Agroforestry and Its Impact in Southeast Asia

Summary

Research during the late 20th and early 21st centuries found that traces of human intervention in vegetation in Southeast Asian and Australasian forests started extremely early, quite probably close to the first colonization of the region by modern people around or before 50,000 years ago. It also identified what may be insubstantial evidence for the translocation of economically important plants during the latest Pleistocene and Early Holocene. These activities may reflect early experiments with plants which evolved into agroforestry. Early in the Holocene, land management/food procurement systems, in which trees were a very significant component, seem to have developed over very extensive areas, often underpinned by dispersal of starchy plants, some of which seem to show domesticated morphologies, although the evidence for this is still relatively insubstantial. These land management/food procurement systems might be regarded as a sort of precursor to agroforestry. Similar systems were reported historically during early Western contact, and some agroforest systems survive to this day, although they are threatened in many places by expansion of other types of land use. The wide range of recorded agroforestry makes categorizing impacts problematical, but widespread disruption of vegetational succession across the region during the Holocene can perhaps be ascribed to agroforestry or similar land-management systems, and in more recent times impacts on biodiversity and geomorphological systems can be distinguished. Impacts of these early interventions in forests seem to have been variable and locally contingent, but what seem to have been agroforestry systems have persisted for millennia, suggesting that some may offer long-term sustainability.

Keywords

agroforestry, Southeast Asia, Papua New Guinea, Borneo, vegetation management, paleoecology, economic prehistory, sustainability, human impact

Introduction

In this article, agroforestry is defined as a cultivation and land-use regime where trees are a significant but by no means exclusive component of the economically significant plants. The plants in agroforestry systems include at least some of humanly managed/propagated trees, shrubs, lianes, or herbs intercalated with varying incidences of spontaneous plants and/or wild vegetation persisting from a previous uncultivated state. This definition broadly follows those of Nair (1985), Torquebiau (2000), and Feintrenie, Chong, and Levang (2010). An agroforest differs from a plantation because it is a biodiverse system where a variety of trees, lianes, shrubs, and herbs may be planted and exploited or will occur naturally—and these spontaneous plants may also be exploited. Agroforestry differs from arable agriculture in the presence of trees and a wide variety of other vegetation, including usually multiple species that are cultivated/tended and exploited. Traditional agroforestry systems in Southeast Asia are characterized by very high biodiversity compared with other productive land uses, and there is good evidence that their social embeddedness and ecosystem functioning can result in long-term sustainability (Belcher, Michon, Angelson, Ruiz Perez, & Asbjornsen, 2005; Wiersum, 1997).

It is important to note that, in the Southeast Asian context, traditional land-use systems have varied—and still vary—enormously in the intensity of human intervention and the physiognomy of the resulting vegetation. This ranges from old-growth forests with minimal manipulation (the decision to leave areas undisturbed is in itself a management decision!), through forests exploited for timber extraction but with no other management, via forests modified to favor naturally occurring economically useful species, forests modified to favor propagated economically useful species, to “forest gardens” where most vegetation is planted and managed actively to finally plantations and field agricultural systems where single species are planted and managed (e.g., Belcher et al., 2005; Michon & de Foresta, 1995; Wiersum, 1997). Not all of these, of course, can be classified as agroforests, but it is likely that many groups would not perceive as a specific type of land use those parts of this continuum that we would perceive as agroforestry.

In Southeast Asia and northern Australasia, the range and diversity of types of agroforestry and agroforestry products and their social embeddedness is considerable (Belcher et al., 2005; Latinis, 2000; Denham, 2005, 2017; Kennedy, 2012; Wiersum, 1997). For instance, Watanabe et al. (1990) recorded tea gardens, some over 100 years old, made by clearing vegetation around naturally occurring bushes in northern Thailand. Aubertin (2004) documented Lao planting medicinal cardamom (*Ammomum* spp.) in forest areas near their villages, and a similar practice by Kelabit in the Kelabit highlands of Sarawak was observed by the author (unpublished observations). Similar is the Penan practice of planting and tending sago (*Eugeissona utilis* Becc.) in riverine forest in the Mulu National Park as part of an economy otherwise dependent on hunting and gathering wild plants (Kedit, 1982). Although Penan in the Kelabit Highlands say that they do not plant sago they certainly tend it, often in ridgetop sites which seem atypical of natural occurrences of this species (Janowski, 2003; Janowski & Langub 2011).

More active management of complex agroforests in Sumatra yields a basket of products, including dammar (resin of white meranti *Shorea javanica* Koord. & Valeton) or benzoin (resin of *Styrax pararelloneurum* Perk.) and rubber (*Hevea brasiliensis* [Willd. ex A. Juss.] M.A.), plus food plants—some of which are planted—including durian (*Durio zibelinthus* L.), langsat (*Lansium domesticum* (Osbeck) K. C.Sahni & Bennet), bitter bean/petai (*Parkia* *speciosa* Hassk.), jenkol (*Pithecellobium jiringa* (Jack) Prain), menteng (*Baccaurea racemosa* (Reinw. ex Bl., Mull.Arg.), chempedak (*Artocarpus integer* Spreng), mango (*Mangifera indica* (Dalz.) Airy Shaw), rambutan (*Nephelium lappaceum* L), coffee (*Coffea* ssp.), cinnamon (*Cinnamomum porrectum* Kosterm.), sugar-palm (*Arenga pinnata* (Wurmmb.) Merr.), betel-palm (*Areca catechu* L.), water apple (*Eugenia* spp.), bananas (*Musa* spp.), and chili pepper (*Capsicum annuum* L.) (Boer & Ella, 2000; de Foresta & Michon, 1997; de Foresta, Michon, Kusworo, & Levang, 2004; Fernàndez, 2004 Michon & de Foresta, 1995). There is evidence that some dammar agroforests have been actively used for more than 200 years in Sumatra (de Foresta et al., 2004), while Gibbs (1914) wrote about dammar and rattan agroforests in Sabah being used since time immemorial.

