

Hawaii and the U.S.-Affiliated Pacific Islands

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Description of the Region

Hawaii and the U.S.-affiliated Pacific Islands (fig. A.1) include a diversity of traditional and modern agroforestry systems that have developed across a broad range of environments, from low coral atolls to high volcanic islands rising to 4,205 meters (m) (13,796 feet [ft]) in Hawaii. The peoples of Micronesia and Polynesia settled their islands as many as 4,000 years ago (Athens and Ward 2004) and brought with them a basic suite of agricultural plants. In the ensuing centuries, they developed highly sophisticated agroforestry systems tailored to meet food security needs within the local environments they inhabited. Having been developed on isolated islands and enduring for centuries or millennia, these agroforestry systems are models of sustainability (Clarke and Thaman 1993). Fertility is largely maintained by the recycling of nutrients, fallowing, and other ecosystem processes. Mulching is also practiced in many

systems. Continuous soil cover prevents erosion. Because the species diversity and structure of tree-based multistory gardens are similar to native forests, these agroforests protect watersheds and water quality, both in streams and near the shore. The productivity over extremely long timeframes based only on local resources attests to their value as models for modern agroforestry systems that can be resilient to environmental stressors of the type that are projected to accompany climate change (table A.1).

The most common traditional system is a tree-based multistory system based on highly productive multipurpose species such as banana (*Musa x paradisiaca*) and coconut (*Cocos nucifera*) (fig. A.2). The traditional staple crops, in addition to breadfruit, include taros (*Colocasia esculenta*, *Alocasia macrorrhizos*, *Cyrtosperma merkusii*, and *Xanthosoma* spp.), yams (*Dioscorea* spp.), bananas (*Musa x paradisiaca*), and sweet

Figure A.1. Map of Hawaii and the U.S.-affiliated Pacific Islands. (Figure from <http://www.PacificRISA.org>, used with permission).

