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Early Agriculture and Plant Domestication in New Guinea and Island Southeast Asia

by Tim Denham

A multidimensional conceptual framework is advanced that characterizes early agriculture as a subset of human-environment interactions. Three cross-articulating dimensions of human-environment interaction are considered that accommodate the varied expressions of early agriculture in different parts of the world: spatial scales, transformative mechanisms, and temporalities of associated phenomena. These ideas are applied and exemplified at two different scales of resolution—contextual and comparative—in terms of early agricultural development in the highlands of New Guinea and the dispersal of domesticates from New Guinea into Island Southeast Asia.

Recent conceptual debates on early agriculture have shifted from definitions based on domestication—namely, phenotypic and genotypic transformations in plants and animals or degree of dependence on domesticates (e.g., Harris 2007; Smith 2001)—to broader understandings of the environmental and social contexts within which early agriculture was practiced (e.g., Cauvin 2000; Ingold 2000; Marshall 2007; Pearsall 2007). Currently, there is neither agreement on nor universal application of a standard definition for identifying early agriculture in the past, with considerable geographical variation (e.g., Barker 2006; Bellwood 2005; Denham, Iriarte, and Vrydaghs 2007).

In this article, a multifaceted framework is proposed that characterizes early agriculture as a subset of broader human-environment relations, thereby incorporating both the biophysical and social realms. The intensive, discursive nature of the Temozon conference contributed greatly to the emergence of these ideas and to my understanding of research into early agriculture across the globe. I am indebted to both the organizers for inviting me and to other participants for their stimulating company.

My intention here is to develop a conceptual framework that can incorporate different emphases in our understanding of early agriculture for different regions of the world rather than to propose a prescriptive definition designed for universal conformity. The purpose is to characterize rather than to define. The multidimensional model is exemplified at two different scales of resolution. The emergence of agriculture in the Upper Wahgi Valley of New Guinea is discussed contextually at the landscape scale. The spread of domesticates from New Guinea to Island Southeast Asia is discussed comparatively at broader spatial and temporal scales. The multidimensional framework potentially has broader application to elicit commonalities and differences for the various regions across the world in which agriculture has emerged, although there is insufficient space for elaboration here.

Early Agriculture: A Subset of Human-Environment Relationships

Early Agriculture: A Subset of Human-Environment Relationships

Animal and plant exploitation, including pastoralism and agriculture, are among the most important subsets of human-environment relations both in terms of human dependence and environmental change. The interpretation of agriculture in the past should consider the multiplicity of factors that converge in any given human-environment interaction, including those of the biophysical realm—such as climate, environment, and the biology of cultivated plants and tended livestock—as well as the social realm—namely, people and various facets of their practices, including cultures, societies, and technologies. Consequently, and inherently, agriculture has multiple socioenvironmental dimensions that are mutually transformative; namely, they are historical, and each acts on and changes the other through time (e.g., from Time_x to Time_{x+1} in fig. 1). It is proposed and demonstrated here that the totality of these dimensions is essential to characterize the emergence of agriculture in any given historicogeographical context.

An inclusive conception of agriculture as a subset of human-environment interactions sheds critical light on the nature of attempts to elicit a singular definition or an ultimate “cause” of agricultural development in the past. Any singular definition of agriculture prioritizes one epiphenomenon

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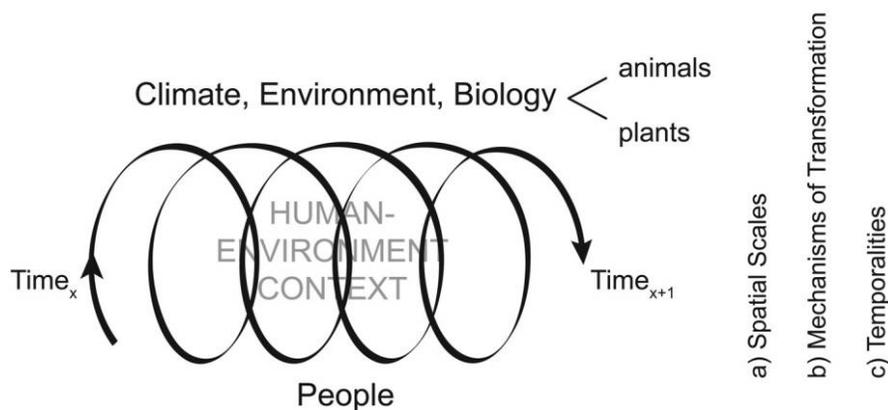


Figure 1. Schematic representation of the multiple dimensions of early agriculture, hereby described as a subset of human-environment interactions. Each dimension (a to c) is characterized in figure 2.

above others. For example, definitions focused on the identification of domesticated animals or plants in the archaeobotanical record or on inferences regarding dependence of people on domesticates fail to fully acknowledge that the morphogenetic transformation of species are not uniform in the past or the present. Numerous factors affect the relative propensity of a species to accumulate anthropically selected traits through time; some are biological (Ladizinsky 1998), while others are environmental (e.g., Pearsall 2007) and social, technical, or practical (e.g., Denham 2007; Marshall 2007). Multiple dimensions of domesticatory relationships influence their archaeological visibility.