It is worth noting that some dammar and benzoin agroforests result from planting of trees in existing forests. Others, however, were initially swidden (slash and burn) plots, used for hill (non-irrigated) rice, then developed as plantations for coffee (*Coffea* spp.) or pepper (*Piper nigrum* L.), among which dammar or benzoin trees were planted, to take over as yields of these crops declined (de Foresta et al., 2004; Fernàndez, 2004). Similarly, in southeast Kalimantan, agroforests known as *simpukng*, from which 143 useful species are harvested, can originate from modified primary or secondary forest or occur by modifying regenerating vegetation after swiddening (Mulyoutami, Riswahan, & Joshi, 2009). Also in Kalimantan, rattan gardens originate where rattan palms (*Calamus* or *Daemonorops* spp.) and sometimes rubber trees are planted in swiddens alongside hill rice. After the rice crop is harvested, the rattans grow in regenerating secondary forest and are harvested annually from about eight years after planting (Pambudhi, Belcher, Levang, & Dewi, 2004). Similar pathways to agroforestry from rice agriculture have been noted in Sulawesi for cocoa, in Lampung for coffee, in eastern Sumatra for rubber (Feintreinie et al., 2010), and in Maluka for diverse agroforests (Latinis, 2000).

Forest gardens are planted, or grow up, on old habitation sites. For instance, the Kelabit of northeastern Sarawak lived in communal longhouses holding about 200 people. After occupying a site for about 5 years, they would move to a new site and plant fruit trees on the old site with an expectation of returning to the site to build a new longhouse in 60 or more years, by which time the trees would be mature and bearing fruit. They would return to old longhouse sites episodically to monitor the growing trees and to clear encroaching vegetation, if necessary (Janowski, 2003).

Agroforests have also been reported from Papua New Guinea and Melanesia among the considerable diversity of land-management systems in the region (Ellen, 2011; Kennedy, 2012; Kennedy & Clarke, 2004; Latinis, 2000; Yen, 1974, 1996). Kennedy (2012) notes that 29 tree crop species are grown in the majority of the provinces of New Guinea, often in cultivation systems involving root crops and arboreal species. Of particular importance in lowland systems and often associated are sago (*Metroxylon sagu* Rottb.), breadfruit (*Artocarpus* spp.), and tulip (*Gnetum gnemon* L.). In the islands, breadfruit (*Artocarpus* spp.), ton (*Pometia pinnata* Forst.), and galip (*Canarium* spp.) are often associated, while in the uplands the key tree is marita (*Pandanus* spp.). Kennedy (2012, p. 143) argues that, in the region, root crops are “inextricably enmeshed . . . with management of tree crops.” There is growing evidence that these systems have considerable antiquity.

Establishing the antiquity and evolution of agroforestry systems is extremely difficult. Direct evidence for human use of plants requires identification and dating of their remains, in association with traces of human activity, and preferably direct evidence for them being processed and used by people. In moist and seasonally wet tropical environments, where organic decay is extremely rapid, preservation of the remains—through waterlogging or charring—has to have occurred for survival of macroscopic remains, such as nutshells, seeds, parenchyma (soft tissue such as the insides of tubers), leaves, and wood. Localities with waterlogged remains are very rare, and although charred remains survive more widely, the general sparsity of archaeological investigations means that at time of writing very few charred macrofossil assemblages have been published. In default of macroscopic remains, microscopic remains such as phytoliths, starch granules (e.g., from yams and taro), and pollen grains may sometimes yield important information, but the direct link with human activity is sometimes less easy to establish than with plant macroremains. Much of the identification of these macroscopic and microscopic plant remains requires high-power optical or scanning electron microscopy, and few specialists are available. The anatomy of many useful plants, particularly at the microscopic level, has not been studied in sufficient detail for conclusive identification, so typically researchers have to build and study their own type collections of botanically attested plants before they can study ancient plant remains.

When did agroforestry become agroforestry, and what were its precursors? And how might we recognize them and their impacts in the past? Below, this contribution summarizes the paleoecology and impact of what appear to be human activities that might be construed as agroforestry or its precursors in Southeast Asia.

One major barrier for work on ancient systems is that it is generally impossible, except in very rare cases, to reconstruct the detailed spatial arrangement of plants required for certain identification of an agroforest system. Therefore, identification of combinations of useful trees, shrubs, herbaceous plants, and tuberous plants is regarded as strongly suggestive of agroforestry, particularly where evidence for open fields is lacking. Neither, at the time of writing, is it possible to identify unequivocally ancient impacts on biodiversity or on the physical landscape. These issues are therefore addressed by reference to contemporary studies or studies of the very recent past.

It is clear from accounts of current and recent historical agroforests that domestication (which typically results in changes to the shape, behavior, and reproduction of a plant) is not necessary for plants to be exploited in an agroforest system. Neither do all useful plants exploited in an agroforest system require positive management, tending, or cultivation, since some may occur spontaneously as the result of natural processes. It is of course the case that people will not always exploit available resources, so evidence for presence is not necessarily the same as evidence for use, and this is a concern, particularly in the absence of macroremains showing clear evidence for human exploitation. It is, however, highly likely that humans exploited those plants, which can be demonstrated to be outside their native range, since the deduction is that these translocated plants were brought into the study area so that they could be used (e.g., Hunt & Premathilake, 2012; Hunt & Rabett, 2014). Unfortunately, the native ranges of several key plants, including taro and some yams, are very poorly known.

It should be pointed out that much of the evidence described and discussed in this article is relatively insubstantial, and some may be subject to alternative explanation. Some modern, highly rigorous studies are difficult to discount, and there is a consistent pattern across this immense region that seems consistent with the hypotheses put forward here. The observations summarized in this article are of significance because they have implications for the successful management of the remaining agroforests—and, indeed, large areas regarded as "natural vegetation" in the region.

The Study Region

The study region is the ancient drowned continent of Sundaland and the northern part of the drowned continent of Sahul and adjoining archipelagos (Figure 1; Hanebuth, Stattegger, & Bojanowski, 2009; Wurster & Bird, 2015). These vast landmasses were exposed during episodes of low sea, caused by evaporative drawdown of the global oceans and the lockingup of vast quantities of precipitation in the great Pleistocene icecaps during the stadial (glacial) stages. Sundaland lay between and incorporated peninsular Southeast Asia and Java, Sumatra, Borneo, and associated islands, with Palawan and the Philippine Archipelago as large islands close offshore. This region was separated by a deep-water channel along the great biogeographical discontinuity we call the Wallace Line, from neighboring Sahul, a drowned continent that incorporated Australia and New Guinea, with numerous sizable adjacent islands including Timor, Flores, and Sulawesi. The Wallace Line is a discontinuity of ancient status and enormous evolutionary significance. It separates the biotas of Asia—marked botanically by families such as the Oaks (Fagaceae) and zoologically by the Ungulates (deer, antelopes) and Carnivora (wolves, tigers)—from those of the ancient southern continent of Gondwanaland, which are characterized botanically by the Eucalypts and zoologically by the Marsupials (kangaroos, opossums) and Monotremes (echidna and platypus).