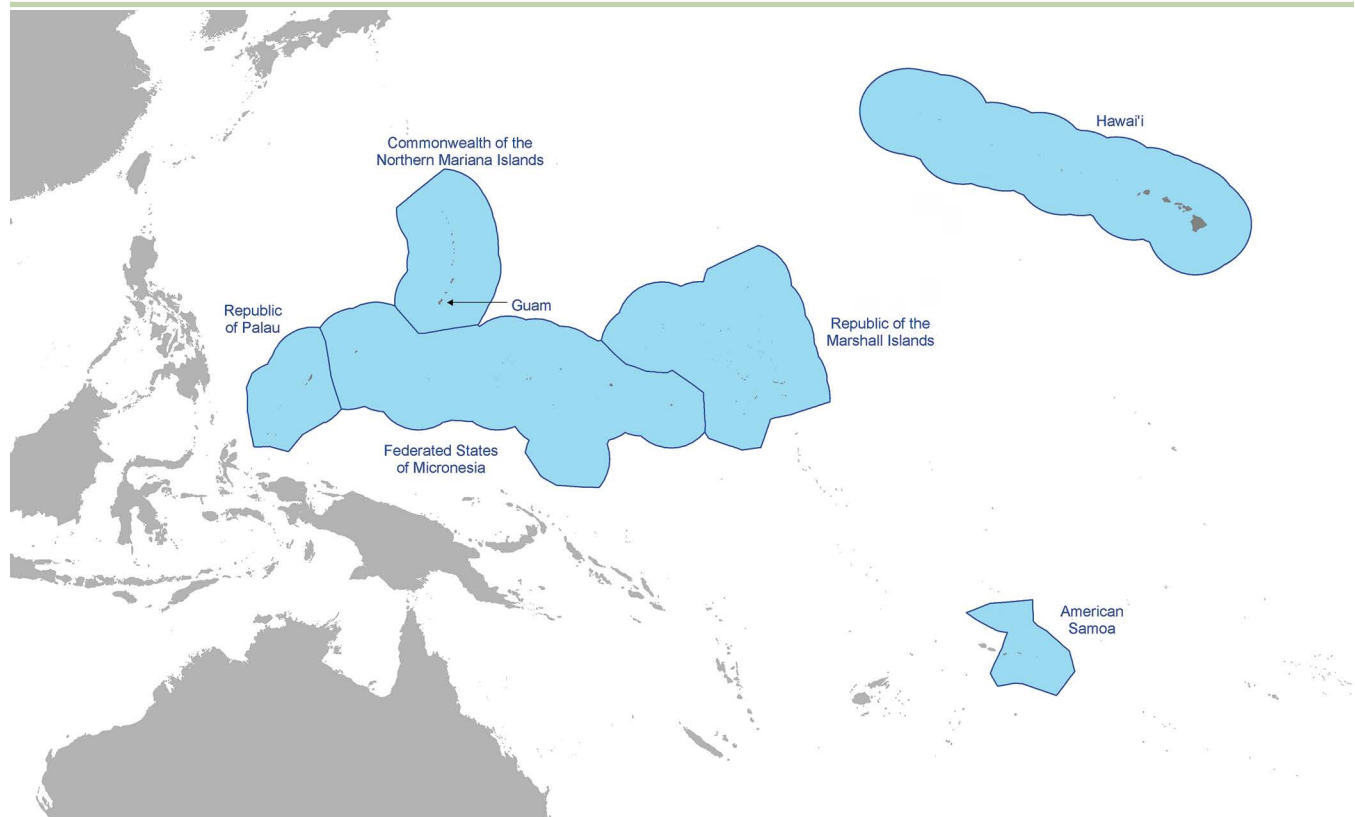


Table A.1. Agroforestry practices that address threats and challenges.

Pacific agroforestry system	Threat/challenge addressed	Mechanism
Multistory agroforest (including homegardens, shade coffee)	Intense rainfall and soil erosion	Dissipates kinetic energy, surface litter, and tree roots with complex canopy.
	Drought	Provides more deeply rooted tree crops than annual crops.
	Sea-level rise	Allows upland agroforests to be less affected by sea-level rise than coastal farms.
Coastal strand windbreak (traditional)	Salt spray	Slows wind and blocks salt spray.
	Storm surge, wave inundation	Reinforces beach berm with roots.
Windbreaks in fields, orchards, pastures	Increased storm intensity and frequency	Dissipates wind energy.
Silvopasture	Increased temperature extremes	Provides shade for livestock.
Intensive tree leaf mulching to create organic soils for tree or annual crops	Drought, storm recovery	Ameliorates sandy soils with organic material.
Taro paddies (mulched with tree/shrub foliage)	Intense rainfall or drought	Manages water use.

Figure A.2. A traditional agroforest on Palau. Crops include soft taro (*Colocasia esculenta*), giant taro (*Cyrtosperma merkusii*), avocado (*Persea americana*), banana (*Musa x paradisiaca*), papaya (*Carica papaya*), betel nut palm (*Areca catechu*), coconut palm (*Cocos nucifera*), and bamboo (*Bambusa* sp.). (Photo by J.B. Friday, University of Hawaii).



potato (*Ipomoea batatas*), with different crops being favored by different cultures and different environments (Kitalong 2008, Raynor and Fownes 1991). Medicinal plants often include kava (*Piper methysticum*), betel nut (*Areca catechu*), and noni (*Morinda citrifolia*) and a diverse array of indigenous and introduced plants (Kitalong et al. 2011). Agroforests also include other useful species such as *Pandanus tectorius*, used for food and fiber, and timber species such as *Calophyllum inophyllum*. These pan-Pacific trees and crops are adapted to a wide range of moisture regimes, although all are tropical and grow best in coastal environments. Since contact with Western civilization in the late 1700s, dozens of new species have been introduced and integrated into Pacific Island agroforests (Clarke and Thaman 1993). This additional species diversity, also called “agrobiodiversity,” can strengthen resiliency of agroforestry systems (Clarke and Thaman 1997). Most modern agroforests include fruit trees such as citrus (*Citrus* spp.), mango (*Mangifera indica*), avocado (*Persea americana*), and soursop and other *Annona* spp., which were introduced in modern times. Other modern cash crops that are sometimes incorporated into agroforestry systems include black pepper (*Piper nigrum*) and cacao (*Theobroma cacao*). On atolls and coastal areas of some high islands, farmers grow giant swamp taro (*Cyrtosperma merkusii*) in sandy soils in excavated pits by mulching heavily with leaves cut from native trees (Manner 1993, 2010). Vegetation is usually preserved along coastlines (a practice now termed “coastal strand buffers”) and along streams (riparian buffers). Windbreaks are also important to protect more delicate plants from wind and salt spray. Shifting agriculture, with or without an enhanced forest fallow, is also practiced for some crops on high islands of Micronesia and on American Samoa (Manner 1993, 2014).

