EVOLUCIÓN DE LA UTILIZACIÓN DE LOS RECURSOS Y EL CAMBIO CLIMÁTICO EN OCEANÍA

Evolution of resources utilization and environmental change in Oceania

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pacific islands, sustainable land use systems, traditional knowledge, markets, global warming

RESUMEN

La larga y paulatina colonización de las islas del Pacífico dio lugar a asentamientos adaptados al medio y con redes sociales cohesionadas en la actualidad, que poco a poco se fusionaron o fueron desplazados por los modos de vida, el comercio y la gobernanza occidentales. Se hace un repaso histórico de los procesos de descubrimiento de islas, domesticación de plantas y de las repercusiones en la vida salvaje, junto con los principales motores socioeconómicos del cambio de la cubierta terrestre. Aunque los estados insulares comparten ancestros y entornos comunes, existen diferencias significativas en la cubierta forestal, la actividad agrícola, la situación de la fauna y el uso tradicional de los biorrecursos. Una reevaluación de los últimos y de la aplicabilidad de las prácticas tradicionales puede ayudar a invertir el círculo vicioso de pobreza con degradación medioambiental en las vulnerables sociedades rurales insulares que tienen que soportar los cambios climáticos y emprender la industrialización de sus pequeñas economías. El documento también pretende desvelar una serie de posibles temas de investigación que, por lo general, no se tienen suficientemente en cuenta en el mundo académico.

ABSTRACT

The long and gradual colonization of the Pacific islands induced environmentally adapted settlements with cohesive social networks today that gradually fused or were displaced by western ways of life, trade and governance. A historical review of the processes of island discovery, plants domestication and of the impacts on wildlife are discussed alongside the main socioeconomic drivers of land cover change. Although the island states share a common ancestry and environments, there are significant differences on forest cover, agricultural activity, wildlife status, and traditional use of bio-resources. A re-evaluation of the last and of the applicability of traditional practices may assist to reverse the vicious cycle of poverty with environmental degradation in vulnerable rural island societies that have to withstand climatic changes and undertake the industrialization of their small economies. The paper also aims to unfold a number of potential research topics that are generally under looked in academia.

INTRODUCTION

Man’s future in the Pacific islands depends largely on his ability to conserve and manage their ecosystems and to revalue native sources of food, building and medicines. The long and slow process of the island’s colonization by waves of immigrants from Southeast Asia, and very likely from America, boosted particular cultures with prevalent social networks that have mingled or were replaced by western ways of social relations and governance. The region covers fifteen island states with a total of 10.8 million people, six of them classified as least developed countries. By their lithology they are volcanic (39%), reef (34%), limestone (20%) and composite islands (7%) (Nunn et al., 2016).

The human demography, gross domestic products, geology, topography and the extent of gardens and of forest cover considerably among the islands, but they all specialize in few export crops like copra, sugar, palm oil, cocoa, banana, taro and squash (Kakazu, 1994) with no influence on commodities prices due to their size and remote location (Ward, 1985). They also import food, in many cases above the volumes that local agriculture and fishing could support, artificially inflating the carrying capacity of the island by reducing the carrying capacity elsewhere [4]. The growing tendency towards markets connections bring new opportunities and risks to the local communities; they tend to favor extractive activities with little concern for environmental issues (Neil & Tykkyläinen, 1998). Several states committed to protect at least 30% of near shore marine resources and 20% of terrestrial resources by 2020 year with varied results (Jupiter et al., 2014). Accelerated land cover changes after 1945 due to demographic growth and modernization (Baillie et al., 2004) contributed to the high rates of biodiversity extinction (Hoffmann, 2011) and unbalances on ecosystems that support rural livelihoods (SPREP, 2014). Agricultural intensification cause soil erosion, pollution, over logging, landslides and wildlife depletion, worsening food security (Nasi et al., 2008).

Governments address agricultural and forestry issues independently when both sectors cannot be separated, and in pursue of development they adopted technologies that were often inappropriate (Dahl, 1985) depending (case of Melanesia) on logging by foreign companies and on imported fossil fuel usage (Jupiter et al., 2014).

MATERIALS AND METHODS

Material for this paper is secondary data of public domain. Relevant literature was selected considering that the spatial and time frames involved are vast (Polynesia, Micronesia and Melanesia), to discuss the major trends on land use systems and the potential possibilities of resources and their management to contribute on the search of an adequate regional environmental conservation planning and livelihoods improvement from within. Tables and graphs were prepared with (Excel, 2016) and (Ilwis, 2021). The main hypothesis is that the re-assessment of bioresources and of their utilization provide alternatives at multiple scales to the problem of balancing economic development with conservation in Oceania; since traditional practices pollute less, are affordable and often promote bio-diversity conservation with gender equality.

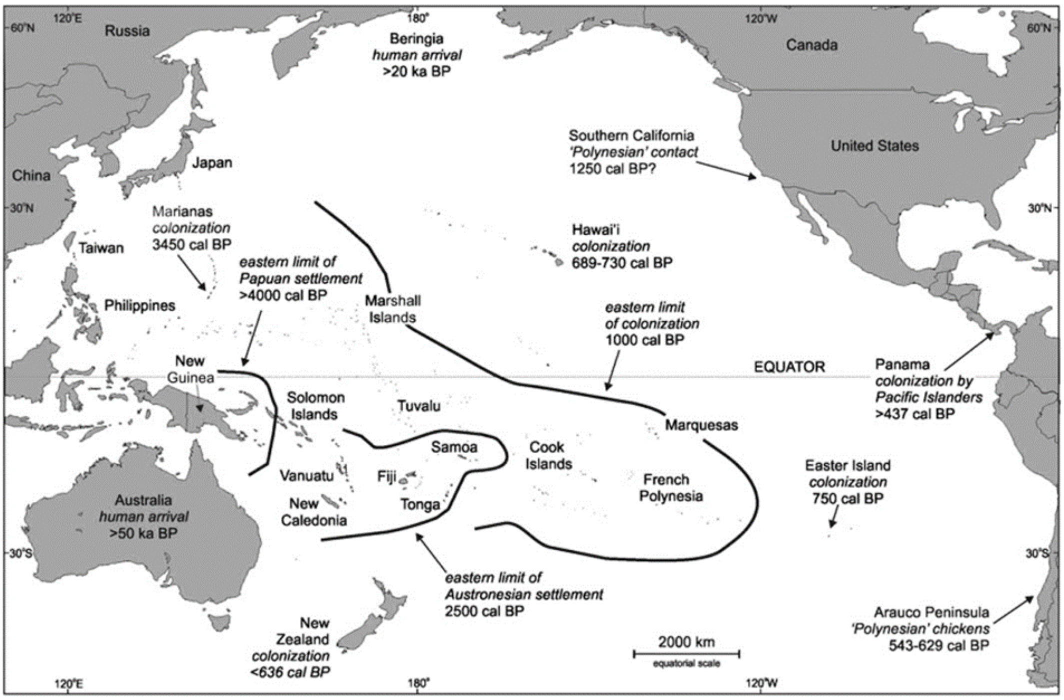
Colonization and translocation of germplasm

The first immigrants moved from Africa to New Guinea and Australia between 40,000 and 60,000 Before Present (BP) reaching Reef and Santa Cruz Islands. A second wave of Lapita groups with Taiwanese origin moved south through the Philippines, Indonesian islands and Near Oceania between 5,000 and 6,000 BP

(Hinkle, 2007), arriving to Samoa and Tonga around 3,000 years BP and sailing east to the Society Islands by AD 1,100 and to Rapa Nui by AD 1,200. The classic Lapita period with distinctive ware pots lasted 1,300 years (Flannery, 1994). They traded obsidian blades, shell ornaments and cooking stones (Strathern et al., 2002) introducing different technologies, adopting oceanic cultivated and wild plants, and probably displacing or incorporating the indigenous population and their languages (McClatchey, 2012). The colonization of eastern Polynesia was driven by the population growth on small islands and by innovations on voyaging (Wilmshurst et al., 2008). There was little contact with prehistoric Micronesia confirmed by the absence of the Pacific rat in this last region (Flannery, 1994). For at least 14000 years the sea level has been raising, people set out to other islands when their own got inundated (Nunn, 1994). During the Little Ice Age (AD 1400-1850) voyaging (Bridgeman, 1983), fishing and the import of stones declined (Rolett, 2002) reflecting an early self-organization in response to change (Silberstein & Maser, 2000).