The recursivity of human-environment interactions hinders the interpretation of a singular or ultimate cause of early agriculture. The positing of any biophysical or social phenomenon as a primary cause is arbitrary because any explanation inevitably folds back into the duality of human-environment relations (drawing on Giddens 1984). It is effectively impossible to determine causation within a recursive spiral; transformation in human-environment interactions is continuous, multifaceted, and multicausal. To exemplify, if climatic amelioration and stabilization at the beginning of the Holocene are posited as the ultimate cause for the emergence of agriculture across the globe (e.g., Richerson, Boyd, and Bettinger 2001), this explanation fails to account for the restricted number of locations in which this actually occurred. Why did agriculture emerge in some places and not in others, and why is there so much temporal variation?

Any account of ultimate causation is soon beset by qualifiers, such as resource availability and species' susceptibility to domestication. Although there are geographical variations in the availability and susceptibility of animal and plant resources to domestication, these do not solely account for why agriculture emerged in some places and not in others during

the early Holocene. For instance, indigenous plants were evidently domesticated in other regions much later (e.g., India [Fuller et al. 2004], parts of Africa [Kahlheber and Neumann 2007], and North America [Asch and Hart 2004]). Any climatic explanation soon shifts sideways from the biophysical realm to the social realm in order to account for the observed spatiotemporal variations. The social realm necessitates a much broader consideration of how people in different locales engaged with their environments such that some developed agriculture and others did not. In logical terms, what may initially be characterized as a cause—whether climatic amelioration, environmental degradation, or social transformation—soon becomes a relatively widespread precondition, which in turn then becomes a relatively benign context.

Three cross-articulating dimensions of human-environment interaction are relevant to the characterization of early agriculture in any historicogeographical context (fig. 2): (a) spatial scales of analysis, type of method, and lines of evidence; (b) transformative mechanisms and archaeological expressions of agriculture; and (c) temporalities of associated phenomena. Each dimension is briefly discussed below.

Articulating Space and Place

There are considerable variations in the spatial scale of analysis through which early agriculture is inferred. The scale of analysis adopted has implications for the ways in which evidence is used—whether conflated, low resolution, or in particular, high resolution—and tends to be associated with a specific methodology—either comparative or contextual, respectively (fig. 2a). Characterizations of early agriculture at the continental and subcontinental scales often conflate data from different locales and of slightly different ages to draw a general comparative picture of agricultural development (e.g., Bellwood 2005; Renfrew 2002). Others draw on locally generated,

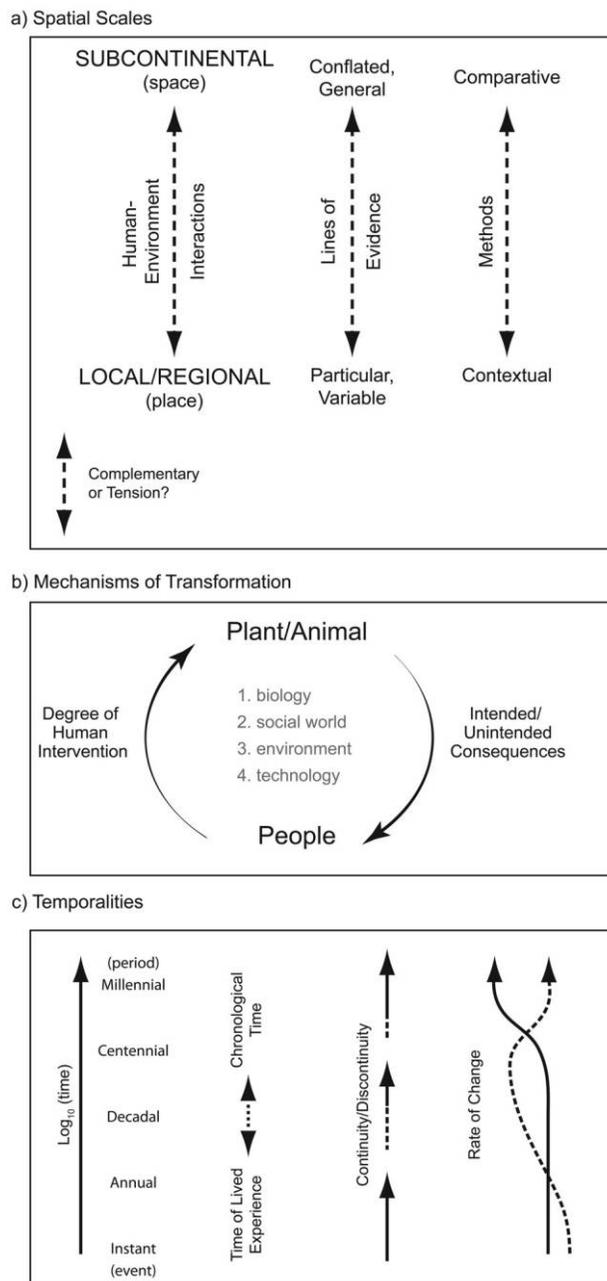


Figure 2. Three dimensions of early agriculture: *a*, correspondences between spatial scale, lines of evidence, and methods; *b*, four domains, or contexts, within which to consider the mutually transformative nature of domesticatory relationships between animals/plants and people; and *c*, temporal considerations.

heavily contextualized evidence to characterize early agricultural development within given landscapes or places (e.g., Denham and Haberle 2008; Pearsall 2007) and emphasize intraregional variability.