Traditional farmers across the Pacific have developed a stunning diversity of cultivars of their main crops. On Pohnpei in Micronesia, Raynor et al. (1992) found names for 177 cultivars of yams (*Dioscorea* spp.). Islanders across the Pacific have developed hundreds of cultivars of breadfruit (Zerega et al. 2004). On Pohnpei alone, Ragone and Raynor (2009, in Balick 2009) identified 48 cultivars of breadfruit. The high agrobiodiversity of Pacific Island agroforestry systems represents adaptation to different environments and also the provision of additional uses. Fownes and Raynor (1993) found that different cultivars of breadfruit on Pohnpei fruited during different months and thus, by growing different cultivars, farmers were able to extend the breadfruit season. By having a range of varieties that can be harvested year round, it is more likely that some of the total harvest will be spared from the effects of extreme weather conditions or events. Englberger et al. (2009, in Balick 2009) estimated that about 50 cultivars of bananas are grown on Pohnpei. Englberger et al. (2004, 2006) showed that

some traditional cultivars of banana were rich in carotenoids and vitamin A and could play an important role in addressing local nutrition problems caused by an overreliance on refined, imported foods. Despite the increasing importance of imported foods such as rice, bread, and canned meat, islanders still enjoy and, in part, depend on locally produced foods, which are seldom marketed commercially but are usually locally available through family connections (fig. A.3). The wide range of varieties and cultivars that still exist within and between islands provides options for changing environmental conditions.

A number of acres on the Pacific islands, representing from 2 to 85 percent of the total forest area on the islands, are dedicated to multistrata agroforests (table A.2). There are still many areas potentially suitable for agroforestry on the islands (table A.2).

Figure A.3. Locally grown agroforestry crops for sale at a market on Yap Island, Federated States of Micronesia. Crops include watermelon (*Citrullus lanatus* var. *lanatus*), taro (*Colocasia esculenta*), calamansi (*Citrus microcarpa*), soursop (*Annona muricata*), chili peppers (*Capsicum* sp.), pineapple (*Ananas comosus*), several varieties of bananas (*Musa x paradisiaca*), passion fruit (*Passiflora edulis*), breadfruit (*Artocarpus altilis*), and Tahitian chestnut (*Inocarpus fagifer*). (Photo by J.B. Friday, University of Hawaii).



Table A.2. Extent of current and potential agroforests on Pacific Islands.

U.S.-affiliated Pacific Island jurisdiction	Total area (acres)	Population (2010)	Multistrata agroforest		Potentially appropriate for agroforestry (not currently in forest or agroforest) (acres)		
			Acres	Percent of total forest	Savanna, other shrubs and grassland, and disturbed vegetation	Cropland	Total
Hawaii ^a	4,127,337	1,360,301			770,085	174,042	944,127
American Samoa (U.S. Territory)	49,280	55,519	15,510 ^b	35			715 ^c
Republic of the Marshall Islands ^d	44,800	67,182	20,000	85	1,134		1,134
Federated States of Micronesia ^e	149,804	106,836	35,655	25	11,852	195	12,047
Commonwealth of the Northern Mariana Islands ^f	113,280	53,883	1,313	3	13,372	918	14,290
Guam (U.S. Territory) ^g	135,680	159,358	1,921	2	44,455		44,455
Republic of Palau	114,560	20,956	2,740 ^h	4			15,329 ⁱ

^a U.S. Department of Agriculture (2012).^b Cole et al. (1988).^c Donnegan et al. (2004b).^d Donnegan et al. (2011c).^e Donnegan et al. (2011b).^f Donnegan et al. (2011a).^g Donnegan et al. (2004a).^h Cole et al. (1987).ⁱ Donnegan et al. (2007).

Note: Blank cells indicate data are not available.

Characteristics of Agroforestry Systems

Pacific Island agroforestry systems can be highly productive. Fownes and Raynor (1993) calculated that the Pohnpeian agroforestry system produced more than 6 metric tons/hectare (ha)/year (2.7 tons/acre/year) of breadfruit alone plus significant yields of starches such as yam, taro, and other crops. Tree-based systems typically have a much higher standing biomass and total carbon storage per unit area than do annual crops. The high perennial biomass results in systems that are both more resistant to change than annual cropping systems and more resilient in the face of change. For example, fruit trees may drop fruits during a drought, but the trees will usually remain in condition to produce when rainfall returns.

