Micronesica 40(1/2): 63-86, 2008

Directions for long-term research in traditional agricultural systems of Micronesia and the Pacific Islands

HARLEY I. MANNER
College of Liberal Arts and Social Sciences, University of Guam, UOG Station, Mangilao, Guam 96923

Abstract— Following a review of the major systems of traditional agriculture, this paper briefly considers the role of traditional agriculture in environmental modification, and the related concepts of sustainability, agricultural intensification, carrying capacity, biodiversity and agricultural disintensification (abandonment). Research interest in traditional agricultural systems of the Pacific Islands has waned considerably since the 1960s and there are few current studies of these systems in Micronesia. Both species and cultivar diversity of the traditional agricultural systems of the region are high and may contribute significantly to their sustainability. However, there is little ongoing research on the role of biodiversity in these traditional systems. Some reasons for the apparent lack of research in the ecology of traditional agricultural systems are presented. The Pacific-Asia Biodiversity Transect (PABITRA) network emphasizes investigation of the function of biodiversity and the health of ecosystems in the tropical Pacific Islands. Accordingly, PABITRA's focus should be on long-term monitoring of traditional agricultural systems in order to define their structural and functional characteristics and the relationship between diversity and sustainability. Given the rapid rate of modernization, the documentation of traditional agricultural knowledge and resources is imperative as this knowledge is rapidly being lost.

Introduction

Traditional agriculture has a profound effect on the biodiversity and landscape ecology of the Pacific Islands. The most viable and sustainable of these traditional systems are those which mimic the structure and function of their corresponding natural ecosystems. The mixed tree garden or traditional agroforest, for example, is associated with biologically rich forest landscapes that display relatively little environmental disruption or modification. By contrast, open field systems require a greater manipulation and alteration of the natural environment. The major types of traditional agricultural systems have also been linked to a continuum of intensification initiated by increased population pressure on land. Additionally, there is the premise that traditional cultivation techniques promote long-term sustainability and that these practices do not harm people or their environment (Plenderleith 1999). However, it has been hypothesized that the practice of intermittent gardening using slash and burn is associated with savanna origin and expansion. While these systems are in the main sustainable, changing socio-cultural conditions and economic aspirations and the pressures associated with increased population growth and modernization are greatly affecting the cultural ecology and, therefore, the sustainability and viability of these traditional systems.

This paper first describes briefly the main traditional agricultural systems of the Micronesia and the Pacific. After defining traditional agriculture it then considers the question of agricultural intensification and related thematic issues relative to the Pacific-Asia Biodiversity Transect (PABITRA) network's concern for biodiversity conservation in landscape ecology. It suggests that questions concerning the sustainability and viability of traditional agricultural systems, the impact of traditional agriculture on Pacific Island landscape ecology, agricultural intensification and abandonment, carrying capacity, biodiversity and environmental degradation can only be answered though the long-term monitoring of such systems. The reasons for focusing on Micronesia's traditional agriculture are twofold. First, discussions on the traditional agriculture of the Pacific Islands center heavily on studies of Polynesia and Melanesia, and rarely on Micronesian-based studies despite the existence of previous works by Barrau (1961), Hunter-Anderson (1991), Clarke & Thaman (1993), among others. As a case in point, Leach's (1999a) recent critique on intensification in the Pacific makes no mention of Micronesian resources. It is only in the "Comment" section by Athens (1999), Kirch (1999) and Sand (1999) and Leach's reply (1999b), that Micronesian agriculture and prehistory are mentioned. Second, for the past 10 years, PABITRA has conducted capacity building projects aimed at training Pacific Islanders in analyzing their terrestrial ecosystems, beginning with Hawaii, Fiji, Samoa and most recently, the Micronesian nation-state of Palau. It is in recognition of PABITRA's efforts in Palau that this paper describes the traditional agricultural systems of Micronesia. A second priority need is to document traditional agricultural information because rapid socio-economic changes in the Pacific are eroding this knowledge base.

DEFINITION OF TRADITIONAL AGRICULTURE

Because traditions change over time, it is not easy to define what we mean by traditional agriculture. Indeed, McClatchey (2005) argues against the use of this term and other terms because of their vagueness, in addition to potentially negative and/or positive connotations. Traditional agriculture can be best understood (defined) in contrast to modernized agricultural systems and as such, traditional agriculture refers to those simple to complex farming systems developed mainly by the indigenous inhabitants of a region primarily for subsistence. These systems are adapted to a localized cultural-ecological context. They do not necessarily rely on the energy-intensive technologies of modern agriculture, namely, mechanization, chemical fertilizers and pesticides. While the emphasis of traditional agriculture is mainly for subsistence, traditional agriculturalists also engage in semi-commercial or market-oriented activities. Additional characteristics and attributes of traditional agriculture include its emphasis on sustainability, local scale self-sufficiency, reliance on locally available natural resources, to name a few (Clarke 1977, Posey 1999). While traditional agriculture is mainly a non-westernized/modernized agriculture, certain elements and innovations of western agriculture have been adopted by traditional societies. In this discussion, "traditional" does not imply a stasis nor an antiquity of knowledge, but that the way knowledge is acquired and used is a socio-cultural process (Posey 1999). Traditional agriculture, perhaps should be thought of as being a part of traditional ecological knowledge (TEK) or indigenous ecological knowledge which mainly includes local knowledge of plants, animals, soils, etc., and the associated experience and wisdom of human interaction with the environment (Slikkerveer 1999: 170). As will be shown later, many of the traditions and practices of traditional agriculture are in danger of being lost because of globalization (modernization) and what some scholars call disintensification. Some of these processes include the migration of rural and often traditional peoples to urban areas, the introduction of a formal westernized educational system, and the adoption of a western lifestyle to name a few.

Traditional Agricultural Systems of Micronesia and the Pacific Islands

The traditional agricultural systems of Micronesia (and the Pacific Islands) can be classified into the following types based on methods of cultivation and land use (Clarke et al., 1999, Falanruw 1994, Manner 1993a). These are: 1. Mixed tree gardening, agroforestry, and arboriculture; 2. Intermittent tree or mixed gardening (shifting cultivation); 3. Intensive open field agriculture in savannas (including ditching for drainage); 4. Wetland cultivation systems for *Colocasia esculenta* and *Cyrtosperma chamissonis*; 5. Kitchen, backyard gardening (home garden); and 6. Animal husbandry. This classification system is used because it is inclusive and more definitive of the agricultural systems of the Pacific Islands. For example, types 1-3 and 5 fit in Coulter's (1998) very broad classification of "Rain-fed arable farming systems other than those involving wetland rice". Ruthenberg's (1980) oft-cited classification excludes any discussion of wetland taro systems, and most agroforestry systems classifications (for example, Huxley (1998) and Nair (1990)) do not include intensive open field agriculture or wetland taro systems. Except for animal husbandry, these systems are briefly described below. A summary of the ecological characteristics (i.e., gross production/standing crop biomass, net community production, species diversity, cultivar diversity, etc.) of traditional Pacific Islands agricultural systems can be found in Manner (2007). Most of these characteristics are based on ecological theory and need to be verified by analytical studies of traditional agricultural systems.

MIXED TREE GARDENING, AGROFORESTRY, AND ARBORICULTURE

The mixed tree garden, which is also known as native agroforest or arboriculture (the culture of trees), is one of the most conspicuous and possibly the earliest forms of agriculture in the Pacific. Evidence from the Mussau Islands of Papua New Guinea indicate the presence of arboriculture from 3,500 years ago. Here the agroforest consisted of coconuts, two to three species of *Pandanus*, *Inocarpus fragifer*, the *Canarium* nut, and the Polynesian vi apple (*Spondias dulcis*), and hardwoods for carving (Kirch 1989). This form of agriculture is a relatively permanent system of landuse that provided indigenous peoples with a wide range of their subsistence needs: timber, leaves for food and thatch, and other culturally valued items; and an understory of annual and perennial plants. From an energetics perspective, the mixed tree gardening is considered to be a very energetically efficient system. While the initial labor and energy requirements for planting and maintenance may be high, once established, little energy and labor are required except for harvesting (OTA 1987). However, Leach (1999a: 321) contends that "by its very nature horticulture is intensive compared with cereal agriculture, especially when vegetatively reproduced root and tree crops are involved, as in the Pacific."

