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DYNAMICS OF AN ISLAND AGROECOSYSTEM

Where to Now?

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Introduction

Yap is a member of the Federated States of Micronesia, located in the northwest Pacific. The State consists of a cluster of four high islands, a raised limestone island and about 133 low-lying coralline islets in atolls scattered over about 260,000 square kilometres of ocean. Many of the low-lying islands are being affected by sea-level rise and concomitant saltwater intrusion. The islands have been administered by Spain (1886 to 1899), Germany (1899 to 1914), Japan (1914 to 1946) and since then, by the United States; initially as a Trust Territory and currently under a Compact of Free Association. Under this Compact, the United States is providing development assistance until 2023.

Small islands like Yap represent ecosystems at a human scale, with definite limits. Swidden agriculturists make use of the ecosystem services of natural systems to develop soil fertility and other conditions conducive to crop growth. The sustainability of swidden systems requires that the ecosystem remains basically intact and is not stressed beyond its limits. As human populations increase, larger areas are needed in order to produce sufficient food, while allowing ample time for soil fertility and tilth to be restored under natural fallows. When it is not possible to expand into larger agricultural areas, it is necessary to intensify efforts in order to compensate for impacts on natural systems.

The islands of Yap have ecosystems with fixed terrestrial boundaries and a history of dense human population. Being unable to expand their area, the people intensified their agricultural systems and integrated them with the islands' ecosystems. This resulted in a wide variety of agricultural systems making use of the full range of

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natural habitats, with specialized methods for managing water and nutrients. This chapter explores the place of swiddens and fallow management in these nature-integrated agricultural systems. Integrating agriculture with natural ecosystems has increasingly important implications for the modern world; however, the spectre of climate change looms, and the fate of these systems and their practitioners, who live at 'ground zero' of sea-level rise, remains to be seen.

Satellite altimetry shows that sea levels in the area of the Federated States of Micronesia have been rising by an average of 5mm to 10mm per year since 1993 – above the global mean of about 3mm per year for this period (Fletcher and Richmond, 2010). Figure 1 shows the location of Yap in the northwest Pacific, with an inset showing the high islands of mainland Yap and the lower-lying outer islands and atolls of Yap State. The average height above sea level for all Yap islands except mainland Yap and Fais is about 1.8m above high-tide level. With predictions of sea-level rise ranging from a conservative 0.2 to 0.6m or more (IPCC, 2007) to 0.6 to 2m during the 21st century (US National Research Council, 2010), with greater and more abrupt rise possible (Meehl, et al. 2007; Ananthaswamy, 2012), it is likely that most or all of the low-lying islands shown in figure 1 will eventually become uninhabitable as fresh-water resources and the ability to produce food are compromised by encroachment of

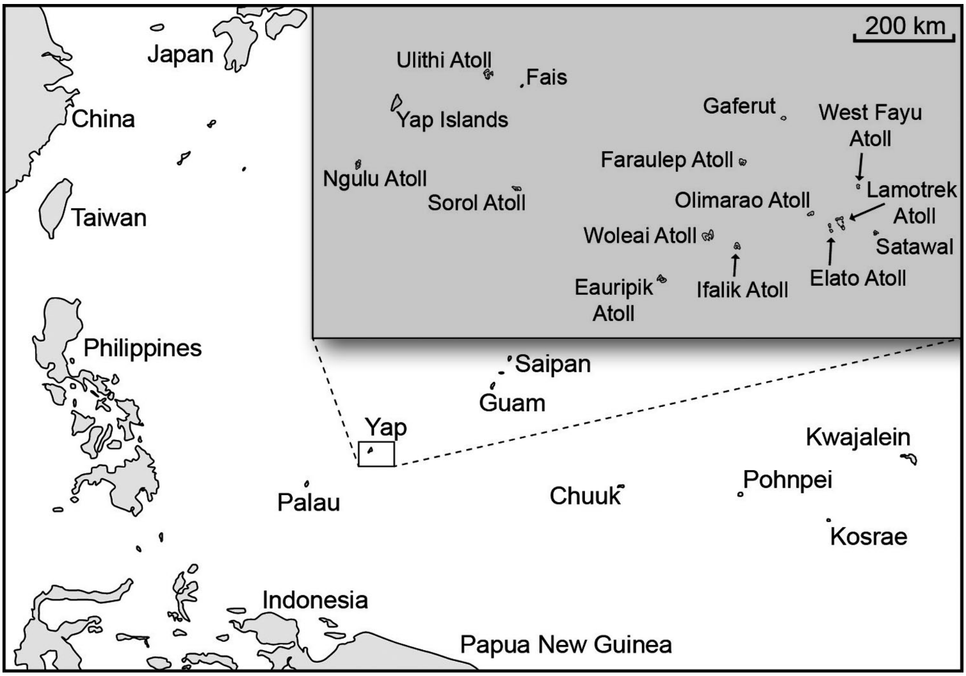


FIGURE 1 The location of Yap in the northwestern Pacific, with an inset showing mainland Yap and the Outer Islands of Yap State. Given predictions of sea level rise, it is likely that all but the islands of mainland Yap and the outer island of Fais will eventually become uninhabitable.

salt water. The most likely place for the displaced population to relocate is mainland Yap, but this island is also being impacted by climate change and sea-level rise.

This chapter describes past interaction of human populations with habitats on mainland Yap and the dynamics of the agroecosystem that developed. Recent changes in this system on mainland Yap are described, followed by a description of the nature and threats to agriculture in the Outer Islands. The chapter concludes by asking "Where to now?" and considers a past agricultural intensification relevant to meeting future challenges.