The high agrobiodiversity of Pacific Island agroforestry systems also increases resistance and resiliency. Evidence indicates that those systems resist (through diversity) and recover from (through fallow) insect and disease problems better than monocultures do (Ferentinos and Vargo 1993). It is hoped that these systems will also resist and be resilient to climate change. If environmental stressors caused by climate change (changes in rainfall, temperatures, or seasonality of flowering and fruiting) cause some crops or varieties to fail, other crops in the system can take their place. For example, if increased ground-water salinity makes cultivation of *Colocasia* taro infeasible, farmers could switch to cultivating *Cyrtosperma* taro, which is generally regarded as being more salt tolerant. Agroforestry systems in the Pacific have a complex spatial structure, both vertically and across the landscape. The complex structure

may lead to improved resistance to change, because the system creates the microclimates for some of the plant species (for example, shade for understory crops). The danger also exists, however, that some microclimates may disappear entirely from some islands as climates change globally, taking with them adapted crop species.

Potential of and Limitations to Agroforestry

Hawaii has significant areas of cropland and pastureland with windbreaks and potential for additional windbreaks. Hawaii's major plantation crops (sugar and pineapple) have been greatly reduced in acreage, and the land released is still in a dynamic state, with potential for increased combinations of orchard and even multistory agroforest. Pasturelands and rangelands in Hawaii, Guam, and the Commonwealth of the Northern Mariana Islands are ecologically suitable for forest and could be restored to forest or partial forest cover with silvopastoral techniques. The potential to return savanna, secondary vegetation, and other shrubs and grasslands to productivity through agroforestry varies with land tenure, soil fertility, and slope. The "potentially appropriate" acreage figures in table A.2 have not been reduced for those factors.

Despite the productivity, resistance, and resilience of traditional agroforestry systems, a major drawback has been low-cash productivity. Most agroforestry products are subsistence foods such as breadfruit, taro, and yams. Farmers across the Pacific frequently neglect traditional agroforestry systems to seek cash employment or convert agroforests to cash crops.

Traditional agroforests can be enriched with high-value crops to perpetuate these resistant and resilient systems while increasing economic output. Examples of cash crops include black pepper (*Piper nigrum*) and sakau or kava (*Piper methysticum*) on Pohnpei (Merlin and Raynor 2005). Some traditional subsistence plants such as coconut can also be used to produce products for sale, such as oil or baskets, if markets exist. As more islanders find cash employment in the market economy, markets for traditional food crops such as yams are developing in population centers, giving farmers another way to earn some cash (Ames et al. 2009). Public campaigns to emphasize the nutritional values of traditional foods (Englberger and Lorens 2004) can also encourage farmers to perpetuate agroforestry systems, and, in some places, traditional crops have entered the cash market.

Threats and Challenges to Agricultural Production and Community Well-Being

Climate change is expected to affect island agroforestry with higher temperatures, changes in precipitation, increased storm intensity (wind and rainfall), and salinization of groundwater, depending on the region (ABM and CSIRO 2014) and local topography. To date, the effects of long-term climate change are difficult to measure and separate from natural medium- and short-term variability. Declines in rainfall in Hawaii during the past century are attributed to climate change but may have been caused partially by volcanic emissions for the past few decades (Giambelluca et al. 2013). The Pacific Decadal Oscillation and the El Niño—Southern Oscillation (ENSO) variously affect sea level, storms, and drought, and Pacific islands are characterized by high natural variability as a result. “ENSO-related precipitation variability on regional scales will likely intensify with long-term global warming” (IPCC 2014).

Sea levels around the western Pacific have risen at rates double or more than double the global averages during La Niña-dominated conditions since 1993 (Keener et al. 2012). In 2014, conditions changed with the apparent onset of El Niño conditions. The National Oceanic and Atmospheric Administration observed that “the below average sea level in Micronesian waters is a huge shift from very high sea levels only a few months ago, and indeed, for most of the past decade” (NOAA 2014). Sea-level rise is expected ultimately to inundate Pacific Island coastal areas and atoll islands. The highest point on most atolls is typically 2 to 3 m (6 to 9 ft) above sea level. Within a generation, the freshwater lenses that underlie atolls and many coastal areas will shrink in volume and/or become increasingly saline as a result of the dynamic interplay between rising sea levels, drought, ocean water inundation events, and over-pumping wells. Increased groundwater salinity may reduce or eliminate the ability of low coral islands to support breadfruit

and taro (Manner 2014). Storms will also deposit coralline material on land in a natural process of island-building (Lobban and Scheffter 1997); however, even where the elevation of the land is thus increased and might seem to balance sea-level rise, it does not result in a steady state with respect to agriculture, because each disturbance event depositing gravel or saltwater requires a significant recovery period before agriculture again becomes productive.

