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Domesticatory Relationships in the New Guinea Highlands

Tim Denham

Introduction

Several characteristics of cultivation practices in the highlands are significant for understanding the emergence of early agricultural practices. Foremost for interpreting the multidisciplinary record, it is important to consider the range of subsistence practices across New Guinea today, with similar variability likely to have characterised the past (Bourke and Harwood 2009; Denham 2011). Despite this diversity, cultivation practices across New Guinea are, and are likely to have always been, predominantly vegetative. The effects of prolonged vegetative propagation on different plants, including what might be termed domestication traits, are poorly understood in the New Guinea context, as well as elsewhere globally. These themes are briefly reviewed here with respect to plant phenology and some of the most important traditional food plants in the highlands.

From gardens to landscapes

Highly variable subsistence practices occur across the island of New Guinea today, including hunting, gathering of invertebrates, fishing (largely confined to the lowlands), rearing of domesticated animals and the exploitation of plants. The exploitation of plants comprises a variable reliance on the gathering of wild plants, the collection of tree crops (often called ‘arboriculture’) and the cultivation of mostly vegetatively propagated root crops and vegetables (‘horticulture’ or ‘agriculture’). The major staples, cultivation practices, intensity of cultivation—whether measured as frequency of use, labour inputs or technology—vary greatly from place to place (Brookfield with Hart 1971: 94–124; Powell 1976a; Bourke 2001; Bourke and Harwood 2009).

In the lowlands, there was traditionally a greater emphasis on tree crops supplemented by garden cultivation, hunting, gathering and marine resources. Many lowland groups are dependent on sago (*Metroxylon sagu*) and other tree crops as their staples. Nearly all lowland groups are also dependent to some degree on the cultivation of other plants, although many of their practices are difficult to classify because they fall between the rather clumsy categories of ‘hunter-gatherer’, or ‘forager’ and ‘cultivator’, or ‘farmer’ (Dwyer and Minnegal 1991; Roscoe 2002; Terrell 2002; Specht 2003). As in other parts of the world, intermediate concepts have been proposed, such as wild-food production (Harris 1989, 2007) and low-level food production (Smith 2001), to accommodate this ‘middle ground’.

In the highlands and highland fringes of New Guinea, people are reliant to a greater degree on the vegetative cultivation of starch-rich staples, vegetables and other minor crops. Diets are supplemented by the periodic or seasonal exploitation of arboreal resources, where available. Cultivation practices vary greatly in type and intensity, including more intensive drainage of wetlands (e.g. Ballard 2001); semi-permanent, raised-bed cultivation on valley slopes (e.g. Waddell 1972); and shifting cultivation in rainforests (e.g. Clarke 1971). Even the most intensive agricultural practices in the highlands (Brookfield and Brown 1963; Powell et al. 1975; Powell with Harrison 1982) are supplemented by a repertoire of other strategies to diversify diets and reduce risk (e.g. Bowers 1968; Waddell 1972; Ballard 1995). For example, people living in the major inter-montane valleys may intensively cultivate artificially drained wetland margins, while also cultivating house gardens and dispersed mixed gardens on valley slopes, maintaining claims over fruit- and nut-bearing trees and exercising rights to hunt and gather in tracts of forest.

Concepts of cultivated and domesticated landscapes that transcend traditional terminology have been proposed to encompass the diversity of subsistence practices across New Guinea, as well as elsewhere (Yen 1989; Latinis 2000; Terrell et al. 2003; Kennedy and Clarke 2004; Denham and Haberle 2008). Landscape-based approaches are useful to understand cultivation practices in New Guinea because ‘they lead us away from a focus on practices within gardens, plots and fields and towards understanding the strategies and range of practices people undertake to obtain food across the landscape’ (Denham 2005b: 292). Just as the conceptual boundary between categories of ‘hunting-gathering’ and ‘cultivating’ becomes more porous in this context, so too the boundary between garden and forest can also begin to dissolve; people utilise ‘wild’ and ‘cultivated’ plants in diverse ways from a variety of environments. Instead of clear-cut demarcations, there are repertoires of practices that people deploy in different contexts (Latinis 2000; Denham 2009), gradients of intervention across the landscape (Terrell et al. 2003; Denham and Haberle 2008), and resultant degrees of domestication for plants under different forms of plant management and cultivation (following Yen 1985, 1990, 1991a; and Caballero 2004). Similar variability is likely to have existed in the distant past (Denham 2005b: 292):

As with contemporary practices, early subsistence across New Guinea probably transcended traditional divisions between agriculture/hunting and gathering, wild/domesticated and forest/garden. Primary forest and gardens represent opposite ends of a resource exploitation continuum within a landscape. People engaged in a variety of practices, utilized a range of faunal and plant resources and impacted on the landscape in numerous ways. The resultant landscape was a mosaic of modified and utilized habitats, in which gardens represent an archaeologically visible and relatively intensive manifestation of co-occurring, constituent practices.

