM, projections suggest that 2°C global warming relates to 1.3 to 1.9°C (CSIRO and SPREP, 2021).





Change in the average annual temperature of FSM east and west at different global warming levels, from the 1850-1900 baseline, and from the more recent baseline of 1986-2005. The bars represent multi-model median and 10th- 90th percentile range. (Source of figure and figure legend: CSIRO and SPREP, 2021. "NextGen" projections for the Western Tropical Pacific: current and future climate for Federated States of Micronesia.)

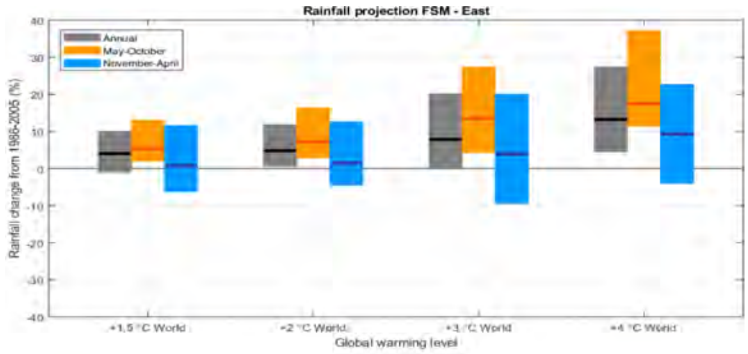
[11] Projections are derived from the Global Climate Model data from the Coupled Model Intercomparison Project, Phase 5 (CMIP5). Projections provided are for the very high emissions scenario, the Representative Concentration Pathway (RCP) 8.5.

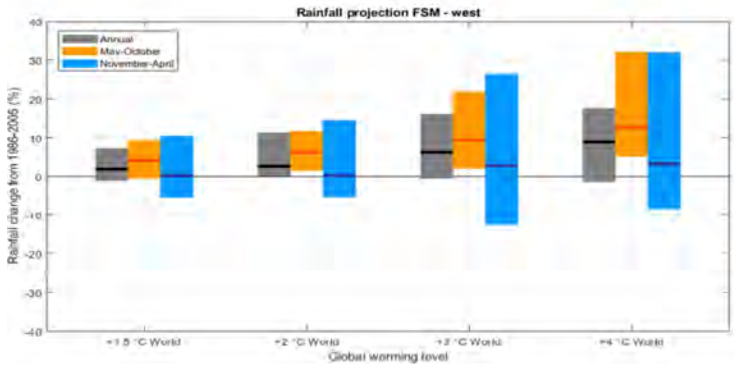
Extreme temperature will also increase as warming will continue in the 21st century for all global warming levels and future emissions scenarios, extreme temperature events and heat stress (*high confidence*; IPCC, 2021), reducing cold extremes including cool nights (Marra et al 2021). Temperature of extremely hot days and extremely cool days will increase by the end of the century.

Projected temperature of the 1-in-20-year hot day in western (Yap and Chuuk) and eastern (Pohnpei and Kosrae) FSM (Australian Bureau of Meteorology and CSIRO, 2014).

Emission Scenario	FSM location	2030	2090
Very low emission – RCP2.6	Eastern	+0.6°C (+1.1°F)	+0.8°C (+1.4°F)
	Western	+0.6°C (+1.1°F)	+0.8°C (+1.4°F)
Very high emission – RCP8.5	Eastern	+0.8°C (+1.4°F)	+3°C (+5.4°F)
	Western	+0.8°C (+1.4°F)	+3.2°C (+5.8°F)

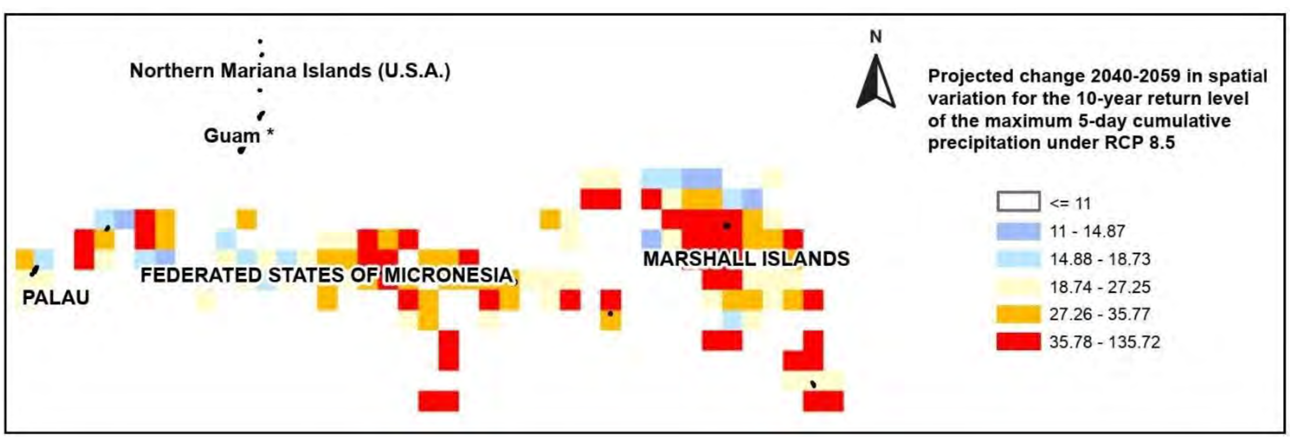
Long-term average rainfall in the FSM is projected, by most models, to increase over the century, particularly under higher warming levels compared to lower levels. For the FSM, rainfall increase is expected to be larger for the wet season (May-October) than for the dry season (November-April). Projected annual total rainfall changes will still be greatly dependent on annual variability and largely determined by whether the ITCZ intensifies or weakens (CSIRO and SPREP 2021). A weakened ITCZ will result in a negative percent change in annual rainfall corresponding to -5 to -10% annual rainfall under low emissions (RCP2.6) and -5% annual rainfall under high emissions (RCP8.5). A strengthened ITCZ will result in an increase in annual rainfall under both low emissions (+15 to 20%) and high emissions (+25%). Long-term trends are unclear, and models show from little change to an increase in total annual rainfall (CSIRO and SPREP 2021).





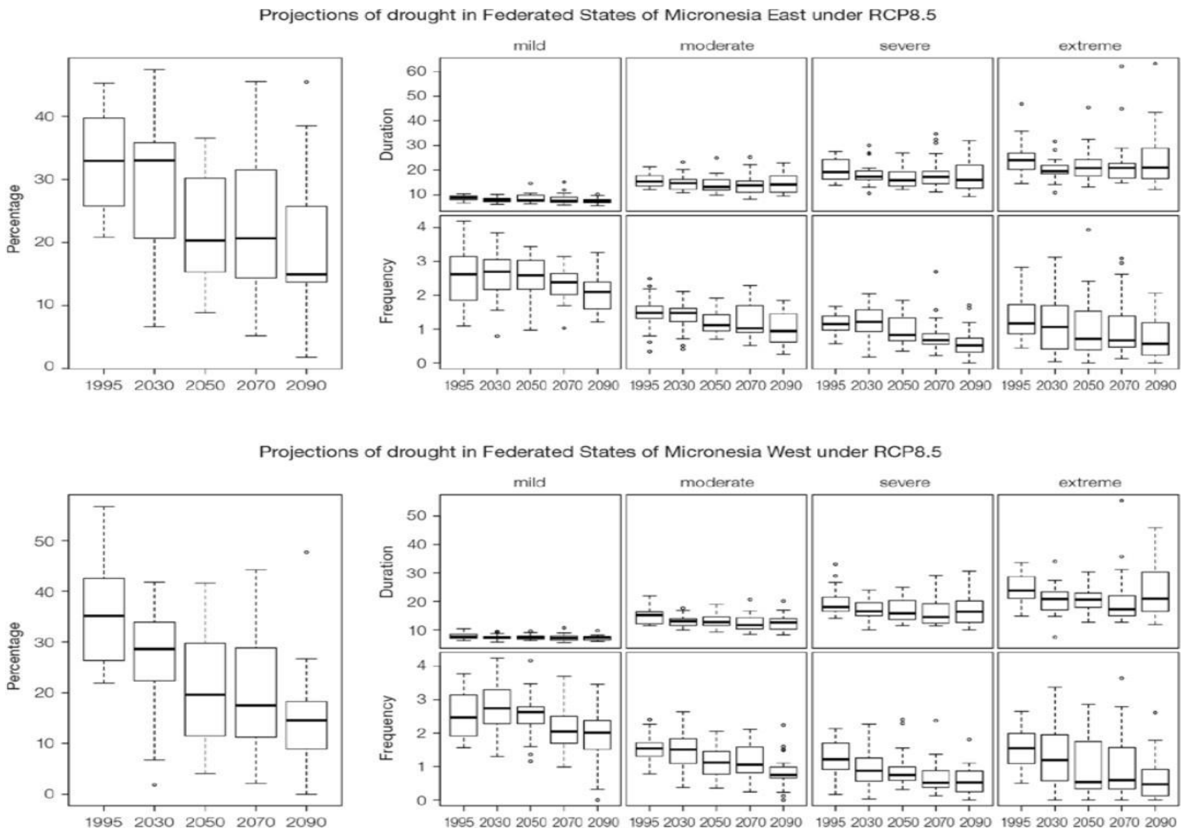
Change in the average annual and 6-month seasonal rainfall in the FSM region at different global warming levels relative to the 1986- 2005 baseline. The bars represent multi-model median and 10th-90th percentile range. (Source of figure and figure legend: CSIRO and SPREP, 2021. 'NextGen' projections for the Western Tropical Pacific: current and future climate for Federated States of Micronesia.)

Extreme rainfall events (heavy rainfall days) including both frequency and intensity are projected to increase by 2030 (*high confidence at 2°C global warming and above*; IPCC, 2021) under the very high carbon dioxide emissions scenario (RCP8.5). By 2090, the eastern FSM will experience an increase in heavy rainfall events from 1-in-20-year to 1-in-7-year event under very low emissions (RCP2.6) and 1-in-6-year under very high emissions (RCP8.5). In western FSM, a 1-in-20-year event would become a 1-in-8-year event under very low emissions (RCP2.6) and a 1- in-4-year event under very high emissions (RCP8.5; Australian Bureau of Meteorology and CSIRO, 2014).



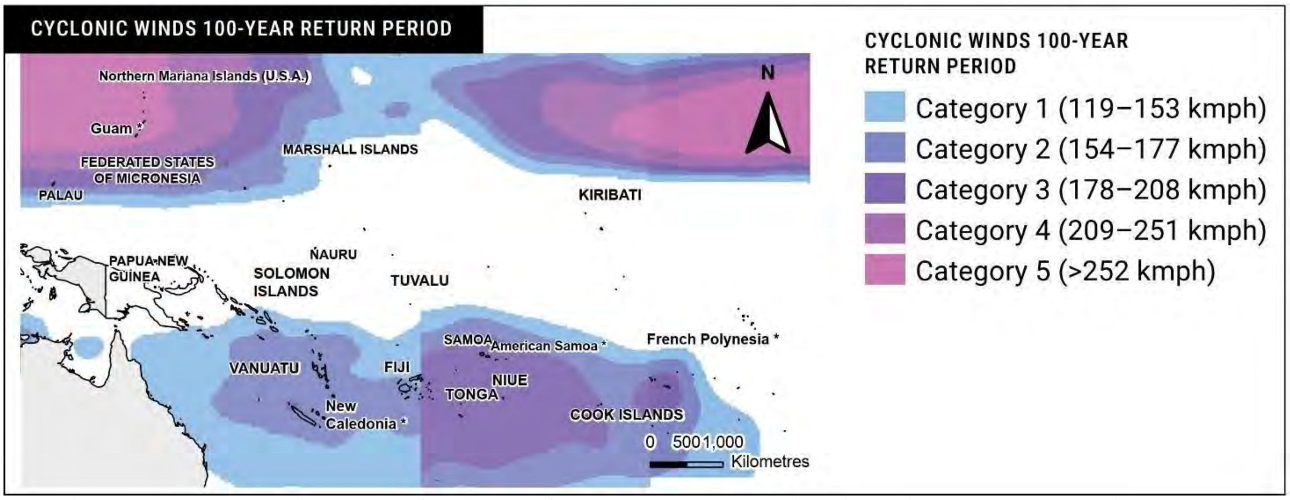
Maximum 5-day cumulative precipitation amount projected to return in a 10-year period in Pacific, RCP 8.5, 2040–2059. (Data source: Sources: Climate Change Knowledge Portal, 2018 and UN Geospatial; Figure source: ESCAP, 2022a)

Drought (changes in proportion of time in drought) frequency and duration are expected to decrease under all scenarios for eastern and western FSM. Under RCP8.5 the frequency of drought in all categories is projected to decrease slightly while the duration of events is projected to stay approximately the same. Under RCP2.6 (very low emissions) the frequency of severe drought is projected to decrease slightly while the frequency of drought in all other categories is projected to remain the same. The duration of events in all drought categories is projected to stay approximately the same under RCP2.6.



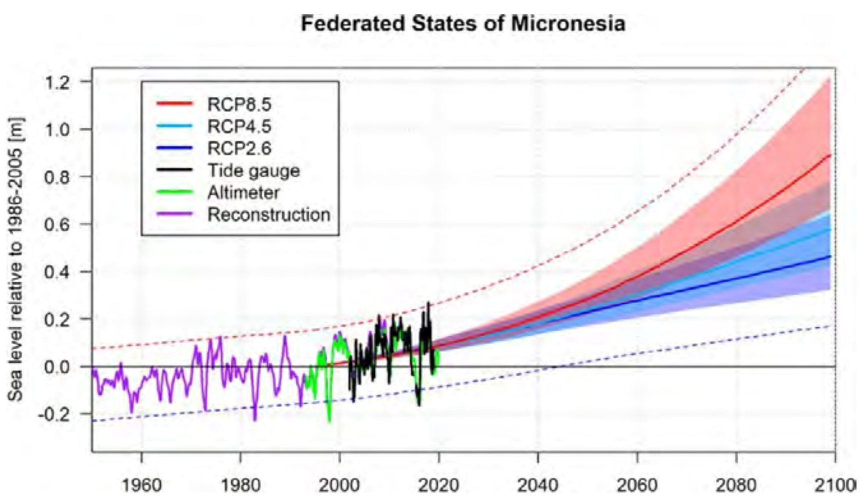
Percent of time in moderate, severe or extreme drought (left hand side), and average drought duration and frequency for the different categories of drought (mild, moderate, severe and extreme) for the eastern (top) and western (bottom) Federated States of Micronesia. These are shown for 20-year periods centered on 1995, 2030, 2050, 2070 and 2090 for the RCP8.5 (very high emissions) scenario. The thick dark lines show the median of all models, the box shows the interquartile (25–75%) range, the dashed lines show 1.5 times the interquartile range and circles show outlier results (Source of figure and figure legend: Australian Bureau of Meteorology and CSIRO, 2014).

Tropical cyclones: Every increment of a degree between 1.5°C and 2°C translates into increased risks of tropical cyclones, particularly in the Pacific. Although TCs are projected to be less frequent their intensity will increase, and annual wind speeds of tropical cyclones will increase as well under the extremely high emissions RCP8.5 (ESCAP, 2022b).



Projected increase in Tropical Cyclones for the Pacific. TC categories are based on the Sar-Simpson scale. (Data sources: ESCAP based on Global Assessment Report on Disaster Risk Reduction (GAR) Risk Atlas, 2015, IPCC WGI Interactive Atlas - Coupled Model Intercomparison Project Phase 6 (CIMP6), 2021, and UN Geospatial; Figure source: ESCAP, 2022b)

Rise in sea level is projected to be in the range of 8 – 18 cm by 2030, under a very high carbon dioxide emissions scenario (RCP8.5). Sea level rise, will cause shoreline to retreat along sandy coasts (IPCC, 2021), accentuating the impact of storm surges and coastal flooding on aquifers and coastal areas.

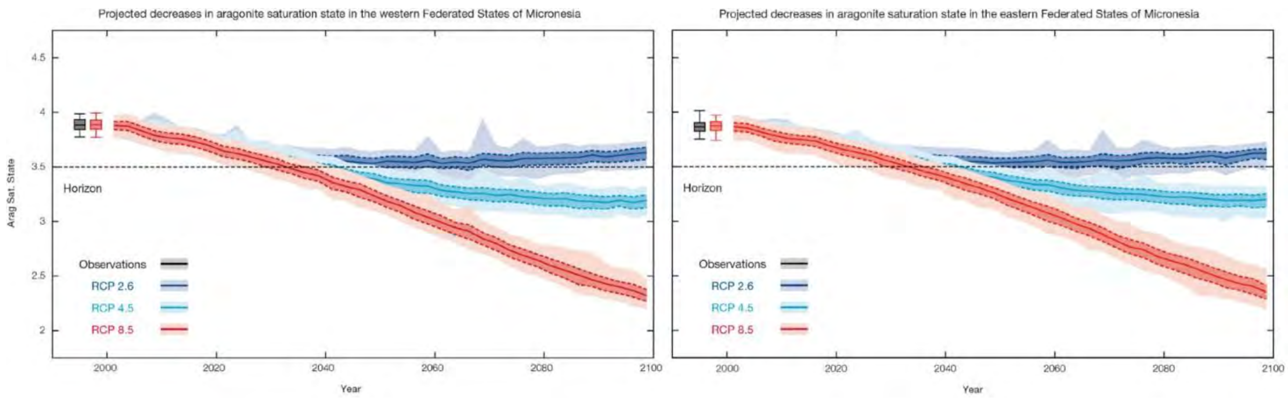


Sea level rise projections for the Federated States of Micronesia. The tide gauge record of relative sea level at Pohnpei is indicated in black, the satellite record in green and reconstructed sea level data is shown in purple, all are monthly means without seasonal cycles and referenced to mean sea level between 1986-2005. Multi-model-mean projections from 1995–2100 are given for the RCP8.5 (red solid line), RCP4.5 (cyan solid line) and RCP2.6 emissions scenarios (blue solid line), with the 5–95% uncertainty range for RCP8.5 and RCP2.6 shown by the red and blue shaded regions respectively. The dashed lines are an estimate of interannual variability in sea level (5–95% uncertainty range) and indicate that individual monthly averages of sea level can be above or below longer-term averages. (Source of figure and figure legend: CSIRO and SPREP, 2021)

Sea Surface Temperature (SST) is projected to increase and will increase further with 1.5°C of global warming (*high confidence*) and with a larger increase at 2°C and higher (IPCC, 2021). This is very likely to cause bleaching and death of corals. Warming temperatures and ocean acidification are expected to have an adverse effect on coral reefs, threatening FSM food security.

Ocean acidification is projected to increase, with consistent decline in aragonite saturation which will reach values below 3.5 by 2030 in the FSM and it is projected to continue declining thereafter.

Based on the IPCC Sixth Assessment Report (2021), ocean acidification will increase further with 1.5°C of global warming and with larger increase at 2°C and higher (*high confidence*).



Projected decreases in aragonite saturation state in western (upper) and eastern (lower) Federated States of Micronesia from CMIP5 under RCPs 2.6, 4.5 and 8.5. Shown on these plots are the median values, the interquartile range (the dashed line), and 5% and 95% percentiles. (Source of figure and figure legend: Australian Bureau of Meteorology and CSIRO, 2014).

A summary of projections for RCP2.6 (very low emission scenarios) and RCP 8.5 (very high emission scenario) are presented[12] for the Eastern (Pohnpei and Kosrae States) and Western (Chuuk and Yap States) FSM, including impacts on population, key sectors and ecosystems.

Summary of Climate Projections

- El Niño and La Niña events will continue to occur in the future, but there is little consensus on whether these events will change in intensity or frequency.
- Tropical cyclones (TCs) are projected to be less frequent but more intense.
- Annual mean temperatures and extremely high daily temperatures will continue to rise.
- There is a range in model projections in mean rainfall, average rainfall is projected to increase, with more extreme rain events.
- The proportion of time in drought is projected to decrease slightly.
- Sea levels will continue to rise under both very low and very high emissions.
- Ocean acidification and ocean warming are expected to continue, overall increasing the risk of coral bleaching.
- Wave height is projected to decrease across the western FSM in the dry season and storm waves height are projected to decrease in December–March. For the eastern FSM, a small decrease in wave height, with no change in period or direction is expected in the dry season and an increase in the height of storm waves is suggested in June.

Data Source: FSM Third National Contribution to the UNFCCC 2023

[12] Projections suggest that climate in the FSM will continue to change in diverse way; however, lack of high-resolution climate projections, as well as the representation and understanding of interannual and decadal variability and their interplay with trends, suggest that some of the changes may be less predictable.

Summary of the projected changes in the Eastern (E) and Western (W) FSM under the low (L) and high (H) emission scenario (RCP2.6 and RCP8.5). Source: Australian Bureau of Meteorology and CSIRO (2014), CSIRO and SPREP (2021) & SOE, 2019.

Climate variable	**Expected change**		**Projected change 2030**	**Projected change 2050**	**Projected change 2070**	**Confidence level**	**IMPACTS**
Surface air (°C/°F)	Annual air temperatures continue to rise.	L	+0.7°C	+0.8°C	+0.8°C		Impacts to human health and health systems related to heat stress if working outside or outdoor recreation. Increased need for cooling systems and energy required for cooling. Air temperature also impacts agriculture and water resources
		H	+0.7°C	+1.4°C	+2.2°C		
Annual total (% change)	Average rainfall is increase over the FSM.	L	2% (W) 3% (E)	3% (W) 4% (E)	2% (W) 6% (E)		Increases in rainfall intensity will lead to increasing flooding, damage to crops, and increases in run-off/pollutants into coastal waters. It is likely to increase vector-borne diseases (e.g. dengue). Impacts will be felt from periods of drought affecting human health, water supply and agriculture.
		H	2% (W) 3% (E)	5% (W) 6% (E)	7% (W) 8% (E)		
Mean Sea level (in/cm)	Mean sea level is projected to increase.	L	~5.1 in |13 cm|	~9.0 in |22 cm|	~12.6 in |32 cm|	High	Sea level rise exacerbates flooding from high tides and storms: likely increase in loss of lives, damage and loss of coastal homes, lands, and infrastructure, contaminated drinking water, and destruction of crops. Increased coastal erosion can result from higher sea levels especially when combined with large waves. Salinity intrusion can damage coastal aquifers and agricultural land.
		H	~5.5 in |14 cm|	~11.0 in |28 cm|	~19.0 in |48 cm|		
Sea Surface temperature (SST)	Sea Surface temperature is projected to increase.	L	~0.6°C	~1–2°C	~2–3°C	High	Coral bleaching is expected to increase. When sea temperatures increase 1–2°C above the normal maximum for > 4–6 week, coral bleaching is likely to occur. Coral bleaching is likely to adversely affect reef-dependent species and
		H	~0.8°C	~1–2°C	~2–4°C		

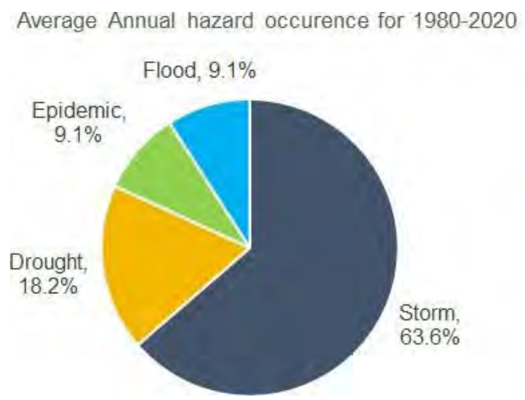
							reduce services reefs provide (tourism; coastal protection; food and livelihoods; habitat; medicine).
Ocean acidification (maximum aragonite saturation state, Ωar)	Ocean acidification will continue to increase		NA	NA	NA	High	Ocean acidification (OA) affects many marine organisms that rely on calcium carbonate to build their shells/skeleton (e.g. corals, clams, mussels). OA can result in decreased growth and reproduction and weaker and more brittle skeletons, prone to increased damage from storms. Coral reefs are critical because they provide habitats for fish, support food and livelihoods, income from tourism, medicines, and coastal protection to islands.
		H	~3.5 Ωar	< 3.0 Ωar	< 3.0 Ωar		
Storm Patterns	Typhoons are projected to be fewer but of higher intensity.		↓ 20–50%	↓ 20–50%	↓ 20–50%	Low	More severe cyclones when they do occur and combined with sea level rise will result in increased flooding and potentially coastal change resulting in damage and loss of lives, coastal homes, land, and infrastructure.

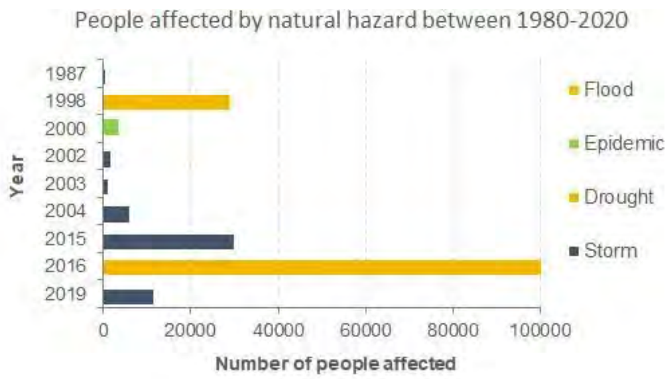
FSM's Food System Vulnerability due to Increased Natural Disasters

The FSM experiences natural disasters regularly. Between 1980-2020, tropical storms top the list of disaster events for the FSM (63%) that directly impact local food production. Droughts have also significantly affected people over the same period (18.2%). In total, tropical storms have affected about 54,000 persons and led to a cumulative sum of US$ 17.5 million (World Bank, 2021). For example, Typhoon Mitag in 2002 caused 1 fatality, devastated food crops, destroyed buildings and caused important economic losses in the FSM. In 2002, Typhoon Chata'an struck Chuuk State with intense rain, causing floods as well as 265 landslides, with 62 major landslides that killed 43 and injured over 100 on six islands (SPC, 2017). Landslides triggered by rainfall events are recurrent in some of the FSM high islands, posing a significant threat to lives, sources of revenue and road networks. However, there is limited data since their occurrence and impacts are difficult to quantify. Recurring losses from climatic disaster events represent an ongoing erosion of development and subsistence assets, which has also a severe impact on the economic growth of the nation and pose a considerable strain on FSM's communities' livelihood and resilience. The FSM is at risk of losing more than 10% of its GDP annually due to climate- related disasters (ESCAP, 2020). The Global Climate Risk Index (CRI) ranks FSM as the third most at risk country amongst the

Pacific Island countries (PICs), considering the long-term CRI (1998–2017).[13]

Since the Second National Communication, disaster events directly affected more than 30,000 people in the FSM. Some of these events prompted a declaration of a state of disaster by the Government.





Natural disasters affecting the FSM population between 1980 and 2020. (Source of data: World Bank Climate Change Knowledge Portal.)

Tropical storms and Typhoons in the FSM

In recent years, the FSM was hit by two damaging typhoons, Maysak and Wutip that devastated local farmers. Typhoon Maysak reached the islands of the FSM in March 2015 causing four fatalities, damaging houses, crops, and public infrastructure, and causing millions of dollars in damage. A Disaster Declaration was issued. Typhoon Maysak was one of the most powerful pre-April tropical typhoons in the North-western Pacific Ocean with nearly one third of FSM's population affected (USAID, 2015). Devastating impacts on island agriculture systems were also recorded, with 90% of the banana, breadfruit, and taro crops destroyed in Chuuk and Yap states. According to the United States Agency for International Development (USAID), more than 29,000 people were directly affected by typhoon Maysak (USAID, 2015), and reconstruction costs to repair and replace homes and public infrastructure damaged or destroyed in the states of Chuuk and Yap, amounted to $42 million USD.

In February 2019, Typhoon Wutip passed over the states of Pohnpei, Chuuk and Yap. Chuuk and Yap's outlying islands were particularly affected. A Disaster Declaration was issued with a request for international assistance to respond to the typhoon related damage. In the immediate aftermath, the most affected islands faced water and food shortage due to the severe damage caused to food crops and water sources from strong winds (75–80 mph and gusts of up to 100 mph) and saltwater intrusion. A joint damage assessment (JDA) carried out by the FSM government with USAID, OFDA and FEMA detected damage to infrastructures, crops and houses, affecting approximately 11,575 persons across 30 islands (IOM, 2019).

The damage from more severe typhoons is increasing FSM's reliance on aids from the global community for immediate response and reconstruction to reduce food and water insecurity, and in the long-term is likely to have an impact on the nation's economy (IMF, 2019). Climate projections indicate that an increase in the intensity of these events is likely to occur and therefore future losses from tropical cyclones compared to the current climate will also increase .

[13] https://www.germanwatch.org/en/16046

Recent known damaging TC events affecting the FSM.

Damage Legend	Minor:	Moderate:	Major:
TYPHOONS			
Typhoons	Affected areas	Level of damage	Damage description
Bopha (Nov 2013)	Chuuk: Kutu, Lukunor, Ta		Properties and livelihoods were damaged with loss of crops, but not major damages were reported
	Yap main		Impacts were felt but were minor
Hayan (Nov 2013)	Yap: Ngulu		The island was inundated by 0.50m of salt water and sustained damages to crops and properties
	Yap main		Some fruit bearing trees were destructed
Hagupit (Dec 2014)	Yap: Ngulu, Eauripik, Woleai, Ifalik		Crops, infrastructures, communication and properties were damaged from wind and inundations
Maysak (Mar 2015)	Chuuk lagoon Yap: Ulithi		Damage to crops and infrastructures, contamination of water, 5 fatalities, around 7,000 people homeless in Chuuk and Yap state. About 29,705 people affected
Dolphin (May 2015)	Pohnpei		Tropical Storm Dolphin passed Northeast of Pohnpei with winds at approximately 80mph causing an Emergency Declaration issued after damage to electrical, roads, uprooting of trees and crops and damaging more than 246 homes, 1 fatality was recorded
Wutip (2019)	Pohnpei main Sapwafik and Nukuoro		Landslides in Pohnpei main island caused 1 fatality and severe damage to houses in Sokhes, Nett, U and Kitti municipalities, destroying 11 houses on a total of 53 houses being damaged. Damage to crops was also recorded
Wutip (2019)	Chuuk: Lukunor Mortlocks Region and Northwest Region Houk, Pollowat, Chuuk Lagoon		Severe to moderate impacts to crops while water supplies were somehow affected but showed signs of recovery. Infrastructures and houses in the Mortlocks Region and Northwest Region were severely damaged, with a total of 140 houses destroyed out of 694 houses affected. Public infrastructures were also affected. State of emergency was declared

Floods impacting FSM's local food production

In the FSM, floods are associated with typhoons, tropical storms, large wind driven swells and extreme tides that can destroy and inundate coastal food crops and freshwater aquifers. The occurrence of these events varies across the country, but coastal flooding from large swell and seasonal high tide events are frequent. Since 2000, FSM has been experiencing periodic rise of sea level in the outlying islands and low-lying coastal areas of high islands (Australian Bureau of Meteorology and CSIRO, 2014). These events are known by the residents as King Tides. In 2007, and again in 2008, many FSM communities were flooded by a combination of large swell and seasonal high tides, which produced higher than normal sea levels. The result of these events was widespread damage on numerous islands, particularly low-lying atoll islands, which eroded beaches, damaged roads, intruded aquifers and wetlands, and destroyed nearly half of the nation's cropland (FSM SNC, 2015; Fletcher and Richmond, 2010). These occurrences are frequent, the most recent was recorded in December 2021, with multiple FSM's states experiencing coastal flooding from a combination of King tides, La Niña elevated sea levels, and strong northerly winds. There have been reports of substantial damage to infrastructures, food crops, and freshwater resources. A state of Emergency was declared, and preliminary assessments estimated damages to agriculture and infrastructures for US $3.4 million only for the State of Chuuk.

Rising ocean waters are increasing the frequency of flooding events, exacerbating coastal erosion and affecting FSM's coastal communities and critical assets, among which are causeways, roads and jetties. These events adversely affect immediate and long-term food and water security, increasingly posing a threat on residents' health, well-being, and socioeconomic security. Also, in the long-term, damage to much of the infrastructure and property located along all parts of the coastal areas will be increasingly more frequent.

Droughts impacting FSM's local food production

Droughts are a recurrent climate feature in the FSM, the intensity and frequency of which is dependent on the intensity and frequency of the ENSO phase. The droughts associated with El Niño years 1982-1983, and 1997- 1998 were especially severe, increasing localized threats to biodiversity and water resources. In January 2024, the Pohnpei State Governor's office issued an Emergency Declaration as a result of an inadequate water supply for the main island of Pohnpei and the outer island communities due to very dry conditions from the effect of El Niño. In these years, agriculture systems were damaged, water resources were adversely impacted, and problems associated with wildfires and invasive species were greatly aggravated.

For example, a strong El Niño that evolved in 2015, continued to impact global weather and temperatures at the beginning of 2016. In 2016, much-below-normal precipitation, causing intense drought, was observed across the FSM, associated with the expected evolution of El Niño (Marra et al., 2017). As a consequence of such intense drought, 2,677 households were affected across the country (IAC, 2019) and the government of FSM promulgated a nationwide Emergency Drought Declaration. Insufficient rainfall caused water and food shortages, with direct impacts on population health and everyday life, due to the closure of schools, water rationing in Yap, Chuuk and Pohnpei, and health

problems associated with the limited access to clean water and malnutrition. Potable water became scarce, particularly in the outlying atoll islands where emergency water supplies had to be delivered by boat (SPC, 2018). Climate projections indicate that the frequency of severe drought will decrease slightly, but the duration of events will remain approximately the same under very high GHG emission. Droughts are slow-onset hazards, spatially extensive that can persist for more than a year with wide-spread consequences for water, food, energy, economic, health and ecosystems. In the FSM, droughts are felt in all sectors, with a general increase in the costs of accessing and delivering water and crop supplies. Drought can also alter rates of carbon, nutrient, and water cycling, further impacting agricultural production and critical ecosystem functions that underpin agricultural systems, and the livelihoods and health of local communities.

Recent known most damaging drought events affecting the FSM.

DROUGHTS			
Drought	Affected areas	Extent of damage	Damage description

1997-1998 El Niño	Yap	●	Water supplies were severely compromised on Yap main and outlying islands. A major drought disaster declaration was promulgated in 1998
	Chuuk	●	Severe impact on water supply system, crops and food security
2007 El Niño	FSM nationwide drought. emergency	●	A nationwide Emergency Drought Declaration was signed in 2007
2016 El Niño	Yap	●	A nationwide Emergency Drought Declaration was signed in 2016. Damage was estimated to be $11.4million. More than 40 wildfires was reported
	Chuuk & Pohnpei	●	
2024 El Niño	Pohnpei	●	Statewide emergency declaration[14]

Summary of vulnerabilities and risks of known damaging climate events affecting the FSM.

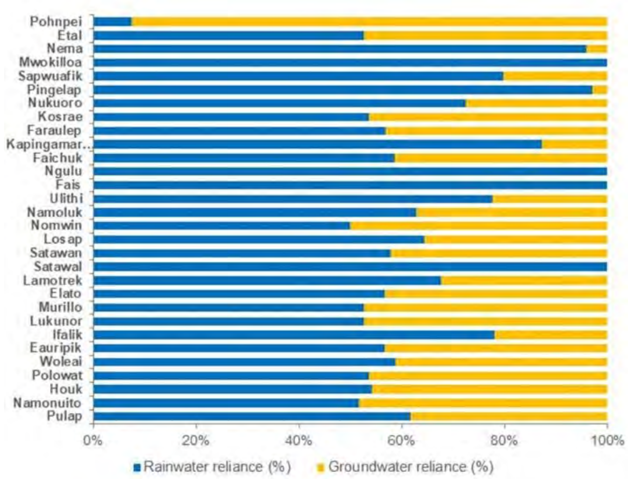
Hazard	Vulnerability and risk	Threat	Impacts	Average annual losses
Tropical cyclone	- Damaging winds, rain and storm surge. - Significant damage at the coast, but the whole islands can be severely affected. - Widespread flooding, landslides and damage to infrastructures, buildings, agriculture and livestock and loss of lives.	- Typhoons are projected to be less frequent but more intense.	- Impacts to infrastructures (roads, seaports, airports), buildings, loss of life. - Indirect impacts such as the disruption of essential services across various sectors of the economy and the interruption of supplies.	- By end-of-century average annual losses are projected to increase from 8.0 million USD to 8.4 million USD, an increase of 4.8% - By the end of the century larger increases in losses are projected for more extreme events (> 50-year return period). - Losses from 1-in-50-year tropical cyclones could increase by as much as 59% in the worst-case climate change scenario[195].
Floods, including coastal and fluvial floods	- Much of the population and infrastructures are located on the coastline and highly vulnerable to coastal floods. - Flash flooding is likely to occur during typhoons, tropical storms and extreme rainfall events. - Flooding in high islands has caused landslides and fatalities	- More extreme rainfall events are projected to increase in intensity and frequency. - Sea level is projected to rise and coastal flooding will become more acute.	- Impacts to infrastructures, buildings, loss of life. - Impact on fresh water resources of outlying islets - Impact on agriculture production. - Indirect impacts such as the disruption of essential services across various sectors of the economy.	- Important cumulative losses, especially on roads and other transport infrastructure and on residential buildings. - A recent coastal flood event (2021) has caused losses greater than US $3 million, and this only for the State of Chuuk.
Drought	- Population, fresh water and agriculture assets in the outlying island atolls in the FSM are particularly vulnerable to droughts. - Severe drought events have an impact on the FSM energy sector (i.e., hydropower in Pohnpei) and essential education services.	- Droughts pose a high level of risk to FSM population and subsistence assets. - The frequency of severe drought will decrease slightly, but the duration of events will remain approximately the same	- Impact on fresh water resources, particularly for outlying islets - Impact on agriculture production. - Indirect impact on services delivery (energy, education) and water supply.	- Severe droughts have important cumulative losses, especially in terms of subsistence agriculture, access and delivery of fresh water and energy and health (waterborne diseases). - Estimates indicate that average annual loss from drought is 4.6% of the nation's GDP and this is likely to increase by the end of the century.[196]

[14] https://pohnpeistate.gov.fm/2024/01/15/emergency-declaration-2024-01-declaring-a-state-of-emergency-relative-to-inadequate-water-supply-for-pohnpei/

Climate Change Threat to FSM's Freshwater

In the FSM, access to safe drinking water varies considerably between and within the four FSM's states due to geologic and geographic settings, socio-economic status, technology, government capacity, village-scale governance, and knowledge base. Households in remote areas are less likely to have constant access to safe drinking water and this condition is exacerbated for poorer households. Water vulnerability is very high particularly in outlying islands and rural remote areas, but migration to high islands and the largely unplanned urban growth is increasing pressure on high islands water resources, affecting water security in urban areas (SPC, 2020).

Public water supplies are limited to high islands and in many cases water systems are underdeveloped and with limited coverage, leaving out part of the population. In Chuuk, public water supplies are available only on the island of Weno with about 8% of households obtaining drinking water from the public water supply systems, which are provided by the Chuuk Public Utility Corporation (ADB, 2020). In Pohnpei, the Pohnpei Utilities Corporation water system covers about two-thirds of the island, providing water to 61% of the island's residents (Deloitte, 2018). Therefore, a significant part of the population in the FSM still relies on rainwater tanks as the source of drinking water, as well as wells (groundwater), streams and springs. This is particularly the case for outlying islands where households have access to individual or community rainwater harvest systems for drinking water, while groundwater from the islets water lens is generally unsuitable for drinking, due to poor water quality and/or salination from saltwater intrusion. However, it also applies to high islands; for instance, in 2015 in the State of Kosrae more than 62% of the households accessed drinking water from rainwater tanks (Bell, 2015).



Site Name	Water vulnerability
Pulap	Extreme
Namonuito	Extreme
Houk	Extreme
Polowat	Extreme
Woleai	Extreme
Eauripik	Extreme
Ifalik	Extreme
Lukunor	High
Murillo	High
Elato	High
Lamotrek	High
Satawal	High
Satawan	High
Losap	Moderate
Nomwin	Moderate
Namoluk	Moderate
Ulithi	Moderate
Fais	Moderate
Ngulu	Moderate
Faichuk	Moderate
Kapingamarar	Moderate
Faraulep	Moderate
Kosrae	Low
Nukuoro	Low
Pingelap	Low
Sapwuafik	Low
Mwokilloa	Low
Nema	Low
Etal	Low
Pakin	Low
Pohnpei	Low
Oroluk	Low

Percentage of households that utilize rainwater and groundwater as a water source for any of their water needs, either for potable or secondary water needs, and water vulnerability at selected sites (Source: SPC Atoll Water Inventory, 2020).

Along with an increased population and modern lifestyles, demand for water continues to increase while its supplies are threatened. Water security depends on several factors, specifically the

---

Pacific Community. Atoll Water Inventory: Background and Methodology. https://storymaps.arcgis.com/stories/9f34ad66403140a5b394fe26b1ebf696 availability of rainwater, the reliability of the network of rainwater catchment systems, and the availability of fresh groundwater as a source to use during periods of low rainfall.

Climate change projections show that in the FSM temperatures will continue to rise, as will the sea level, sea temperatures and ocean acidification. Extreme temperatures will likely be more frequent, as well as changes in precipitation patterns, prolonged inter-annual sea level inundations, and tropical cyclone frequency and intensity are expected to exacerbate coastal erosion, increasing the risk of flooding events which affect freshwater availability across the country. The establishment and maintenance of water infrastructures that are resilient to climate change and natural disaster are crucial for FSM adaptation. Relocation of most vulnerable water service infrastructure has been indicated as adaptation solution to future climate change impacts for the state of Kosrae (Ramsay, 2013).

The long-term average air temperature over the FSM is projected to rise 1-2°C by 2050, potentially intensifying impacts from ENSO events with adverse effects on water resources across the country. In the years of drought events, FSM's low-lying atolls were particularly affected since their fragile freshwater resource base can be quickly depleted when there is a lack of rainfall becoming more vulnerable to saltwater intrusion. FSM's low- lying atolls communities depend on safe drinking water supplies for their survival and well-being and the only source of fresh water to recharge natural systems—freshwater lenses—and man-made rainwater catchments come from rainfall.