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The vegetational record of these vast landmasses over the last ~50,000 years seems to be locally contingent, depending on altitude, substrate, continentality, and exposure to oceanic prevailing winds, but the general impression during stadial phases (cold periods in the Northern Hemisphere during the last glacial period—defined as extending from ~75,000 to 11,500 years ago) is of generally lower effective humidity and temperatures lower by 5 to 10°C than those of the late 20th and early 21st centuries CE (e.g., Hope et al., 2004; Hunt Gilbertson, & Rushworth, 2012; Hunt, Kealhofer, Premathilake, Rushworth, Gilbertson, Jones, & Barker, 2016; Partin, Cobb, Adkins, Clark, & Fernandez, 2007; Wurster et al., 2010). During interstadials (warm intervals in the Northern Hemisphere during the last glacial period) and the current temperate phase, known as the Holocene (which extends from 11,500 years ago to the time of writing in 2019), a consensus of evidence suggests that effective humidity and temperatures seem to have been fairly similar to those of the late 20th and early 21st centuries (e.g., Anderson & Muller, 1975; Anshari, Kershaw, & van der Kaars, 2001; Anshari, Kershaw, van der Kaars, & Jacobsen, 2004; Flenley, 1979; Hope, 2009; Hope et al., 2004; Hunt et al., 2012, 2016; Kamaludin & Azmi 1997; Maloney & McCormack, 1996; Partin et al., 2007; van der Kaars & Dam, 1995, 1997; van der Kaars, Wang, Kershaw, Guichard, & Setiabudi, 2000; van der Kaars et al., 2001; van der Kaars, Bassinot, De Deckker, & Guichard, 2010; White, Penny, Kealhofer, & Maloney, 2003). In subrecent times, most of this vast region was covered with ever-wet or seasonal forests, which are being eroded rapidly at the present day.

The nature of the archaeological and paleoecological record is an issue in any plant-based reconstruction of the past. There are few well-researched archaeological and paleoecological sites, particularly of Pleistocene age, in this enormous region. Part of this can be ascribed to the difficulty of locating archaeological sites in forested terrain, but it also reflects the lack of local archaeological research traditions in some developing economies and the sparseness of interest from international researchers. Many of the well-researched archaeological sites are caves, and of these, only at Niah Cave is there a pollen record (Hunt et al., 2012, 2016). Macrofossil paleobotany has been done on only a handful of sites (e.g., Barker, Hunt, & Carlos, 2011; Barton, Paz, & Carlos, 2016; Bellwood et al., 1992; Doherty, Beavitt, & Kerui, 2000; Paz, 2005), and studies involving phytoliths and starch are also still very rare (e.g., Barker et al., 2011; Hunt et al., 2016; Jones, Hunt, Barton, Lentfer, & Reimer, 2013a; Jones, Hunt, & Reimer, 2013b; Kealhofer 2002, 2003; Kealhofer & Piperno 1994; Lentfer, Pavlides, & Specht, 2010). We are therefore dealing with sparse and patchy evidence. Nevertheless, broad patterns of human activity and vegetational response can be identified.

Traditional Livelihoods and Plant Use in Sundaland and Sahul

In some traditional societies in Southeast Asia, the separation of roles identified in Western societies between hunters, cultivators, and foresters would not be recognized (e.g., Barker & Janowski, 2011; Belharte, 2011; Janowski, 2003; Janowski & Langub, 2011). People forage wild resources, manage forests and agroforests, and cultivate plants without drawing strong distinctions between most of these activities. The exception is monoculture rice, which often has cultural significance (Barker, Hunt, Hill, Jones, & O'Donnell, 2019; Barker & Janowski, 2011), but this is grown in swiddens or paddy fields, so is not part of arboricultural systems per se, although former rice cultivation sites often become incorporated in arboricultural activities. Trees are an important component of the totality of cultivated plants, but the distinction between wild and cultivated plants is extremely indefinite and flexible. People go into the forest to gather wild plants to cultivate in their gardens, and plants escape from cultivation into the wild (Janowski, 2003; Kennedy, 2012).

In general, selective breeding of cultivated plants does not happen easily, since the gene pools of cultivated and wild plants intermix because of the lack of geographic separation, because people take plants from the wild to cultivate, and because cultivated plants escape easily into the forest. On the other hand, some plants appear to have been modified by long association with people. Thus, some sago palms die after flowering or are killed by the cutting of the main stem to extract sago, but the predominant form of Hill Sago (*Eugeissona utilis* Becc.) in the Kelabit Highlands of Borneo forms long-lived clumps by throwing new shoots from the base of the plant, thus providing a long-lived resource that withstands repeated cropping. Some yam (*Dioscorea*) varieties in the Kelabit Highlands do not flower and only seem to be reproducible through cuttings, thus conforming to the pattern seen in domesticated yams in Papua New Guinea (Denham, 2005, 2011).

Late Pleistocene Landscape Management and Plant Food Production

Sea level change led to profound changes to the geography of Southeast Asia during the Late Pleistocene and Holocene (Figure 1; see also Wurster & Bird, 2015). During times where sea levels were low, the Sunda Shelf was exposed and the Southeast Asian archipelago became part of the Eurasian landmass. We call this extended Southeast Asian landmass “Sundaland.” At these times, continentality increased dramatically, and large parts of the interior in this larger landmass became too dry for forest vegetation, resulting in the spread of savannah grasslands (Bird, Taylor, & Hunt, 2005; Hunt, Gilbertson, & Rushworth, 2007; Hunt et al., 2012, 2016). During high-sea stages, the continental shelf became flooded, rainfall rose, and continentality diminished, leading to the spread and rise in density of forest vegetation.

It has been suggested that modern humans left Africa during the last interglacial period and teeth in China (Liu et al., 2015) have been attributed to these early colonists. Early dates have also been suggested for the colonization of Australia (Clarkson et al., 2017). Humans seem to have reached Niah Cave in Borneo around 53,000 years ago (Hunt et al., 2012), although an earlier date cannot be excluded. From the beginning of activity at Niah, people were hunting ground fauna (mostly bearded pig but including a wide variety of other animals) and canopy-dwellers such as monkeys and orangutans (Barker et al., 2007; Piper & Rabett, 2016).