The mixed tree garden has been described for Pohnpei (Raynor & Fownes 1993), Yap (Falanruw 1994) and Palau (McCutcheon 1981). The typical Pohnpeian mixed tree garden is three-layered and species rich. The understory is characterized by herbaceous food species, including *Alocasia macrrorhiza*, *Piper methysticum*, *Ananas comosus*, *Colocasia esculenta* and *Cyrtosperma chamissonis*, *Curcuma* spp. and other spontaneous species. Cultivar diversity is likewise high. Older agroforests are often indistinguishable from mature secondary or early primary forests and as they are often 100 years of age and older, they lend support to the idea of sustainability. In Yap, food trees were planted on the raised and drained areas along village paths and around home sites to form "home tree gardens" which over time coalesced with other plantings to form the mixed tree gardens of today.

On most atolls the mixed tree gardens consist of two main types dominated by either coconuts or breadfruit. The location of these agroforests depend mainly on the salinity of the groundwater. As an example, the breadfruit-dominated mixed tree gardens are located mainly towards the islet's interior, where the potential for salt water and salt spray damage to the vegetation and the freshwater lens is less. These forests are usually found in association with the wetland swamp cultivation of *Colocasia* and *Cyrtosperma* taro. *Alocasia macrrorhiza* and *Xanthosoma brasiliensis* are often planted as understory species. Other food species found in the understory include *Crateva speciosa*, *Muntingia calabura*, *Carica papaya*, *Capsicum frutescens*, bananas (*Musa* spp.), and *Tacca leontopetaloides*. Various species of the genera *Pandanus* and their cultivars are important understory species in the Marshall Islands and the Eastern Carolines.

INTERMITTENT TREE OR MIXED GARDENING (SHIFTING CULTIVATION)

Intermittent tree gardening, also known as shifting cultivation is a less permanent form of landuse that involves the short term cultivation of crops in forest clearings and their abandonment to fallow after 1–2 years, although longer periods of cultivation have been observed. Garden site abandonment to fallow results in succession to forest. Useful trees, such as breadfruit and coconuts, are often planted in these sites and may be bearing when the site is again cleared for a garden. Agricultural species and varietal diversity is very high. Burning of the litter was not universal. The literature on this type of traditional agriculture is very extensive. Detailed descriptions of this type of agricultural system can be found in the work of Rappaport (1968, 1971) and Clarke (1971) who have described shifting cultivation as a very energetically efficient form of agriculture.

INTENSIVE OPEN FIELD AGRICULTURE IN SAVANNAS (INCLUDING DITCHING)

Savannas, dominated either by ferns or grasses, are a conspicuous vegetation type in most of the high islands of Micronesia. While the origins of these savannas are still debated (Falanruw 1993, Hunter-Anderson 1991), a more intensive form of agriculture was practiced there mainly in the more fertile areas. In Palau, these areas are known as ked, and are the characterized by rugged terrain, acid soils, and a sparse vegetation of ferns (*Nepthenthes*, *Lycopodium*) and *Spathoglottis* orchids at one extreme, or a secondary regrowth following garden abandonment. The more fertile areas are characterized by a thicker topsoil, the presence of tall grasses, sensitive plants, passion flowers, pandanus and coconuts. Burning, turning the soil, and contour ridging are common practices. These ked areas can remain in production for up to 20 years without fallowing, and crop rotation is practiced in order to reduce insect damage. Commonly grown food plants included *Ipomoea batatas*, *Disocorea* spp., and *Manihot esculenta*.

Cultivation of the grassland is practiced in other parts of Micronesia. The savannas of interior Yap are known as the *tayid* or *ted* (Hunter-Anderson (1991). Here sweet potatoes are grown in a manner not unlike the sweet potato mounds found in the Eastern Highlands of Papua New Guinea. These mounds or *milai* (Műller 1917) are rectangular in shape and surrounded by ditches closed at the ends. The mounds are prepared by slashing the grass cover and covering them with blocks of soil about 50 cm square that have been cut from the top 15 cm of the mound (Falanruw 1993, Hunter-Anderson, 1991). Soil accumulations in the ditches and vegetative litter are also added to the mound (Falanruw 1993). On the lower hills of Weno, Chuuk, sweet potatoes and cassava are planted as row crops in small grassland patches. Fire is sometimes used to burn the grass and simple tools, such as a spade are used to turn the soil. There is little attempt at mulching. Merlin et al. (1993) state that crop plants were cultivated in the grasslands (*acn mahmah*) or fern covered areas (*in fa*) of Kosrae for a number of generations, and today, that pineapple is planted in open burned areas.

WETLAND CULTIVATION SYSTEMS FOR *COLOCASIA ESCULENTA* AND *CYRTOSPERMA CHAMISSONIS*

The wetland cultivation of *Colocasia esculenta* and *Cyrtosperma chamissonis* taro, is probably the most labor and capital intensive system of traditional agriculture in the Pacific Islands. A wide variety of cultivation methods and structures were created to grow taro. In Hawai'i, streams were diverted for the cultivation of *C. esculenta* in the *lo'i*. In the upland areas of Ra Province, Fiji, *C. esculenta* was cultivated in irrigated terraces or *tuatua* (Kuhlken 1994). Taro is also grown in terraces in Grande Terre, New Caledonia. In the Rewa Delta of Fiji, *C. chamissonis* is grown in "raised fields" (*vuci*, *solove*) (Kuhlken 1994). On Pohnpei, *C. chamissonis* is often found in forest depressions and streams. In Yap, taro patches were created in land reclaimed from the sea and in small, swampy depressions for the cultivation of *C. chamissonis*. In Palau, lowland swamps were modified for the cultivation of *C. esculenta* in the *mesei*. For Palauans "The taro swamp is the mother of life", and the wealth of this swamp was C. esculenta (*kukau*) (McKnight & Obak 1960). In Guam, Palauan women residents are cultivating *C. esculenta* and *C. chamissonis* using the less labor intensive dechel system.

The cultivation of taro in pits and depressions is a very distinctive and adaptive form of agriculture found in Pacific atolls, particularly Micronesia. While this system has been described by many explorers and ethnographers of the Pacific (Kramer 1929, Damm & Sarfert 1935, Murphy 1950, Wiens 1962, Barrau 1965), the many subtypes, composition, and productivity of these systems are not fully known. In Kiribati, *C chamissonis* is cultivated in "bottomless baskets" of pandanus and coconut leaves anchored to the bottom of freshwater depressions (Lambert, 1982). On Puluwat Atoll, *C. chamissonis* and *C. esculenta* are cultivated on 1 m high *ma'a*, or the raised organic matter islet (Manner & Mallon 1989, Manner 1993b). On Ulithi Atoll, these taro islets are more closely spaced, elongated and triangular in shape (Manner, 1993c). Also on Ulithi, taro is cultivated in abandoned landing barges and concrete tanks. On most atolls, the cultivation of *C. chamissonis* is simpler than that described for Kiribati or Puluwat. The bottom of excavated pits or depressions is covered with a layer of organic materials and then planted with *C. chamissonis*. Trees surrounding the pit were left standing to provide shade. While the initial pits are relatively small, perhaps 5-20 m square, continued excavation of the pits over time resulted in their coalescence into large patches, often separated by drainage canals. On Kapingamarangi Atoll, taro patches were found to measure 10.3 ha (Niering 1956).