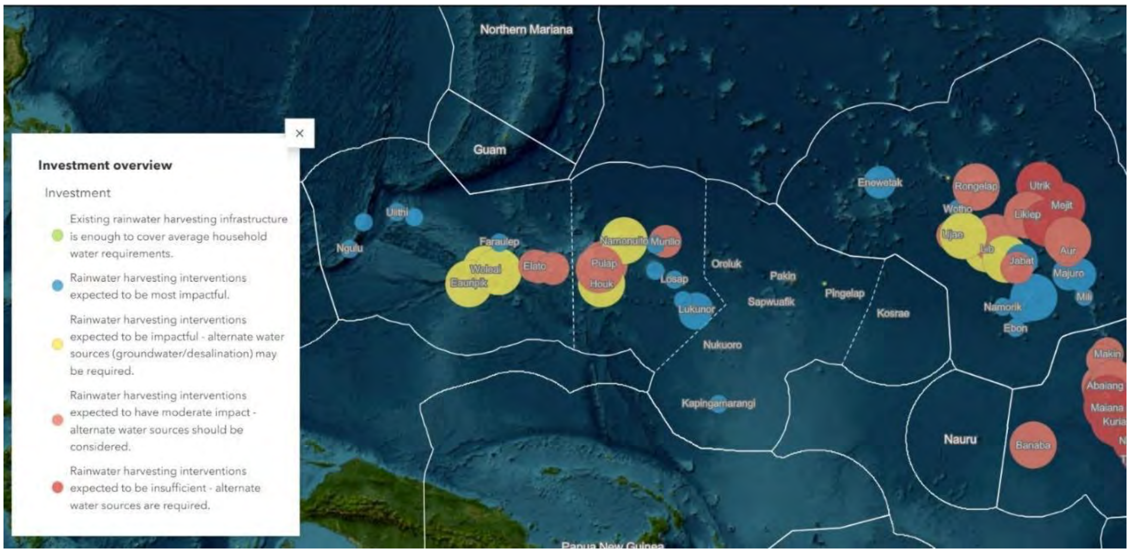
During the 2016-ENSO event, drought conditions were reported throughout the FSM impacting both water quality and quantity. Potable water was shipped to many of the outer islands of Yap and Pohnpei States, and water rationing was started in some areas of Yap Proper, Chuuk and Pohnpei. In Kapingamarangi, one of the outlying remote islands of Pohnpei state, drinking water supply was depleted and water supplies had to be delivered by ship from Pohnpei (SPC, 2018). In such instances, communities across the FSM used a variety of coping mechanisms to deal with decreased drinking water availability such as reverting to the use of wells water, where possible, but also utilizing coconut water as supplement to the rainwater. FSM's states response was varied, for example in Yap a State El Niño Mitigation Plan was prepared to guide the emergency response to water scarcity.

Typhoons and tropical storms magnify the impacts of droughts, since damage to infrastructures, rainwater catchment systems and crops (i.e., coconuts) further reduces the opportunity to access safe drinking water. Drought has an important social dimension since it can affect genders differently. For instance, productivity of women may be adversely affected by time taken away from productive activities such as paid employment, since women may have to spend more time fetching water for their family. Similarly, children and youth education can be adversely affected since water rationing may require schools to be closed. This was the case, in 2016, in Pohnpei State, where schools were closed for several months, impacting access to education.

In the FSM's coastal areas, freshwater contamination from saltwater intrusion is frequent following typhoons, sea swells, anomalous tides, storm surges, and coastal flooding events are exacerbated by the loss of coastal ecosystems and coastal erosion. Following Typhoon Wutip (2019) an Initial Damage Assessment (IDA) indicated damaged areas in Pohnpei, Chuuk and Yap states due to storm surges, strong winds and saltwater inundation. Groundwater resources of 11 outlying islands across Chuuk and Pohnpei were severely impacted, although they were rapidly recovering due to heavy rainfall events in the region. At the time of the IDA, water lenses of 4 out of the 11 islets were still slowly recovering (USAID and FEMA, 2019).

Vulnerabilities of the water sectors are varied and dependent by the age and design of the infrastructures and low climate-proofing standards. For instance, sewage systems in low-lying areas are subject to significant submersion during flooding events increasing the probability of runoff intrusion into the water treatment plants and the likelihood of polluting the environment. Poor watershed management and intense runoff causing soil erosion are likely to decrease the quality of water sources, compromising its treatability and increasing the costs for water treatment facilities. Increasing the resilience of island water systems will require upgrading, repairing and in some context relocating water infrastructures, while considering climate-related construction standards in designing and developing these infrastructures. Increasing water capacity of outlying islands will also be crucial to increase their adaptive capacity. Under the FSM Infrastructure Development Plan (IDP) for 2004- 2023 water development and management was considered as a top priority for the nation and this priority was reflected in the States IDP. States water management plans (WMP) would be an important strategy to address the issues of saltwater intrusion and protect freshwater aquifers. Examples of WMP exist at local level; for instance, the Adaptation Fund[16] a project implemented by the FSM government is working with the communities of the inhabited atoll islets of Nukuoro and Kapingamarangi to develop water management plans to enhance their water security.

Most impactful water intervention requires investments in the most vulnerable locations, particularly for increasing rainwater harvesting capacity and enhancing alternative water sources (e.g., from groundwater and/or desalination). The type of intervention is determined by the remoteness, geography and geology of the islands. Given the FSM's strong focus on water security, several projects have been and are being implemented by the government of the FSM in collaboration with communities and state governments to increase their water adaptive capacity.



Water security interventions to reduce water vulnerability in the FSM (Source: SPC Atoll Water Inventory. https://storymaps.arcgis.com/stories/9f34ad66403140a5b394fe26b1ebf696).

Agriculture and Agroforestry in the FSM

Agriculture plays an important role in the FSM as a source of food for communities and livelihood. In the FSM agriculture is central to ensuring food security and it is a risk-coping strategy that provides resilience to economic shocks and disasters, with traditional subsistence practices serving as social safety nets, while preserving traditional culture and knowledge (Patagan, 2022).

16 https://www.adaptation-fund.org/project/enhancing-climate-change-resilience-vulnerable-island-communities-federated-states-micronesia/

Throughout the FSM, traditional agriculture systems are based on biotic diversity and the practice of polyculture (e.g., such as agroforestry) rather than larger-scale monoculture. This historic approach has sustainably supported subsistence livelihoods, community obligations, and food security over generations while also preserving the soil and forests. Properly managed, these home garden/agroforestry systems can be highly productive while also contributing important environmental services such as soil stabilization, carbon sequestration, clean water and air.

Agroforestry is practiced in all four FSM states and fertile volcanic islands such as Pohnpei main island has extremely nutrient-rich soil that has the potential to successfully grow a wide array of crops that are currently only being imported into the country. Pohnpei's traditional agroforestry is commonly practiced, integrating economically important trees with annual or perennial crops to create a sustainable farming system. Such a practice preserves and can improve soil fertility, protect crops from extreme weather, and create new markets for timber and non-timber forest products. Traditional agroforestry can also contribute to the conservation of FSM's endemic forests and biodiversity.

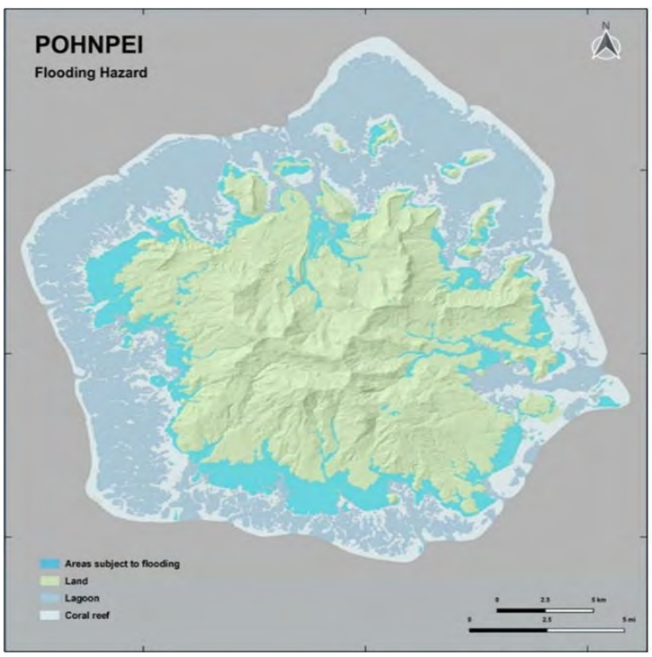
The FSM government considers agriculture including agroforestry as a key priority for the nation's long-term economic development; the sector is one of the three prioritized areas for development under the FSM's National Strategic Development Plan 2003-2023. This contributed to the adoption of the FSM Agriculture Policy 2012-2016 which recognizes the crucial role played by agriculture for livelihood and food security, and the importance of a community-based and culturally sensitive approach to propel the development of this sector. About 77% of the FSM population live in rural areas and are engaged in either pure or mixed subsistence production for their livelihoods. This sector consists largely of subsistence activities based on localized, small-scale production in family farms and home gardens (FSM Agricultural Policy 2012–2016). Local foods are primarily composed of traditional crops (i.e., taro, breadfruit, yam, banana, etc.), which generally have greater nutritional and health qualities compared to imported convenience starch foods, such as rice and flour-based products. The informal sector plays an important and often unacknowledged role in the economy, with 92% of agricultural workers being unpaid. Since 2005 the agriculture sector had an upward trend of 1.2% per year, indicating that subsistence production in the FSM has increased, whereas commercial agriculture remains underdeveloped (IAC, 2019).

A vulnerability assessment conducted by the FAO and summarized in the GCF proposal for the project "*Climate resilient food security for farming households across the Federated States of Micronesia (FSM)*", reports the levels of vulnerability for agriculture in the four FSM States and indicates that all States have high sensitivity, medium adaptive capacity, and high vulnerability for this sector (MCT, 2021).

Most of the FSM outlying island atolls lie within the 2-meter zone of potential sea level rise, and all lie within a 5-meter zone of storm surge, further increasing the vulnerability of agricultural systems to the impacts of natural variability and climate change for the most remote communities in the FSM. Coastal flooding impacts have been reported as a key factor limiting agriculture productivity for 5-15% of FSM households (IAC, 2019). Extreme weather events (typhoons, storms, drought, flooding) have already affected people's food security and livelihoods by damaging staple crops and terrestrial and marine ecosystems (MCT, 2021). Climate hazards are projected to severely threaten FSM communities' food security—primarily because of crop loss, degraded arable land, price/supply shocks, and forced migration of outlying communities. There is a strong correlation between the extreme climate vulnerability of FSM and the livelihoods of communities, as a large share of the population heavily relies on natural resources. Household vulnerability to poverty and hunger is most often associated with threats to livelihoods and would increase over time with repeated shocks that erode productive assets.

Agriculture productive lands are increasingly subject to flooding as well as seawater inundation and intrusion from sea level rise. Low-lying atolls are especially vulnerable to inundation events and even losing arable land from projected sea level rise and extreme tide events. Due to rising sea level the risk of saltwater intrusion from the outlying islands water table is of concern for staple crops like taro (Henry and Jeffery, 2008). The SNC already reported on past inundations that induced a decline of taro production in outlying islands (SNC, 2015) and these events are projected to increase by 2030 (MCT, 2021). However, flooding hazard from sea level rise on high islands is still of concern since most of the agricultural areas are located around the coastal zone and are already enduring increased flooding and drainage problems. In the near future, climate impacts to food systems are likely to generate a rapid increase of communities that migrate or relocate from the low-lying islands to the high islands, increasing the need for enhanced food systems on high islands. However, in some of the states, the existence of a strong communal support system that includes the rights and obligations tied to food production and exchange can mitigate hunger and malnutrition associated with localized impacts of sea level rise in vulnerable coastal villages (Perkins and Krause, 2018).

Projections of increased sea level rise, under all climate scenarios, and an increase in extreme high tide events due to climate change, indicate that FSM's agricultural sector vulnerability to climate change will increase in the future. Currently about 97% of high tides are less than 2 meters, but by 2030 and 2050, due to sea level rise, dangerous high tide events are expected to exceed the 2-meter threshold 12% and 27% of the time respectively, substantially increasing the risks for saltwater inundation and/or intrusion from storm surges, extreme high tides and swells, threatening crop productivity on FSM atolls and lowland areas of high islands, where most of the fertile soil is located,[17] thus increasing the risk for food security and loss of agricultural production.



Sea Level Rise and Flood Hazard Maps for Pohnpei and Yap (Map source: MCT, 2021).

The projected sea level rises for the main island of Pohnpei indicate that there will be coastal changes due to sea level rise by 2055 as well as saltwater inundation of low-lying areas. The main island of Chuuk and the other islands located in Chuuk Lagoon are also projected to experience coastal changes due

[17] 210 Federated States of Micronesia State-Wide Assessment and Resource Strategy 2010 – 2015 +. https://www.stateforesters.org/wp- content/uploads/2018/08/FSM-FAP.pdf

to sea level rise by 2055 along with saltwater inundation, which will affect several agroforest and urban cultivated areas along the coastline. The main island of Kosrae is projected to experience sea level inundation of low-lying areas up through 2090 (Biza, 2013).

In Yap main island 68% of areas suitable for traditional taro production are located in the watershed at 5 m elevation or under. These areas are prone to saltwater intrusion reducing taro productivity and yield. The projected sea level rise for Yap main islands indicates that there will be inundation of large parts of existing coastline and low-lying areas, with severe consequences for the already impacted agroforest activities. Traditionally, in Yap main island, women tend to taro patches, with 62% of women engaged in the production of this important staple crop. In all the states, women play an important role in managing home gardens, which are generally close to the coastal areas and therefore prone to saltwater inundation. The loss of these agricultural systems would have a direct impact on the loss of the FSM's traditional knowledge for food production, also impacting the role that women play in their households and communities, further increasing their vulnerability to climate change impacts. Therefore, an assessment on saltwater intrusion in taro patches was conducted for the main island of Yap. The Taro Patch Salinity Project evaluated traditional practices in watershed management and made recommendations through a series of resource maps for a comprehensive watershed–based approach to food security and adaptation that integrated traditional food production knowledge with modern geospatial science and technology (Ruegorong et al, 2016; Perkins and Krause, 2018).

Vulnerability of Yap taro patches to saltwater intrusion. (Map Credit: US Forest Service, Yap Institute of Natural Resources, Yap Division of Agriculture & Forestry, and Queens University; Link to the map: https://storymaps.arcgis.com/stories/762ed9cd19bc4ae7a96b77974500d29e).

Although projections for El Niño–La Niña events are still uncertain, droughts will likely still occur in the future adding further pressure to agricultural systems already stressed by the impacts of extreme events and sea level rise. The Second National Communication (2016) reported that intense droughts during ENSO years caused, especially in the more water deficient outer atolls, severe food shortages (including staples such as taro, breadfruit, banana, yam, and sweet potato), impacted terrestrial habitats, triggered wildfires, and increased the distribution and incidence of pests and diseases that affect crops and livestock. For instance, in Pohnpei, an Emergency Declaration was issued in 2016 due to severe drought damaging crops and water on Pohnpei main island and the outer islands estimated to be $11.4million. More than 40 wildfires were reported (SPC, 2016). The FSM Integrated Agriculture Census (IAC, 2019) indicated that 2- 47% of households in the FSM already report issues with drought as a key negative driver for agriculture productivity. Specifically, the severe drought event triggered by El Niño in 2016 had impacts on food security for 45% of households in Yap and 21% of households Chuuk (IAC, 2019). Droughts can also alter rates of carbon, nutrient, and water cycling—all of which can impact agricultural production, critical ecosystem functions that underpin agricultural systems, and the livelihoods and health of FSM communities. Under high emission scenario, projected increases in temperature of 1.5 and 2°C are likely to pose a significant physiological stress to many agroforest staple crops cultivated in the FSM (i.e., taro, yam, breadfruit, etc.; Taylor et al, 2016). Specialty crops such as vegetables, kava, betelnut and medicinal herbs, are more vulnerable to increased temperatures and droughts and have a higher value per unit of land/water increasing the risk for economic loss in drought (Taylor et al, 2016).

Most staple food crops and horticultural products are highly vulnerable to extreme weather events, accounting for many of the losses that occur in the Pacific. For instance, Typhoon Maysak destroyed 90% of crops, including staple foods in both Chuuk and Yap affected areas, requiring temporary food assistance to be provided to about 29,000 people in FSM. The FSM government assisted communities in the outer islands providing support and material to reestablish agroforest systems where these were lost or partially damaged (i.e., seeds, seedlings, hand tools). Intensifying rainfall and storm events from climate change also exacerbate the risk of landslides in high islands, where some of the agriculture activities are now encroaching into the steep mountainous slopes, increasing deforestation, and reducing the health of the watersheds. In 2018, Tropical Depression Jelawat passed over the FSM, bringing heavy rainfall to Pohnpei that resulted in flooding, landslides and damage to agriculture. An agriculture damage assessment conducted in Pohnpei identified the needs for agricultural damage rehabilitation assistance in landslide and flood-affected areas. Again, in 2019, Typhoon Wutip caused landslides that impacted agricultural fields in Pohnpei, Chuuk and Yap, requiring further rehabilitation assistance (USAID, 2019). Previous reports on extensive crop damage and loss, due to extreme weather- induced landslides include Tropical Storm Chata'an in 2002 and Typhoon Sudal in 2004. Furthermore, the projected increases in mean annual rainfall are likely to have a significant damaging effect on crop production in locations where rainfall is already high to very high (MCT, 2021).

The projected extreme weather events including storm surges and King Tides, and the resulting salinization of fertile soil, are most likely to have the greatest impact in the short- to medium-term timescale (2030–2050; compared with changes in mean temperature where significant impacts are not expected before 2050 (Bell and Taylor, 2015; Taylor et al, 2016). Nevertheless, extreme warming could alter the distribution of native plants and animals in forest ecosystems and increase the threat of invasive species (Taylor et al, 2016).

Impacts of climate change on the production of agricultural products (Source: Bell and Taylor, 2015)

Crop or livestock	Short term (2030)	Medium term (2050)	Long term (2090)
Staple food crops			
Taro	Low to moderate	Moderate to high	High
Swamp taro	Moderate to high	High	High
Giant taro	Insignificant to low	Low	Low
Breadfruit	Insignificant to low	Low to moderate	Low to moderate
Banana	Low	Low to moderate	Low to moderate
Wild yams	Insignificant to low	Low	Low
Domesticated yams	Moderate to high	High	High
Cassava	Insignificant to low	Low to moderate	Low to moderate
Sweet potato	Moderate	Moderate	Moderate to high
Export commodities			
Coconut	Low	Low to moderate	Low to moderate

High-value horticulture crops			
Papaya	Low to moderate	Moderate to high	High
Mango	Low to moderate	Moderate	Moderate to high
Citrus	Insignificant to low	Low	Low
Pineapple	Insignificant	Low to moderate	Low to moderate
Watermelon	Low to moderate	Low to moderate	Moderate
Tomato	Moderate	Moderate to high	Moderate to high
Kava	Low	Moderate	Moderate
Betel nut	Insignificant to low	Low	Low
Livestock			
Pigs	Low	Moderate	Moderate
Poultry	Moderate	High	High

Subsistence farming in the FSM is crucial to maintain population dietary requirements, combat the rampant increase in Non-Communicable Diseases (NCDs) and reduce the economic burden that increased costs of imported food can have on households. Reduced food security, from climate change threats, will have a wide impact on FSM's population. Loss of arable land, declining crop yields, spread of pests affect food security and FSM population health, potentially decreasing local nutritious food intakes and promoting dietary changes with further upsurge in the incidence of NCDs in the country.

The Impact of Climate Change on FSM's Fisheries

Climate change is expected to produce drastic changes in the marine environment via warming sea waters, ocean acidification, sea current variability and reduced nutrient availability. The impacts will be felt by marine organisms, affecting the supply of coastal fish to local communities. Coastal fisheries in the FSM support protein intake and livelihood for high and low-lying islands communities. A large number of households engage in subsistence fishing and in many communities both men and women contribute to these fishing activities.

In recent decades, coral reefs and fish populations have been damaged due to unsustainable fishing practices and natural disasters. For instance, coral reefs in Chuuk State have been negatively impacted by extreme climatic events such as Typhoon Maysak and the invasive Crown-of-Thorns starfish that by preying on live coral can destroy entire areas of reefs, is of increasing concern in all states. Increased sea surface temperatures in 2016, caused corals to bleach across the country and in some areas bleaching-associated mortality was observed (Eakin et al., 2016).

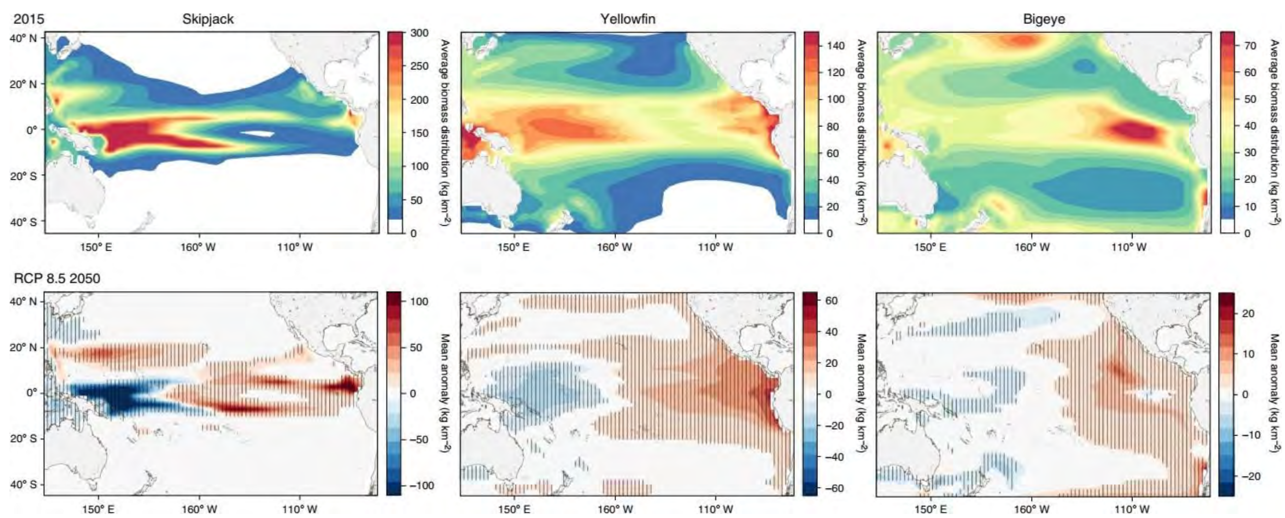
The 6th IPCC report (2022) indicates that projected climate change, combined with non-climatic drivers, will cause loss and degradation of much of the world's coral reefs, severely affecting coastal fisheries. Under warming of 1.5 °C coral reef degradation is catastrophic with projected loss of 70-90% of coral reefs globally. Under 2°C, ocean acidification will impact reefs, fisheries and biodiversity with severe implications for island communities, economies and cultures.

For the FSM, climate change projections indicate that under the very high GHG emission scenario (RCP8.5) sea surface temperatures will increase by approximately 1-2°C by 2050, resulting in degradation of coral reefs, which reduces their ability to support fish. Aragonite saturation will reach the threshold that inhibits the development of many marine organisms that produce calcium carbonate shells and skeletons. Both warming oceans and ocean acidification affect the fitness of fish species, including their reproduction and growth (Oue, 2018). The occurrence of less frequent, but more intense typhoons will have direct impacts on coral reef and mangrove ecosystems, which hold juveniles of many local fish and marine organisms. Heavy rainfall will cause greater sediment and nutrient runoff further damaging coral reefs and seagrass habitats. The projected sea level rise will adversely impact mangroves and seagrass growth, which are nursery areas for many coastal fish species. Under a high GHG emissions scenario in the Pacific mangroves are expected to decrease by 50-70% by 2050 and seagrass habitats by 5–35% by 2050 (Bell et al., 2018). These changes will cause coastal fisheries production to decline by 20–35% by the end of the century (Bell et al., 2016). Fishing communities in the outlying islands and remote areas, as well as elderly and children in low-income households, will be the most vulnerable to these changes that will likely increase the risk of malnutrition.

In the case of the economically vital tuna fishery, climate change is forecast to change migration patterns, potentially affecting FSM economy that relies heavily on income from foreign fishing licensing fees. The distribution and abundance of tuna species is influenced by natural climate variability through the influence of climate drivers like El Niño–Southern Oscillation (ENSO), which affects the survival of tuna larvae. Warmer waters in the Western Pacific are likely to shift the spawning grounds for tropical tuna (skipjack, yellowfin and big eye) to the central and eastern equatorial regions of the Pacific, which for the FSM could potentially lead to decreases in tuna biomass within its Exclusive Economic Zone, reducing the economic benefits the nation derives from tuna fishing (Bell et al, 2016).

In the FSM, the average annual tuna-fishing access fees, for the period 2015−2018, contributed 47.6% to the government revenue. Bell et al. (2021), estimated that under the extremely high GHG emission scenario (RCP8.5) in the FSM purse-seine tuna catch will decline by 13% by 2050, corresponding to 5.9% decline of government revenue from tuna fishing access fees.

FSM's Biodiversity and Natural Environment



Effects of climate change (RCP8.5) on the average biomass distributions of the three tuna species (skipjack, yellowfin, bigeye) caught by purse-seine fishing in the Pacific Ocean. (Image source: Bell et al., 2021).

In the FSM, biodiversity goes beyond the provisioning of materials for human welfare and livelihoods, it is interwoven into daily life, and is an intrinsic part of the diverse traditional cultures and practices that remain strong across the FSM (FSM R&D, 2020). Marine and terrestrial food production depends on biodiversity for the genetic diversity of marine organisms, crops, nutrient recycling and disease control and prevention. Therefore, in order to increase the FSM's adaptive capacity to climate change, it is of paramount importance to protect, conserve and sustainably use the nation's biodiversity and ecosystems. The FSM has a rich and unique genetic, species and ecosystem biodiversity, that harbors a considerable variety of endemic plants and animals, which if lost, will be extinct. Island biodiversity is extremely fragile as species are generally limited to a small geographical area, with low population numbers and already under pressure from human-induced threats such as pollution, habitat fragmentation and land-use changes.

The rate at which climatic changes are occurring is beyond the adaptive threshold of many island plants and organisms, making them highly vulnerable to climate change. Threats to species and ecosystems, particularly in biodiversity hotspots like the FSM, will increase with increasing warming, escalating the risk of local extinction. FSM's ecosystems are highly vulnerable to climate change and are expected to be at high risk in the near term at 1.2˚C global warming levels due to mass plants mortality, coral bleaching and mass mortality events from marine heatwaves (IPCC, 2022).

Climate change can have adverse effects on species, environmental networks, and ecosystems by impacting the basic physiological functions of plants and organisms (Kumar et al., 2020), as well as by altering the provision of ecosystem services for the communities living on high and low-lying islands (Franco and Sawdey, 2017). For instance, plants are vulnerable to mean and extreme air temperature increases, droughts and heavy rainfall, which can modify the time of fruiting, decrease plant fitness, and increase their exposure to diseases and pests. Drought can alter the ecological balance of natural systems and harm wildlife and plant species, as well as the services that ecosystems provide to human communities. In the marine environment, the unbalance of physiological functions from projected increase of sea surface temperatures and ocean acidification combined with non-climatic drivers (i.e., overfishing, destructive fishing practices), will cause loss and degradation of much of the world's coral reefs (IPCC, 2022). The 6th IPCC report (2022) indicates that under warming of 2˚C virtually all coral reefs in the region may be lost (98% loss) with severe implications for biodiversity and island communities, economies and cultures. Ocean acidification will impact the rate at which many marine organisms construct their skeletons, resulting in a slower recovery of reefs damaged by bleaching or other agents (Kumar et al., 2020). Furthermore, increases in the intensity of storms and cyclones concurrently cause further damage to coral reefs reducing their structural complexity.

The degradation of ecosystems such as mangroves, coral reefs, estuaries, seagrasses, and wetlands due to climate change can adversely affect dependent species and reduce ecosystem services provision of food, fresh water, medicinal resources, flood and storm protection, erosion regulation, pest control, micro-climate regulation (Brander et al., 2021). Climate-driven impacts on terrestrial and marine ecosystems have caused economic losses and projected changes in climate will have serious implications to the livelihoods and well-being of FSM's population, potentially altering cultural practices. A study conducted by Brander et al. (2021) indicates that in the FSM, projected climate change–induced loss of coral reef ecosystem will potentially cause a reduction in annual income from harvested resources of almost USD$ 8.8 million per year, which may increase migration of those communities that are most dependent on natural resources for subsistence and income.

Healthy ecosystems will be better able to respond and cope with changing conditions; therefore, their sustainable use and protection, through the provision of conservation areas, is an essential route to building the nation's resilience to climate change. For example, healthy watershed forest ecosystems are vital for protection against potential landslides caused by increasingly intense precipitation and extreme events under changing climatic conditions (FSM R&D, 2020). Communities across the FSM have always used protective strategies such as locally managed areas and seasonal closures, to ensure their continued security. As they face new challenges and a world imperiled by climate change, the FSM's Protected Areas Network (PAN[18]) is seen as a key component in promoting communities to scale up traditional approaches and

[18] In the FSM the Protected Areas Network is implemented through state law or regulations guided by the FSM's Protected Areas Network National Guiding Policy Framework

protect traditional knowledge in support of the nation's biodiversity and ecosystems. Furthermore, innovative forms of biodiversity protection in the FSM are the Yela Forest conservation easement and the implementation of fire breakers to safeguard watershed biodiversity in Tamil (Yap). In Kosrae the Yela Forest valley includes the last standing forest of *Terminalia carolinensis* in the world; to protect this hotspot of biodiversity the USDA Forest Service's through the Forest Legacy program launched the first conservation easement in the FSM. Maintaining healthy and functioning forest systems increases their resilience to climate change. Native forests and mangroves can require at least 10- 15 years to fully recover from natural and climatic shocks and provide the same level of ecosystem services they did prior to a catastrophic event, provided that no additional pressures from human development and polluting activities occur.

FSM Food System Vulnerability to Extreme Weather

The most severe challenge to the food system in FSM is the increase in frequency and impact of extreme weather events which reduce the amount of arable land suitable for farming as well as reduce crop yields. FSM's islands are particularly vulnerable because the anticipated sea level rise will threaten fertile coastal plains as saltwater intrudes into previously fertile land. These climate change impacts will make it increasingly difficult for FSM to produce enough food to meet its populations' needs.

Close to 100% of the nearly 35 inhabited outer islands in FSM lie within the 2-meter zone of potential sea level rise and within a 5- meter zone of storm surge. Due to saltwater inundation, many of these outer island communities have had to abandon their taro patches, a key food security crop (Keim, 2010, FSM, 2015). It is anticipated that the high volcanic islands of the FSM will need to prepare for population increase in the form of climate change refugees from low-lying islands, while at the same time, enhancing and adapting their own food production systems. Aside from direct crop damage from inundation and erosion, increasing soil salinity is the greatest threat to crop productivity on the atolls of the FSM. Saltwater intrusion from coastal erosion, sea level rise, and extreme events are critical risks for food security and agricultural production. The 2016 Integrated Agriculture Census highlighted that at least 60% of households with land for agriculture have experienced some loss from weather, diseases, pests, or other reasons for any crop with weather damage reported as resulting in ten percent (6, 903 acres) or more land parcels with crop losses.

Chuuk State
Photo Credit: FSM R&D

Crop Forecasting for 5 Staple Crops in the Federated States of Micronesia

As the Federated States of Micronesia is experiencing rapid climate change, the ability to use science to forecast future staple crop yields is critical for the nation's sustainable food system development and food security strategies.

Climate models are one of the primary tools that scientists use to project how a region's climate will change. The Coupled Model Intercomparison Project (CMIP) is a collaborative modeling framework designed to improve climate change projections. Coupled models are computer-based models of the earth's climate, in which different types of environmental data (such as atmosphere, oceans, land, ice) are coupled together to create more holistic ecosystem-based simulations.

The previous generation Coupled Model Intercomparison Project phase 5 (CMIP5) general circulation models and the representative concentration pathway (RCP) emission scenarios informed the Pacific islands crop forecasting analysis conducted by Belle and Taylor et al. (2016).

As of the writing of this report, the latest climate models are from the CMIP6 effort and utilize narrative emissions scenarios in the form of shared socioeconomic pathways (SSPs) that offer additional socioeconomic and political drivers of how emissions may evolve over the 21^{st} century (Eyring et al., 2016). The conventional wisdom is that these updated models do not necessarily show dramatically different projections compared to the CMIP5 suite of climate models but represent an advancement in computation methodology and are better at simulating synoptic processes (Adeyeri, 2022).

Taylor et al. (2016) cite a range of RCP emission scenarios climate projections from CMIP5, which should be reevaluated to ensure the conclusions drawn for individual crops are in accordance with the updated CMIP6 modeling framework. Following the framework of CMIP5, Taylor and others presented a suite of warming scenarios: RCP2.6, RCP4.5, RCP6.0, and RCP 8.5 which are associated with low to very high warming respectively (Table 1). In recent years, the trajectory presented by RCP8.5 is no longer considered a very likely scenario (e.g., Hausfather and Peters, 2020). Therefore, it is recommended that this range be updated to correspond with the new SSP projections and differences considered where appropriate.

All data used in this analysis come from the Intergovernmental Panel on Climate change (IPCC) Working Group 1 Interactive Atlas (Iturbide et al., 2021; Gutiérrez et al., 2021; Interactive-atlas.ipcc.ch).



Temperature

Table 1 Reproduced from Taylor et al. (2016).

Table 2.4: Projected tropical Pacific air temperature change, from 1986–2005, for three time slices and four RCPs. The 5th-95th percentiles of the range of projections are rounded to nearest 0.5°C.

RCP	2030	2050	2090
RCP2.6	0.5–1.0°C	0.5–1.0°C	0.5–1.0°C
RCP4.5	0.5–1.0°C	0.5–1.5°C	1.0–2.0°C
RCP6.0	0.5–1.0°C	0.5–1.5°C	1.5–3.0°C
RCP8.5	0.5–1.0°C	1.0–2.0°C	2.0–4.0°C

Table 2. SSP warming in °C for the Northwest Tropical Pacific relative to the mean of 1986-2005. Note SSP5-8.5 is provided but as with RCP8.5, could be considered very unlikely. Median values are presented with the 5th–95th percentile in parentheses.

SSP	2030	2050	2090
SSP1-2.6	0.8 (0.5–1.0)	1.0 (0.6–1.4)	1.0 (0.6–1.4)
SSP2-4.5	0.8 (0.5–1.1)	1.2 (0.9–1.6)	1.8 (1.2–2.3)
SSP3-7.0	0.7 (0.4–1.1)	1.3 (1.0–1.8)	2.6 (2.0–3.5)
SSP5-8.5	1.3 (1.0–1.7)	2.0 (1.6–2.6)	3.8 (2.9–4.8)

In comparison with Taylor et al. (2016) Table 2.4 (Table 2), the range of warming for analogous scenarios is broadly the same, with SSP1-2.6 and SSP2-4.5 showing a 0.4 and 0.3 °C higher upper range compared to the reported RCP2.6 and RCP 4.5 in Taylor et al. (2016). Similarly, the upper range of SSP5-8.5 is 0.6 – 0.8 °C warmer than the analogous RCP8.5 from the CMIP5 models. Note that Table 2 values were rounded to the nearest 0.5°C and otherwise broadly remain in line with the SSP projections for the low (SSP1-2.6) to high (SSP3-7.0) emissions scenarios. For a more likely high emissions scenario, SSP3-7.0 may be more appropriate for guidance compared to RCP8.5.

Rainfall

Taylor et al., (2016) reported total precipitation change relative to 1986–2005 as a percent change by 2090 for RCP4.5 and RCP8.5 by regional island locations (west and east FSM). This synopsis will just provide the percent changes from the CMIP6 models for the Northwestern Tropical Pacific as a whole for comparison.

Table 3. Comparison of CMIP6 and CMIP5 model simulations for analogous SSP and RCP emissions scenarios. Values are presented as a percent change in total seasonal precipitation from 1986–2005 mean

values by 2090. The median value is presented with the 5th through 95th percentile range presented in parentheses.

CMIP6			
SSP2-4.5 November-April	**SSP2-4.5 May-October**	**SSP5-8.5 November-April**	**SSP5-8.5 May-October**
2.1 (-10.0–13.1)	4.7 (-1.9–10.8)	3.5 (-10.6–21.2)	7.1 (-2.7–19.9)
CMIP5			
RCP4.5 November-April	**RCP4.5 May-October**	**RCP8.5 November-April**	**RCP8.5 May-October**
5.8 (-8.8-22.3)	4.8 (-2.8-11.0)	11.8 (-2.8-23.6)	12.1 (-2.8-18.9)

Table 3 presents a comparison between the summary percent change in total rainfall of the Northwestern Tropical Pacific for the CMIP5 RCP simulations and the CMIP6 SSP simulations that are very broadly analogous (i.e., producing the same radiative forcing by 2100). Note the CMIP5 modeled percent changes are generally 3-5% higher for the November to April season than presented in Taylor et al. (2016) specifically for the Federated States of Micronesia, as the results in Table 3 represent an average of a wider area. So, when considering specific impacts to Micronesia, it may be beneficial to consider a smaller change in that season. Regardless, while the SSP2-4.5 and RCP4.5 have a very similar percent change, all of the other seasons for RCP4.5 and RCP8.5 project a consistently higher change in total rainfall compared to the analogous SSPs. When considering changes to total seasonal precipitation for use in crop management practices, it may be that the impact of total rainfall may be a bit smaller than anticipated by Taylor et al. (2016). However, the 5th–95th percentiles are still close between the two modeling efforts.

Models of Climate Change Impacts on Staple Crops

A summary of projected effects of climate change on the production of selected staple crops in the Federated States of Micronesia are presented in Table 4 (modified from Bell and Taylor, 2015). This summary provides estimates on the impacts of climate change on the production of five major staple crops in the FSM over the short, medium and longer-term time periods (2030, 2050 and 2090).

Staple Food Crop	**Short term (2030)**	**Medium term (2050)**	**Long Term (2090)**
Bananas	Low	Low to moderate	Moderate to high*
Breadfruit	Low*	Low to moderate	Low to moderate
Coconut	Low	Low to moderate	Moderate*
Taro	Low to moderate	Moderate to high	High
Swamp Taro	Moderate to high	High	High
Giant Taro	Insignificant to low	Low	Low
Yam, Wild	Insignificant to low	Low-Moderate*	Moderate*
Yam, Domesticated	Moderate to high	High	High

Bell and Taylor (2015) first presented the above table in a more expanded version and in their estimates had considered a wider range of major agricultural products across all Pacific Island countries and territories. In this synopsis, after careful analysis of that work as that of Taylor et al. (2016) and the 2023 FSM family farming household baseline survey (Rutgers University, 2014), we present a modified version of their projected models of climate change impacts to five of the staple crops grown in the Federated States of Micronesia (See Table 4). Based upon evaluation for these individual crops relative to the updated CMIP6 modeling framework and noting that total rainfall may be less than that projected by Taylor et al (2016) upon which the Bell and Tayler (2015) table was built, we estimate slightly different staple crop impacts over the short, medium, and long term. As temperature rise along with increasing sea level rise continue, the rainfall extremes, coastal floodings, saltwater instruction, and short-term adverse storms and droughts coupled to the increased pressure of diseases and insects with a predicted increased production of these crops and with the continued pressure of invasive weed species (including vines), we estimate that some of the staple crops in the FSM are will be impacted slightly more than that estimated by Bell and Taylor (2015). The changes that deviate from their projection are highlighted in Table 4 and noted with an asterisk. In general, our minor projected crop changes moved some projected impacts to be one category more 'severe' (that is based upon the range of categories defined as insignificant, low, moderate, to high impact on the crops production due to climate change).

The climate change impacts on crops by Taylor et al. (2016) were comprehensive and inclusive of a larger geographical range of Pacific Islands, while our estimates reflect FSM only, and in part were also shaped by the > 600 family farmers across the FSM that reported crop losses for these illustrative five staple crops by climate change. Family farming households reported crop losses associated with a range of climate change indicators for each of the staple crops such as flooding, excessive rains, landslides, coastal erosion, riverbank erosion, extreme heat, cyclones/hurricanes, saltwater inundation, drought, pests and disease, invasive species, (Rutgers University, 2024, pages 171-175). Current climate models do not have sufficient data points that are site and crop specific within the FSM to enable higher resolution projection capacity relative to the impact of short-term flooding, strong winds and associated damage to crops and the environment, timing, and frequency of rainfall over the years relative to the impact on each crop. Taylor et al. (2016) included an extensive review of climate change impacts and plant growth and yields, listing specific pests and diseases concluding that such biotic stresses would have differential impact on specific crops and that the inclusion of improved germplasm would be beneficial. They also reported that in some areas some of these staple crops are projected to be subjected to salt intrusion with sea level rise that would lead to inundation or more frequent flooding, affecting some crop production, such as swamp taro, which could be lost and as such was listed as under 'high impact risk' due to climate change. Subsistent family farming households reported significant losses of each of these staple crops to climate change and given their responses to specific staple crops, we provide estimates that indicate a slightly greater negative impact on some of the staple crops from climate change even under the newer CMIP6 models that don't take into the earlier worse-case scenarios relative to temperature increases.

In comparing annual average temperature and seasonal precipitation changes, while the CMIP6 models provide an improvement in modeling, the results are broadly very similar, apart from the median total seasonal precipitation change. The 5^{th}–95^{th} percentiles are still similar between the modeling efforts. Given how close these projections are and that their use in Taylor et al. (2016) was used as general guidance for potential crop impacts based on the direction of climate variables (warming temperatures, more rainfall), **it is likely that the impacts guidance model presented by Taylor et al. (2016) remains consistent with modern model projections**. One note is that this assessment does not include changes in rainfall extremes, storms, or ENSO which were considered in the Taylor et al. (2016) guidance.

