TARO (*COLOCASIA ESCULENTA* (L.) SCHOTT) IN THE ATOLLS AND LOW ISLANDS OF MICRONESIA

HARLEY I. MANNER

Professor of Geography, University of Guam, Mangilao, Guam 96923

Abstract

In comparison to *Cyrtosperma chamissonis*, *Pandanus tectorius*, and breadfruit (*Artocarpus altilis* and *A. mariennensis*), the significance and cultivation of *Colocasia esculenta* (L.) Schott in the atolls and low islands of Micronesia are not well known. In some atolls, the species is represented by many cultivars. The changeover in these varieties is sometimes rapid. The productivity of *Colocasia* taro in the atolls is not well documented.

This paper considers the geographic distribution and cultural ecology of *Colocasia esculenta* with respect to the atoll environment. The cultivation of *Colocasia esculenta*, problems posed by the atoll environment and the impacts of socio-economic change, and the significance of cultivar diversity are discussed. This study is based on observations, fieldwork, and a review of the literature.

Introduction

Unlike the favorable ecological conditions for taro cultivation found in the high islands of Micronesia and the Pacific, the atolls have significant physical constraints to taro cultivation. Small islet size and the resultant limitation of freshwater resource, drought, salinity, salt spray, and infertile and thin soils are constraints to taro cultivation. Biotic and socio-cultural constraints and modernization have also affected the cultivation of taro in the atolls. Despite these constraints, Micronesian atoll islanders developed sustainable systems of taro cultivation, well adapted to their atoll environment. However, in contrast to the other main food crops of atoll Micronesia, namely, *Cyrtosperma chamissonis*, *Pandanus tectorius*, and breadfruit (*Artocarpus altilis* and *A. mariennensis*), the significance and cultivation of *Colocasia esculenta* (L.) Schott in the atolls and low islands of Micronesia are not well known. Sproat's (1968) monograph on subsistence agriculture in Micronesia virtually ignores taro agriculture in the atolls of Micronesia.

This paper considers the geographic distribution and cultural ecology of *Colocasia esculenta* in the Micronesian atolls. This summary of the cultivation of *Colocasia esculenta*, constraints posed by the atoll environment, and the impacts of socio-economic change is based on observations, fieldwork, and a review of the literature. A sustainable system of *Colocasia esculenta* cultivation from Puluwat and Ulithi atolls is described. The paper suggests that with modernization and change in Micronesia, the significance of *Colocasia esculenta* will be diminished.

Micronesia Defined

Micronesia (literally, small islands), as a geographic and cultural region, is located in the central and western Pacific. The total land and sea areas are 3,145 km^2 and 11,649,000 km^2, respectively (Pernetta 1990), of which less than one percent of the area is dry land (see Table 1). Politically, Micronesia includes the Republic of the Marshall Islands, Republic of Belau (Palau), the Federated States of Micronesia (Kosrae, Chuuk, Yap, and Pohnpei), the Territory of Guam, Commonwealth of the Northern Mariana Islands, Nauru, and Kiribati (see Fig. 1). Two Polynesian outliers (areas of Polynesian culture) in Micronesia are Kapingamarangi and Nukuoro, both of which are located in Pohnpei State (FSM). Most of the area is also known as the Eastern and Western Caroline Islands.

Geomorphologically, the majority of islands in Micronesia are atolls or low lying reefs of hermatypic corals resting atop a sunken volcanic base. Kiribati and the Marshall Islands consist almost totally of atolls. Nauru is an upraised coral limestone island; the other political entities consist of a combination of atolls, raised limestone, and volcanic islands. The dry land areas of the atolls are the islets (also known as sandbanks, cays, and motus) composed mainly of coral rubble and sands.

There are approximately 300 atolls in the Pacific Ocean (Douglas 1969, Sullivan and Pernetta 1989). In Micronesia alone, there are 50 atolls and 58 low coral island groups. Located on these atolls and low islands are approximately 1,600 islets, many of which are uninhabited. For example, of the 1,118 islets and low islands of the Republic of the Marshall Islands, only 40 are inhabited. Some of these islets, however, have a very high population density. On Ebeye Islet, the density of population is more than 25,000 per km^2 (Heine 1984).

Table 1. Micronesia--area and island type by country.

Country	Area (km²) Land	Sea	Number of island by type Volcanic	Mixed	Metamorphic	Atoll	Raised Coral	Unknown	Total
Federated States of Micronesia	727	2,978,000	8	4		266/03	7	10	295/59
Guam	549	218,000	1						1
Kiribati	690	3550,000				109/16	19/17		136/33
Marshall Islands	171	2131,000				1085/28	5		1118/33
Nauru	21	320,000						1	1
Northern Mariana Islands	475	1,823,000	11	2			1		14
Palau	512	629,000	1	2		6+/3	97/27	6	112/39
Total	3145	11,649,000	20	9		1466/50	130/58	16	167/180

Notes: */* = number of islets/number of atolls or raised coral islands
Source: Pernetta 1990.