Human activities and vegetation dynamics in the past

The vegetation of Yap reflects the impacts of climate and human activities. Palynological studies indicate that Yap was mostly forested prior to human occupation. A major period of forest decline took place about 3300 years ago, as indicated by a decrease in pollen from forest trees and an increase in charcoal and spores and pollen of savannah species. The proportion of savannah species peaked about 300 years ago, when the island's population was highest (Dodson and Intoh, 1999). Today, the island's major vegetation types include mangroves, a mosaic of remnant native forest, secondary vegetation and secondary forest with savannah lands mostly devoid of a tree canopy, and anthropocentric tree garden/taro patch agroforest. Historical descriptions of Yap's vegetation and more recent vegetation maps show that this basic pattern is of long standing, with fluctuations in the relative proportions of these vegetation types.

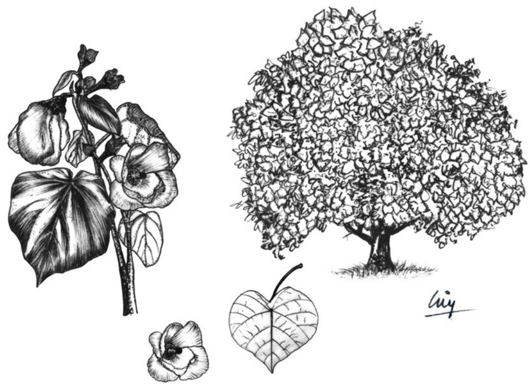
Tetens, who visited Yap several times between 1862 and 1868, first described the island as 'a most picturesque site. Fresh green fruit-bearing fields cover the tops of gently rising hills; below, thick forests of coco palms stretch almost to the beach' (Tetens [1888] 1956, p63). On his last visit, however, he reported war, and said 'the beautiful countryside was laid waste, its forest destroyed for years to come' (Tetens, 1956, p97). Twenty-five years later, the Spanish governor of Yap mentioned deforested mountains, extensive forests of coconut trees, tall thick mangroves and only about 17% forest. He described agricultural production around houses, taro patches in low swampy areas and ditched beds in the hills (de Oca, 1893, p257). Volkens (1901), who was on Yap for seven months in early 1900, reported drought and wildfires, and wrote that about 75% of Yap was covered with savannah. It appears that in the 38 years since Teten's 1858 report, the cultivation of Yap's interior hills had been largely discontinued. Particularly dry conditions may have contributed to this change. More severe droughts are associated with El Niño – Southern Oscillation (ENSO) events. Major ENSO events were reported in 1877-1878 and 1891. While no such events were reported in 1899 or 1900, Volkens reported a period of drought when only 156mm of rain fell between mid-January and the beginning of June. Socially, the period was one of turmoil. It was marked by the establishment of the first trading stations and colonies of outsiders bringing new diseases, a declining population and serious alcohol problems among Yap's leaders (Hezel, 1995). These were not optimal conditions for intensive land management.

Between 1900 and 1976, the major trend was a reduction in the area of savannah, from 75% of the island as reported by Volkens (1901) to 32%, demarcated in a vegetation map by Johnson et al. (1960), based on aerial photos taken in 1946, to 22%, based on aerial photos taken in 1976 (Falanruw et al. 1987). The decrease in the area of savannah between 1900 and 1946 cooincided with a decrease in Yap's population.

Dynamics of Yap's agroecosystem

Yap's agricultural system consists of intermittent mixed gardens (swidden systems), open-canopy gardens on ditched beds in savannah areas, and taro patches – in marshes or integrated with tree gardens in agroforests. Detailed descriptions of these systems, based on participant observation and data on 104 gardens and agroforest sites, is provided in Falanruw (1995), and Falanruw and Ruegorong (2007). These systems might be described in an intensification sequence beginning from a base of swidden systems in which wild forest or secondary forest was killed, generally by burn-girdling tree trunks, to open a skylight in the forest, with crops planted in the rich forest soil. Within the basic pattern of swidden, a number of intensifications – such as special techniques for growing yams – could be used. At the end of the gardening cycle, the site may be left to revert to a wild secondary fallow, or the fallow may be managed to varying degrees. Secondary species believed to contribute to soil fertility, such as the tree hibiscus (*Hibiscus tiliaceous*) may be planted or allowed to grow. When old garden sites are revived, cultivars left from the previous garden are often still present and need only improved conditions to begin producing. It is especially exciting for gardeners to find bits of heritage yam varieties left in the soil by previous generations.

A survey of species present on seven sites prior to, and two to five years after, an indigenous swidden-gardening cycle showed that most species that had been present prior to clearing for the garden reappeared during the fallow (Falanruw, 1995). However, some species characteristic of better-developed forest did not grow within this period, and a number of introduced species invaded sites that were burnt a second time. These included the invasive weed *Chromolaena odorata*, which smothered tree seedlings and made the sites more vulnerable to wildfires. Gardens made by young women as the population increased in the years following World War Two tended to be larger than those made by previous generations; they included numerous ditched beds in individual gardens. Government



Hibiscus tiliaceus L. [Malvaceae]

Grown in fallows as a contributor to soil fertility agricultural projects opened even larger areas. This allowed the spread of new weedy and invasive species, making gardening and fallow management more difficult. Such sites were also more vulnerable to wildfires, which impeded natural regeneration of soil-restoring forest.

To compare species dynamics in the aftermath of traditional swidden practices with those of modern agriculture, the species succession in the fallow of a traditional swidden garden was compared with that of a government demonstration garden established by a consultant with the aid of a bulldozer. Two years after the demonstration garden was abandoned and the traditional garden allowed to lie fallow, the species composition of both sites was compared. Seventy three percent of the species growing in the traditional garden were native species, compared with only 48% in the demonstration garden. Most of the remaining species in the abandoned demonstration garden were introduced weeds, some of them invasive. Sixty-six per cent of all species present in the indigenous swidden garden were useful. They included feral crops that would produce small harvests as well as provide planting material for a subsequent garden. In contrast, only 20% of the species in the abandoned demonstration garden were useful (Falanruw and Ruegorong, 2007).