FSM's Economic Vulnerabilities

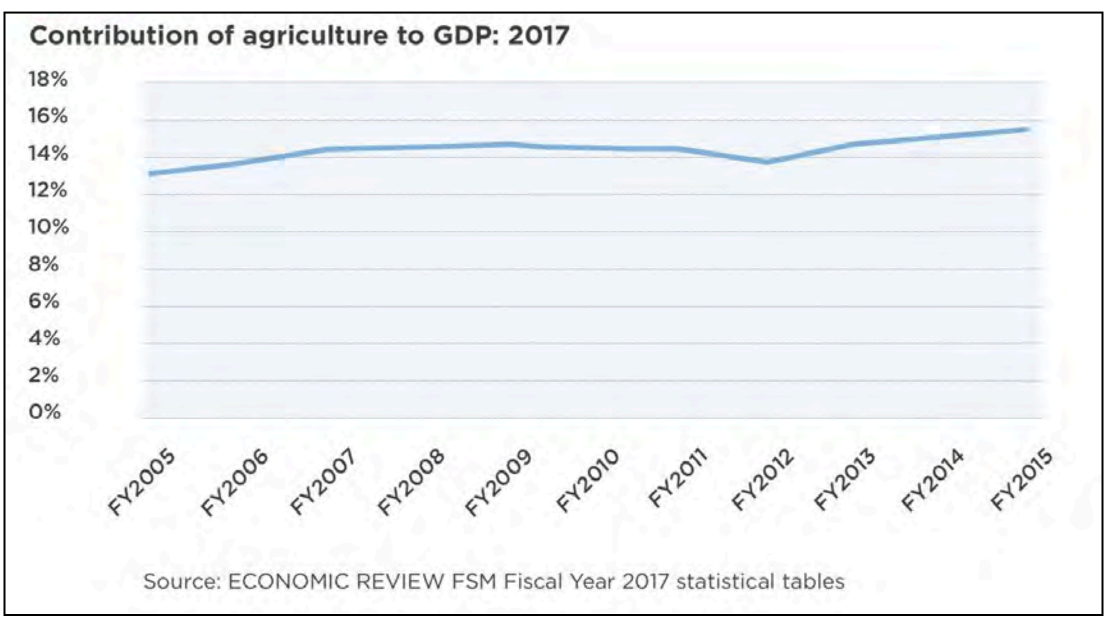
The 2013/14 HIES indicates 31.4 percent of the FSM population live below the national basic needs poverty line with a slight increase from 2005 to 2013. Poverty levels are not uniform in the states. The poverty incidence is higher or more severe in Pohnpei and Chuuk than in Yap and Kosrae. ANd while the majority of FSM residents practice some form of subsistence farming, agriculture only contributes to about 15% of the nation's GDP providing little reliable cash income.

The FSM is heavily dependent on external assistance, with budget grant income estimated to account for 43 percent of its gross domestic product (GDP), with a large share of that coming from the CoFA with the United States. As it stands, any significant interruption in the flow of this external assistance will greatly affect the economy, disproportionately so to those already facing hardship conditions.

Source: FSM HIES 2013/2014

State	% of households with no electricity	% of households with no improved sanitation	% of households with no improved water sources	% of households with poor quality housing	% of households with poor cooking fuel	% of households with few assets (radio, television, auto, phone, etc.)	% of households with no child attending school	% of households with no one working
National	17.4	27.1	13.9	22.7	33	25.1	1.6	2.5
Yap	18.5	42.4	1.9	26.4	41.5	30.2	1.4	3.9
Chuuk	38.1	29.0	27.9	24.8	41.1	46.6	4.4	1.6
Pohnpei	9.3	35.9	24.4	26.4	33.7	15.2	0.6	1.0
Kosrae	3.6	1.1	1.3	13.3	15.4	8.4	0.0	3.2

While annual incomes have risen by 18.85% for the period 2004-2018, inflation has eroded real wages, where there have been disposable income decreases for combined public and private sectors of the economy of 16.66%. Additional alternative income opportunities need to be supported. Although average



annual incomes have gone from $6,627 in 2004 to $8,485 in 2018, due to inflation over that timeframe, real wages (at FY2004 prices) have actually decreased from $6,627 to $4,961, a fact that shows that not only are earnings stagnant, they are regressing.FSM's minimum wage is US$2.65 per hour for employment with the national government. State government workers: $2.00 in Pohnpei,$1.25 in Chuuk,$1.42 in Kosrae, and $1.60 in Yap (FSM 2020 VNR).

Although the GDP per capita increased from $3,079 in 2007 to $3,393 in 2018 (FSM 2016, TNC 2023), the FSM has faced food security challenges during the COVID-19 pandemic era in the last few years. The economy of the State depends on the funding received from the national government of FSM which is still firmly dependent on US aid and Compact funding (TNC 2023).

Dependence on imported foods has had a negative impact on FSM's local production and the overall economy. The traditional importance of agriculture in the FSM is in competition with the rise and reliance of the FSM on imported foods (annual import of food in 2018 accounted for about US$ 56 million, excluding beverages - EconMap2019). This means that there is a higher cost to produce and purchase local foods, making competing with food imports harder. At the same time, the people of FSM are spending a larger percentage of their expenditures on food. The *FSM Second National Communication to the UNFCCC highlighted that imported food constitutes up to 43% of FSM households' diets*.

The 2023 Green Climate Fund Baseline Survey of Climate Resilience Among Farming Families in the FSM found that the food expenditure share, reflecting the percentage of a FSM household expenditures that goes to the purchase of food, is **71**% across the nation, *indicating* ***moderate food insecurity nationwide.***

Food Expenditure Share measures a households' economic vulnerability.

The higher the share of a household's consumption expenditures on food – out of the total consumption expenditure – the more vulnerable the households are to food insecurity.

Food Expenditure Share:

For FSM as a nation, 71% of household expenditure is on food out of total expenditure

	Category	Score	Yap	Pohnpei	Chuuk	Kosrae	FMS
			% Sample	% Sample	% Sample	% Sample	% Sample
1.	Food Secure	0-49%	7	45	17	17	11
2.	Marginally Food Secure	50% - 64%	17	11	25	15	17
3.	Moderately Food Insecure	65% - 74%	32	21	25	18	24
4.	Severely Food Insecure	75% - 100%	44	63	33	51	48

EconMAP (2019). Federated States of Micronesia Fiscal Year 2018 Statistical Appendices. Retrieved from: https://pubs.pitiviti.org/fsm-fy18- economic-statistics (Accessed January 2022).

FSM's Health Vulnerability from Food Related Diseases (NCDs)

FSM's many years of reliance on imported foods of poor nutritional value has resulted in malnutrition and significant diet related Non-Communicable Diseases (NCDs) including diabetes, high blood pressure, cardiovascular disease, anemia, vitamin A and iron deficiencies, low birth-weight and high infant mortality. Obesity and related chronic diseases can create large adverse impacts on individuals, families, communities, and the state as a whole, and the people of Pohnpei are especially vulnerable due to the limited healthcare infrastructure. NCDs are currently the leading causes of death for FSM citizens and mortality rates are projected to increase in the future.

The prevalence of obesity in FSM's adult population increased from 42.9% in 2012 to 45.9% in 2016 (FAO 2021). At present, almost half of all women and over one-third of all men in the FSM are classified as obese (WFP Regional Food Security Atlas of the Pacific) which has been associated with an increased risk for diet related chronic diseases, such as type 2 diabetes, hypertension, cardiovascular disease. These can result in increased absenteeism, and early mortality (FAO 2021), and lead to decreased economic opportunities, increased health care costs, and a stress on the economy that is unnecessary and preventable.

Non-Communicable Diseases (NCDs) remain a vast and pervasive issue for the FSM, accounting for more than 70% of deaths. According to estimates provided by the Institute of Health Metrics, the leading causes of premature death in FSM in 2010 were NCDs. The disease burden of NCDs has increased rapidly, with FSM witnessing almost epidemic rises in diabetes (81 per cent change since 1990) and chronic kidney disease (63 per cent change).

NCDs account for more than 80% of referrals for off-island medical treatment, adding a huge financial burden on the healthcare system in FSM (FSM MiCare data). Obesity and overweight appear to be a particular problem among the female population of FSM: 75 % of females are considered overweight compared with 64% of males; and 44 % of females are considered obese compared with 31% of males (FSM Voluntary National Review)

An unhealthy society is a society at risk. NCDs such as obesity, heart disease, diabetes, hypertension, cancer and chronic obstructive pulmonary disease (COPD) are the leading cause of mortality and morbidity, and more than half of the population is at high risk of developing them.

State	Diabetes	Hypertension
Yap	24.62%	15.20%
Chuuk	35.40%	15.20%
Pohnpei	33.29%	13.11%
Kosrae	43%	20%
FSM	34.07%	15.88%

Source: Moses Pretrick, FSM Environmental Health Coordinator, COVID-19 Briefing, May 2020

FSM's Food Security Goals

In the FSM, local agriculture and fishing skills and practices can serve as a means to develop all three pillars of sustainability: economic, environment and social.

As per 2020 Voluntary National Review, FSM's has prioritized six targets related to Food Insecurity and Sustainable Development Goal #2 that includes under nutrition in children, adolescent girls, pregnant and lactating women, the elderly, income of small scale producers, agricultural area in use, sustainable agriculture, genetic resources as well as official flows and development aid in the sector.

Target 2.1
End hunger and ensure access by all people, in particular the poor and vulnerable, to safe, nutritious and sufficient food all year round.

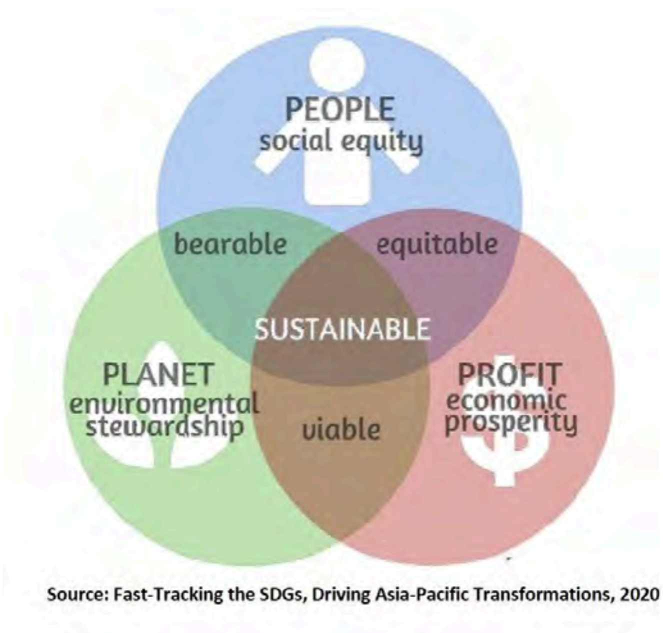
Target 2.2
End all forms of malnutrition, and address the nutritional needs of children under five, adolescent girls, pregnant and lactating women and older persons.

Target 2.3
Double the agriculture productivity and incomes of small-scale food producers, through secure and equal access to land, financial services, markets and opportunities for value addition and non- farm employment.

Target 2.4
Ensure sustainable food consumption with agricultural that increase production, maintain ecosystems, strengthen adaptation to climate change and improve soil quality.

Target 2.5
Maintain genetic diversity of seeds.

Target 2.6
Increase investment in rural infrastructure.



Assessing climate change impacts on FSM's food producers

FSM has been actively engaged in assessing the impact of climate change to FSM local food producers and the nation's overall food security with the goal of identifying and implementing adaptation measures and establishing food security policies designed to strengthen local food production. A key method to assess the vulnerability of FSM's local food system is to directly survey FSM's subsistence food producers most impacted by climate change.

Two important assessments of climate change's impact on local food producers were conducted in 2010 on 14 atoll islands in the States of Pohnpei, Chuuk and Yap and then again in 2023, focussing on the main islands of Pohnpei, Kosrae and Yap and all 16 islands within the Chuuk Lagoon.

2010 food security survey on 14 atoll islands

In 2010, the FSM Government conducted food security vulnerability and adaptation assessments on 14 atoll islands in the States of Pohnpei, Chuuk and Yap, as part of the preparations for completing the Second National Communication to the UNFCCC (2015).

That survey was the first comprehensive ecosystem approach to assess the likely impacts of climate change on food security for outer island atoll communities throughout FSM. Assessments were undertaken by seven working groups, covering the following thematic areas: Socio-economic Enumeration; Water Security and Coastline; Soils; Forest and Vegetation; Pests / Invasive Species; Marine Rapid Ecological Assessment; and Disaster and Risk Management.

Methods used to survey atoll communities in 2010. The islands covered in the assessment were: (a) Pohnpei Atolls: Nukuoro, Sapwuahfik; (b) Chuuk Atolls: Kuttu, Namoluk, Losap, Nomwin, Pisarach, Pollap; and (c) Yap Atolls: Satawal, Elato, Lamotrek, Gaferut, Falalop (Woleai), and Fadrai (Ulithi). The selection of islands was undertaken in consultation with the affected states, as well as the National Government Departments of Transportation Communications and Infrastructure, Resources and Development, and OEEM. The major criteria for selection were island attributes being: (i) representative of other islands as well as representing some unique characteristics; (ii) islands that can capture the various attributes that fill out the baseline data; (iii) islands that are considered most vulnerable; (iv) geographic location so that travel distances and time were minimized; and
(v) overall cost and duration of the study.

The vulnerability and adaptation assessment included the agroforestry and marine food stock that supports atolls' food security and resiliency. A specific objective was to determine disease impacting local crops such as taro, breadfruit and bananas, which are main food sources on atolls (Englberger et al., 2010). Vulnerability of food security was assessed using the four determinants of food security—food availability, food access, food utilization and stability (Halavatau, 2010). Results from the 2010 survey showed that with regard to food availability, most households on the atolls grew their own food. The main staple crops were used to assess vulnerability of domestic production to climate change.

The survey revealed that forests and planted trees helped local communities adapt to climate change through livelihood diversification and provision of ecosystem services. Sustainable management of forest and tree resources increases the resilience of people and ecosystems to cope with extreme weather patterns and therefore safeguarding food security.

Atoll staple crops were found to be vulnerable to climate change and especially the impacts of sea level rise in terms of increasing salinity (Halavatau, 2010). Important data was collected on local food staples, including heat, rain and saltwater tolerance of swamp taro, breadfruits, pandanus, and bananas.

Increasing soil salinity from saltwater intrusion was found to be the greatest threat to crop productivity on the atolls of FSM. Increasing soil salinity of atoll soils to 6ds/cm kills crops like cassava, pawpaw and yams. And when soil salinity is increased to 12ds/cm (a condition caused by sea water inundation), only coconut and the dryland giant taro can survive.

All atolls were found to be food secure from the point of view of food availability, but the dependency on imported processed foods (especially cereals) was high. Easy access to processed, imported food also adversely impacted community engagement in local agriculture and food production. The 2010 analyses showed that stability of food supply in the atolls is affected by shipping and by natural disasters such as cyclones and droughts.

With regard to household food access, a household can access food either by producing its own food or by procuring food. Indicators to measure household access include access to land, household food production and household incomes. At least 70% of households in the atolls own land, with sizes ranging from 0.2 acres to over 10 acres (0.1 to four hectares). A majority of the land is of average to good quality. Most of the households who own land produce their own food. Most households produce enough food crops and catch enough marine foods, but local meat production is not enough for all of the atolls.

Adaptation measures include addressing food production issues, as discussed under food availability. Each atoll should also develop income opportunities to improve the purchasing power of households.

With regard to food utilization, indicators such as dietary diversity, perception of food sufficiency and security, and number of meals per day can be used. However, the study used meal frequency. This revealed a risk of moving into reliance on imported foods. Atoll populations also face increased occurrence of NCDs in a substantial percentage of the households.

In 2010, the atolls families surveyed were understood to be vulnerable to climate change impacts on their food security in the following ways:

- Local food production was recognized as vulnerable to climate change due to:
  - Sea level rise
  - Poor soil
  - Pests
  - Disease
- Household food access was also vulnerable because of limited income
- Food consumption was vulnerable because of a dependence on imported foods

There is also a trend of NCDs on the atolls related to overeating and maybe changing dietary patterns to imported low quality foods.

Increasing food security was seen as a major priority for all four states especially with respect to climate change and sea level rise (FSM Department of Forestry, 2010). Most of the agricultural areas that were located around coastal areas were already enduring increased flooding and drainage problems (FSM Department of Forestry, 2010).

In 2010, it was expected that high islands of the FSM will need to begin now to prepare for rapid population increase in the form of climate change refugees from low-lying islands, while at the same time, enhancing and adapting their own food production systems.

Another challenge the rural areas faced was accessing arable or cultivable land to grow food. This was understood to be especially serious in the atoll communities with high population density. The other problem faced by atoll communities was the dynamic nature of the islands, leaving them vulnerable to sea level rise and other impacts of climate change. Evidence showed that most taro patches were already affected by saltwater inundation. There was little effort to address food processing of seasonal food crops like breadfruit, which is abundant and wasted during the fruiting season.

2023 Green Climate Fund Baseline Survey:

Climate Resilient Food Security for Subsistence Farmers in the FSM

In 2021, the Green Climate Fund (GCF) project titled "Climate-resilient food security for farming households across the Federated States of Micronesia (FSM)" was awarded to the FSM national government through the Micronesia Conservation Trust. This project is the first comprehensive national effort to focus on increasing the resilience of FSM's most vulnerable populations, especially subsistence farming families, with the goal of strengthening food security for all FSM communities impacted by climate change. Thus, this GCF initiative seeks to develop holistic, integrated and adaptive strategies intended to enhance food security, strengthen livelihoods, and increase the resilience of all FSM communities to future risks from a rapidly changing climate. Planned measures include introducing sustainable agricultural practices and developing a climate-resilient food system across all four FSM states.

Key objective of GCFSAP020 Baseline Survey

- To learn how climate change is impacting the local farmers and fishers and each of their local staple crops
- To learn the aspirations of FSM subsistence farmers and fishers for increased health and nutrition, increased food production, production for market sales and improved livelihoods
- To learn perceived challenges to achieving local farmers food production goals
- To learn the tools that farmers/fishers say they need to meet their goals

Supporting FSM States' Individual Food System Development Goals:

This GCF Baseline Survey of climate resiliency among FSM's farming households was prepared and implemented to assess the key food security risks associated with a changing climate in the FSM. This assessment will be used to develop Climate-Smart Agriculture (CSA) tailored to the specific needs of the diverse communities across each of FSM's four independent states. One of the primary aims of developing a CSA for the FSM communities will be to increase access to locally and sustainably grown nutritious food while building a supply chain that integrates with the local communities to make them *economically, socially, and environmentally more sustainable in a changing global climate*.

The Green Climate Fund project's targeted outcomes align with FSM's 2015 Second National Communication on climate change by supporting three key adaptation strategies specifically:

1) Conserving and promoting island and oceanic ecosystem services;

2) Preserving and promoting traditional culture;

3) Improving food and water security with a focus on domestic production that supports local economies.

The Second National Communication built on the National Climate Change Strategy (2009), which established national goals to develop and implement appropriate strategies to improve food production and new opportunities for communities and decision makers to access technical skills and knowledge to respond to climate change impacts.

Community Based Survey Methods: Giving Voice to Farming Families and Local Food Producers

The GCF Baseline survey tools designed by the Rutgers food system science team to provide valuable data that can be used for Climate-Smart Agriculture (CSA) development taking a systems approach to increasing access to locally and sustainably grown nutritious food while building a supply chain that helps communities become more economically, socially, and environmentally sustainable.

Working with local NGOs and local governments in each of the four states, local enumerators were trained to capture the authentic answers and concerns of FSM's farming families and local food producers.

Importantly, for purposes of this GCF baseline survey conducted with Micronesian communities **a farming family is defined** as *any* ***FSM household that produced/procured/harvested/ raised their own food by agriculture, agroforestry, fishing, aquaculture, poultry, or livestock.***

Definition of Farming Family:
For purposes of the Green Climate Fund baseline survey, a farming family is defined as any FSM household that produced/procured/harvested/raised their own food by **agriculture, agroforestry**, **fishing**, **aquaculture**, **poultry** and/or **livestock**.

The core **criteria for selection** of the communities from which farming families were interviewed was done in consultation with the state government, local NGOs and MCT to ensure:

(i) geospatial distribution across each of the states to ensure representation across each of the townships/districts;

(ii) inclusion of communities living in coastal areas;

(iii) inclusion of communities that had been impacted by prior environmental challenges / weather / storms;

(iv) inclusion of communities that participated in prior national surveys as a result of their vulnerability.

Data from this baseline survey of FSM's subsistence farmers is intended to support each state's plans for initiating and implementing sustainable food system development that is place-based, culturally and socially relevant and meaningful to the people of FSM.

Coconut Oil Farmer, Yap State
Photo Credit: Dena Seidel, Rutgers University

Thus, the GCF SAP020 project seeks to support local farmers and strengthen FSM's local food production in the face of climate change. Sustainable holistic food system development increases local jobs and income opportunities that benefit the nation's economy while reducing reliance on imported foods.

GCFSAP020 Baseline Survey Methodology

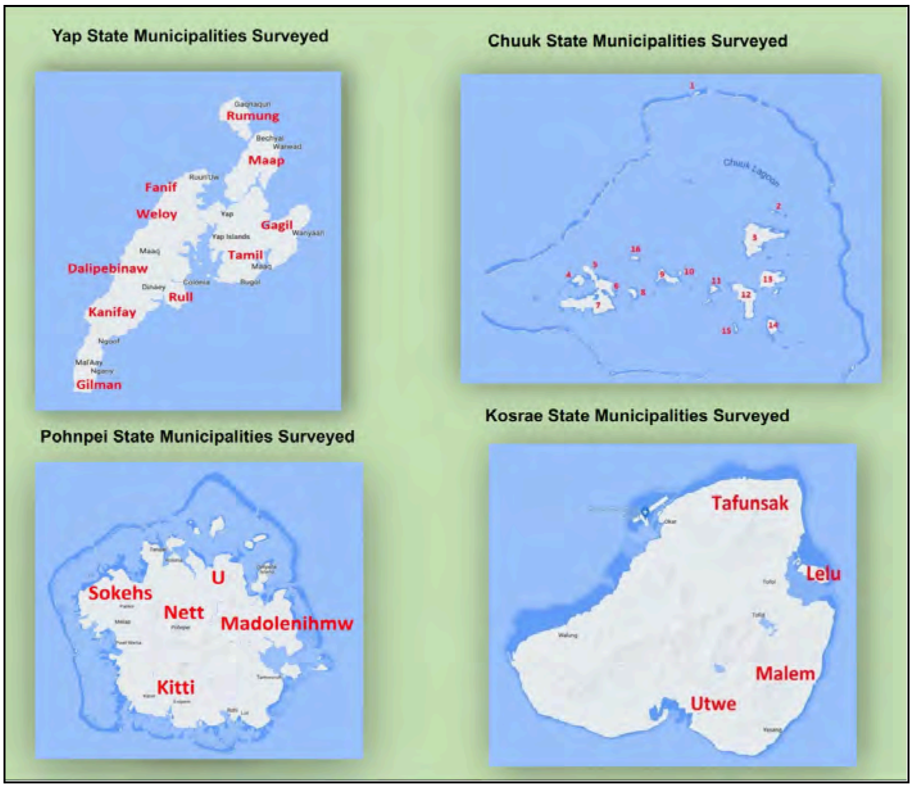
Surveys were written in English yet **administered in local languages** as needed to ensure accuracy in capturing responses across the FSM.

The survey implementation **specifically identified farming families in remote locations** impacted by climate change. Families were selected using geospatial distribution of farming communities across main islands of Pohnpei, Yap and Kosrae states and all sixteen of the islands within the Chuuk lagoon.

IRB approved surveys conducted **<u>in local languages</u> by local NGOs**

Capacity Building - more than 50 local enumerators trained and received international CITI certification in human subject data collection

More than 600 farming families interviewed (150 per state) on the main islands of Yap, Pohnpei and Kosrae and in all 16 islands within the Chuuk lagoon.



Criteria for selecting farming families was done in consultation with the State governments, local NGOs, and Micronesia Conservation Trust.

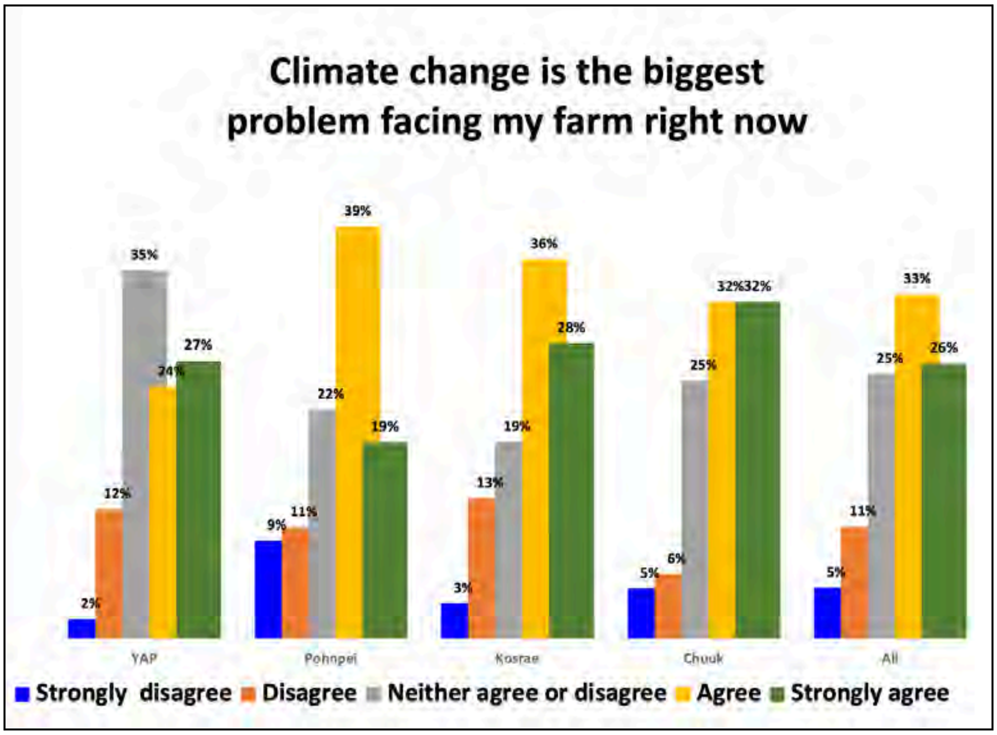
It was important that the baseline surveys be **<u>conducted in the local languages</u>** and at the homes and residents of those being interviewed to ensure interviewees were most comfortable with the questioning process and that they were interviewed by enumerators who were from their local communities and municipalities.

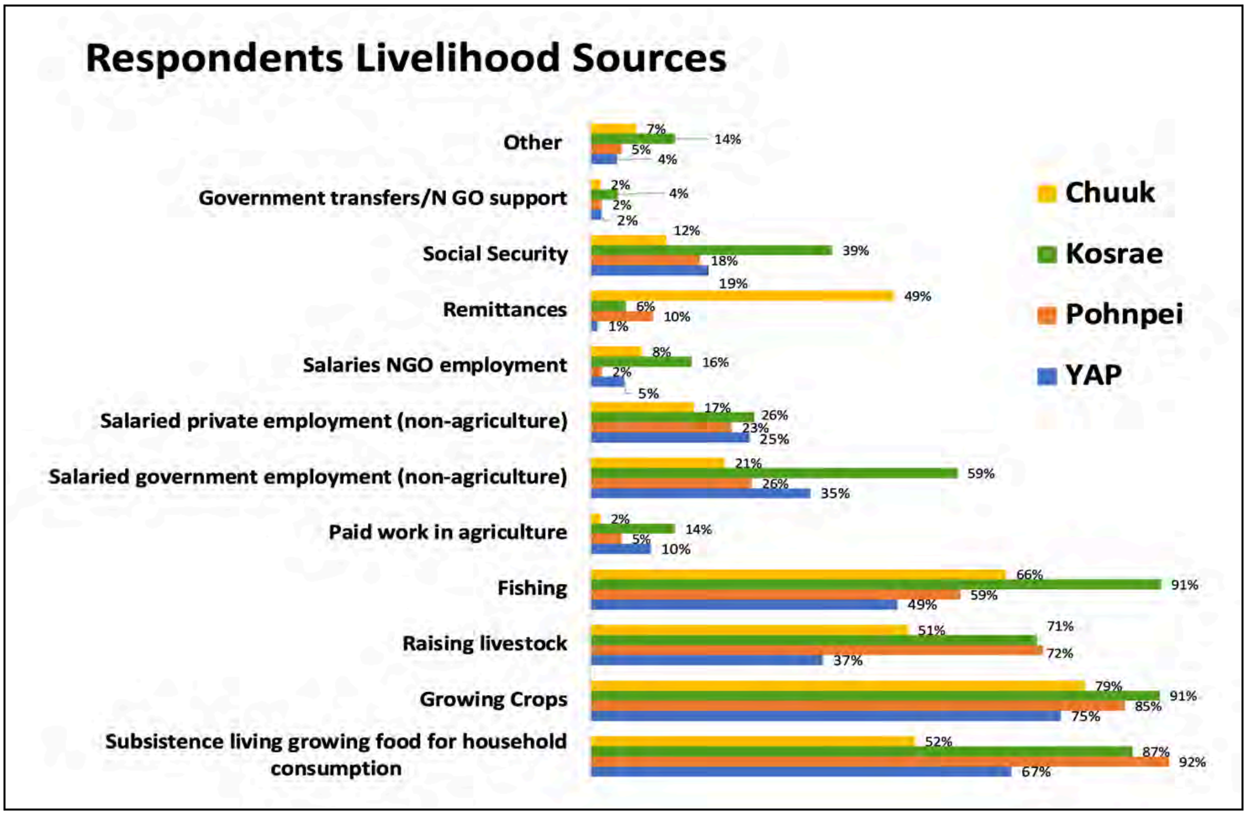
GCFSAP020 Enumerators Interview Farmers in Pohnpei
Photo Credit: Lara Brindisi, Rutgers University

Additional data was captured by way of focus group discussions with women's associations, agricultural/farmers' associations, and fishers' associations, along with key players involved in commercial food production analysis and report dissemination, as described in detail above.

The 2016 FSM Integrated Agriculture Census (IAC) reported that of the 15 545 households across the nation, 74% of those surveyed farmed the land for home consumption. The results of both the FSM IAC and the 2023 **GCFSAP020 Baseline Survey** showed that agriculture activities remain crucial to the livelihood of FSM households.

The majority of those surveyed as part of the GCFSAP020 Survey confirmed that they are subsistence farmers/fishers with 92% of those from Pohpnei saying they grow food for household consumption as the base of their livelihoods. A total of 59% of families surveyed in the 2023 GCFSAP020 Survey reported that the either agree or strongly agree that Climate Change is the biggest problem facing my farm right now.

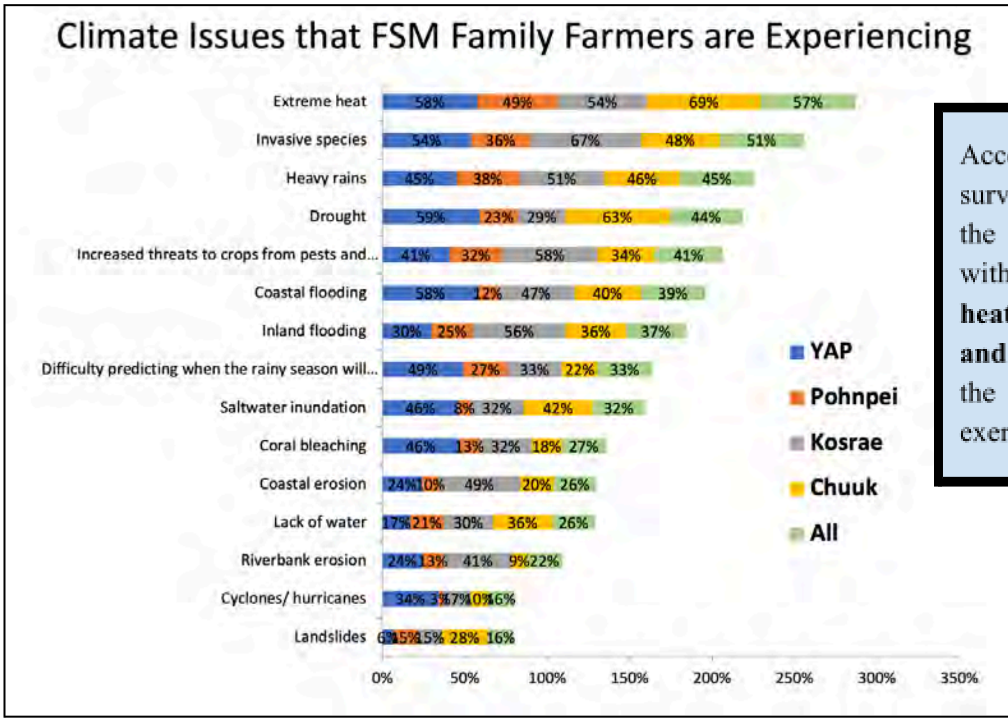




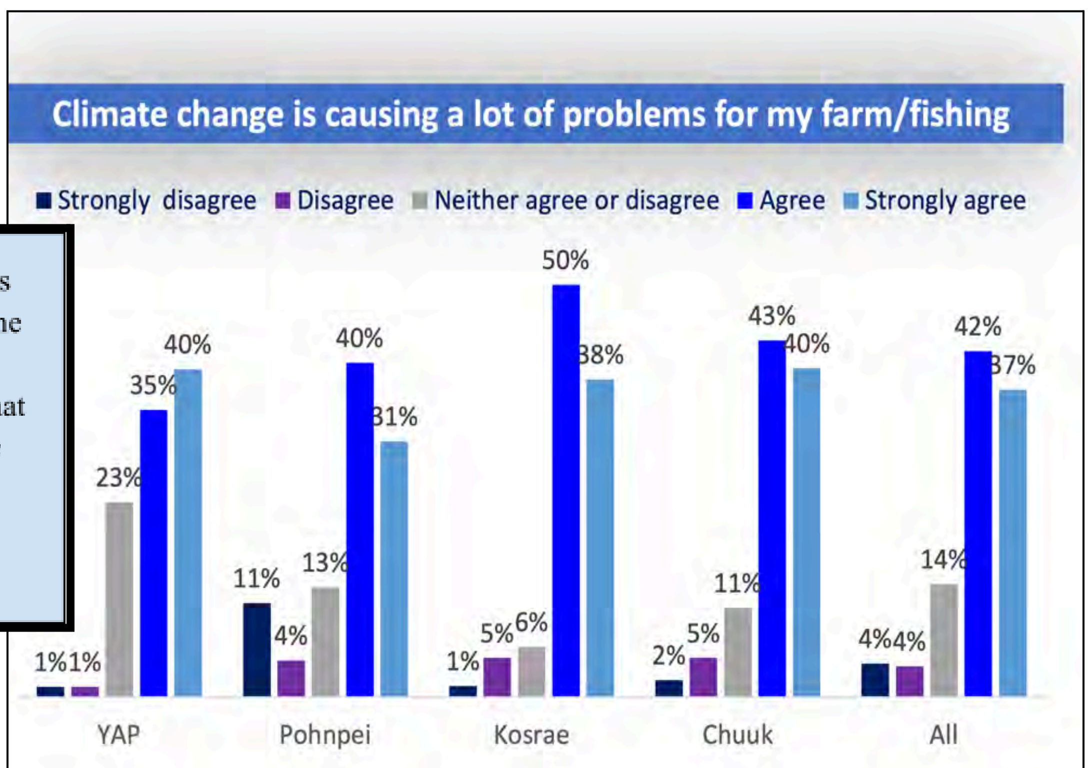
GCFSAP020 Survey Results:

FSM Farming Families' Experience of Climate Change

Despite important distinctions between states' current conditions, there are issues and common concerns across the FSM. For example, in all states, the main events associated with crop loss are extreme heat, heavy rains, flooding and drought, which shows the impact that climate exerts on food systems.

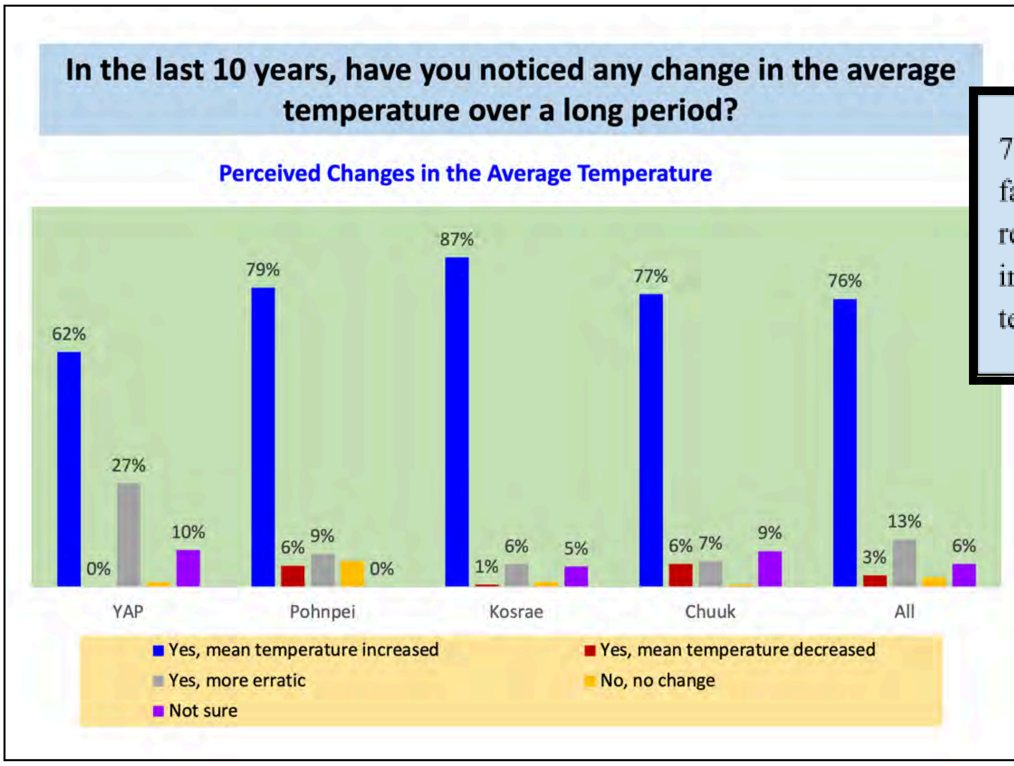


According to the farmers surveyed, in all FSM states, the main events associated with crop loss are **extreme heat, heavy rains, flooding and drought,** which shows the impact that climate exerts on food systems.



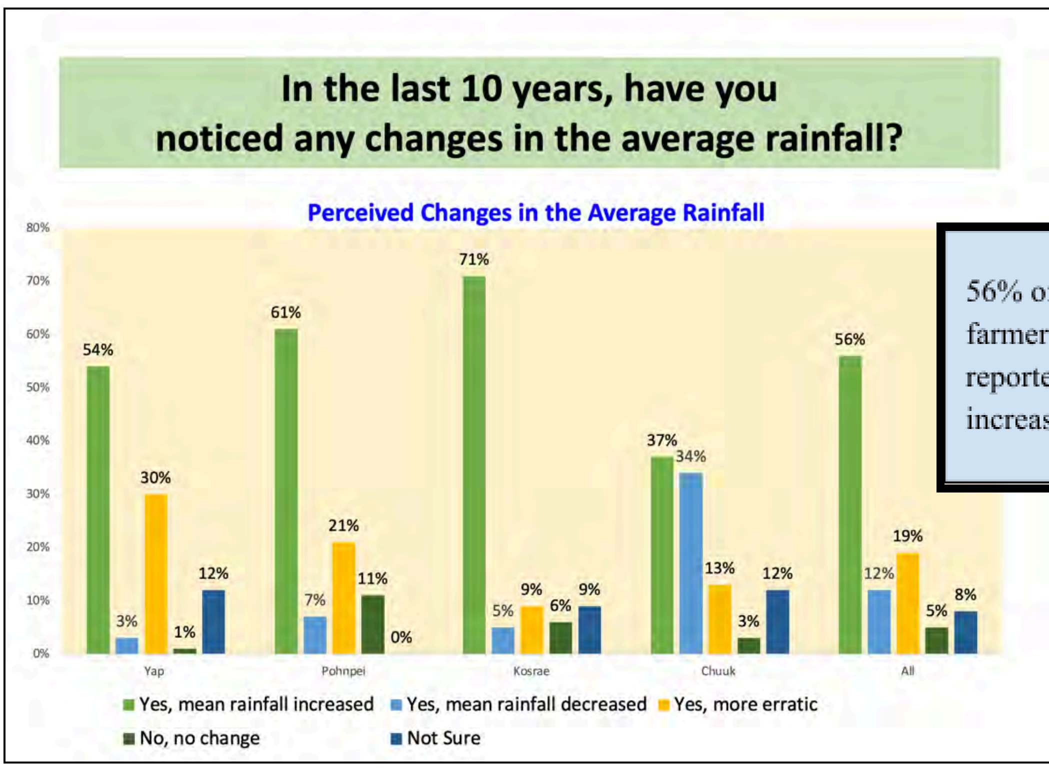
79% of all farmers surveyed across the FSM agreed or strongly agreed that ***climate change is causing a lot of problems for my farm/fishing.***

76% of those surveyed indicated that they observed an increase in temperature over the last ten years with the largest percentage, 87% of Kosrae's respondents stating they experienced warming temperatures.