In seeking to understand how early agriculture emerged on the island in the past, the diversity of practices in the recent past suggests that it is not appropriate to conflate multidisciplinary evidence from across the island to generate a single macro-interpretation of early agriculture and plant domestication (see Denham 2009, 2011). Any such attempt would be liable to bring together plant exploitation practices and suites of domesticates that never co-occurred in the past; namely, the whole would create a false coherence for practices and plants that never actually co-occurred in the past (Denham 2011: S383). In order to avoid these types of issues, it is essential to construct a multidisciplinary record—comprising archaeology, archaeobotany, geomorphology and palaeoecology—from a single landscape to create a regional history of early agriculture and plant domestication. Such an approach has been adopted for Kuk Swamp, within the context of other wetland archaeological and palaeoecological sites in the upper Waghi Valley (Denham 2007a, 2009; Denham and Haberle 2008).

Vegetative reproduction

Vegetative propagation utilises a plant's capacity for asexual or clonal reproduction, whereas seed-based propagation harnesses a plant's capacity for sexual reproduction. Vegetative propagation entails the removal, transportation and planting of a reproductively viable part of a plant—whether a cutting of a branch, stem or stolon or a whole corm, sucker, rhizome or tuber (Hather 1996). The associated term 'vegeculture' is applied to forms of cultivation that are dependent upon vegetative propagation, as opposed to reproduction from seed (Hather 1996; Shuji and Matthews 2002). Vegeculture can also reflect a common orientation to the vegetative reproductive capacity of plant resources, an orientation that can be shared by foragers as well as cultivators and be associated with distinctive social practices (Barton and Denham 2011; see Textbox 25.3 here).

Cultivation practices in the highlands are, and probably always have been, predominantly vegetative and can be referred to as vegecultural. In the highlands, a wide range of plant types was vegetatively propagated for food and other uses (Powell 1976a), including:

- *Karuka* pandanus (*Pandanus julianettii*)
- Shrubs – *aibika* (*Abelmoschus manihot*)
- Grasses – edible *pitpit* (*Setaria palmifolia*/*Saccharum edule*) and sugarcane (*Saccharum officinarum*)
- Herbs – bananas (*Musa* spp.) and *rungia* (*Rungia klossii*)
- Root crops – greater yam (*Dioscorea alata*) and taro (*Colocasia esculenta*).

Even palms and trees are usually transplanted as seedlings, although they can also be reproduced through the planting of seed. For example, *Casuarina oligodon* tree-fallowing is thought to originate around 1200 years ago in the highlands (Haberle 2007; see Chapter 14 here).

Some more recently introduced crop plants, including the South American domesticates sweet potato (*Ipomoea batatas*) and manioc (*Manihot esculenta*), were readily amenable to incorporation in New Guinea cultivation practices because they are vegetatively propagated. However, New Guinea agriculture is not, and probably never has been, exclusively vegetative. For example, wax gourd (*Benincasa hispida*) is planted from seed (French 1986) and the earliest find dates to 3000–2000 years ago at Kana in the middle Wahgi Valley (Matthews 2003; Muke and Mandui 2003). Similarly, other crops reproduced from seed, such as maize (*Xea mays*) and even rice (*Oryza* sp.), are increasingly being adopted and inter-cropped in mixed gardens.

Even though people know that many vegetatively propagated plants can be reproduced from seed, cultivators in New Guinea propagate them vegetatively, a preference that has been documented elsewhere in the world (e.g. for *Ensete ventricosum* in Ethiopia; Hildebrand 2007). Vegetative propagation is preferred because it offers greater control over the gene pool and the best opportunity to reproduce desired phenotypic, often morphological, characteristics, such as colour, size, taste, toxicity and so on. On occasions when vegetatively cultivated crops adventitiously reproduce from seed, for example some traditional varieties of taro, cultivators may adopt the resultant lineage as a new variety within their vegetatively propagated stock (Kennedy and Clarke 2004; see Clement et al. 2010).