It seems likely that garden sites that were reused or burnt repeatedly during periods of peak population density were unable to produce sufficient biomass to escape transition to secondary vegetation or savannah-like conditions devoid of a canopy. A comparison of the number of garden plots and house platforms surveyed in one municipality on Yap (Mahoney, 1958) provided evidence that fallow periods would have had to be less than two years – far short of the time needed for a forest canopy to redevelop (Falanruw, 1995). With a pre-Western-contact population density on Yap estimated to be as high as 241 to 386 people per square kilometre (Hunter-Anderson, 1983; Underwood, 1969), fallow periods could not have been long enough to permit the regeneration of the forest canopy. Without the ecological services of forests, more intensive methods were needed to improve soil fertility and structure. This was addressed by ditched-bed technology, in which garden beds were formed by cutting or pressing grass and other herbaceous vegetation and covering it with sections of sod dug from the perimeter of the garden and turned root-side up. This formed a layer of mulch covered with soil, and the removal of the sod created a ditch around the bed (figure 2). The ditches then served to drain the garden bed. Shallow ditches closed at either end were sometimes added within the bed to maintain the soil moisture. The fertility of the beds was later enhanced by the transfer of rich soil and silt from the ditches onto the garden beds.

Further downslope, where more water accumulated, ditches were widened into depressions that collected nutrient-rich silt. These were used to grow taro (figure 3). If people settled in the area, fallows would be managed by planting a variety of trees useful for food and other purposes in drained areas. In these more shaded areas, the giant swamp taro *Cyrtosperma merkusii* (syn. *C. chamissonis*), which is more shade tolerant, was grown. Soil from ditches and taro-patch depressions was also used to develop paved pathways and house platforms. The result was a taro patch/tree garden

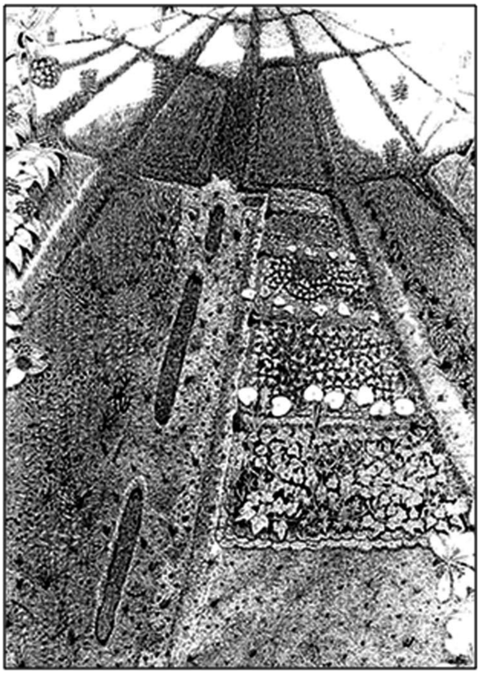


FIGURE 2 Reworked ditched garden beds on savannah hillside with *Colocasia* taro planted in shallow ditches formed within the garden bed

FIGURE 3 A series of *Cyrtosperma* taro patches, illustrating the landscape architecture and water management, which forms a basis for figure 4

agroforest that was integrated with the watershed. While it looked like a forest and provided the ecological services of a forest, it also served as a supermarket, hardware store and pharmacy. Agroforests were also a convenient and pleasant place to live (figure 4). At this point, the vegetation was almost all anthropocentric: made up of species that people found useful or pleasing, and had planted or allowed to remain. Such systems were relatively site-stable and "nature-integrated", with relatively low-energy but frequent maintenance by the gardeners.

Figure 5 relates Yap's agroecological system to canopy cover and the degree to which the environment has been modified for anthropocentric production. Above the dashed horizontal line demarcating upland systems from wetland systems, vegetation types are arranged in order of decreasing standing biomass. Native vegetation lies to the left of the diagram and more anthropogenic vegetation lies to the right. Swidden cultivation is here called "intermittent mixed garden". Arrows represent major directions of change.

Under wetland conditions (at the bottom of figure 5), drainage ditches are enlarged and elaborated into taro-patch systems. While species characteristic of swamp forests occur on Yap, it appears that most swamp forest on the island has been converted to taro patches. Some areas of mangroves, especially in bays, were converted into marshes by construction of dikes across the bay. This prevents drainage, and a rise

FIGURE 4 A Yapese tree garden/taro patch agroforest.

in water level on the landward side of the dike drowns the mangrove trees. The area then becomes filled with tall *Phragmites karka* reeds. These marshes can then be converted to shifting or permanent taro patches for *Colocasia esculenta* and/or *Cyrtosperma merkusii* (Cycle D).

The overall system portrayed in figure 5 provides complementary crop production throughout the year, in spite of variable rainfall and tropical cyclones, and can be adapted to meet the needs of different levels of population – up to a point. Some shifts in vegetation occur less readily than others. A shift from an intermittent mixed garden back to secondary vegetation with a low canopy provided by a characteristic set of secondary tree species can occur in about four to seven years. Development back to secondary forest takes longer, and a return to mature forest, longer still. The only two study sites observed with a well-developed native forest over ditched beds – indicating previous gardens – had been fallow for 25 to 70 years. Site recovery depends on the degree to which the site has been deforested in the gardening phase, the soil type and the incidence of wildfires.

Most of the vegetation types shown in figure 5 were mapped in Falanruw et al. (1987). The diagram can thus be used as a model for improving the sustainability of land use for food production, as well as for the conservation of biodiversity, by influencing the direction of the cycles shown in the diagram.