Alongside hunting, people were gathering and processing sago (*Caryota mitis* Lour. or *Eugeissona utilis* Becc.), yams (*Dioscorea* spp.), aroids (*Alocasia* spp., *Cyrtosperma merkusii*

(Hassk.) Schott), *Canarium* nuts, and other plants (Table 1; Barton, 2005; Barton et al., 2016; Paz, 2005). These were all wild plants, but there is palynological evidence for landscape burning associated with three rather wet interstadial episodes around 53,000, 50,000, and 43,000 cal. BP, whereas there was no convincing evidence for landscape burning during dryer cooler climates between these episodes, perhaps suggesting that forest margins close to Niah Cave were burned purposefully when forest vegetation became dense (Hunt et al., 2007, 2012, 2016). Burning would have initiated forest regeneration, providing attractive habitats for bearded pig, sago palms, and tuberous starchy plants. At Niah, use of *Alocasia* spp., *Colocasia* cf. *esculenta*, sago, and many other plants seems to have continued through the Late Pleistocene, although the sedimentary record is discontinuous (Barton et al., 2016; Hunt et al., 2016).

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Vegetation manipulation for Papua New Guinea was suggested by Les Groube and Jack Golson (Golson, 1985, 1989; Golson & Hughes, 1980; Groube, 1989) and dated to 48,000 cal. BP at Kosipe in the Ivane Valley, where waisted axes, with yam (*Dioscorea alata* L.), starch and charred *Pandanus* nuts, have been found in association with evidence for burned forest (Summerhayes et al., 2010, 2017). The site lay above the natural altitudinal limit for yams at this time; it is thus possible that people translocated them into the valley (Summerhayes, Field, Shaw, & Gaffney, 2017). Data for much of the rest of the Pleistocene is very sparse, although forest burning and use of *Pandanus* is known to persist in some parts of the New Guinea Highlands until the Last Glacial Maximum (Fairbairn, Hope, & Summerhayes, 2006; Haberle, 1998, 2005; Haberle, Hope, & van der Kaars, 2001; Hope, 1998, 2009; Summerhayes et al., 2010, 2017), and forest burning appears at low altitude 35,000 years ago (Lentfer et al., 2010). Early colonists elsewhere in the Sahul region also seem to have practiced biomass burning (e.g., Kershaw et al., 2003; van der Kaars et al., 2001; 2010). In both Sundaland and Sahul, people manipulating vegetation and using wild food plants during the Pleistocene cannot be regarded as agroforestry as such but perhaps a stage of land use that developed knowledge and capabilities which later made possible this type of land use.

The finding of yams and taro in the Late Pleistocene/Early Holocene on both sides of the Wallace Line (the major and very ancient biogeographical discontinuity and deep-water barrier separating the Eurasian and Australian biogeographical provinces) is difficult to explain without invoking human agency since it is unlikely that these plants could have crossed this significant barrier by natural means, and the biogeographical separation is so ancient that evolution would have separated taxonomically those plants which persisted on both Eurasia and Australia from Pangaea (the ancient mega-continental landmass that broke up in the Mesozoic). A similar argument is made by Denham (2004, 2011). Given that yams and taro seem to have been exploited both sides of the Wallace Line during the latest Pleistocene (Table 1), it is tempting to suggest that these important food plants were dispersed by the first modern human colonists in the region. Similar suggestions have been made about the dispersal of economically important animals across the region during the Late Pleistocene (summarized in Hunt & Rabett, 2014).

Early Holocene Agroforestry

Evidence, although patchy, is more widespread for what might be called agroforestry-related activities from the Early Holocene, 11,200 years ago (Figure 2). There is more evidence for plant translocation, particularly of plants probably originating in New Guinea. For instance at the Bubog 1 site on Ilin Island, in the Philippines, 11,000-year-old *Dioscorea alata* parenchyma was sufficiently similar to that of modern domesticated varieties for Pawlik et al. (2017) to suggest that cultivation of these yams was occurring, along with gathering of wild plant foods including *Canarium* nuts. A similar suggestion was made for Ille Cave, Palwan, where charred *Canarium* and *Celtis* nuts, parenchyma comparable with wild *Dioscorea hispida* Dennst, domesticated *D. alata*, *Colocasia esculenta* (L.) Schott, and seeds of the fibre plant *Boehmeria*, was reported in deposits 10,000 to 9,500 years old (Barker et al., 2011). There is also evidence for *Dioscorea hispida* at Mabangog Cave, Luzon, around 10,000 years ago (Paz, 2005).

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The 42-m-deep Loagan Bunut borehole in lowland Sarawak sampled shallow back-estuarine sediments dating between 11,500 and 6500 cal BP. Hunt and Premathilake (2012) identified pollen of several sago palms (Table 1). After each species appeared, it was present consistently in the core. They are associated with evidence for a significant and consistent pattern of forest burning and disturbed, regenerating vegetation during the early and mid-Holocene. Very abundant wild rice phytoliths, many of them burned, were also recorded through the same interval (Hunt et al., 2016).

It seems likely that people at Loagan Bunut burned vegetation in near-freshwater wetlands at the back of the ancient estuary to allow wild rice to flourish and that plants on dryland sites nearby were controlled to enable the growth of sago palms, which would otherwise struggle in high lowland rainforest. This raises the distinct possibility that people were carrying out activity similar to *molong* practiced by the modern Penan, who plant seeds of sago palms, keep vegetation from encroaching on the growing plants, and then harvest the mature stems, although most of their economy is based on foraging (Barker et al., 2019; Kedit, 1982). It is possible that the type of burning regime which seems to have occurred at

Niah during the Pleistocene was still practiced, but on a more regular basis at Loagan Bunut to maintain productive forest-edge habitats. *Metroxylon* is adapted to grow on peat mires, whereas the other sago palms in the pollen record at Loagan Bunut are dryland taxa. It is thus possible to hypothesize that acquisition of this species enabled the people at Loagan Bunut to extend the range of their food production into otherwise rather unproductive peat swamps. *Metroxylon* is indigenous to New Guinea, so its presence during the Early Holocene in Borneo is very likely to be linked to long-distance networks of exchange (for archaeological evidence for Early Holocene exchange networks involving material culture such as stone axes, see, e.g., Blench, 2010; Bulbeck, 2008). The role of tuberous plants cannot be demonstrated from the Loagan Bunut site, but it would be surprising, given their use during the Pleistocene at Niah (which is less than 80 km away), if they were neglected in the Early Holocene. What appears to have been long-term cultivation starting ca. 6,500 years ago was also recorded in the swamps close to Niah (Hunt & Rushworth, 2005).