Although there are some conceptual tensions between comparative and contextual approaches (cf. Renfrew 1973, 2002;

Thomas 1996), they are not necessarily incompatible. A key aim of archaeological research is “to use archaeological data to gain an understanding of the indeterminate relations between large-scale processes and individual lives” (Hodder 1999:175). For those seeking an understanding of early agriculture, reconstructions at the local level need to be situated

within broader regional, interregional, and continental processes. Highly specific and contextual information can be cautiously situated within broader historical and geographical processes, although the converse is more problematic because of the lack of resolution and specificity in conflated data sets.

Transformative Mechanisms and Archaeological Expression

Agriculture is based on the management of plants and animals for human exploitation. Agriculture is predicated on varying degrees of human intervention in the life cycle of plants, which in turn yield intended and unintended consequences in terms of plant biology and the utility of managed plants for people. The nature of the mutually transformative interaction between animals/plants and people is differentially expressed in given historicogeographical contexts; it is not restricted to the biological domain even though issues of domestication have been the focus of most debate.

Four domains have a bearing on the character of agriculture, namely, how agriculture is expressed archaeologically in any historicogeographical context (fig. 2*b*; cf. Sayer 1984): (1) biology: degrees of domestication (phenotypic and genotypic change), gene expression, and phenotypic elasticity; (2) social world: demography, dependence, Neolithic traits, orientation to resources, sedentism, and sociopolitical change; (3) environment: human and natural influences, transformation, rate of change, sensitivity to change; and (4) technology: translocation, propagation, cultivation, harvesting, processing, and storage.

Academic discourses draw variably on different domains and lines of evidence to construct arguments for or against early agriculture in different parts of the globe. In part, these positions reflect the definitions of agriculture adopted, which are usually either inherited from research in Eurasia or developed to suit the available evidence within a region. These domains are variably expressed, articulated, and aligned in different instances of early agriculture. Particular factors seem to be important and correspond in some regions whereas in others they do not; however, they are all relevant.

Temporalities of Associated Phenomena

Debates concerning early agriculture tend to project unilinear or multilinear trajectories from the past to the present; namely, they are teleological. Time is viewed as continuous; processes are viewed as cumulative (e.g., Richerson, Boyd, and Bettinger 2001), as if they lead somewhere significant other than solely toward the present. Three aspects of time, and the temporality of things (namely the temporal extension of something, or its being in time; Thomas 1996), are significant. Although time and temporality are implicit to any discussion of early agriculture and subsequent transformations, they are rarely made explicit (fig. 2*c*).

First, the temporality of things is usually assumed to be continuous, or semicontinuous. In part this reflects the punc-

tuated nature of archaeological finds and the need to place fragmentary finds into chronological-geographic sequences (e.g., Scarre 1988). Interpretations adopt various lines of reasoning—from uniformitarian to Occam's razor to historical materialist to postprocessualist—to place archaeological finds in time, namely, to temporalize them, inferring their temporal extension and position in a sequence. Although discontinuities can be recognized in prehistory, such as the abandonment of a crop or technology, these can be hard to determine with confidence because of the absence of evidence, which is not evidence of absence.

Second, rates of change are rarely considered, which in part can be a function of the records and partly a function of perspective. For example, domestication is a process that operates at variable rates for different species and subspecies in different historicogeographical contexts. Some species—perhaps those with annual life cycles subject to intensive human selection and a high degree of genetic isolation—would be anticipated to accumulate traits resulting from human management at a relatively rapid rate. Conversely, these same species not subject to the same degrees of human selection and genetic isolation, as well as other species with longer life cycles (such as trees and some animals), would be anticipated to accumulate traits at a slower rate. The rate of accumulation of domestication traits within an organism is a function of the human-environment context, namely, a function of the multiple domains associated with a domesticatory relationship. Thus, experimental farming can yield high rates of change in cereals within decades (Hillman and Davies 1990), perhaps because of the high degrees of human selection and genetic isolation, whereas archaeobotany suggests the accumulation of these traits actually occurred over thousands of years in Southwest Asia (Tanno and Willcox 2006), perhaps because of continual genetic interaction between wild and cultivated stock as much as to selection through management practices (see Jones and Brown 2007). It follows that the accumulation of domestication traits in trees can be anticipated to occur over centuries or millennia (Yen 1996).