KITCHEN OR BACKYARD GARDENING (HOME GARDEN)

In many ways, the kitchen, backyard garden, or home garden is an individualized extension of the mixed tree garden. By definition, home gardens "comprise an assemblage of plants which may include trees, shrubs, and herbaceous plants or vines growing in or adjacent to a homestead" (Landauer & Brazil 1990: vii). Home gardens in the Pacific islands according to Thaman (1990:45) include gardening activities on rural and urban bush allotments, or other idle land belonging to the government or another landowner, "often at some distance from the home." In the urban areas, these gardens are in the main, supplementary in nature to a wage income. Citrus, coconuts, breadfruit, and bananas are the most commonly found of an extensive list of fruit trees. Ornamental trees and shrubs, some of which have ritual or ceremonial significance, are other components of kitchen gardens. *Areca cathecu* (betel nut palm) and *Piper betle* (betel pepper vine) are common in most yards and villages of Guam, Palau and Yap. In Guam, the "pickle" tree (*Averrhoa bilimbi*), *Averrhoa carambola*, mango, coconuts, *Annona muricata*, *Annona squamosa*, *Capsicum frutescens* and, *Bixa orellana* or the annatto tree are likewise conspicuous. *Crateva speciosa* has special importance in the central Caroline islands (Sproat, 1968) and many household in Chuuk will have a "bell apfel" tree (*Eugenia* sp.). *Eugenia malaccensis*, or the *kavika* (mountain apple) is a very common species throughout the high islands of Micronesia. In the urban areas of Pohnpei island, *Cyrtosperma chamissonis* can be found growing in the yards of immigrant Mortlockese in small artificial swamps.

Themes and Concepts in Traditional Agriculture

INTENSIFICATION

In the mid-1960s, E. Boserup (1965) proposed that in response to increasing population pressure, and the need to feed a growing population, and given an inelasticity of land area, people would develop more labor-intensive systems of agriculture. Based on her analysis of subsistence agricultural systems, she proposed a unilinear continuum of five stages of agricultural intensity. At one end of the continuum, where population density was low, a low labor input system of long forest fallow and short cultivation prevailed. At the other end, with a much higher population density, one would find a labor intensive, multicropping system with little or no fallowing.

While Boserup's hypothesis has been useful as a framework for analyzing traditional agricultural systems, it has initiated a continuing and stimulating debate on the interrelationship between population pressure, environmental modification and agricultural intensification. Brookfield (1972:31) wrote that: "The primary purpose of intensification is the substitution of these inputs for land, so as to gain more production from a given area, use it more frequently, and hence make possible a greater concentration of production." It was soon recognized that there were two major types of intensification: landesque capital intensification (the construction of terraces, irrigation canal works, etc), and cropping cycle intensification (reduction of fallow length and increase in cultivation length) as initially proposed by Boserup. Other criticisms of Boserup's continuum include a multiple, rather than a unilinear developmental sequence (Kirch 1994, Morrison 1996), the primacy of shifting cultivation as a starting point of the continuum (Farrington 1985, Yen 1973), whether the use of degraded and marginal ecosystems reflects the process of intensification or expansion of the cultivated area (Leach 1999a) into degraded or marginal habitats (Umezaki, et al. 2000), whether horticulture (mixed tree gardening) is more intensive than shifting cultivation (Leach 1999a), and problems associated with the definition of the term "intensification".

The mixed tree garden or agroforest and intermittent gardening in forest or bush are examples of extensive agricultural systems. Additional characteristics of extensive systems include the use of simple tools for cultivation, polyculture, and short periods of cultivation followed by longer periods of fallow that allowed for the return of forest. Extensive systems favor the return of the forest and maintenance of both species and cultivar diversity. Environmental modifications of the natural system are impermanent. By contrast, intensive subsistence systems are characterized by a higher input of human labor for production relative to output, its practice in areas of higher human population density, the use of more sophisticated tools for cultivation, longer periods of cultivation relative to lengths of fallowing, the reliance on one or few crops for subsistence (monoculture), and the use of more anthropogenically degraded and impoverished ecosystems. Clarke (1966), for example, using side by side examples from Highlands Papua New Guinea, has suggested a successional sequence of increasing agricultural intensification that accompanies increasing population pressure on land resources and lowered carrying capacity. In this sequence both crop cycle and landesque capital intensification are required in order to cultivate lands that are becoming increasingly impoverished for agriculture. A comparison of the energetics of extensive (Tsembaga Marings; Rappaport 1971) and intensive (Raiapu Enga; Waddell 1972) subsistence systems also indicates a decreased labor efficiency with intensification. For the Mountain Ok of Papua New Guinea, however, Ohtsuka (1996) notes that since the sweet potato tolerates lower temperatures and poorer soils, the gradual transition from taro to sweet potato tends to increase productivity in thinly populated and less-modernized societies. By abandoning pig raising and changing other subsistence practices, the Irakia Awa of the Okapa District, Papua New Guinea now have a less intensive agricultural system (Boyd, 2001). Except for the work by Ohtsuka (1996) and Umezaki, et al. (2000), there are too few direct observations that increased population pressure on land resources has led to a shortening of fallow periods and thus, the adoption of more intensive systems of cultivation in order to meet increased demand for food.

Not all intensive systems of traditional agriculture can be readily explained by Boserup's hypothesis of increasing population pressure on degrading land resources. The wetland taro systems such as the Puluwatese *ma'a* (taro island), the Hawaiian *lo'i* (irrigated taro patch) and the Fijian *tuatua* (taro terrace), are often singular components of much larger agricultural systems. While on one hand, these systems may be a part of the intensification process, as cultivation types, they are often found in conjunction with more extensive systems of agriculture, and as such may be a response to social pressure (Sand 1999, McCutcheon 1981), the obligation for surplus production, or simply, the cultivation of a preferred food crop in its preferred environment—a freshwater wetland, whether natural or one modified by human action.

INTENSIFICATION AND CARRYING CAPACITY

In addition to the concept of intensification, another concept which bears mentioning is that of carrying capacity. Carrying capacity has been defined as "the maximum number of people that a given land area will maintain in perpetuity under a given system of usage without land degradation setting in" (Allan 1949 in Ohtsuka 1983). In an absolute sense, any alteration or use of the natural environment for agriculture causes some degree of degradation and a decrease in carrying capacity. The many types of intensification described earlier can be considered modifications of the agricultural environment to either support a stable population in an environment where the carrying capacity is decreasing as it is being used, or one in which an expanding population requires a higher carrying capacity or productivity from the land.

Unfortunately, there are problems with the definition of carrying capacity. For one, degradation is not or rarely operationally defined, and as Clarke (1977) and others have noted, it is theoretically impossible to use an ecosystem without initiating any degradation. A second problem is that carrying capacity is variable and not wholly dependent on the natural environment; the level of technology employed in agriculture is a very important factor that affects carrying capacity (Street 1969, Fukui 1993). Finally, existing populations and their systems of cultivation are often taken as living within or at the carrying capacities of their environments though they may be lower than those found in surrounding areas (Rappaport 1968, Ohtsuka 1994a, 1994b). In this regard and with respect to Rappaport's (1968) study, Healey (1990: 27-28) commented that "Maring densities are considerably lower than those recorded in more densely settled regions of the central highlands..is not enough to support any claims that Maring densities are well within the carrying capacity of the land and the demographic pressure on resources is unlikely to lead to environmental degradation." Indeed, Healey (1990: 28) is quite adamant against its use: "Practical and theoretical difficulties associated with the concept of carrying capacity render any attempt to specify population limits superfluous." In a similar vein, Fukui (1993: 316) suggests that the concept of carrying capacity cannot be applied when there are external sources of resources. A fuller discussion of the shortcomings of carrying capacity can be found in Street (1969) and Brush (1975).