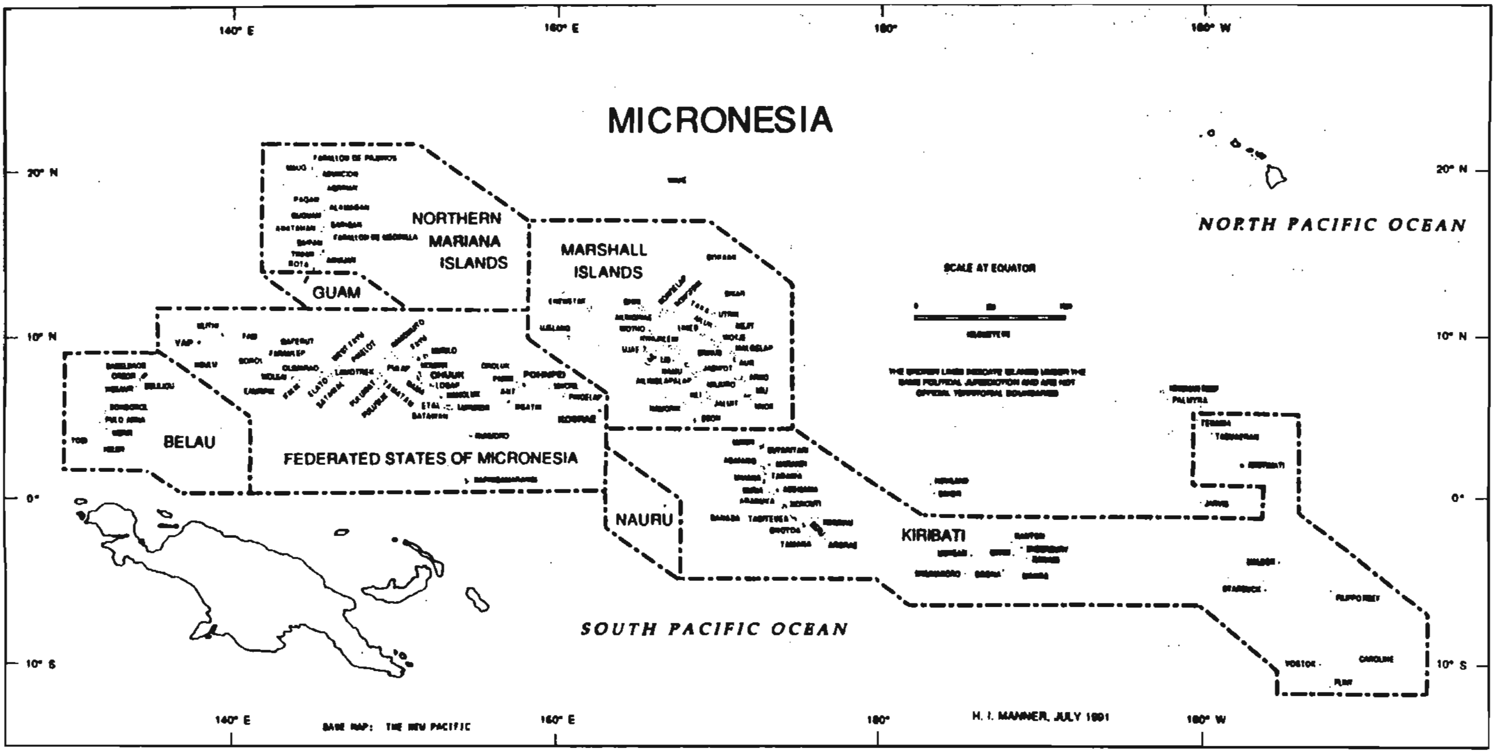

Fig. 1. Place map of the islands of Micronesia. Source: Isla, A Journal of Micronesian Studies.

Biogeographic and Environmental Factors of the Atoll Environment

Climate

The climates of the Micronesian atolls and low islands are determined largely by the characteristics of the surrounding ocean, their low latitudinal location, and the dominant atmospheric circulation system. While all climates are tropical (warm), there are desert climates in eastern Kiribati (Koppen BWh) and transitional semi-arid to moist climates in the Central and Western Pacific (Koppen BSh, Aw, and Af). This discussion will be brief as fuller discussions of Micronesian climates can be found in Thomas (1965), Prasad and Coulter (1984), and Manner (1990a).

Temperature

Because of their low latitudinal and mid-oceanic location, annual air temperatures are high, but there is little seasonal variation between the warmest and coldest months. At Kapingamarangi Atoll, the annual temperature averages 29.9°C, ranging between 31.7°C to 28.0°C (Niering 1963). Days are warm and nights cool, with the diurnal range of temperature greater than the annual range of temperature. For example, at Kapingamarangi, the highest and lowest July temperatures were 34.4°C and 23.3°C, respectively (Wiens 1962). Despite the moderating influence of the ocean, daytime temperatures can be very high and nighttime temperatures relatively low, especially in the absence of cloud cover. At Kwajalein, the highest and lowest temperatures recorded were 36.1°C and 21.1°C, respectively. Relative humidity percentage is in the high 70s throughout the year and averages in the mid-80s at night.

Precipitation

Precipitation and drought in the atolls is greatly determined by the islands' location with respect to the atmospheric circulation systems of the Pacific. Greatly simplified, three climatic regions can be defined for atoll Micronesia:

1. An eastern equatorial zone of aridity that extends from the west coast of South America to 175° W longitude. The eastern atolls of Kiribati (for example, Nikumaroro, Canton, Enderbury, and Kiritimati) are generally uninhabited and have few plant species. The rainfall at Canton averages 607 mm per year (U.S. Weather Bureau 1965). The rainfall at Kiritimati averaged 83.2 cm for 1951-1984 (Prasad and Coulter 1984). Some of these islands are deserts (Thomas 1965), with relatively few plant species.

2. The seasonally shifting Intertropical Convergence Zone (ITCZ) of high, but variable precipitation. The majority of atolls in Micronesia (including the islands of the Eastern and Western Caroline Islands, the western Kiribati, and the parts of the southern Marshall islands) are located in this zone. Precipitation generally increases from east to west, partly as a consequence of monsoonal Asian influences. The annual rainfall for 1946-1984 at Tarawa (Kiribati) in the East averaged 198 cm (Prasad and Coulter 1984), while at Ulithi Atoll in the West, the rainfall averaged 261 cm per annum, with July through October receiving more than 25.4 cm per month (U.S. Weather Bureau 1965). Atolls in this region have a fairly diversified and more luxuriant flora.

3. The Northeast trade wind region of relatively low precipitation throughout the year. The northern- most Marshall Islands are located in this zone. Wake and Johnston Islands have annual rainfall totals of 88.4 and 67.1 cm per annum, respectively (U.S. Weather Bureau 1965).

Rainfall in the atolls is highly variable, and periodic and extended droughts are not uncommon. This variability is highest in the eastern equatorial arid zone, moderately high in the ITCZ, and least variable in the trade wind zone. Wiens (1962) noted that Fanning Island received its highest annual rainfall of 527.8 cm in 1905 but received only 70.6 cm in 1952. Interseasonal variations are usually higher than interannual differences. At Kapingamarangi Atoll, which receives 274.3 cm of rainfall annually, a two-year drought occurred in 1916-1917, killing 80 to 90 people (Wiens 1962).

Evapotranspiration

The limited data indicate that given the high temperatures, evapotranspiration rates for the atolls are high. For example, the Penman potential evapotranspiration value for Tarawa during 1946-1984 averaged 189.0 cm (Prasad and Coulter 1984). For the moister atolls, where precipitation exceeds 200 cm per year, precipitation is generally adequate throughout the year, although moisture stress on the semi-arid and dry atolls is often a constraining factor.

Typhoons and Other Extreme Events

Typhoons (hurricanes) and tropical storms are common occurrences in Micronesia, with western Micronesia experiencing a greater number of typhoons than eastern Micronesia. Hatheway (1953) reported that Arno Atoll in the Marshall Islands experiences about four hurricanes per century while between December 1986 and January 1990, three hurricanes struck Ulithi Atoll. As atolls are low-lying islands, a typhoon and its attendant storm surge is often disasterous to an atoll's subsistence economy. These effects include the toppling of breadfruit, coconut, and other trees; burial of vegetation by sand and gravel; in-filling and salinization of taro pits; topsoil scouring; salinization of soils and groundwater reserves; islet fragmentation; loss of land area, marine resources, homes, and life; and the creation of new islets (Hatheway 1953, Wiens 1962). In one account of the typhoon of November 1947 on Kapingamarangi Atoll, 67 breadfruit trees, ten coconut trees, and 30 houses were blown over, and six *puraka* (*Cyrtosperma chamissonis*) pits, mostly on Ringutoru Islet, were damaged by salt water (Wiens 1956). Atolls devastated by a typhoon can now rely on emergency relief supplies of food, water, medicine, and shelter to alleviate the destruction caused by a typhoon. In earlier times, migration, reciprocal exchanges of food resources, reliance on famine foods, or starvation and death were commonplace alternatives.

Most food plants do not withstand well the effects of a hurricane-strength winds, its associated storm surge, salt spray, and seawater contamination of soils and groundwater supplies. Usually plants native to the atolls are best adapted to hurricanes and the ecological conditions present on atolls (Wiens 1962, Sachet 1983) and are often the colonizing species following a hurricane (Hatheway 1953).

Biogeographic and Physical Geographic Factors

The atolls of Micronesia have a limited flora. While low precipitation and drought are doubtless important determinants of floristic diversity, island biogeography as well as the physical geography of atolls are likewise important. As to the former, immigration of plant propagules was controlled by distance from a colonizing area, while extinction was controlled by island size and associated attributes, particularly groundwater resources (MacArthur and Wilson 1967, Pielou 1979, Abbott 1974, Niering 1956). A comparison of the sizes of Pacific islands' floras indicates a decrease in species numbers as one moves eastward from the Indomalaysia seed source (Good 1947, Thorne 1963, Mayr 1953, Merrill 1945). Similarly, floristic diversity decreases with decreasing island size as the ecological conditions or habitats necessary for species survival and reproduction is less on small islands. Thus, for Kapingamarangi Atoll, Niering (1956) found eight to 12 drift-dispersed strand species on islets 1.4 ha or less in size; with increasing islet size, there was a rapid increase in total and introduced species, which was related to the presence of fresh water lenses (Niering 1956) and the greater ecological diversity found on larger islets (Whitehead and Jones 1969).