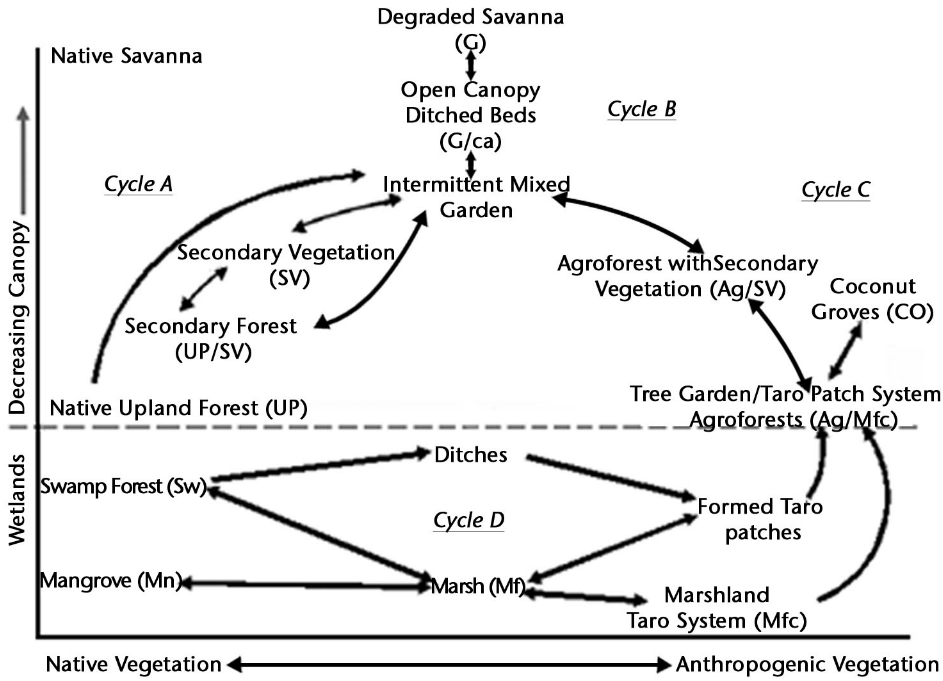


FIGURE 5 Hypothetical sequences of long-term vegetation dynamics involving traditional agricultural systems on Yap

Notes: Much of the native upland forest has been used for swidden agriculture and little mature forest remains. Swiddens ('intermittent mixed garden'), can progress in three directions: 1. If left to natural succession, these sites are likely to revert back to secondary vegetation and secondary forest (Cycle A); 2. In savannahs or sites that have been cropped or burnt too frequently, biomass is exhausted and the soil impoverished. People must resort to more intensive ditched-bed gardening under full sun with only a grass fallow (Cycle B). Ditched-bed gardening sites can revert to forest, as old ditched beds can be found below forest today; 3. If people settle in an area used for swidden gardening, the fallow may be managed to select and plant useful trees and the site developed into an agroforest (Cycle C). Should agroforests become weedy or threaten to shade out taro patches, the system may be reconditioned by killing less-useful trees, severely pollarding useful ones, and converting the area into an intermittent garden for a time. Under German and Japanese direction, some coastal areas were converted into coconut groves. Most of these have since become mixed agroforests or secondary vegetation.

Rise and fall of swidden agriculture on Mainland Yap

Swidden agriculture provides resiliency. It can be carried out with a minimum of tools and, with soils enriched by forests, the ratio of human energy inputs is low compared to calories harvested. It can be carried out extensively, minimizing human inputs but requiring more land, or more intensively, by those familiar with special techniques such as a system used to grow fine yams on pyramidal trellises. This method was probably developed at a time when garden plots and trees were limited, so that intensified methods were needed to produce as much as possible from a small plot. The method can be used even on soils that are only moderately fertile, as mulching contributes to soil fertility. In some cases, yams are grown in the mulch left from deeply mulched banana gardens made in ditched beds in poor savannah soils. Banana mulch is rich in potassium, which contributes to the growth of yam tubers.

In the traditional trellis method, rather than burn-girdling trees to use as yam trellises, the trellises are built in a pyramid shape. Yam bits are planted at the base of the trellis in specially prepared mounds. The yam vine is allowed to grow up a bamboo pole for a number of days, and then it is gently unwound from the pole and wrapped around the perimeter of the pyramidal trellis, gently tied, and left to grow up another pole. After a number of days the vine is again unwound and wrapped about the trellis (figure 6). This process is repeated until the trellis is covered with a spiral of vines. Since the trellis is pyramid-shaped, there is minimal shading of lower leaves. The repeated unwrapping and repositioning of the vines seems to induce thigmomorphogenesis – an effect induced by mechanical stimuli on plant growth and development – that results in a thickening of the vine, shorter internodes and greater leaf area.[1] All of this contributes to a bigger harvest of yam tubers. A trial was carried out to compare this method of cultivating yams with the less-intense method of using burn-girdled trees as trellises. At harvest, the weight of yams produced per mound from vines that had been wrapped around a pyramidal trellis was an average of 2.5 times greater than the harvest from yam vines allowed to grow up sacrificed trees. While more intensive, the method produced larger yields and required less in terms of forest resources.

Yap's long period of depopulation ended in the early years of the American administration, which began in 1946. At this time there was a high ratio of fallowed gardens to gardeners. With little more than a knife, digging bar, and matches, Yap's main gardeners – its women – turned to swidden agriculture as the most human-energy-efficient means of producing food for growing families. A climatic period with more frequent droughts made it easier to burn-girdle trees and contributed to more extensive swidden gardening, with high yields from the forest-enriched gardens. Most crops were used to feed the gardeners' families, and harvests greatly exceeded market sales. The ability of Yapese gardeners to respond to increased market demand was shown by six- and 13-fold increases in sales of bananas and pumpkins, respectively, when they gained access to an off-island market in 1991. The importance of production for traditional social events was shown by the

FIGURE 6 *Dioscorea alata* yams growing on a pyramidal trellis. The vines here are ready to be unwound from the poles and repositioned around the trellis

quantity of fine yams presented for a memorial observance for a deceased chief in the same year. About 711 baskets of yams were contributed by 69 households, with a total weight between 9663 and 10,876kg – six to seven times greater than the average quantity of yams sold at the public market in an entire year.

More recently, there have been increased opportunities for younger women to gain a formal western education and find employment. At the same time, experienced traditional gardeners – older women – have been removed from the gardening workforce to baby-sit the increasing proportion of young children. This has resulted in an overall decline in the quality and quantity of indigenous agricultural production, while government and international-development efforts have failed to raise agricultural output by other means. Even today, most local agricultural production comes from traditional gardens and agroforests, using little more than a knife, a digging bar and traditional knowledge.