In Papua New Guinea there is evidence for the use of taro, a yam, wild bananas, and pandanus in what was probably an incipient agroforestry system at Kuk Swamp in the Waghi Valley from 10,000 years ago (Denham et al., 2003). Although the precise interpretation of the evidence is still to be settled, the earliest phase seems to have included the cultivation of taro, cane grass (perhaps *Setaria palmifolia* (K. D. Koenig) Stapf.), Musa bananas, gingers (Zingiberaceae), yam (*Dioscorea* sp.), vegetables (*Coleus* sp., *Oenanthe javanica* (Blume) D.C., *Solanum* sp.), berries (*Rubus* spp.), and trees (*Castanopsis* sp., *Pandanus* spp.) (Denham et al., 2003; Denham, Golson, & Hughes, 2017a; Denham, Haberle, & Lentfer, 2004; Haberle, Lentfer, & Denham, 2017; Lentfer & Denham, 2017). The natural altitudinal limit for taro is below the altitude of the Waghi Valley sites at Kuk, so its presence there at 10,000 years ago was argued by Denham et al. (2003) to be the result of human import and cultivation. This early system seems to have morphed into mound-based agriculture and swiddening on adjacent hillslopes by ~7,000 years ago (Denham et al., 2017a; Denham, Golson, & Hughes, 2017b, 2017c).

In the Sepik lowlands here are suggestions of systems using galip (*Canarium* sp.), ton (*Pometia pinnata* Forst.), coconut (*Cocos nucifera*. L.), and *Pandanus* fruits at 6,900 to 6,670 cal. BP at Dongan (Fairbairn, 2005). There is also phytolith evidence for what appears to have been agroforestry from ~6,500 years ago at Yombon, New Britain (Lentfer et al., 2010), with bananas and later sago and other plants.

Later in the Holocene, there is scattered evidence for the dispersal and use of starchy plants. Maritime connectivity through the region is indicated by the appearance in Sri Lanka of phytoliths comparable with those of domesticated bananas around 6,000 years ago, less than a millennium after their first appearance in Papua New Guinea (Premathilake & Hunt, 2018). Phytolith studies of suitable sites for the period in Southeast Asia have not been done (the Loagan Bunut sequence ends just too early), but it is possible that they would show the appearance of domesticated bananas across the region around this time.

Jones et al. (2013a) and Barker et al. (2019) report the brief appearance of fruit tree and *Caryota* sago pollen in the Kelabit Highlands of Sarawak ca. 6,000 years ago and the appearance and then consistent presence of taro and *Eugeissona* from ca. 4,200 years ago. These plants are not recorded from the Pleistocene in the highlands, so appear to have been translocated from the lowlands.

Taro appears with Cucurbitaceae seeds and *Canarium* nuts at Leang Burung, Sulawesi, ca. 5,500 years ago, and *Ipomoea batatas* (L.) Lam. and *Vigna* seeds appear there 3,500 and 3,000 years ago, respectively (Paz, 2005). *Ipomoea* is particularly noteworthy because it derives from South America, suggesting a maritime connection by this time—if this can be further substantiated.

At Kuk, the early Holocene mound-based cultivation system was replaced by a field system defined by ditches around 4,000 years ago. Both are probably better defined as agriculture rather than agroforestry, because trees do not seem to have been significant (Denham et al., 2017b, 2017c).

Taro and the yam *Dioscorea alata* L. appear at Madai (Sabah) 1,500 to 2,000 years ago (Paz, 2005). Finally, Gibbs (1914) documents large-scale agroforestry and managed secondary forests in Sabah at the beginning of the 20th century.

In most of these cases the context of the growth of these plants is uncertain. Where evidence is available, most seem to be associated with evidence for wild tree species, for instance, the presence of *Canarium* nuts and other tree-derived seeds (Barker et al., 2011; Barton et al., 2016; Pawlik et al., 2017; Paz, 2005). Palynological evidence of the general aspect of the vegetation where there are good grounds to infer agroforestry or other forms of cultivation is present at the Niah, Loagan Bunut, Kelabit Highlands, Kuk, and Yombon sites, where there is evidence for rather disturbed forest with canopy openings or more extensive areas of open ground (Barker et al., 2019; Denham et al., 2003, 2017a; Haberle, Lentfer, O'Donnell, & Denham, 2012; Hunt & Premathilake 2012; Hunt et al., 2016; Hunt & Rushworth, 2005; Lentfer et al., 2010). Contrarily, a significant proportion of Holocene pollen sites in Island and Mainland Southeast Asia show evidence for significant long-term forest disruption but as yet without evidence for economically useful plants (especially in Sumatra; e.g., Hunt & Rabett, 2014; Maloney, 1980, 1985, 1999; Morley, 2000; Newsome & Flenley, 1988). There is, however, no site comparable with that at Kuk Swamp in the Papua New Guinea highlands (Denham, 2011; Denham et al., 2003, 2004, 2017a, 2017b, 2017c; Haberle et al., 2012), where early to mid-Holocene cultivation features, phytoliths, and palynological evidence occur together, enabling the recognition of an independently evolved agricultural/arboricultural system. Nevertheless, it seems likely that a range of land management/food production practices, including systems we would recognize as arboriculture, were operating during the Holocene in the wider region.

Biotic Impact of Arboriculture

The very wide spectrum of attested arboricultural and landscape management regimes in the region, mentioned in the Introduction, suggests that there is likely to have been an equally variable range of impacts. Nevertheless, all of these are likely to have been less severe than the impacts of monocultural rice cultivation or industrial forestry at the present day. There is evidence that biodiversity remains high (including retaining some critically endangered mammal species) in contemporary arboricultural systems compared with plantations or rice fields, although lower than in primary forest (Bowman, Woinarski, Sands, Wells, & McShane, 1990; Kenzo et al., 2010; Michon & de Foresta, 1995; Poffenberger, 2006; Rerkasem et al., 2009). It is worth noting that crude biodiversity measures may not tell the whole story—disruption of ecosystems can in some circumstances increase overall biodiversity because of the incoming of exotic taxa, but a consequence may be the loss of those species that are vulnerable to disruption and their replacement by tough generalist taxa of low conservation value. In the forests of Southeast Asia, the incoming species following forest disruption are tough, rapidly growing early successional taxa such as *Macaranga*, *Artocarpus*, and *Ficus* (e.g., Brearley, Prajadinata, Kidda, Procter, & Suriantata, 2004; Hunt & Rabett, 2014; Kenzo et al., 2010; Slik, Verburg, & Kessler, 2002), and it may take several hundred years for the more vulnerable old-growth taxa to re-establish.