Figure 1

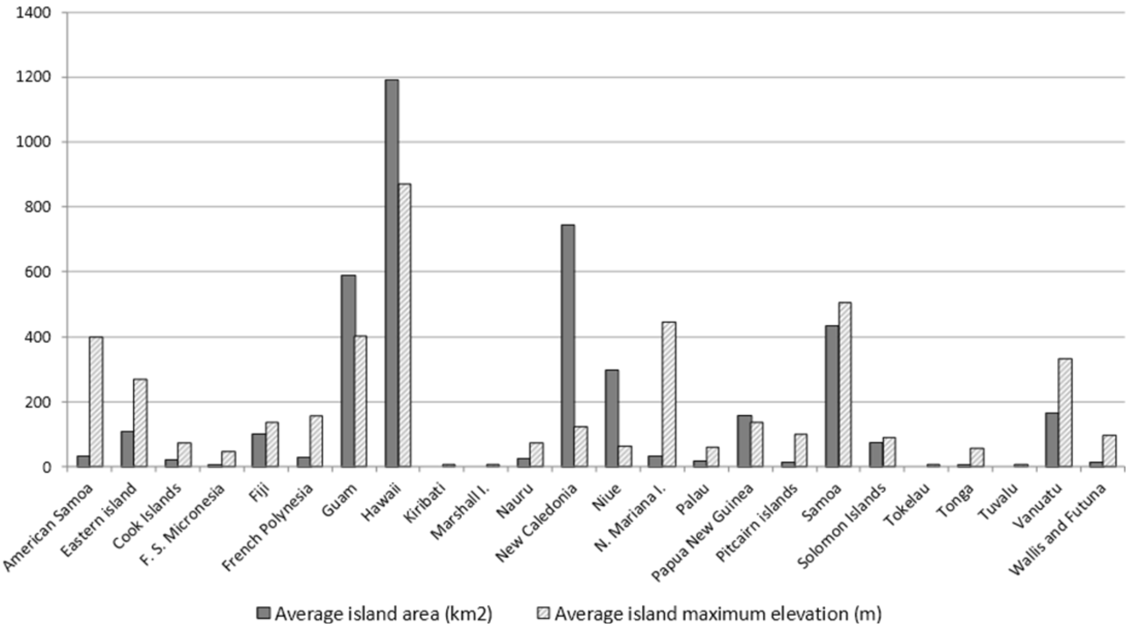
Colonization routes in the Pacific



Note: Colonization routes in the Pacific showing the directions of Austronesian expansion from Taiwan and likely timing of expansion into the Pacific (Hather & Weisler, 2000). Dates are based on current archaeological evidence (Matisoo-Smith, 2007).

Figure 2

Island countries according to their average area (km2) and maximum elevation (m).



Note: Average Island areas for Kiribati, Marshall Islands, Tokelau and Tuvalu include several islands. Adapted from [1].

Islands with higher elevations are on average of bigger size. They are associated with higher rainfall and mixed landscapes that supply diverse products and restrict the disturbance of upland forests (Matisoo-Smith, 2007). They demographically grow at the expense of the small islands (figures 1 and 8).

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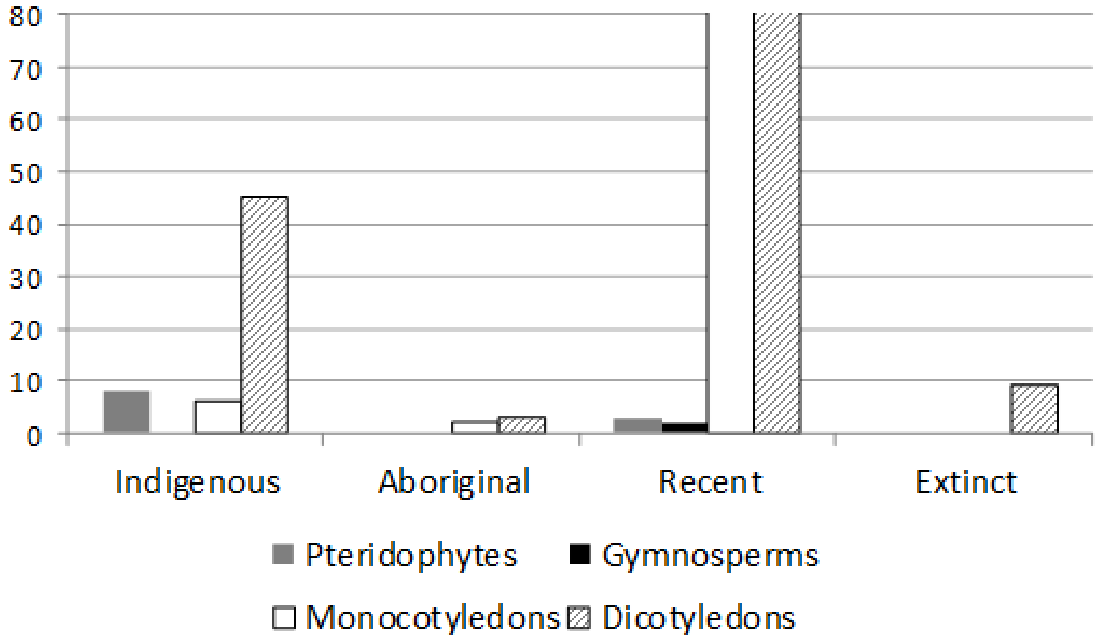
Arboriculture

South Pacific natural forests have been of significant importance even though its total area is a very small fraction of the global figure [(Wilke et al., 2002), (Millerstrom & Coil, 2008)]. Most of the utilized trees are multipurpose (table 1); few like the coconut palm and noni trees are commercially planted. The total cover of coconut plantations in the islands today ranges from 9.2% (Tonga) to 66.6% (Tokelau) (MELAD, 2014).

Around 400 tree species are traditionally used and/or cultivated (ONU, 1993). In Namoluk Atoll 64% of the plants have a medicinal use (Marshall & Fosberg, 1975) for healers with a diminishing influence since the advent of Christianity (Katz, 1983). Other islands, like Nauru, have few indigenous plants (figure 3). Access to woody resources in the islands depended on social rank and site function (Sarout & Chae, 2015).

Figure 3

Number of flora species of Nauru.



Note: Number of flora species of Nauru in terms of whether species are presumed to be indigenous; aboriginal; post-European-contact introductions or extinct. Adapted from (Thaman & Fosberg, 1994).

The old practice of shifting cultivation involves land clearing for subsistence agriculture, then left for fallow after some crop cycles. Samoans practiced it for three millennia (Leach, 1999); highlanders of New Guinea complemented it with legume rotations, composting, mounding, drainage, soil retention barriers, tillage (Bourke, 2001), and the use of cut down trees as soil erosion barriers (Schieffelin, 1975).

Current feral species of *Canarium* and *Barringtonia* in remote Oceania were domesticated in the past (McClatchey, 2012). The frequency of *Canarium indicum* remains in excavations evidence its dominance as a nut source in New Guinea islands 3,500 years ago (Yen, 1993). Up to the 17th century trees like *Ficus benjamina, Artocarpus altilis, Fagraea berteroana, Thespecia populnea, Calophyllum inophyllum, Aleurites moluccana* and *Casuarina equisetifolia* were planted in association with religious structures (marae) and Polynesian elite occupation; their timber was also highly valued for tools making. *Thespesia populnea* is a durable wood with an attractive grain and scent (Whistler, 2009). It is a coastal tree sometimes found inland reflecting intentional planting (Decker, 1970). The Moluccan ironwood (*Intsia bijuga)*, extensively used for timber and carving, became extinct in many islands (SPREP, 2014).

Inocarpus fagifer, Aleurites moluccana, Spondias dulcis and *Homalanthus sp.* were common fuelwood sources. *Cocos nucifera* and *Artocarpus altilis* were burnt only when becoming fruitless; *Santalum sp, Erythrina variegate, Hibiscus tiliaceus* and *Cordyline* were used in food offerings on *marae* (Orliac, 1986). The leaves of *Ficus* sp., *Gnetum* sp., *Morinda citrifolia, Polyscias sp.* and *Pseuderanthemum sp.* are still eaten when crops fail (McClatchey, 2012). These cultivated trees transformed natural forests into productive tree landscapes [(Stevenson et al., 2015), (Millerstrom & Coil, 2008)]. Large human induced changes occurred at different periods. Over the last 2,000 years *Podocarpus* and palm trees forests in the South Pacific were replaced by angiosperm trees (Wilmshurst et al., 2008). A century ago, the sandalwood forests of Hawaii were converted into sugar plantations by foreign traders (Strathern et al., 2002); decades ago, the traditionally cultivated *Pandanus sp.* in Kiribati was replaced by government assisted coconut plantations [(Stevenson et al., 2015), (Thaman, 1990)].

Naturalized trees that are currently cultivated include kapok (*Ceiba pentandra*), frangipani (*Plumeria rubra* and *P. obtusa*), allspice and bay rum (*Pimenta dioica* and *P. racemosa*), jambolan (*Syzygium cumin*), leucaena (*Leucaena leucocephala*) and guava (*Psidium guava*). Exotic trees planted in small scale for timber are *Albizia falcataria*, silky oak (*Grevillea robusta*), eucalyptus (*Eucalyptus sp.*), cedar (*Cedrela odorata*), mahogany (*Swietenia macrophylla*) and Caribbean pine (*Pinus caribaea*) (Clarke W. & Thaman, 1993).

Table 1

Common ancient multipurpose trees of Oceania.

Species	A	B	C	D	E	F	G	H	I	J
Artocarpus altilis		X	Cp	2, 3		3	X			X
Barringtonia edulis			Ct4	2		3		X		
Burckella sorei		2		3						
Burckella obovata		2		3						
Canarium salomonense		1, 2		2, 4				X		
Cocos nucifera		3	Cf2, Ct2	2, 4		3				X
Dracontomelon vitiense		2		2, 3						
Ficus microcarpa		2	Ct1, Ct4		X	2		X	X	
Gnetum gnemon			Cf1	1, 2						X
Hibiscus tiliaceus		2, 3 ("tapa")	Cf4, Cf5		X	3		X		
Inocarpus fagifer		3	Ct4	2, 3		1		X		
Metroxylon sagu		3		5		3				
Morinda citrifolia			Cf3, Ct3	3						
Pandanus julianettii		3		2						
Pangium edule	X		Cf1, Ct1	2, 3						

Species	A	B	C	D	E	F	G	H	I	J
Pometia pinnata		2		3				X		
Spondias dulcis				1, 3						
Syzygium malaccense			Cf1,4,5; Ct1,4,5	3						
Terminalia catappa		1,2	Ct1	2, 3		3				
Thespesia populnea		1, 2			X					

Note: Descriptors: House building (A), Canoe making (B1), Carpentry (B2), Thatching/mats (B3), Medical-anti-inflammatory: leaves (Cf1), seeds (Cf2), fruit (Cf3), bark (Cf4), root (Cf5); Medical antibiotic: leaves (Ct1), seeds (Ct2), fruit (Ct3), bark (Ct4); Pesticide (Cp). Food: leaves (D1), seeds (D2), fruit (D3), oil (D4), starch (D5); Ornamental (E); Windbreak (F1), Soil stabilization (F2), thrives in difficult environments (F3); Fodder (G); Firewood (H); Latex (I); Agroforestry (J). [Compiled from (Clarke W. & Thaman, 1993), (Westphal & Arora, 1989), (Elevitch et al., 2006), (Barwick & Barwick, 2004)].