On 9 April 2004, Yap was struck by Typhoon Sudal, with powerful winds that battered the islands at a time of peak spring tides. The storm surge inundated coastal areas and the island was declared a disaster area. Typhoon-recovery assistance provided emergency water, food supplies and assisted with reconstruction. For the first time, assistance was also provided to gardeners to renovate food-production systems, especially taro patches, in order to avoid long-term dependence on food aid. In addition to the storm surge of salt water, the typhoon deposited piles of debris into taro patches and, with normal water circulation impeded, eutrophication set in. Many taro patches were filled with dark, putrid water. The programme provided a stipend for experienced gardeners and taro-patch experts to supervise a group of workers, mostly young women, who received a smaller stipend, to renovate food-production systems in their respective villages. The programme was well received, and there were cases of older women almost crawling to sites to supervise 'the younger gardeners at work' – a certain sign of concern for food security.

A major part of the work involved the renovation of water-flow ditches associated with taro patches as well as the resurrection of some older ways of raising taro in low-lying coastal areas. One such method was taro 'basket culture', in which baskets of woven coconut fronds were filled with soil to provide elevated planting spots for *Colocasia esculenta* taro. Levees (retaining walls) were also renovated or constructed to prevent sea water from entering taro patches. A group from one village located on a narrow coast with limited habitat for taro patches installed such a levee between an area that was intermittently flooded with freshwater during periods of heavy rainfall and by sea water at high tide. A pipe with a 45-degree angle was installed through the levee. The top portion of the pipe could be lowered to drain excess rainwater at low tide and raised to prevent flooding by sea water at high tide, thus making it possible to grow taro.

Due to the number of taro patches that had been inundated by salt water, aid workers anticipated a long period of food aid. However, as soon as heavy rains rinsed the salt water out of renovated taro patches, most of them flourished – just as the older women said they would. The programme proved to be a good investment, as typhoon-relief food aid was discontinued much sooner than in the aftermath of other typhoons on other islands.

After the series of storms and typhoons that culminated in Typhoon Sudal, La Niña conditions set in, and have continued ever since, accompanied by increased sea levels. Coastal lowlands have experienced salt-water intrusion. Basket-cultured taro, *kang kong* (*Ipomoea aquatica*) growing in taro patches, and *Hibiscus tiliaceous* trees growing in swampy areas, have died. The rainfall pattern has also changed (figure 7), with more rain and shorter periods of dry weather. This has made it difficult for women to develop intermittent mixed gardens (swiddens), as conditions are too wet to complete the burning needed to initiate such gardens. The production of yams, the most prestigious crop of shifting gardens, has suffered as a result and Yap's rich genetic pool of yam varieties is threatened, as perishable bits of yams harvested in one year are needed to produce crops in following years.

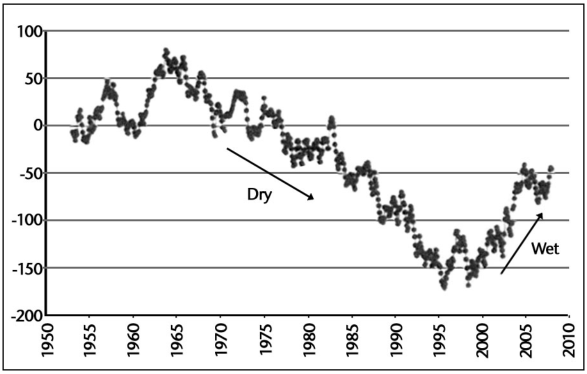


FIGURE 7 Long-term surpluses and deficits in rainfall between 1950 and 2009

Source: Landers, 2010

Nowadays, when people are being encouraged to eat more local food in order to combat an epidemic of lifestyle diseases such as diabetes and hypertension, the cost of most local produce has risen beyond that of its imported counterpart, principally rice. The availability of local produce is sparse and the type of produce sold at the few small local markets has also changed. Bananas have become more prominent and a variety of items that were not previously offered for sale are now being brought to market, including the tips of bird's-nest ferns (*Asplenium nidus*), new varieties of dry-land *kang kong* (*Ipomea aquatica*), pumpkin-vine tips and abiich fruit, or 'garlic pear' (*Crataeva speciosa*). Such foods have long been part of the Yapese diet, but were not previously considered as something appropriate for marketing as they were growing around most people's homes. The generation of Yapese whose parents juggled a subsistence lifestyle augmented with some salaried work, are now moving more completely into a monetized society, at a time when development aid under the Compact of Free Association with the United States is declining and sea levels are rising.

Yap's Outer Islands

Yap's Outer Islands include a raised limestone island (Fais), the low island of Satawal and 13 atolls, nine of which include currently inhabited islets. Altogether, there are about 133 coralline islets collectively referred to as the Yap 'Outer' or 'Neighbouring' islands, whose people are known as *Remathau* – people of the deep sea. By the 2010 census, Outer Islanders made up about 45.5% of the state's population, while the total land area of the Outer Islands was only about 15% of the total land area of the state. In the winters of 2007 and 2008 especially, these islets experienced very high 'king tides' that eroded beaches, brought salt-water intrusion into taro patches and soils, and in some cases, inundated parts of villages. Soils were damaged and crops destroyed on an estimated 60% of inhabited outer islands in the Federated States of Micronesia (Fletcher and Richmond, 2010). High sea levels continue, and Yap's Division of Land Resources has recently acquired equipment to begin collecting data on island elevations with respect to sea level. Using a Topcon Total Station and Trimble GPS units, staff go aboard a ship on irregularly scheduled field trips, storing their precious instruments in limited cabin space and sleeping on deck. They have established permanent-reference points with respect to sea level at high tide. From these points they measure highest and lowest areas of land on inhabited islets and the elevation of public places such as schools, dispensaries and residential areas. Plans are to repeat measurements on the same month of each year. Preliminary results for 17 inhabited islets indicate an average maximum elevation of 1.8 metres above high tide. Two islets had the highest elevations of 5.5m and 4.7m. The highest points on the rest of the islands were 3m or less above high tide level, with four islets below 2m, and seven islets rising less than 1m above high tide. The surveys have also shown that six islets have areas including schools, a residence and a dispensary that are 0.1m to 0.3m below high tide level, but are protected from inundation by higher land around the islets' perimeter (Waayan, 2011.)[2]