Domesticatory relationships under vegeculture

Domesticatory relationships refer to the ways in which people engage with plants in their world. The idea of characterising people–plant relationships in these terms is to avoid simplistic distinctions of 'wild' and 'cultivated', or 'domesticated', plants. Within the New Guinea context,

these types of binary differentiation have little relevance for many plants under traditional forms of plant management and cultivation. Rather, it is more appropriate to view plants co-existing with people along gradients of domestication. These degrees of domestication reflect the cumulative effects of human interference in the life cycle and dispersal of plants.

The varying degrees of domestication evident in traditional New Guinea cultivars represent the accumulation of phenotypic and genotypic attributes derived from practices that have varied spatially and through time (Denham 2009, 2011). Stepped changes in the degree of human intervention in the life cycle of plants can be hypothesised to include, among others: selective exploitation of favoured ecotypes; management of favoured groves and stands; and both movement and continuous vegetative propagation beyond the natural range. The latter two practices result in the increasing reproductive (i.e. genetic) isolation of cultivated plants: movement beyond natural range prevents fertilisation of cultivated plants by wild plants of the same species, although sexual reproduction with other cultivated plants of the same species may still occur, and continuous vegetative propagation beyond the natural range completely isolates the gene pool of favoured varieties.

Prolonged asexual reproduction in a plant, whether humanly or environmentally induced, can lead to the suppression of characteristics important for sexual reproduction, resulting in further reliance on vegetative propagation. This has been noted for clonally reproducing plants generally, even though the precise mechanisms are poorly understood (Eckert 2002). For example, some clonally reproduced plants, such as greater yam (*Dioscorea alata* L.) and *marita* (*Pandanus conoideus* Lam.), have no known sexually reproducing wild progenitor. However, molecular analyses suggest sexual reproduction likely occurred in the past, such as for the greater yam (Lebot et al. 1998).

People may also have selected asexually reproducing plants because of the associated phenotypic traits. For example, reduced seed size and increased pulp size enhances the caloric yield of some fruits, such as bananas. Some of the important changes to the phenology of vegetatively propagated plants in New Guinea are briefly discussed here (extracted and amended from Denham and Barton 2014).

Parthenocarpy, namely the development of fruit to maturity without fertilisation, is a genetic mutation that has been selected for in numerous cultivated plants, including bananas (*Musa* spp.; De Langhe and de Maret 1999) and figs (*Ficus carica* L.; Condit 1947). Although parthenocarpic plants can often reproduce sexually if fertilised, such as occurs with some diploid banana cultivars (Perrier et al. 2011) and all cultivated figs (Denham 2007b), the development of parthenocarpy frees a plant from remaining within its natural range, as well as climates within which sexual reproduction is viable in terms of reproductive phenology, pollen sources and pollinators. Consequently, a parthenocarpic plant can be vegetatively moved beyond its natural range and can still be productive.

Sterility, namely the inability of a plant to reproduce sexually, is often achieved through polyploidy, such as the development of triploids in bananas (Perrier et al. 2011) and taro (Matthews 2004) and various polyploids in yams (Arnau et al. 2010). Triploid cultivars, although sterile, are often favoured because of greater starch production, as well as increased robustness and tolerance of environmental stress, pests and disease. Sterile cultivars are reliant on humans to be moved geographically, although they can self-spread given the right environmental conditions.

Effective sterility can also be achieved through the asynchronic flowering of male and female plants. This means that pollen production and fertilisation could feasibly occur but does not because male and female plants are sexually active at different times of the year. This has been

noted in the greater yam (*Dioscorea alata* L.; Abraham and Gopinathan Nair 1991). No wild precursor of this cultivar has been found and it is not known whether asynchronous fertility is a result of human selection or not.

Seed suppression, namely the reduction in the size of seeds so that they are no longer viable, is selected for by people because it increases the size of the edible pulp or starchy part of the fruit. Seed-suppressed cultivars are no longer able to reproduce from seed and are reliant on vegetative means. For example, vestigial seeds are present in most of the major cultivar groups of banana (*Musa* spp.). In this respect, breadfruit and breadnut (*Artocarpus* spp.) are unusual (Zerega, Ragone and Motley 2004). Most widespread cultivars of breadfruit in the Indo-Pacific have been selected for edible pulp, with a concomitant reduction in size of the seeds, which are not eaten. In contrast, on the mainland of New Guinea people selected some *Artocarpus* sp. cultivars for the consumption of seeds. As a result, the seeds have increased in size and are eaten, while the pulp is discarded.