Genotypic and phenotypic changes are a continuum of change along which measures of domesticity, as opposed to wildness, are determined. Variations in the rate of domestication, whether measured genetically or phenotypically (as is customary in archaeobotany), can be anticipated to vary depending on whether a plant is propagated sexually or clonally; the accumulation of selected somatic mutations in the latter is a qualitatively different type of process to the accumulation of selected mutations through sexual reproduction (Yen 2003). Additionally, genotypic and phenotypic traits resulting from human management should not be anticipated to accumulate at the same rate within a species, or between species, especially given latent issues of gene expression and phenotypic elasticity for some plants under cultivation (Gremillion and Piperno 2009). The generation of phenotypic varieties in some plants, such as bananas and yams, need not correspond to genotypic change but may solely represent a phenotypic

response or the differential expression of a gene due to the environment of cultivation and growth.

Third, the archaeology of early agriculture has tended to view time in the abstract, namely, chronologically, and not from the perspective of lived experience or experiential time. Issues of plant domestication are generally considered from the perspective of how many years before traits x and y become apparent in the archaeobotanical record; they are rarely considered from the perspective of how these traits accumulated through the day-to-day activities of people and were passed on from generation to generation. The time of lived experience is a precondition for the constitution of chronological time (Heidegger 1962) and processes thereby inferred.

Existential aspects of time are glossed or avoided because they can be considered to be attempts to get inside the minds of people in the past. Although partly true, this is always the case, because discussion of domestication often considers whether traits were intentionally or unintentionally accumulated, namely, to understand the intent, or mindset, of the people involved. The intentionality of the domesticatory process requires a consideration of experiential time whether to understand the deliberate selection of a taro corm or cereal grain or the qualitatively different temporal perspective of planting a tree. The former yields within a year, whereas the latter may take decades before yielding and requires an intergenerational perspective (Ingold 2000; Terrell 2002).

Contextual: Early Agriculture in the Highlands of New Guinea

Landscape Scale of Analysis

In New Guinea, as elsewhere, there are high degrees of regional variability in the nature of plant exploitation practices across the island (e.g., in major crop plants; Bourke and Harwood 2009; Kennedy and Clarke 2004), the nature of cultivation practices (Bourke 2001), and the degree of reliance on cultivation (Roscoe 2002; Terrell 2002), with similar variability likely to have characterized the recent and more distant pasts (see fig. 3; Denham 2005*b*). Consequently, it may not be meaningful to conflate evidence over broad sociospatial scales—from across the highlands or lowlands, for the island of New Guinea, or for Near Oceania—together into a single macrochronology or macrointerpretation of plant exploitation in the past. By so doing, plant exploitation practices and suites of domesticates that never co-occurred may be erroneously brought together into a single historical narrative; namely, the whole can be misleadingly coherent and much greater than the sum of the parts.

The interpretation of the emergence and transformation of agriculture in Highland New Guinea has sought to avoid teleological interpretations by focusing on the expanding repertoire of plant exploitation practices (including various forms of cultivation) toward the present and the spatial manifes-