The limestone foundation of atoll islets is generally porous, with interstitial spaces filled with water. Rainfall, being less dense than sea water, tends to collect in pools that float on the denser sea water within these still spaces. A fresh-water 'lens' (so named because the layer of fresh water is thicker at its centre) forms toward the interior of islets, generally along their long axis. Towards its centre, the fresh-water lens may rise slightly above sea level as it is buoyed up by the salt water below. Fresh water within the lens tends to fluctuate with tidal action, and this mixes fresh and salt water at the edges of the lens. Many factors influence the size, shape and existence of fresh-water lenses on atoll islets, but the location and characteristics of the freshwater lenses not only strongly influence atoll vegetation, but they also determine whether islets are inhabitable.

Atoll agriculture is severely constrained by the availability of fresh water, nutrient-limited soils, limited area, salt spray and potential for inundation and salt-water intrusion. Taro patches are confined to areas within reach of the fresh-water lens, and other gardening is confined to areas with better soil, or where soil has been improved by mulching. Given these restrictions, there is limited prospect for shifting agriculture on inhabited islands. However, uninhabited islets are visited from time to time to harvest semi-wild foods such as *Syzygium* spp. (apples) and *Crataeva speciosa* fruit,, as well as coconut crabs and sea turtles. Prior to the advent of large field-trip ships with relief supplies, people relocated to other islands or obtained food from neighbouring islands for a time following damaging typhoons. The need to tap resources of other islands has been a big factor in keeping traditional canoe voyaging and navigation alive in the Outer Islands, where some of the last practitioners of this traditional skill are found.

With saline impacts on taro patches, there have been shifts on the Outer Islands to more hardy types of taro.[3] *Colocasia esculenta* is the most esteemed taro, but also requires the most care. *Cyrtosperma merkusii* taro is more hardy, but requires a longer period before it can be harvested. Both of these types are generally grown in taro patches, and are thus vulnerable to salinization. *Xanthosoma sagittifolium*, a taro introduced during the Spanish period that can be grown on 'dry' land, has been promoted with mixed results. *Alocasia macrorrhiza* taro, which has long been used in the Outer Islands, is planted in individual pits dug through rocky substrate and is hardy enough to persist for some time, even without care. Like *C. merkusii*, it requires at least two to three years before the corm is large enough to be harvested. *A. macrorrhiza* requires special preparation as a human food because of its particularly high concentration of irritating calcium oxalate crystals, a factor that has led Outer Islanders to select less 'itchy' varieties. Breadfruit is the quintessential agroforest species. However, it is seasonal and production is influenced by both rainfall and storms. Bananas are an important crop that is vulnerable to saline soils and there have been shifts to types that are somewhat more salt tolerant.

Challenges to food production and the availability of field-trip ships has led to increasing reliance on rice and other imported foods. This trend is now exacerbated by salt-water intrusion and inundation of taro patches and gardening areas as a result of 'king tides' and storm surges. On low-lying atoll islets where there is no watershed, salinized taro patches and garden soils are not readily rinsed out. Taro patches on most inhabited outer islands have thus become unproductive, although there are a few exceptions, such as on the tiny islet of Euarpik, where a recently dug and deeply mulched taro patch remained productive. Efforts to combat the effects of salinization on the islet of Woleai included the construction of windbreaks to shield crops from salt spray and the development of raised beds for growing taro. Initially the raised beds were successful. However, on 8 December 2008, the islet experienced a 'king tide' in which the ocean kept rising until it flowed into the village, inundating even the raised taro beds.

The intrusion of the ocean on garden patches that are almost sacred in their social value has a profound effect, particularly on the women. The anguish brought by such an event on Ulithi atoll was recorded in a church newsletter by Father J. Hagileiram, SJ (2011):

> 'On Falalop Ulithi, the women, the custodians of the taro patches, reported that over 90 per cent of all the taro patches on the island had been rendered useless wasteland. For some reason it seems that their traditional taro patches, the ones they inherited from their great ancestors, are the ones mostly affected. They held these taro patches in esteem, for they represented something of their past

as well as their future. Louisa, who led me to her patch, cast a despairing look on the desolate patch in front of us as she related her despair: "This was the patch that grandma used to work in. My mother and I used to spend many hours in here. It is the only thing I used to think I could count on as a lasting gift I could leave behind for my children. Look at what has happened to it."

Culturally, the taro patches mean a lot to the women. They are reserved for very special occasions like the *Raaliire Mwaale*, Men's Day, when they like to show off their biggest and best taros. It is in these traditional taro patches where taros for very special people, like their children, their brothers and uncles, are kept. A taro can be harvested and re planted so that one taro plant can feed many generations of dear ones. Mothers take pride in that very special taro that is kept in the traditional taro patch. They nurse it with that special mother pride, as they often collect the wilted leis from their children and dear ones and use them as compost around that very special taro. The son who returns home after a long absence is welcomed with that very special taro. Losing these taro patches is like losing a very significant part of your identity as a woman. It is the worst thing that can happen to you as a mother' (Hagileiram, 2011).

Salt-water intrusion into taro patches and soil is insidious. Unlike a storm surge or inundation by a 'king tide', it seeps unseen into a taro patch or soil from below. In some cases, salt water seems to bubble up from below. Salt-water intrusion is exacerbated by the withdrawal of too much fresh water from the fresh-water lens, decreasing the weight of fresh water keeping salt water at bay. One response to salt-water intrusion has been the construction of concrete taro patches. The cemented bottoms of these shallow enclosures prevent salt-water intrusion. They are rain fed, with drainage ports for water management. Organic matter is added to develop a loamy soil and plantings are deeply mulched. After several years, these artificial taro patches are generally productive, but they are quite limited in size and have no family history.