These debates on the process of intensification and carrying capacity have been most intense amongst archaeologists whose unenviable task is to interpret prehistoric Pacific landscapes on sometimes very limited evidence, anthropologists concerned with the cultural development of the Pacific Islands peoples, and geographers concerned the relationship of people and their environment. As a PABITRA conservation scientist, while mindful of the themes and concerns expressed above, I feel that our emphasis must center on the issues of sustainability and the conservation of biotic diversity for present and future Pacific Islanders and their ecosystems. The review of traditional Micronesian agriculture shows a wide range of systems and practices that vary greatly in their intensity of cultivation effort, etc. However, whether these systems are extensive or intensive and practiced in rainforests, marginal or anthropogenically modified and/or degraded environments, they do have wide-reaching effects on the conservation of biotic diversity and the integrity of the land to support people. Perhaps the key issues for PABITRA conservation scientists are the linkages between system sustainability, carrying capacity and the prevention of environmental degradation. These themes are emphasized in recent studies on traditional agriculture by geographers, agriculturalists, and foresters (See for example, Falanruw 1994, Clarke & Thaman 1993, Ohtsuka 1994a, 1994b, 1996, Umezaki et al. 2000).

Traditional Agriculture as a Sustainable System

Within the past 30–40 years, traditional agriculture has achieved the mantle of sustainability. This is particularly true of those systems where trees are an important component of the cultivation cycle. Geertz (1963: 16), for example, considered shifting cultivation as sustainable when it was "integrated into and, when generally adaptive, maintains the general structure of the pre-existing ecosystem into which it is projected, rather than creating and sustaining one organized on novel lines and displaying novel dynamics." Some of the characteristics of sustainable agricultural systems are the following: "long-term maintenance of natural resources and agricultural productivity; minimal adverse environmental impacts; adequate economic returns to farmers; optimal production with purchased inputs used only to supplement natural processes that are carefully managed; satisfaction of human needs for food, nutrition, and shelter; and provision for the social needs of health, welfare, and social equity of farm families and communities." (NRC, 1993:22). The Hawaiian *ahupua'a* is an excellent example of a sustainable land use management system that provided people with all of their physical and spiritual requirements through the enhancement and modification of the natural environment. Briefly, the *ahupua'a* was a "vertically oriented land division and management approach that combined the upland and lowland ecosystems into an integrated human support system" (Mueller-Dombois 1999: 258). Elsewhere, the label of sustainability has been applied because some of these traditional systems have remained in production for millennia.

The question of sustainability is also colored by a romantic perspective of traditional peoples living in an idealistic harmony with their bountiful nature. Examples of these viewpoints (and their underlying untestable premises) can be readily found in the UNEP compendium Cultural and Spiritual Values of Biodiversity (Posey 1999). For example, Plenderlieth's (1999: 290) statement that "Traditional knowledge and cultivation techniques promote long-term sustainability", because "the practices are more predictable, do not harm people or their environment, and farmers can retain their independence and their cultural identity as they are the innovators as well as practioners" is difficult to examine. Emic approaches and statements on traditional agriculture in Posey's (1999) compendium, are also difficult to verify. In a more realistic vein, Clarke (1993:233) points out that while traditional knowledge is often seen as "a magical treasure trove of knowledge, technique, and wisdom that will save the village, if not the world, from environmental degradation….it is not a miracle fix."

One of the best cases for the sustainability of traditional agriculture is Clarke's (1977) principles of permanence, which were based on his studies of the Bomagai-Angoiang of Simbai Valley of Papua New Guinea. Briefly, the Bomagai-Angoiang practice an extensive form shifting cultivation in forest clearings, using simple tools, biodegradeable materials and non-polluting practices. Their net energy yields (agricultural returns to labor) are positive and are based on the products of "bound time" (rather than fossil fuels). Their system is essentially self-sufficient with its energy flow being locally controlled by its participants, rather than by the outside, which would then need specialized channels for its distribution. The Bomagai-Angoiang consider resources as productive capital, to be conserved as in the sense that the forests are considered as "garden mother". The system is based on biotic diversity and the practice of polyculture rather than monoculture. Clarke's principles of permanence were based on fieldwork, observations and reflections of more than 10 years. Similar expressions of the sustainability of traditional agriculture can be found in Altieri (1999a, 1999b) and Barsh (1999).

Agricultural sustainability may be accomplished in a number of different ways. Elsewhere in Papua New Guinea, Otsuka's (1996) research on the Gidra subsistence system over an extended time period (1971, 1981 and 1989) indicates that the introduction of high yielding varieties of food crops could result in large increases in food production if appropriate agricultural technologies are also introduced. Otsuka (1996) also found that the productivity of local staples are not stable and are vulnerable to long-term natural environmental fluctuations. In the Tari Basin of Papua New Guinea, Umezaki et al. (2000) found that the responses of traditional agricultural communities to population pressure and increasingly degraded environments depends on the indigenous environment and subsistence pattern; they suggested four possible scenarios to meet the increasing demand for food: 1. Expansion of the garden area; 2. Advancement of agricultural technologies; 3. Out migration; and 4. Increase in cash income. These studies by

Ohtsuka (1996) and Umezaki et al. (2000) clearly suggest the need for longer termed studies than those of Clarke (1971, 1977) and others before definitive statements about the stability and sustainability of these systems can be made.

As suggested previously, traditional agricultural systems are more sustainable and conservative of the environment than modernized, commercial systems of agriculture. With regards to the Yapese traditional system of agriculture and resource management, Falanruw (1994: 5) suggests: "The system is characterized as nature-integrated. Nature-integrated systems are relatively sustainable and efficient, but they require an ecosystem that is intact and not stressed beyond its limits of tolerance." However, in many islands of the Pacific, where the indigenous inhabitants of the islands have traditional rights to the resources of the forest, an increasing amount of environmental degradation has occurred in response to increased market demands for agricultural produce by a modernized and more urban Pacific. In Pohnpei, clearance of the forest for agriculture, agroforestry, and particularly the cultivation of *sakau*, a psychoactive beverage made from the roots of *Piper methysticum*, for commercial consumption has led to a 70 + percent reduction of the forest cover between 1975 and 2002 (Raynor, 1994) which has been described as Pohnpei's greatest environmental disaster since it was first inhabited (Merlin and Raynor 2005:247).

This discussion points out the need for long-term monitoring studies on traditional and modern systems of agriculture in order to determine the sustainability of these systems, the factors affecting sustainability, and the impacts of traditional agriculture on the biodiversity of Pacific Island ecosystems, or as Falanruw (1994) has articulated their "limits of tolerance".

Biodiversity and Sustainable Traditional Agriculture

Various studies have suggested that the sustainability of traditional agriculture is directly related to biodiversity. For example, Altieri (1999b: 29) writes that as biodiversity "performs key ecological services and if correctly assembled in time and space can lead to agroecosystems capable of sponsoring their own soil fertility, crop protection and productivity…Correct biodiversification results in pest regulation through restoration of natural control of insect pests, diseases and nematodes and also produces optimal nutrient recycling a soil conservation by activating soil biota, all factors leading to sustainable yields, energy conservation, and less dependence on external inputs." Earlier, Clarke (1977) suggested that permanent systems of subsistence are based on biotic diversity and the practice of polyculture rather than monoculture, and regard resources such as forests as "garden mother."

Research and observations of the traditional agricultural systems of Micronesia attest to their diversity in both species and cultivars. The Yapese mixed tree gardens (agroforest) contain some 55 species of trees producing for spice products and another 62 species of useful shrubs and herbs (Falanruw, 1993). In the Kosrean system of shifting cultivation, Wilson (1968) recorded 8 varieties of coconuts, 26 of *Musa* spp., 13 of *Colocasia esculenta*, 14 of

Cyrtosperma chamissonis, and 25 of *Artocarpus altilis*. The Pohnpeian traditional agricultural system recognizes 131 cultivars of breadfruit, 177 cultivars of yams (*Dioscorea*), bananas and plantain (55), *Cyrtosperma* taro (24), *Colocasia* (16), *Alocasia* (10), coconut (9), sugarcane (16), and *Piper methysticum* (3) (Raynor & Fownes 1993). Despite the diversity of cultivars, some varieties were more prominent than others and were more heavily relied on as food sources. In the Pohnpei study, Raynor & Fownes (1993) found that the breadfruit variety "Meiniwe" constituted more than 50 % of the trees recorded in the survey and five cultivars made up over 75 % of all of the trees recorded. "Keph en Dol", a variety of *Dioscorea alata* made up 18 % of all yams found in the study, while coconut was dominated by 2 varieties.