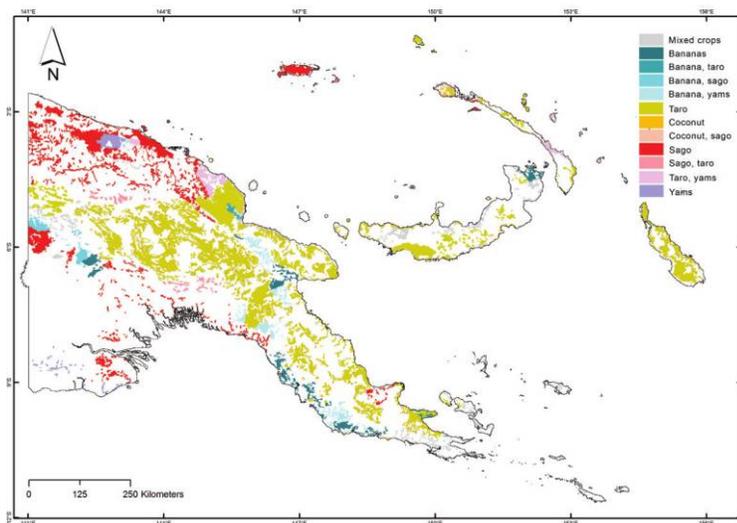
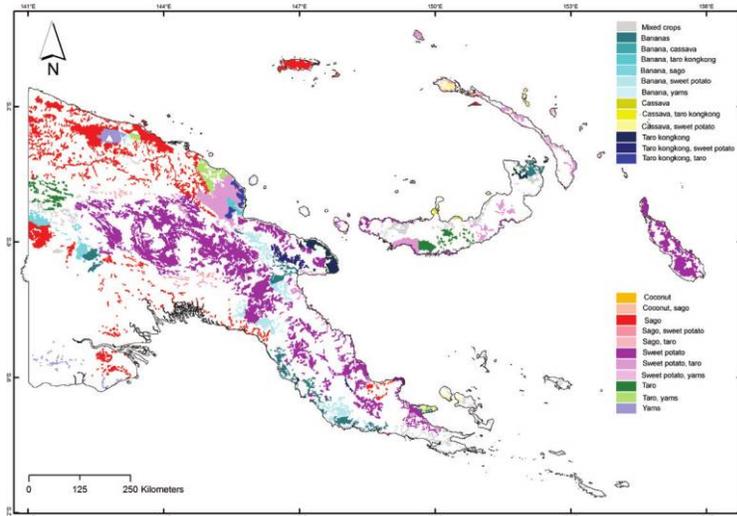
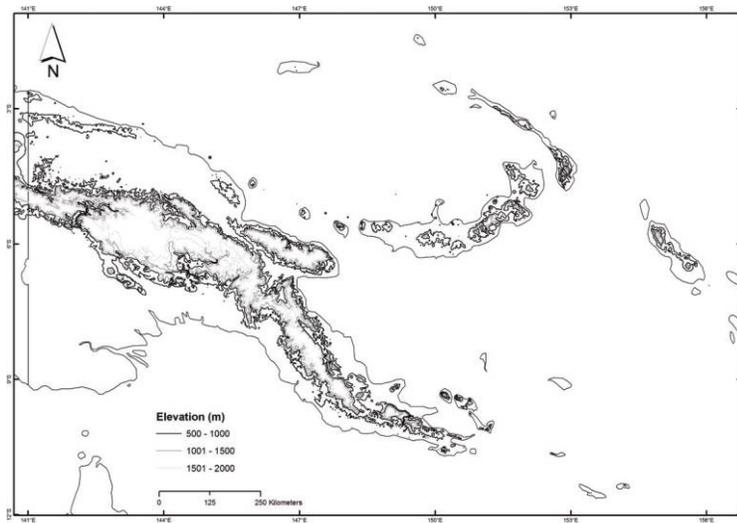
tation of each within the Upper Wahgi Valley (Denham 2009; Denham and Haberle 2008). In this landscape, a teleological unfolding is at one level unavoidable because agriculture did emerge from previous foraging practices at some point in the early Holocene. However, if the island of New Guinea is taken as a whole, a unilinear or multilinear characterization does not hold, because multiple types, including ambiguous types of plant exploitation, were being practiced up to the modern era.

The multidisciplinary evidence from a relatively restricted region or landscape can be relied on as the primary context for interpreting the emergence and transformation of agriculture (Denham 2008; Denham, Fullagar, and Head 2009; Denham and Haberle 2008). The multisite records from the Upper Wahgi Valley are the most detailed in New Guinea for eliciting plant exploitation and associated landscape changes in the past, primarily because of numerous archaeological and paleoecological investigations at wetlands bearing evidence of past manipulation for plant exploitation, including early agriculture (figs. 4, 5; table 1; reviewed in Denham and Haberle 2008 and supplemented by Coulter et al. 2009; Denham, Haberle, and Pierret 2009; Denham et al. 2009; Sniderman, Finn, and Denham 2009). The evidence from these sites of food production will eventually be complemented by the multidisciplinary results (once complete) from the excavations of proximal occupation sites along an altitudinal gradient on the valley wall (Christensen 1975; Donoghue 1989).

Transformative Mechanisms and Domestication Histories

The phenotypic or genotypic (application of ancient DNA) transformation of plants from wild to domestic forms has not been clearly charted through time and across space for any plant in the New Guinea region despite variable claims (Denham 2004*b*; Donoghue 1989; Golson introduction in Christensen 1975; Haberle 1995; Lentfer 2009; Yen 1996). As a result, the case for early agricultural development in New Guinea has leaned heavily on archaeological evidence of technologies and past practices (Denham 2005*a*, 2006, 2007, 2009; Denham and Haberle 2008; Golson 1982) and environmental transformation (geomorphology and paleoecology: Denham, Golson, and Hughes 2004; Denham et al. 2003; Golson and Hughes 1980; Haberle 1994, 2003, 2007; Hope and Haberle 2005). There is limited understanding of the social world inhabited by early agriculturalists (Golson and Gardner 1990; Haberle and Chepstow-Lusty 2000) largely because few occupation sites dating to the early Holocene have been excavated in the highlands, and most of these have not been published in full (except White 1972).

Types of archaeological information often considered to accompany early agricultural development in other parts of the world are equivocal or absent in the New Guinea record (e.g., Diamond 2002; Piggott 1954). In the absence of cemeteries or ossuaries, demographic signatures of early agriculture have been inferred using crude proxies, such as number



of archaeological sites (Haberle and Chepstow-Lusty 2000). Several Neolithic traits often associated with early agriculture (e.g., pottery and domesticated animals) are absent. The relationship between sedentism and early agriculture is equivocal; there are questionable claims for Pleistocene-aged settlements in the highlands at NFX (Watson and Cole 1977) and Wañelek (Bulmer 1977), but most settlements postdate 4000 cal BP. Archaeobotanical investigations at occupation sites are few (excepting Christensen 1975) and incomplete, and consequently shed little light on plant-food consumption preferences and practices. In a similar vein, sociopolitical transformations are poorly known, although the rise of putatively patrilineal, highly territorial descent groups and the big-man form of leadership have been inferred from agricultural history (Denham and Haberle 2008; Golson and Gardner 1990).