Where to from here?

A recent report of the Pacific Climate Change Science Programme (PCCSP, 2011) gave projections of average changes expected within the territory of the Federated States of Micronesia, with associated confidence levels based on climate models. For the western part of this territory, which includes Yap State, the programme predicted with very high confidence that temperatures would continue to increase over the course of the 21st century, with moderate confidence that average temperatures would increase by 1^{0}C by 2030 and by more than 2.5 C by 2090. There was high confidence that rainfall would increase, with moderate confidence of little change by 2030, but moderate confidence, also, of an increase of 0.5% to 15% by 2090. There was also high confidence of increased intensity and frequency of days with extreme rainfall, but moderate confidence that the number of tropical cyclones and the proportion of severe storms would decrease. There was also very high confidence that mean sea level would continue to rise, with moderate confidence of a rise of 5cm to 15cm by 2030 and 20cm to 60 cm by 2090. However, some researchers posit a significant uncertainty of ice-sheet contributions to sea-level rise, and say higher levels cannot be excluded (Meehl et al, 2007). Some reports suggest that sea levels could be higher and their rise could be rather abrupt (Ananthaswamy, 2012).

With Outer Islands already lying barely above high tides, rising sea levels can be expected to push fresh-water lenses out of existence. At some point, more than 40% of Yap's population, from the Outer Islands, will probably seek to relocate. Migration to mainland Yap is already underway. Food security is a growing issue, and the conservation of biodiversity necessary to provide the ecosystem services needed to maintain food security is an even greater challenge. Locally produced GIS maps indicate that most large taro patches and more fertile soils are located towards the coast and are vulnerable to sea-level rise and storm surge. It will become necessary to move agricultural production upland. However, higher areas have less fertile soils and support little more than savannah, or in a few cases, precious remnants of native forest.

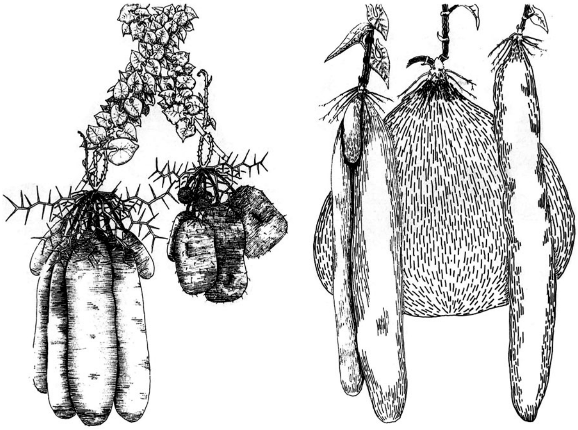
All of Yap's mangroves, which are important to inshore fisheries, lie within about a metre of sea level. As the interface between fresh and sea water moves inland, we can expect mangroves to follow, as they need some fresh water. If mangroves are to continue to support inshore fisheries and protect the coastline, they will have to be allowed to move inland. However, this is contrary to the general practice of keeping mangroves at bay or crushing them under landfill. Mangroves have recently been found to be among the most carbon-rich forests in the tropics (Donato et al, 2011). Research on Yap shows that while mangroves comprise about 12% of the island's vegetation, they sequester about 34% of the carbon held by all of the island's vegetation (Donato et al, 2012). This has implications for future carbon markets. The Yapese use mangroves in many ways, one being the enhancement of mangrove habitat by various methods to increase production of the mangrove clam *Anodontia edentula*, without killing the mangroves. This is another nature-integrated food-production system.

In many areas, marshes and taro patches – or potential taro patches – lie inland of the mangroves. Some of Yap's best taro, both *Colocasia esculenta* and *Cyrtosperma merkusii*, is grown in shifting plots within these marshes. Rising sea levels threaten the marshes and their taro patches and there is a tendency to build levees and roads between coastal mangroves and taro patches to protect against salt-water inundation. This needs to be done with care in order to manage the interface between fresh and salt water, so that mangroves can still get the fresh water they need and continue to protect the coast. Levees alone won't protect the taro patches from salt-water intrusion from below; it is also important to maintain a reservoir of fresh-water pressure at the interface of fresh and salt water. Historically, Yapese gardeners apparently understood the need to manage this interface of fresh and salt water, as they lined the bottom of taro patches lying near the sea with rocks, in order to raise the bottom of the taro patch and maintain a reservoir of fresh water below the taro patch to prevent salt-water intrusion.

On top of rising sea levels, storm surges can be expected to push salinization further inland, so it will eventually be necessary to move agricultural activities upland. Ideally this would be done without destroying the limited remnants of native forest. Increased emphasis on the importance of protecting biodiversity has led Micronesian governments to declare a 'Micronesia Challenge', which pledges to effectively conserve 20% of land biodiversity and 30% of near-shore marine biodiversity. In the case of Yap, where there is little well-developed wild forest left, this will mean that new agricultural activities will need to take place in areas of secondary vegetation and savannah. Lacking a tree canopy other than scattered *Pandanus tectorius* trees, most savannahs have impoverished, heavy, waterlogged soils and strategies to enable their use for food production are needed. Among these strategies should be the restoration of forests on savannah lands as advanced preparation for swidden cultivation. It would also seem wise to examine traditional practices and evidence that remains etched on the landscape. Old ditched-bed systems can clearly be seen from the air in areas of savannah. They are present throughout Yap, from savannah uplands to lowlands, beneath forest canopies, within agroforests and even in marshes. Water management via ditches further extends into mangroves and even into inshore marine areas. Ditched-bed technology involves a lot of work and for its remnants to be so pervasively stamped on the landscape, it must have been effective.