Atoll agriculture is characterized by few cultivated species, and in contrast to traditional agriculture on the high islands of the Pacific, a strategy of cultivar diversity is evidenced. The number of varieties of taro, breadfruit, pandanus and other cultivated plants is large in view of the harshness of the atoll environment (Thaman 2008). For example, on Woleai Atoll, there are 16 varieties of *Cyrtosperma chamissonis*, 19 varieties of *Colocasia esculenta*, and nine varieties of breadfruit (*Atocarpus altilis*, *A. mariannensis*, and hybrids) (Alkire, 1974). On Puluwat Atoll, the corresponding numbers present in 1988 were 24, 29, and 36, respectively (Manner & Mallon 1989). On Ulithi Atoll, there are 11 varieties of breadfruit (Lessa 1977). Research indicates that the turnover in varieties may be quite high. Some varieties recorded 50 years ago are no longer present, having been replaced by newer introductions. Except for the coconut, some varieties of *Pandanus*, and the Polynesian arrowroot (*Tacca leontopetaloides*), few of these species and varieties have become naturalized to the atoll environment.

While species and varietal diversity is a prominent feature of traditional agriculture, the direct and indirect contributions of this diversity to the functioning and maintenance of Micronesian and Pacific Island systems are largely unknown. For the most part and aside from the Raynor & Fownes (1993) study cited earlier, there is almost no information of the relative importance of the cultivated varieties, either ecologically or as a part of the household consumption patterns of Pacific Islanders. Thus, in contrast to other parts of the tropics, for the Pacific Islands and particularly in Micronesia, there is almost no information and very little ongoing research on biodiversity's key ecological services and how these services contribute to sustainable agriculture.

The Disintensification of Traditional Agriculture in Micronesia

The previous discussion has focused on the theme of intensification and related issues. To be sure, intensified use of land through the reduction in fallow length results in a decreased quality or carrying capacity of the land to support people. This degradation may be compensated for by the increased application of labor, other energy inputs, the expansion of agricultural land elsewhere, or the adoption of higher yielding and more productive varieties and crop species. Environmental degradation can also cease through the abandonment of agriculture. However, alternative, meaningful ways of making a living would be required in its place.

In Micronesia, a process of agricultural disintensification that began in the early 1800s is also evident. Simply defined, disintensification is the abandonment of intensive agricultural practices and the reduction in the amount of labor devoted to agriculture (Conelly 1994). Abandonment can occur for a number of reasons, and include the replacement of subsistence economy by a wage economy, loss of agricultural labor and production due to migration, the introduction of trade stores and store bought foods, the replacement of human labor by machinery (albeit at a higher energy cost), to name a few. A few specific examples from Micronesia but also prevalent in other parts of the Pacific include:

1. The development of copra plantations and the abandonment of swamp taro cultivation. Since the mid 1800s, the development of the copra plantations and a cash economy in many atolls led to the abandonment of many taro pits in many of the islands as people grew coconuts for cash at the expense of maintaining the taro pits. This "copra tin can economy" (Doty 1954) led to large-scale changes in land use patterns that occurred when people began to produce coconuts for cash. On many atolls, up to 70 % of the total land area was converted to coconut woodlands (Hatheway 1953). Other reasons for abandonment include pig damage to the taro pits on Arno Islet (Hatheway 1953), the availability of rice and flour (Alkire, 1989), depopulation, and infilling of pits for airstrips and military installations during World War II on Ulithi Atoll (Manner 1993c).

2. Replacement of *Colocasia esculenta* taro by *Cyrtosperma chamissonis,* which is more drought resistant, tolerant of salt and higher yielding, longer lived, and requires less labor intensity (Manner, 1993b). Additionally, for much of Micronesia, the abandonment of wetland taro cultivation is the rule today (Hunter-Anderson 1991). Other reasons for this change include typhoon and pest damage to taro, government encouragement of cassava and sweet potatoes production to alleviate the shortage of *Colocasia esculenta* (McCutcheon 1981), the time and labor constraints associated with an urban lifestyle (Hunter Anderson, 1991), and the attractions associated with modernization and urbanization (Connell 1994).

3. Involvement of males in the cash economy and formal sector and government employment, high wages, aid, compensation payments, and migration from "outer" to "inner" islands and elsewhere (Connell & Maata 1992) for the Marshall Islands but are applicable to the whole Pacific.

4. In Palau, *mesei* taro cultivation is also now done by men from Bangladesh and the Philippines, a result of unrestricted labor migration. Such cultivation was the province of Palauan women and a source of their social standing. Ironically, some 30 migrant Palauan women are now cultivating taro in the Agana Swamp of Guam using the less intensive *dechel* method.

5. The impact of education and other aspects of westernization. The result has been a decreased interest in agriculture and working with one's hands. An office job, particularly with government is considered to be a superior and better way of making money. In the northern nation-states of Micronesia, there is great dependence on governmental infrastructure, including jobs, which has been funded by the United States, but will end with the termination of the Compacts of Free Association later this century.

6. Cash cropping of specialty agricultural products. In Pohnpei, the cultivation of *Piper methysticum* (*sakau*) for the domestic market has severely reduced the extent of the primary forest. In Palau, the cultivation of *Morinda citrifolia* (noni) for the export market may remove lands normally devoted to traditional agriculture.

One implication or result of these trends is the erosion and loss of traditional knowledge of agricultural practices and resources (i.e., cultivars). This is worrying because traditional agricultural knowledge and practices promote sustainability and the conservation of biotic diversity (Plenderleith 1999). Knowledge of traditional conservation management may be effective in reversing the trend of biodiversity loss. In the example of the loss of forest resources because of the cultivation of *sakau* on Pohnpei Island, Raynor & Kostka (2003) suggest that the combination of traditional knowledge and modern conservation practices has had some success in protecting the forest resources from further destruction. The prospect of continuing loss of traditional knowledge suggests an objective for PABITRA: documentation of the traditional and largely sustainable practices and resources of the Pacific Islands before they are lost forever.

Present State of Research in Pacific Islands' Traditional Agriculture

Since the beginning of this millenium and excluding the studies referenced previously in this paper, unlike other regions of the world, there are very few current studies on the traditional agricultural systems of Micronesia and the Pacific and not much progress has been made in quantifying their ecological characteristics. This is particularly distressing as some of the first studies to suggest the sustainability of traditional systems and the relationship of diversity and agricultural sustainability are the works of anthropologists and geographers such as Rappaport (1968) and Clarke (1971) in their studies of the cultural ecology of New Guinea communities. While many of these studies were instrumental in articulating the relationships between population pressure, environmental change and carrying capacity, there is little current effort in defining the ecological and biophysical interactions of these systems and their components. There are few studies on the ecological/biophysical interactions, tree-crop interactions or nutrient cycling of the agricultural systems of Micronesia. Since 2000, only two articles in Agroforestry Systems are based solely on research of the traditional agriculture of Micronesia and the Pacific Islands: one on the nutrient status of New Guinea soils (Hartemink 2005), and the other on the domestication potential and marketing of *Canarium indicum*

(Nevenimo et al. 2007). A paper by Conroy et al. (n.d.) on the status of agroforestry in *Terminalia* wetlands in Kosrae, FSM is currently under review. This paper contains data on the diversity of agricultural species. There are various articles on organic swamp soil that have relevance to taro cultivation in wetlands in Micronesia (Yang et al. 2007, Chimner & Ewel 2004, Drew et al. 2005, Murukesan et al. 2005). Also, there is strong interest in ethnobotany as evidenced by the number of articles published in *Economic Botany* and the online *Ethnobotany Research & Applications*. However the majority of these studies are focused on traditional knowledge and its application, or specific cultivated crops (i.e., *Piper methysticum*, *Saccharum officianarum*, *Musa* spp.), rather than the analysis of ecological functioning and processes of these systems.