Measuring biodiversity in the past is extremely difficult because the way that remains arrive at deposition sites and are preserved in them impact the biodiversity of the resulting fossil assemblage. The successional floras that follow forest disruption and charred material resulting from fire are easier to see (Hunt & Rabett, 2014). During the Pleistocene, it is likely that most—if not virtually all—vegetational disturbance was climatic in origin, occurring during phases of extremely rapid environmental change at the end of interstadials (Hunt et al., 2012)—although what appear to be wildfire events during arid phases were identified during the Late Pleistocene in upland Borneo (Jones, Hunt, & Reimer, 2015). Climatic disruption of vegetation is far less likely during the Holocene, simply because extremely high-amplitude climatic swings did not occur. Where there is fairly strong evidence for arboriculture (e.g., at Loagan Bunut where the presence of the exotic *Metroxylon* can be used to infer the purposeful manipulation of plants), there is also evidence for the consistent very strong representation of regeneration floras (Hunt & Premathilake, 2012). At Loagan Bunut, the levels of regeneration taxa through ~4,000 years of the Early Holocene lie consistently between 15% and 25%, rising to 50% (Hunt & Premathilake, 2012), well above the levels seen during Pleistocene temperate stages at Niah, which are typically between 0% and 15% (Hunt et al., 2012). This might suggest that arboricultural activity entailed the consistent disruption of forest vegetation and the maintenance of early successional stages. The confounding factors here, of course, are the natural processes that lead to regeneration, such as storms, wildfire, and natural treefall, but it can be argued that they would not lead to these consistently high levels of disturbance.

Geomorphological Impact of Arboriculture

There is not enough work in the region to come to a firm viewpoint about the geomorphological impacts of agroforestry. From first principles, one might expect that swidden clearance is likely to lead to marked soil erosion because of the exposure of the ground surface to rainsplash erosion and overland flow, but it might be hypothesized that maintenance of a partial forest canopy and ground cover under arboriculture might mitigate the impact of these erosive processes. Swidden cultivation in the region has indeed been linked to soil erosion (e.g., Bruun, de Neergaard, Lawrence, & Ziegler, 2009; Hurni, 1982; Schmidt-Vogt, 2001; Ziegler, Bruun, Guardiola-Claramonte, Giambelluca, & Lam, 2009) and this is of concern because swiddening is the precursor of some agroforestry systems. There is less information for agroforestry, although a study in West Java concluded soil erosion rates under agroforest were statistically indistinguishable from those under primary forest (Kusumandari & Mitchell, 1997).

In terms of past land use systems, data are rather rare for both swiddening and arboriculture. Close to Niah Cave, Hunt and Rushworth (2005) documented what appeared to be thick colluvial deposits dating from 6,500 years ago to subrecent, which they attributed to cultivation, possibly of rice. The paleoecology of these sediments was, however, poorly resolved. The best available data is from the Kelabit Highlands of Borneo (Barker et al., 2019). Here, repeated cycles of swiddening for hill rice and consequent hill-slope erosion interspersed with periods of stability associated with arboriculture are evident in colluvial and alluvial sediments which have accumulated over the last 6,000 years around Bario and Pa’Dalih (e.g., Figure 3, which shows the repeated destabilization of slopes during swiddening, and their stabilization during arboricultural phases).

<COMP: INSERT FIGURE 3 NEAR HERE>

Conclusions

This article has sought to trace the development and impact of agroforestry in Southeast Asia since the first colonization of the region. It is likely that during the Late Pleistocene, early colonists sought to modify wet tropical forests using fire to encourage the growth of starchy plants associated with regenerating forest margins and improve access to animals. This practice seems to have been a precursor to agroforestry. The knowledge gained during early experiments with fire would most likely have underpinned more systematic attempts to control vegetation, which we might recognise as agroforestry. Early experiments at vegetation control became more necessary once disruption of vegetation ceased as climate stabilized during the Early Holocene.

After 14,000 and before 6,000 years ago, the successful long-distance translocation of key starchy plants—including the tubers *Dioscorea alata, D. hispida, Cyrtosperma merkusii, Alocasia* spp,. and *Colocasia esculenta* and bananas and sago palms such as *Metroxylon sagu*—seems to have occurred. There is some evidence, not very solid, that the earliest translocations were somewhat earlier than this, but more work is urgently needed to substantiate this. Translocation almost certainly happened most of the time by processes of small-scale diffusion, with groups carrying starchy plants with them as they moved through the landscape or island-hopped in small-scale migratory rounds, as many groups continued to do into and through the historic period. There must have been, however, long-distance sea crossings, which are also manifested during the early to mid-Holocene by exchange of material culture items. The origins of many of these starchy plants and the directions in which translocation occurred are still rather obscure—we cannot necessarily regard the first occurrences identified in Table 1 as definitive until many more sites have been investigated.

Where palynological or other evidence is available, the presence of the translocated species is associated with vegetation modification by fire. It almost inescapably follows that after translocation to a locality, the resulting plants would have been placed in environments modified to be suitable for them if they were to survive. The translocated plants would then have been monitored and, if necessary, tended. This activity would likely be recognized as a form of agroforestry using the criteria discussed in the Introduction, and it is probable that the activities we recognize in the modern world as agroforestry may have developed from these early land-management practices.

During the Holocene, the translocation of starchy plants continued, involving more taxa—including sago palms—and became more extensive spatially. This pattern of activity occurred alongside long-distance exchange of material culture. Forest disturbance by fire seems to have continued and become more extensive during the Holocene. Unfortunately, the number of studies is still vanishingly small and few provide the multi-method evidence required to resolve whether true arboricultural activity was present.