Given the limited knowledge of the biological and social domains in the early and mid-Holocene, the following discussion of the transformation of plant exploitation through time focuses on people's orientation to plants within the Upper Wahgi Valley as inferred from the cross-articulation of archaeobotanical (plants), archaeological (technology/practice), and paleoecological (environment) evidence.

Archaeobotanical and paleoecological research provides information on food plants that were available locally at Kuk and in the Upper Wahgi Valley as well as for the processing and inferred cultivation of some staples (Denham 2005*b*, table 2). Evidence for the presence of a food plant does not indicate that it was exploited in the past even if its use has been documented ethnographically (Powell 1982). However, on-site evidence of food plants in association with archaeological features representing either foraging or a form of agriculture is more suggestive of potential exploitation, even if adventitious. By contrast, archaeobotanical evidence for processing or cultivation enables more direct comparison with, and the direct integration of plants into, the plant exploitation chronology for the region (e.g., Denham 2009; Denham and Haberle 2008). At present, significant archaeobotanical evidence is limited to bananas (*Musa* spp.), *karuka* Pandanus (*Pandanus julianettii/iwen/brosimos*), taro (*Colocasia esculenta*), and a yam (*Dioscorea* sp.; Denham, Haberle, and Lentfer 2004; Denham et al. 2003; Donoghue 1989; Fullagar et al. 2006, 2008).

Because of evidential deficiencies, the domestication histories of significant crop plants can only be hypothesized in

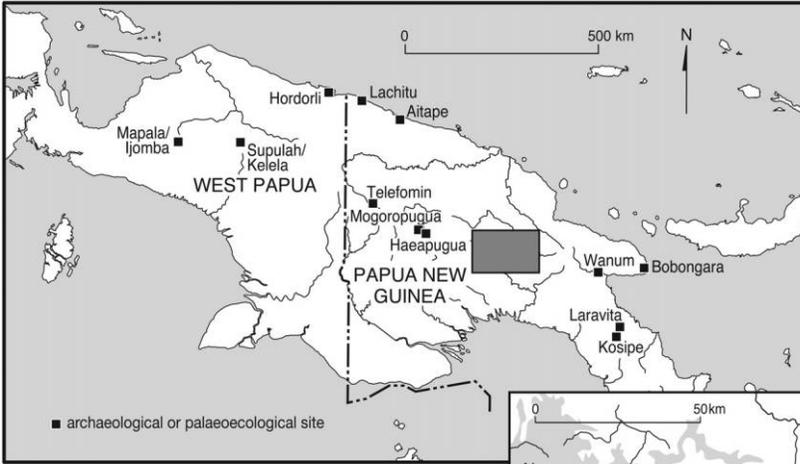
terms of current understandings of how plant exploitation practices changed through time. For the Upper Wahgi Valley, these hypotheses can be formulated with respect to bananas, taro, and a yam (e.g., Denham 2009). Each crop plant had been considered to be of lowland derivation and brought to the highlands by people (Hope and Golson 1995; Yen 1995), although they potentially grew naturally in the highlands during the early Holocene (Denham, Haberle, and Lentfer 2004; Haberle 1993). Only two early steps in the domestication process can be hypothesized from the archaeological and archaeobotanical evidence: planting and cultivation.

First, planting of these three plants from wild stock is hypothesized to have occurred in the early Holocene before mounded cultivation dating to 7000–6500 cal BP on the wetland margin at Kuk (radiocarbon dating for Kuk is presented in Denham et al. 2003). Some form of swidden cultivation is likely to have preceded more intensive forms of cultivation (Denham and Haberle 2008). It is still unclear whether initial planting was through seed or vegetative propagation, although the latter is the dominant characteristic of highlands agriculture and some other forms of plant exploitation in New Guinea. Indeed, domestication has led to the development of numerous cultivars that are no longer able to reproduce sexually under normal growing conditions. Consequently, vegetative propagation is generally considered to have always been the dominant mode of plant reproduction under cultivation in New Guinea (Denham 2005*b*), although some plants are grown from seed. Planting encouraged the development of “cultiwild” populations, namely, cultivated or managed populations of effectively wild plants, which may still interbreed with any wild populations growing in the vicinity (following De Langhe et al. 2009).