The relative absence of research into traditional agricultural systems is not surprising if one considers that most of the Pacific Islands are classified as developing countries, and as such, lack the infrastructure and scientific capacity to conduct such research. In the Pacific, a university degree is still uncommon. In the Solomon Islands in 1999, for example, only 59 held a PhD in various disciplines (Solomon Islands 2006); while only 15.5 % of the population of the Commonwealth of the Northern Mariana Islands in 2000 had a bachelor's degree or higher (US Census Bureau 2003). Except for Hawai'i, the tertiary educational institutions in the Pacific are relatively young, with most having establishment dates from the mid-1900s and onward. For example, the establishment dates for the University of the South Pacific and the former Territorial College of Guam (now the University of Guam) are 1968 and 1952, respectively. The Micronesian entities that made up the former Trust Territory of the Pacific Islands (Palau, Federated States of Micronesia, and the Marshall Islands, and the Commonwealth of the Northern Mariana Islands) and Guam also have the dubious distinction of being a restricted area under the control of the US Navy following the end of World War II and up until 1963. According to Hezel (1995: 300): "All Micronesia was closed for reasons of military security, and official navy authorization was required for all visitors except those on official duty." This restriction had a chilling effect on regional development, including educational and research opportunities for which Micronesia became the model of what some have called "benign neglect". Another reason for the lack of such research may be the lack of appreciation by western-trained agricultural scientists who may view traditional agricultural systems as inferior to commercial, fossil-fuel based monocultures and therefore not worthy of study. The fact that traditional agricultural systems are biotically complex, culturally defined modifications of the natural ecosystems must be daunting to many researchers. Few anthropologists, geographers and ethnographers have the necessary training to study ecological interactions. On the other hand, few biologists, foresters and agricultural scientists feel comfortable studying human modified ecosystems.

Few Pacific Islanders have the background and training to analyze the structure and functioning of their island ecosystems, let alone their traditional systems of agriculture. In recognition of this lack, the Pacific Science

Association initiated the PABITRA concept in the late 1990s. The evolution of PABITRA as a PSA task force for coordinating ecosystem research for the sustainable use of island landscapes in the Pacific Islands is articulated by Mueller-Dombois (2008). A primary PABITRA objective is the involvement of Pacific Islanders in the study of ecosystem dynamics and their effects on island landscapes. Thus, a major focus of PABITRA is scientific capacity building of indigenous Pacific Islanders for ecosystem and biodiversity research so that they can conduct the studies needed to enhance the sustainability of their ecosystems in the face of increasing pressures for development and ecosystem modification. The PABITRA philosophy is that this capacity building is the most effective way to develop scientists who best understand both indigenous aspirations for economic development and biodiversity dynamics associated with ecosystem functioning. The network is hopeful that PABITRA-trained local scientists will begin to study and monitor their traditional agricultural systems, as they are integral to the conservation and sustainability of island ecosystems. Such research could validate the ecological characteristics of traditional agricultural systems and define the conditions of agricultural sustainability for each system.

Conclusion

The traditional agricultural systems of the Pacific Islands are in the main, sustainable. After describing the major agricultural systems of Micronesia, the paper considers the related issues of agricultural intensification, environmental degradation, and carrying capacity and biodiversity. The sustainability of traditional agricultural systems because they are largely “nature-integrated” (Falanruw 1994:5), require an intact ecosystem and one that is not stressed beyond its limits of tolerance. In order to define these limits, long-term monitoring of traditional agricultural systems is required. Such monitoring will help also to determine the impact of traditional agriculture on landscape ecology, which is an important objective of PABITRA. The issues of agricultural intensification and abandonment, carrying capacity, and environmental degradation can only be answered though the long-term monitoring of such systems. While species and cultivar diversity is a characteristic feature of traditional agricultural systems of the Pacific, relatively little is known of the ecological role or function of these diversities. A second priority area of research is the need to document traditional agricultural knowledge because of rapid socio-economic changes are eroding this nature-conservative knowledge base. While traditional knowledge is not the miracle fix, the knowledge of traditional land management practices and processes (as described earlier by Raynor & Kostka 2003), may be very useful in resolving the conflicts between biodiversity conservation on the one hand and the environmental problems stemming from the pressures of economic growth and development in a modernizing Pacific. At the very least, additional research in traditional agriculture would define and validate the sustainability of and the ecological rationale of traditional agricultural practices.

Acknowledgements

A preliminary version of this paper was presented at the PABITRA symposium on long-term ecological change research in the Pacific at the 21st Pacific Science Congress in Okinawa, Japan (June 12-18, 2007). Funding for this presentation was made possible by a grant from the APN (Asia Pacific Network for Global Change Research, Japan: Capable grant # CBA2006-01NSY) and the University of Guam. I also wish to thank Professor Emeritus Dieter Mueller-Dombios, Dr. Curtis Daehler, and Dean Mary Spencer and Associate Dean James Sellmann, both of the College of Liberal Arts and Social Sciences at the University of Guam for their support.

References

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

Alkire, W. H. 1989. Lamotrek Atoll and inter island socioeconomic ties. Waveland Press, Inc., Prospect Heights, Illinois.

Allan, W. 1949. Studies in African land usage in northern Rhodesia. Rhodes-Livingston Papers 15. Oxford University Press, Capetown.

Altieri, M. A. 1999a. The agroecological dimensions of biodiversity in traditional farming systems. *In* D. A.Posey (ed), Cultural and Spiritual Values of Biodiversity, pp. 291-297. United Nations Environmental Programme, Nairobi, Kenya.

Altieri, M. A. 1999b. The ecological role of biodiversity in agroecosystems. Agriculture, Ecosystems and Environment 74: 19-31.

Athens, J.S. 1999. Comments. Intensification in the Pacific: A critique of the archaeological criteria and their application. Current Anthropology 40: 321-322.

Barrau, J. 1961. Subsistence agriculture in Polynesia and Micronesia. B.P. Bishop Museum Bulletin 223. Bishop Museum Press, Honolulu.

Barrau, J. 1965. L'humide et le sec: an essay on ethnobiological adaptation to constrastive environments in the Indo-Pacific area. Journal of the Polynesian Society 74: 329-46.

Barsh, R. L. 1999. Indigenous knowledge and biodiversity. *In* D. A. Posey (ed), Cultural and Spiritual Values of Biodiversity, pp. 73-76. United Nations Environmental Programme, Nairobi, Kenya.

Boserup, E. 1965. The conditions of agricultural growth: The economics of agrarian change under population pressure. Aldine Publishing Co., Chicago.

Boyd, D. J. 2001. Life without pigs: Recent subsistence changes among the Irakia Awa, Papua New Guinea. Human Ecology 29: 259-282.

Brookfield, H. C. 1972. Intensification and disintensification in Pacific agriculture: A theoretical approach. Pacific Viewpoint 13: 30-48.

Brush, S. 1975. The concept of carrying capacity for systems of shifting cultivation. American Anthropologist 77: 799-811.

Chimner R. & K. Ewel. 2004. Differences in carbon fluxes between forested and cultivated Micronesian tropical peatlands. Wetlands Ecology and Management 12: 419-427

Clarke, W.C. 1966. From extensive to intensive shifting cultivation: an example from central New Guinea. Ethnology 5: 347 359.

Clarke, W.C. 1971. Place and People: An Ecology of a New Guinean Community. Berkeley, University of California Press.

Clarke, W. C. 1977. The structure of permanence: the relevance of subsistence communities for world ecosystem management. *In* T. Bayliss-Smith & R. Feachem (eds.), Subsistence and survival: Rural ecology in the Pacific, pp. 364 384. Academic Press, London.

Clarke, W. C. 1993. Afterword: Learning from Ngirapo: Indigenous knowledge and sustainable agricultural development. *In* E. Waddell & P. D. Nunn (eds), The Margin Fades: Geographical itineraries in a world of islands, pp. 231-266. Institute of Pacific Studies, USP, Suva, Fiji.

Clarke, W. C. & R. R. Thaman, (eds). 1993. Agroforestry in the Pacific Islands: Systems for sustainability. United Nations University Press, Tokyo.