Groundwater and Salinity

As a rule, the presence and extent of freshwater lenses is proportional to the size of the islet. The lens is thickest (and fresher) towards the islet's center and thins out towards the edge (Buddemeier and Oberdorfer 1989, Connell and Roy 1989). In theory, large islets with their larger Ghyben-Herzberg lenses have more habitats and can support a more varied vegetation than a small islet with its small and impermanent freshwater lenses. Likewise, groundwater resources on small islets are saltier and the likelihood of saltwater contamination because of drought or draw down is greater than on larger islets. The vegetation on small islets is largely composed of a few, salt-tolerant and strand species. Agriculture and human habitation are largely absent on small islets. Weeds are often chlorotic on small islets because of excessive salt (Na) and the resultant low K and other nutrient deficiencies (Fosberg 1949). Such weeds are mainly shallow-rooted species; their roots are concentrated in topsoil leached of salts (Fosberg 1949).

On larger islets, there is a zonation of vegetation that roughly parallels the concentration of salt in the groundwater and exposure to wind-driven salt spray. The more salt-tolerant species often forms the outermost zone of vegetation, while the least salt-tolerant species are found towards the islet's interior (Fosberg 1949, Niering 1956, Manner and Mallon 1989). Trees such as the coconut (*Cocos nucifera*), *Tournefortia argentea*, and *Guettarda speciosa* are more tolerant of salt than breadfruit (*Artocarpus altilis* and *A. mariennensis*). Sachet (1983) has observed that "breadfruit trees never thrive if underground water is too salty or if they are exposed to sea spray, and they are easily killed when villages or plantations are flooded with sea water, or hit with strong salt-laden winds."

Almost all introduced food plants are intolerant of salinity because of the increased osmotic potential of soil water solution, and at a salinity level of EC_e of 4 mmho/cm, the growth and yield of most agricultural species are restricted (El-Swaify 1987). Soluble salts such as boron, chlorides, sodium, bicarbonates, nitrate, ammonium, and certain trace elements may be toxic to certain agricultural species (El-Swaify, 1987). Based on their tolerance to salt and the need for maintenance and care, atoll food plants have been classified into two broad categories by Lefroy (1987):

1. Those which grow where there is a lot of salt and need little care, and;

2. Those which will not grow where salt levels are high and need protective planting and constant attention. *Colocasia esculenta* is such a species.

Soils

Most atoll soils are Entisols (recent), characterized by little profile development, consisting of a thin layer of organic rich coral sand overlying the coralline substratum and a poorly developed or nonexistent B horizon (Morrison 1987). These psamments are infertile, contain few soluble bases, and are chemically inactive. Causal factors responsible for these characteristics include the nature of the parent material and the relative youth of atoll soils. Repeated removals of surficial horizons by hurricanes and storm-driven waves account for the immaturity of atoll soils. In moist, undisturbed sites, Mollisols characterized by high base saturation and organic matter have been found, and on Tarawa soils with deep anthropogenically-developed organic matter layers have been classified as anthropic ustipsamments (Morrison 1987). These soils are commonplace in the taro (either *Colocasia esculenta* or *Cyrtosperma chamissonis*) pits of Micronesian atolls. These soils have an anthropic, histic epipedon derived from organic matter in various stages of decomposition. Often, this horizon is more than 0.5 m in depth.

Agronomically, organic matter is an extremely important component of atoll soils as many of the soil properties (for example moisture retention, cation exchange capacity) are related to the organic rather than mineral fraction of soils. Furthermore, organic matter moderates the effects of high levels of $CaCO_3$. As atoll subsoils are dominated by high levels of $CaCO_3$ (usually > 90 percent in the substrate), Calcium is the dominant cation in cation exchange, phosphorous and potassium availability is low, pH is high, and micronutrient solubilities are low (Morrison 1987, Caiger 1987). Table 2 presents the chemical analyses of Tuvalu topsoil and subsoil characteristics. More detailed discussions of atolls' soils are contained in Stone (1951), Morrision (1987), Caiger (1987), Bruce (1972), Seru and Morrision (1985), Morrison and Seru (1985), and Tercinier (1969).

Few fertilizer trials have been conducted on *Colocasia esculenta* on atolls. Trials using other crop plants have indicated increased yields at high rates of application. Yields up to 10 mt/ha of sweet potatoes have been achieved in trials using Fe, K, Mn, Cu, Zn, N, and P with ferrous sulfate applied at a rate of 1,000 kg/ha (Scott 1987). These increases attest to the low nutrient availability of atoll soils and suggest high yield increases for taro if fertilizers are applied.

Table 2. Chemical data for Tuvalu soils[2].

Determination		Topsoil	Subsoils
pH 1.5 H_2O		7.4 - 8.6	8.1 - 9.1
E.C. ms/cm 1.5 H_2O		0.13 - 0.45	0.10 - 0.21
$CaCO_3$ (%)		42 - 96	80 - 96
Exch. cations	Na	0.1 - 0.9	0.2 - 0.3
(cmol (p+)/kg)	K	0.0 - 0.2	0.0 - 0.2
	Mg	2.1 - 7.6	3.8 - 5.9
CEC (cmol (p+)/kg)		3.7 - 27.1	1.8 - 4.2
Total N (%)		0.2 - 0.65	0.05 - 0.13
Organic C (%)		1.97 - 14.66	0.3 - 1.12
Olsen P (ppm)		9 - 480	4 - 560
	P	560 - 58,500	845 - 54,500
	K	100 - 400	100 - 200
Total (mg/kg)	Mn	15 - 60	20 - 100
	Cu	25 - 90	45 - 95
	Fe	10 - 400	10 - 500
	Zn	10 - 250	10 - 230
Hot H_2O sol. B (ppm)		0.3 - 1.9	0.3 - 0.4

Source: Morrison (1987)

Fauna

A significant factor, albeit one that is rarely studied, is the fauna which may directly or indirectly impact the ecology of atoll islands. The viability and numbers of plant species have been associated with the bird guano of Canton (Hatheway 1955) and Gaferut (Niering and Sachet 1960), respectively. The limited distribution of *Cordia subcordata* on Canton Island has been attributed to predation by hermit crabs and the moth *Achaea janata* (Degener and Gillaspy 1955, Hatheway 1955).

The impact of insects and plant diseases on *Colocasia esculenta* in the atolls is not well known. The recent survey of taro cultivation on Ulithi Atoll observed predation of *Colocasia esculenta* by the taro army worm *Spodoptera litura* (Manner 1990b). For Kiribati, *Papuana hubneri* Fairmaire, *Aphis gossypii*, *Oryctes rhinoceros*, *Ferrisiana virgata*, and *Pseudococcus* sp. have been identified as *Cyrtosperma* pests (Lambert 1982). *Spodoptera litura*, *Hippotion celerio*, and *Pycnoscelus surianamensis* are other taro pests (Ali and Asghar 1987). With respect to plant diseases, a marginal leaf scorch due to K deficiency (Lambert 1982) and chlorosis because of excessive salt concentration in the soil-water have been observed on many atolls (Fosberg 1949). The root-knot nematode (*Melodogyne* spp.) is a constraint to vegetable production in the atolls (Scott 1987, Reboul 1982). *Icerya aegyptiaca*, a serious pest of breadfruit in Kiribati, also damages *Cyrtosperma chamissonis* (Ali and Asghar 1987).