Forest cover ranges from less than 1% (Marshall Islands and Nauru) to 76-96% of the total land area (Cook Islands, Palau and the Solomon Islands) (Wilke et al., 2002). The Melanesian islands are heavily forested (figure 5), from 47% (Fiji) to 93% (Papua New Guinea), with 5-10 ha of forest land per capita, with exception of Fiji ($1ha^{-1}yr^{-1}$) (FAO, 1995).

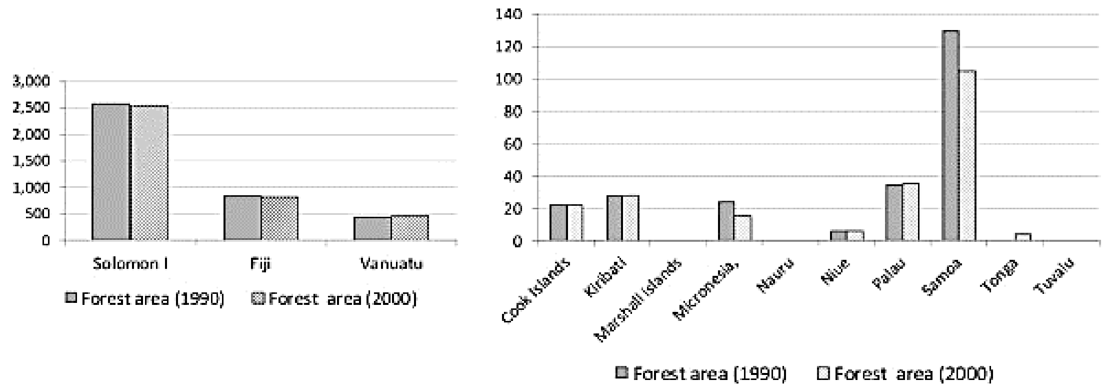
In a survey at Kolombangara island, Solomon Islands, the basal areas ranged between 20 and $43m^2$/ha, which are lower than in temperate conifer plantations; and the volumes ranged between 30 and $55m^3$/ha, which are lower than yields from South Asian forests (Marten, 1985). However, average diameter increments at Guadalcanal woodlots are higher than those from overseas, 2.4 to 2.75cm yr–1 for *Tectona grandis,* 2.5 to 2.64cm yr–1 for *Acacia mangium*, 1.8 to 2.4cm yr–1 for *Swietenia macrophylla,* and 4.867cm yr–1 for *Eucalyptus deglupta* (Lopez, 2021).

Land cover changes

Trees control erosion and stabilize the littoral by holding sediments and building up land, reducing the force of storm surges and waves, providing an amenity and a source of food and materials for coastal community, and creating habitat corridors for wildlife. Islands natural forests were gradually being harvested for timber, fuelwood, food and medicines and converted to secondary forests, farms and grasslands, raising concerns for the sustainability of land use planning in the region [(Lopez & Rao, 2011), (Keppel G. et al., 2014)]. Meanwhile subsistence agriculture has rapidly decreased in the Pacific islands (Kakazu, 1994). Large food imports at the expense of traditional food supply affects food security, leading to higher incidence of heart disorders, cancer, diabetes and pneumonia, besides social disorders (Minerbi, 1994). The major land use changes in the last decades per island state, and their relation with socio-economic factors are summarized below.

Figure 4

Forest area (1000ha) in 1990 and in 2000 year for Micronesia and Polynesia islands.

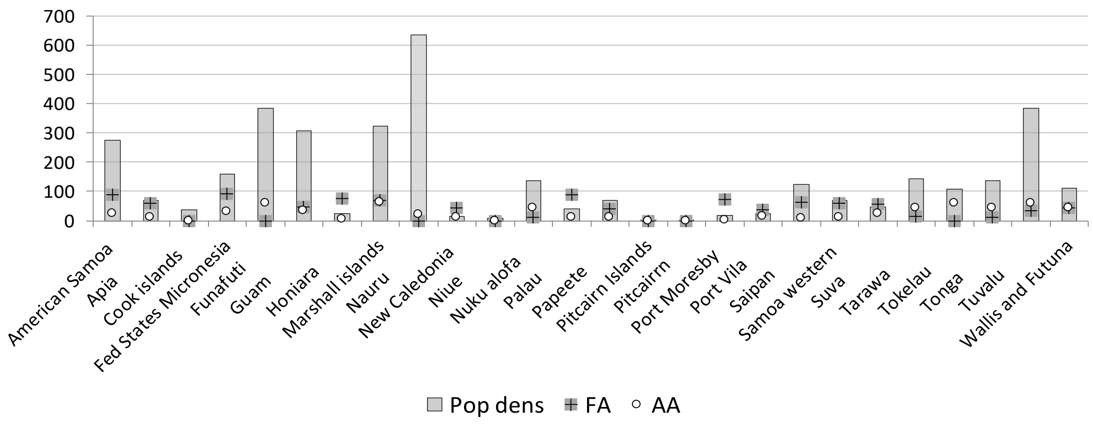


Note: Adapted from [23].

Papua New Guinea (PNG) forest land (not shown) declined from 31730ha (1990) to 30601ha (2000). PNG is the largest island and the world's third largest exporter of tropical hardwood logs with an annual trade of over USD $220 million (FAO, 2000). Solomon Islands (SI) exported more than 3 million cubic meters of logs in 2017, nearly 20 times the recommended sustainable annual harvest. One in every 20km of logging road in the country is above 400masl, despite the official regulations to avoid that. Within Melanesia, only Vanuatu will enlarge its forest cover by 6000ha in a decade (figure 4).

Figure 5

Countries with low rates of population density and correspondingly high forest cover rates.

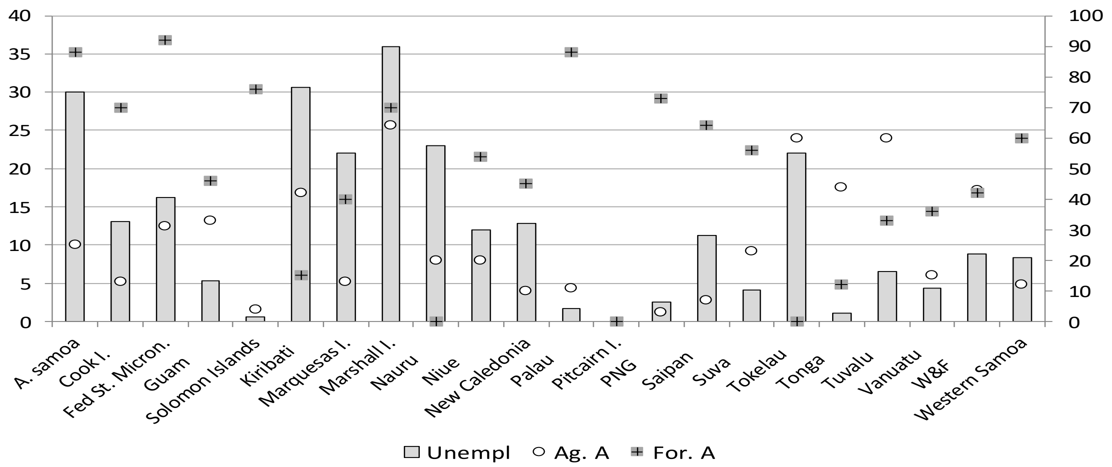


Note: Countries with low rates of population density and correspondingly high forest cover rates are Palau (88% forest area, 39hab/km2), Solomon Islands (76%, 23hab/km2), PNG (73%, 19hab/km2), Fiji (56%, 48hab/km2), New Caledonia (45%, 15hab/km2), and Vanuatu (36%, 24hab/km2). Their corresponding totals for GDP are 2138, 15859, 6 267, 9443 and 3124USD per capita. American Samoa and Guam although with high population densities also have high rates of forestland [(World Data, 2020), (Mundi, 2020)].

The total forest cover in the Pacific islands is inversely correlated with the total agricultural land cover (r=-0.4838, p=0.9869), the population density (r=-0.3488, p=0.9442), and the percentage of unemployed people (r=-0.1901, p=0.8016). It is positively correlated with the GDP (r=0.0228, p=0.46), evidencing how a strong economy contributes to the maintenance of forestlands in an island.