Ditched beds revisited

The 'fresh green fruit-bearing fields to the tops of hills' observed by Tetens prior to 1888 are likely to have included bananas. While cultivation of ditched beds on hills in savannahs is largely abandoned today, elders remember their use for growing bananas in the savannah hills. Bananas seem to have been more important in the past. Old texts (Mueller, 1917) contain chants that mention the burying of bananas to be used as food at traditional gatherings. Even today, Yap has a particularly rich diversity of banana cultivars, suggesting that it once had a well-developed system of banana culture. A method for growing bananas on ditched beds with deep mulching in poor savannah soils is sometimes used to grow heritage bananas for special occasions. In this system, bananas are deeply mulched, with soil alternately added from a ditch around the perimeter of the bed. Following the banana harvest, prestigious yams can be grown in the potassium-rich mulch on pyramidal trellises. as described earlier. The ditched-bed system is also said to have been used to grow *chab chab*, or Polynesian arrowroot (*Tacca leontopetaloides*), for its starchy tubers; and *Cyrtosperma* taro. Turmeric (*Curcuma longa*) was grown as a spice, and especially for the culturally important golden powder that can be made from its tubers and used cosmetically, medicinally and for prestigious exchange. Ditched beds continue to be used to grow bananas and yams for special occasions, for mixed crops and especially for sweet potatoes.



Dioscorea esculenta (Lour.) Burkill (left) and Dioscorea alata L. (right) [Dioscoreaceae]

Some of the many varieties of yams that thrive on the island of Yap

Most swidden gardens developed in secondary vegetation and secondary forest make use of ditched-bed architecture left by previous generations. The ditches help to drain waterlogged soils, and shallow ditches – closed at both ends – on top of ditched beds can be used to maintain moisture in the upper layers of soil. Brookfield (1984) pointed out that the practice of constructing ditched beds reduced the total area of a garden. This may be true for the drained phase of ditched-bed systems. However, the ditches on Yap are thereafter not lost to agriculture, as they may be widened and used to grow taro. The process of ditching and transferring soil from ditches to garden beds may also link human efforts to biological and chemical processes.

In examining the contrasts between swidden agriculture and wet-rice cultivation, Geertz (1971) pointed out that intensification in swidden systems led to regression of forests to grasslands and reduced soil fertility and yields, while wet-rice culture responded positively to intensification. He proposed a reason for the puzzling difference:

> '[It] almost certainly lies in the paramount role played by water in the dynamics of the rice terrace. Here, the characteristic thinness of tropical soils is circumvented through the bringing of nutrients onto the terrace by the irrigation water to replace those drawn from the soil; through the fixation of nitrogen by the blue-green algae which proliferate in the warm water; through the chemical and bacterial decomposition of organic material, including the remains of harvested crops in that water; through the aeration of the soil by the gentle movement of the water in the terrace; and, no doubt, through other ecological functions performed by irrigation which are as yet unknown' (Geertz, 1971, pp29–30).

The dichotomy between swidden agriculture and wet rice in some areas of Southeast Asia might be compared with the Yapese intermittent mixed gardens (swidden) and taro-patch dichotomy, with ditched beds being intermediate between shifting and ponded-field systems. In a paper entitled 'The role of standing water and waterlogged soils in raised-field, drained-field and island-bed agriculture', Vasey et al (1984) pointed out that 'a strategy of partial drainage was once applied throughout vast areas of the tropics' prior to the colonial era. The authors then reviewed the conditions under which the management of waterlogged soils could result in *in situ* generation of nitrogen (N) and the mobilization of phosphorus (P), the two nutrients that most often limit crop growth, and concluded: 'Short term algal N-fixation rates under favourable conditions compare favourably with the rates associated with fodder legume species" (Vasey et al, 1984, pp69).

In shallow-water systems, total nitrogen is tied up in micro-organisms and free organic compounds and is especially concentrated in bottom sediments. The transfer of organic matter from the aquatic system to the crop system is an important means of making use of this process. The N-fixing process is self-limiting, with high levels of nitrogen suppressing N-fixation. The frequent removal of nitrogen-rich organic matter from ditches helps to maintain high algal N-fixation. Many soils contain higher levels of available phosphorus (P) when anaerobic than when aerated, especially soils that are high in hydrous iron oxide clays (Chac´on et al, 2006), such as some soils of Yap. The mobilization of P under anaerobic conditions in ditches and the subsequent transfer of these soils onto garden beds may thus contribute to crop growth.

Pending experimental data on Yap's systems, we are left with the hypothesis that Yapese gardeners of old developed a series of technologies for producing food utilizing nutrients from biomass, and where biomass was exhausted or not present, by making use of microbial and biochemical processes in ditches and anaerobic soils. There has been limited research and extension on ways to grow food in the degraded savannah areas on Yap. Nevertheless, a number of Yapese families have moved to such areas and, on their own, have developed gardens and the beginnings of agroforests around their homes. When asked how this was achieved, the Yapese simply reply that the presence of people makes things grow well.

In the name of modern development, most consultants and commercial growers today resort to heavy machinery and inorganic fertilizers that tend to suppress natural processes and make farmers dependant on imported inputs and fossil-fuelled technologies. This is closely related to another threat, which, along with climate change, jeopardizes long-term food security: development programmes and big commercial investments. These tend to transform indigenous people, who have experience and adaptive instincts that enable them to work with their ecosystem to produce food, into yet another group dependant on money, fossil-fuelled technologies and strong chemicals. This in turn contributes to the problem of climate change and sea-level rise that now places the Yap islands, and indeed much of the world, under such dire threat.

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Notes

1 Scientists named this phenomenon 'thigmomorphogenesis' in the 1970s. Yapese had been making use of it long before it was named by science.

2 These measurements above high-tide level may be compared with the effect of seasonal typhoons in the Western Pacific. Typhoon Sudal produced a storm surge of around 4m. Typhoon Bopha was forecast to generate a storm surge of 6m to 10m at peak intensity. It passed just out of range of Yap in early December 2012.

3 The term 'taro' is used loosely in this chapter for all of the edible aroids mentioned. Technically, however, it refers just to *Colocasia esculenta*.