When combined with soils of low moisture retention, a permeable limestone substrate, and poor groundwater reserves, drought and the subsequent increased concentration of salts may kill the most hardy and salt-resistant atoll plant species (Fosberg, 1955). Native plant species are more tolerant of drought conditions (Moul 1957). Owing to the variability in the factors cited above, atoll vegetation ranges between the desert-like vegetation of Malden Island (Fosberg 1949) to the mesophytic forests on Kapingamarangi Atoll (Niering 1956).

The Geographic Distribution of *Colocasia esculenta* in Micronesia

The geographic distribution of *Colocasia esculenta* is restricted to but few atolls and low islands in Micronesia. In their checklist of the Micronesian monocots, Fosberg et al. (1987) listed *Colocasia esculenta* as present on the atolls and low islands of Ulithi, Fais, Woleai, Faraulap, Ifaluk, Lamotrek, Satawal, Puluwat, Pulusuk, Namonuito, East Fayu, Murilo, Nomwin, Nama, Losap, Etal, Lukunor, Satawan, Nukoro, Kapingamarangi, Ant, Mokil, and Pingelap in the FSM; Lae, Aur, Jabwot, Ailinglapalap, Majuro, Arno, Kili, Jaluit, and Ebon in the Marshall Islands; Butaritari, Tarawa, and Tabiteuea in Kiribati. The species has also been reported for Namoluk Atoll (Marshall 1975), Nauru (Thaman et al. 1985), Likiep Atoll (Wiens 1957), and Peliliu, Angaur, Kayangel, and Tobi Atoll in Palau (McKnight and Obak 1960). It was not grown traditionally on Sonsorol, Pulo Ana, and Merir, the latter of which in now uninhabited (McKnight and Obak 1960). Thus, *Colocasia esculenta* is found on only 45 of the approximately 108 atolls and low islands of Micronesia. The distribution of taro in the Micronesian atolls is related to physical and cultural geographic factors. The species is not found in the drier arid zones of Micronesia or on islands which are uninhabited or have been abandoned by a previous indigenous population. Often the species is a recent introduction to the atoll. Canton Island is instructive in this matter. Wester (1985) notes that *Colocasia esculenta* was reported by Keyte (1861) and that Bryan (1942) saw it in cultivation on Fanning, and in all likelihood, it was probably introduced by European and Polynesian coconut planters/workers in mid-1800. The species has not been observed on the other Line Islands. The rainfall for Canton is low, approximately 48.3 cm per year (Degener and Gillaspy 1955), as it is located in the arid wedge of the central Pacific. Although the island was once inhabited by Polynesians, it was uninhabited at the time of European arrival in the Pacific (Wester 1985). Furthermore, in addition to the low rainfall on Canton Island, Degener and Gillaspy (1955) note:

"The paucity of native land plants on Canton is ... due to the scarcity of rain and its unfavorable distribution during the year, to the salty or nitrogen- and phosphates-impregnated character of the barren soil, to the low elevation enabling waves during storms and very rare tsunamis or tidal waves to scour the atoll bare of most life, and to the army of omnivorous hermitcrabs. Canton is not so isolated that seeds and other propagules of land plants cannot reach its shores. Almost all such castaways evidently find conditions to be unfavorable for survival."

Atoll Agriculture

Given the combination of factors discussed above, the atoll presented a harsh physical environment for human settlement. Terrestrial resources required for human sustenance was limited by the small size of the islands and the lack of habitat diversity and, in many cases, inadequate or non-existent freshwater reserves. Drought, typhoons (and the attendant potentials for salinization of soils and groundwater and destruction of the vegetation), infertile soils, and faunal predation of the vegetation were other important factors. The interplay of distance from seed sources and the lack of habitat diversity resulted in a vegetation dominated by relatively few salt-tolerant species on small islets. With increasing islet size, freshwater resources and habitat diversity were greater. However, relatively few food plants were native to the atoll. The small list of edible plants found on the atolls included purslane (*Portulaca* sp.), *Boerhavia* sp. (roots), seaweed, *Pandanus* sp. (Wiens, 1962), *Asplenium nidus* (Parham, 1971), *Pisonia grandis* (Niering, 1956), *Calophyllum inophyllum*, *Terminalia* spp., and *Cordia subcordata*. *Physalis minima*, *Ipomoea litorallis*, *Morinda citrifolia*, and *Ficus tinctoria* served as famine food plants and had minimal importance. The majority of food plants were introduced to the atoll environment, beginning with the indigenous settlement of the atolls. These early introductions included banana (*Musa* spp.), taro (*Colocasia esculenta* and *Cyrtosperma chamissonis*), arrowroot (*Tacca leontopetaloides*), *Crateva speciosa*, and breadfruit (*Artocarpus altilis, A. mariennsis*). Coconut (*Cocos nucifera*) and sweet potato (*Ipomoea batatas*) are also considered aboriginal introductions to the Pacific (Fosberg 1949, Wiens 1962).

These introductions were planted in zones that matched their agronomic requirements. Some species required modification of the atoll environment for cultivation. Thus, as evidenced by the zonation of vegetation, coconuts are a dominant component of the halophytic woodlands and forests which form a marginal forest fringe on islets.

Breadfruit, which is intolerant of salt, is found in transitional and mesophytic forests located inland of the salt-tolerant coconut woodlands. *Colocasia esculenta* and *Cyrtosperma chamissonis* were planted in freshwater depressions found in the interiors of larger islets. The surrounding forests serve as protective buffers and windbreaks for taro depression agriculture. Smaller islets (less than 1.4 ha in size) were not planted to taro, largely because of the absence of freshwater lenses; instead, the vegetation was dominated by coconuts or strand species.

Pit Cultivation of Aroids and Associated Plants

Despite the widespread distribution of *Cyrtosperma chamissonis* and *Colocasia esculenta* throughout atoll Micronesia, there are few details of *Colocasia esculenta* cultivation. The cultivation of *Cyrtosperma chamissonis* has received greater attention. On Kiribati, as described by Lambert (1982), *Cyrtosperma* is planted in pits measuring about 20 m x 10 m and 2-3 m in depth. *Cyrtosperma* is planted in holes dug 60 cm below the water level, and the holes are filled with layers of leaves (*Guettarda speciosa* and *Tournefortia argentea*) and black humic sand. The leaves of *Artocarpus altilis, Boerhavia* sp., *Wedelia biflora, Triumfetta procumbens, Hibiscus tiliaceus, Cordia subcordata,* and *Sida fallax* are also used as compost. The corm and compost is secured to the bottom by a "bottomless basket" of *Pandanus* or coconut leaves and covered with layers of chopped leaves and soil. The pit is mulched at least four times a year until harvest two to three years later.

When first dug, individual pits are quite small, measuring 20 to 30 m^2. However, with time and increasing pressure on atoll resources, the pits are enlarged and coalesce with each other. On Kapingamarangi Atoll these pits total 10.3 ha, or slightly less than ten percent of the total land area (Wiens 1956).