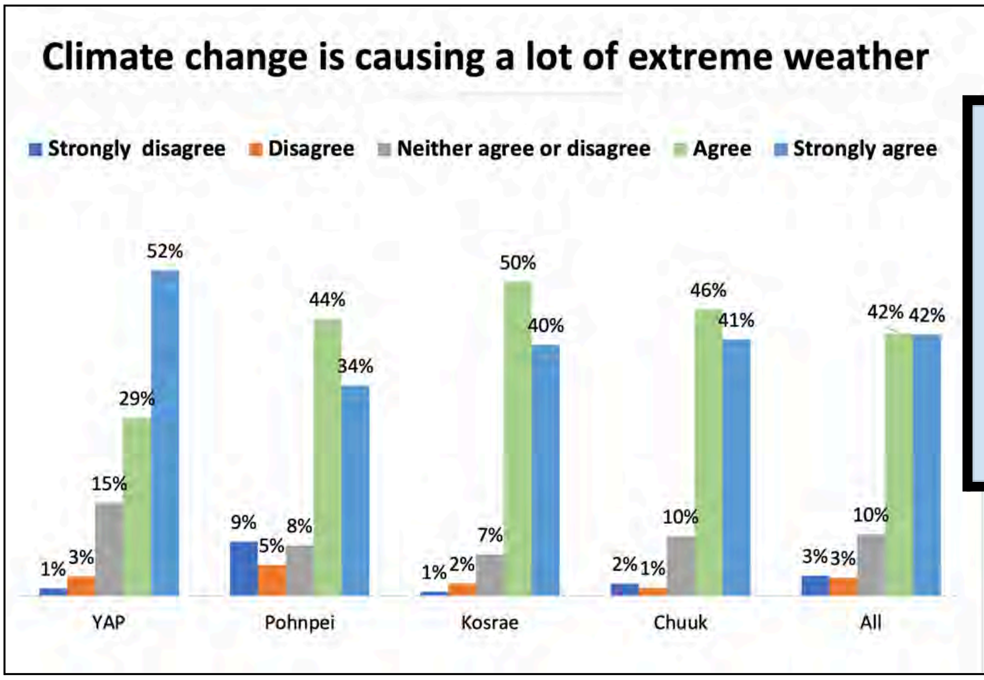
76% of all FSM farmers surveyed reported an observed increase in average temperature.

56% of all FSM farming families surveyed observed an increase in rainfall with 71% of those in Kosrae responding *'yes, mean rainfall increased'*.



56% of all FSM farmers surveyed reported an observed increase in rainfall.

More than 80% of all farmers either agree or strongly agree that climate change is causing a lot of extreme weather.



All farmers across the FSM report experiencing extreme weather with more than 80% agreeing that climate change is responsible.

The GCFSAP020 Survey asked farming families specific questions about their experience and/or observation of with some of climate change's environmental expression such as King Tides, arable land loss, saltwater inundation of crops and soil erosion.

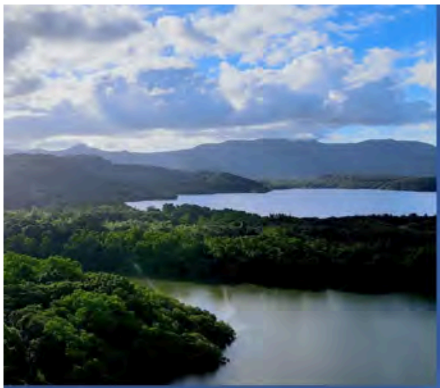
60% of farmers in Chuuk report having experienced King Tides, substantially more than farmers in any other FSM state.

A substantial percentage of farmers in Yap and Chuuk have experienced saltwater intrusion of their crops with more than 50% of farmers in Chuuk impacted.

Experienced Saltwater Intrusion:

Have you or your family experienced saltwater intrusion impacting your crops in the past year?

Yap		Chuuk		Pohnpei		Kosrae	
NO	60%	NO.	43%	NO	95%	NO	71%
YES	40%	YES.	57%	YES	5%	YES	29%



Experienced Arable Land Loss:

Have you or your family experienced any arable land loss due to climate change/extreme weather in the past year?

Yap		Chuuk		Pohnpei		Kosrae	
NO	68%	NO.	44%	NO	87%	NO.	67%
YES	32%	YES.	56%	YES	13%	YES.	33%

Farmers across the FSM are experiencing loss of arable soil, with Chuuk farmers reporting arable soil loss at four three times that of Pohnpei farmers.

Experienced and Observed Soil Erosion:

Have you experienced/observed soil erosion on your land?

Yap		Chuuk		Pohnpei		Kosrae	
NO	59%	NO.	37%	NO	76%	NO	34%
YES	41%	YES	63%	YES	23%	YES`.	66%

All farmers across the FSM are experiencing significant amounts of soil erosion, with Kosrae and Chuuk respondents reporting the most observed erosion.

According to the survey, farmers in Yap are experiencing soil erosion at nearly double the rate of farmers in Pohnpei. Chuuk and Kosrae are experiencing soil erosion at nearly 3 times the rate of Pohnpei where mangrove forests protect the shorelines.

As part of the GCFSAP020 survey, the potential annual risk of coastal soil erosion due to water runoff in the FSM was assessed using the Revised Universal Soil Loss Equation (RUSLE). The RUSLE equation is based on five contributing factors:

1. Rainfall Erosivity (*R*) – MJ mm ha^{-1} h^{-1} y^{-1}
2. Soil Erodibility Factor (*K*) – Mg ha h MJ^{-1} ha^{-1} mm^{-1}
3. Slope Length and Steepness Factor (*LS*) – dimensionless
4. Cover Management Factor (*C*) – dimensionless
5. Conservation Practice Factor (*P*) – dimensionless

Average annual soil loss (*A*) due to water erosion can be calculated as:
$A = R\ K\ LS\ C\ P$

The mean soil erosion risk across each island is typically high, with Pohnpei being the lowest at 41.8 tons $hectare^{-1}$ $year^{-1}$ and the highest being Chuuk at 422 tons $hectare^{-1}$ $year^{-1}$. These values are variable across each island, with some of the greatest erosion values being along steep slopes, rivers, and regions with limited tree cover (Figure 1).

Table 1. Weather station locations and estimated rainfall erosivity

Station	Latitude	Longitude	Rainfall Erosivity (MJ mm ha^{-1} h^{-1} y^{-1})
Pohnpei			
Pohnpei	6.9667	158.2167	16196
Chuuk			
Chuuk	7.45	151.8333	12215
Kosrae			
Kosrae	5.3544	162.9533	17649
Tofol	5.3264	163.005	19506
Utwa	5.2739	162.9742	16107
Yap			
Dugor	9.5367	138.1211	13365
Gilman	9.45	138.0667	11361
North_Fanif	9.5667	138.1167	11667
Rumung	9.6333	138.1667	9583
Tamil	9.55	138.15	11511
Yap	9.4833	138.0833	11650

Similar estimates are generated for the islands on slopes less than 50% grade. In this case, it is likely that erroneously high erosion estimates generated through this technique along the islands are disproportionately affecting the mean. The median estimates are much more in line with other humid tropical region estimates, though often being somewhat higher (Millward and Mersey, 1999; Labrière et al., 2015). Overall, these higher values compared to other humid tropical regions likely indicate the limitations of the RUSLE approach with limited ground-truthing. Similarly, there is a level of uncertainty with the calculation of each contributing variable to the RUSLE equation that would need to be constrained by field measurements. In particular, the *R* and *C* factors would need to be locally calibrated from higher temporal resolution data for R and on-site measurements of *C* across the Micronesian islands.

Table 3. Mean and median erosion estimates in tons hectare^{-1} year^{-1}. Note both estimates for the whole island and just those lands with slopes less than 50% grade are provided.

Island	Mean Erosion	Median Erosion	Mean Erosion (Slope < 50%)	Median Erosion (Slope < 50%)
Pohnpei	41.8	16.5	33.4	13.3
Chuuk	422.0	66.5	373.3	70.9
Kosrae	252.4	40.4	210.0	22.1
Yap	155.0	36.2	151.1	32.2
Mean	217.8	39.9	192.0	34.6

For practical usage and reporting, this report suggests using the median erosion estimates in Table 3 as being more representative of the islands overall. A second suggestion would be to use the values estimates for just the slopes less than 50% grade as the maximum suggested slope for the above method as cited by Panagos et al. (2015) is about 50%. If a mean value as opposed to median value is desired, this report recommends reporting the mean for the slopes less than 50% from Table 3.

Future assessments of soil erosion in Micronesia need to consider the unique conditions of each island. Given the tropical setting, potential for intense rainfall, and sleep slopes on many of these islands, it is important to effectively calibrate any erosion modeling for soil loss to these conditions. Assumptions for the slope steepness factor, for example, may want to be reassessed using models calibrated for alpine environments despite the climate setting being very different. Finally, note that the erosion values are extremely variable between islands primarily due to land cover classification and topography. Certain land cover classes such as forestry and agroforestry have very different literature C values but may be similar in practice in Micronesia. Subsequent analyses would need to try to bridge the differing land cover classifications utilized on each island for more consistent erosion values.

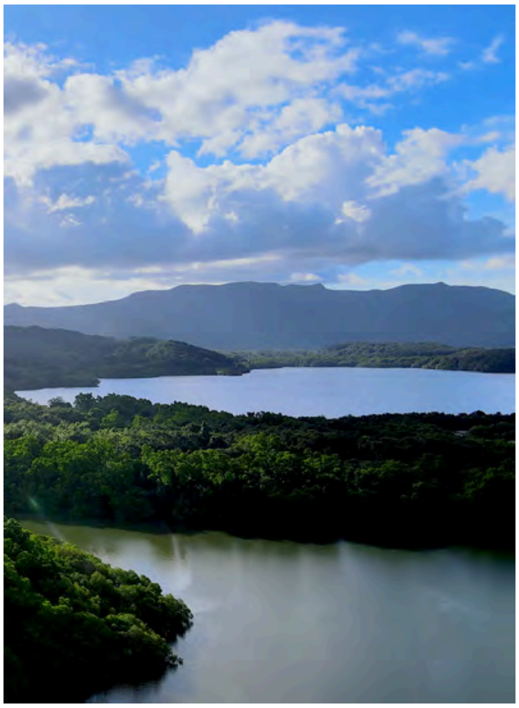
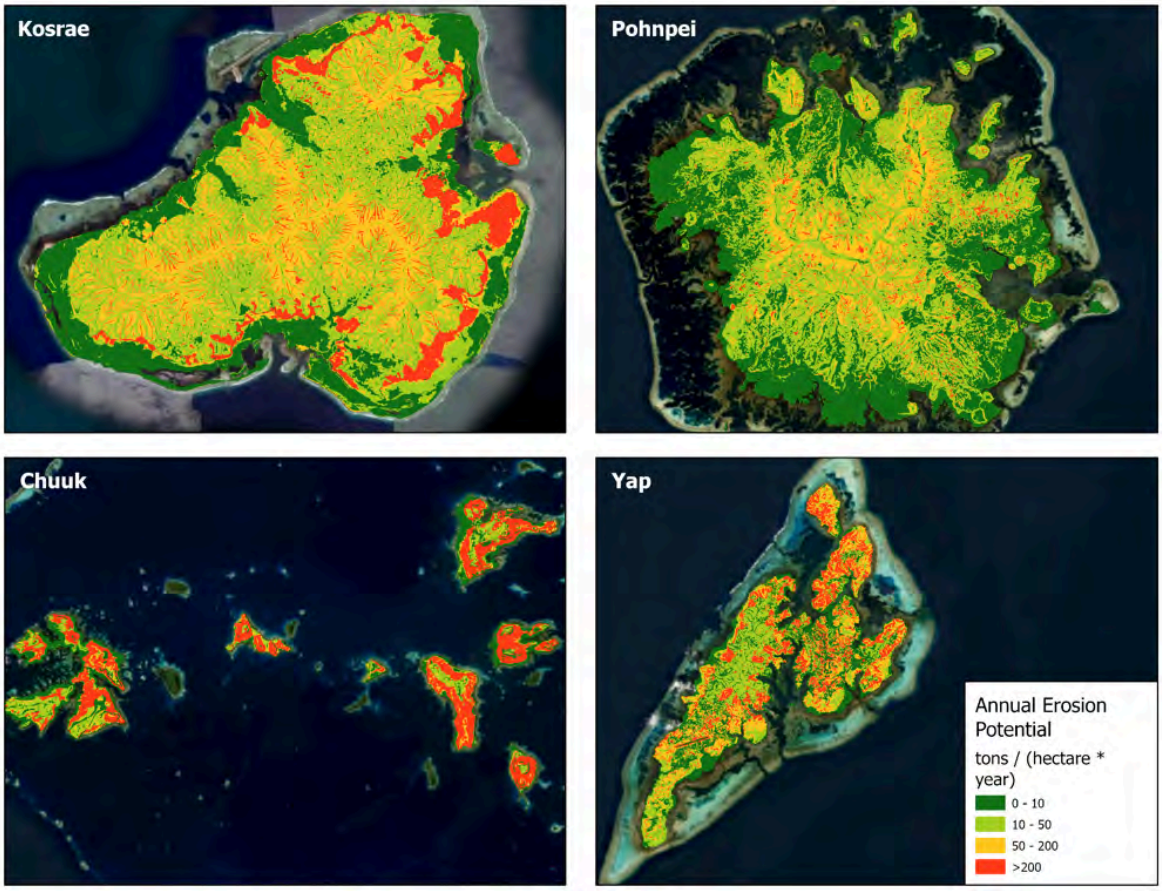


photo credit: Micah Seidel, Rutgers University

Spatial distribution of rainfall-driven erosion risk across the main islands of the Federated States of Micronesia



FSM Farming Families' Access to Clean Drinking Water

FSM receives considerable precipitation. According to FSM's 2020, Voluntary National Review, data provided by the National Oceanic and Atmospheric Authority affiliate weather stations in FSM measured annual mean rainfall over a 20 years of 180.61 for Pohnpei, 174.58 inches for Kosrae, 168.92 for Chuuk and 125.99 for Yap.

About 60% of water resources in FSM exist as surface water in the form of small, intermittent streams that drain catchment areas of limited aerial extent. 40% of the water resources and groundwater which is accessed through extractive wells. Shallow wells are common, particularly in the outer islands and Chuuk lagoon.

The piped water systems in FSM are of two basic types. Systems that utilize streams as water sources consist of a small intake across the stream, a raw water main to the treatment plant (for those few systems which incorporate treatment) and a transmission and distribution network. Often, these systems supply a single community of villages and are managed by the community.

Pohnpei and Kosrae largely use surface water as a source of drinking water, but this is prone to bacterial contamination and requires extensive and costly treatment to reduce high turbidity. Concerns regarding water-related diseases are high, since leptospirosis, hepatitis and amoebiasis are endemic in some of the four states.

Proceedings of the Pacific Regional Consultation on Water in Small Island Countries – Country Briefing Papers, SPREP (https://www.sprep.org/att/IRC/eCOPIES/Countries/FSM /28.PDF).

Water treatment is by rapid filtration, followed by chlorination. Only 5 systems out of about 70 have treatment facilities, and most systems supply untreated water. The main problems faced in operating these surface water systems arise from the bacteriological contamination of the water sources and supply problems during extended dry and/or drought periods. Insufficient access to clean water is a direct contributor to disease and illness and overall vulnerability of the FSM population (Freshwater Distribution in Pohnpei, FSM, GIS in Water Resources Fall 2017).

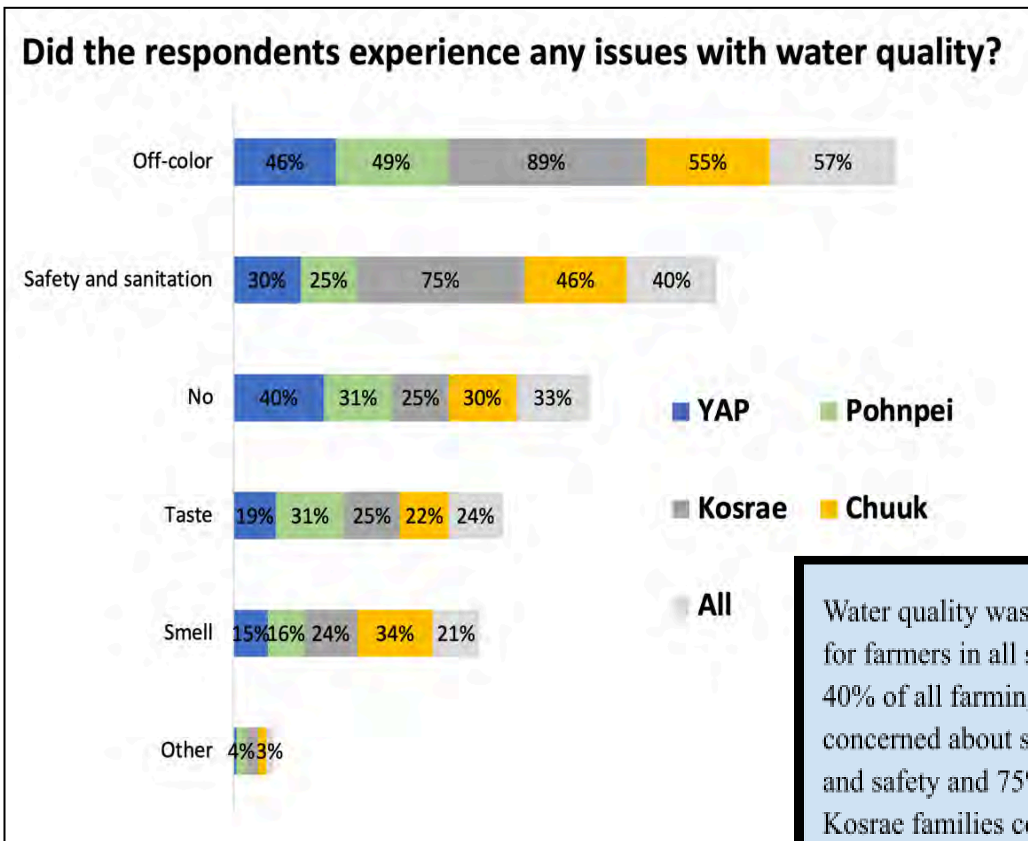
GCFSAP020 Survey Results: FSM Farming Families' Access to Clean Drinking Water

Access to Clean Drinking Water:

Does your household have **regular** access to clean drinking water?

Yap		Chuuk		Pohnpei		Kosrae	
NO	8%	NO	52%	NO	19%	NO	11%
YES	92%	YES	48%	YES	81%	YES	89%

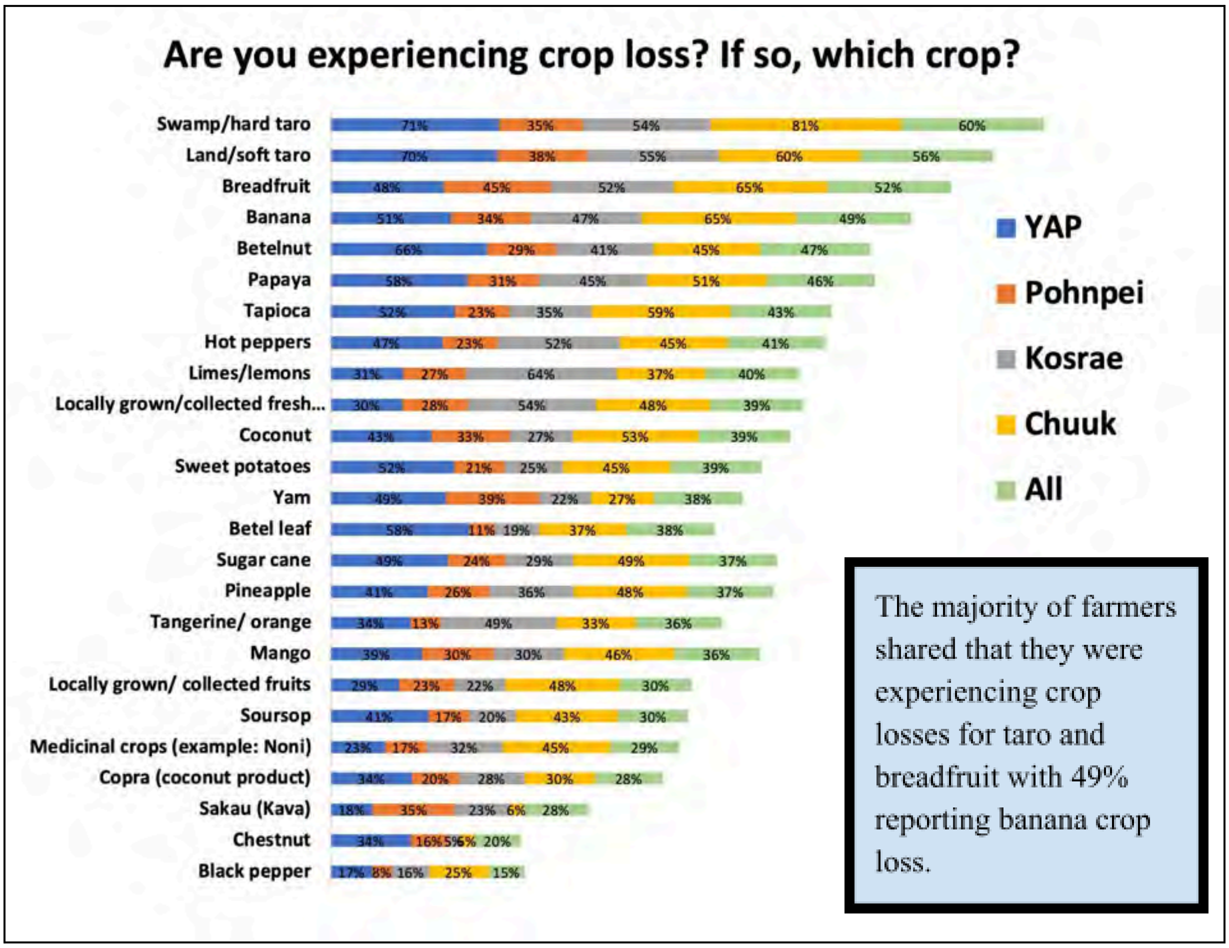
The majority of farming families surveyed shared that they had access to clean drinking water with the exception of **Chuuk farmers** with more than 50% reporting that **they do not have access** to clean drinking water.



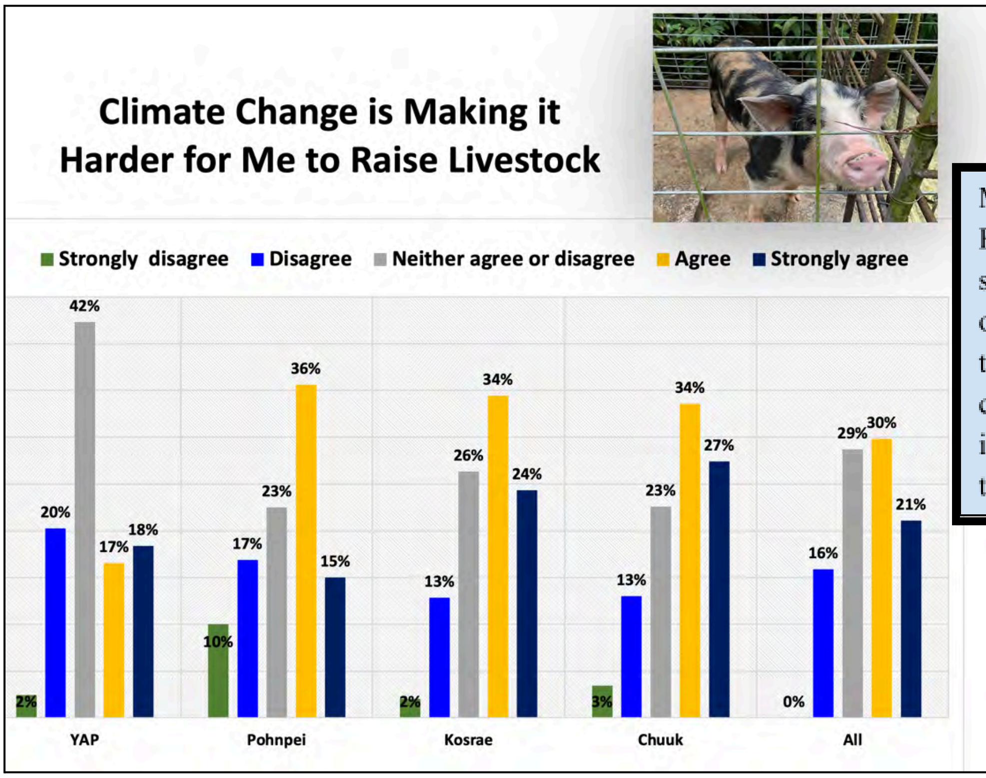
Water quality was a concern for farmers in all states with 40% of all farming families concerned about sanitation and safety and 75% of Kosrae families concerned about sanitation and safety.

Farming Families Perceptions of Water quality: While some areas in the FSM receive among the highest rainfall in the world, with Pohnpei known for its rich water resources, clearly, access to clean and safe drinking water remains a critical concern across the FSM. The lack of water in the atolls and outer islands is due to periods of drought across the FSM, during which water is limited, particularly public water, and continues to contribute significantly to vulnerability among many in the FSM. This was observed in 2010 and again in 2022–2023. In 2022–2023, over 15% of those surveyed reported they had issues with water shortages. While excessive rains were reported as a real concern that food producers face, leading to crop loss, in the 2022–2023 survey, nearly half of the households also reported issues with water quality, from off color being the most common concern, to other issues, including taste and smell. Slightly more than 25% responded they were concerned with water safety and sanitation. Further probing suggested that those concerns largely relate to likely contaminants from effluent runoff coming from livestock, swine and poultry waste and entering into water sources. Yet, to some respondents, it could also include the intrusion of salt and brackish water into fresh water. The 2010 survey focused on local water availability. In the 2022–2023 survey, respondents, including those who reported water shortages to be an issue, were asked if they did anything to collect rainfall or groundwater for home or agricultural use. Only a few constructed water collection systems to capture excessive rainfall for use in times of drought. The introduction and construction of household and farm fresh-water collection systems should be considered. The lack of fresh and safe water impacts not only direct consumption by families but the ability to provide irrigation to plants and terrestrial-based crops as well as for use in feeding poultry and livestock. Systems for storing water for later use would reduce vulnerability to water shortages.

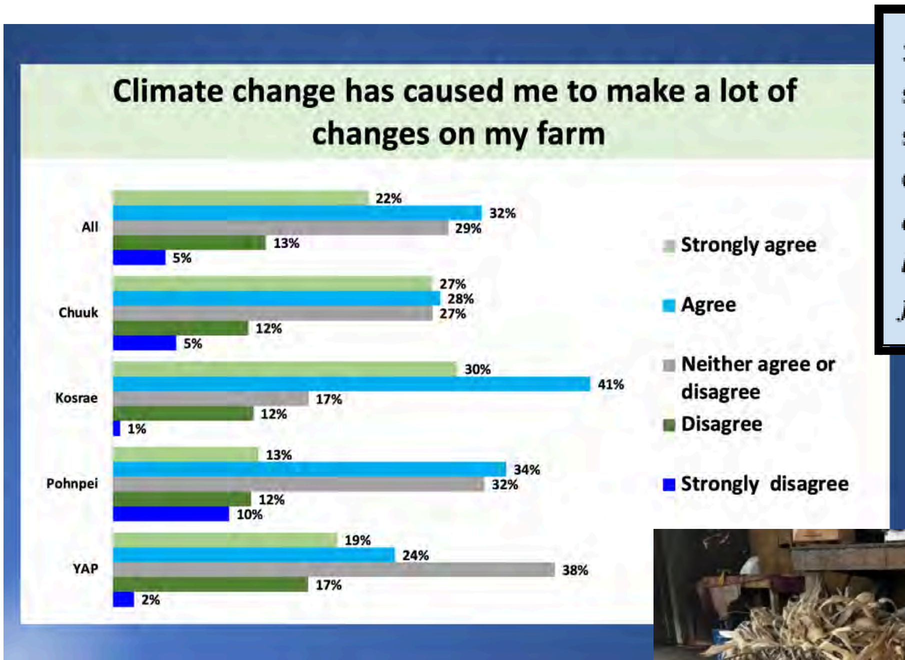
<u>**GCFSAP020 Survey Results: FSM Farming Families' Experience of Crop Loss**</u>



Climate change is not only impacting FSM subsistence agriculture but livestock husbandry.



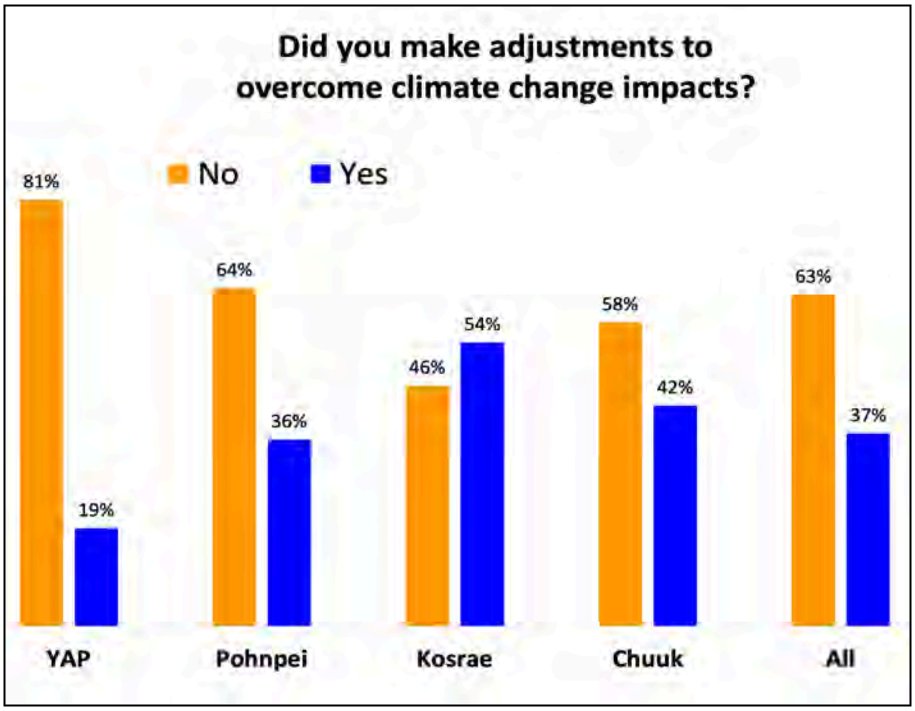
More than 50% of FSM farmers surveyed agreed or strongly agreed that climate change is making it harder for them to raise livestock.



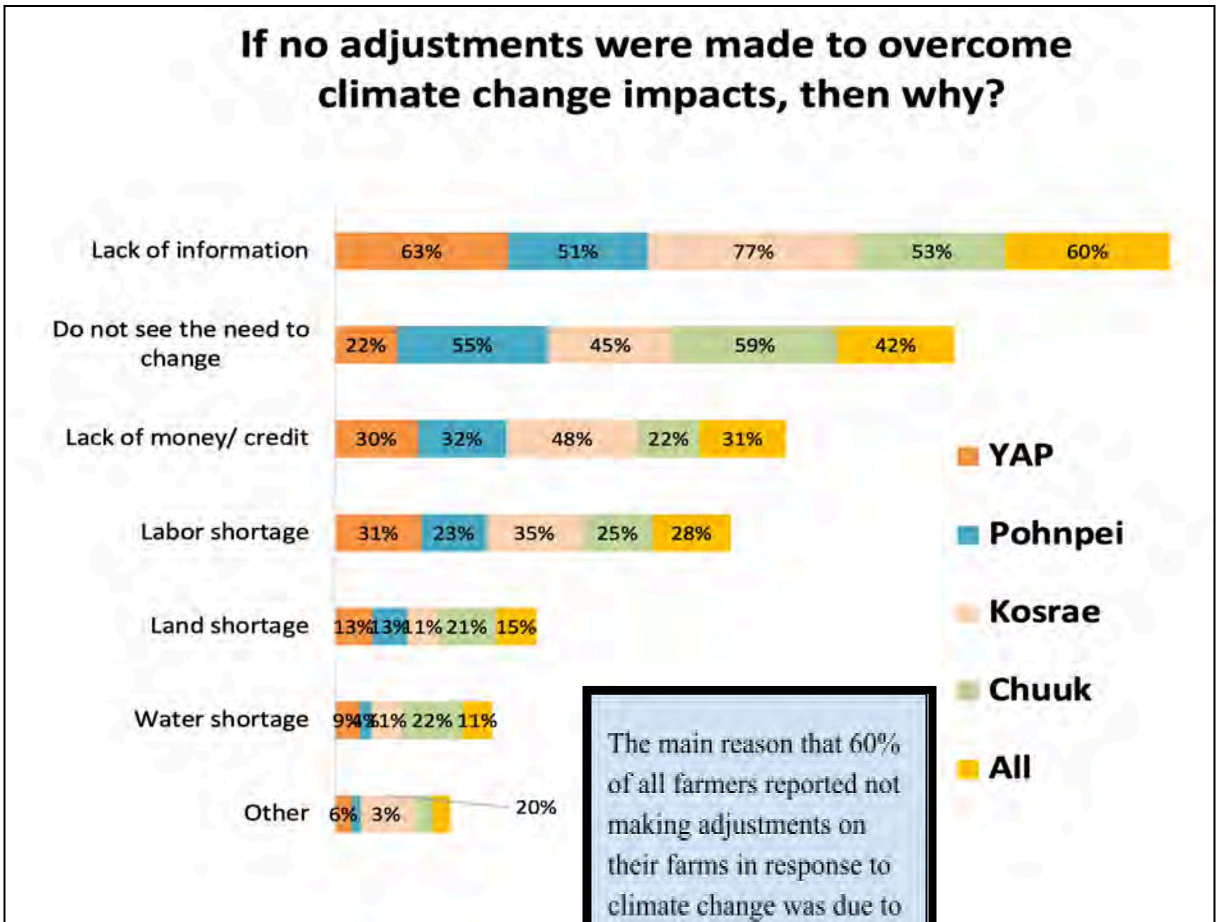
55% of FSM farmers surveyed agreed or strongly agreed that climate change is ***causing me to make a lot of changes to my farm.***

Farmer, Yap State. Photo Credit: Dena Seidel, Rutgers University

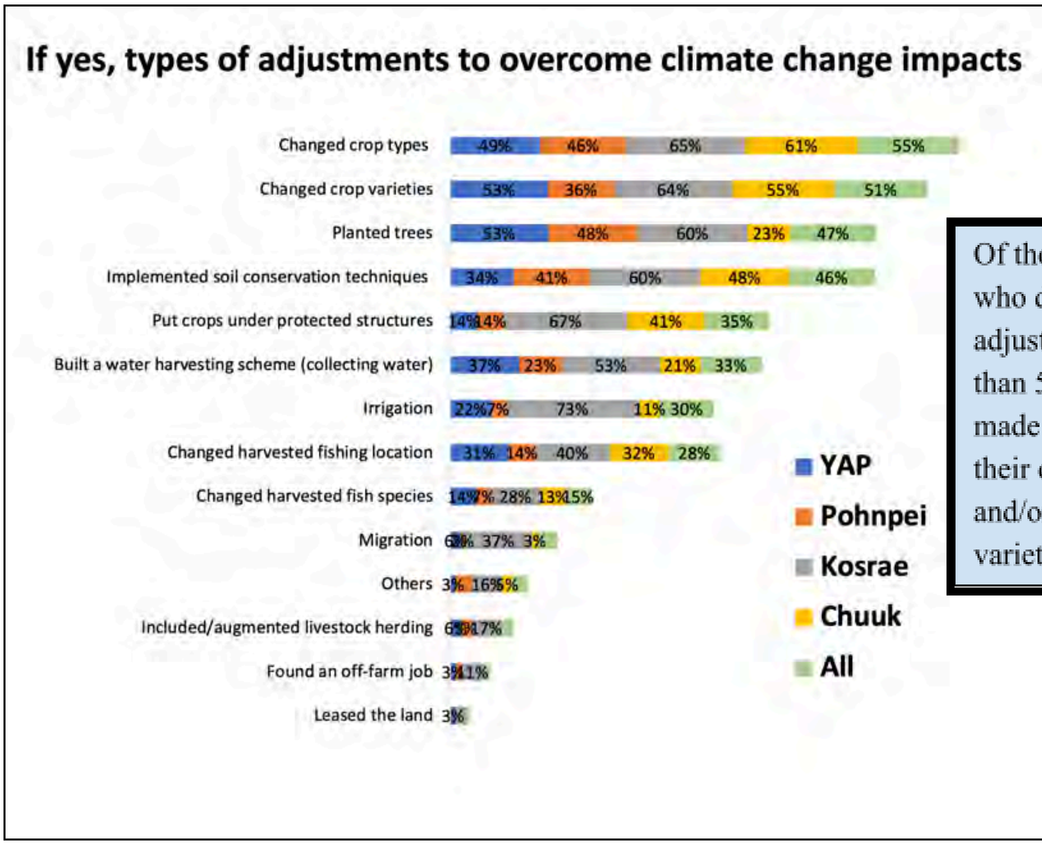
GCFSAP020 Survey: Farmers' response to Climate Change Impacts



While nearly 80% of farmers surveyed said that climate change was causing a lot of problems for their farming and fishing, nearly 65% said they **did not make** adjustments to overcome climate change impacts.



The main reason that 60% of all farmers reported not making adjustments on their farms in response to climate change was due to **lack of information.**



Of those farmers who did make adjustments, more than 50% said they made changes to their crop types and/or their crop varieties.

Results from the 2022–2023 GCFSAP020 Survey indicate that only 40% of the FSM's households have made adaptive adjustments to overcome or face climate change, largely by planting trees, changing crop types and varieties, implementing soil conservation techniques and other approaches; the other 60% have not made any changes. When asked why no adjustments were made, households report that they do not see a need to change because they do not know what will help, that there is a lack of information and guidance as to what to do, there is a lack of money/credit to finance any change, and there is a current labor and land limitation**.**

% of FSM farming households that observed soil erosion and implemented Soil Conservation Techniques (to prevent erosion or soil contamination)

13.6% (85 families out of 623 families surveyed)

Implemented Soil Conservation Techniques	Respondent %
Yap	8 %
Pohnpei	15 %
Kosrae	20 %
Chuuk	13 %

The current mean Soil Erosion across the FSM was estimated to be 34.6 tons of soil/hectare/year.

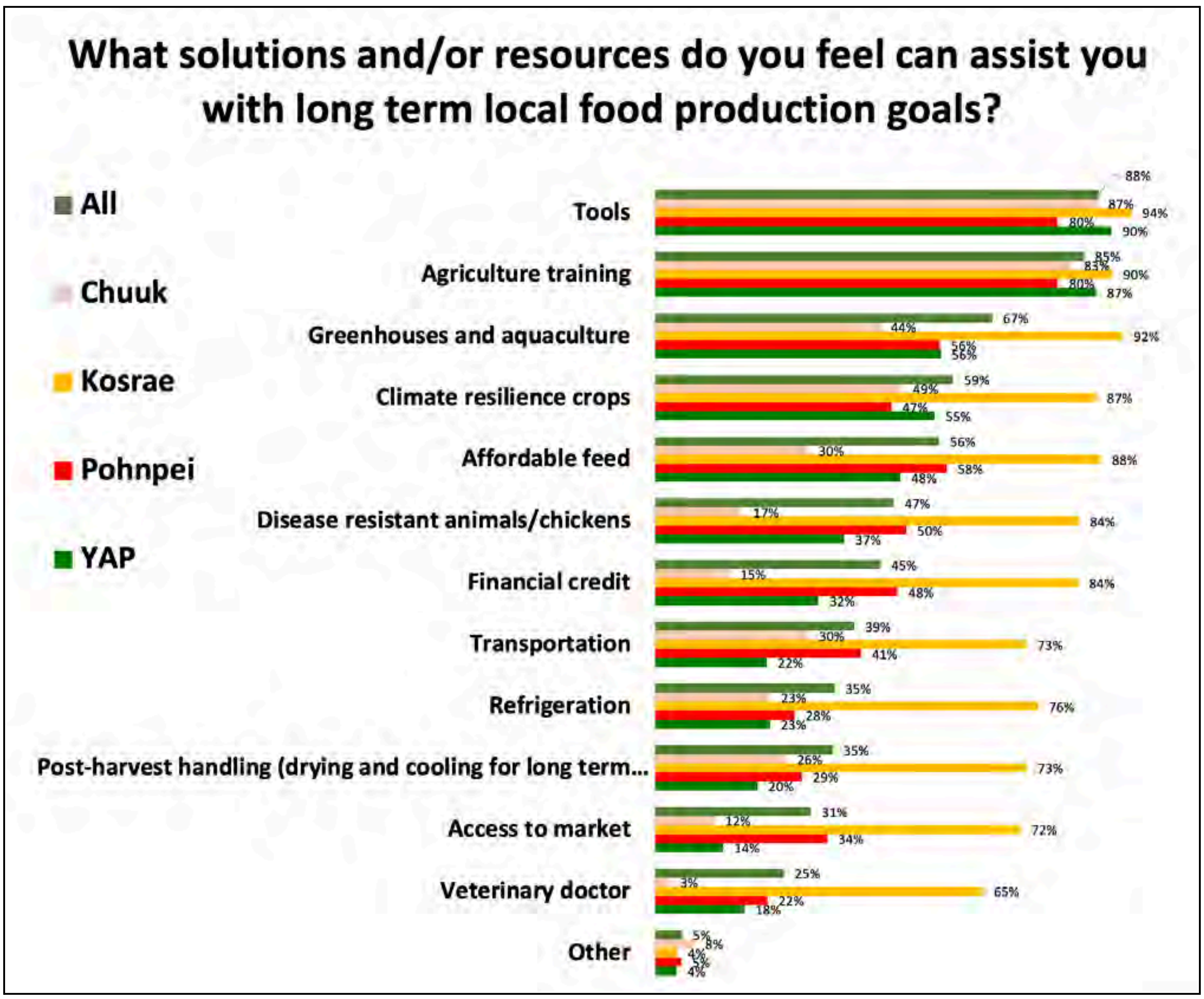
Yet, only, on average 13.6% of households are currently using soil erosion practices.

Data from the GCFSAP020 baseline survey of FSM's subsistence farmers is intended to support each of FSM's state plans for initiating and implementing sustainable food system development that is place-based, culturally and socially relevant and meaningful to the people of FSM.

Developing a local food system must begin with understanding the needs of the local food producers.

Here, subsistence farmers across all four FSM states were asked with resources they feel they need to reach their food production goals.

Availability of tools and agricultural training were cited as the most common needs to provide solutions to what most respondents saw as their pressing current limitations and constraints as well as need for additional resources including access to financial capital. Yap, Chuuk and Pohnpei respondents reported that these solutions would assist them with their longer-term local food production goals and food security needs, while in Kosrae, the answer was similar relative to need for availability of tools and agricultural trainings but there the need for greenhouses and aquaculture were also among their most frequent responses.