The cumulative effects of plant domestication in New Guinea have been achieved through prolonged vegetative propagation and include decreased acidity, toxicity and inedible seed sizes and increased edible portions. For most plants, the processes of domestication are not straightforward because many still interbreed with wild/feral plants and wild/feral plants are still planted in gardens (Kennedy and Clarke 2004). Consequently, the ways in which people continue to exploit many plants in New Guinea prevent them from being readily identified as 'domesticated', although some are. Others do not seemingly differ greatly from wild forms and yet others are considered 'semi-domesticated' (Yen 1990).

Similarly, and perhaps unsurprisingly, archaeobotanical data provide glimpses of the presence, processing and cultivation of many food plants. As yet, there is no clear morphological transformation of plant microfossils or macrofossils that might be expected to accompany the domestication process for any food plant through time (cf. Haberle 1995; Yen 1996). The absence of a robust archaeobotanically derived chronology does not necessarily reflect a lack of domesticatory relationships, but rather the nature of those relationships (as discussed above) and the low archaeobotanical visibility of likely domestication traits in many plants in New Guinea (as well as the relatively little systematic archaeobotanical research done on the island; see Chapter 10 here).

Even though the nature of plant domesticatory relationships in New Guinea is sometimes ambiguous, and despite the lack of clear domestication signatures in the archaeobotanical record, it is possible to use the multidisciplinary record to develop scenarios—effectively hypotheses—to understand the cumulative effects of prolonged cultivation on some of the most important food plants in the highlands.

Crop plants in the highlands

We need to focus research on the evolutionary history of individual crops and regional crop associations, and to adopt a more rigorous approach to the identification and dating of archaeologically-recovered plant remains (Harris 1990: 15).

Until the last 20 years, New Guinea was considered a relatively minor area of plant domestication (Sauer 1952; Zhukovsky 1962; Hawkes 1983; Vavilov 1992; Balter 2007). Although a range of indigenous plant domesticates was known (Barrau 1955; Yen 1973; Simmonds 1976a, 1976b), most staples were inferred to have dispersed in ancient times to the island from Southeast Asia, or in post-Magellan times from the Americas. However, recent archaeological, genetic and linguistic research is beginning to reveal more complex histories of plant domestication in the

New Guinea region (following Lebot 1999). A new picture of New Guinea is emerging, in which the island is a major centre of plant domestication for a range of globally significant subsistence and cash crops (FAO 2012).

In this section, a brief overview of important traditional and exotic food plants cultivated in the highlands is provided (following Powell 1976a; Sillitoe 1983; Bayliss-Smith 1985a, 1988; French 1986; Schmid 1991; Kennedy and Clarke 2004; Bourke and Harwood 2009; see Chapter 4, Tables 4.1–4.4 for altitudinal tolerances of different plants). Given that communities traditionally exploited hundreds of plants for a variety of different purposes, the focus here is only on major food plants of highlands agriculture. The uses of each plant, major transformations inferred to result from prolonged cultivation (i.e. domestication traits) and the history of domesticated relationships are all indicated.

Bananas (*Musa cvs*)

Bananas are usually cultivated for edible fruit, although a variety of other uses is known (Kennedy 2009). In general terms, domestication has transformed wild, large-seeded forms with little edible pulp into cultivated, vestigially seeded forms with abundant edible pulp. Bananas are usually propagated vegetatively through the transplantation of suckers growing at the base of the plant pseudo-stem.

The predominant banana cultivars in the highlands are hybrids descended, to some degree, from *Musa acuminata* ssp. *banksii*, which is indigenous to the New Guinea region. Although a variety of banana cultivars are known, the most significant in terms of global food production are those descended from *M. acuminata* ssp. *banksii*. Edible diploids of this subspecies are thought to have undergone initial domestication in New Guinea, including the development of parthenocarpy. Subsequent westward dispersal to Island Southeast Asia has been reconstructed using genetic and linguistic lines of evidence, and major diploid and triploid cultivar groups are thought to have emerged within this maritime landscape through interspecific and inter-subspecific hybridisation to produce parthenocarpic, seed-suppressed and sterile forms (De Langhe and de Maret 1999; Kennedy 2008; Denham and Donohue 2009; Perrier et al. 2011).