Figure 6

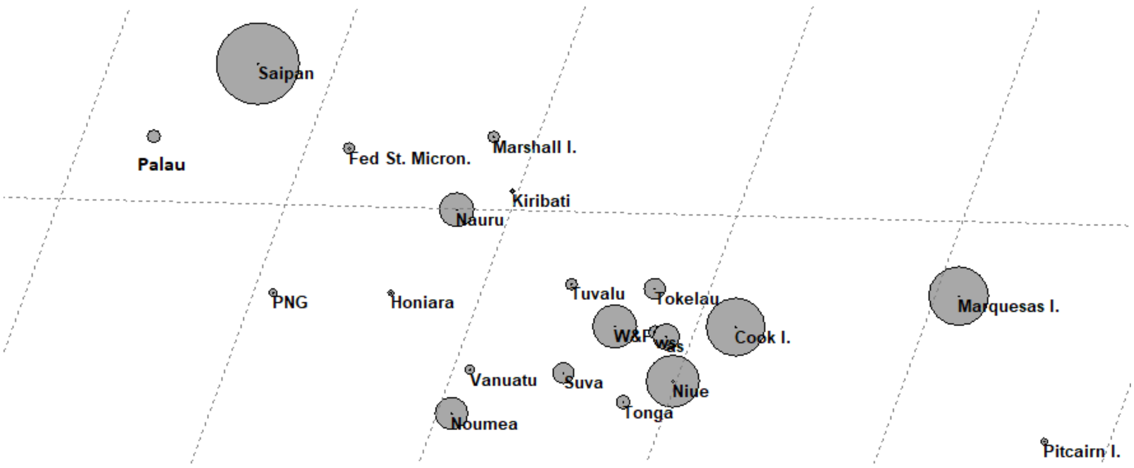
Countries with low rates of unemployment and correspondingly high forest cover rates.



Note: Countries with low rates of unemployment and correspondingly high forest cover rates are SI (0.6%, 76%), Palau (1.7%, 88%), and Fiji (4.1%, 56%). Marshall Islands, with a high unemployment rate still has a high forest cover. Source: [(World Data, 2020), (Mundi, 2020)]

Figure 7

GDP per capita.



Note: GDP per capita (grey circles) in Oceania with Ilwis 3.8 GIS by the author. Scale: 1: 30,000,000 at 30ºS. Mercator projection. The symbol size was stretched from 3 to 100pt to improve the representation of the GDP values. Data source: [(World Data, 2020), (Mundi, 2020)].

Countries with large forested lands correspondingly have higher GDP values. The trend of the lasts do not follow closely the rates of agricultural land rates, with exception of Marshall Islands, American Samoa, and Tuvalu. Some official statistics do not follow standard criteria, case of the Solomon Islands where most of the population engage on subsistence agriculture, however its rate of agricultural land appears low; its agricultural area per capita in 2006 decreased by one third compared to 1966 due to internal social turmoil (Birch-Thomsen & Reemberg, 2014).

Islands with low rates of population density and correspondingly high forest cover rates are: Palau (88% forest area, 39hab km2), SI (76%, 23hab km2), PNG (73%, 19hab per km2), Fiji (56%, 48hab per km2), New Caledonia (45%, 15hab per km2), and Vanuatu (36%, 24hab per km2). Their corresponding GDP per capita (USD) are 15859, 2138, 2757, 5013, 9443 and 2919. American Samoa and Guam have both high population and high rates of forestland. Countries with low rates of unemployment and correspondingly high forest cover rates are SI (0.6%, 76%), Palau (1.7%, 88%), and Fiji (4.1%, 56%). Marshall Islands has both a high unemployment rate and high forest cover (figure 6).

Islands with larger rates of agricultural land compared to forested lands are Tokelau (60% agricultural land), Tuvalu (60%), Tonga (44%), and Wallis and Futuna (43%). Their corresponding rates of unemployment are 22%, 6.5%, 1.1%, and 8.8%; their corresponding rates of population density are of 107, 384, 138, and 112 habitants per km2; and of GDP (USD) are 6257, 3701, 4364 and 12640 per capita. In the SI the rate of agricultural land per capita decreased by one third from 1996 to 2006 due to internal turmoil (Birch-Thomsen & Reemberg, 2014).

Agricultural evolution

Many islands were covered with forests and grasslands, the last a sign of burning due to shifting cultivation. Deforestation exposed to erosion fertile and thick soils, sometimes a thin A horizon overlaying the regolith or weathered bedrock (Nunn, 1994); the areas recovered following the farmers migration to the lowlands (Nunn, 1997) to open up swamps for taro cultivation (Hughes et al., 2007). While upland rainforests cycle little nitrogen (Briggs & Smithson, 1992), lowland rain forests cycle little phosphorous that can be exhausted within few hours if not replenished by weathering (Vitousek & Sandford, 1986). Phosphorous losses from farms in PNG are five times greater than from forests or grasslands (Lopez & Rao, 2011). Atoll soils have little clays, the silts are mainly calcium carbonates with no significance for plant nutrition (Stone et al., 2000), deficient on macro and micronutrients (Halavatau, 2018). Human led wildfires since the sixteenth century (Kirch, 1982), and the proliferation of Pacific rats (Hunt, 2007) led to the use of grasses and twigs as fuelwood (Orliac, 1986) and to the decline of further voyaging to other islands (Weisler, 1997).

Plant species harvested in Near Oceania were more abundant than in Remote Oceania (McClatchey, 2012). Western New Guinea has more than one thousand plant genera, with the number decreasing sharply east of the SI. Fiji, Samoa and Western Carolines islands house more than 300 genera whereas the eastern islands 100 to 200. Hawai'i island being five times bigger than Samoa has 230 genera, while Fiji Islands, with a similar area as Hawai'i has 460 (Weisler, 1997).

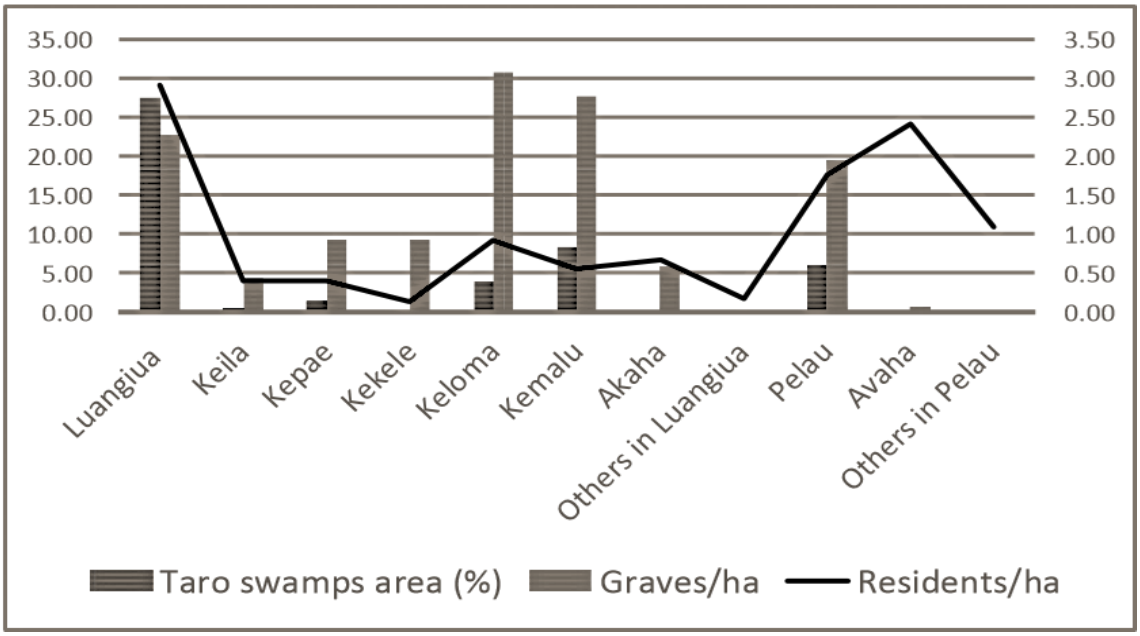
If not introduced on the first voyages, most cultigens were distributed throughout Polynesia between 1,000-1,500 AD (Hather & Weisler, 2000). The first Europeans who landed on Easter Island documented the cultivation of bananas, sweet potatoes, yams and sugar cane (*Saccharum officinarum*) (Rull, 2019). Mountain fields were planted with yams and bananas whereas coastal plains with taro and bananas (Cauchois, 2002). Today they coexist with exotic crops like citrus, papaya, water melon, tomatoes and industrial crops like sugar-cane (*Saccharum officinarum*), coconuts (*Cocos nucifera*) and cotton (*Gossypium sp.*) (Nunn, 1994).

The introduction of *Ipomoea batatas* (sweet potato or *kūmara*) to Polynesia remains questionable (Rull, 2019). It was found in dry soil planting pits and in mounds of Rapa Nui and South Island (New Zealand) conforming to a widespread Oceanic yam agronomy. *Kūmara* was preferred for transoceanic transfer for being of fast growth (three to six months to mature) and hardy (Barber, 2012). It tolerates a variety of soils including coastal dunes (Barber, 2004) and demands less labor than other crops, all of which prompted its popularity in the SI in the last fifty years (Birch-Thomsen & Reemberg, 2014). In contrast, yam (*Dioscorea*) and tree cultivation dominate on drier lands, yam needs at least nine months to mature [(Handy et al., 1991), (Kirch, 1994)]. Factors that restrict the agricultural production in the atolls are temperatures rise and salt-water intrusion, poor access to markets, demographic increase, depopulation of outer islands and limited suitable areas for farming (Halavatau, 2018). With possible Southeast Asian origin, the domestication of taro (*Colocasia esculenta*) occurred on a wide geographic area involving diverse wild forms (Yen, 1993). Irrigated taro was intercropped with drought resistant breadfruit as a backup for dry seasons (Millerstrom & Coil, 2008).