Clarke, W. C., H. I. Manner & R.R. Thaman, 1999. Agriculture and forestry. Chapter 29. *In* M. Rapaport, (ed). The Pacific Islands: Environment & Society, pp. 353-365. Honolulu, Bess Press.

Connell, J. 1994. Beyond the Reef: Migration and agriculture in Micronesia. Isla: A Journal of Micronesian Studies 2: 83-101.

Connell, J. & M. Maata, 1992. Environmental Planning, Climate Change and Potential Sea Level Rise. Report of a mission to the Republic of the Marshall Islands. SPREP Reports and Studies, No. 55. Apia, Western Samoa.

Conelly, W. T. 1994. Population pressure, labor availability, and agricultural disintensification: The decline of farming on Rusinga Island, Kenya. Human Ecology 22: 145 170.

Conroy, N. K., Fares, A., Ewel, K., & T. Miura. n.d. The status of agroforestry in Terminalia wetlands in Kosrae, Federated States of Micronesia. Agroforestry Systems. Unpublished manuscript.

Coulter, J. K. 1998. Rain-fed arable farming systems and their improvement. Chapter 6. *In* C.C. Webster & P. N. Wilson, (eds), Agriculture in the Tropics, pp. 144-177. Third Edition. Oxford, Blackwell Science.

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 Wissenschaftliche Siftung um Notegemeinschaft der Deutschen Wissenschaft. Friedrichsen, De Gruyter and Co. Hamburg.

Doty, M. S. 1954. Part 1. Floristic and ecological notes on Raroia. Atoll Research Bulletin 33: 1-41.

Drew, W., K. Ewel, R. Naylor & A. Sigrah, 2005. A tropical freshwater wetland: III. Direct use values and other goods and services. Wetlands Ecology and Management 13: 685-693.

Falanruw, M. V. C. 1993. Micronesian agroforestry: Evidence from the past, implications for the future. *In* B. Raynor & R. Bay (Technical Coordinators), Proceedings of the Workshop on Research Methodologies and Applications for Pacific Island Agroforestry; July 16-20, 1990; Kolonia, Pohnpei, Federated States of Micronesia, pp. 37-41. General Technical Report PSW-GTR-140. Pacific Southwest Research Station, Forest Service.

Falanruw, M. V. C. 1994. Food production and ecosystem management on Yap. Isla. A Journal of Micronesian Studies 2: 5-22.

Farrington, I.S. (ed). 1985. Prehistoric Intensive Agriculture in the Tropics. 2 Volumes. British Archaeological Reports International Series, 232.

Fukui, H. 1993. Food and Population in a Northeast Thai Village. Monographs of the Center for Southeast Asian Studies, Kyoto University, English Language Series, No. 19. University of Hawaii Press.

Geertz, C. 1963. Agricultural Involution: The processes of ecological change in Indonesia. Berkeley, University of California Press.

Hartemink, A. E. 2005. Nutrient stocks of short-term fallows on a high base status soil in the humid tropics of Papua New Guinea. Agroforestry Systems 63: 33-43.

Hatheway, W. H. 1953. The land vegetation of Arno Atoll, Marshall Islands. Atoll Research Bulletin 16: 1-68.

Healey, C. 1990. Maring Hunters and Traders: Production and Exchange in the Papua New Guinea Highlands, University of California Press, Berkeley.

Hezel, F.X. 1995. Strangers in Their Own Land: A Century of Colonial rule in the Caroline and Marshall Islands. Pacific Island Monograph Series 13. Honolulu, University of Hawaii Press.

Hunter-Anderson, R. 1991. A review of traditional Micronesian high island horticulture in Belau, Yap, Chuuk, Pohnpei, and Kosrae. Micronesica 24: 1-56.

Huxley, P. A. 1998. Agroforestry. Chapter 9. In C.C. Webster & P. N. Wilson, (eds), Agriculture in the Tropics, pp. 222-256. Third Edition. Oxford, Blackwell Science.

Kirch, P. V. 1989. Second millennium B.C. arboriculture in Melanesia: archaeological evidence from the Mussau Islands. Economic Botany 43: 225-240.

Kirch, P. V. 1994. The Wet and the Dry: Irrigation and Agricultural Intensification in Polynesia. University of Chicago Press, Chicago.

Kirch, P. V. 1999. Comments. Intensification in the Pacific: A critique of the Archaeological criteria and their application. Current Anthropology 40: 326-328.

Kramer, A. 1929. Palau. *In* G. Thilenius (ed), Ergebnisse der Sudsee Expedition, 1908 1910. II. Ethnographie: B. Mikronesien. Volume 3. Friederichsen, de Gruyter and Co., Hamburg.

Kuhlken, R. 1994. Tuatua ni Nakauvadra: A Fijian irrigated taro agrosystem. *In* J. Morrison, P. Geraghty & Crowl, L. (eds), Land Use and Agriculture: Science of Pacific Island Peoples, Vol. II., pp. 51-62. Institute of Pacific Studies, USP, Suva, Fiji.

Lambert, M. 1982. The cultivation of 'taro' *Cyrtosperma chamissonis* Schott in Kiribati. *In* Regional Technical Meeting on Atoll Cultivation. South Pacific Commission Technical Paper 180, pp. 163-165. South Pacific Commission, Noumea.

Landauer, K. & M. Brazil, (eds). 1990. Introduction. Tropical Home Gardens, pp. vii-viii. Tokyo, United Nations University Press.

Leach, H. M. 1999a. Intensification in the Pacific: A critique of the Archaeological criteria and their application. Current Anthropology 40: 311-330.

Leach, H. M. 1999b. Reply. Intensification in the Pacific: A critique of the Archaeological criteria and their application. Current Anthropology 40:331-335.

Lessa, W. A. 1977. Traditional uses of the vascular plants of Ulithi Atoll, with comparative notes. Micronesica 13: 129-190.

Manner, H. I. 1993a. A review of traditional agroforestry in Micronesia. In, B. Raynor & R. Bay, (Technical Coordinators), Proceedings of the Workshop on Research Methodologies and Applications for Pacific Island Agroforestry; July 16-20, 1990; Kolonia, Pohnpei, Federated States of Micronesia, pp. 32-36. General Technical Report PSW-GTR-140. Pacific Southwest Research Station, Forest Service.

Manner, H. I. 1993b. Taro (*Colocasia esculenta*) in the atolls and low islands of Micronesia. *In* L. Ferentinos (ed), Proceedings of the Sustainable Taro Culture for the Pacific Conference, pp. 88-100. HITAHR Research Extension Series, 140. Honolulu.

Manner, H. I. 1993c. Ulithi. *In* L. Ferentinos & A. Vargo, (eds), Taro Production Systems in Micronesia, Hawaii and American Samoa, pp. 79-84. HITAHR Research Extension Series, 139. Honolulu.

Manner, H. I. 2007. Traditional agroecosystems. *In* D. Mueller-Dombois, K.W. Bridges, and C. Daehler (eds) Biodiversity Assessment of Tropical Island Ecosystems: PABITRA Manual for Interactive Ecology and Management, pp. 89-104. Bishop Museum Press, Honolulu,

Manner, H. I., & E. Mallon. 1989. An annotated list of the vascular plants of Puluwat Atoll. Micronesica 22: 23-63.

McClatchey, W. 2005. Exorcizing misleading terms from Ethnobotany. Ethnobotany Research & Applications 3: 1-4.

McCutcheon, M. S. 1981. Resource Exploitation and the Tenure of Land and Sea in Palau. Ph.D. dissertation in Anthropology, University of Arizona, Tuscon.

McKnight, R. K. & A. Obak, 1960. Taro Cultivation in the Palau District. Taro Cultivation Practices and Beliefs. Part I. The Western Carolines. Anthropological Working Papers, No. 6. Staff Anthropologist, Trust Territory of the Pacific Islands, Guam, Mariana Islands.