2022 Survey of Outer Islanders living on main Island Yap

While the 2022/23 GCF baseline survey focused on farming families living in the main islands of each state, some respondents were outer islanders who moved to the main islands for several reasons including, and in part due to, a changing climate. Surveys were intentionally conducted in Yap targeting outer islanders from Faraulep, Woleai, Falalop, Fadrai, Euripek, Satawal, and Ifalik—and villages of Ruu, Makiy, Daboch, Gargey, Gitam and Madrich who had moved to the main island Yap. About 67% of these outer islanders responding to the baseline survey reported that they grow crops for subsistence living. The majority shared that their ability to grow food on their land had been impacted by a change in climate and that climate change has impacted their overall crop yields.

Growing crops (93%), subsistence living (67%), fishing (40%) and social security (40%), were the most frequently mentioned livelihoods sources for the households. The vast majority (93%) of outer island respondents farm and/or harvest local food crops and around 60% farm and/or harvest medicinal crops. Around 40% of respondents raise livestock and/or poultry and 47% fish or harvest ocean food sources. Coastal flooding and coastal erosion, saltwater inundation, difficulty predicting when the rainy season will come, increased threats to crops from pests and disease and coral bleaching are the most frequently mentioned as big farm problems associated with climate by outer island respondents.

More than 73% of outer island respondents grow and/or harvest food crops and, from those, 100% does so for family consumption, 84% for sale and 64% for traditional exchange. Extreme heat, lack of water and increased threats to crops from pests and disease are the main issues causing crop loss according to respondents of this survey. Lack of sufficient income, coupled to higher expenses for many commodities and supplies due to the additional shipping charges to the more remote areas, further contribute to the difficulty in reducing vulnerability. The observations by these outer islanders living on the main island of Yap are in agreement with the overall results from other respondents but with greater intensity of the hardships that they face and with fewer options that would have allowed them to stay on the outer islands.

2022 Survey of Outer Islanders living on main Island Yap: Has your ability to grow food been affected by climate change?

Question	Responses	Percent
Has your ability to grow food been affected by a change in climate?	No	40.00
	Yes	60.00
	Total	100.00
Has a change in climate impacted your crop yield?	No	26.67
	Yes	73.33
	Total	100.00

The top limitations for expanding crop production were the availability of land, tools and equipment and feed for their livestock. Crop loss was a significant issue facing outer islanders and others across the FSM, from increasing brackish and salt water intrusion, to insects and diseases, and lack of postharvest options beyond the traditional food security approach used successfully with taro and other products. Lack of sufficient income, coupled with higher expenses for many commodities and supplies due to the additional shipping charges to the more remote areas, further contribute to the difficulty in reducing vulnerability.

GCFSAP020 Survey Highlights Vulnerabilities of FSM Farmers

The GCF Baseline survey results provide important insights into FSM's food system strengths and vulnerabilities as well as the food system development goals and needs for FSM farming communities across all four states. Data from this baseline survey of FSM's subsistence farmers can be used to inform each state's plans for initiating and implementing sustainable food system development that is place-based, culturally and socially relevant and meaningful to the people of FSM.

Families throughout the FSM still rely heavily on local food crops for family consumption (reaching as high as 98%) and also for social cohesion by way of traditional exchange (reaching as high as 80%). This dependency on local land for food makes these families vulnerable to climate change.

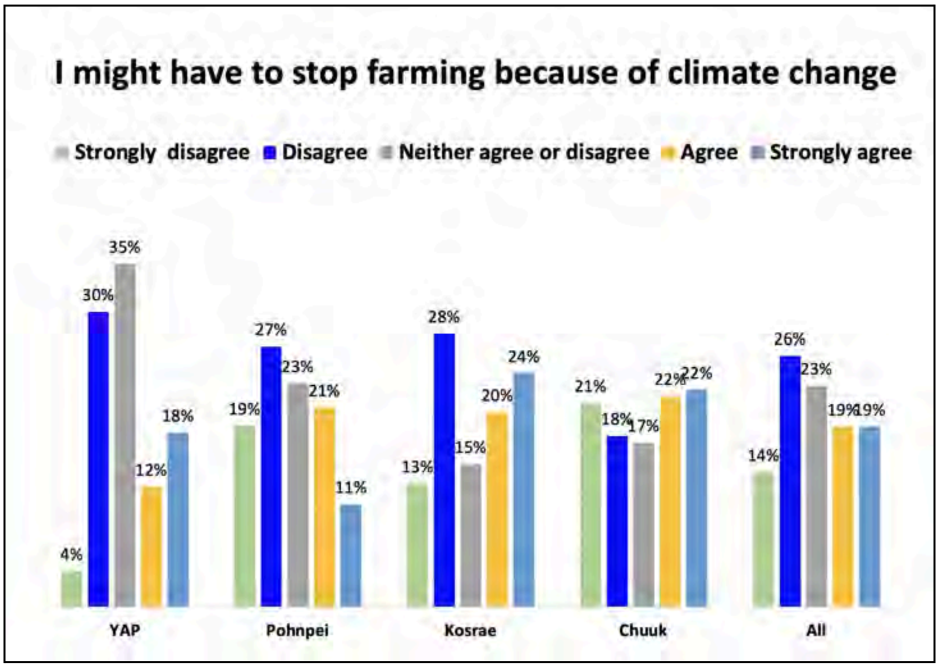
The majority of the farming households surveyed believe in climate change, with over 70% of FSM households indicating that climate change is causing a lot of problems when it comes to their ability to produce food primarily due to altered weather patterns, including extreme heat, droughts, heavy rainfall, and inclement weather. Over 40% of respondents indicated that climate change is making it harder for them to grow food or harvest wild crops and fish.

Despite the important distinctions between states' current conditions, there are issues and common concerns across the FSM. For example, in all states, the main events associated with crop loss are extreme heat, heavy rains, flooding and drought, which shows the impact that climate exerts on food systems.

Over 30% of respondents indicated they may have to move or stop food production due to the challenges from climate change.

From the GCFSAP020 survey, 90% of the respondents indicated that the climate will impact the food that they eat.

38% of respondents either agreed or strongly agreed that they may have to stop farming because of climate change.



Reducing Food System Vulnerability in the FSM

Supporting Traditional Farming and Fishing Practices:

The majority of agricultural production in the FSM is for domestic and family consumption. Most of the land used for agriculture and agroforestry is freehold land or held with customary titles. Just over 90% of households recorded in the 2016 Federated States of Micronesia Integrated Agriculture Census had access to land they used for their specific agriculture needs.

Supporting local farming and food system production and development is an adaptive strategy that reduces several vulnerabilities now facing the people of the FSM including health, nutrition, economic and capacity-building vulnerabilities. The FSM's sustainable local food production efforts provide myriad climate change adaptation measures that are most cost effective. Implementation of community-based holistic food systems that build upon local and traditional agriculture, agroforestry and marine production support economic and cultural sustainability and climate change adaptation. The recognition and promotion of traditional farming, fishing and agroforestry systems that have sustainably supported subsistence livelihoods, community obligations, and food security over generations can improve household food security and economic resilience.

In 2015, FSM's Second National Communication included Food System Technological options that are understood to support community adaption to climate change, specifically:

- **Introduction of salt-tolerant species** to prepare for anticipated increase in soil salinity due to salt water intrusion from rising sea levels and increased storm surges. Salt-tolerant varieties of current harvested and cultivated crops (swamp taro, breadfruit and banana) could be sourced and/or new salt-tolerant crops should be made available to FSM farming families.

- **Crop research and introduction of heat tolerant crops** to reduce local dependence on introduced European cool vegetables such as cabbages, tomatoes, potatoes, etc. With the expected temperature increases as part of climate change, there is a need to support the local production of heat-tolerant vegetable crops both for domestic consumption and for potential export. In addition, crop research is needed to assess the most productive, most nutrient dense, most climate resilience and most desired food crops for local consumption.

- **Improved pest and disease management** to prepare for anticipated increase in pests and food crop diseases that threaten the local food systems and biodiversity. Such management plans should include development of climate and disease resilience local food crops and training in ecologically sensitive pest management strategies that do not introduce harmful toxins into FSM's vulnerable ecosystems.

- **Restoration of degraded lands** to support local agriculture. Sea level rise will result in land degradation and thus there is a continued need to uphold land restoration policy to ensure lands are available for agricultural purposes.

- **Farm relocation for coastal farmlands** impacted by sea level rise. Climate change–induced sea level rise will result in flooding and inundation of some coastal farmlands and such affected farms should be relocated to locations still fit for farming.

- **Agricultural diversification** plans have been suggested for vulnerable area including potential non- agricultural developments better fitted to the anticipated climate conditions in the vulnerable areas.

- **Promotion of traditional agroforestry** as essential to support local food system development within FSM's limited land resources. Many of FSM's current farming system problems are related to unsustainable and foreign cultivation methods introduced to FSM. Promoting traditional agroforestry supports protection of local biodiversity and ecosystems when combined with sustainable harvest practices.

Mangroves and Restorative Ecology: On the FSM's volcanic islands where the largest populations of people reside, coastal mangrove forests provide natural infrastructure and protection to local communities by preventing coastal erosion and absorbing the impacts of storm surges. Throughout the FSM, mangroves are essential to island ecosystems, providing habitat to many species the people of the FSM depend upon, including a wide variety of fish and shellfish. Mangrove forests also effectively sequester more than their share of atmospheric carbon, storing the carbon deep in the ocean mud floor. Mangroves' complex and dense root systems filter water, improving local water quality while helping to bind and build coastal soils.

Yet mangroves are under great threat throughout the FSM. Mangroves are often harvested for fuelwood and construction and they are impacted by changing ocean conditions. The unsustainable harvesting of mangroves for firewood is greatest in Kosrae and Chuuk. Most FSM states have developed, or are developing, mangrove management plans. Expert advice on coastal management of the nation's mangrove forests is urgently needed to guide these conservation activities in the FSM.

Coral Reefs: Restorative ecological actions that preserve and rehabilitate the FSM's coral reefs, beaches and ocean fronts while providing opportunities to enhance reseeding and repopulating aquatic species are cost-effective means to protect essential natural resources from environmental degradation. The people of the FSM have long depended on coral reefs for coastal protection as well as food as reef fish have long served as regularly available sources of protein. Establishment of Marine Protected Areas (MPAs) is an example of a strategy that has been and can continue to contribute to the sustainability of fish and shellfish populations, fostering greater biodiversity and ecosystem health while generating income through ecotourism and sustainable fishing. If managed appropriately it also provides means to protect from the over-exploitation of local resources from large export markets.

Vulnerability Reduction through Environmental Conservation

Good stewardship of the available land is necessary to maintain agricultural productivity, ensure economic growth, protect biological and cultural diversity, maintain the watersheds that provide clean water and meet the increasing food demands of a growing population. Restorative ecological actions that preserve and rehabilitate the coral reefs, beaches and ocean fronts foster preservation and protection from environmental degradation while providing opportunities to enhance reseeding and repopulating aquatic species support local adaption to climate change. Establishment of Marine Protected Areas (MPAs) is an example of a strategy that has been and can continue to contribute to the sustainability of fish and shellfish populations, foster greater biodiversity and ecosystem health and generate income through ecotourism and sustainable fishing. If managed appropriately it also provides means to protect from the over-exploitation of local resources from large export markets.

Improved Forecasting for Disaster Preparedness and Prevention

Proactive approaches are required to develop resilient management strategies that protect and conserve marine and terrestrial habitats from the impacts of climate change. Forecasting seasonal shifts in habitats and species will inform adoption of management strategies to sustain farming, fishing and aquaculture operations as well as to identify suitable future food production opportunities. Over the long-term, rising sea levels will impact the island atolls and shoreline, however "living" shorelines have been demonstrated to have beneficial impacts to minimize shoreline erosion. Site surveys exist that provide good characterizations of local habitat and should be used to inform MPA establishment, management and sustainability, and the potential establishment of zones specifically delineated for aquaculture.

As the FSM's economy and environmental well-being is tied to the health of the nation's ocean ecosystem, ocean observation and ocean monitoring capacity building should be considered. The development of environmental monitoring strategies can be informed by global and regional forecasts. Working with the international community, improved forecast skills could be achieved by densifying the atmosphere and ocean observation to inform regional forecasts models. Beyond the climate forecast implications, these efforts have the potential for shorter term weather forecasting, storm surge modeling and potential flooding. These efforts could be facilitated by ensuring the FSM helps steer the development of western Pacific Global Ocean Observing System (https://www.goosocean.org/). These assets combined with international partnerships can be used to assist in the development of the FSM preparedness plans.

Reducing health and nutrition vulnerabilities through access to local, healthy foods

Nutritional security is provided through consumption diets that comprise safe, healthy foods rich in micronutrients. At present, almost half of all women and over one-third of all men in the FSM are classified as obese (WFP Regional Food Security Atlas of the Pacific), which has been associated with an increased risk for nutrition-related chronic diseases, such as type 2 diabetes, hypertension, cardiac disease, increased absenteeism, and early mortality (FAO 2021). The cluster of disease and consequences of consuming a highly processed diet extends to decreased economic opportunities, increased health care costs, and a stress on the economy that is unnecessary and preventable.

Increasing access to local, healthy foods is a cost-effective way to increase the health of the FSM population while supporting sustainable economic growth through the development of local agriculture. The 2022–2023 data from the Green Climate Fund food security baseline survey for farming households showed high interest in consuming local foods in place of imported foods if made available. The majority of those surveyed in Yap and Pohnpei said they would prefer to consume locally produced vegetables, fruits, meats and fish. The survey also revealed an interest in substituting specific imported foods now consumed with locally produced replacements. More than 70% of those surveyed in Pohnpei and Yap indicated interest in replacing imported rice with local, nutrient-rich starch crops such as taro and breadfruit. A majority of respondents in Yap and Pohnpei also expressed interest in replacing cow's milk with locally produced coconut milk if made affordable and available.

Establishing an Inventory of Local Famine and Emergency foods

Historically, local farmers in the FSM have relied on a wide array of "emergency" or "famine foods" that are resilient to climate disasters such as hurricanes, droughts or plant pathogens. A survey carried out in the 2000s (Balick 2009) listed a handful of the potentially edible famine/emergency foods, and further investigation into this area is warranted. Ethnobotanical surveys include interviewing knowledgeable people about native or introduced species that can be eaten in times of famine, if and when conventional crops and imports are not sufficient to feed the community. The intention would be to identify species widely found in the FSM that can supplement caloric needs, rather than taking over for the more conventional foods. One species that can be used as a caloric supplement is *Tacca leontopetaloides*, which is not widely cultivated, but is easy to grow. Species such as *Adenanthera pavonina* (edible seeds and leaves when processed correctly), *Bambusa vulgaris* (young shoots are eaten), *Asplenium nidus* (young dark green leaves containing high levels of provitamin A, lutein and zeaxanthin) and *Cordia subcordata* (ripe fruits are edible) are just a few of the many species that could help supplement caloric and/or nutritional needs. This information would then be made widely available to the community.

Improved Pest management

Climate change is altering the movement and prevalence of many insects, arthropods and microbes, pests that impact humans, animals, marine organisms and plants. Since temperature is the most important environmental factor affecting insect population dynamics (Schneider et al. 2022), global climate warming could trigger an expansion of their geographic range, increased overwintering survival, increased number of generations, increased risk of invasive insect species and insect-transmitted plant diseases, as well as changes in their interaction with host plants and natural enemies (Skendzic et al. 2021) and alterations to forest insect dynamics (Liebhold and Bentz, 2011). Some of these insect and pests also carry infectious and noninfectious diseases that can be transmitted to humans and agricultural and marine food species, and others can result in significant crop and forest loss. In combatting this, scientists are using strategies that mitigate such risk. These include improving the plants genetic resistance to biotic (fungal, bacterial, insect) and/or abiotic stress (e.g., salt water, drought/heat) to developing an integrated pest management approach that combines using the best germplasm with environmentally sustainable management.

Improved pest and disease management is essential to prepare for anticipated increase in pests and food crop diseases that are now or can threaten the local food systems and biodiversity. Such management plans should include development of climate and disease resilient local food crops, training in ecologically sensitive pest management strategies that do not introduce harmful toxins into FSM's vulnerable ecosystems, and the elimination of invasive species. The introduction of legally approved pesticides and herbicides need to be approached with caution as the short- term benefit for their particular application(s) needs to be balanced with certainty that the users (applicators) are duly trained, and the processes associated with their use including safe and clean area for calibrating the spray equipment, cleaning the spray equipment, the proper storage, disposal of such toxic products can be handled safely, and the assurance the chemicals do not end up in the water supply and/or into the community households. Ongoing training programs relative to handling and safety, available options are needed at the community and state level. Monitoring insects and pests locally and sharing the information widely would be beneficial to communities, allowing them the opportunity to respond proactively.

Protecting Biodiversity through Climate-Smart Agriculture and Agroforestry

The FSM's traditional agriculture systems are based on biotic diversity and the practice of polyculture (e.g., such as agroforestry) rather than larger-scale monoculture. Properly managed, these home garden / agroforestry systems can be highly productive while also contributing important environmental services such as soil stabilization, carbon sequestration, clean water and air. Traditional agriculture and agroforestry land-use systems integrate agriculture with tree forest harvesting and livestock within the same land for environmental, economic and social benefits. The FSM agroforestry systems evolved over hundreds of years under different physical, cultural and socio-economic conditions.

Current climate-smart, climate-resilient agroforestry efforts build upon traditional practices while exploring and integrated new approaches and training for Soil Management; Water Management; Crop Management; Tree & shrub Management; Livestock Management; Climate Change and Disaster Management; Tools and Equipment; Agroforestry Communities; Agroforestry for Enhancing Biodiversity; Agroforestry for Economic Development; and Agroforestry Research.

Climate-smart conservation agriculture approaches, designed to helps farmers to maintain and boost yields and increase profits while reversing land degradation protecting the environment in the midst of climate change, are based on the interrelated principles of (1) minimal mechanical soil disturbance, (2) permanent plant-based soil cover, (3) crop diversification through rotation or intercropping (Tuivavalagi, 2022).

Suggested Paths Forward to strengthen FSM Food Resiliency

FSM as a Nation: The majority of the GCFSAP020 survey respondents expressed interest in replacing imported foods with locally produced foods. Respondents said that they were willing to replace imported rice with local starch crops such as taro and breadfruit and replace imported milk products with coconut milk products for cooking if they are more available and affordable. More than 80% of respondents in all four states would be more willing to buy locally produced foods if they knew that those foods were healthier than imported and/or processed foods. This information is important because it shows that there is an enormous potential to expand the market of locally produced foods, with a strong demand that can be further increased by educational campaigns showing the environmental and personal health implications of consuming fresh, local foods. Paths forward in each state would work most effectively with proactive public-private, community-based partnerships involving for example, COM, CRE, local high schools, vocational with the different offices in the state and federal government. With a combined public and private sector commercial focus FSM can develop short- and long-term programs, coupled with state and national policies enabling the further protection of the environment, reversal of current ecological degradation and sustainable production/collecting and catching of natural resources for economic and food security applications.

Suggested Sustainable Development Paths Forward by FSM State:
Paths forward for each state were developed based on the results from the farming household survey, commercial producer survey, focus group meetings, and personal conversations during the visits. Recognizing that there are many common overlapping actions for paths forward for each state, the following offers a selected illustrated project that can improve household food security and strengthen community and household resilience to climate change for each state. In general, recommendations for each state, several paths forward for agribusiness and aquaculture development are presented with each needing to be aligned with state goals and objectives in support of food security activities that can mitigate risk to climate change, significantly reduce the importation of fresh and processed products that can be grown and sold in each state.

While the following suggested paths for each state focuses on food security and environmental conservation in face of climate change, each state food security sustainable development plans would benefit by considering (I) Leadership, governance, and co-ordination of local food system development; (2) Improving and establishing public policies that impact food availability, cost, access, and consumption; (3) Increasing and improving the sustainable production and productivity of local agriculture and marine food production; (4) Supporting enterprises in agriculture and aquaculture that link food producers to local (schools, hospitals government) and export markets; (5) Prioritizing access to and awareness of local, nutritious foods including knowledge of traditional food production and preparation practices and conservation of natural resources that yield food; (6) Strengthening and reinforce proven strategies to improve nutrition for all FSM residents but especially most vulnerable including women and children; (7) Increasing educational and training opportunities in food security related fields; (8) Strengthening emergency preparedness and responsiveness; and of course always accompanied with (9) Effective monitoring and evaluation.

Suggested Paths Forward for Chuuk:
Among the FSM states, Chuuk is most advanced in commercial production and very strong in developing grower and marketing associations. Interviewees expressed serious interest in expanding both their

terrestrial and ocean/aquaculture and in developing added-value to their current food production so that food processing, packaging, marketing and sustainability becomes integrally linked to their production and harvesting. There is a great awareness and concern to preserve and protect and not over-exploit their natural resources. Given the adverse weather and storms, programs to protect their homes and environment is a major concern and need.

1. Value addition: Adding value to crops by processing them into finished products such as chips, jams, and sauces can increase their value and create new markets. This can also lead to the development of cottage industries and support small-scale entrepreneurs.
2. Diversification of crops: Chuuk's agricultural sector is currently dominated by taro and yam. Diversifying the crop base to include high-value crops such as fruits, vegetables, and spices can create new opportunities for agribusiness development. These crops can be sold locally and exported to other markets, including neighboring islands.
3. Aquaculture: Chuuk is surrounded by water, and aquaculture can be a promising area for agribusiness development. This can include the production of fish and other seafood, as well as seaweed farming. These products can be sold locally and exported to other markets, including neighboring islands.
4. Sustainable agriculture: Adopting sustainable farming practices can improve the quality of Chuuk's crops, increase productivity, and create a niche market for high-quality, eco-friendly products. This can also attract eco-tourism and contribute to the conservation of Chuuk's natural resources.
5. Technology adoption: Adopting new technologies, such as precision farming and greenhouse farming, can improve crop yields, reduce input costs, and create new markets for crops. This can also support innovation and entrepreneurship in the agribusiness sector.
6. Public-private partnerships: The government of Chuuk State can partner with private sector entities to develop the agribusiness sector. This can include developing infrastructure such as storage facilities, providing training and technical assistance to farmers and fishers, and establishing market linkages to ensure that farmers have access to markets for their products.
7. Development of export markets: Chuuk State can explore export markets for its agricultural and aquaculture products. This can include working with neighboring islands, such as Guam and Palau, to develop trade relationships and export products to international markets.

Overall, developing the agribusiness sector in Chuuk State requires a multi-faceted approach that involves adding value to crops, diversifying the crop and aquaculture base, promoting aquaculture, adopting sustainable farming practices, adopting new technologies, establishing public-private partnerships, and developing export markets. By pursuing these paths, Chuuk State can create new opportunities for economic growth and development and ensure food security for its population.

Suggested Paths Forward for Kosrae:

Those in Kosrae are very proud and committed to expanding and strengthening their fishing and aquaculture industries. Programs focused on maintaining aquatic species diversity and water quality were expressed as priorities. Shipping was identified as a key constraint. Thus, improving national and state policies and port authorities to improve the shipping of agricultural products out and agricultural supplies and equipment into Kosrae were noted as key factors to strengthen their food security. A need to ensure reliable and affordable transportation to other islands, nations and territories of fresh and processed plant and fish products is key to all of FSM.

1. Value addition: Adding value to crops by processing them into finished products such as chips, jams, and sauces can increase their value and create new markets. This can also lead to the development of cottage industries and support small-scale entrepreneurs.
2. Diversification of crops: Kosrae's agricultural sector is currently dominated by taro and yam. Diversifying the crop base to include high-value crops such as fruits, vegetables, and spices can create new opportunities for agribusiness development. These crops can be sold locally and exported to other markets, including neighboring islands.
3. Organic and sustainable agriculture: Adopting organic and sustainable farming practices can improve the quality of Kosrae's crops, increase productivity, and create a niche market for high- quality,

eco-friendly products. This can also attract eco-tourism and contribute to the conservation of Kosrae's natural resources.

4. Aquaculture: Kosrae is surrounded by water, and aquaculture can be a promising area for agribusiness development. This can include the production of fish and other seafood, as well as seaweed farming, sea grapes, ornamental clams, and giant clams. These products can be sold locally and exported to other markets, including neighboring islands.

5. Technology adoption: Adopting new technologies, such as precision farming and greenhouse farming, can improve crop yields, reduce input costs, and create new markets for crops. This can also support innovation and entrepreneurship in the agribusiness sector.

6. Public-private partnerships: The government of Kosrae State can partner with private sector entities to develop the agribusiness sector. This can include developing infrastructure such as storage facilities, providing training and technical assistance to farmers and fishers, and establishing market linkages to ensure that farmers have access to markets for their products.

7. Development of export markets: Kosrae State can explore export markets for its agricultural and aquaculture products. This can include working with neighboring islands, such as Guam and Palau, to develop trade relationships and export products to international markets.

Overall, developing the agribusiness sector in Kosrae State requires a multi-faceted approach that involves adding value to crops, diversifying the crop and aquaculture base, adopting sustainable farming practices, promoting aquaculture, adopting new technologies, establishing public-private partnerships, and developing export markets. By pursuing these paths, Kosrae State can create new opportunities for economic growth and development and ensure food security for its population

Suggested Paths Forward for Pohnpei:

Pohnpei's strength in agroforestry could be expanded upon. With so many people sharing land, and much still undeveloped, the increased sustainable cultivation, coupled by the eradication of invasive weeds open up land and opportunity for strengthening farming. With the state involved for many years in the R&D with hatcheries and small projects in aquaculture by farming communities, each is poised to move ahead with the right investments and support for commercialization using a private sector or a public: private sector approach. Among all FSM, the raising of livestock, mainly pigs, has been shown to be successful. With champions in local foods, the development of food products based upon breadfruit and taro and other crops creates promising opportunities if guided with an environmental/cultural/economics sustainable commercial focus.

1. Diversification of crops: Pohnpei's agricultural sector is currently dominated by staple crops such as taro, yam, and cassava. Strengthening the value chain of these crops as well as diversifying the crop base to include high-value crops such as fruits, vegetables, and spices can create new opportunities for agribusiness development. These crops can be sold locally and exported to other markets, including neighboring islands and regionally to US military bases and others.

2. Organic and sustainable agriculture: Adopting organic and sustainable farming practices can improve the quality of Pohnpei's crops, increase productivity, and create a niche market for high- quality, eco-friendly products. This can also attract eco-tourism and contribute to the conservation of Pohnpei's natural resources.

3. Value-addition: Adding value to crops by processing them into finished products such as juice, jams, sauces, chips, can increase their value and create new markets. This can also lead to the development of cottage industries and support small-scale entrepreneurs. Establishing local collecting centers can be used for community-based processing facilities and/or transportation to larger fresh market wholesale and retail markets and also used for gathering staple local crops for drying and processing into other food products (chips, flour, etc.). Centralized food innovation centers serving as an incubator for processing may help small growers to participate and produce final high-value products. The Innovative

Center at COM can serve as a model research site while commercially operated private sector or public: private sector incubators/distribution facilities could actually engage in commercialization in support of local food product manufacturing. A small incubator center for food processing and preservation could be transformative in processing and packaging of taro and breadfruit chips, and other food products.

4. Technology adoption: Adopting new technologies, such as precision farming and greenhouse farming (protected cultivation) can improve crop yields, provide year-round supply of fresh produce), reduce input costs, and create new markets for crops. This can also support innovation and entrepreneurship in the agribusiness sector. Introduction of leap-frog technology (technologies found to be developed elsewhere and adaptable to a new area) into Pohnpei could include low-cost affordable coolers for extension of shelf-life and improve food safety with solar refrigeration systems.

5. Aquaculture: Aquaculture has been studied for a long-time yet the transition from R&D to commercial hatcheries and commercial enterprise development is still in its embryonic stage and can be a promising area for agribusiness development. This can include the production of fish and other seafood, as well as seaweed farming, sea cucumbers, and rabbitfish. These products can be sold locally and exported to other markets, including neighboring islands.

6. Agroforestry: Agroforestry is common and one of the strengths in Pohnpei. The practice of integrating trees with crops to create a sustainable farming system. It can improve soil fertility, protect crops from extreme weather, and create new markets for timber and non-timber forest products. This can also contribute to the conservation of Pohnpei's forests and biodiversity. Toward this end, the continued focus on elimination of invasive weeds is important.

5. Public-private partnerships: The government of Pohnpei should consider partnering with private sector entities to develop the agribusiness sector. This can include developing infrastructure such as storage facilities, providing training and technical assistance to farmers, and establishing market linkages to ensure that farmers have access to markets for their products. Such pilot programs in egg and poultry production, greenhouse production, aquaculture production and the establishment and strengthening of the COM Entrepreneurial Center are among a few promising areas.

6. Focus on ecological restoration of coral reefs and mangrove forests

7. Environmental and Cultural-Based Tourism: Strategic expansion into tourist industry based upon surfing, the World Heritage site and more can not only generate significant job creation opportunities but also create demand for local foods, and a resurgence in local arts and crafts. Public policy relative to charging non-FSM citizens special visa entry with funds at least partially going toward the development of environmental preservation and maintenance of parks and forests.

Overall, developing the agribusiness sector in Pohnpei requires a multi-faceted approach that involves diversifying the crop base, adopting sustainable farming practices, adding value to crops, adopting new technologies, promoting agroforestry, and establishing public-private partnerships. By pursuing these paths, Pohnpei can create new opportunities for economic growth and development and ensure food security for its population under changing climate.

Suggested Paths Forward for Yap:

One of Yap's great strengths is their continued practice of traditional culture and respect for traditional methods of sustainable food production. Most interviewees expressed strong interest in working within the traditional system along with the modern government system to ensure a vibrant commitment to environmental and cultural long-term sustainability. Given the serious and continued issues with coastal and soil erosion, and saltwater inundation (here and in other FSM states too), programs to protect and rehabilitate these vulnerable areas are a priority for long-term household food security. Introduction of perennial nitrogen-fixing trees/shrubs and other plants, coupled to the introduction of salt-tolerant plants with appropriately-scaled technologies for fresh fruits and vegetables would improve household food security.

1. Value addition: Adding value to crops by processing them into finished products such as chips, jams, and sauces can increase their value and create new markets. This can also lead to the development of cottage industries and support small-scale entrepreneurs.
2. Diversification of crops: Yap's agricultural sector is currently dominated by taro and yam. Diversifying the crop base to include high-value crops such as fruits, vegetables, and spices can create new opportunities for agribusiness development. These crops can be sold locally and exported to other markets, including neighboring islands.
3. Organic and sustainable agriculture: Adopting organic and sustainable farming practices can improve the quality of Yap's crops, increase productivity, and create a niche market for high- quality, eco-friendly products. This can also attract eco-tourism and contribute to the conservation of Yap's natural resources.
4. Agroforestry: Agroforestry is the practice of integrating trees with crops to create a sustainable farming system. It can improve soil fertility, protect crops from extreme weather, and create new markets for timber and non-timber forest products. This can also contribute to the conservation of Yap's forests and biodiversity.
5. Technology adoption: Adopting new technologies, such as precision farming and greenhouse farming, can improve crop yields, reduce input costs, and create new markets for crops. This can also support innovation and entrepreneurship in the agribusiness sector.
6. Public-private partnerships: The government of Yap State can partner with private sector entities to develop the agribusiness sector. This can include developing infrastructure such as storage facilities, providing training and technical assistance to farmers, and establishing market linkages to ensure that farmers have access to markets for their products.
7. Development of export markets: Yap State can explore export markets for its agricultural products. This can include working with neighboring islands, such as Guam and Palau, to develop trade relationships and export products to international markets.

Overall, developing the agribusiness sector in Yap State requires a multi-faceted approach that involves adding value to crops, diversifying the crop base, adopting sustainable farming practices, promoting agroforestry, adopting new technologies, establishing public-private partnerships, and developing export markets. By pursuing these paths, Yap State can create new opportunities for economic growth and development and ensure food security for its population.

Tropical Forests of Pohnpei. Photo Credit: Micah Seidel, Rutgers University

Least Expensive Adaptation Practices

Climate Smart Agriculture Techniques:

1. Agroforestry Systems for Sustainable Food Production
2. Climate Resilient Crops and Cropping Systems
3. Sustainable Land Management
4. Sac and Container Gardening and Composting
5. Climate Resilient Water Management Systems for Smallholder Farmers
6. Zero Energy Cool Chamber: Post Harvest Handling

Climate Resilient Agriculture Module 1: Agroforestry Systems for Sustainable Food Production in the Federated States of Micronesia

Erik Gomes, Tori Rosen, Dena K. Seidel, Ramu Govindasamy and James E. Simon

Rutgers Center for Agricultural Food Ecosystems

Agroforestry is a type of land management that consists of combining trees and/or shrubs with crops and/or livestock in order to maintain economic productivity, cultural utility, and ecological stability of agricultural and forestry systems (AFTA, 2024; Elevitch, 2000).

Agroforestry has been traditionally practiced in the Federate States of Micronesia and other Pacific Islands for thousands of years (Manner, 1993). Agroforestry utilizes the natural features of an ecosystem by promoting the symbiosis of plants and animals in a self-sustaining system. Such systems can provide comparative crop yields when compared to traditional monoculture systems. Agroforestry systems create strong vibrant ecosystems rich in plant and animal life and rich in humus and microbes leading to nutrient recycling. Considering the below environmental and economic benefits, farmers can increase their income per area, while meeting sustainable development goals (Waldron et al., 2017).

Environmental Benefits	Economic Benefits
• Water quality enhancement[1] • Carbon sequestration[1] • Enhanced soil productivity through nitrogen fixation, nutrient cycling, and deep capture of nutrients[1,2,4] • Reduced soil erosion from heavy rain and winds[2,4] • Birds and insect pollinators benefit from increased habitat diversity[2] • Reduced likelihood of pest outbreaks from increased plant diversity[2] • Increased shade from excessive sun and heat, reduce canopy and soil temperatures[1,2,4]	• Mixed short- and long-term returns on investment from varied harvest intervals among annual and perennial crops[2] • Reduced dependence on external inputs (e.g. chemical fertilizers, pesticides)[2,3] • Additional income opportunities from tree-based products[3] • Additional income from Non-Timber Forest-based products • Decreased crop loss due to heavy winds and flooding[2]

[1]Nair, 2011; [2]Elevitch, 2014; [3]Waldron et al., 2017; [4]Quintus et al., 2019.

Food insecurity remains an issue for Micronesians. In the recent GCF Baseline Survey (Rutgers University, 2024), almost 34% of respondents in the FSM mentioned that they sometimes worried they wouldn't have enough healthy and nutritious food to eat, while 22% indicated that they sometimes ate less than preferred because there wasn't enough money for food. That suggested the lack of available 'cash' to spend at a formal grocery/supermarket. Yet, for decades, agroforestry systems have provided a wide range of foods and plant-based products to farmers and communities over the entire year. Agroforestry systems have the potential to improve the availability of food, often reducing the 'travel time' to get to foods that can when ready can be harvested. Thus, a reliance on and strengthening of agroforestry can reduce food insecurity in the region, as this activity has been reported as an alternative solution and a strategy for food security in Small Island Developing States (Johansen and Thulstrup, 2021).

Agroforestry is currently being practiced by many farming households now in the States of the FSM as reported in the recent GCF baseline survey for FSM farming families (Rutgers University, 2024). Agroforestry thus also offers the opportunity to build upon its own historically recognized rich traditional 'farming systems' while now also being able to incorporate modern technologies into the already existing framework of traditional local knowledge. The combination of using traditional local knowledge in support of the preservation and conservation of the forests, coupled with the recognition that modern or newer technologies including the replanting and incorporation of improved climate-resilient food crops into the forest can increase the productivity of the system including an increase in the available foods that can be wildcrafted and harvested as well as other plant-based products needed.

Moreover, The Federated States of Micronesia (FSM) is particularly vulnerable to the projected impacts of climate change, especially regarding a higher incidence of flooding from sea level rise, rising temperatures, and changes in weather patterns, which threaten food security. Again, from the GCF Baseline Survey (Rutgers University, 2024) many household families reported their perception that there has been a rise in temperature, increased periods of drought and excessive heat, and a change in the time and frequency of rains. The practice of Agroforestry can be a key component to offset these observed changes in climate. An agroforestry system creates a hedge and resiliency against such abiotic stressors and can mitigate the risk of crop loss compared to monocultural crop production. As such, well-managed, agroforestry systems work as a buffer and climate-resilient production system in the region.

Will agroforestry limit food production?

It is a common misconception that agroforestry systems allow for lower food productivity when compared to monocultures. Yet, well-managed, agroforestry systems can be highly productive, and at times surpass the yields of traditional monoculture systems of food production (Lehmann et al., 2020), improving food and nutritional security and sovereignty, while mitigating environmental degradation (Nair, 2007). Often the additional 'minor products' that come out of an agroforestry system are less documented and as such under-recognized and under-valued, yet may also contribute to the lifestyle and health/nutrition of the community and serve as an income-generating opportunity or provide the raw materials (e.g. building materials for houses, fences, animal/poultry housing, boats, etc.) that may not otherwise have been affordable and available for use. Mushrooms, honey, insects, spices, botanicals, and medicinal plants in a global context are often cited as such undervalued non-timber forest products that come from such agroforestry systems.

Agroforestry systems are more complex than monocultures, demanding long-term planning, good management, and a holistic understanding of the ecosystem, demanding a multidisciplinary approach and a collective effort including local traditional knowledge, farmers, scientists, and government workers, among others. In the following sections, we highlight the main practical aspects of agroforestry systems as well as some possible scenarios for the strengthening of this traditional food production system and practice in the FSM. We also mention some of the concerns with agroforestry, notably if there is 'excessive land clearing of some forested areas' for the introduction of very high-value crops such as sakau, based upon the kava plant (*Piper methysticum)*.

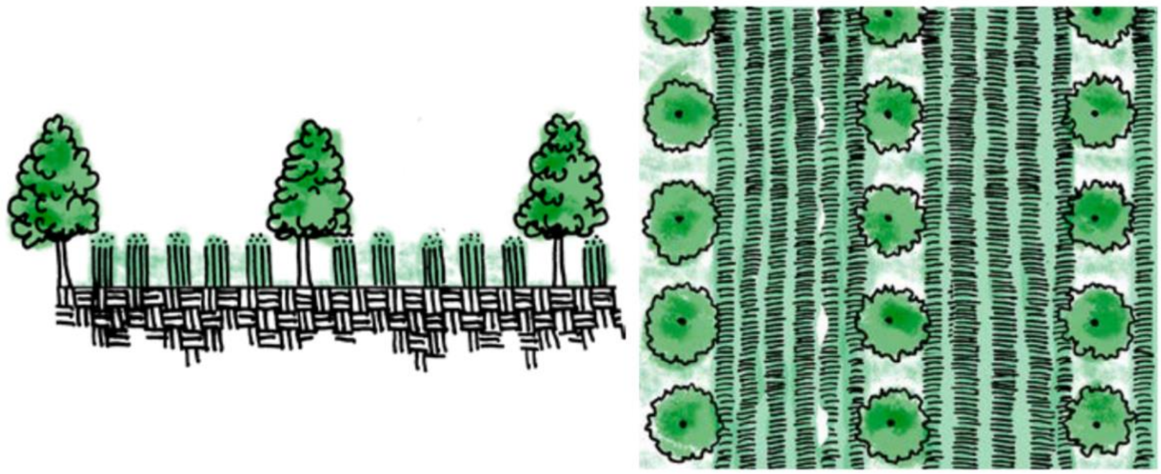
How can agroforestry be used for non-food-related products?

In the FSM, forests are not only used as food crops but serve many cultural and ecological functions. Timber can be used to create furniture, tools, instruments, fishing equipment, containers, and firewood. Trees provide protection from sun and heat for livestock and farmers, while their root systems reduce soil erosion and reach nutrients far below the roots of annual crops. Trees serve as a barrier to salt spray, typhoons, and heavy winds. Some nitrogen-fixing legumes such as *Leucaena leucophylla* have many uses as animal food, for wood, energy, are fast growing and serve to stabilize soils and thereby reduce soil erosion while providing nitrogen and other nutrients to the soil for other plants and crops to use. Forests are a source of traditional medicines and insect repellants. Forests are also places of meeting sites and ritualistic exchange (Elevitch, 2000).

Types of agroforestry

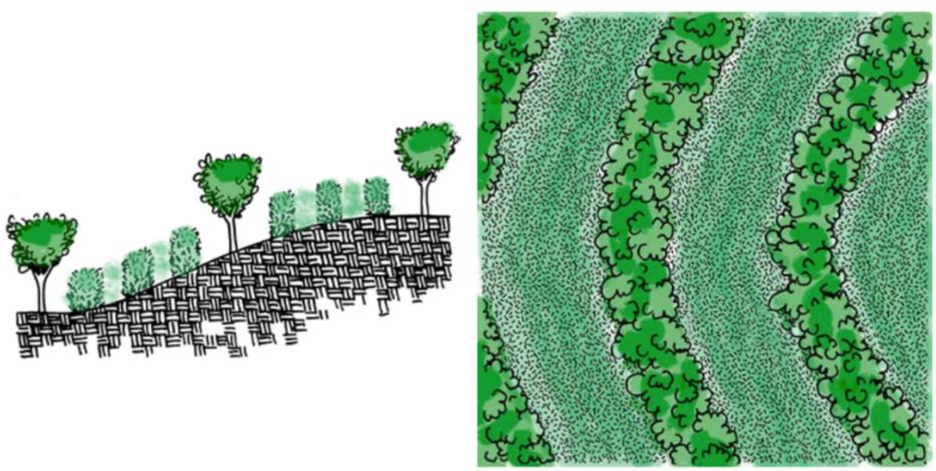
The main traditional agroforestry systems in Micronesia are mixed tree gardening, intermittent tree gardening, kitchen and backyard gardens, and wetland taro cultivation (Manner, 1993) and the mixed cropping system in which food crops are introduced into the forest providing mixed canopies and crops within a dense area. Each of these systems has been reviewed by Manner (1993). Thus in this module we will focus on the broader, common Pacific Island agroforestry practices as described by the United States Department of Agriculture (USDA, 2024) and *A Grower's Guide to Pacific Island Agroforestry Systems, Information Resources, and Public Assistance Programs (*Elevitch, 2014), which we present below, to serve as a basic illustrative guide for starting or understanding an agroforestry system, or to adapt already existing systems that have potential for increased productivity.