Main systems are shifting cultivation, intensive dry field cultivation, irrigation and drainage, arboriculture and animal husbandry (Kirch, 1982). Agriculture surpluses accumulates for special occasions (Brookfield, 1972). At times intensive like in the highlands of PNG (Strathern et al., 2002) where “garden masters” recognized with special titles (Malinowski, 1935) focus on individual plants (Clarke, 1994). Land ownership systems remain mostly cooperative, land allocates to groups based on common descent, location, and participation in social and economic activities (SPC, 2016). The ongoing discussion on land privatization must ponder the fact that it will not automatically lead to sustainable investments (Riddel, 2000). Most of the community owned gardens are of less than an acre (Kakazu, 1994). A plantation based on non-remunerated family labor generates more rents without necessarily developing a “farmer economy” oriented by the capital; however, a hypothesis to test is whether the ongoing land fragmentation in the region ignites agricultural innovation (López, 2003). The restriction to wild foods prompted the first settlers to explore marine food resources until gardens were established (McClatchey, 2012). Alike Australian aboriginals, they manipulated fruit and rhizome-bearing plants (Sharrok & Frison, 1998). The banana tree (*Musa acuminata)* was one of the earliest plants to be domesticated, first in Southeast Asia and possibly PNG, then eastern Indonesia and the Philippines; for its fibers, leaves for thatching and its edible male buds (Sharrok & Frison, 1998). Hawaiians had short-fallow dry gardens on the leeward slopes and pond fields in the windward valleys. Anutans combined short-fallow gardening with longer ones, swidden in gullies, arboriculture, and perennial cropping on the coastal lowlands (Yen, 1993).

Figure 8

Taro gardens expansion and human demographic change.



Note: Taro gardens expansion (right axis) and human demographic change (left axis) in Ontong Java during 1970-71 (Bayliss-Smith et al., 2010).

Taro gardens are frequent in densely populated islands. Soil tillage is traditionally done with digging sticks and spades without farm animal or machines (Lopez & Rao, 2011) mounding soil for deepening it, and applying compost in trenches or in planting holes (Stone et al., 2000). Modern large plantations of taro in Fiji and Samoa, of ginger and kava in Fiji and Micronesia and of squash in Tonga (Buresova & McGregor, 1990) were reported to cause soil erosion of about 24–79-ton ha^{-1} yr^{-1} (Nunn, 1990), affecting the local economy through reduced food supplies, lower income and increased landlessness. Cropping destabilizes the soil structure and increases soil bulk density, which lowers the water infiltration rate and accelerates runoff and erosion with an equivalent cost of 5-10% of the agricultural sector production (Young, 1998). Remote island communities adapt to global commercial trends, Ontong Java diving groups reassemble when bêche-de-mer trade reopens abandoning copra production and decreasing taro cultivation (Christensen, 2011).

Nitrogen fixing trees include beach pea or Vigna, Canavalia, garden beans, and the introduced leucaena and casuarina (Stone et al., 2000). Pandanus is tolerant to soil salinity and salt spray on atolls, growing where other plants cannot survive, and tolerates drought better than the coconut tree. Native crops with similar characteristics are hedge panax (*Polyscias fruticosa*), Chaya (*Cnidoscolus aconitifolius*), drumstick (*Moringa oleifera*), ofenga (*Pseuderanthemum whartonianum*), amaranth (*Amaranthus sp.*), kangkong (*Ipomoea aquatic*) and beach cowpea (*Vigna marina*) (Edis R. et al., 2017). *Nypa fruticans*, the only palm adapted to the mangrove biome is used in basketry and thatching; nipa palm sap fed pigs on dry seasons at Roti and Savu islands (WCSP, 2017); sago palm (*Metroxylon sp.)* is harvested for thatching material and starch (McClatchey, 2012).

Around 130 breadfruit cultivars are recognized by Pohnpei Island farmers, and 40 in Western Samoa (Fownes & Raynor, 1998). They do not survive sea waves intrusion (Cloud, 1952). Main crops in Oceania today are coconut, breadfruit, pandanus, banana, swamp taro, ground taro, sweet potato, cassava and yam. Traditional root and tree cropping are in decline in most of the islands; the expansion of mechanized agriculture on usually rented lands does not favor agroforestry practices (Clarke W. & Thaman, 1993). Copra is a major agricultural export, but production is limited. Pests like taro beetle and taro leaf blight caused by Phytophthora fungus are partially controlled by crops rotation and by the use of clean planting material (Halavatau, 2018). Intensive livestock production is with few exceptions scarce (Kakazu, 1994).

Ancient agricultural engineering

Tikopians still practice tree improvement for certain species (Handy et al., 1991) and plant *Calophyllum* trees to stabilize cobble seawalls along sand dunes (Kirch, 1982). Ancient Rapa-nuis practiced lithic mulching by placing rock walls up to 2m high around their gardens in order to preserve heat and moisture and prevent soil erosion (Cloud, 1952). Terraced fields along streams are common in Fiji between 200-300masl, some of their stonewalls are of over 2m height (Kuhlken, 1994). The artificial islands of Solomon Islands and Micronesia built 1000 to 2000 years ago (Nunn, 1994) had seawalls and basalt boulders breakwaters (Strathern et al., 2002). The planting of giant swamp taro (*Cyrtosperma merkusii)* in baskets of compost set dug down to the level of the water table in Micronesia (Weisler, 1997) alongside storage techniques (pit fermentation) to cover seasonal shortages, terracing, irrigation systems and raised fields to control the water table, increased food supply at the expense of more labor (Ward, 1985). Food preservation pits spread crops yields over time (Yen, 1993). Among the factors of terracing decline are the resettlement of communities after European contact, their depopulation due to new diseases, the imposition of land use regulations, extensive grazing, establishment of plantation agriculture, and the low opportunities for wage labor (Kuhlken, 1994).

Hunting and wildlife extinction

The native mammals in Oceania are limited to a few marsupials, rats (*Rattus, Melomys*) and bats; only the large blossom-eating bat (*Pteropus sp.*) and the small insectivorous Hoary Bat (*Lasiurus cinereus*) dispersed further into remote Oceania. Most of the reptiles are found in Near Oceania or in the large islands (Zeagler, 2002). The number of marine fauna species also decreases from west to east (Akimichi, 2000).

Seabirds and land birds account for the greatest diversity of vertebrates in the Pacific islands; they were abundant when humans arrived. An incentive for exploration was the reward of finding large bird colonies in unknown islands (Akimichi, 2000); they also hunted snakes, lizards, bats and rats. Some Papuans have detailed knowledge of the nesting, breeding, feeding, courting, and calling behavior of around 150 bird species (Feld, 1991). Similarly, Polynesians could name and determine the movements, time and spawning places of over 300 finfish species (Klee, 1980). Mullet and milkfish artificial ponds were common in Hawaii (Strathern et al., 2002), by 1778 there were at least 360 fishponds producing 900,000 kg of fish per year (Costa-Pierce, 1987).

New Caledonia's toxic soils, its small size and its position above the Tropic of Capricorn derived in low biological productivity where species that need large home ranges can sustain only small populations; and with reptiles, more abundant than birds, filling diverse ecological niches (Flannery, 1994). Two cases of evolutionary adaptation are the omnivorous banded iguana (*Brachylophus fasciatus*) that thrives in wet areas and the herbivorous crested iguana (*B. vitiensis*) found only in the outer islands of Viti Levu, Fiji Islands (Nunn, 1994).

Marsupials like cuscus (*Phalanger orientalis*), *Possum (Trichosurus vulpecula*) and ringtail possum (*Pseudocheirops archeri*) were relocated from New Britain to other islands 20,000 years ago (Flannery, 1994). Pigs remains were associated with marae religious sites; today pigs in atolls are sometimes fed with *Pisonia grandis* leaves, a preferred nesting tree for the black noddy tern *(Anous tenuirostris*) (Thaman, 1990). Faunal remains in cave sites occupied during the *lapita* age contain fruit bats *(Pteropus sp*.), chickens (*Gallus gallus*) and several species driven to extinction including crocodiles (*Volia athollandersoni)*, megapodes *(Megapodius alimentum*) and other terrestrial birds [(Worthy & Anderson, 2009), (Matisoo-Smith, 2007)]. The Pacific rat (*Rattus exulans*) was a massive predator of palm fruits (Hunt, 2007); introduced black rats (*Rattus rattus*) became a plague in the Marquesas Islands 200 years ago (Decker, 1970), decimating chickens in Mangareva Island (Green et al., 2014) and nine of the fifteen endemic land bird species at Lord Howe Island (Flannery, 1994).

The introduction of commensal species like the Pacific rat (*Rattus exulans*), pig (*Sus scrofa*), chicken (*Gallus gallus*), lizard (*Lipunia noctua*) and the land snail (*Partula hyaline*) altered the environment. Animal husbandry was difficult since livestock competed with man for food crops (Whytlaw et al., 2013). When livestock is not available bush meat is an important source of protein in Melanesia. It is accessible, transportable, has a high value-weight ratio, and is preserved at low cost (Inamdar et al., 1999); reasons for which hunting seasons and bag limits need regulation (López, 2010). Pig-killings during festivals in the highlands of New Guinea are accompanied with elaborate politically oriented rituals well in advance of any environmental degradation (Rappaport, 1968). Feral rabbits in Hawaii (Lisianski island) so depleted the vegetation that they starved to death, allowing the vegetation regrowth thereafter (Nunn, 1990). Feral pigs may destroy almost every sea turtle nest at one beach (Bay-Petersen, 1983); together with native crocodiles they consume sea turtle eggs and hatchlings, spoiling the beach for future nesting when digging up nests [(Lethbridge et al., 2013), (Whiting & Whiting, 2011)]. Other sea turtle predators are cats, dogs, gulls, herons, water rats, crabs, tropical fire ants and hermit crabs [(Guinea, 2013), (Hilmer et al., 2010)]. Predation by introduced animals is a concern in remote areas where regular patrols, control measures and monitoring are infrequent or not possible. Pollution is another factor of wildlife decline; phosphate mining at Christmas Island destroys habitats of endemic booby (*Sula abbotti*) and robber crab (*Birgus latro*) (Nunn, 1994). Nature responses are variable; once phosphate mining ended at Nauru, the first colonizers were exotic weeds that were in turn displaced by native plants later (Manner H. et al., 1985). The 93% of the invasive species in Fiji Islands are plants and trees, the 5% are terrestrial animals, and the 2% are freshwater species. Compared to their neighbors Fiji Islands implemented an efficient border and quarantine controls (DEF, 2014). Over half of the 40 indigenous bird species disappeared from the Hawaiian Islands when Polynesians arrived by AD 400 (McNeil, 1991). They and the sea turtles are affected by the migration of their prey with the rising water temperatures (Portner et al., 2014), and by the flooding of coastal nests respectively (Poloczanska et al., 2010).