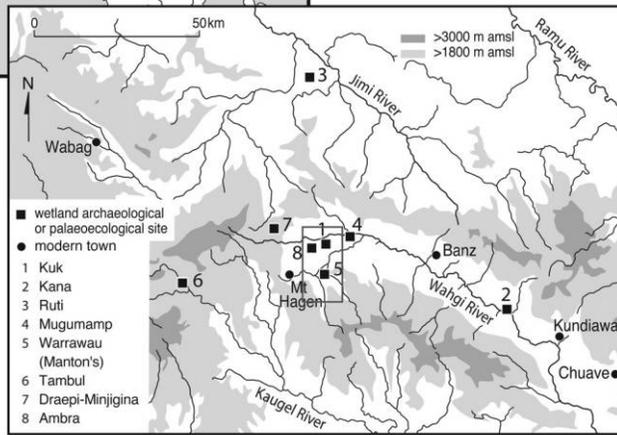
Second, an increased reliance on vegetative propagation and the systematization of agricultural practices in the highlands, exhibited with the development of mounded cultivation by at least 7000–6500 cal BP and of ditched field systems by ca. 4000 cal BP, led to increasing degrees of domestication (Caballero 2004) in managed stands and the creation of an array of cultivars through anthropic selection and increasing genetic isolation of favored plants. Genetic isolation prevented inbreeding between cultivated and wild stock and was achieved through a combination of intentional and unintentional practices, including plant translocation, environmental degradation, and vegetative propagation of cultivated stock. Translocation brought managed plants from lower altitudes to the

Figure 3. Maps depicting the variability in plant exploitation across Papua New Guinea. *Top*, contour map of Papua New Guinea; *middle*, geographical distribution of major crop plants today (from Bourke and Harwood 2009); *bottom*, interpretation of the geographical distribution of major crop plants following the exclusion of recently introduced crops. Crop plants likely to have been introduced within the last 500 years comprise sweet potato (*Ipomoea batatas*), cassava (*Manihot esculenta*), and taro kongkong (*Xanthosoma sagittifolium*).

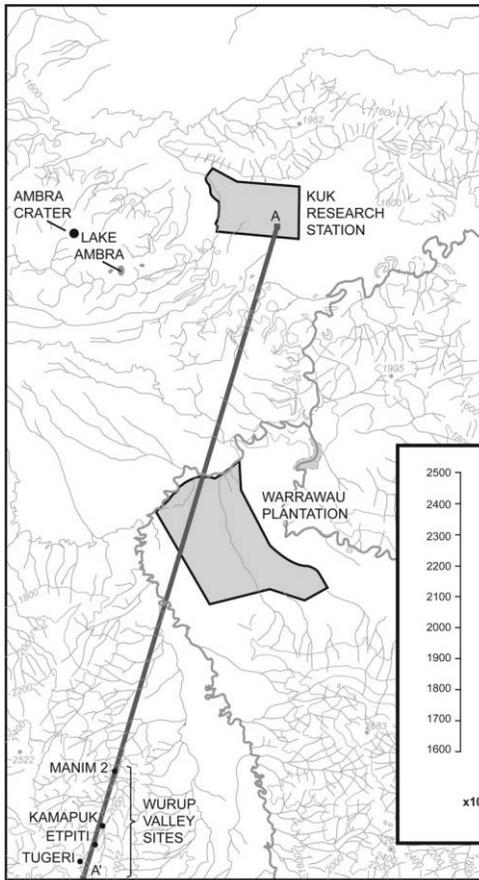
a)



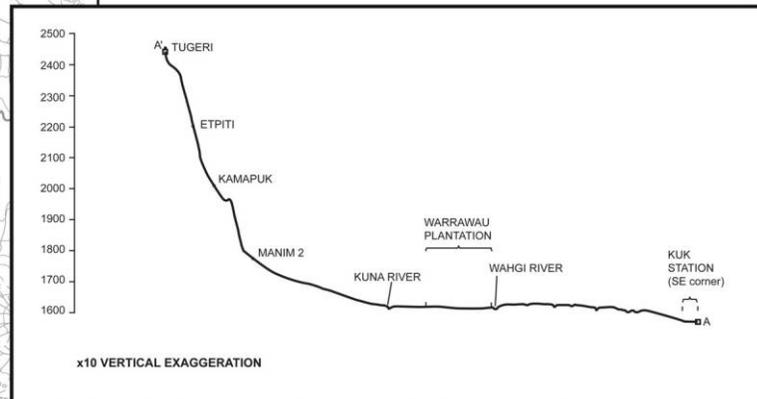
b)



c)



d)



A BP 7049 ±595 c. 1560m

A' BP 7000 ±430 c. 2440m

LENGTH c. 17km

— Streams/creek

— River

— Indefinite edge

○ Lake

— 200m contour intervals

• Peak height



N

floor of the Upper Wahgi Valley, in which wild stands of the same species were rare or absent. The degradation of forest to grasslands on the floor of the Wahgi Valley in the vicinity of Kuk by ca. 7000 cal BP would have removed the habitats of wild stands of banana, taro, and yam, if present, thereby further isolating cultivated stock. The focus on vegetative propagation isolated cultivars genetically through clonal reproduction, albeit with somatic mutation, thereby partially selecting against sexually reproduced plants and increasing the isolation of cultivated stands from wild gene pools. Some cultivars in New Guinea are still interfertile with wild populations, especially some diploid banana cultivars, and interbreeding is encouraged in some areas (Kennedy and Clarke 2004); however, this would be dependent on the survival of local pollen sources and pollinators in heavily altered environments.