The huge diversity of agroforestry at the present day and recent past makes it difficult to evaluate its impact, since this will depend on the precise type of activity carried out. The limited work available suggests that agroforestry is less damaging to biodiversity and has less of a geomorphological impact than do swiddening or other forms of clear-felling. At the same time, it is inescapable that species sensitive to even minor human activity will be eliminated from agroforests and probable that the manipulation of vegetation by agroforestry is likely to lead to enhanced rates of soil erosion. Nevertheless, agroforestry is clearly less damaging environmentally than plantations or open field agriculture, while still providing forest products and agricultural produce. In tropical regions, agroforestry offers a relatively sustainable land use for the long term.

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Figure 1. The drowned continents of Sundaland and Sahul and adjoining landmasses, showing key late Pleistocene (~50,000–11,500 years ago) sites mentioned in the text. (*Source*: C. O. Hunt.)

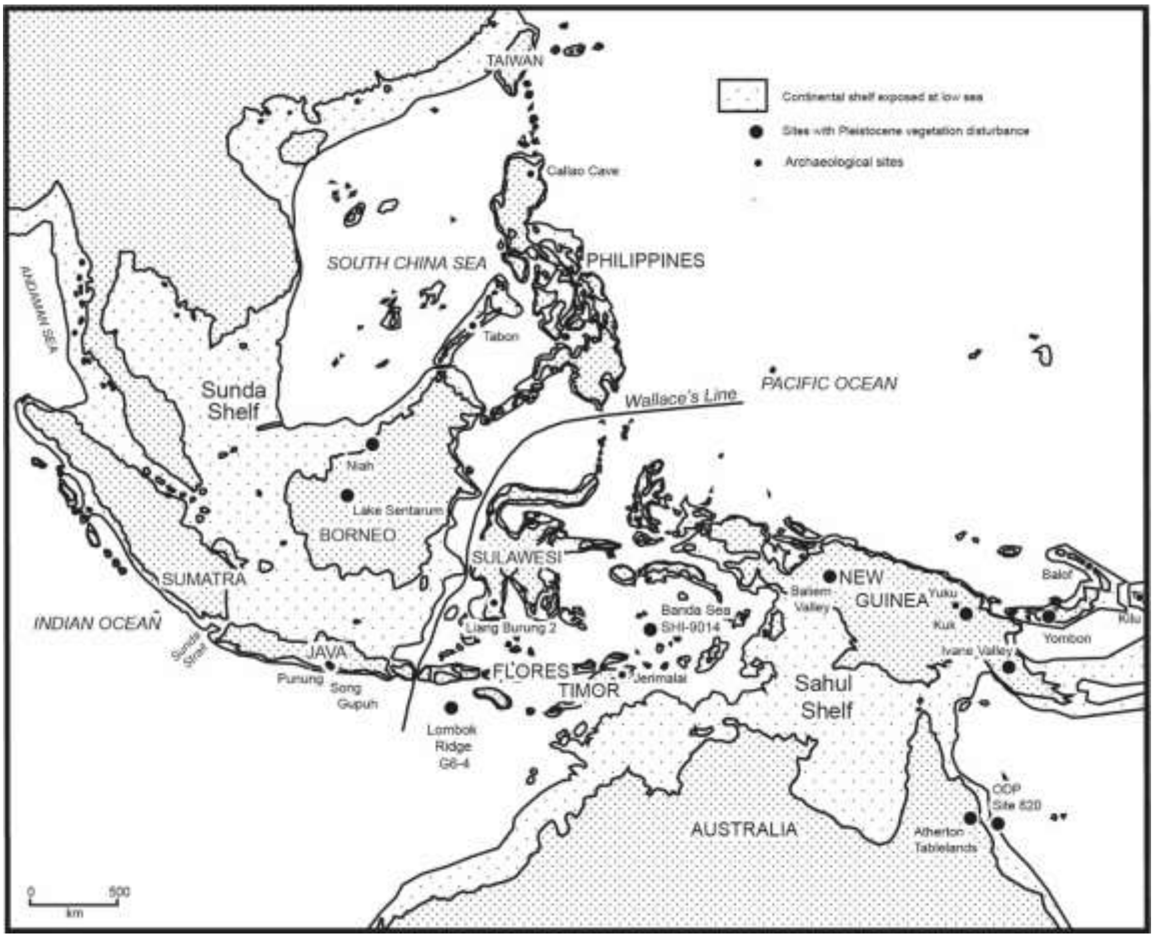

Figure 2. Distribution of sites where long-term forest disturbance and fire is evident during the Holocene (the last 11,500 years) and of key archaeological sites that have yielded evidence for plant use. (*Source*: C. O. Hunt.)