Corals and sea level rise (SLR)

Since 1993 the western South Pacific experienced a sea level rise almost three times faster than the global average of 3.4mm/yr [(CSIRO, 2015), (IPCC, 2021)], projected to be 0.4-0.8m at the end of this century (Aucan, 2019). However that prediction did not consider the small islands dynamic geology [(Piesse, 2019), (Nunn, 1997)]. The coral reefs developed a dynamic equilibrium with the environment being subject to readjustment, erosion and sedimentation in response to varying sea levels, wind patterns and storms (Neumann & Macintyre, 1985). Reefs accrete to maintain positive freeboard while retreating lagoon ward (Masselink et al., 2021). Mangrove forests thrive if the SLR remains under 5 mm/yr (NTU, 2020). They can reduce wave height by 86-90% and the wave energy by 25% [(Mazda et al., 1997), (Massel et al., 1999)] being an affordable multipurpose solution for coastal defense, considering that engineering techniques have to comply with standards on concrete quality, walls depth and height, and addition of geotextiles (Bormann et al., 1994). Mangroves are also home to a rich biodiversity, absorb pollution including heavy metals and serve as a source of timber, firewood, food and medicines to the local communities (Thaman, 1990).

CONCLUSION

Although the Pacific Island states differ in their geographic, biological, social, cultural, and economic characteristics, they share common problems on conservation biology and on the sustainability of land and marine resources utilization. Their degrees of economic development, agricultural expansion and conservation status vary. Theories regarding their discovery and population are not conclusive; however, evidences of sophisticated techniques on navigation, farming in extreme conditions, arboriculture, building of artificial islands and ethnobotany, provide inroads to the quest of sustainable ways of resources use in the islands. Extensive land modifications during millennia are evidenced by buried ashes and by first photographs that show large patches of scarred lands and/or covered by grasslands. Slash and burn agriculture are, rather than a manifestation of migratory agriculture, a broadening of sedentary peasant agriculture that can be a sustainable if relies on long fallows. Although agricultural intensification can reduce deforestation by tying up labor and capital, on frontier areas it might instead promote further agricultural expansion. Island countries with higher GDP per capita have larger rates of forested areas, whereas countries with firstly high population density and secondly of high unemployment, have larger proportions of cropped areas. Land fragmentation, logging, pollution, predation and over hunting impact on wildlife populations; the pressure lessens by improving rural livelihoods. Exotic plants and animals had also a severe impact on native wildlife and vegetation. Several of the chronic socioeconomic problems have solutions on traditional knowledge including the build-up of artificial islands to confront sea level rise and high demographic increase. Several native roots are adapted to high salinity and swampy terrain, and several native fruit and nut tree species are highly nutritious, they also supply timber, firewood and medicines on isolated areas. The replacement of native woods and associated wildlife diminished the soil's productive capacity, increasing their vulnerability to cyclones and sea level rise. The first colonists replaced the natural forests with coconut and breadfruit plantations and their attendant weed species; they altered the phosphate balance by driving away the sea-birds, by exporting large quantities of copra (source of phosphorus) and by burning. Soil remediation involves composting and agroforestry practices. Mono-cropping and mechanization are not ecologically friendly as the traditional digging stick and fire. Between radical options exist a suite of alternate solutions that reflect the dynamic nature of islands change, and allow planning and soft engineering strategies like seawalls building, water harvest techniques, and the planting of multipurpose plants to rebuild the top soil layer, stabilize the ground, contribute to food security and materials supply. Terracing is also recommended but the needed labor and funds are limiting factors [47]. Government assistance on planning agroforestry practice, permaculture, ecotourism, and soft credits for small-scale conservation projects are needed. Politicians, academics and farmers need to propose consensual adaptive management plans that acknowledge social needs while ensuring ecological stability (Richardson, 1985). Lasting results depend on political will, grassroots empowerment and international support.

Customary land tenure systems may hinder investments on natural resources exploration and exploitation but may also provide effective regulations that prevent a potential overuse of the resource. The focus has to shift from who has the right over land to who has the right to use a determined area for a specific purpose (Riddel, 2000). An African popular credo applies here: "land belongs to a vast family of which many are dead, a few are living and countless numbers are still unborn".

REFERENCES

Akimichi, T. (2000). *The sea and the humans. In: K. Omoto, T. Hamashita, Y. Murai and H. Yajima (eds.), Maritime Asia, Vol. 1*, pp. 3-30. Tokyo: Iwanami.

Anderson, A. (1996). *Adaptive voyaging and subsistence strategies in the early settlement of East Polynesia*, in Prehistoric Mongoloid Dispersals: 359-373, ed. T. Akazawa and E. J.E. Szathmary. Oxford: Oxford University Press.

Aucan, J., Hoeke, R., Storlazzi, C. (2019). Waves do not contribute to global sea-level rise. *Nature Clim Change 9*(1), 2 https://doi.org/10.1038/s41558-018-0377-5.

Baillie, J., Stuart, S., Hilton-Taylor, C. (eds). (2004). *IUCN Red List of Threatened Species. A Global Species Assessment*. IUCN, Gland, Switzerland and Cambridge, UK.

Barber, (2004). *Crops on the border: The growth of archaeological knowledge of Polynesian cultivation in New Zealand*. In Change Through Time: 50 Years of New Zealand Archaeology. L. Furey and S. Holdaway (eds):169-192. New Zealand Archaeological Association Monograph 26.

Barber, I. (2012). A fast yam to Polynesia: New thinking on the problem of the American sweet potato in Oceania. *Rapa Nui Journal* Vol. 26 (1) May 2012.

Barwick, M., Van, Barwick, C. J. (2004). *Tropical & subtropical trees: A worldwide encyclopaedic guide*. London: Thames & Hudson.

Bayliss-Smith, T., Gough, K., Christensen A. and Kristensen S. (2010). 'Managing Ontong Java atoll: social institutions for production and governance of atoll resources in Solomon Islands'. *Singapore Journal of Tropical Geography*, *31*(1) 55-69. https://doi.org/10.1111/j.1467-9493.2010.00385.x

Bay-Petersen, J. (1983). Competition for resources: The role of pig and dog in the Polynesian agricultural economy. Journal de la Societe des Oceanistes, 39 (77) 121-129. https://doi.org/10.3406/jso.1983.2793

Birch-Thomsen, T., Reenberg, A. (2014). The Dwindling Role of Population Pressure in Land Use Change—a Case from the South West Pacific, in M. Fischer-Kowalski et al. (eds.), Ester Boserup's Legacy on Sustainability, 45 Human Environment Interactions 4, DOI 10.1007/978-94017-8678-2_4. Pp. 45-60.

Bormann, B., Cunningham, P., Brookes, M., Manning, V., Collopy, M. (1994). *Adaptive ecosystem management in the Pacific Northwest*. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 22 p. https://doi.org/10.2737/PNW-GTR-341

Bourke, R. (2001). *Previous conferences devoted to food production or human nutrition in PNG (1970–99)*. In: Bourke RM, Allen MG, Salisbury JG, editors. Food Security for Papua New Guinea. Proceedings of the Papua New Guinea Food and Nutrition 2000 Conference. ACIAR Proceedings No. 99. Canberra: Australian Centre for International Agricultural Research. pp 889– 892.

Bridgeman, H. (1983). Could climate change have had an influence on the Polynesian migrations?. *Paleo geography, Palaeoclimatology. Palaeoecology, 41*(3-4), 193-206. https://doi.org/10.1016/0031-0182(83)90087-1

Briggs, D., Smithson, P. (1992). *Fundamentals of Physical Geography*. New Jersey: Rowman & Littlefield Publishers.

Brookfield, H. ((1972). Intensification and des intensification in Pacific Agriculture. *Pacific Viewpoint*, *13*(1), 30-48, https://doi.org/10.1111/apv.131003.

Buresova, N., McGregor, A. (1990). The economics of soil conservation: the case study of the Fiji ginger industry. In RR Ziemer, CL O'Loughlin and LS Hamilton (eds) Research needs and applications to reduce erosion and sedimentation in tropical steep lands. *International Association of Hydrological Sciences*, Wallingford, United Kingdom, 247–256.

Cauchois, M. (2002). Dryland horticulture in Maupiti: An Ethno archaeological study. *Asian Perspectives*, *41*(2), 269-283. https://doi.org/10.1353/asi.2003.0003

Christensen, Andreas. (2011). Marine gold and atoll livelihoods: The rise and fall of the bêche de mer trade on Ontong Java, Solomon Islands. *Natural Resources Forum, 35*(1). 9 - 20. https://doi.org/10.1111/j.1477-8947.2011.01343.x

Clarke W. (1994). *Traditional Land Use and Agriculture in the Pacific Islands*. In Morrison, J., Geraghty, P. and Crowl, L. (eds.). 1994a. Science of Pacific Island Peoples. Land Use and Agriculture. Volume 2. Institute of Pacific Studies, Suva. Pp. 11-38.