Merlin, M., R. Taulung & J. Juvik. 1993. Sahk Kap ac Kain in Acn Kosrae: Plants and Environments of Kosrae. Environment and Policy Institute, East-West Center, Honolulu.

Merlin, M. & B. Raynor, 2005. Kava cultivation, native species conservation, and integrated watershed resource management on Pohnpei Island. Pacific Science 59: 241-260.

Morrison, K.D. 1996. Typological schemes and agricultural change: Beyond Boserup in South India. Current Anthropology, 37: 583-608.

Mueller-Dombois, D. 1999. Biodiversity and environmental gradients across the tropical Pacific islands: A new strategy for research and conservation. Naturwissenschaften 86: 253-261.

Mueller-Dombois, D. 2008 The evolution of PABITRA in the Pacific Science Association. Micronesica 40: 1-7.

Műller, W. 1917. Yap. *In* G. Thilenius, (ed), Ergebnisse der Sudsee Expedition, 1908 1910. II. Ethnographie: B. Mikronesien. Volumes 1. L. Friederichsen and Company, Hamburg.

Murphy, R. 1950. The economic geography of a Micronesian atoll. Annals of the Association of American Geographers 40: 58-83.

Murukesan, V. K., E. van den Berg, L. R. Tiedt, P. C. Josekutty & D. De Waele. 2005. Corm rot of giant swamp taro (*Cyrtosperma merkusii*) caused by the burrowing nematode *Radopholus similis* (Nematoda: Pratylenchidae) in the Pacific. Nematology 7: 631-636.

NRC (National Research Council). 1993. Sustainable Agriculture and the Environment in the Humid Tropics. Committee on Sustainable Agriculture and Environment in the Humid Tropics, National Academy of Sciences, Washington, D. C.

Nair, P.K.R. 1990. Tropical agroforestry systems and practices. *In* J.I. Furtado, W.B. Morgan, J.R. Pfafflin & K. Ruddle (eds), Tropical Resources Ecology and Development, pp. 227-250. Harwood Academic Publishers GmbH, Switzerland.

Nevenimo, T., J. Moxon, J. Wemin, M.Johnston, C. Bunt & R. Leakey. 2007. Domestication potential and marketing of *Canarium indicum* nuts in the Pacific: 1. A literature review. Agroforestry Systems 69: 117-134.

Niering, W. A. 1956. Bioecology of Kapingamarangi Atoll, Caroline Islands: Terrestrial aspects. Atoll Research Bulletin 49: 1-32.

Ohtsuka, R. 1983. Population structure and dynamics. *In* R. Ohtsuka, & T. Suzuki (eds), Population Ecology of Human Survival: Bioecological Studies of the Gidra in Papua New Guinea, pp. 195 218. University of Tokyo Press, Tokyo.

Ohtsuka, R. 1994a. An ecological assessment of the low population density of taro monoculturalists in the highland fringe of Papua New Guinea. Man and Culture in Oceania 10: 103 115.

Ohtsuka, R. 1994b. Subsistence ecology and carrying capacity in two Papua New Guinea populations. Journal of Biosocial Science 26: 395 407.

Ohtsuka, R. 1996. Agricultural sustainability and food in Papua New Guinea. *In* J. I. Uitto & A.Ono (eds), Population, land management, and environmental change, pp. 46-54. The UNU Global Environmental Forum IV. The United Nations University, Tokyo.

OTA (Office of Technology Assessment). 1987. Integrated Renewable Resource Management for U. S. Insular Areas, OTA-F-325. Congress of the United States. U.S. Government Printing Office, Washington, D. C.

Plenderleith, K. 1999. The role of traditional farmers in creating and conserving agrobiodiversity. *In* D. A. Posey (ed), Cultural and Spiritual Values of Biodiversity, pp. 287-291. United Nations Environmental Programme, Nairobi, Kenya.

Posey , D. A. 1999. Introduction: Culture and Nature - The inextricable link. *In* D. A. Posey (ed), Cultural and Spiritual Values of Biodiversity, pp. 3-16. United Nations Environmental Programme, Nairobi, Kenya.

Rappaport, R.A. 1968. Pigs for the Ancestors: Ritual in the Ecology of a New Guinea People. Yale University Press, New Haven.

Rappaport, R. A. 1971. The flow of energy in an agricultural society. Scientific American 225: 116-132.

Raynor, B. 1994. Resource management in upland forests of Pohnpei: Past practices and future possibilities. Isla: A Journal of Micronesian Studies 2: 47-66.

Raynor, B., & J. Fownes. 1993. An indigenous Pacific Island agroforestry system. *In* B. Raynor & R. Bay (Technical Coordinators), Proceedings of the Workshop on Research Methodologies and Applications for Pacific Island Agroforestry; July 16-20, 1990; Kolonia, Pohnpei, Federated States of Micronesia , pp. 42-58. General Technical Report PSW-GTR-140. Pacific Southwest Research Station, Forest Service.

Raynor, B., & M. Kostka. 2003. Back to the future: Using traditional knowledge to strengthen biodiversity conservation in Pohnpei, Federated States of Micronesia. Ethnobotany Research & Applications 1: 70-79.

Ruthenberg, H. 1980. Farming Systems in the Tropics. Third Edition. Oxford, Oxford University Press.

Sand, C. 1999. Comments. Intensification in the Pacific: A critique of the Archaeological criteria and their application. Current Anthropology 40: 329-330.

Slikkerveer, L. J. 1999. Ethnoscience, 'TEK' and its application to conservation: Introduction. *In* D. A. Posey (ed), Cultural and Spiritual Values of Biodiversity, pp. 169-177. United Nations Environmental Programme, Nairobi, Kenya.

Solomon Islands. 2006. Tertiary qualification category by age 1999. National Statistics Office, Honiara, Solomon Islands. (http://www.spc.int/prism/Country/sb/stats/Social/Education/Tertiary.htm).

Sproat, M. N. 1968. A Guide to Subsistence Agriculture in Micronesia. Agricultural Extension Bulletin No. 9, Trust Territory of the Pacific Islands, Division of Agriculture. TTPI Publications Office, Saipan, Mariana Islands.

Street, J. M. 1969. An evaluation of the concept of carrying capacity. The Professional Geographer 21:104 107.

Thaman, R. R. 1990. Mixed home gardening in the Pacific Islands: Present status and future prospects. *In* K. Landauer & M. Brazil, (eds) Tropical Home Gardens, pp. 41-65. Tokyo, United Nations University Press.

Thaman , R. R. 2008. Atolls – The "biodiversity cool spots" vs hot spots: A critical new focus for research and conservation. Micronesica 40: 33-61.

Umezaki, M., Y. Kuchikura T. Yamauchi & R. Ohtsuka. 2000. Impact of population pressure on food production: An analysis of land use change and subsistence pattern in the Tari Basin in Papua New Guinea Highlands. Human Ecology, 28: 359-381.

US Census Bureau. 2003. Commonwealth of the Northern Mariana Islands: 2000. Social, Economic and Housing Characteristics. 2000 Census of Population and Housing, PHC-4CNMI. US Department of Commerce, Washington, DC. (http://www.censusbureau.biz/prod/cen2000/phc-4-cnmi.pdf).

Waddell, E. 1972. The Mound Builders: Agricultural Practices, Environment and Society in the Central Highlands of New Guinea. University of Washington Press, Seattle.

Wiens, H. J. 1962. Atoll Environment and Ecology. Yale University Press, New Haven.

Wilson, W. S. 1968. Land, Activity and Social Organization of Lelu, Kusaie. PhD dissertation in Anthropology, University of Pennsylvania, Philadelphia.

Yang, J., J. Liu, J. Yu, J. Wang, S. Qin & X. Li. 2005. Effects of water table and nitrogen addition on CO2 emission from wetland soil. Chinese Geographical Science 15: 262-268.

Yen, D. E. 1973. The origins of Oceanic agriculture. Archaeology and Physical Anthropology in Oceania 8: 68-85.

Received 17 Oct. 2007, revised 10 Dec. 2007