Other groups of bananas occur on the island, including the highland *Musa ingens* (Ingentimusa section) and cultivated varieties descended from species of Callimusa section bananas (formerly Australimusa section). The starchy pith of the pseudo-stem of *Musa ingens* is sometimes eaten, although it is only a very minor food plant (French 1986). Of Callimusa bananas, Fe'i bananas are cultivated in the highlands for fruit, but they are more important in lowland New Guinea and the Pacific (Kennedy 2009).

Pandanus—*karuka* and *marita*

There are two main varieties of pandanus, or screwpine, cultivated on the island of New Guinea today (Stone 1982, 1984; Hyndman 1984; French 1986): highland *karuka* (members of the *Pandanus julianettii/iwen/brosimos* complex) grown for its calorie-, oil- and protein-rich nuts; and *marita* (*Pandanus conoideus*) grown for its energy and oil content. The classification of *karuka* is problematic, with multiple authors suggesting that a cline exists between 'cultivated' *P. julianettii* and 'wild' *P. brosimos*, with *P. iwen* as a possible intermediate form (Cook 1999). Both *karuka* and *marita* are periodically—and in many places seasonal—sources of food for groups in the highlands and lowlands of New Guinea (Bourke 1996; see Chapter 4 here).

These pandans have relatively discrete altitudinal ranges: wild *karuka* ordinarily occurs between 2400–3100 m, whereas cultivated *karuka* ordinarily occurs between 1800–2600 m; by contrast, *marita* is ordinarily cultivated between 0–1700 m, but is not important below 500 m

and is common in mid-altitudes, with an upper altitudinal extreme of 1980 m (Chapter 4, Tables 4.3–4.4). Potentially, prolonged cultivation may have ‘forced’ the cultivation of *karuka* to lower altitudes, whereas *marita* was ‘forced’ into higher altitudes. As a result, an altitudinally intermediate pandanus, *P. antaresensis*, which ordinarily grows between 1000–2350 m, may have been replaced as a food source. Today, *P. antaresensis* is a minor food, partly due to the difficulty of extracting the nut from its kernel relative to other nuts, whereas archaeological excavations in the Wurup Valley (in the upper Wahgi) show that this species was utilised during the early Holocene (Christensen 1975; Donoghue 1989). Although speculative, altitudinal forcing may have led to the replacement of *P. antaresensis* as a food source in altitudes that were intermediate between the former altitudinal ranges of *karuka* (above 2400 m) and *marita* (below 1000 m) before prolonged cultivation extended their ranges.

Taro (*Colocasia esculenta*)

Taro is grown primarily for its edible corm, or enlarged underground storage organ, although in many parts of the world its leaves are also cooked as a green vegetable. The corm is abundant in starch, although it contains other compounds such as oxalates that make processing and cooking necessary prior to consumption. The transition between wild and domesticated forms is usually marked by increasing corm size and decreasing acidity. In part, these phenotypic changes are a function of growth environment. Diploid cultivars can reproduce sexually with each other and with wild plants, whereas triploid cultivars are sterile.

Wild-type taro (*Colocasia esculenta* var. *aquatilis*) occurs over a vast area from northern India to the New Guinea region and northern Australia (Matthews 1991, 1995). Taro is likely to have undergone multiple, possibly independent domestications within its natural range, including Southeast Asia and New Guinea (Lebot 1999). It is not known where taro was first cultivated or domesticated in New Guinea (Yen 1995; cf. Denham, Haberle and Lentfer 2004). Molecular analyses suggest limited genetic admixture, or gene flow, between geographical regions, such as between New Guinea and regions to the west (Lebot et al. 2004). Furthermore, traditional taro cultivars in New Guinea and the Pacific were diploids, whereas those in Southeast Asia include diploids and triploids (Matthews 2004). Taro was probably the major staple across much of the highlands before the introduction of sweet potato (cf. Chapter 4; for a revisionist view see Chapters 14 and 15). Over the last several decades, taro varieties recently introduced to New Guinea are replacing most traditional ones in many communities (personal observation).

Yams (*Dioscorea* spp.)

Yams are exploited for starch-rich tubers that usually occur underground, although they sometimes produce above-ground, or aerial, bulbils that can also be eaten. Multiple yam species can readily be cultivated in many parts of the highlands, including *Dioscorea alata*, *D. bulbifera* and *D. nummularia*, while others (*Dioscorea esculenta* and *D. pentaphylla*) approach the upper altitudinal range of cultivation around 1500–1600 m (Table 4.1). Prior to the introduction of sweet potato, yams were probably a more significant crop in the highlands and lowlands. Today, yams are rarely cultivated in the Kuk vicinity, although wild yams of unknown species have been recorded growing in the upper Wahgi Valley (Powell et al. 1975: 35).