1. Alley cropping: the planting of rows of trees and/or shrubs to create alleys in which crops are produced.



Alley cropping schematic (Elevitch, 2014)

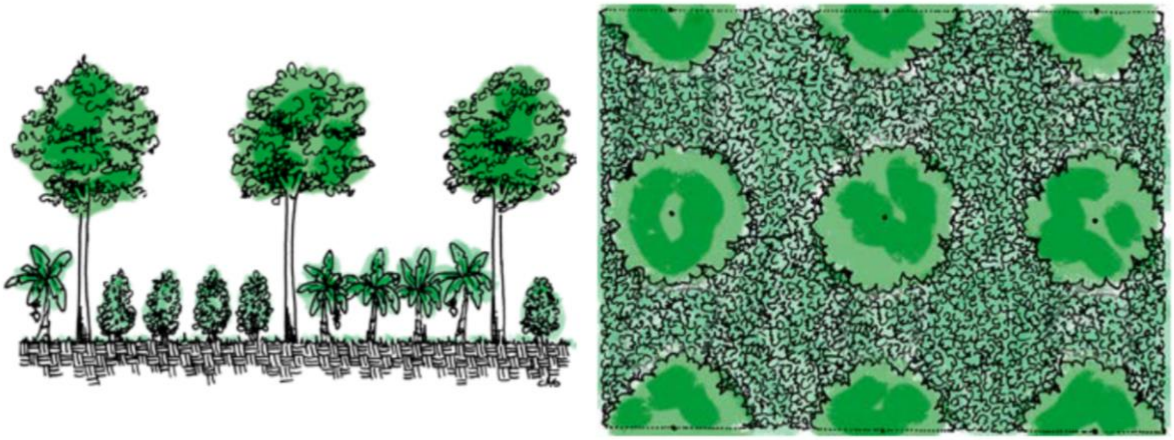
2. Contour hedgerows: a type of alley cropping on sloping lands. The rows are created or adapted to go in directions that protect the soil such as across slopes. Such systems produce mulch and animal fodder while slowing water runoff and reducing sedimentation in nearby bodies of water.



Contour hedgerow schematic (Elevitch, 2014)

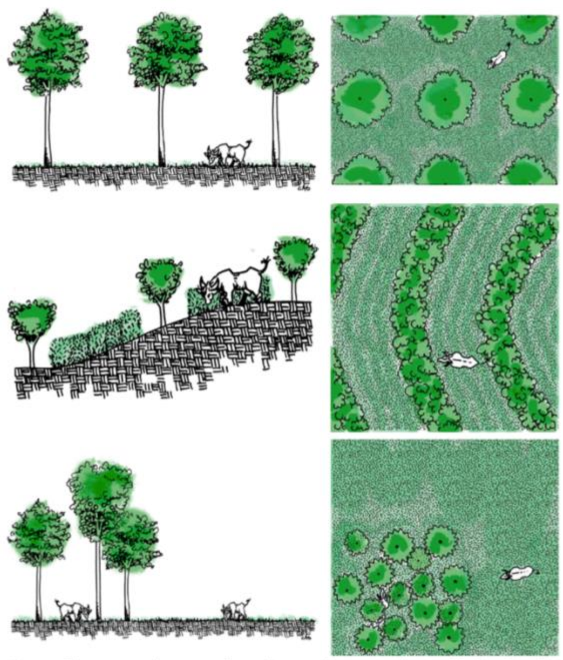
3. Forest farming: the cultivation of crops under the protection of a tree canopy. While this illustrative diagram by Elevitch (2014) provides a easy to see visual, in reality forest farming is often not so clear with trees in uniform rows or equidistant from each other. Nor, where understory trees and shrubs and bushes are also in rows and equidistant. That is in forest systems, it far more 'messier' with trees and understory shrubs and differential canopies developing in what may even appear as a random pattern. Nevertheless, the key is to understand the light requirements of the forest plants, to introduce a wide range of plants into the system and to utilize open areas and the slope and orientation to almost

maximize the planting of perennial food crops within a complex ecosystem.



Forest farming schematic (Elevitch, 2014)

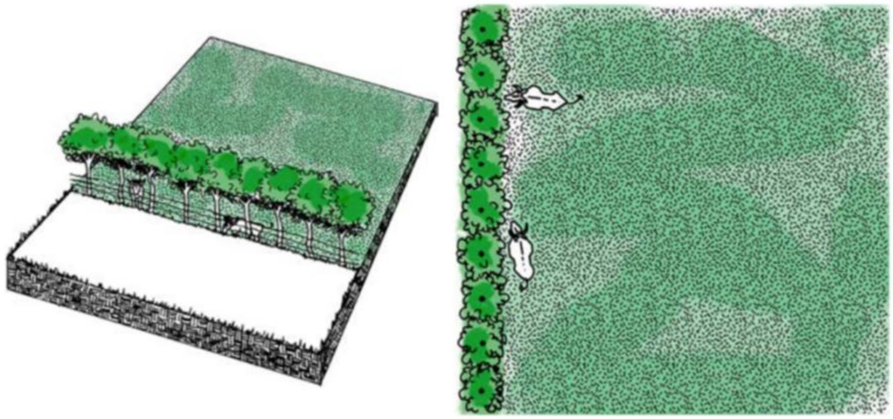
4. Silvopasture: the combination of trees with forage and animal production. This system is common in other countries where open land is more plentiful and animal production and livestock (goats, sheep, cows) are more common. In the FSM, with farms characterized in general by smaller land holdings, limited available public lands, and where little production is oriented to forage crops. this a less familiar system. Yet, in certain areas (e.g. Yap) it may provide some ideas for growers and communities. With animals and poultry often 'free range' the incorporation of grasses, legumes, and perennial crops (e.g. Moringa, *Leucaena leucophylla*) into food systems is desirable, particularly as a strategy to raise plants and plant waste for animal and poultry feedstock for pigs and poultry.



Silvopasture schematic (Elevitch, 2014)

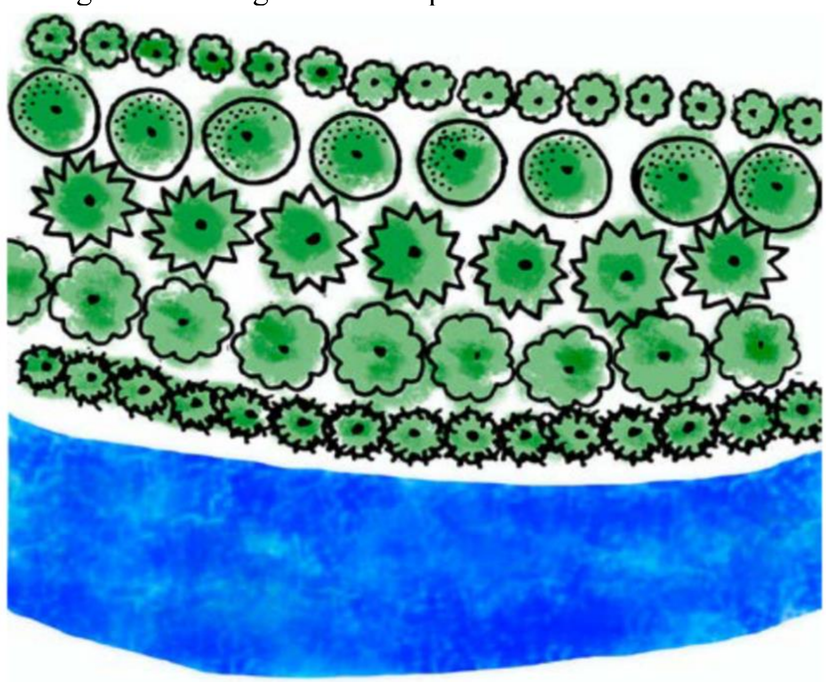
5. Living fence: trees and/or shrubs create a natural enclosure for livestock. Systems can use live plants to serve as buffer for security, to 'hold' animals, livestock, poultry or to delineate

property lines or different enterprises. The selection of such plants can also be done to provide additional value to the household- (e.g. wood, fruits, N-fixing leguminous trees or shrubs, fruits, other edibles, live trees upon which climbing vines such as pepper can be trellised up and grown). Such living fences also provide shade and act as wind barriers.



Living fence schematic (Elevitch, 2014)

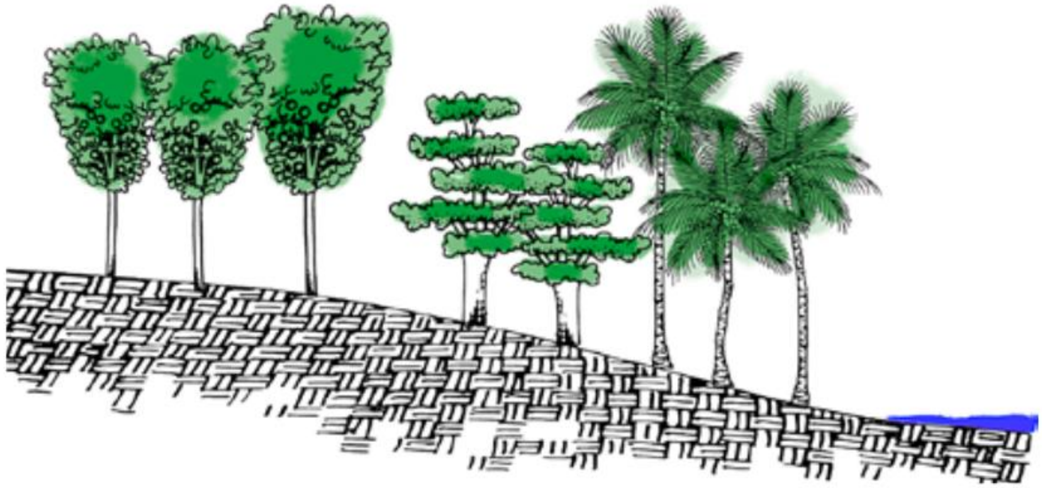
6. Riparian forest buffers: Combination of trees, shrubs, and/or other perennial plants in an area adjacent to a stream, lake, or wetland primarily to provide conservation benefits, such as biodiversity conservation, water temperature control and protection of the water source. Riparian buffers can also include trees and shrubs that produce harvestable products and can range in their heights and canopies.



Riparian forest buffers schematic (Elevitch, 2014)

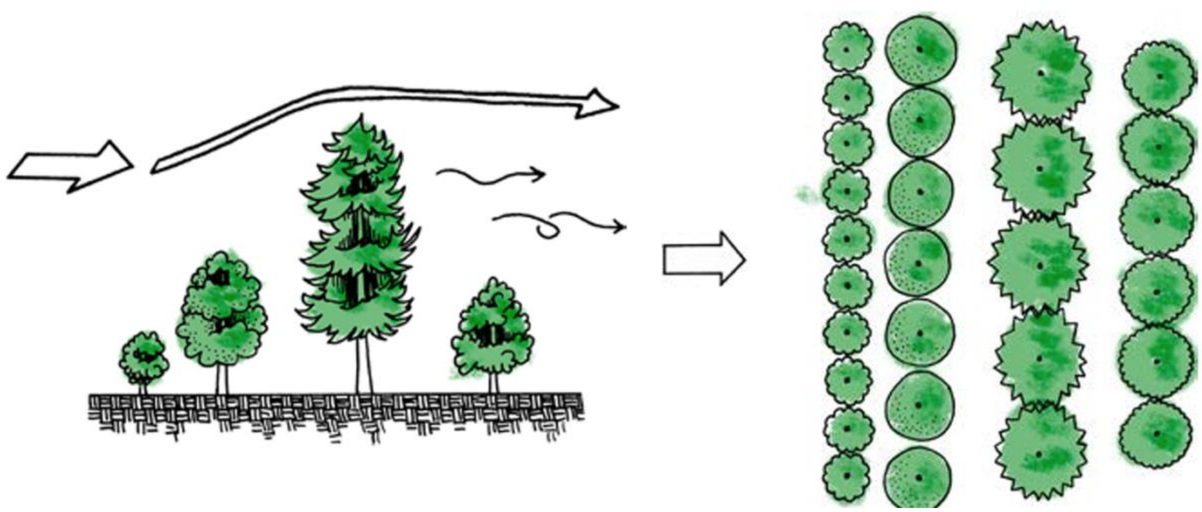
7. Coastal strand forest buffers: dense trees, shrubs, and vines along the shoreline that serve to break strong winds and saltwater sprays and in more extreme cases tidal surges and

typhoons. Whenever possible the introduction and expansion of mangrove trees of themselves provide significant benefits to the shoreline and coastal areas and have been used to both stabilize and extend over time the land mass.



Coastal strand forest buffer schematic species (Elevitch, 2014)

8. Windbreaks: Use of planting of trees and shrubs relative to the direction of incoming winds and heavy rains are used to slow the wind, protect crops from wind damage, and also to reduce soil erosion, among other benefits. In addition to slowing down the wind, the properly planned planting of trees can also provide shade for livestock, recreational opportunities, production of wood and non-timber forest products, enhancement of biodiversity, wildlife habitat, carbon storage, pollinator habitat, and soil and water quality protection, among other benefits (USDA, 2024).



Windbreaks schematic (Elevitch, 2014)

Which type should I implement?
First, it is important to consider what you currently have and are doing. Take time to identify and see what other successful neighbors or lead farmers are doing with their farming and forests and what they will share with you. If your forest has been neglected for many years or if you have open areas, recognize it may take several years to develop a canopy for a forest farming system. So, if there is already a forest on your land, it would be preferential to use this system rather than removing trees from the property to then just build an alley cropping system.

When implementing a new system from the ground up, one study found that alley cropping and silvopastoral systems were the most sustainable to boost farm income in their country (Singh and Singh, 2023). Yet, such studies are site and country specific. FSM is different, so select and embrace the agroforestry system(s) that best fits into your own land and area while focusing on the core pillars of an agroforestry system. Such core pillars to consider when deciding on which path to take in an agroforestry system are your long-term goals for the land, the current situation of the land in terms of preexisting structure intended crop production and your needs, and the local components of the agroforestry system, which will be discussed in the next section.

Main components of an agroforestry system.
Agroforestry systems are multi-layered agro-ecosystems, therefore possessing numerous components, here we describe the most common ones, based largely upon a Food and Agriculture Organization of the United Nations report (FAO, 2024):

1. Environment: Identify the initial conditions of the land, including topography, soil characteristics, present plant biodiversity (e.g. what plants are now present), water availability, soil conditions, wind occurrence, and history of land use. These factors will likely define the choice of the other components in your agroforestry. Availability of labor, capital, and long-term goals should also be considered when deciding which components to use in your system.
2. Trees/shrubs: The native indigenous or naturalized trees/shrubs are fundamental components of the agroforestry system. When seeking to establish an agroforestry system from open available land be careful about choosing the tree species to be employed. Consider the intended product or purpose of the tree, which can be to produce fruit, timber, and medicinal products, as well as provide nitrogen fixation, windbreak, reduction of soil erosion, etc. Once your purpose is defined, it is fundamental to account for tree-crop competition, a topic that has been extensively reviewed and discussed by Friday (2020). Some interesting points to consider: In some systems, trees that have thin canopy such as *Moringa* spp., may be ideal to allow sunlight to penetrate; in the same direction, trees with a more compact canopy will compete less with crops for sunlight (Friday, 2020). Ultimately, the decision of the species needs to take into consideration the nature of the food crop/understory shrubs and crops/livestock that will be associated, their growth habit and ability to grow within such a system. For those that already have a forest and now seeking to make it more productive, a similar process should be considered. In this case, taking an inventory as to what plants are in the forest and their location is important. Those trees/shrubs that are growing but have little value to you, or those species that are barely surviving and are of little to no interest, or these trees and shrubs that have fallen from storms should be inventoried and placed on a list to be removed and then replaced with a

productive food crop and/or other trees/shrubs. That is you are seeking to repopulate your forest with more productive plant species that complement each other as described earlier. In particular, invasive weeds should be removed, and if safe for animal consumption could be used for animal food or minimally made into compost for other purposes as soil amendments, but their removal is important as it will help make your forest more productive. Invasive weeds often out-compete (for light, access to the sun, water, nutrients) your core indigenous plants reducing the overall productivity of the forest.

3. Crops: Staple foods can be grown under agroforestry systems, although many of the common staple foods from around the world such as corn, wheat, and rice are commonly full sun plants, having significant yield reductions even with moderate levels of shading (Friday 2020). Yet, in the FSM, staple crops are already part and parcel of agroforest systems such as banana, breadfruit, taro and yams. Their inclusion discussed in greater detail below, requires proper planning to achieve high productivity in agroforestry systems. Even vegetables and other fruits (guavas, mango, others) can also be part of an agroforestry system, as well as nitrogen-fixing crops such as beans and perennial shrubs.
4. Forage: The term forage refers to the growing of crops upon which animals can graze/feed on independently as well as crops used to feed livestock. Some forage crops are used to both feed animals and also assist with improving the fertility of the soil with nitrogen fixation species. In the FSM, forage cropping is not common, yet in some areas may have potential (e.g. in open areas in Yap). Some forages are also perennial thus can also provide soil cover to protect soil biodiversity, reduce erosion and some can be used as green fertilization and when cut used as feed or compost.
5. Animals: In addition to providing food, livestock can fertilize the soil and eat pests, reducing the need for fertilizers and pesticides in the system. Yet, while the use of livestock feeding in open range forage crops is common around the world, it’s not a central part of agricultural systems in the FSM. Given the animals and poultry raised (pigs, chickens) and consumed in the FSM as reported in the GCF survey (Rutgers University, 2024), the production of forage crops is less relevant and would only be very small-scale. Pigs would not be compatible to left to freely feed in an agroforestry setting as they could damage the crops and roots of the forest plants. Thus, the animal husbandry found in the FSM would benefit from an agroforestry setting but more from the ability of the farmer to produce their own local low-cost plant-based materials that could then be used for litter and/or animal and poultry or acquaculture feed.

Agroforestry systems in the FSM:

Agroforestry in Micronesia has been practiced for thousands of years, providing food and living resources for local communities (Raynor 1993). Although modern techniques and technologies can be applied, it is important to recognize the importance of the local knowledge, built through local experiences over time (Raynor 1993), as a starting point and a guide to implementing agroforest systems that work for the people of the FSM in terms of meeting their needs in terms of food and environment conservation for future generations.

In this section, we present some ideas on how to integrate the main staple crops, as defined and reported in the GCF baseline survey by the people of FSM, in agroforestry systems (Rutgers University, 2024).

1. Yam and Taro: As some of the main starchy crops consumed in the FSM, these crops are of extreme importance for food security and food sovereignty in the region. As discussed above, major grain crops such as maize and rice are not shade tolerant, but fortunately, taro and yam can be grown successfully in an agroforestry setting. Cultivars of these species can have different shade tolerances, with some even tolerating up to 50% shade without significant yield losses (Friday 2020, Rogers and Iosefa, 1993). These plants can adapt well to being part and parcel in a larger polyculture agroforestry setting and historically have been planted and grown with other crops and trees. Taro and yam are well suited also for the alley cropping system too, with some adaptations allowing for more sunlight. More sunlight can be achieved by removing some of the shade-inducing trees surrounding the taro and yam and by ensuring invasive weeds and other nonproductive plant species are roughed out.
2. Bananas: Banana plants do not tolerate shading (Israeli et al., 1995), so when planning to use this species in an agroforestry system, it is important to take this into account and plant new bananas in forested areas following a storm incident or other where some older trees have been removed or fallen. Banana plants can be used as components of the agroforestry system, providing shade and organic matter to the crops, particularly to understory crops. Bananas also can be grown with high productivity in alley cropping systems or at the border of riparian buffer forests, or, even as a component of low-density forest cropping systems.
3. Coconut and Breadfruit: Coconut and breadfruit are the usual overstory species in traditional systems in most of the Pacific Islands (Friday 2020). Each provides shade and protection to the crops, while also producing valuable food resources. Betelnut, another important crop, and yams are reported to be trained to grow up into the canopy of breadfruit trees (Friday, 2020) thus allowing for their productivity in forest cropping systems.

The combination of these staple crops with other food and useful including income-generating species, such as vegetables in agroforestry systems can be an alternative to reduce food imports and include a diversity of fresh food in the community. Ultimately, the specific conditions of the land are going to be determinant for what system to utilize, and which species to produce and combine.

A cautionary note for agroforestry systems is to be careful not to clear excessive forested areas to become open and clear in large tracts for the introduction and production of high-value income-generating crops. The danger and risk to the ecosystem is high, as excessive land clearing can result in serious soil erosion and soil degradation resulting from the heavy rains impacting not only the area that was cleared but surrounding areas particularly those further down the slope. The debate relative to the expansion of forested land being cleared for the production of sakau, based upon the kava plant (*Piper methysticum*) needs to be clarified and sorted. At present, there are rules and guidelines relative to land use on public land but on private land, this will become an increasingly serious issue unless it's resolved. The authors are not suggesting that sakau should not be grown in the forest given that it is so culturally important and has become a significant income-generating forest crop, but that acceptable guidelines be discussed and agreed upon by both the sakau growers, communities, and government to allow for income generation while protecting the forest and the ecosystem.

Growers are urged to keep records of their agroforestry practices, including what crops that they are growing, what crops have they introduced (and where), have they observed changes in runoff, flooding, forest health (e.g. as observed by fallen trees, changes in forest composition). Keeping written records as to their plantings, their inputs, and final yields coming out of their agroforestry system are needed to guide and inform the grower as to which recommendations provided are leading to improved plant growth and increased yields and thus a health sustainable agroforestry system.

Selected References:

AFTA. (2024). What is Agroforestry? https://www.aftaweb.org/about/what-is-agroforestry.html. Accessed January 2024.

Elevitch, C. R., and K.M. Wilkinson, 2000. Information Resources for Pacific Island Agroforestry. Agroforestry Guides for Pacific Islands #1. Permanent Agricultural Resources, Holualoa, Hawaii, USA. Web site: http://www.agroforestry.net

Elevitch, Craig R., Garien Behling, Michael Constantinides, and James B. Friday. 2014. Grower's Guide to Pacific Island Agroforestry Systems, Information Resources, and Public Assistance Programs. In: Elevitch, C.R. (ed.). Food-Producing Agroforestry Landscapes of the Pacific. Permanent Agriculture Resources (PAR), Holualoa, Hawaii. http://www.agroforestry.org

Elevitch, C.R., and D. Ragone. (2018). Breadfruit Agroforestry Guide: Planning and implementation of regenerative organic methods. Breadfruit Institute of the National Tropical Botanical Garden, Kalaheo, Hawaii and Permanent Agriculture Resources, Holualoa, Hawaii. www.ntbg.org/breadfruit and www. agroforestry.net.

Friday, J.B. (2020). Managing Tree-Crop Competition. Chapter 2 In: Elevitch, C.R. (ed.). Agroforestry Design for Regenerative Production—With emphasis on Pacific Islands. Permanent Agriculture Resources (PAR), Holualoa, Hawai‘i. design.agroforestry.org

FAO (Food and Agriculture Organization of the United Nations). (2024). Sustainable Forest Management (SFM) Toolbox: Agroforestry. https://www.fao.org/sustainable-forest-management/toolbox/modules/agroforestry/in-more-depth/en/. Accessed January 2024.

Israeli, Y., Z. Plaut and A. Schwartz. (1995). Effect of shade on banana morphology, growth and production. Scientia Horticulturae 62(1-2):45-56.

Johansen, M., and A. Thulstrup. (2021). Sustainable Land Use Systems in Natural Resource Policies: The Role of Agroforestry in the Rio Conventions for Small Island Developing States. Small Island Developing States. The World of Small States: Small Island Developing States: Vulnerability and Resilience Under Climate Change, 9:113-136.

Lehmann, L.M., J. Smith, S. Westaway, A. Pisanelli, G. Russo, R. Borek, M. Sandor, A. Gliga, L. Smith and B.B. Ghaley. (2020). Productivity and economic evaluation of agroforestry systems for sustainable production of food and non-food products. Sustainability 12(13): 5429. https://doi.org/10.3390/su12135429

Manner, H. I. (1993). A review of traditional agroforestry in Micronesia. Proceedings of the Workshop on Research Methodologies and Applications for Pacific Island Agroforestry. United States Department of Agriculture. Kolonia, Pohnpei, Federated States of Micronesia

Nair, P. R. (2007). The coming of age of agroforestry. Journal of the Science of Food and Agriculture 87(9):1613-1619.
Nair, P. R. (2011). Agroforestry systems and environmental quality: introduction. Journal of Environmental Quality 40(3):784-790.
Quintus, S., J. Huebert, P.V. Kirch, N.K. Lincoln and J. Maxwell. (2019). Qualities and contributions of agroforestry practices and novel forests in pre-European Polynesia and the Polynesian outliers. Human Ecology 47(6):811–825. https://doi.org/10.1007/s10745-019-00110-x
Raynor, B. (1993). Preface. Proceedings of the Workshop on Research Methodologies and Applications for Pacific Island Agroforestry. United States Department of Agriculture. Kolonia, Pohnpei, Federated States of Micronesia
Rogers, S. and T. Iosefa. (1993). Shade levels for taro cropping systems. Agroforestry Today 5(2):9-12.
Rutgers, The State University of New Jersey. (2024). Baseline Assessment in Support of Climate-resilient food security for farming households across the Federated States of Micronesia. Technical Report to Micronesia Conservation Trust, Federated States of Micronesia and the Green Climate Fund
Singh, S. and G. Singh. (2023). Agroforestry for sustainable development: Assessing frameworks to drive agricultural sector growth. Environment, Development and Sustainability 1-37.
United States Department of Agriculture (USDA). (2024). Agroforestry Practices. https://www.fs.usda.gov/nac/practices/index.shtml. Accessed January 2024
Waldron, A., D. Garrity, Y. Malhi, C. Girardin, D.C. Miller and N. Seddon. (2017). Agroforestry can enhance food security while meeting other sustainable development goals. Tropical Conservation Science 10:10.1177/1940082917720667

Climate Resilient Agriculture Module 2: Climate-resilient Crops and Cropping Systems Relative to Climate Change in the Federated States of Micronesia

Tori Rosen, Erik Gomes, Dena K. Seidel, Ramu Govindasamy and James E. Simon

Rutgers Center for Agricultural Food Ecosystems

Climate-resilient crops are crops and crop varieties that can maintain yields under stress conditions such as drought, flooding (submergence), heat, chilling, freezing, salinity, and others (Acevedo et al., 2020). The ability for crops to successfully grow and produce under increasing abiotic or biotic stresses has become increasingly important due to changes in temperature, rainfall, rainfall intensity/frequency, and seasonality, and the presence of pests including newer pests that may not have been a concern previously.

In addition to individual climate-resilient crops, a climate-resilient cropping system considers several or all of the agroecosystem components (i.e., soil, water, biodiversity, polyculture cropping, presence of trees, nitrogen-fixing legumes, and more) when building a farming arrangement for improved resistance to adverse environmental effects on food production.

Current models and predictions for climate change point to the increased occurrence of abiotic stresses such as droughts, heat waves, and floodings, among others, which can negatively impact crop yields and threaten food security across the globe (Rivero et al., 2021). Additionally, these same environmental climate changes can also shift the range and the presence and occurrence of pests and diseases that can impact crops as well as animals, poultry, and people. Climate resilient crops are a fundamental step to ensure food supply under these conditions and are especially important to locations more vulnerable to changes in climate patterns.

Why are climate-resilient crops important to the FSM?
The FSM is severely threatened by long-term global warming, being particularly vulnerable to sea-level rise and longer lasting El Nino droughts (UNDP, 2024) and expected changes in weather (e.g., increased temperature, alterations in rainfall). Climate resilient crops and cropping systems, along with other measures, can aid the country in providing a stronger foundation for the production of local foods thus increasing its food security and food sovereignty under these conditions in the future.

According to the recent GCF Baseline Survey conducted by Rutgers University (2024) and coupled with the many predictions of climate change impacting the Pacific including the FSM (Bell and Taylor, 2015; Government of the FSM, 2023; IPCC, 2021; CSIRO and SPREP, 2021), the main weather events threatening the productivity of crops and livestock in the FSM are:

1. Extreme heat
2. Heavy rains
3. Drought
4. Increased pests and diseases
5. Coastal flooding
6. Inland flooding
7. Saltwater inundation

Each of these events can be detrimental to the physiology and metabolism of the crops grown in the FSM, making it important to introduce and/or maintain those climate-resilient crops and systems in the region as well as to encourage the development and/or introduction through proper importation and regulatory frameworks improved germplasm (genetic materials including improved varieties) that are tolerant to such abiotic and biotic stressors.

Examples of climate-resilient crops around the world

Worldwide, there are many examples of plants known for their weather resiliency. Pearl millet (*Pennisetum glaucum*), for example, has a higher heat tolerance than many other cereals (Dhankher and Foyer, 2018) and can also sustain prolonged water deficit, such as the related plant sorghum (*Sorghum bicolor*) (Chaturvedi et al., 2023).

Regarding salinity, asparagus, spinach, and sugar beets are widely regarded as some of the most tolerant edible crops (Shannon and Grieve, 1998, Hossain et al., 2017).

Amaranth (*Amaranthus* spp.) is another impressively resilient crop, with tolerance to low soil moisture, high salinity, and high air temperature, as well as resistance to pests and diseases (Kopeć, 2024). In the same family of amaranths, quinoa, *Chenopodium quinoa*, is another species reported to be tolerant to heat and drought stresses (Zohry and Ouda, 2022), while producing grains with higher nutritive value than traditional cereals, becoming a promising worldwide crop for human consumption and nutrition (Vega-Gálvez et al., 2010).

Therefore, among the staple crops grown and consumed in the FSM, it is imperative to consider the following activities at the household, community, and state level:

*Maintenance of a robust collection of the different types (e.g., landraces and ecotypes) of each staple crop that is available.
*To identify those types (e.g., landraces and ecotypes) that growers and households report to have survived well and remained productive under extreme stress.
*To identify educational, research, or other sites that could collect, maintain, and make available such planting materials via cutting/propagules/grafted materials/seeds/clones of such plants from each staple crop.

The incorporation and inclusion of multiple landraces and ecotypes of climate-resilient staple crops in a cropping system can provide safety and reduce risk in case of an unusual adverse weather and pest event(s). Yet, the movement of plants and plant materials of certain species into the FSM from outside the FSM must adhere to national rules and regulations as some may be prohibited (See: https://www.fsmlaw.org/fsm/regulations/piv_x.htm) due to concerns about the accidental introduction of serious diseases and pests that could be devastating to the crops already in the FSM.

Relative to staple crops of the FSM this would include but not limited to bananas, beans, palms including coconuts, sweet potato, cassava, taro and yams (https://www.fsmlaw.org/fsm/regulations/Table1.htm). These rules are to protect the safety and to limit the introduction of serious diseases and pests. There are exceptions to such rules for example in the case of certified disease-free tissue cultured bananas, taro and yams. Disease-free seedstock with some species may also be permissible. The introduction of any live materials should first be determined with discussion with the national government and adhering to national regulations, procurement of permits and the inclusion of phytosanitary certificates of the introduced germplasm (see: https://www.fsmlaw.org/fsm/regulations/piv_x.htm). FSM also has in place laws that prohibit the movement of live plants and plant materials of some species from one State of the FSM to another State of the FSM (see: https://www.fsmlaw.org/fsm/regulations/Table2.htm. This includes staple crops such as bananas, coconut, sweet potato and cassava.

Thus, the establishment of live nurseries and germplasm banks for propagation and distribution of currently available germplasm is needed to be established in each state. Yet for the introduction and evaluation of new and improved varieties and the sharing of such materials across communities and FSM states must also be done properly and within the rules and regulations of the nation. There are many places and sites in each state in the FSM where such germplasm can be established and maintained; and there is local expertise within the FSM to work with such crops. Whether these germplasm banks be included in botanical gardens and/or implemented by the public sector (e.g. COM or other research or other community centers) and/or the private sector in each state will be decided by the actors engaged in and willing to support such an endeavor, but the ability to establish, nurture and ensure such climate resilient high quality germplasm materials are available to be shared would improve food security and be useful in the education of the public.

Possibilities for climate-resilient staple crops in the FSM

The major staple crops in the FSM, according to the GCF Baseline Survey of 2023 (Rutgers University, 2024) are: taro, yams, breadfruit, bananas, and coconuts. In this section, we will illustrate a few examples of different cultivars of these species that have shown, in different parts of the world, resistance to different types of stresses.

1. **Taro** is an extremely climate-resilient crop, withstanding harsh conditions of outer atolls in Micronesia, including heat, drought, sandy soils, strong winds, and hurricanes. It is a starchy food that is available all year round, unlike yam and breadfruit which have specific harvest windows. Taro corms can remain in the soil for decades and still be edible, making them important crops in times of food scarcity (Englberger et al., 2017). Taro is a high-maintenance plant to cultivate in nutrient-poor soils of the outer atolls, which is causing communities to turn away from its production for easier starches like imported rice. Once thriving taro fields have become neglected, and their production is further limited by saltwater intrusion and drought on outer atolls. Mainland taro production is less labor-intensive and large farms exist where many families will cultivate small patches.

There are four species of taro grown in FSM, each having environmental benefits. *Cyrtosperma* (swamp taro) plants produce very large and hardy corms and are subject to relatively low insect and disease pressure. *Colocasia* (hard taro) corms take much less time to grow before harvest. It is grown in dryer soil and its leaves have been historically eaten as a meat substitute. *Alocasia* (giant taro) used to be the most preferred type of taro, which is often used as a substitute for breadfruit or yam during the offseason but is now rarely consumed and by some considered inedible. *Alocasia* is hardy and more drought tolerant than *Cyrtosperma* and *Colocasia* varieties. It is believed that the sites where *Alocasia* grows well indicates a place where other crops will also grow well. *Xanthosoma* (elephant's ear) plants are closely related to *Colocasias* and have low acridity, or bitterness, and longer storage life than their relative (Englberger et al., 2017).

Taro corm rot and leaf blight are common diseases seen in Micronesia. Corm rot can be controlled by adding wood ash and lime to the soil around young plants and not planting in the same site for more than three consecutive years. Resistant and tolerant varieties include *Erderid*, *Homusted*, *Ngetmadei, Renged,* and *Dungersuul.* To reduce the severity of leaf blight, farmers should be careful to pick up diseased taro leaves in the morning and physically remove them from the fields. Use of soaking tools in 10% Chlorox solution and planting multiple varieties in a patch are also quite helpful. Known taro leaf blight-resistant varieties from Hawaii include *Ngesuas*, *Ngeruuch*, *Homusted*, and *Kerdeu*.

Palau has a well-documented taro germplasm collection (Del Rosaria, 2015), which has been used to introduce genetic resistance to leaf blight in Samoa. There are gene bank collections at the Pilot Farm in Pohnlangas, Madolenihmw and The Center for Pacific Crops and Trees (CePaCT) in Fiji.

2. **Yam** is an important food crop with deep ceremonial ties. Farmers compete on the size and vigor of their tubers. The most commonly cultivated species of yam are *Dioscorea alata*, *Dioscorea nummularia* and *Dioscorea esculenta*. Yams are an integral part of traditional agroforestry in Micronesia, as their planting sites are located largely based on surrounding trees that can support their vines (Raynor et al., 2017). First harvests are often dedicated and given as offerings to the traditional leaders.

   Traditional yam cultivars from *D. alata* that had been grown for many years are now becoming rare, due yam dieback disease, or anthracnose, which will typically arise after intense rain. Symptoms of anthracnose include brown spots on the young leaves, which will grow with the leaf and eventually develop pale yellow rings around the spots. Infected leaves will eventually fall off of the plant. This disease can either completely kill a young susceptible plant or cause a great reduction in tuber yield (Wright et al., 2000). Anthracnose is spread from water splashes during heavy rains. Over the past twenty years, rainfall has increased during Micronesia's dry season (January-March) during which yams are typically planted and the young plants are especially susceptible. It is critical to find tolerant varieties of yam that will withstand the increase in anthracnose during those critical months of development. *D. nummularia* has shown a higher tolerance to this disease and has successfully been crossed with *D. alata* (Lebot et al., 2017). Resistant varieties of *D. alata* have been found in the Caribbean and are being introduced to the Pacific Islands.

There are currently 179 known cultivars of yam on Pohnpei (Raynor et al., 2017) and 30 on Yap (Krishnapillai, 2014). There are 20 cultivars located at the Chinese Agricultural Demonstration Farm in Pohnlangas, Madolenihmw.
Pigs are a common predator of yam. Farmers have to take extra precautions to fence or physically keep the wild pigs from the yam plants.

3. **Breadfruit** is an important starch in Micronesia, particularly between the months of May to September. It is a major source of carbohydrates, fiber, provitamin A, B vitamins, potassium, and magnesium. Breadfruit also contains relatively high levels of protein, vitamin C, iron, calcium, phosphorus, manganese, zinc, and folic acid. It is recognized as a climate-resilient crop with great potential to combat global food insecurity as a nutrient-dense starch (Klyver et al., 2022; Mausio et al., 2020). Although there are dozens of distinct varieties of breadfruit in the FSM, a single cultivar, Meiniwe, makes up over 55% of those cultivated and naturalized (Ragone & Raynor, 2017). This lack of plant diversity is a potential concern as an introduced pathogen or abiotic stress that could differentially negatively impact this variety could be devastating to this significant food supply.

   Breadfruit was most frequently cited as the food often subject to shortages in the FSM and weather damage is reported to have been a significant contributor to decreased breadfruit production (FAO, 2016). Extreme heat and heavy rains were cited as the most frequent issues in breadfruit production in the GCF Baseline Survey (Rutgers University, 2024). Phytophthora, or breadfruit rot, spreads from rain splashing infected soil on the fruits. Rotted fruit mummifies on them, causing defoliation and branch dryback. Excessive heat or drought can kill the tree if too much dryback has occurred (Ragone & Raynor, 2017; Sangchote et al., 2003). The increased frequency of heavy rain events can cause epidemics of breadfruit rot, especially on susceptible late-season *Meinsahrek* cultivars.

   The lack of diversity among breadfruit cultivars also facilitates the spread of disease, so it is becoming increasingly important to find climate-resilient genetics. Whether local ecotypes that vary from each other are available in each state is worth exploring and then maintaining. The National Tropical Botanical Gardens in Maui, Hawaii has an extensive germplasm collection with 150 distinct cultivars.

4. **Banana** has over 50 known varieties across the Federated States of Micronesia, varying in color, taste, texture, nutrient content, and susceptibility to diseases. Bananas are relatively inexpensive, easy to grow, and available all year and have been an integral part

of FSM's traditional Agroforestry product system. Certain varieties of bananas have sparked interest in recent years due to their cultural importance and nutrient-density. Karat bananas is one of those to have among the highest known provitamin A content in bananas. Provitamin A helps with vision, heart disease, has anti-cancer and anti-diabetes properties (Zia-Ul-Haq et al., 2021). Karat is becoming rarer on islands, due to its difficulty to grow and more fertile soil requirements compared to other banana cultivars. Daiwang, although traditionally seen as a lower quality banana cultivar, has grown in popularity due to its health benefits (Englberger, 2017; Thakorlal et al., 2014).

In the GCF Baseline Survey (Rutgers University, 2024), farmer household participants cited salt stress, extreme heat, heavy rains, and disease as the largest contributors to crop loss. These stresses are experienced in banana farms around the world and significant research efforts are discovering genetic sources of resistance (Miao et al., 2018; Vidya et al., 2018; Negi et al., 2018).

Black leaf streak and fusarium wilt are the most common banana diseases in Micronesia. Leaf streak spores travel in the wind and typically infect newly emerging banana leaves. The pathogen thrives in hot, sunny, humid environments, and shade has been seen to limit the severity of the disease. Farmers rely on fungicides to limit the spread of disease, so it is important to find more sustainable approaches moving forward, most importantly finding genetic resistance in banana plants (Churchill, 2011).

The pilot farm in Pohnlangas, Madolenihmw holds a germplasm collection.

5. **Coconut** is perhaps the most economically important crop in Micronesia, hence its known as the tree of live given each and every part is used and respected. Its cream is used in many Micronesian dishes, its kernel produces coconut oil, or copra, coconut waste from copra can be used as livestock feed, its leaves and water are used as medicine, and dried plant matter can be used as fire fuel, husks can be used as fertilizer for other crops, old stems can be used as timber, and so many more uses (Chan & Elevitch, 2006). Coconut oil is a great source of healthy saturated fatty acids and vitamin E. Coconut has bioactive compounds that exhibit anticancer and antidiabetic properties. Coconut water is a great source for electrolytes, which are important for hydration. According to the GCF baseline survey (Rutgers University, 2024), farming family household respondents expressed interest in replacing imported milk products with locally sourced coconut milk.

   Well-established coconut trees are resilient to high winds and heavy rains, making them ideal windshields during typhoons. They grow well in infertile sand and are salt-tolerant. Coconuts require full sun for maximum fruit production. Yet, coconut production has still been negatively impacted by climate change, according to respondents in the 2023 GCF Baseline Survey (Rutgers University, 2024). Drought and heat stress have become problems for coconut production in Micronesia. As excessive heat and periods of drought are becoming more common, it is important to identify genetic diversity with increased tolerance and to re-establish and plant new groves of coconuts.

Papua New Guinea is home to the International Coconut Genebank, but it is currently under threat from Bogia Coconut Syndrome. The Center for Pacific Crops and Trees (CePaCT) has a growing germplasm collection in response to the disease pressure in Papua New Guinea.

The examples mentioned above illustrate strategies for the staple crops of the FSM to become even more climate resilient, through the sharing of well-performing current ecotypes now in each state and coupled to the introduction of new cultivars from different parts of the world (when allowed), and also through the establishment of local germplasm banks and the initiation of local selection programs to identify the best top performing landraces to strengthen local and traditional food systems. In addition, by making available the best germplasm or genetic materials, and when permitted by the proper introduction of improved abiotic and biotic stress-resistant, climate-resilient varieties, stronger climate-resilient systems can be forged, particularly with adoptions of techniques for sustainable land management (Module 3) and agroforestry (Module 1). The correct soil management has the potential to create a microbiome that helps crops resist changes in the climate such as salinity, and the use of agroforestry systems can help to mitigate the effects of increasing temperatures as well as to aid in water retention during prolonged droughts. Maintaining food security in the face of climate change is a collective and multidisciplinary task, which will only be achieved through sustainable practices, in concert with local communities and the environment, and in concert with the state and national government.