Clarke W., Thaman R. (1993). *Agroforestry in the Pacific Islands: Systems for Sustainability*. C. (Editors), University Press, Tokyo, ISBN 92808-0824-9.

Cloud, P. (1952). Preliminary report on geology and marine environments of Onotoa Atoll, Gilbert Islands. *Atoll Research Bulletin, 12*, 1–73. https://doi.org/10.5479/si.00775630.12.1

Costa-Pierce, B. (1987). Aquaculture in ancient Hawaii. *BioScience. 37* (5), 320–331. https://doi.org/10.2307/1310688

CSIRO, Australian Bureau of Meteorology, & SPREP. (2015). *Climate in the Pacific: A regional summary of new science and management tools*. Pacific-Australia Climate Change Science and Adaptation Planning Program Summary Report.

Dahl, A. (1985). *The South Pacific regional environment programme*; in Environment and resources in the Pacific. UNEP No 69: 3-7.

Decker, B. (1970). *Plants, man, and landscape in Marquesan Valleys, French Polynesia*. Unpublished PhD dissertation, University of California, Berkeley.

Department of Environment of Fiji Islands (DEF). (2014). Fiji's fifth national report of the United Nations Convention on biological diversity. 102p.

Edis R., Geoff D., Lyons G. (2017). How food gardens based on traditional practice can improve health in the Pacific. The Conversation. https://theconversation.com/how-food-gardensbased-on-traditional-practice-can-improve-healthin-the-pacific-75858.

Elevitch, C. R., Abbott, I. A., & Leakey, R. R. B. (2006). *Traditional trees of Pacific Islands: Their culture, environment, and use*. Hōlualoa, Hawaiʻi : Permanent Agriculture Resources. ISBN: 0970254458.

Excel. (2016). Microsoft Corporation, 2018. Available at: https://office.microsoft.com/excel.

FAO. (1995). *Forest Resources Assessment 1990 Global Synthesis*. FAO Forestry Paper. ISBN 9251036667.

FAO. (2000). *FAO Yearbook of Forest Products 1996-2000*. FAO Forestry Series no. 35. Rome.

Feld, S. (1991). *Voices of the Rainforest: A Day in the Life of the Kaluli People*. CD. The World series, Mickey Hart, ed. Boston: Rykodisc.

Flannery, T. (1994). *The Future Eaters: An Ecological History of the Australasian Lands and People*. ISBN 0-8021-3943-4.

Fownes, J. & Raynor, W. (1993). Seasonality and yield of breadfruit cultivars in the indigenous agroforestry system of Pohnpei, Federated States of Micronesia. *Trop. Agric. (Trinidad) 70*(2),103-109.

George, M. (1998). The return of Lata: Building an authentic Polynesian voyaging canoe. *Sea History Journal 84*, 40-42.

Green, R., Marshall, I., Weisler, R. (2014). Prehistoric introduction and extinction of animals in Mangareva, Southeast Polynesia. *Archaeology in Oceania 39*(1), https://doi.org/10.1002/j.18344453.2004.tb00555.x.

Guinea, M. (2013). *Surveys of the Sea Snakes and Sea Turtles on Reefs of the Sahul Shelf*. Monitoring Program for the Montara Well Release Timor Sea - Monitoring Study S6 Sea Snakes/Turtles. Darwin. School of Environment, Faculty of Engineering, Health, Science and the Environment, Charles Darwin University, pp 91.

Halavatau S. (2018). *Growing root crops on Atolls.* Secretariat of the Pacific Community. ISBN: 978-982-00-1147-2.

Handy, E; Craighill, S. & Pukui, M. (1991). *Native Planters In Old Hawaii: Their Life, Lore, and Environment.* B.P. Bishop Museum Bulletin 233. Honolulu: Bishop Museum [revised edition].

Hather, J., Weisler, M. (2000). Prehistoric giant swamp taro (Cyrtosperma chamissonis) from Henderson Island, southeast Polynesia. *Pac Sci 54*(2), 149-156.

Hilmer, S., Algar, D., Johnston, M. (2010). Opportunistic observation of predation of loggerhead turtle hatchlings by feral cats on Dirk Hartog Island, Western Australia. *Journal of the Royal Society of Western Australia 93*(3) 141-146.

Hinkle, A. (2007). Population Structure of Pacific Cordyline fruticosa (Laxmanniaceae) with Implications for Human Settlement of Polynesia. *American Journal of Botany*, 94(5), 828-839.

Hoffmann, U. (2011). *Some reflections on climate change, green growth illusions and development space*. UNCTAD Discussion Papers, No 205. United Nations Conference on Trade and Development, Geneva, Switzerland.

Hughes, T., Gunderson, L., Folke, C. (2007). Adaptive management of the great barrier reef and the Grand Canyon world heritage areas. Ambio 36:586–592. https://doi.org/10.1579/0044-7447(2007)36[586:AMOTGB]2.0.CO;2

Hunt, T. (2007). Rethinking Easter Island's ecological catastrophe. Journal of *Archaeological Science* 34, 485-502.

Ilwis 3.8. (2021). Integrated land and water information systems (Ilwis) Software. 52°North Spatial Information Research GmbH, https://52north.org/software/softwareprojects/ilwis/ (20 June 2021).

Inamdar, A., Brown, D., Cobb, S. (1999). What's special about wildlife management in forests? - concepts and models of rights-based management, with recent evidence from West Central Africa, in *Natural Resource Perspectives* No. 44. London, UK: Overseas Development Institute: 15 pp.

Index Mundi. (2020). *Indexmundi*. http://www.indexmundi.com/, downloaded on July 20, 2020.

IPCC. (2021). *Summary for Policymakers*. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J., Matthews, T., Maycock, T., Waterfield, O., Yelekçi, R., Zhou B. (eds.)]. In Press.

Jupiter, S., Cohen, P.; Weeks, R.; Tawake, A. & Govan, H. (2014). Locally-managed marine areas: multiple objectives and diverse strategies. *Pac. Conserv. Biol. 20*(2), 165–179.

Kakazu, H. (1994). Sustainable development of small island economies. Boulder: Westview Press"

Katz, R. (1983). The Straight Path of the Spirit. Rochester: Park Street Press.

Keppel G., Morrison, C., Meyer, J., Boehmer, H. (2014). Isolated and vulnerable: the history and future of Pacific Island terrestrial biodiversity. Pac. Cons. Biol. in press.

Kirch, P. (1982). The impact of the prehistoric Polynesians of the Hawaiian ecosystem. Pac Sci 36(1): 1-14.

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

Klee, G. (1980). World Systems of Traditional Resource Management. London.

Kuhlken, R. (1994). Agricultural Terracing in the Fiji Islands, LSU Historical Dissertations and Theses. 5696, https://digitalcommons.lsu.edu/gradschool_dissthes es/5696.

Leach, H. (1999). Intensification in the Pacific: A Critique of the archaeological criteria and their application. Current Anthropology, 40(3): 311-339.

Lethbridge, M., Andrews, L., Jennings, S., Mutze G., Mitchell J., Stead, M., Harper, M. (2013). Advice on Effectiveness of Vertebrate Pest Animal Control on Condition of Native Vegetation: Part B – Case Studies and Methodology Development. Adelaide.

Lobban Ch., Schefter, M. (1997). Tropical Pacific Island Environments. University of Guam Press, DOI:10.5860/choice.35-5051.

López D. (2010). Status and potential of the Peroryctidae family to improve food security in Papua New Guinea. Journal of Tropical Forest Management, Bogor Agricultural University, Vol XVI (3): 155-160.

Lopez, D. (2021). Volumetric yields in small scale plantations of Guadalcanal Island. NZ Journal of Forestry, August 2021, 66(2): 34-42.

López, D. ((2003). Characteristics and change of land use in the central Andes of Peru, a case study. Japanese Journal of Forest Planning 9:6177.

Lopez, D., Rao, R. (2011). Land Use Effects on Soil Erosion in the Lowland Humid Tropics of Papua New Guinea, JMHT Vol. XVII, (1): 17–23, April 2011.

Malinowski, B. ((1935). Coral Gardens and their Magic. A Study of the Methods of Tilling the Soil and of Agricultural Rites in Trobriand Islands. Vol. 1: The Description of Gardening; Vol. 2: The Language of Magic and Gardening. Allen & Unwin, London.

Manner H., Thaman, R., Hassall D. (1985). Plant succession after phosphate mining of Nauru. Australian Geographer 16(3):185-194.

Marshall, M., Fosberg, F. (1975). The natural history of Namoluk Atoll, Eastern Caroline Islands. With identifications of vascular flora by F. R. Fosberg,Atoll Research Bulletin. 189:1–54. https://doi.org/10.5479/si.00775630.189.1

Marten, K. (1985). Tropical forestry in Melanesia and some Pacific islands, in Environment and resources in the Pacific. UNEP No 69: 115-128.

Massel, S., Furukawa K., Brinkman, R. (1999). Surface wave propagation in mangrove forests. Fluid Dyn. Res., 24: 219-249.

Masselink, R. McCall, E., Beetham, P., Kench, C., Storlazzi. (2021). Role of Future Reef Growth on Morphological Response of Coral Reef Islands to Sea Level Rise. Journal of Geophysical Research: Earth Surface, 126, 2.

Matisoo-Smith, E. (2007). Animal translocations, genetic variation and the human settlement of the Pacific. Pp. 157–170 in Genes, Language and Culture History in the Southwest Pacific, ed. Jonathan S. Friedlaender. Oxford: Oxford University Press.