The most significant and most widely grown yam globally is the greater yam, or water yam (*D. alata*). Although the precise locus of greater yam domestication is not known, and a wild-type or precursor has not been identified (Lebot et al. 1998), multiple lines of genetic and morphological evidence suggest the New Guinea region as a source (Denham 2010: 14):

In the absence of clear genetic evidence, several lines of inference, or a triangulation method, can be used to assess where *D. alata* originated, which is likely to be the place of initial domestication. Firstly, AFLP-fingerprinting profiles show that *D. alata*, *D. nummularia* and *D. transversa* are closely related and that '*D. alata* may belong, together with *D. nummularia* and *D. transversa*, to a Southeast Asian-Oceanian gene pool which is rather confined to the former Sahulian and Wallacean regions' [Malapa et al. 2005: 928], namely, Eastern Indonesia, New Guinea and Australia. Secondly, several authors have proposed New Guinea as the place of origin because it is the centre of greatest genetic diversity [Lebot 1999: 625]. Thirdly, Martin and Rhodes noted that primitive cultivar types [1977: 2], 'most bizarre and least improved types' [1977: 5], and most types found elsewhere [1977: 5] occur in New Guinea. Fourthly, '[b]ecause it [*D. alata*] flowers naturally in Melanesia, it might be assumed that its area of greatest diversity is also its area of origin' [Lebot 1999: 625]. Although circumstantial, these multiple lines of evidence suggest the New Guinea region as the place of *D. alata* origin and domestication, from which cultivar clones have dispersed widely across the globe.

Given these uncertainties, caution is needed when inferring where the plant was initially domesticated. The analysis of new accessions from eastern Indonesia in particular, and Island Southeast Asia generally, may radically alter current scenarios of yam domestication.

The greater yam, like other yams, is propagated vegetatively. The plant is effectively sterile due to asynchronic flowering. Genetic analyses have inferred sexual reproduction in the past, although the vast majority of genetic variability among greater yam populations represents somaclonal variation resulting from prolonged asexual, or vegetative, reproduction (Lebot et al. 1998; Malapa et al. 2005). Geographically discrete populations of greater yam are generally assumed to have become established through human translocation, even though plants can spread readily in some environments once established within a region.

Most yams exhibit considerable phenotypic plasticity, namely, the morphology of yam tubers can represent environmental controls as much as specific genetic traits. In West Africa, where these issues have been studied, there is no clear correspondence between morphological and genetic traits to differentiate 'domestic' from 'wild' plants once they have been brought into cultivation (Mignouna and Dansi 2003; Scarcelli et al. 2006). A working hypothesis is that the domestication of yams in New Guinea, as in other parts of the world, has sought to increase tuber size, as well as to promote culturally specific and idiosyncratic traits associated with colour, edibility, shape and taste.

Sweet potato (*Ipomoea batatas*)

Sweet potato is a South American domesticate that is primarily grown in tropical and subtropical locations for its edible, starch-rich subterranean storage roots. In Papua New Guinea, sweet potato is probably the most widely eaten food and fodder plant. Under cultivation, sweet potato is propagated vegetatively by taking a cutting of the vine, stem or slip, rather than using part of the underground storage organ as with English potatoes (*Solanum tuberosum*). The plant can also reproduce and disperse from fertilised seed, as suggested for the interior of New Guinea (Bulmer 1966).

Sweet potato is the dominant staple crop for people and pigs across vast tracts of the highlands today. Across much of its present-day range, sweet potato replaced taro because it provides higher yields on poorer soils in the highlands, although it is frost- and flood-intolerant. Even though the plant is probably a post-Magellan introduction to New Guinea, that is within the last 550 years (Roullier et al. 2013), the plant has enabled major social and environmental transformations. Sweet potato is accredited with increasing populations of pigs and people, with attendant social transformations to exchange practices and the development of the historically recorded 'big-man' institution (e.g. Modjeska 1982; Denham 2013a).