Growers need to keep records of what crops and varieties that they are growing, where they are grown and their field performance. Keeping written records as to that information as well as to time of planting, their agricultural inputs, presence or absence of pests and insects and final crop yields are needed to guide and inform the grower whether the specific crop varieties and land races are performing as good as in the past and/or as good relative to specific locations where production is located. Such written records as described above are simple to track and are needed to monitor the comparative growth and development, health and resiliency of the staple crops so growers and others can use the results to determine whether particular varieties or types exhibit improved resiliency to the climate changes faced.

Selected References

Acevedo, M., Pixley, K., Zinyengere, N., Meng, S., Tufan, H., Cichy, K., Bizikova, L., Isaacs, K.
Ghezzi-Kopel, K. and J. Porciello. (2020). A scoping review of adoption of climate-resilient crops by small-scale producers in low-and middle-income countries. Nature Plants 6(10): 1231-1241.

Bell J and Taylor M. 2015. Building climate-resilient food systems for Pacific Islands. Penang, Malaysia: WorldFish. Program Report: 2015-15.

Breadfruit Collections - National Tropical Botanical Garden (2023). National Tropical Botanical

Garden. September 22, 2023. https://ntbg.org/breadfruit/about-breadfruit/conservation/
Cahyanti, L. D., E. Santosa, D. Sopandie and H. Purnamawati. (2024). Response production of 17 genotypes of taro on drought and waterlogging stress. In: AIP Conference Proceedings (Vol. 2957, No. 1). AIP Publishing.
Chan, E., and C.R. Elevitch. (2006). *Cocos nucifera* (coconut). Species Profiles for Pacific Island Agroforestry (Ver. 2.1) www.traditionaltree.org
Chaturvedi, P., M. Govindaraj, V. Govindan and W. Weckwerth. (2022). Sorghum and pearl millet as climate resilient crops for food and nutrition security. Frontiers in Plant Science: 13:851970.
Churchill, A. C. L. (2011). *Mycosphaerella fijiensis*, the black leaf streak pathogen of banana: Progress towards understanding pathogen biology and detection, disease development, and the challenges of control. Molecular Plant Pathology 12(4):307–328. https://doi.org/10.1111/j.1364-3703.2010.00672.x
CSIRO and SPREP (2021). ‘NextGen’ Projections for the Western Tropical Pacific: Current and Future Climate for Federated States of Micronesia. Final report to the Australia-Pacific Climate Partnership for the Next Generation Climate Projections for the Western Tropical Pacific project. Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Secretariat of the Pacific Regional Environment Programme (SPREP), CSIRO Technical Report, Melbourne, Australia. https://doi.org/10.25919/tjw0-j296
Del Rosaria, A.G., N.M. Esguerra and T. Taro. (2015). Taro Production in Palau. College of Micronesia Palau Community College.
Dhankher, O. P., and C.H. Foyer. (2018). Climate resilient crops for improving global food security and safety. Plant, Cell & Environment 41(5):877-884.
Englberger, L., K. Albert, A. Lorens, A. and A. Levendusky. (2017). Chapter Five: Taro: An Important Pohnpei Staple Food. In: M. J. Balick (Ed.) Ethnobotany of Pohnpei (pp. 132-164). University of Hawaii Press. https://doi.org/10.1515/9780824837495-007
Englberger, L., A. Lorens, A. Levendusky, A. and D. Daniells. (2017). Chapter Four: Banana and Essential Crop of Pohnpei. In: M. J. Balick (Ed.) Ethnobotany of Pohnpei (pp. 89-131). University of Hawaii Press. https://doi.org/10.1515/9780824837495-006
Foale, M., and H. Harries. (n.d.). Farm and Forestry Production and Marketing Profile for Coconut (*Cocos nucifera*). Specialty Crops for Pacific Island Agroforestry: http://agroforestry.net/scps.
Government of the Federated States of Micronesia. Third National Communication and First Biennial Update Report to the United Nations Framework Convention on Climate Change. pp. 301.
Hossain, M.S., A. I. El Sayed, M. Moore and K.J. Dietz. (2017). Redox and reactive oxygen species network in acclimation for salinity tolerance in sugar beet. Journal of Experimental Botany 68(5):1283-1298.
IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp. doi:10.1017/9781009157896.

Klyver, J.M., I. Haugen, L. Schulz, LaPais Wiscard-Kardin, C. Saint-Fleur, S.J. Starke, J. Piersaint, A.S. Rizzo and K.M. Saraze. (2022). Addressing malnutrition and food insecurity with breadfruit in a rural, developing country: a case study and lessons learned in Thomassique, Haiti. Journal of Global Health Reports: 2022;6: e2022024. doi:10.29392/001c.34233.

Kopeć, P. (2024). Climate Change—The Rise of Climate-Resilient Crops. Plants, 13(4): 490.

Krishnapillai, M. V. (2014). Assessment of yam cultivar diversity in Yap State, Federated States of Micronesia.

Lloyd, G.R., A. Uesugi and R.M. Gleadow. (2021). Effects of salinity on the growth and nutrition of taro (*Colocasia esculenta*): Implications for food security. *Plants 10*(11):2319.

Lebot, V., R. Malapa and K. Abraham. (2017). The Pacific yam (*Dioscorea nummularia* Lam.), an under-exploited tuber crop from Melanesia. Genetic Resources and Crop Evolution, 64(1): 217–235. https://doi.org/10.1007/s10722-016-0475-z

Mabhaudhi, T. and A.T. Modi. (2015). Drought tolerance of selected South African taro (*Colocasia esculenta* L. Schott) landraces. *Experimental Agriculture 51*(3):451-466.

Mausio, K., T. Miura and N.K. Lincoln. (2020). Cultivation potential projections of breadfruit (*Artocarpus altilis*) under climate change scenarios using an empirically validated suitability model calibrated in Hawai'i. PLOS ONE, 15(5): e0228552. https://doi.org/10.1371/journal.pone.0228552

Miao, H., P. Sun, J. Liu, J. Wang, B. Xu and Z. Jin. (2018). Overexpression of a novel ROP gene from the banana (MaROP5g) confers increased salt stress tolerance. International Journal of Molecular Sciences 19(10):3108–3108. https://doi.org/10.3390/ijms19103108

Needham, A., R. Jha and N.K. Lincoln. (2020). The response of breadfruit nutrition to local climate and soil: A review. Journal of Food Composition and Analysis 88:103451. https://doi.org/10.1016/j.jfca.2020.103451

Negi, S., H. Tak and T.R. Ganapathi. (2018). A banana NAC transcription factor (MusaSNAC1) impart drought tolerance by modulating stomatal closure and H2O2 content. Plant Molecular Biology 96(4-5):457–471. https://doi.org/10.1007/s11103-018-0710-4

Phytophthora palmivora Pests and Diseases of American Samoa Number 12. (n.d.). https://www.ctahr.hawaii.edu/adap/ascc_landgrant/dr_brooks/brochureno12.pdf

Ragone, D. and B. Raynor. (2017). Chapter Three: Breadfruit and its Traditional Cultivation and Use on Pohnpei. In M. J. Balick (Ed.), Ethnobotany of Pohnpei (pp. 63–88). University of Hawaii Press. https://doi.org/10.1515/9780824837495-005

Raynor, B., A. Lorens and J. Phillip. (2017). Chapter Two: Yams and their Traditional Cultivation on Pohnpei. In M. J. Balick (Ed.), Ethnobotany of Pohnpei (pp. 40–62). University of Hawaii Press. https://doi.org/10.1515/9780824837495-004

Rivero, R.M., R. Mittler, E. Blumwald and S.I. Zandalinas. (2022). Developing climate-resilient crops: improving plant tolerance to stress combination. Plant Journal 109(2):373-389.

Rutgers, The State University of New Jersey. (2024). Baseline Assessment in Support of Climate-resilient food security for farming households across the Federated States of Micronesia. Technical Report to Micronesia Conservation Trust, Federated States of Micronesia and the Green Climate Fund.

S. Sangchote, Wright, J. G., Johnson, G. I., & Ploetz, R. C. (2003). Diseases of breadfruit, jackfruit and related crops. CABI Publishing EBooks, 135–144. https://doi.org/10.1079/9780851993904.0135

Shannon, M. C. and C.M. Grieve. (1998). Tolerance of vegetable crops to salinity. Scientia Horticulturae 78(1-4):5-38.
Thakorlal J., C.O. Perera, B. Smith, L. Englberger and A. Lorens. (2014). Resistant starch in Micronesian banana cultivars offers health benefits. Pacific Health Dialog 16(1). https://pubmed.ncbi.nlm.nih.gov/20968236/
UNDP (United Nations Development Programme). (2024). Micronesia (Federated States of). https://www.adaptation-undp.org/explore/asia-and-pacific/micronesia-federated-states. Accessed January 2024.
Vega-Gálvez, A., M. Miranda, J. Vergara, E. Uribe, L. Puente, L. and E.A. Martínez. (2010). Nutrition facts and functional potential of quinoa (*Chenopodium quinoa* Willd.), an ancient Andean grain: a review. Journal of the Science of Food and Agriculture 90(15):2541-2547.
Vidya, S.M., K.V. Ravishankar and R.H. Laxman. (2018). Genome wide analysis of heat responsive microRNAs in banana during acquired thermo tolerance. Journal of Horticultural Sciences 13(1): 61–71. https://doi.org/10.24154/jhs.v13i1.35
Wright, J., J. Peters, G.V.H. Jackson, F.J. Newhook and J. Winch. (2000). Yam anthracnose ([2nd ed.]). Secretariat of the Pacific Community.
Zia-Ul-Haq, M., S. Dewanjee and M. Riaz. (Eds.). (2021). Carotenoids: Structure and Function in the Human Body. Springer International Publishing. https://doi.org/10.1007/978-3-030-46459-2
Zohry, A.E.H. and S. Ouda. (2022). Climate-Resilient Crops. Climate-Smart Agriculture: Reducing Food Insecurity. Springer Verlag:115-135.

Climate Resistant Agriculture Module 3: Sustainable Land Management Relative to Climate Change in the Federated States of Micronesia

Tori Rosen, Erik Gomes, Dena K. Seidel, Ramu Govindasamy, Nisha Khanna and James E. Simon

Rutgers Center for Agricultural Food Ecosystems

Sustainable land management is a collection of practices that use land resources to produce goods while ensuring the long-term productive potential of these environmental resources (FAO, 2021). Humans currently influence, and depend on, all the land resources on the planet. These include soil and agriculture, ecosystems, and the services they provide, and human infrastructure. The land is under ever-increasing pressure from demand for food and other agricultural products, timber and forest products, residential and industrial development, and other human factors. There is increased awareness of the depletion of this critical resource under historic and contemporary unsustainable management practices. With limited land, the responsible management of this resource becomes even more critical.

Land degradation and soil erosion are serious concerns for each of the island states of Micronesia because of their topography including in some cases vulnerable exposure to the ocean, naturally hilly geography, and increased severity of flooding and periods of drought due to climate change (Grecni et al., 2023). According to the GCF Baseline Survey of more than 600 family farming households (Rutgers University, 2024), mean soil erosion across the FSM was estimated to be approximately 34.6 tons of soil/hectare/year. Mean soil erosion estimates were particularly concerning in Chuuk (70 tons/hectare/year of soil erosion) and Yap (32 tons/hectare/year of soil erosion). Yet only 13.6% of households were actively implementing soil erosion practices. These numbers reflect only the main islands and not the outer atolls though they did include islands in the Chuuk lagoon. This suggests a real need to recognize the importance of sustainable land management across the country and with vulnerable sites- those closest to the ocean and water, and those farmed land areas in the hills and forests. Availability and access to land are also limited in the FSM. With access and the amount of public land limited, with the area of family holdings in general quite small in size, and with the recognition that not all land is ideal for agriculture and some due to the slope and nature quite vulnerable to soil erosion, the need to ensure that a sustainable land management plan is in place is important for the successful and productive use of the land as it relates to food production, food security, income generating opportunities and the preservation of the land.

Main components of sustainable land management and mitigation measures:

Nutrient management: Nutrients are essential for plant growth and development. Improper nutrition can lead to a reduction in yield and lower quality of the harvested products. Essential nutrients include nitrogen, phosphorus, potassium, magnesium, calcium, sulfur, iron, zinc, and many others. Nutrient management is the process by which you ensure the plants receive the level of nutrients needed for their growth and development. This is done in several ways from the application of commercial fertilizers to the application of green manure crops, composts, organic fertilizers, recycling waste materials, or a combination of both practices. The key is to enhance soil fertility either by harnessing nutrients that are already present in the soil or being added to the soil by natural means or by adding nutrients through fertilizing (SLM Training Manual, 2021).

Soil and water management: Soil and water management practices improve water capture and utilization that limit soil erosion and the depletion of soil nutrients (SLM Training Manual, 2021). Soil practices that reduce runoff from heavy rains is also particularly important due to excessive rains and/or flash floods to mitigate excessive standing water. Each practice is essential for sustainably increasing crop yields and managing land to improve soil health and provide strategies to ensure the staple crops get water when they need water (naturally via precipitation or via irrigation) is important to mitigate against drought. And, soil practices to reduce as much as possible standing water on the staple crops from excessive rains is also needed to reduce crop damage from lack of soil aeration.

Agronomic practices: Agronomic practices are methods to increase climate resilience in crop systems using effective production systems and the incorporation of the best germplasm that is available. The use of improved genetics and new varieties through breeding can enhance sustainable crop production. Sustainable agronomic practices aim to address plant stresses like drought, heat, flooding, pests, and diseases, and weed control. The goal is to employ techniques that limit the need for chemical pesticides and fertilizers without compromising crop health, growth, and yield.

Integrated pest management (IPM): Integrated pest management (IPM) refers to environmentally sustainable practices to protect against pests and diseases. This includes monitoring and scouting for the presence and severity of pests and diseases, the proper identification of such biotic stressors, and the implementation of strategies to control pests and diseases.

Main causes for land degradation:

Land degradation primarily affects the fertile topsoil of agricultural and forest lands and has serious implications for longer-term agricultural productivity and the associated food security and livelihoods (Eekhout and de Vente, 2022). Agricultural land degradation results in reduced productivity and can lead to serious issues such as loss is soil stabilization, mudslides, loss of arable land, and runoff into waterways and streams, thus directly jeopardizing food security and the livelihoods of farmers. In addition, it can cause a devastating negative spiral by causing further exploitation of land resources, like clearing more forests for more agriculture. These interacting factors are accelerated by climate change. Direct causes of land degradation include deforestation, unsustainable farming practices, overgrazing by livestock, commercial development, population pressure, land tenure, and climate change (Wairiu, 2017).

Strategies for sustainable land management and considerations for the FSM:

1. Improved nutrient management
   Composting – The use of compost and adding soil amendments to the soils into which staple crops are to be grown can improve the long-term sustainability of the land, increase crop yields and reduce the severity of weeds that otherwise compete with the crop for essential nutrients as well as water and in some cases- light. The preparation and then application of compost, or humus, combines food waste, animal waste, green manure, and soil to create a nutrient-rich soil fertilizer and soil amendment. Composting piles can accumulate different essential nutrients depending on the plant material, or green manure, that is added. For example, amaranth greens can add iron (Byrnes et al., 2017), swamp taro, cassava, and hard taro add manganese, and seaweed will add potassium (ACIAR, 2022c). These nutrients not only help with plant growth and development but are also essential in a healthy diet. Compost piles also need sources of carbon, which are readily available as coconut husks, and nitrogen, which can be provided as fruit waste or pig waste. Pig manure can be layered in a compost pile, and mixed with nutrient-rich leaves, coconut husks, and soil. Piles should be turned weekly to allow for airflow and watered during dry periods. Compost piles will naturally generate heat in the middle, but if there is a strong odor more coconut husks and soil should be added, and the pile turned more frequently. The composting process can take around 2-4 months before it's ready for use. The addition to the increase fertility provided by composts and soils amendments, the use of composts are often done to improve poor soils (soils with lower water holding capacity, largely sandy) and lighten and improve the tilth of clay or heavier soils thus to improve drainage and aeration.

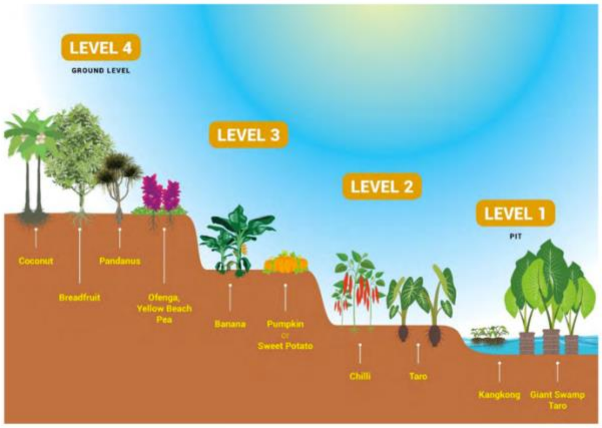
Examples of compost piles in Kiribati and Tuvalu (ACIAR, 2022b).

Animal and poultry manure – Waste from pigs and poultry are rich in nitrogen and other nutrients, which are essential nutrients for plant growth. Pig manure is a cheap and environmentally sustainable source of fertilizer for crops, either as solid waste fed into compost piles or as liquid waste washed out of the pen and fed directly onto the soil or into a holding tank or pit being careful not to allow the effluent to run off into the waterways. To use pig manure as liquid fertilizer, you either plant crops downhill from the pig farm and create a gutter system that will collect liquid pig waste that is washed away at the end of the day; or pump and move the manure fertilizer to wherever your crops are growing. There should be a filter set in place to trap any solid material. Liquid manure will travel by gravity down the gutter system and onto the crops' roots. In general, we recommend that pig manure first be digested/composted. Thus, such effluent from livestock can be used in a variety of forms- liquid, dry as part of a larger compost, slurry, and more. The availability of poultry manure will be limited as long as so few households are raising chickens for eggs or meat. However, given that poultry houses need to be cleaned out daily, should such enterprises develop, then the waste and associated liter should be collected, composted and used in a similar manner as pig waste.

Photos from Fertilizing with pig waste: a guidebook for Pacific Island farmers (https://www.ctahr.hawaii.edu/pigsinparadise/techreferences/Fertilizing%20with%20Pig%20Waste.pdf).

2. <u>Soil and water conservation</u>
   Mulching – Mulching helps conserve soil moisture, reduce runoff through flooding and wind erosion, prevent weed growth, control soil temperature, and conserve soil structure. Mulch can be made of coconut husks and fronds, banana leaves, breadfruit leaves, betel nut wastes, forest trees, cardboard, and chipped typhoon debris (USDA NRCS 484) and most green organic materials. Mulches should be added to staple crops yet as mulches degrade the bacterial decomposition process can also tie/bind up some of the nutrients precluding some of the nitrogen to reach the crops. Therefore, its recommended to also add compost or fertilizer to under the mulch layer.

   Terracing – Growing staple crops on flattened or contoured levels on hillsides so lower levels will catch water and nutrient runoff from upper levels. This practice allows for many crops to be grown at once and reduces water and soil runoff in water sources below (Spencer & Hale, 1961). This style of farming has its roots in ancient agricultural production systems. This terracing can also help the staple crops to be exposed to more sunlight which then accelerates their growth. Terracing practices also can reduce the impact of excessive rainfall and flash flooding on the crop and mitigate against standing water on the staple crop.



Terracing schematic from ACIAR (2022c)

Rainwater harvesting and storage – Rainwater catchment systems are integral to life in the FSM. This approach has applications not only in the many low-lying atolls that have limited freshwater resources and groundwater suffers from contamination (Dillaha Iii & Zolan, 1985) but on the main islands of Chuuk, Kosrae, Pohnpei, and Yap. Rainwater can be collected on roofs of private homes and public buildings and stored in aboveground cisterns or water tanks (See Module 3, 2024). Though not often practiced on the main islands where there is a concept that rain will always be available, recent issues with drought and the lack of rainfall suggest that a safer approach would be to capitalize on building rainwater harvesting and storage systems for your staple and high value crops as well as for household use. When designing these units, it is most important to consider fecal and bacterial contamination for safe drinking water. Small amounts of chlorine in water catchment systems limit contamination. Catchment systems should also have filters to keep out extraneous materials and need to be cleaned multiple times per year. Water should be filtered and tested regularly to ensure its safety particularly if collected from rusted and other surfaces that can bring in metals and microbial contaminants (CDC, 2024; Macomber, 2010). Stored water can be used in crop irrigation systems, also described in Module 3 (2024).

Even if smaller water collection systems can be beneficial when growing starting seeds, growing out of transplants and clonal materials for later field transplanting. The quality of the young seedling and transplant impacts the success of the plants later field performance.

3. <u>Agronomic practices</u>
   Improved production systems –Working to ensure proper soil preparation and seedbed is important. Introducing organic materials to improve soil fertility and tilth prior to planting is often desirable. Removal and clearing of the area from weeds are also important and then the planting into that cleared area the seeds, clonal vegetative materials, or transplants into raised beds. Complete your planting with the addition of

organic composted materials, or the application of organic fertilizer and addition of mulch around the plants, as needed to reduce soil moisture loss and reduce weed pressure.

Improved crop varieties – Use the best germplasm materials available. If you have such options, use those staple crop varieties that have high tolerance to climate-induced stresses like heat, drought, salt, flooding, disease, and pest pressure. Genetic resistance to such stresses if available can result in higher-yielding, nutrient-dense, and culturally preferred crop varieties to promote sustainable food production (See Module 6: climate resilient crops). Sometimes it can be difficult to access and procure improved crop varieties. Growers should seek out others- such as researchers within the state government; the College of Micronesia; and those in the private sector or other lead growers to see if any improved genetic materials are available to them. Growers should identify their most promising plants particularly when they observe clear differences in their field performance. Identifying and tagging those plants that appear to have survived best following adverse weather events (storms, floods) or following a disease event, should be tagged, propagated and used in future field plantings.

Crop rotation – Crops should be rotated at a specific planting site in a defined number of years to limit the depletion of nutrients in the soil, reduce the buildup of pest pressure, and need for chemicals to maintain productivity in the growing site. An example of crop rotation is one year of high-feeding crops, followed by a year of nitrogen-fixing crops, then a year of deep-rooted crops. This will allow for the cycling of nutrients in and out of the soil. When land is limited, crop rotation is a more difficult practice to follow, but try not to have the same crop continually cropped/grown on the same site but try to rotate with crops from different backgrounds. In short, following the production and harvest of a staple crop, it is recommended to plant another staple crop or nitrogen-fixing legume in that same spot. Continuous replanting of the same staple crop in the exact same land area can lead to increased disease and insect pressure and increased risk of crop failure.

Intercropping – Intercropping is the planting of multiple crops at once in a single agricultural site. Within one year, nitrogen-fixing and deep-rooting plants will work together to replenish nutrients in the soil. This method controls weed growth and soil erosion by growing valuable crops across the entire field. Intercropping or the use of polyculture is the norm in much of the FSM. Consideration relative to shading smaller crops needs to be considered. Staple crops growing together will compete against weeds that will naturally occur in fields. The aim is to have crops outcompete the weeds by both ensuring high-density intercropping and that the crop plants will eventually also shade out many of the weed species.

4. Integrated pest management
   To limit the spread of pests on an intercropped farm, make sure that the plants are not alternate hosts for the same pathogen. Similarly, when selecting crops for rotation on a field, pick ones that are not susceptible to the same diseases so the pathogens will not live throughout multiple planting cycles. Natural genetically resistant crops, if available, should be selected to limit other necessary intervention strategies like the application of

pesticides. Tools should always be disinfected using a 10% bleach solution before use to kill any pathogens before they are transferred onto a crop. Infected plant part should be pruned from the plant or ground and disposed of. Be cautious of introducing new crop varieties to the farm, as seeds or tubers may carry new diseases that can devastate a field. Pesticides can be applied in combination with all these practices. In outdoor production, a pathogen is rarely eliminated, but these techniques will help limit the spread and severity of these pathogens.

Weed control, though often overlooked, and often not discussed is a major factor in the successful production of sustainable land management and farming. Weeding accounts for a significant amount of a farmers' time and labor. Therefore, special attention is needed to rouge out (physically remove) any/all invasive weeds. These plant species often out-compete and can take over larger tracts of land. These plants outcompete the crop plants for sunlight, nutrients, and water reducing the productivity of the land. Invasive plants should be cut and removed from your field and composted or dried out to use as litter or soil amendment. After removal of any invasive weeds, sustainable land management plans should also include the continual removal of any weeds through physical hoeing, the use of a machete to cut and remove, or through the application of mulch to suppress the germination of weeds. Best to have crops and/or perennial plant species that can provide nitrogen or green manure to cover the land to improve its productivity and not to leave land 'open' without any plant cover.

Growers need to keep records of their land, including what crops that they are growing and where they are grown (if land is sufficiently large or diverse plots and areas are being farmed). Keeping written records as to time of planting, agricultural inputs, presence of pests and insects and final crop yields are needed to guide and inform the grower whether the recommendations provided above are leading to increased yields and are leading to a sustained land management relative to what they currently are practicing. The recommendations are provided to mitigate grower and environmental risk.

Selected References

ACIAR. (2022b). Compost recipe gives Pacific Island countries a nutrient boost. ACIAR. https://www.aciar.gov.au/media-search/blogs/compost-recipe-gives-pacific-island-countries-nutrient-boost

ACIAR. (2022c). Improving soil health, agricultural productivity, and food security on atolls. ACIAR. https://www.aciar.gov.au/project/smcn-2014-089

Byrnes, D. R., Dinssa, F. F., Weller, S.C. and J.E. Simon. (2017). Elemental micronutrient content and horticultural performance of various vegetable amaranth genotypes. Journal of the American Society for Horticultural Science 142(4):265–271. https://doi.org/10.21273/JASHS04064-17

Dillaha Iii, T.A. and W.J. Zolan. (1985). Rainwater catchment water quality in Micronesia. Water Research, 19(6), 741–746. https://doi.org/10.1016/0043-1354(85)90121-6

Eekhout, J.P.C. and J. de Vente. 2022. Global impact of climate change on soil erosion and potential for adaptation through soil conservation. Earth Sci. Rev. 226, 103921.

Anon. Fertilizing with pig waste: a guidebook for Pacific Island farmers. Translated and adapted from easy ways to use and store pig waste in the Pacific Islands. https://www.ctahr.hawaii.edu/pigsinparadise/techreferences/Fertilizing%20with%20Pig%20Waste.pdf

Grecni, Z., C. Bryson and E. Chugen. (2023). Climate change in the Federated States of Micronesia: Indicators and considerations for key sectors. Zenodo. https://doi.org/10.5281/ZENODO.8125584

Macomber, P. (2010). Rainwater catchment systems for Hawaii. https://www.ctahr.hawaii.edu/hawaiirain/Library/Guides&Manuals/HI_Guidelines_2010.pdf

USDA. Mulching for moisture, weed control and soil protection USDA NRCS Practice (484). (n.d.). Retrieved February 25, 2024, from https://www.ctahr.hawaii.edu/wq/publications/Final_FactSheets/Mulch484.pdf

Anon. Rainwater collection. (2024). https://www.cdc.gov/healthywater/drinking/private/rainwater-collection.html#:~:text=Prevent%20illness,that%20you%20intend%20to%20eat.

Anon. Ridge to reef project sustainable land management. A training manual for local farmers in Tuvalu. (2021). Retrieved February 25, 2024, from https://www.pacific-r2r.org/sites/default/files/2020-08/SLM%20Training%20manual%20final.pdf

Rutgers, The State University of New Jersey. (2024). Baseline Assessment in Support of Climate-resilient food security for farming households across the Federated States of Micronesia. Technical Report to Micronesia Conservation Trust, Federated States of Micronesia, and the Green Climate Fund.

Spencer, J.E. and G.A. Hale. (1961). The Origin, nature, and Distribution of Agricultural terracing. Pacific Viewpoint, 2(1), 1–40. https://doi.org/10.1111/apv.21001

FAO. (2021). Sustainable Land Management. Fao.org. https://www.fao.org/land-water/land/sustainable-land-management/en/

Wairiu, M. (2017). Land degradation and sustainable land management practices in Pacific Island Countries. Regional Environmental Change 17:1053-1064.

Climate Resilient Agriculture Module 4: Sac and Container Gardening and Use of Composting for Household Vegetable and Fruit Production

James E. Simon, Ramu Govindasamy, Nyabinda Nama

Rutgers Center for Agricultural Food Ecosystems

The nationwide survey of FSM family households indicated that most of the respondents in all four states expressed interest in growing more food. While many had sufficient land, the ability of households and schools to grow fruits and vegetables has been hampered by excessive heat, drought, and other environmental stress. Open field production of fruit and vegetables outside of planting and growing in a traditional agroforestry system has been impacted by adverse weather including heavy rains, flooding, and drought. There are many approaches to use locally in developing climate-resilient farming practices. This module will focus on the production of fresh produce (fruits/vegetables) using containers and as an example using 'sacs'. Such an approach minimizes one's footprint on the environment and provides an inexpensive platform for the household that is inexpensive, reduces the risk of excessive rains and floods, can be protective of the plants, and fosters the family to use and consume more fresh produce while reducing water input needs. This CRA module does not replace other gardening and agriculture open field farming practices that incorporate strategies to strengthen resiliency per se or modules on agroforestry, soil and ecological restorative ecology, or others but part and parcel of framing activities that can be achieved by households and communities.

Sack gardens in which nutrient-dense vegetables and fruits are grown in earth-filled sacks/earthen-made containers using local materials also foster and embed the use of local materials and locally-made compost that are appropriate as organic soil amendments (Gallaher et al., 2015; Pascal and Ring, 2009; Brindisi et al. 2020). Sack garden programs in other countries have shown the potential to increase household dietary diversity, increase social capital, and mitigate food shortages (Weller et al., 2015). Vegetable management skills, harvesting techniques, water management, and learning to recycle kitchen and farm wastes into compost to provide fertilizer and improve soil health are positive learning outcomes when introducing such a gardening system.

Communities and households can construct these containers and sac gardens contributing to the skills needed to grow and making local fresh produce more accessible. With plants protected and above the ground, they are more resilient to incoming flash floods and adverse weather. Sac and containerized gardens also require less water and in general use water more efficiently. Community groups, schools, and families can also use harvested produce to contribute toward their daily meals with fresh vegetables from their own sack gardens in their backyards. Sac and containerized gardening can be one of the best ways of reducing the expenditure for a family on fresh vegetables while providing the incentive for increasing consumption. Excess vegetables can be given/traded/bartered or even sold for income generation.

Containerized Gardening including sacs and containers:

Many areas in the FSM are fortunate to have high rainfall, yet excessive rainfall can also lead to flash flooding, soil erosion, crop, and food loss rain. Gardens can be periodically flooded, crops lost, and fertile topsoil washed away. The use of gardening in sacks and or in pots is common around the world and provides an efficient system to engage families and children in gardening. The use of sac gardens and growing in pots also can reduce the amount of water used to grow the plants and reduce the footprint relative to land needed. The systems are easy, low cost, and can be expanded as needed. Key elements needed are seeds (or live transplants), soils, clean sacs, or clay pots, soil, and compost. Raising local fruits and vegetables requires knowledge and management skills. In this module, we focus on 'sacs'- clean sacs, but such systems can be done in older tires, wood, and ceramic/brink framed raised beds as well.

Step 1: Set up the Sack

1. Make 5 holes in the bottom of the 90 kg sack for drainage
2. Place the empty sack on the ground.
3. Take a bucket and cut away the bottom while keeping the bucket's shape
4. In the middle of the empty sack place the empty, bottomless bucket.
5. Place the stick or pole in the middle of the bucket and fill the remaining space in the bucket with rocks (for water drainage).

Step 2: Filling the bag

1. Fill the sack with a 3:2 mixture of soil and compost until only the top of the bucket is visible
2. Slide the bucket up along the pole/stick
3. Fill the empty space in the bucket with rocks (for water drainage)
4. Repeat the above steps 1-3 until the sack is full

Step 3: Mark the Bag and Plant

1. Mark out the placement for the 70 plants with a permanent marker.
2. Plants should be equal distance apart (~15 cm). Plants can be planted in the open space on the sack top.
3. Use a sharp knife or scissors to cut a hole in the sack for each plant
4. Use a stick to make a 1.5 cm wide opening. Plant a seedling or sucker in each of the openings.

Figure 1. An illustrative approach in constructing a sac garden in Kenya used for household and community level.

How to build a sac garden container:

Sack gardens are constructed by filling 90 kg grain sacks with rocks (1-3 cm) at the center core for water drainage and filling the remainder of the sack with a 3:2 mixture of soil and compost (Fig. 1).

Both soil and compost are used to fill the sac. The compost can be made locally from composted and aged kitchen wastes, animal manure (e.g., swine/poultry), and other plant materials. Approximately 70 holes (1.5 cm wide) are cut into the sides of each sack for the transplants. Holes are staggered and distanced approximately 15 cm. Plants (n=4) can also be grown on the top of the sack.

Whether you are growing crops in the soil or in sacks and/or pots, the soil needs to be as healthy and fertile as possible. And well drained with high aeration. One of the best ways to improve soil health, increase aeration, and improve soil fertility is to mix aged compost with local soil. Compost in excess as to what is needed to fill your sacs and/or other planting containers can be used in gardens and your farms.

Preparation of Compost: Gather food waste and green kitchen waste, locally available materials, and raised bins. Place waste materials are collected and placed on top of the ground in piles or into specially constructed open boxes made of any local materials. Composts should be placed away from toilets and streams. Materials are placed into heaps or piles normally about 1m x 2m and stacked to it reaches 1m in height. The piles need to be 'watered' during dry periods, but otherwise simply turned with a shovel or hoe every few weeks. The more poultry or animal manure that is added the better. This accelerates the decomposition process and makes the compost more uniform. If space is available, the compost pile can be placed within a wooded frame. Normally the media (soil plus compost) that is added into the sac is in a 60 to 40% ratio by volume).

Selected References:

Ampath. 2021. Training module for Family Preservation Unit, Eldoret, Kenya. Training Manual for Project Officer. Production of African leafy vegetables. Sac, tire, and square meter gardening. 10pp.

Brindisi, L., E.V. Merchant, B. Eliver, J. Odhiambo, E. Night, T. Nyawir, N. Nyabinda, S. Weller, J.E. Simon, and D. Hoffman. 2020. Comparative nutritional analysis between African Indigenous Vegetables grown by urban farmers and those available for purchase in Kibera, Nairobi, Kenya: A Case Study. J. Medicinally Active Plants 9(3):166-180.

Gallaher, C. M., WinklerPrins, A. M. G. A., Njenga, M., & Karanja, N. K. (2015). Creating Space: Sack Gardening as a Livelihood Strategy in the Kibera Slums of Nairobi, Kenya. Journal of Agriculture, Food Systems, and Community Development, 5(2), 155-173. https://doi.org/10.5304/jafscd.2015.052.006

Peggy PASCAL, and Emmanuel RINCK. 2009. Soaring food prices and nutrition in urban areas-Sack gardens in KENYA - FAO Nutrition and Consumer Protection Division (AGN).

Weller, S.C., Van Wyk, E., and Simon, J.E. 2015. Sustainable production for more resilient food production systems: case study of African Indigenous Vegetables in Eastern Africa. Acta Horticulturae 1102: 289-298.

Climate Resilient Agriculture Module 5: Climate Resilient Water Management Systems for Smallholder Farmers

James E. Simon, Ramu Govindasamy, Emil Van Wyk, Nyabinda Nama

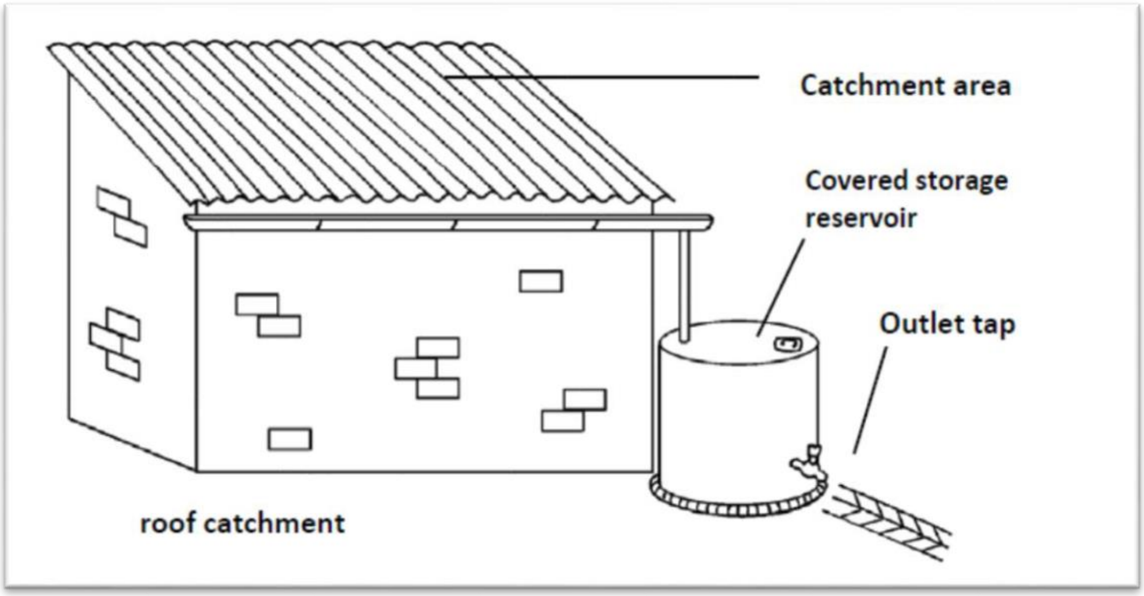
Rutgers Center for Agricultural Food Ecosystems

Creating a climate-smart water management system for smallholder farmers in the Federated States of Micronesia (FSM) involves integrating various components such as rooftop rainwater collection, storage, and efficient irrigation methods like drip irrigation. Results from the national household farming survey (Rutgers University, 2024) highlighted that water is a serious issue for many farming and home needs in the FSM. Whether related to access, availability, and/or quality, the need to reduce the vulnerability of households and farms from not having sufficient quality water when needed to having enough water is a critical component within a climate-smart agricultural strategy. Water management is key for successful farming and gardening and a critical component in strengthening resiliency against climate change. Therefore, water management from building collection and catchment systems to applications of using water efficiently to be prepared to mitigate risk against excessive water are all part and parcel of strengthening your household and community. This module has been divided into: Rooftop Rainwater Collection System, Rainwater Storage System, Drip Irrigation System, Sensor-Based Smart Irrigation, Community Engagement, and Conclusions.

Rooftop rainwater collection system

We focus here on Rooftop Rainwater Harvesting, a simple technique through which rainwater is captured from the roof, and roof catchments and stored in collecting tanks or can be directed into small ponds or catchments. The advantages of such a water collection system are that it provides a low-cost way to have water in reserve when there is a drought, water is limited, and even during the rainy seasons when it can reduce flooding around the home. Such rain collecting systems have also been shown to reduce soil erosion and provide off-the-grid full or partial self-sufficiency for your water supply reducing your vulnerability to water shortages. From the rain, the quality of the water should be high, low in minerals, and barring contaminants (extraneous debris from the roof such as particulates) clean. On the islands, in the forest on hillsides, roof-top rainwater harvesting can help mitigate against the impact of drought and excessive heat with increasing demands on water use. Harvested rainwater can be stored in above-ground or sub-surface groundwater reservoirs by adopting artificial recharge techniques to meet household needs through storage in tanks.

Rainwater from rooftops should be captured or carried through down-take water pipes or drains to a storage/harvesting system. Water pipes should be UV resistant (ISI HDPE/ PVC pipes) of required capacity. Rainwater collected from the roof is diverted to a storage tank(s). The storage



tank or water collection tank or number of tanks needed is designed according to the water requirements, rainfall, and catchment availability. Farmers using it for gardening and small-scale farm use will normally need greater water catchments than a household collecting for home use (cooking, cleaning). From the roof to the gutters or drainpipe, be sure that each drainpipe should have a mesh filter at the mouth and first flush device before connecting to the storage tank. Each tank should have an excess water overflow system. Excess water could be diverted to a recharge system or additional water tanks. Water from the storage tank(s) is used for domestic and gardening purposes. It is the most cost-effective way of rainwater harvesting. Additional pipes to catch overflow water beyond the capacity of your holding tanks can be diverted away from your home to a garden, bush, heavy grassy area, or area that can safely accept the additional water.

Water collected in any system does not make it automatically safe to drink. While the rains are clean and healthy to drink, the moment rainfall contacts any surface, including roofs, any contaminants from metallic rust to other soil, wood, or other particulates, even chemicals that are washed away from preservatives and other chemicals used in the treatment against insects as well as microbes such as bacteria. For human drinking purposes, rainwater that is collected should first be filtered, purified, or more easily boiled for 3-5 minutes before drinking and using it for cooking. Water may also be disinfected regularly before use by chlorination. For use to irrigate and water plants, then water can be directly used.

Gutters and downspouts need to be kept cleaned, oriented correctly, and tested to ensure smooth and unimpeded water flow, elimination of leaks, and proper orientation to connect each part to ensure minimum water loss. Installation of multiple barrels instead of just one, will help in capturing the excess rain once your prime barrel is full.

It is important to have a good drainage system on the ground around your water barrels so that extra water is routed away from the home and/or is directed into additional containers.

The Rooftop Rainwater Collection System is a key component of the climate-smart water management module designed to harness rainwater for agricultural use, specifically for smallholder farmers in the Federated States of Micronesia (FSM). The system comprises various elements that work together to efficiently capture and store rainwater for subsequent use in drip irrigation. Here's a detailed description of the rooftop rainwater collection system

1. Design and Planning:

- Analysis: Utilize historical rainfall data to determine the average annual rainfall and seasonal variations in the FSM region. This data is crucial for estimating the potential volume of rainwater that can be collected.
- Roof Selection: Choose roofs made of suitable materials (metal, tiles) with consideration for size and slope to optimize rainwater collection.