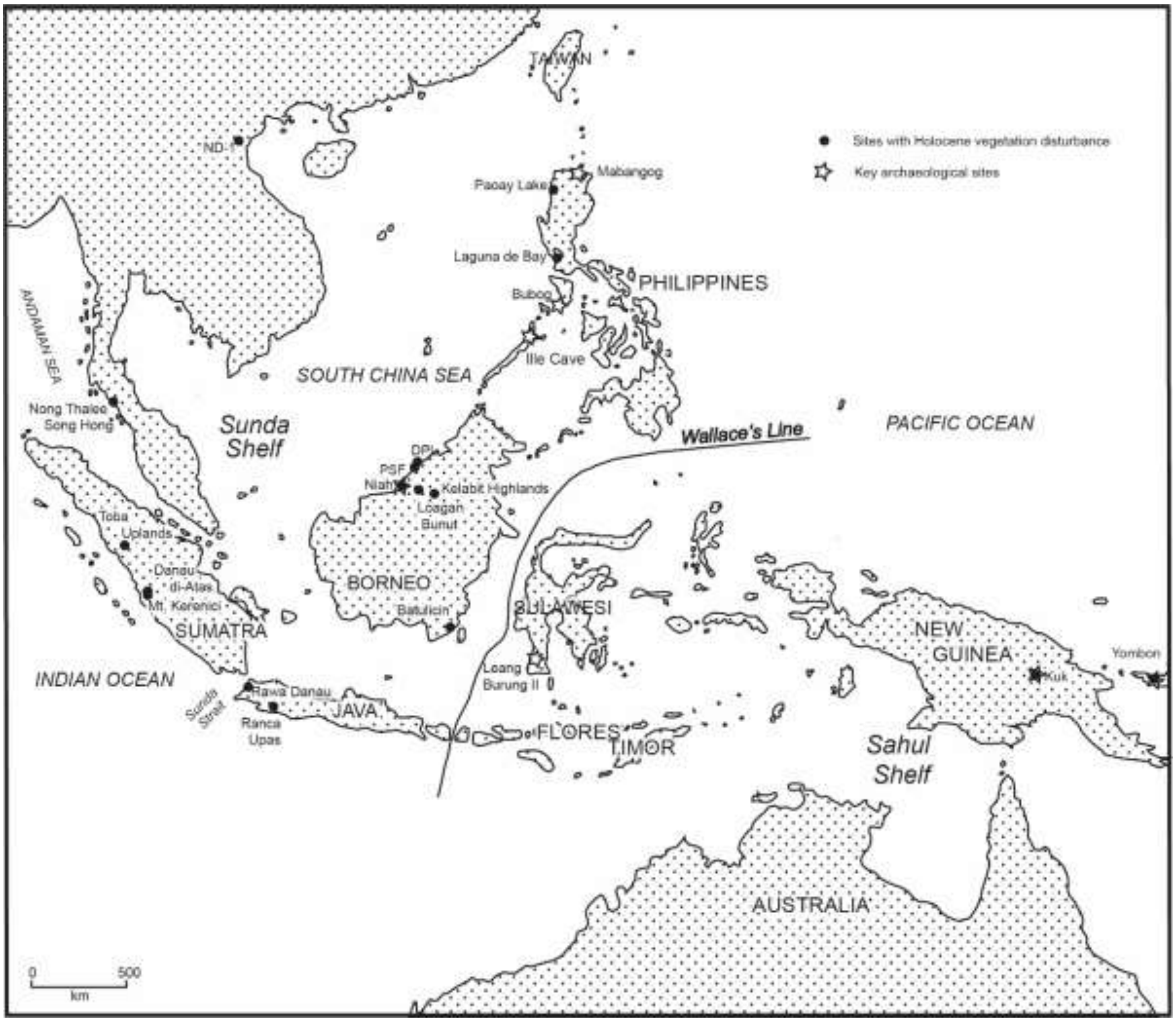

Figure 3. Buried soils and colluvial sediments at BIO53 near Bario, Sarawak. These reflect periods of soil development when the slope was vegetated with fruit and trees, interspersed with erosion and colluviation during swiddening for hill rice. Charcoal in the lowest soil (Layer 6) relates most probably to the late 17th and 18th centuries CE; that in the overlying colluvium (Layer 5) to the 18th century CE; that in the middle soil (Layer 4) to the 19th or early 20th century; that in the pit fill (Layer 2) to the 19th or early 20th century, and that in the most recent soil (Layer 1) to the 20th century. It must be borne in mind that dates on charcoal tend to be older than the sediments or soils in which it lies, because the radiocarbon age reflects the time when the tree laid down the wood. The fruit trees growing above this section were, according to local informants, about 25 years old, suggesting perhaps that the

uppermost soil started forming in the mid- to late 20th century. (Radiocarbon dates calibrated using Calibomb by Barker et al., 2019.)

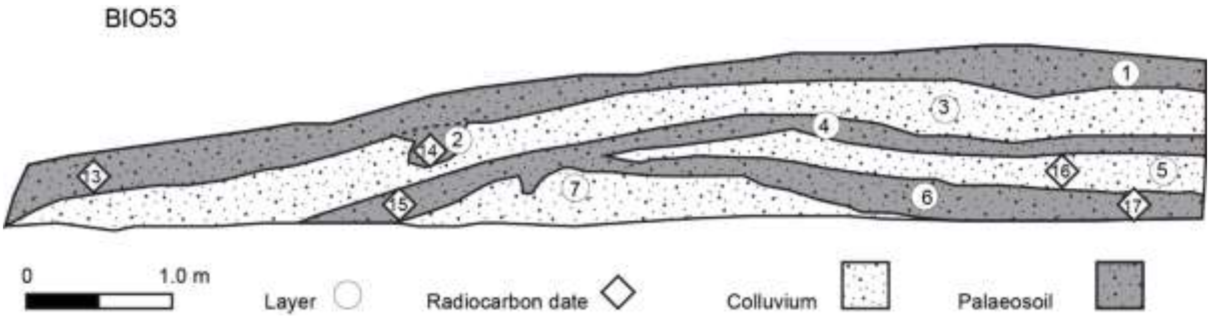

Table 1. *Pleistocene and Holocene Use of Starchy Taxa on Both Sides of the Wallace Line*

Species Part	Author(s)	West	East
Dioscorea alata starch	Summerhayes et al. (2017)		48,000
Dioscorea alata parenchyma	Barton et al., 2016; Pawlik et al., 2017	11,000	
Caryota phytoliths	Hunt et al. (2016)	48,000	
Eugeissona/Caryota starch	Barton et al. (2016)	47,000[a]	
Dioscorea sp. Starch	Barton et al. (2016)	40,000	
Cyrtosperma merkusii starch	Barton et al. (2016)	>31,000[a]	
	Barton & White (1993)		14,000
Alocasia sp. Starch	Barton et al. (2016)	25,500	29,000
Colocasia esculenta parenchyma	Barton et al. (2016)	23,400[a]	
Colocasia esculenta starch	Loy et al. (1992)		28,000
Dioscorea hispida parenchyma	Barton et al. (2016)	25,500[a]	
Alocasia macrorrhiza starch	Barton & White (1993)		14,000
Dioscorea bulbifera starch	Barton & White (1993)		14,000
Dioscorea esculenta starch			14,000
Eugeissona utilis pollen	Hunt & Premithilake (2012)	11,000	
Arenga spp. Pollen	Hunt & Premithilake (2012)	10,600	
Metroxylon sagu pollen	Hunt & Premithilake (2012)	10,400	
Caryota mitis pollen	Hunt & Premithilake (2012)	7,800	
Musaceae phytoliths	Denham et al., 2003		7,000
	Premathilake & Hunt, 2018	6,100	

Ipomea batatas parenchyma	Paz, 2005		3,500

[a] Slightly doubtful identifications.

Sources: Barker et al., 2011; Barton & White, 1993; Barton et al., 2016; Denham et al., 2003; Hunt & Premathilake, 2012; Lentfer et al., 2010; Loy et al., 1992; Pawlik et al., 2017; Paz, 2005; Summerhayes et al., 2017.