The *Colocasia esculenta* Islets (*Maa*) of Ulithi and Puluwat Atolls

Recent investigations in Micronesia, some undertaken by the LISA taro project, have provided some detail of *Colocasia esculenta* cultivation in the atolls. A *maa* or raised islet cultivation of *Colocasia esculenta* and other food and ornamental plants has been recently described for Puluwat and Ulithi atolls (Manner and Mallon 1989, Manner 1990a, Manner 1992). On Puluwat Atoll *Colocasia esculenta* is grown on islets constructed in the interior swampy depression of Puluwat Islet. The islets are about 1 m high and stand approximately 0.5 m above the water table. The islets are oval in shape and are formed by anchoring coconut and pandanus trunks to the bottom of the excavated depressions. The base is then filled with organic litter, trunks, and other rotted vegetation to form a friable, organic (histic anthropic) soil layer, 0.5 m in depth. These organic materials are also collected from fallowed or abandoned islets and by sieving the water. The sides of the islets may also be constructed of coconut husks, and plaited coconut fronds are usually placed on the edges as an ornamental fringe and/or to keep the organic soils in place. The coconut fronds serve as a mulch, weed suppressant, and when decomposed, a source of fertility. Weeds are buried in the islet to form more soil and as a source of fertility. *Cyrtosperma chamissonis* and other food plants and ornamentals are also grown on the *maa*. The islets are separated from each other by 1.5-m wide drainage canals. For Puluwat Atoll, the *maa* is found only on Puluwat Islet. On the other islets of Puluwat, *Cyrtosperma chamissonis* is planted in partly excavated and natural depressions. On Ulithi Atoll, the islets are triangular in shape and more closely spaced (Manner 1990b). Minor plantings of *Colocasia esculenta* are sometimes found near house sites.

The cultivation of *Colocasia esculenta* throughout the atolls of Micronesia is traditionally done by women. On Mogmog Islet, Ulithi Atoll, the *Colocasia esculenta* islets are forbidden to men. On Puluwat, men may help construct the *maa*. On Losap Atoll, taro cultivation is men's work. Fertilization of the taro pits is accomplished by alternating coconut fronds with *Digitaria violescens*. As *Digitaria violescens* is in limited supply, demand for it is high. A 50-lb bundle costs approximately $30.00. These brief comments on the cultivation of *Colocasia esculenta* represent the little information available on taro production in Micronesia.

There is little information on the planting density, productivity, or energetics of *Colocasia esculenta* in the atolls. Manner (1990b) found 12 *Colocasia* and 43 *Cyrtosperma* plants per 16 m^2 in the large (0.4-0.6 ha) taro swamp on Mogmog Islet, Ulithi Atoll. Other cultivated species were *Saccharum officinarum* and *Musa* spp. Alike (1989) estimated for Lamotrek Atoll that:

> "In areas of intense cultivation *Cyrtosperma* and *Colocasia* averaged 36 plants per 100 square feet, or more than 15,000 plants to the acre. In peripheral areas the *Cyrtosperma* density was less than half this figure: 15 per 100 square feet. Projecting these figures to the whole swamp means there are around 500,000 taro plants on the island, of which some 80 percent are *Cyrtosperma*.... Assumming an average yield per plant of one pound...this would mean each acre has a potential output of 15,000 pounds."

Table 3. Vernacular names of *Colocasia esculenta* in Micronesia.

Place	Vernacular names	Cultivar names
Ant	*oht* (Glassman, 1953)	*ohtinyap, ohton kusaie, gilifit, uotayalus,*
Kapingamarangi	*sara* (Stone, 1966)	
Losap	*ot* (Sana, D., pers. comm. Sept. 21, 1992)	*otocha* (red petiole), *otoka*
Likiep	*kotak* (Wiens, 1957)	
Mokil	*tawa, chawa* (Glassman, 1953)	*chawasa, peeter, tawah, pehmeru, chawa-n-jaban*
Majuro	*katak* (St. John, 1951)	*katak Majol, katak in kabelin*
Mortlock	*oni* (Williams, A., pers. comm., Sept. 15, 1992)	
Namoluk	*oat* (Girschner, 1911; Marshall, 1975)	*oat en iap, anor, otoput, pamoru, otoput, palapal, ke*
Nauru	*detaro* (Thaman, Manner and Hassall, 1985)	
Palau	*kukau* (McKnight and Obak, 1960)	
Pingelap	*sawa* (St. John, 1948)	*bokor, tawang, mesawso, koso, sawa Pingelap, sauk, pemeru*
Puluwat	*woot* (Manner and Mallon, 1989)	*aimaimw, namoluk, nenniku, rangasei, tawa, wenea, wotocca,*
	woot (Elbert, 1975)	*wotokucc, wotokuuh, wotomarewuw, wotonmeripwa, wotoorhaar, wotopei*
	wodj (Damm and Sarfert, 1935)	*wotopwer, wotopwul, wotowupwuupw.*[1] *faitacha, kariingan, otorhol, allinga,*
waaniko,		
		kaaka, annipo, wenea, autun-uur, rhimek, marepwa, hamal, rhal.[2] *haroway, kannipwo, karaatik, kiriim, lipweringo, luukiyo, mwaat, nafeeyirek, raangooy,*
riip,		
		tikilep, took, wotoniyaap, wotoroolinpolowat, yamelangeer, yariimaar,
yawutunuur.[3]		
Satawal	*wot omalu* (Fosberg, 1969)	
Woleai	*uot* (Alkire, 1974)	*rangoi, gareial, wichit, waligo, gachimar, gaimweim, uotalisapan, iligurug,*
uotachal,		
		oluwa, pei, gailimang, garatig, uotalifachailap, leligu, ganibwo, lamalug, gilifit, uotayalus
Ulithi	*ioth* (Lessa, 1977)	*ioth cha, ioth bwech*

[1] Varieties listed by Elbert (1975) and still present on Puluwat.
[2] Varieties introduced to Puluwat since 1967.
[3] Varieties listed by Elbert (1975), but not present on Puluwat today.

On Ontong Java in Melanesia, taro (*Colocasia esculenta* and *Cyrtosperma chamissonis*) is intensively cultivated in pits which occupy five percent of the land area, but contributes 29 percent of dietary energy. On Ulithi Atoll, *Colocasia esculenta* is also grown in abandoned World War II landing barges and other large containers. On Asor Islet, cement tanks measuring 2.6 m x 6.1 m x 0.8 m (length x width x height), and 0.1 m in thickness have been built in order to grow *Colocasia* and *Cyrtosperma* taro. These tanks are partly filled with organic materials and water and planted with taro. The taro and organic substrate floats on the water which can be regulated by opening a stoppered hole. This method of cultivation affords protection from salt water contamination by high tides and storm waves. This system is also found on Fais Island (Rubenstein, pers. comm. 1991).

Cultivar Diversity

The diversity of atoll food plants is limited. On Puluwat Atoll, there are 28 food-plant species, some of which are of minor importance. For the main staple food crops, however, there are a surprisingly high number of cultivars of *Colocasia esculenta* (46), *Cyrtosperma chamissonis* (44), *Artocarpus altilis* (40), *A. mariennensis* (7), *Cocos nucifera* (11), and *Musa* spp. (34). In Kiribati, *Pandanus tectorius* is represented by at least 12 cultivars (Moul 1957) and 24 cultivars of *Cyrtosperma chamissonis* (Ali and Asghar 1987). A list of the vernacular names of *Colocasia esculenta* cultivars is presented in Table 3. As suggested elsewhere, the large number of cultivars may be an attempt by atoll dwellers to enlarge their narrow food resource base through the selection of species that vary in resistance to disease, pests, salinity, drought, and productivity characteristics (Manner and Mallon 1989). The Puluwat data also indicate a rapid turnover in taro cultivars. Thirteen of the 46 varieties of *Colocasia esculenta* seem to have been introduced into Puluwat since 1967 (Manner and Mallon 1989).