Typhoons and tropical storms such as super typhoon Pongsona in Guam in 2002, Typhoon Sudal in Yap in 2004, Typhoon Bopha in Palau in 2012, and Hurricane Iselle in Hawaii in 2014 are particularly destructive to small islands. The Intergovernmental Panel on Climate Change (IPCC) (IPCC 2014) predicts that “extreme precipitation events... over wet tropical regions will very likely become more intense and more frequent.” Upland agroforestry systems will be damaged by high winds, and coastal systems may be highly degraded by storm surges. Although the forest cover provided by agroforestry protects against surface erosion, heavy rainfall can cause mass wasting events that devastate entire watersheds, as when Typhoon Chata’an caused several hundred landslides in Chuuk, including many that carried away the entire agroforest and soil horizon from some plots and inundated other plots with debris and mud (USGS 2002).

Droughts often occur in the Pacific under El Niño conditions and, under climate change, may increase in frequency and intensity, even though average rainfall is predicted to increase on most islands. Droughts may be particularly severe on coral atolls and the leeward sides of high islands such as Hawaii (Keener et al 2012). Guam and the Northern Marianas Islands already have seasonally dry climates (Mueller-Dombois and Fosberg 1998). The Northern Marshall Islands experienced a severe drought during 2013 and 2014, which resulted in the loss of much of the breadfruit crop. Tree-based agricultural systems, although resistant to moderate changes in climate, can be pushed past a breaking point when shifts in temperature and precipitation are so severe that the trees die, causing catastrophic losses. Droughts will also lead to increases in wildfires, which damage native forests and agroforests on the drier islands of the western Pacific, including Guam, Palau, and Yap.

Invasive plants, pests, and diseases brought to the Pacific Islands as a result of increased transportation and migration threaten the sustainability of agroforestry systems. Changing climates and the interaction with other disturbance may exacerbate the competition of nonnative species with native and traditionally cultivated species.

Finally, loss of traditional knowledge of cultivation techniques and cultivars is an important threat to Pacific Island agroforestry systems. Loss of knowledge is exacerbated by movement into towns and cities for jobs and migration from smaller islands

to larger ones, including to Hawaii and Guam and also to the mainland United States. In part, migration is fueled by concerns of climate change.

Conclusions

Pacific Islanders recognize the need to adapt to shifting weather and climatic conditions. The traditional agroforestry systems are not static and have evolved to take advantage of new plants, new markets, and new methods of cultivation since western contact. A major need is for cultivars that are more drought and salt tolerant and new methods of cultivation, because it is likely that drier and more saline conditions will prevail in the future (Friday 2011). Because these systems exist across the Pacific, farmers on wetter islands may be able to learn from those living on drier islands today. Recognizing the increased threat from sea-level rise and storm surges, islanders have expressed needs for plants for coastal stabilization and windbreaks and systems that are more resistant to damage by storms. Addressing these new threats is an appropriate job for Pacific Island universities and local agriculture and natural resource agencies. Often these efforts are facilitated through farmer-led research and training, especially farmer-to-farmer programs. On small islands, it is particularly evident how agriculture is linked to nutrition, employment, and economic activity. Establishing and nurturing traditional agroforestry systems to enhance their resiliency to climatic variability and food security will have benefits across society.

Key Information Needs

- Documentation of traditional agroforestry systems and knowledge of indigenous Pacific Islanders regarding growth, phenology, and management of these systems.
- Better agroecological understanding of how to apply agroforestry at farm and landscape levels to address various climate change scenarios and establishment on degraded or abandoned lands within the Pacific Islands.
- Development of methodologies to identify and manage for invasive species that are increasingly affecting agroforestry and other plant systems in the Pacific Islands.
- Identification of current economic and cultural impediments to adoption and retention of island agroforestry practices and of practical interventions that can enhance agroforestry's appeal and use.
- Development of tools that can help assess differences in production and natural resource services in conventional monocropped systems and agroforestry systems under changing climatic conditions.

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