2. Gutter System:

- Size and Material: Install appropriately sized gutters made of durable materials like PVC or metal to handle the expected rainfall. The size is determined by the roof area and anticipated precipitation.
- Installation: Secure gutters with brackets at regular intervals to maintain proper slope for efficient water flow towards downspouts.

3. Downspouts and Conveyance Pipes:

- Downspout Placement: Strategically position downspouts, typically at each corner of the roof, to ensure even water distribution.
- Conveyance Pipe Material: Use high-quality, corrosion-resistant pipes for conveying rainwater from the gutters to storage tanks. Install pipes securely to prevent leaks.

4. First Flush Diverter:

- Purpose: Redirect the initial runoff from the roof to prevent contaminants (dust, bird droppings) from entering the storage system, thereby improving the quality of harvested rainwater.
- Installation: Place the first flush diverter at the beginning of the conveyance system. Periodically clean or replace it to maintain effectiveness.

5. Leaf Filter:

- Function: Prevent leaves and debris from entering the rainwater collection system, ensuring the harvested rainwater is clean.
- Installation: Install leaf filters at key entry points, such as the connection between gutters and downspouts. Regular cleaning or replacement is necessary to prevent clogging.

6. Integration with Storage System:

- Inlet Design: Design an effective inlet into the storage tanks to prevent sediment and debris from entering. A calming inlet minimizes disturbance and settles suspended particles.

- Overflow Prevention: Implement an overflow system to divert excess rainwater away from the storage tanks during heavy rainfall. Connect overflow pipes to suitable drainage areas.

7. Water Level Indicator:

- Purpose: Enable farmers to easily monitor the water level in storage tanks. This information assists in planning irrigation schedules based on available water.
- Installation: Install a reliable water level indicator on the storage tank, ensuring it is visible and accessible to farmers.

8. Maintenance and Cleaning:

- Regular Inspections: Schedule routine inspections of the entire rainwater collection system to identify and address issues promptly.
- Cleaning Schedule: Establish a cleaning schedule for gutters, downspouts, first flush diverters, and leaf filters. Educate farmers on the importance of regular maintenance.

9. Water Quality Assurance:

- Water Testing: Conduct periodic water quality tests to ensure harvested rainwater meets safety standards. Address any contamination issues promptly.
- Water Treatment (if needed): Integrate water treatment methods such as chlorination or UV disinfection if water quality concerns arise. Guide appropriate treatment measures.

The Rooftop Rainwater Collection System, when properly designed, installed, and maintained, ensures a sustainable and clean water supply for smallholder farmers in the FSM, supporting their agricultural activities through efficient drip irrigation practices.

Rainwater Storage System using pond:

Some farmers and communities may have opportunities to build and develop ponds to be used for agriculture, aquaculture, and other development needs. Recognizing any such structures may require permission and permits from traditional leaders and the municipality and state government.

Fig. 1. A pond lined with plastic to reduce seepage and to hold water as a catchment for irrigation and community water use. The photo is to illustrate the pond only- not the removal of trees and vegetation surrounding the pond as was done here in eastern Zambia. The retention of vegetation including shrubs and trees and the least disturbance to the land with the building of a pond area to which your community's excess rain can be channeled is the goal. Soil erosion must be kept to a minimum, all traditional leaders and public policy must be followed so check in advance for permission as needed.

Runoff from roads or hillsides and small streams can be stored in ponds. Ponds contain larger volumes of water than the rooftop harvesting tanks. The stored water is used for irrigation and animal and poultry production.

Water from the farm ponds can be used for an irrigated area for open cultivation or greenhouse production Most farmers use it for supplementary irrigation of vegetables. The pond is used in a dry week interval or to finish the production when the rainy season has stopped. With appropriate seeds, fertilization, and crop management high production levels can be achieved. Irrigated areas and the pond itself are often protected by a fence.

Sometimes ponds when dug in sandy hillsides need lining to avoid water loss through seepage. Special plastic is normally available for this purpose. These sheets need to be handled with care to avoid damage and water loss through the holes. The ponds have a pipe at the bottom to release the water for irrigation. Where that is not possible a treadle pump is used to pump the water out.

The Rainwater Storage System is a crucial component of the climate-smart water management module, serving as a reservoir for collected rainwater from rooftop runoff. This stored water is then used for drip irrigation in smallholder farming operations in the Federated States of Micronesia (FSM). Here's a detailed description of the rainwater storage system:

1. Storage Tanks:
    - Material Selection: Choose appropriate materials for the storage tanks, such as polyethylene or concrete, considering durability and compatibility with harvested rainwater.
    - Capacity Planning: Determine the storage capacity based on water demand, crop requirements, and the anticipated frequency and duration of dry spells between rainfall events.
2. Filtration System:
    - Sand Filters and Mesh Filters: Integrate sand filters and mesh filters to remove impurities, sediments, and debris from the harvested rainwater before it enters the storage tanks.
    - Maintenance Access: Ensure easy access to filters for regular cleaning and maintenance to sustain the quality of stored water.
3. Overflow System:
    - Design and Implementation: Develop an overflow system to prevent overfilling of the storage tanks during heavy rainfall. Connect overflow pipes to suitable drainage areas to avoid waterlogging or damage to the storage structure.
4. Water Level Indicator:
    - Purpose: Install a water level indicator on the storage tank to allow farmers to monitor the available water at any given time.
    - Visibility and Accessibility: Ensure that the water level indicator is easily visible and accessible for farmers to make informed decisions regarding irrigation scheduling.
5. Calming Inlet:
    - Function: Implement a calming inlet at the point where rainwater enters the storage tank. This helps minimize turbulence, allowing suspended particles to settle at the bottom.
    - Sediment Removal: Periodically clean the sediment settled at the bottom of the tank to maintain water quality.
6. Anti-Algae Measures:
    - Tank Color: Choose tank colors that limit sunlight penetration to reduce algae growth. Dark colors absorb more sunlight, helping prevent algae formation.
    - Algae Treatment (if needed): If algae growth occurs, consider safe treatment methods to control and prevent its proliferation.
7. Access Points and Manholes:
    - Accessibility: Design and install manholes or access points for ease of inspection, maintenance, and cleaning activities.

8. Inlet and Outlet Pipes:

- Efficient Flow: Ensure properly sized inlet pipes for efficient filling of the tank and outlet pipes for controlled distribution of water during irrigation.
- Anti-Contamination Measures: Install screens or filters on the inlet to prevent debris from entering the tank.

9. Mosquito Control:

- Mesh Covers: Install mesh covers on tank openings to prevent the breeding of mosquitoes and the entry of other contaminants.

10. Secure Tank Foundation:

- Stability: Ensure that the tank is placed on a stable foundation to prevent tilting or damage during adverse weather conditions.

11. Labeling and Instructions:

- Educational Information: Label the tank with instructions and educational information on safe water use, maintenance, and any necessary precautions.

A well-designed and maintained Rainwater Storage System is essential for ensuring a reliable and clean water supply for smallholder farmers in the FSM. The storage system, when integrated into the overall climate-smart water management module, enhances the resilience of agricultural practices by providing a sustainable water source for efficient drip irrigation. Regular monitoring and maintenance are crucial to the long-term success of the rainwater storage component.

Drip Irrigation System:

In farming, crops and animals need water to produce high yields and high quality. Depending upon the weather and rainfall pattern, irrigation may or may not be needed but if water is needed and not available, crop yields and animal and poultry husbandry will be reduced. To address the changing climate and to increase crop resiliency, water is needed. Here too, simple technologies can be introduced to collect rainwater and store it in tanks and/or underground or above-ground containers/cisterns. Yet pumps are needed to move the water and as such, use of treadle pumps (human energy), generators, or on-grid electricity are among the most common power systems used. Today, however, the introduction of small-scale solar-powered systems can be used to pump water collected into holding tanks that can be used for farming applications, home use for drip irrigation, and other agricultural purposes.

In manufacturing, locally built water storage tanks constructed of fiber cement are another example of simple technology that utilizes locally available materials. Plastic ‘caps and gutters’ placed on homes and divert rainwater during wet times of the year into large containers/cisterns to later be used as needed. Annual and periodic maintenance and cleaning are needed to keep the system operational and safe.

The Drip Irrigation System is a vital component of the climate-smart water management module, providing an efficient and water-conserving method for smallholder farmers in the Federated

States of Micronesia (FSM). This system utilizes rainwater collected from rooftops and stored in tanks to irrigate crops precisely. Here's a detailed description of the drip irrigation system:

1. Drip Tapes or Hoses:

- Selection: Choose high-quality drip tapes or hoses suitable for the crops and soil conditions in the FSM.
- Material: Opt for durable materials that resist clogging and degradation over time.

2. Emitters:

- Type: Select appropriate emitters based on the water needs of different crops. Common types include inline emitters and point source emitters.
- Uniformity: Ensure uniform water distribution to avoid overwatering or underwatering of plants.

3. Filters:

- Function: Install filters to prevent clogging of emitters caused by sediment, debris, or organic matter.
- Maintenance: Schedule regular cleaning or replacement of filters to maintain system efficiency.

4. Pressure Regulators:

- Importance: Integrate pressure regulators to maintain consistent water pressure throughout the drip irrigation system.
- Optimal Pressure: Set pressure levels based on the manufacturer's recommendations and the specific requirements of the emitters.

5. Mainline and Sub-Main Pipes:

- Material: Use durable pipes for the mainline and sub-main to ensure longevity and resilience to weather conditions.
- Installation: Lay out pipes strategically to cover the entire farming area while minimizing pressure loss.

6. Drip System Layout:

- Spacing: Plan the spacing of drip lines to meet the water requirements of different crops and optimize water use.
- Zoning: Divide the farm into zones based on crop types, ensuring efficient water delivery to each area.

7. Automation and Control:

- Timer Systems: Implement timers or automated controllers to schedule irrigation cycles.

- Soil Moisture Sensors: Integrate soil moisture sensors to provide real-time feedback for precise irrigation management.

8. Fertilizer Injection System:

- Purpose: Optionally, include a fertilizer injection system to deliver nutrients directly to plants through the drip system.
- Precision Farming: Enhance nutrient efficiency and crop yield through targeted fertilization.

9. Protective Measures:

- Mulching: Encourage mulching around plants to conserve soil moisture and reduce evaporation.
- Drip Line Protection: Implement measures to protect drip lines from damage by animals, machinery, or foot traffic.

10. Training and User Manuals:

- Farmers Training: Provide training to farmers on the operation, maintenance, and troubleshooting of the drip irrigation system.
- User Manuals: Supply user manuals with clear instructions on system components and usage.

11. Regular Maintenance:

- Inspections: Conduct regular inspections of the entire drip irrigation system to identify and address any issues promptly.
- Cleaning Schedule: Establish a cleaning and maintenance schedule for filters, emitters, and other system components.

A well-designed Drip Irrigation System, when integrated into the broader climate-smart water management module, enables smallholder farmers in the FSM to efficiently utilize rainwater collected from rooftops. This precise and controlled irrigation method not only conserves water but also contributes to increased crop yields and sustainable agriculture practices in the region. Ongoing training, maintenance, and user support are crucial for the successful implementation and long-term success of the drip irrigation system.

Sensor-Based Smart Irrigation:

Sensor-Based Smart Irrigation is an advanced component of the climate-smart water management module, designed to enhance the precision and efficiency of water use in smallholder farming operations in the Federated States of Micronesia (FSM). This system integrates various sensors and automated control mechanisms to optimize irrigation practices. Here's a detailed description of the Sensor-Based Smart Irrigation component:

1. Soil Moisture Sensors:

- Deployment: Install soil moisture sensors at different depths within the root zone of crops.
- Data Collection: Continuously monitor soil moisture levels to determine the actual water content in the soil.

2. Weather Stations:

- Sensor Types: Utilize weather stations equipped with sensors for measuring temperature, humidity, wind speed, and solar radiation.
- Data Integration: Integrate weather data to adjust irrigation schedules based on prevailing environmental conditions.

3. Automated Control System:

- Data Processing: Implement an automated control system that processes data from soil moisture sensors and weather stations.
- Decision-Making Algorithms: Develop algorithms that consider real-time data to make informed decisions on irrigation timing and duration.

4. Precision Irrigation Adjustment:

- Dynamic Scheduling: Adjust irrigation schedules dynamically based on current soil moisture levels, upcoming weather forecasts, and crop water requirements.
- Optimal Water Use: Ensure that water is applied precisely when and where it is needed, avoiding both over-irrigation and under-irrigation.

5. Remote Monitoring and Control:

- Connectivity: Enable remote monitoring and control of the irrigation system through mobile applications or web interfaces.
- Alerts and Notifications: Implement alert systems to notify farmers of critical events or system malfunctions.

6. Integration with Drip Irrigation System:

- Communication Protocols: Ensure seamless communication between the sensor-based smart irrigation system and the drip irrigation components.
- Automated Valve Control: Integrate automated valve control to regulate water flow to different zones based on sensor feedback.

7. Water Use Efficiency Metrics:

- Data Analysis: Collect and analyze data on water use efficiency, irrigation effectiveness, and crop performance.
- Feedback Loop: Establish a feedback loop to continuously improve the irrigation system based on performance metrics.

8. Energy-Efficient Components:

- Solar-Powered Systems: Consider using solar-powered sensors and control units to minimize energy consumption.
- Energy-Efficient Pumps: If applicable, integrate energy-efficient pumps to further reduce operational costs.

9. Training and Capacity Building:

- User Training: Provide comprehensive training to farmers on the use and understanding of the sensor-based smart irrigation system.
- Troubleshooting Skills: Equip farmers with troubleshooting skills to address minor issues and ensure the continuous operation of the system.

10. Advisory Services:

- Expert Support: Establish a mechanism for expert support or advisory services to assist farmers in optimizing the use of the sensor-based smart irrigation system.
- Best Practices Guidance: Provide guidance on best practices for maximizing the benefits of the system.

The integration of Sensor-Based Smart Irrigation into the overall climate-smart water management module elevates the precision and sustainability of water use in smallholder farming in the FSM. By harnessing real-time data and advanced control mechanisms, this system optimizes irrigation practices, conserves water, and contributes to the resilience of agricultural activities in the face of changing environmental conditions. Ongoing support, training, and system refinement are crucial for the successful implementation and adoption of sensor-based smart irrigation practices.

Community Engagement

Community engagement is a crucial aspect of the climate-smart water management module, fostering collaboration, knowledge-sharing, and collective efforts to ensure the success and sustainability of the system. Here's a detailed description of the community engagement component:

1. Awareness Campaigns:

- Objectives: Raise awareness about the benefits of the climate-smart water management system among the local community.
- Communication Channels: Utilize various communication channels such as community meetings, radio broadcasts, and informational pamphlets.

2. Training and Capacity Building:

- Farmers Workshops: Conduct workshops to train smallholder farmers on the implementation, operation, and maintenance of the water management system.

- Skill Development: Provide hands-on training to develop skills in water conservation practices and efficient agricultural techniques.

3. Demonstration Farms:
   - Establishment: Set up demonstration farms where the climate-smart water management system is implemented and functioning effectively.
   - On-Site Learning: Allow community members to visit these farms to observe the system in action and learn best practices.
4. Farmers' Field Schools:
   - Learning Platforms: Organize field schools where farmers can actively engage in learning sessions, share experiences, and discuss challenges.
   - Knowledge Exchange: Encourage the exchange of traditional farming practices with modern, climate-smart techniques.
5. Community Meetings and Forums:
   - Regular Gatherings: Hold regular community meetings and forums to discuss the progress, challenges, and improvements related to the water management system.
   - Inclusive Discussions: Ensure that all community members have the opportunity to voice their opinions and share their experiences.
6. Collaborative Decision-Making:
   - Inclusive Decision-Making: Involve community members in decision-making processes related to the water management system.
   - Local Expertise: Leverage local knowledge and expertise to refine and adapt the system to the specific needs of the community.
7. Community-Based Monitoring:
   - Monitoring Committees: Form community-based monitoring committees responsible for overseeing the performance and maintenance of the water management system.
   - Reporting Mechanisms: Establish mechanisms for reporting issues or suggesting improvements.
8. Community Networks:
   - Establishment: Create community networks focused on sustainable agriculture, water management, and climate resilience.
   - Information Sharing: Facilitate the sharing of information, resources, and experiences among community members.
9. Incentive Programs:

- Recognition: Introduce incentive programs to recognize and reward community members who excel in implementing and maintaining the water management system.
- Community Competitions: Organize friendly competitions to encourage participation and innovation.

10. Community Empowerment:
    - Ownership: Foster a sense of ownership among community members by involving them in the planning and implementation stages.
    - Empowerment Programs: Implement programs that empower community members, especially women and youth, to actively participate in sustainable agriculture practices.
11. Continuous Support Services:
    - Extension Services: Provide ongoing extension services to address queries, offer technical assistance, and ensure the sustained success of the water management system.
    - Adaptive Management: Be adaptable and responsive to community feedback, making adjustments to the system as needed.

Community engagement is integral to the success of the climate-smart water management module, creating a sense of shared responsibility and collaboration. By involving the local community in every stage of the process, from planning to implementation and ongoing maintenance, the module can foster a sustainable and resilient water management system that meets the specific needs of smallholder farmers in the FSM. Continuous communication, inclusive decision-making, and empowerment are key elements in building a strong and supportive community around climate-smart agriculture practices.

Conclusions:

In implementing the Climate-Smart Water Management System, encompassing rooftop rainwater collection to drip irrigation for smallholder farmers in the Federated States of Micronesia (FSM), alongside robust community engagement initiatives, several significant outcomes and lessons have emerged.

Technical Success:

1. Efficient Water Utilization: The integration of rooftop rainwater collection and drip irrigation technologies has proven highly effective in optimizing water utilization. The precise application of water through the drip system has led to improved crop yields, while the rainwater collection system ensures a sustainable and reliable water supply.
2. Sustainability and Resilience: The sensor-based smart irrigation system, coupled with climate-responsive technologies, has enhanced the overall resilience of the system. By dynamically adjusting irrigation schedules based on real-time data, the system adapts to changing weather patterns, contributing to climate-smart agricultural practices.

3. Community Empowerment: The engagement of smallholder farmers in training sessions, workshops, and collaborative decision-making has fostered a sense of ownership and empowerment. Farmers are not only users of the system but active contributors to its success, incorporating traditional knowledge with modern technologies.

Community Impact:

1. Knowledge Sharing: The establishment of demonstration farms, field schools, and regular community forums has facilitated knowledge sharing among community members. This exchange of information has not only improved the understanding of the water management system but has also promoted a culture of continuous learning.
2. Inclusivity and Collaboration: Inclusive decision-making processes and collaborative efforts have strengthened community bonds. Farmers, irrespective of age or gender, actively participate in discussions, ensuring that the system aligns with the diverse needs and contexts of the local community.
3. Sustainable Agriculture Practices: The module's emphasis on sustainable agriculture practices, supported by community networks and incentive programs, has led to the adoption of climate-smart techniques beyond the water management system. This holistic approach contributes to the long-term sustainability of agriculture in the FSM.

Climate-Resilient Smart Water Management System, with its technical innovations and community-centered approach, marks a transformative step toward sustainable agriculture in the FSM. By harmonizing traditional wisdom with modern solutions, we envision a resilient, self-sufficient farming community capable of navigating the complexities of climate change and ensuring food security for future generations.

Selected References:

Fulton, C and E. Va Wyk. AgriSmart. Maintenance guide: Drip irrigation. 2019. Commercial Agricultural Sustainable Horticulture (CASH), Lusaka, Zambia. 2 pp.

Rutgers, The State University of New Jersey. (2024). Baseline Assessment in Support of Climate-resilient food security for farming households across the Federated States of Micronesia. Technical Report to Micronesia Conservation Trust, Federated States of Micronesia and the Green Climate Fund.

Climate Resilient Agriculture Module 6: Zero Energy Cool Chamber

James E. Simon, Ramu Govindasamy, Emil Van Wyk

Rutgers Center for Agricultural Food Ecosystems

The Federated States of Micronesia (FSM), located in the Western Pacific, encounters distinctive agricultural challenges attributed to its tropical climate and susceptibility to climate change. In the pursuit of sustainable and climate-smart agriculture, the incorporation of innovative techniques becomes imperative. A promising approach in this context is the adoption of Zero Energy Cool Chambers (ZECC) to enhance post-harvest storage and preservation methods.

Understanding Zero Energy Cool Chambers:

ZECC is an on-farm rural household storage structure that operates on the principle of evaporation cooling, this is an on-farm storage chamber, for fresh fruits, vegetables, and flowers to extend their shelf life and marketability. Due to their high moisture content fruits and vegetables have a very short life and are liable to spoil. Moreover, they are living entities and carry out transpiration, respiration, and ripening even after harvest. Spoilage of fruits and vegetables can be controlled by reducing the storage system. The chamber can keep the temperature 10-150C cooler than the outside temperature and maintain about 90% relative humidity.

Zero Energy Cool Chambers are economical and environmentally friendly structures designed to store and preserve agricultural produce without reliance on electricity. They do not replace refrigerators! The size and cooling ability will be dependent upon the seasonal temperatures so in the FSM it may not work in all areas every month. Operating on passive cooling principles, these chambers utilize natural ventilation and insulation to maintain optimal temperature and humidity levels. By providing a controlled environment, ZECCs extend the shelf life of perishable goods, thereby reducing post-harvest losses and enhancing food security.

Advantages of Zero Energy Cool Chambers:

1. Energy Efficiency: ZECCs operate without electricity, making them an ideal solution for remote areas in the FSM where access to reliable power sources may be limited. This not only reduces operational costs but also ensures sustainability amid fluctuating energy availability.
2. Climate Resilience: The ZECC design is adaptable to local climatic conditions, offering resilience against temperature variations, high humidity, and other environmental factors.

This makes it particularly suitable for the FSM, where the climate can be unpredictable and extreme.

3. Cost-Effectiveness: In comparison to conventional cooling systems, ZECCs are affordable to construct and maintain. The use of locally available materials further contributes to accessibility, making it feasible for small-scale farmers in the FSM.
4. Reduced Post-Harvest Losses: By maintaining a consistent and cool environment, ZECCs contribute to the reduction of post-harvest losses. This is crucial for farmers in the FSM to preserve the harvest, which directly impacts livelihoods.

Implementation in the Federated States of Micronesia:

1. Local Adaptation: The design and construction of ZECCs can be tailored to suit the specific needs and conditions of different regions within the FSM. Active participation of local communities in the adaptation and construction process promotes community engagement and ownership.
2. Capacity Building: Implementing ZECCs necessitates training and capacity-building initiatives to ensure local farmers have the knowledge and skills for effective use and maintenance. Collaboration with agricultural extension services and NGOs can provide crucial technical support and education.
3. Government Support: Widespread adoption of ZECCs requires educational awareness, and placement of pilot systems to demonstrate to others and those involved in extension to teach and train others. Such support encourages farmers to embrace this climate-smart agricultural technique.
4. Monitoring and Evaluation: Establishing regular monitoring and evaluation programs is essential to assess the effectiveness of ZECCs in different regions of the FSM. This data can inform adjustments to design and implementation strategies, ensuring continuous improvement and adaptation.

Constructing a Zero Energy Cool Chamber:

Constructing a Zero Energy Cool Chamber involves creating a facility that minimizes or eliminates the need for external energy inputs for cooling. The concept of a Zero Energy Cool Chamber typically focuses on using passive cooling techniques and renewable energy sources. Here's a general guide on how to construct such a facility:

1. Site Selection:
    - Choose a site that is well drained, level, receives adequate natural ventilation, shade, and near a water source. If shade is not available, then you can build the ZECC under a shaded structure.

- Consider the prevailing wind direction and design the facility to maximize airflow.

2. Design Considerations:
    - Orientation: Align the chamber to maximize exposure to prevailing winds and minimize direct sunlight.
    - Insulation: Use insulation materials to reduce heat transfer into the chamber.
    - Ventilation: Design openings for natural ventilation to allow cool air to flow through the chamber.
    - Shading: Provide shading using local materials or vegetation to reduce direct sunlight.
    - Cover for the chamber: Use lightweight cloth or woven grass to cover the open chamber
3. Construction Materials:
    - Use locally sourced and sustainable materials to minimize environmental impact.
    - Opt for materials with high thermal mass to regulate temperature.
4. Passive Cooling Techniques:
    - Thermal Mass: Incorporate materials with high thermal mass (e.g., concrete) to absorb and release heat slowly.
    - Earth Coupling: Use earth berms or underground structures to take advantage of the stable ground temperature.
    - Evaporative Cooling: Install systems that allow for evaporative cooling, such as using water features or wetted surfaces.

Figure 1: Process of constructing ZECC

5. Renewable Energy:
    - If possible, integrate renewable energy sources such as solar panels or wind turbines to power any necessary equipment, like fans or sensors.

- Consider energy-efficient appliances and lighting.

6. Water Harvesting and Watering:
    - Implement rainwater harvesting systems to collect water for cooling purposes and irrigation.
    - The ZECC may need to be watered 2-3 times/day to keep the evaporative cooling operating.
7. Monitoring:
    - Use sensors to monitor temperature, humidity, and other relevant parameters.
8. Local Expertise and Community Involvement:
    - Involve local communities and utilize traditional knowledge in construction methods.
    - Train local people in the maintenance and operation of the cool chamber.
9. Educational Programs:
    - Establish educational programs to raise awareness about the benefits of Zero Energy Cool Chambers and how to maintain them.

Before embarking on the construction of a Zero Energy Cool Chamber, it's crucial to conduct a thorough site assessment and engage with local communities.


Estimated Budget for Building a 3x10 ZECC in the FSM:

Constructing a 3x10 Zero Energy Cool Chamber in the FSM involves various components, each with associated costs. The provided budget is an estimate, and actual costs may vary based on local factors, material availability, and labor costs. A detailed assessment is crucial for accurate budgeting. Engaging local communities and utilizing locally available materials promotes sustainability and cost reduction.

Materials:

- Insulation material (e.g., straw, coconut coir) or coarse sand: free locally produced
- Building materials (bamboo, wood, or local alternatives): free locally produced
- Ventilation components (mesh, vents): $300
- Flooring materials: $200
- Sealant and adhesives: $100

Labor:

- Skilled labor for construction: $200
- Unskilled labor for assistance: $100

Transportation:

- Transportation of materials to the construction site: $50

Tools and Equipment:

- Basic construction tools (saws, hammers, drills): $0.00. Assuming you have the tools or the person you are hiring will have such tools
- Thermometers on long handle or sensors to monitor temperature: $20

Contingency:

- Contingency fund for unforeseen expenses: $300

Total Estimated Budget: $700 (or less as estimates are conservative and introduce paid labor to build)


You create two brick walls- normally in a rectangular shape and no more than 3 ft wide and 6-8 ft long (interior dimensions). Place straw or coconut coir or pebbles/small rocks in between pack in tight- and water the insulation. Make a reed or mat cover as shown above. Keep a temperature probe and monitor temperature outside and inside the ZECC. Re-wet materials between both walls when they dry out.

Conclusion:

Incorporating Zero Energy Cool Chambers into the agricultural practices of the Federated States of Micronesia offers a sustainable and climate-smart solution to address post-harvest challenges. By promoting energy efficiency, climate resilience, and cost-effectiveness, ZECCs can significantly contribute to enhancing food security, reducing post-harvest losses, and supporting the livelihoods of local farmers. Collaborative efforts involving government, communities, and support organizations can harness the potential of ZECCs to build a resilient and sustainable agricultural future in the FSM.

References:

Ashitha, G., P.R. Sonaraj and P. Shilpa. 2021. Zero energy cooling chamber and zero energy colling system in building wall. International J. Engineering Res and Tech 9(6): 2278-0181.

Ghosal. M.K. and J.R. Rath. 2019. Storage of Vegetables in Zero Energy Cool Chambers: a Review. EAS Journal of Nutrition and Food Sciences 1(4): 68-73.

Rutgers, The State University of New Jersey. (2024). Baseline Assessment in Support of Climate-resilient food security for farming households across the Federated States of Micronesia. Technical Report to Micronesia Conservation Trust, Federated States of Micronesia and the Green Climate Fund

Singh, A.K., S. Poonia, P. Santra and D. Mishra. 2017. Design, Development and Performance Evaluation of Low Cost Zero Energy Improved Passive Cool Chamber for Enhancing Shelf-life of Vegetables. Agricultural Engineering Today 41(4):1-8.

References and Contributing Sources

Adeyeri, O.E., W. Zhou, X. Wang, *et al.* (2022). The trend and spatial spread of multisectoral climate extremes in CMIP6 models. *Sci Rep* **12**, 21000. https://doi.org/10.1038/s41598-022-25265-4

Ashok, K., Behera, S. K., Rao, S. A., Weng, H., & Yamagata, T. (2007). El Niño Modoki and its possible teleconnection. Journal of Geophysical Research: Oceans, 112(C11). https://doi.org/10.1029/2006jc003798

Bailey R.T., Jenson J.W. (2011). Groundwater resources analysis of atoll islands in the FSM using an algebraic model. Technical Report No. 134.

Balick, M.J., ed. (2009). Ethnobotany of Pohnpei: Plants, people and island culture. New York Botanical Garden/University of Hawaii Press. Honolulu.

Bell J. and Taylor M. (2015). Building climate-resilient food systems for Pacific Islands. Penang, Malaysia: WorldFish. Program Report: 2015-15.

Bell J., Taylor M., Amos M., Andrew N. (2016). Climate change and Pacific Island food systems. CCAFS and CTA. Copenhagen, Denmark and Wageningen, the Netherlands. https://cgspace.cgiar.org/bitstream/handle/10568/75610/Pacific%20Booklet%20Final%20web.pdf?sequence=6&isAllowed=y

Bell J.D., Cisneros-Montemayor A., Hanich Q., Johnson J.E., Lehodey P., Moore B.R., Pratchett M.S., Reygondeau G., Senina I., Virdin J., Wabnitz C.C.C. (2018). Adaptations to maintain the contributions of small-scale fisheries to food security in the Pacific Islands. Marine Policy 88, 303-314.

Biza S. (2013). Vegetation and land cover vulnerability geospatial analyses due to sea level rise modeling. Final report. College of Micronesia, FSM.

Blue Prosperity Micronesia https://www.blueprosperitymicronesia.org/

Cassels, S. (2006). Overweight in the Pacific: links between foreign dependence, global food trade, and obesity in the Federated States of Micronesia. Globalization and Health, 2, 1-8.

Chand S. S., 2020: Climate Change Scenarios and Projections for the Pacific. In: Lalit Kumar (eds) Climate Change and Impacts in the Pacific, Springer Climate. Springer, Cham. https://doi.org/10.1007/978-3-030-32878-8_3

Commonwealth of Australia. (2024). Pacific Climate Change Data Portal. Australian Government Bureau of Meteorology. http://www.bom.gov.au/climate/pccsp/

Connell, J. (2015). Food security in the island Pacific: Is Micronesia as far away as ever?. *Reg Environ Change* 15, 1299–1311. https://doi.org/10.1007/s10113-014-0696-7

Donnegan, J.A., Butler, S.L., Kuegler, O., & Hiserote, B.A. (2011). Federated States of Micronesia's forest resources, 2006. *Resource Bulletin PNW-RB-262*, 56.

Eakin M., Liu G., Gomez A., De La Cour J., Heron S., Skirving W., Geiger E., Tirak K., Strong A. (2016). Global Coral Bleaching 2014-17. In: Encounter, 31 (1), Number 43, April 2016. The News Journal of the International Society for Reef Studies, ISSN 0225-27987. https://coralreefs.org/wp-content/uploads/2019/01/Reef-Encounter-43-April-2016-HR.pdf

Eckstein, D., Hutfils, M.-L., & Winges, M. (2018, November 27). Global climate risk index 2019. Germanwatch. https://www.germanwatch.org/en/16046

Enhancing the climate resilience of vulnerable island communities in Federated States of Micronesia. Adaptation Fund. (2021, September 24). https://www.adaptation-fund.org/project/enhancing-climate-change-resilience-vulnerable-island-communities-federated-states-micronesia/

Elevitch, Craig R., Garien Behling, Michael Constantinides, and James B. Friday. (2014) Grower's Guide to Pacific Island Agroforestry Systems, Information Resources, and Public Assistance Programs. In: Elevitch, C.R. (ed.). Food-Producing Agroforestry Landscapes of the Pacific. Permanent Agriculture Resources (PAR), Holualoa, Hawaii. http://www.agroforestry.org

Eyring, V., S. Bony, G.A. Meehl, C.A. Senior, B. Stevens, R.J. Stouffer and K.E. Taylor. (2016). Overview of the coupled model intercomparison project phase 6 (CMIP6) experimental design and organization. Geosci. Model Dev., 9, 1937–1958, https://doi.org/10.5194/gmd-9-1937-2016.

FAO. (2014). Food and Agriculture Organization of the United Nations. Policy measures to increase local food supply and improve food security in the Federated States of Micronesia, 1-44.

FAO. (2021). Food and Agriculture Organization of the United Nations. Poverty, malnutrition and food security in Pacific Small Island Developing States. Bangkok.

FSM and USFS. (2010). Federated States of Micronesia State-Wide Assessment and Resource Strategy 2010 – 2015 +. State Foresters. https://www.stateforesters.org/wp-content/uploads/2018/08/FSM-FAP.pdf

FSM. (2014) Household Income and Expenditure Survey 2013-2014 https://microdata.pacificdata.org/index.php/catalog/720

FSM. (2014). Federated States of Micronesia: Fifth National Report to the Convention on Biological Diversity.

FSM. (2015) 2023 Action Plan. 2023 Planning Committee, Palikir, Pohnpei https://dofa.gov.fm/wp-content/uploads/2018/12/FSM-2023-Action-Plan.pdf

FSM. (2020). The Federated States of Micronesia Sixth National Report to the Convention on Biological Diversity. Retrieved from: https://www.cbd.int/doc/nr/nr-06/fm-nr-06-en.pdf (Accessed: July 2021).

FSM. (2023a). National Biodiversity Strategy and Action Plan. https://www.cbd.int/doc/world/fm/fm-nbsap-v2-en.pdf

FSM. (2020). *Proceedings of the Pacific Regional Consultation on Water in Small Island Countries - Country Briefing Papers*. SPREP. https://www.sprep.org/att/IRC/eCOPIES/Countries/FSM/28.PDF

FSM FNC. (1997). First National Communication to the United Nations Framework Convention on Climate Change, https://unfccc.int/sites/default/files/resource/Micronesia%20INC.pdf.

FSM SNC. (2015). Second National Communication to the United Nations Framework Convention on Climate Change, https://unfccc.int/sites/default/files/resource/fsmnc2.pdf (last accessed June 2021).

FSM DECEM. (2016). Department of Environment, Climate Change & Emergency Management.

Integrated Agriculture Census 2016, https://fsm-data.sprep.org/dataset/federated-statess-micronesia-integrated-agriculture-census.

FSM DECEM. (2021). A Blueprint for Conserving the Biodiversity of the Federated States of Micronesia. https://fsm-data.sprep.org/dataset/blueprint-conserving-biodiversity-fsm

FSM DECEM. (2023b). Federated States of Micronesia's Strategic Development Plan (2004-2023), 1-193. https://fsm-data.sprep.org/resource/strategic-development-plan-2004-2023

FSM National Weather Service Office. (2015). Current and future climate of the Federated States of Micronesia. Pacific-Australia Climate Change Science and Adaptation Planning Program. https://www.pacificclimatechangescience.org/wp-content/uploads/2013/06/7_PACCSAP-FSM-11pp_WEB.pdf

FSM R&D. (2012). Department of Resources and Development. Federated States of Micronesia Agriculture Policy 2012-2016. FSM National Government: Palikir, Pohnpei.

FSM R&D. (2020). Department of Resources and Development. Federated States of Micronesia Forest Action Plan 2020-2030. Palikir, FSM.

FSM R&D SDG. (2020). Department of Resources and Development, SDG Working Group. First Voluntary National Review Report on the Implementation of the 2030 Agenda for Sustainable Development. Palikir, Pohnpei, FSM.

FSM R&D and SPC. (2019). Federated States of Micronesia Department of Resources and Development Fisheries Section. Aquaculture Management and Development Plan.

FSM TNC. (2023). Federated States of Micronesia Third National Contribution (TNC) and First Biennial Update Report to the United Nations Framework Convention on Climate Change, https://unfccc.int/sites/default/files/resource/NC3%20BUR1%20MICRONESIA%20UNFCCC.pdf

FSM Voluntary National Review. (2020.) https://hlpf.un.org/countries/micronesia/voluntary-national-review-2020

Graduate School USA PITI-VITI. (2019). *Federated States of Micronesia Fiscal Year 2018 Statistical Appendices.* EconMAP. https://pubs.pitiviti.org/fsm-fy18-economic-statistics (Accessed January 2022).

Gutiérrez, J.M., R.G. Jones, G.T. Narisma, L.M. Alves, M. Amjad, I.V. Gorodetskaya, M. Grose, N.A.B. Klutse, S. Krakovska, J. Li, D. Martínez-Castro, L.O. Mearns, S.H. Mernild, T. Ngo-Duc, B. van den Hurk, and J.-H. Yoon. (2021): Atlas. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press. Interactive Atlas available from Available from http://interactive-atlas.ipcc.ch/

Hausfather, Z. and G. Peters. (2020). Emissions – the 'business as usual' story is misleading. Nature Comment Article. January 29, 2020. https://www.nature.com/articles/d41586-020-00177-3.

Henry R., Jeffery W. (2008). Waterworld: the heritage dimensions of 'climate change' in the Pacific. Historic Environment 21 (1), 12-18. https://australia.icomos.org/wp-content/uploads/Waterworld-The-Heritage-Dimensions-of-Climate-Change-in-the-Pacific-vol-21-no-1.pdf

Holbrook, N.J, Hernaman, V., Koshiba S., Lako J., Jules B. Kajtar, P.A., Singh A. Impacts of marine heatwaves on tropical western and central Pacific Island nations and their communities, Global and Planetary Change, Volume 208, 2022, 103680, ISSN 0921-8181, https://doi.org/10.1016/j.gloplacha.2021.103680

IPCC. (2022). Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C.

Iturbide, M., J. Fernández, J.M. Gutiérrez, J. Bedia, E. Cimadevilla, J. Díez-Sierra, R. Manzanas, A. Casanueva, J. Baño-Medina, J. Milovac, S. Herrera, A.S. Cofiño, D. San Martín, M. García-Díez, M. Hauser, D. Huard and Ö. Yelekci. (2021) Repository supporting the implementation of FAIR principles in the IPCC-WG1 Atlas. Zenodo, DOI: 10.5281/zenodo.3691645. Available from: https://github.com/IPCC-WG1/Atlas.

Micronesia Conservation Trust (MCT). (2021). Gather Baseline Data for Staple Crops and Marine Species for Local Aquaculture Development, and Other Foods and Model Climate Change Impacts.

National Centers for Environmental Information. (n.d.). NOAA: Most recent standard climatological period (1991-2020) for precipitation data. U.S. Climate Normals Quick Access Tool. https://www.ncei.noaa.gov/access/us- climate-normals/#dataset=normals-annualseasonal&timeframe=30&location=FM (Accessed 26 December 2021)

National Oceanic Fisheries Investment Policy for the FSM 2021-2026: A Policy to Maximize Value of Participatory Rights under the Vessel Day Scheme. Retrieved from: https://gov.fm/files/FSM_NATIONAL_OCEANIC_FISHERIES_INVESTMENT_POLICY_2021-2026_final_draft_as_of_9_1_2021.pdf (Accessed February 2021).

Oue Y.P. (2018). "Pacific in Peril: Micronesia's Food Security, Development, and Health under A Changing Climate". Student Theses 2015-Present. https://fordham.bepress.com/environ_2015/66

Pacific Adaptation Strategy Assistance (PASAP). (2021). Securing Food Resources in the Federated States of Micronesia.

Pacific Community. (2020, November 23). Atoll water inventory. ArcGIS StoryMaps. https://storymaps.arcgis.com/stories/9f34ad66403140a5b394fe26b1ebf696

The Pacific Community and Government of Pohnpei. (2016). Pohnpei Joint State Action Plan for Disaster Risk Management and Climate Change. The Pacific Community.

Patagan R. (2022). Social protection in the Federated States of Micronesia: Spotlight in subsistence and food security. In: Pacific Economic Monitor, December 2022. Asian Development Bank, Manila, Philippines.

Perkins, R. M., and Krause, S. (2018). Adapting to climate change impacts in Yap State, Federated States of Micronesia: the importance of environmental conditions and intangible cultural heritage. Island Studies Journal, 13(1), 65–78. https://doi.org/10.24043/isj.51.

PIO. (2024, January 15). Emergency Declaration 2024-01 Declaring a State of Emergency relative to inadequate water supply for Pohnpei. Office of the Governor Pohnpei State FSM. https://pohnpeistate.gov.fm/2024/01/15/emergency-declaration-2024-01-declaring-a-state-of-emergency-relative-to-inadequate-water-supply-for-pohnpei/

Pohnpei State, Federated States of Micronesia. (2023). Pohnpei State Department of Resources and Development Food Security Policy and Food Production Master Plan.

Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.

Rutgers, The State University of New Jersey. (2024). Baseline Assessment in Support of Climate-resilient food security for farming households across the Federated States of Micronesia. Technical Report to Micronesia Conservation Trust, Federated States of Micronesia and the Green Climate Fund.

Taylor M., McGregor A., Dawson B. (2016). Vulnerability of Pacific Island agriculture and forestry to climate change. The Pacific Community (SPC), Noumea, New Caledonia.

University of Notre Dame. (2024). Country Index. Notre Dame Global Adaptation Initiative. https://gain.nd.edu/our-work/country-index/.

USAID. (2019). USAID/OFDA Program Summary. Federated States of Micronesia and Republic of the Marshall Islands.
https://reliefweb.int/report/micronesia-federated-states/usaidofda-program-summary-federated-states-micronesia-and-3

USGS. The Impact of Sea-Level Rise and Climate Change on Pacific Ocean Atolls
https://www.usgs.gov/centers/pcmsc/science/impact-sea-level-rise-and-climate-change-pacific-ocean-atolls

The World Bank Group. (2021). *Micronesia, Fed. Sts. Country Summary*. Climate Change Knowledge Portal. https://climateknowledgeportal.worldbank.org/country/micronesia-fed-sts