Mazda, Y., Magi, M., Kogo M., Hong, P. (1997). Man-grove as a coastal protection from waves in the Tong King delta, Vietnam. Mangroves Salt Marshes, 1:127-135.

McClatchey, W. (2012). Remote Oceania wild food plants. Acta Soc Bot Pol 81(4):371–380.

McNeil, R. ((1991). Nocturnality in shorebirds. Acta Int. Ornithol. Congr. 20:10981104.

MELAD. (2014). Fifth national report of the United Nations Convention on biological diversity. Ministry of Environment, Lands and Agricultural Development, 96p.

Merril, E. (1981). Plant Life of the Pacific World, C.E. Tuttle Company, 297 p.

Millerstrom, S. & Coil, J. (2008). Pre-Contact Arboriculture and Vegetation in the Marquesas Islands, French Polynesia: Charcoal Identification and Radiocarbon Dates from Hatiheu Valley, Nuku Hiva. Asian Perspectives, 47 (2) 330-351.

Minerbi, L. (1994). Hawaiian Sanctuaries, Places of Refuge and Indigenous Knowledge in Hawaii Honolulu: L. Minerbi, in John Morrison, Paul Geraghty, Linda Crowl eds. Science of Pacific island People Land Use and Agriculture Vol 2, pp.89-130, Institute for Pacific Studies.

Nanyang Technological University (NTU). (2020). Mangroves at risk if carbon emissions not reduced by 2050, international scientists predict. Science DOI 10.1126/science.aba2656.

Nasi, R., Brown, D., Wilkie, D., Bennet, E., Tutin, C., Van Tol, G., Christophersen, T. (2008). Conservation and use of wildlife-based resources: the bush meat crisis. Secretariat of the Convention on Biological Diversity, Montreal, and Center for International Forestry Research, Bogor. Technical Series no. 33, 50 p.

Neil, C., Tykkyläinen, M. (1998). An introduction to research into socioeconomic restructuring in resource communities, chapter 1 in: Local economic development: A geographical comparison of rural community restructuring, eds. Cecily Neil and Markku Tykkuläinen, Tokyo: United Nations University Press: 3-24.

Neumann, A., Macintyre, I. (1985). Reef response to sea-level rise: keep-up, catch-up, or give-up. In Proceedings of the Fifth International Coral Reef Congress, Tahiti. Vol. 3, pp. 105–110.

Nunn, P. (1990). Recent Environmental Changes on Pacific Islands. The Geographical Journal, 156(2), 125-140. doi:10.2307/635320.

Nunn, P. (1994). Oceanic Islands. Oxford, Blackwell. 418 pp.

Nunn, P. (1997). Keimami sa vakila na liga ni Kalou (Feeling the hand of God): human and nonhuman impacts on Pacific island environments. Suva, Fiji: School of Social and Economic Development, The University of the South Pacific. (3rd revised edition), 72 pp.

Nunn, P., Kumar, L., Eliot, I. (2016). Classifying Pacific islands. Geosci. Lett. 3,7. https://doi.org/10.1186/s40562-016-0041-8.

Orliac, C. (1986). Identification botanique effectuée sur cinq Ti'i des Iles Marquises. CNRS UA 275. Ethnologie préhistorique. 13 pp.

Piesse, M. (2019). Papua New Guinean Agriculture: Significant Opportunity and Much Peril. A Future Directions International. https://apo.org.au/node/251201.

Poloczanska, E., Limpus, C., Hays, G. (2010). Vulnerability of marine turtles to climate change. Advances in Marine Biology (Vol. 56). https://doi.org/10.1016/S0065-2881(09)56002-6.

Portner, H., Karl, D., Boyd, P., Cheung, W., Lluch-Cota, S., Nojiri, Y. Zavialov, P. (2014). Ocean systems. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 411– 484. https://doi.org/10.2134/jeq2008.0015br.

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

Richardson, D. (1985). Tropical forestry in Melanesia and some Pacific Islands. in Environment and resources in the Pacific, UNEP 69: 107-113.

Riddel, M. ((2000). Housing market dynamics under stochastic growth: an application to the housing market in Boulder, Colorado, Journal of Regional Science, Vol. 40(4), 771-788.

Rolett, B. (2002). Voyaging and interaction in ancient East Polynesia. Asian Perspectives, 2002.

Rull, V. (2019). Human Discovery and Settlement of the Remote Easter Island (SE Pacific). Quaternary. 2. 15. 10.3390/quat2020015.

Sarout, D., Chae, X. (2015). Not just carbon: Assessment and prospects for the application of anthracology in Oceania. Archaeology in Oceania. -22. 10.1002/arco.5041.

Schieffelin, E. (1975). Felling the trees on top of the crop: European contact and the subsistence ecology of the Great Papuan Plateau. Oceania 46(1):25–39, https://doi.org/10.1002/j.18344461.1975.tb01885.x.

Sharrok, S., Frison, E. ((1998). Musa production around the world - trends, varieties and regional importance". Networking Banana and Plantain. International Network for the Improvement of Banana and Plantain (INIBAP) & Bioversity International. pp. 42–47. Retrieved July 23, 2020.

Silberstein, J., Maser, C. (2000). Land-Use Planning for Sustainable Development. Sustainable Community Development Series, CRC Press LLC.

SPC. ((2016). Vulnerability of Pacific Island agriculture and forestry to climate change. edited by Mary Taylor, Andrew McGregor and Brian Dawson, ISBN: 978-982-00-0882-3.

SPREP. (2014). State of Conservation in Oceania 2013. Regional volume. Secretariat of the Pacific Regional Environment Programme, Apia.

Stevenson, C., Wozniack, J., Haoa, S. (1999). Prehistoric agricultural production on Easter Island (Rapa Nui), Chile. Antiquity 73, 801-812.

Stevenson, J., Benson, A., Athens, J., Kahn, J., Kirch, P. (2015). Polynesian colonization and landscape changes on Mo'orea, French Polynesia: The Lake Temae pollen record. The Holocene 27 (12) 1963-1975.

Stone, E., Migvar, L., Robison, W. (2000). Growing plants on atoll soils. UCRL-LR-137517 U.S. Department of Energy, Lawrence Livermore National Laboratory. University of California, Livermore, CA.

Strathern, A., Stewart, P., Carucci, L., Poyer, L., Feinberg, R., Macpherson, C. (2002). Oceania: An Introduction to the Cultures and Identities of Pacific Islanders. Durham, N.C.: Carolina Academic Press, 249p.

Thaman, R. (1990). Coastal restoration and agroforestry as immediate ameliorative measures to address global warming and to promote sustainable habitation of low-lying coastal areas. In Streets, DG, and Siddiqi T.A. (Eds.) Responding to the threat of global warming: options for the Pacific and Asia. Argonne National Laoratory, Argonne, pp. 4.33-4.57.

Thaman, R., Fosberg, F., Manner, H., Hassall, D. (1994). The flora of Nauru, Atoll Research Bulletin. 392:1–223.

United Nations University. (1993). Agroforestry in the Pacific Islands: Systems for Sustainability. Tokyo, 297p.

Vitousek, P., Sanford, R. (1986). Nutrient cycling in moist tropical forests. Annual Review of Ecology and Systematics 17:137–167.

Ward, R. (1985). Agriculture, size and distance in South Pacific island futures, in Environment and resources in the Pacific. UNEP No 69: 19-27.

Weisler, M. (1997). Prehistoric Long-Distance Interaction in Oceania: An Interdisciplinary Approach. New Zealand Archaeological Association Monograph No. 21. Auckland: New Zealand Archaeological Association.

Westphal, E., Arora, R. (1989). Plant resources of South-East Asia. Prosea Project.

Whistler, W. (2009). Plants of the Canoe People. National Tropical Botanical Garden, Lawai, Kaua'i, Hawai'i.

Whiting, S., Whiting, A. (2011). Predation by the saltwater crocodile (Crocodylus porosus) on sea turtle adults, eggs, and hatchlings. Chelonian Conservation and Biology 10: 198-205.

Whytlaw, P., Will, E., Bradley, C. (2013). Marine turtle nest depredation by feral pigs (Sus scrofa) on the Western Cape York Peninsula, Australia: implications for management. Wildlife Research 40(5), 377-384.

Wilke, M., Eckelmann, C., Laverdiere, M., Mathias, A. (2002). Forests and forestry in Small Island Developing States. International Forestry Review. 4(4): 257-267.

Wilmshurst, J., Atholl, A., Higham, T., Worthy, T. (2008). Dating the late prehistoric dispersal of Polynesians to New Zealand using the commensal Pacific rat. PNAS 105 (22) 7676-7680.

World Checklist of Selected Plant Families (WCSP). (2017). Nypa fruticans, Royal Botanic Gardens, Kew. Retrieved 9 January 2017.

World Data. (2020). The world in numbers. Available at www.worlddata.info [accessed 15 April 2020].

Worthy, T., Anderson, A. (2009). Results of paleofaunal research. in Geoffrey Clark and Atholl Anderson (ed.), The Early Prehistory of Fiji, ANU ePress, Canberra, Australia, pp. 41-62.

Yen, D. (1993). The Origins of Subsistence Agriculture in Oceania and the Potentials for Future Tropical Food Crops. Economic Botany, 47(1), 3–14. Retrieved from www.jstor.org/stable/4255478.

Young, A. (1998). Land resources: now and for the future. Cambridge University Press, Cambridge, UK.

Zeagler, A. (2002). Hawaiian natural history, ecology and evolution. Honolulu: University of Hawai'i Press.