Pit Abandonment, Taro Substitution, and the Future

Within an atoll group, the distribution of *Colocasia esculenta* was limited to larger islets where fresh water was present during extended droughts. On Puluwat Atoll, the species was found mainly in the *maa* of Puluwat Islet where it was co-dominant with *Cyrtosperma chamissonis*. It was also present as a minor cultivar in the swamp depressions on Alei Islet where *Cyrtosperma chamissonis* was the dominant aroid, but absent on the smaller islets. On Hao and To islets, *Cyrtosperma chamissonis* is present. While this pattern of aroid distribution reflects the significance of environmental constraints, it also belies the role of socio-cultural, economic, historical, and other factors, in particular, the changing role of *Colocasia esculenta* and *Cyrtosperma chamissonis* during a period of rapid socio-economic development in Micronesia.

For much of the Caroline Islands, *Colocasia esculenta* was the prestige aroid of presentation, ritual, and subsistence (McKnight and Obak 1960, Alkire 1989). In contrast to *Cyrtosperma chamssionis*, the cultivation of *Colocasia esculenta* required a greater intensity of labor effort. *Cyrtosperma chamissonis* is a hardier species and is more tolerant of salt. Some cultivars can remain in the ground for up to 15 years before harvesting (Lambert, 1987). By locating the *maa* close to the villages of Puluwat Islet, travel time to the taro fields was reduced, thus increasing the efficiency of *Colocasia* cultivation (Manner 1992). As for Alei Islet, the cultivation of aroids was more extensive in the past than it is today. Before World War II, the islet was inhabited. During the 1930-1940s, the inhabitants were forced to relocate to Puluwat Islet. The taro pits on Alei were destroyed when the islet was converted into an Japanese air base. Although some rehabilitation of the taro pits occurs today, the process has been slow. On Ulithi Atoll, where infilling of the taro pits took place during World War II, the islanders have requested a backhoe from the government in order to dig taro pits in the compacted coral runway.

On Kapingamarangi Atoll, *Colocasia esculenta* is found only as a minor plant on Werua Islet (Niering 1956). By contrast, *puraka* or *Cyrtosperma chamissonis* pits were found on 11 of the 33 islets of Kapingamarangi Atoll. The *puraka* pits have been abandoned on three of the smaller islets. In the 1950s, Niering (1956) reported an increase in the number of pits with an increase in population, and that while *Cyrtosperma chamissonis* was now the most common aroid, *Colocasia esculenta* was the dominant taro in the past:

> "Apparently the more vigorous drought-resistant puraka crowded out the less successful taro. Today the latter occurs only as scattered isolated specimens" (Niering 1956).

This replacement has been rapid. In an account of the history of Kapingamarangi, Wiens (1956) wrote:

> "The sixth ship brought Tiaki (Jack) Lee with his native wife Nuri from Nukuoro. He was responsible for the introduction of the valuable puraka plant which has become one of the staples of diet and which supplanted the smaller taro plant in the pits and dugout fields."

Tiaki (Jack) Lee arrived on Kapingamarangi sometime between 1877 and 1892.

On Namoluk Atoll, the taro pits on Amwes Islet were abandoned when the islet was abandoned by the inhabitants (Marshall 1975), while in the Marshall Islands, the pit cultivation of taro (mainly *Cyrtosperma chamissonis*) has been abandoned on Utirik, Ailuk, and Lae atolls (Fosberg 1955), and on Airik Islet on Maloelap Atoll (Wiens 1957) for a variety of reasons. On Arno Islet, pig damage to the pits have been cited as a reason for abandonment (Hatheway 1953). On other islets, the displacement of taro by the "copra tin can economy" (Doty 1954), the availability of rice and flour, depopulation, and infilling of pits for airstrips and military installations during World War II (Manner 1990a) have been suggested as reasons for pit abandonment. For Lamotrek Atoll, Alkire (1989) argues that despite "modernization" trends,

> "taro and breadfruit are still the staples, but the percentage of purchased foods consumed has increased as the amount of locally available money has grown. Rice, canned meat, and canned fish are eaten more frequently and in larger quantities than in the 1960s."

In brief, the European intervention in the Pacific resulted in far-reaching socio-economic-political changes to atoll life and *Colocasia esculenta*.

Even further abandonment of the taro islets and pits and the replacement of *Colocasia esculenta* by *Cyrtosperma chamissonis* can be expected as the Micronesian atolls become less isolated and more integrated into a more westernized world. Even further changes to the nature of the atoll subsistence economy can be suggested as a consequence of migration. With the signing of the compacts of free association between the United States and the Federated States of Micronesia, citizens of the FSM now freely migrate to the United States and its territories. An estimated 6,500 Chuukese, many from the atolls, now reside on Guam, and despite the ravages of Typhoon Omar on the economy and housing infrastructure of Guam, further migration from the outer islands of Chuuk is expected. As O'Collins (1989) has suggested, such migration will have "important economic and social consequences, both for those who leave to form a new community and those who remain behind." We can expect an increased consumption of store-bought foods, decreased subsistence production, and changing subsistence-gender-age work roles, to name a few. Although there will always be centers of *Colocasia esculenta* cultivation, as on Puluwat and Ulithi, the significance of *Colocasia esculenta* in atoll Micronesia will be greatly diminished.

Conclusion

Despite the harshness of the atoll environment, *Colocasia esculenta* is an important component of agriculture in Micronesia. However, little is known of *Colocasia esculenta* cultivation in the atolls and low islands. Recent studies have indicated the presence of a large number of cultivars of *Colocasia* taro and the *maa* method of taro cultivation on Puluwat Atoll. Although the *maa* system described in this paper is sustainable, in the absence of date, it is classified as labor intensive. Unfortunately, the available evidence suggests that *Colocasia* taro is being replaced by *Cyrtosperma* taro, and further erosion of *Colocasia esculenta* cultivation is postulated as atoll Micronesia becomes more integrated into the modern world. Migration from the atolls will also affect the cultivation of *Colocasia* taro, yet we have largely ignored the socio-cultural aspects of atoll agriculture. These aspects may be more important than the agronomic aspects of *Colocasia esculenta* cultivation, but in the absence of such research, these effects are unknown. The traditional subsistence cultivator is the source of the sustainable technologies described in this paper. One of the objectives of the LISA taro project for the Pacific is the extension of low-input knowledge to farmers in the region. The major beneficiaries of the LISA research on sustainable *Colocasia* systems and technologies will be the commercial or semi-commercial producer, with little extension or benefit directed to the subsistence cultivator. For the Pacific islands, and in particular atoll Micronesia, where sustainable systems of *Colocasia esculenta* cultivation are in danger of dying out, it is only proper and imperative that our extension efforts, including the introduction of other appropriate, sustainable, and low-input technologies for *Colocasia* taro cultivation are directed to the traditional cultivator (an appropriate technology for the atolls might be the hybridization of high-yielding taro cultivars suitable for the atoll environment). To not do so would be immoral and hasten the decline of their cultures and their cultivation of *Colocasia esculenta*.

References Cited

Abott, I. 1974. Numbers of plant, insect and land bird species on nineteen remote islands in the Southern Hemisphere. Biol. J. Linn. Soc., 6: 143-152.