Manioc or cassava (*Manihot esculenta*)

Over recent decades, manioc or cassava (*Manihot esculenta*), another South American domesticate, has increasingly been cultivated for food and fodder in the highlands of New Guinea. Manioc adapts well to marginal environments, is drought-resistant and has a flexible growth cycle and relatively abundant yields per unit area of land (Lebot 2009). Manioc is usually reproduced vegetatively under cultivation; a portion of the stem is cut and replanted. However, cultivated manioc can also produce viable seed, which has been important for the domestication process and generation of cultivar diversity (Clement et al. 2010). Adventitiously generated seedlings can be incorporated into cultivated stock and subsequently vegetatively propagated.

Although the antiquity of manioc in New Guinea is uncertain, it was introduced ahead of direct European contact in some parts of the interior. People often say that they do not plant and eat manioc, even though it is inter-cropped in their gardens (Mike Bourke, pers. comm., 2010). The agronomic importance of manioc is likely to increase further in the future as a source of food and fodder because of its relatively high yields in marginal environments.

Sugarcane (*Saccharum officinarum*)

Of the various cane grasses domesticated in New Guinea, the most significant is sugarcane. Traditionally, sugarcane is cultivated vegetatively in order for the sugar-rich sap to be sucked from the stalk. Today, sugarcane is generally considered a snack food, although it was potentially a staple in drier areas of the eastern highlands in the past (Daniels and Daniels 1993).

The domestication history of sugarcane has not been fully reconstructed (Simmonds 1976b; Daniels and Daniels 1993; Lebot 1999; Grivet et al. 2004). Most authors suggest initial domestication of *Saccharum robustum* in New Guinea for its sugar-rich sap, with subsequent westward dispersal and interspecific hybridisation with *Saccharum spontaneum* in Island Southeast Asia to generate *Saccharum officinarum*. Alternative scenarios exist that shift the locus of domestication further towards Asia. Even though the initial stages of the domestication of bananas and sugarcane plausibly occurred in the New Guinea region, globally dominant cultivar groups are thought to derive from interspecific or inter-subspecific hybridisations in Island Southeast Asia before reintroduction to the island (Grivet et al. 2004; Perrier et al. 2011). Many indigenously derived cultivars of banana and sugarcane are, however, still cultivated on the island (Kennedy and Clarke 2004) and were probably more significant in the past.

Minor food plants

A variety of minor food plants are known to have been domesticated in New Guinea, some of which are indigenous to the highlands. Of these, several are still widely cultivated, including possibly winged bean (*Psophocarpus tetragonolobus*) and other legumes, edible cane grasses—*Setaria palmifolia* and *Saccharum edule*—and several leafy greens (collectively called *kumu*), including *aibika* (*Abelmoschus manihot*), *Ficus copiosa*, *rungia* (*Rungia klossii*) and *Oenanthe javanica*.

A number of other minor crops have been introduced to New Guinea at various times in the past. Some of these introductions are likely to be ancient, such as wax gourd (*Benincasa hispida*) dating to 3000–2000 years ago and bottle gourd (*Lagenaria siceraria*) potentially earlier (Powell 1970b; Golson 2002). However, the antiquity of many, such as kudzu (*Pueraria lobata*), still remain a mystery.

Kudzu is a legume that is generally considered to be an Asian domesticate, yet it is cultivated in the highlands for its tuber, which is slow-maturing and a ceremonial, reserve or famine food (Watson 1964b, 1968; Strathern 1969; Sillitoe 1983: 46–48). French (1986: 18) notes that

wild forms can self-seed and usually grow between 30–1860 m, whereas cultivated forms are vegetatively propagated and are common at higher altitudes ‘up to 2700 m’. A long time-depth for kudzu cultivation is implied by its ceremonial use, which suggests considerable cultural significance.

Animal domesticates

In contrast to plant domesticates, the three animal domesticates present in the highlands before the early 20th century—chicken (*Gallus gallus*; Liu et al. 2006), dog (*Canis familiaris*; Savolainen et al. 2004) and pig (*Sus scrofa*; Hongo et al. 2002)—all ultimately originate from mainland Eurasia. Although highlanders are known to periodically capture and raise cassowaries (*Casuarius* spp.), these animals are kept for exchange and consumption, rather than for rearing. Similarly, although marsupials were introduced to various islands in Wallacea and the Bismarck Archipelago in the Terminal Pleistocene and Holocene (Heinshohn 2010), these translocations represent resource improvement or stocking of landscapes with wild animals, rather than domestication in a classic sense.