Ali, A. & M. Asghar. 1987. The agronomy of *Cyrtosperma chamissonis* Schott in Kiribati. Alafua Agricultural Bulletin, 12(3): 81-88.

Alkire, W. H. 1974. Native classification of flora on Woleai Atoll. Micronesia 10: 1-5.

Alkire, W. H. 1989. Lamotrek Atoll and Inter-island Socioeconomic Ties. Waveland Press, Inc., Prospect Heights, Illinois.

Bruce, J. G. 1972. Soils of Maruae and Palmerston Islands, two coral atolls in the Cook Islands. New Zealand J. of Agricultural Res. 15: 605-619.

Bryan, E. H., Jr. 1942. American Polynesia and the Hawaiian Chain. Tongg Publishing Co., Honolulu.

Buddemeier, R. W. & J. A. Oberdorfer. 1989. Climate change and island groundwater resources. pp. 16-27. *In* J. C. Pernetta and P. J. Hughes (eds.), Studies and Reviews of Greenhouse Related Climatic Change Impacts on the Pacific Islands. SPC/UNEP/ASPEI Intergovernmental Meeting on Climatic Change and Sea Level Rise in the South Pacific (Majuro, Republic of the Marshall Islands, July 16-20, 1989). Association of South Pacific Environmental Institutions, University of Papua New Guinea.

Caiger, S. 1987. Corraline soils of Tuvalu: their analytical characteristics and fertilizer requirements. Alafua Agricultural Bull. 12(3): 31-37.

Connell, J. & P. Roy. 1989. The greenhouse effect: The impact of sea level rise on low coral islands in the South Pacific. pp. 106-133. *In* C. J. Pernetta and P. J. Hughes (eds.), Studies and Reviews of Greenhouse Related Climatic Change Impacts on the Pacific Islands. SPC/UNEP/ASPEI Intergovernmental Meeting on Climatic Change and Sea Level Rise in the South Pacific (Majuro, Republic of the Marshall Islands, July 16-20, 1989). Association of South Pacific Environmental Institutions, University of Papua New Guinea.

Damm, H. & E. Sarfert. 1935. Inseln um Truk. 2 Halbband. *In* G. Thilenius (ed.), Ergebnisse der Sudsee-Expedition 1908-1910. II. Ethnographie: B. Mikronesien. Band 6. Hamburgische Wissenschaft.

Friederichsen, De Gruyter and Co., Hamburg.
Degener, O. & E. Gillaspy. 1955. Canton Island, South Pacific. Atoll Research Bulletin 41: 1-51.
Doty, M. S. 1954. Floristic and ecological notes on Raroia. Atoll Research Bulletin 33:1-41.
Douglas, G. 1969. Draft checklist of Pacific oceanic islands. Micronesia, 5(2): 327-463.
Elbert, S. H. 1975. Puluwat Dictionary. Pacific Linguistic Series C, No. 24. School of Pacific Studies, Australian National University, Canberra.
El-Swaify, S. A. 1987. Soil and water salinity aspects of irrigated agriculture on atolls. Alafua Agricultural Bulletin 12(3): 39-50.
Fosberg, F. R. 1949. Atoll vegetation and salinity. Pacific Science 3: 89-92.
Fosberg, F. R. 1955. Northern Marshall Islands expedition, 1951-1952. Narrative. Atoll Research Bulletin, 38: 1-37.
Fosberg, F. R. 1969. Plants of Satawal Island, Caroline Islands. Atoll Research Bulletin 132: 1-13.
Fosberg, F. R., M. Sachet & R. Oliver. 1987. A geographical checklist of the Micronesian Monocotyledonae. Micronesia 20(1-2): 19-129.
Girschner, M. 1911. Die Karolineninsel Namoluk und ihre Bewohner. Bessler-Archiv 2(3 & 4): 123-220.
Glassman, S. F. 1953. New plant records from the Eastern Caroline Islands, with a comparative study of the native plant names. Pacific Science 7: 291-311.
Good, R. 1947. The Geography of the Flowering Plants. Longmans, Green and Co., London.
Hatheway, W. H. 1953. The land vegetation of Arno Atoll, Marshall Islands. Atoll Research Bulletin, 16: 1-68.
Hatheway, W. H. 1955. The natural vegetation of Canton Island, an Equatorial Pacific atoll. Atoll Res. Bull. 43: 1-9.
Heine, A. 1984. Urbanization and social change in the Marshall Islands. Ambio 13(5 & 6): 313-315.
Keyte, G. S. 1861. Fanning's Island: An incident. The Friend 18: 31.
Lambert, M. 1982. The cultivation of 'taro' *Cyrtosperma chamissonis* Schott in Kiribati. pp. 163-165. *In* Regional Technical Meeting on Atoll Cultivation. Technical Paper 180. South Pacific Commission, Noumea, New Caledonia.
Lefroy, E. 1987. Growing food on coral atolls. Alafua Agricultural Bull. 12(3): 61-65.
Lessa, W. A. 1977. Traditional uses of the vascular plants of Ulithi Atoll, with comparative notes. Micronesia, 13(2): 129-190.
MacArthur, R. H. & E. O. Wilson. 1967. 1967. The Theory of Island Biogeography. Princeton University Press, Princeton.
Manner, H. I. 1987. Atoll flora and vegetation. Alafua Agricultural Bull. 12(3): 67-80.
Manner, H. I. 1990a. A review of atoll agriculture and ecology with respect to climate change and sea level rise in the Pacific Basin. pp. 41-64. *In* P. J. Hughes and G. McGregor (eds.), Global Warming-related Effects on Agriculture and Human Health and Comfort in the South Pacific. Association of South Pacific Environmental Institutions, University of Papua New Guinea.
Manner, H. I. (Preparer). 1990b. Report of a visit to Ulithi Atoll. pp. 147-153. *In* A. Vargo (ed.), A Rapid Rural Appraisal of Taro Production Systems in Micronesia, Hawai'i and American Samoa. LISA, USDA.
Manner, H. I. & E. Mallon. 1989. An annotated list of the vascular plants of Puluwat Atoll. *Micronesia* 22(1): 23-63.
Manner, H. I. 1992. The taro islets (*maa*) of Puluwat Atoll. Paper presented at the Science of Pacific Island Peoples Conference (July 6-10, 1992), Suva, Fiji.
Marshall, M. 1975. The natural history of Namoluk Atoll, Eastern Caroline Islands with identifications of vascular flora by F. R. Fosberg. Atoll Res. Bull. 189: 1-65.
Mayr, E. 1953. Fragments of a Papuan ornithogeography. *In* Proc. of the Seventh Pacific Science Congress, (New Zealand) 4: 11-19.
McKnight, R. K. & A. Obak. 1960. Taro cultivation in the Palau District. Taro Cultivation Practices and Beliefs. Part 1. The Western Carolines. Anthropological Working Papers No. 6. Staff Anthropologist. Trust Territory of the Pacific Islands, Guam, Mariana Islands.
Merrill, E. D. 1945. Plant Life of the Pacific World. Macmillan Co., New York.
Morrison, R. J. 1987. Chemistry and classification of Pacific low atoll soils. Alafua Agricultural Bull. 12(3): 25-30.
Morrison, R. J. & V. B. Seru. 1985. Soils of Abatoa Islet, Tarawa, Kiribati. Environmental Studies Report No. 27. Institute of Natural Resources, USP, Suva, Fiji.
Moul, E. T. 1957. Preliminary report on the flora of Onotoa Atoll, Gilbert Islands. Atoll Res. Bull. 57: 1-48.
Niering, W. A. 1956. Bioecology of Kapingamarangi Atoll, Caroline Islands: Terrestrial aspects. Atoll Res. Bull. 49: 1-32.
Niering, W. A. 1963. Terrestrial ecology of Kapingamarangi Atoll, Caroline Islands. Ecological Monographs, 33(2): 131-160.

Niering, W. A. & M. Sachet. 1960. Observations on Puluwat and Gaferut, Caroline Islands. Historical and climatic information of Gaferut Island. Atoll Res. Bull. 76: 1-15.

O'Collins, M. 1989. Social and cultural impact: A changing Pacific? pp. 94-105. *In* J. C. Pernetta and P. H. Hughes (eds.), Studies and Reviews of Greenhouse Related Climatic Change Impacts on the Pacific Islands, SPC/UNEP/ASPEI Intergovernmental Meeting on Climatic Change and Sea Level Rise in the South Pacific (Majuro, Republic of the Marshall Islands, July 16-20, 1989), Association of South Pacific Environmental Institutions.

Parham, B. E. V. 1971. The vegetation of the Tokelau Islands with special reference to the plants of Nukunonu Atoll. New Zealand J. of Botany 9: 576-609.

Pernetta, J. C. 1990. Projected climate change and sea level rise: A relative impact rating for the countries of the Pacific Basin. pp. 14-24. *In* J. C. Pernetta and P. J. Hughes (eds.), Implications of Expected Climate Changes in the South Pacific Region. UNEP Regional Seas Reports and Studies No. 128. UNEP, Nairobi.

Pielou, E. C. 1979. Biogeography. J. Wiley and Sons, New York.

Prasad, R. & J. D. Coulter. 1984. Climatology on small islands. pp. 224-238. *In* Water Resources of Small Islands. Technical Proceedings (Pt. 2) of the Regional Workshop on Water Resources of Small Islands (27 June - 9 July, Suva, Fiji). CSC Technical Publication Series No. 154. Commonwealth Science Council. London.

Reboul, J. L. 1982. XIV. Motu crops in French Polynesia. The cultivation of vegetables on coral islets on Huahine (Leeward Islands) and the potential application of this system on atolls. pp. 112-133. *In* Regional Technical Meeting on Atoll Cultivation (Papeete, Tahiti, French Polynesia, 14-19 April 1980). SPC Technical Paper No. 180. South Pacific Commission, Noumea, New Caledonia.

Sachet, M. 1983. Takapoto Atoll, Tuamotu Archipelago: Terrestrial vegetation and flora. Atoll Res. Bull. 277: 1-46.

St. John, H. 1948. Report on the flora of Pingelap Atoll, Caroline Islands, Micronesia, and observations on the vocabulary of the native inhabitants: Pacific plant studies 7. Pacific Science 2: 97-113.

St. John, H. 1951. Plant records from Aur Atoll and Majuro Atoll, Marshall Islands, Micronesia. Pacific plant studies 9. Pacific Science 5: 279-286.

Scott, M. 1987. British government support for research into coral atoll agriculture. Alafua Agricultural Bull. 12(3): 115-116.

Servu, V. B. & R. J. Morrison. 1985. Two soil sequences from South Tarawa, Kiribati. South Pacific J. of Natural Sci. 7: 132-156.

Sproat, M. N. 1968. A guide to subsistence agriculture in Micronesia. Agricultural Extension Bulletin No. 9. Department of Resources and Development, Trust Territory of the Pacific Islands, Saipan, Mariana Islands.

Stone, B. C. 1966. Some vernacular names of plants from Kapingamarangi and Nukuoro Atolls, Caroline Islands. Micronesia 2(2): 131-132.

Stone, E. L., Jr. 1951. The soils of Arno Atoll, Marshall Islands. Atoll Res. Bull. 5: 1-56.

Sullivan, M. & J. Pernetta. 1989. The effects of sea level rise on atolls and motu. pp. 1-15. *In* J. C. Pernetta and P. J. Hughes (eds.), Studies and Reviews of Greenhouse Related Climatic Change Impacts on the Pacific Islands. SPC/UNEP/ASPEI Intergovernmental Meeting on Climatic Change and Sea Level Rise in the South Pacific (Majuro, Republic of the Marshall Islands, July 16-20, 1989). Association of South Pacific Environmental Institutions.

Tercinier, G. 1969. Note de synthese sur les sols du Motu Faucon (etude pedologigue d'une portion representive de l'atoll de Mururoa). Cahiers du Pacific 13: 17-46.

Thaman, R. R., H. I. Manner & D. C. Hassall. 1985. Nauruan plant names. Environmental Studies Report, No. 21. Institute of Natural Resources, University of the South Pacific, Suva, Fiji.

Thomas, W. L., Jr. 1965. The variety of physical environments among Pacific islands. pp. 7-37. *In* F. R. Fosberg (ed.), Man's Place in the Island Ecosystem: A Symposium. Bishop Museum Press, Honolulu.

Thorne, R. F. 1963. Biotic distribution patterns in the tropical Pacific. pp. 311-350. *In* J. L. Gressitt (ed.), Pacific Basin Biogeography: A Symposium. Tenth Pacific Science Congress, Honolulu (1961). Bishop Museum Press, Honolulu, Hawai'i.

U. S. Weather Bureau. 1965. Dicennial Census of the United States Climate: Climatic Summary of the United States; Supplement for 1951-1960 Hawai'i and Pacific. Climatography of the United States No. 86-44. U. S. Dept. of Commerce, Washington, D. C. Government Printing Office.

Wester, L. 1985. Checklist of the vascular plants of the Northern Line Islands. Atoll Res. Bull. 287: 1-38.

Whitehead, D. R. & C. E. Jones. 1969. Small islands and the equilibrium theory of insular biogeography. Evoulution 23: 171-179.

Wiens, H. J. 1956. The geography of Kapingamarangi Atoll in the Eastern Carolines. Atoll Res. Bull. 48: 1-93.
Wiens, H. J. 1957. Field notes on atolls visited in the Marshalls, 1956. Atoll Res. Bull. 54: 1-23.
Wiens, H. J. 1962. Atoll Environment and Ecology. Yale University Press, New Haven.

The Editor

L. Ferentinos is the Project Coordinator of the Taro Production Systems Project at the University of Hawai'i at Manoa.

Jane C. Muench, an independent editor with J.C.M. Office Services, provided technical support.

Publication was supported in part by a grant from the USDA/CSRA Sustainable Agriculture Research and Education Program (formerly called L.I.S.A.). Additional support was provided by American Samoa Community College, College of Micronesia, Northern Marianas College, University of Guam, Yap Institute of Natural Science, and the University of Hawai'i under the Agricultural Development in the American Pacific (ADAP) Project.

The Library of Congress has catalogued this serial publication as follows:

Research extension series / Hawaii Institute of Tropical Agriculture and Human Resources.—001—[Honolulu, Hawaii]: The Institute, [1980–
v. : ill. ; 22 cm.
Irregular.
Title from cover.
Separately catalogued and classified in LC before and including no. 044.
ISSN 0271-9916 = Research extension series - Hawaii Institute of Tropical Agriculture and Human Resources.
1. Agriculture—Hawaii—Collected works. 2. Agriculture—Research—Hawaii—Collected works. I. Hawaii Institute of Tropical Agriculture and Human Resources. II. Title: Research extension series - Hawaii Institute of Tropical Agriculture and Human Resources.
S52.5R47 630'.5—dc19 85-645281
AACR 2 MARC-S
Library of Congress [8506]