The principal domesticates of New Guinea agriculture, chicken (*Gallus gallus*) and pig (*Sus scrofa*), together with the dog (*Canis familiaris*), were most likely introduced to New Guinea within the last 3500 years (O’Connor et al. 2011). All three are rare in archaeozoological assemblages in the highlands before c. 2000 years ago and mostly of uncertain provenance (Sutton et al. 2009). As Golson (1982: 125–130) observed for pigs, archaeological evidence sheds little light on the antiquity of animal domesticates in the highlands. Ethnographic accounts, however, suggest that the adoption of pig husbandry occurred relatively recently among some groups, perhaps within the last few hundred years (e.g. Riebe 1974 and Bulmer 1982).

Irrespective of antiquity, the adoption of animal husbandry would have represented a major shift in the way highlanders thought about their relationship to the environment, the things within it and, eventually, to each other. Previously, highlanders would have exchanged and kept wild animals for consumption, trade or curiosity, but this did not extend beyond the life cycle of an individual animal. Although similar rationales can be envisaged for the earliest introduced domesticates, namely that they were exchanged as wealth items or as curios, at some point people began to care for animals in an intergenerational sense. The social implications of this reorientation are unknown, but they plausibly had significance for a range of things: protein in the diet; community health and resultant demography; people’s use of landscapes, potentially including a lower reliance on hunting especially in cultivated, grassland and degraded forest environments, although there were plausibly greater returns from hunting with dogs (Sillitoe 2002); and as a means of storing food surpluses, thereby intensifying exchange relationships and political stratification (Modjeska 1982).

Even today reproduction among some domesticates is only loosely controlled. For example, female pigs are kept and intensively managed, but they are often allowed to interbreed with feral boars. Similarly, reproduction among dogs is unregulated, although progeny of specific dogs may be selected for traits associated with their parents.

Animal domestication is not significant in terms of the periods associated with the genesis of agricultural practices in the highlands, whether at 10,000 years ago (Chapter 11) or with the initiation of mound cultivation by at least 6950–6440 years ago (Chapter 12) or with the advent of ditched field systems by 4400–4000 years ago (Chapter 13). However, animal domesticates became increasingly important during more recent ditched field systems, including

those corresponding to Phases 5 and 6 at Kuk (Chapters 15 and 16). Potentially, the earliest archaeological evidence for pig husbandry in the highlands is the construction of fences along the edges of ditching to keep wild pigs out of cultivated plots (see Chapter 19).

Concluding points

While it has generally been assumed that early agriculture and the domestication of major staples, including bananas, taro and yams, initially occurred in the lowlands and moved to the highlands during the early Holocene (Golson 1991b; Yen 1995), this is uncertain (Denham, Haberle and Lentfer 2004). Although forcing plants under cultivation to higher altitudes is possible, it is not clear whether they could have grown wild in the highlands and been domesticated there. The ultimate loci of early cultivation are unlikely to be determined with any accuracy until additional multidisciplinary data is forthcoming from the lowlands. These data need to include a range of archaeological, ecological and genetic information.

Foremost, relatively little is known about the ecology of several major food plants, including their original habitats and natural ranges. Without such information, and in the absence of detailed genetic information on cultivar groups and wild populations across a vast area, it will not be possible to determine where plants were initially brought into cultivation and ultimately entered into domesticatory relationships with people.

Archaeobotany indicates that several plants—including taro, yams and other tuberous plants—have a long history of exploitation extending back into the Pleistocene across a vast area of Island Southeast Asia, New Guinea and Island Melanesia (Loy, Spriggs and Wickler 1992; Barton and Paz 2007; Summerhayes et al. 2010). However, with the exception of bananas (Perrier et al. 2011), there is a lack of detailed archaeobotanical evidence to ground genetic interpretations for plant domesticatory relationships in these regions. In part, the absence of archaeobotanical data is a product of the nature of the plants involved: they often do not produce the type of archaeobotanical remains that are readily preserved or identifiable (except with the advent of relatively new microfossil techniques); in part it is a result of limited systematic archaeobotanical investigation at sites on the island (see Chapter 10).

Irrespective of these concerns, perhaps the biggest problem facing our understanding of plant domesticatory relationships in the past are processes that are happening in the present. The genetic diversity of traditional crop plants is increasingly being eroded by replacement with introduced varieties of the same plants. The reduction in genetic diversity of indigenous cultivars is not only a loss for understanding agricultural history, it is a greater loss for crop improvement in the future.

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