These domestication scenarios are currently hypotheses; the purpose is heuristic and not intended to suggest that these processes were restricted to the Upper Wahgi Valley region. Rather, similar types of process were probably widespread, if variable, across New Guinea and plausibly in adjacent regions. The net effects of these domesticatory relationships are visible in the phylogenies that shed light on the natural distributions, geodomestication pathways, and anthropic spread of major crop plants in New Guinea and Island Southeast Asia.

Comparative: Dispersal of Domesticates and Plant Management in Island Southeast Asia

At present, there are no multidisciplinary records of plant exploitation elsewhere in New Guinea comparable to those from the Upper Wahgi Valley. Tentative comparisons can be made with similar types of records from locales within neighboring regions of northern Australia (Denham, Fullagar, and Head 2009) and Island Southeast Asia (Barton and Denham, forthcoming). These comparisons suggest that the plant exploitation mosaics characteristic of New Guinea may have extended possibly into northern Australia before European arrival (Denham, Donohue, and Booth 2009; Jones and Meehan 1989) and into Island Southeast Asia before the advent of Austronesian speakers (Barker 2006; Barton and Denham, forthcoming). At present these mosaics are largely invisible,

although the dispersal of plants considered to be domesticated in the New Guinea vicinity sheds a clearer light on plant exploitation practices, effectively the orientation of people to plant resources, within these regions (Denham 2010; Donohue and Denham 2010). Currently, knowledge of the social and technological domains of early plant exploitation through Island Southeast Asia is limited; they can only be implied through broadscale and low-resolution (both spatially and chronologically) comparisons of the dispersal and nondispersal of crop plants from New Guinea.

Traditionally, the suite of domesticates considered indigenous to New Guinea included a range of highland and lowland plants, most of which were insignificant or absent outside the region. Highland domesticates included the *karuka* Pandanus complex (*Pandanus julianettii/iwen/brosimos* complex), edible *pitpit* (*Setaria palmifolia*), and *Rungia* (*Rungia klossii*), whereas lowland domesticates included species of *marita* Pandanus (*Pandanus conoideus*), *Canarium* spp., and *Terminalia* spp., as well as sago (*Metroxylon sagu*; Barrau 1955:46). Species with broad altitudinal ranges included sugarcane (*Saccharum officinarum*; Simmonds 1976b:104–108) and Australimusa bananas (*Musa* spp.; Simmonds 1976a:211–215). The domestication locus of *Pueraria lobata* (Watson 1964), a tuberous plant formerly cultivated in the highlands, is questionable. Interpretations of origin and domestication have largely been based on centers of greatest genetic diversity and the presence of ancestral wild forms from which domesticated forms arose (Yen 1985, 1991). Domestication processes in New Guinea, as elsewhere, focused on decreasing toxicity (e.g., taro), decreasing seed size in some fruits (e.g., some breadfruit, bananas), and increasing the edible portions of most root crops, fruits, and nuts.

The application of genetic tools to modern-day plant populations has been revolutionary and suggests that a whole range of important pantropical food plants underwent initial or separate domestication in the New Guinea region (table 2; Kennedy and Clarke 2004; Lebot 1999). Many of these food plants were previously thought to have been domesticated in Southeast Asia, and potentially the locus of domestication may change again as additional cultivated and wild populations are included within the analysis. Of particular significance for understanding the history of agriculture in New Guinea, Island Southeast Asia, and beyond are four globally significant starch-rich plants (elaborated in Denham 2010).

Figure 4. Depictions of (a) significant archaeological and paleoecological sites on the island of New Guinea; (b) significant archaeological and paleoecological sites in the western highlands of Papua New Guinea (shaded box in a); (c) the locations of Ambra, Kuk, Warrawau, and Wurup sites in the Upper Wahgi Valley (box in b); and (d) the relative locations of Kuk, Warrawau, and Wurup sites along an altitudinal transect from the floor to the upper walls of the Upper Wahgi Valley (reproduction of Denham and Haberle 2008, fig. 1).

Date (cal BP)	Form of plant exploitation	Kuk ^a	Warrawau ^{b,c}	Mugumamp ^b	Kana ^{c,d}	Ruti ^d	Tambul ^e	Haeapugua ^c
2750-2150	↑ ↑ ↑ Intensive cultivation (mounds) Intensive cultivation (drainage ditches) Foraging		X		X			X
pre-3260-2800		X			X			
(3980-3630) ^e		X						
c.4350-3980		X						
(3980-3630) ^e								X
c.4840-4440		X			X	X?	X?	
6440-5990 6950-6440		X	X					
10,220-9910		X						

Figure 5. Relative intersite chronology for early and mid-Holocene remains at wetland agricultural sites in the interior of New Guinea. This table is an updated version of Denham 2007, table 5.3. ^aThe dates at Kuk are based on tephrochronology and radiocarbon dates (see sections in Denham 2003b). ^bThe relative dates of mounded paleosurfaces at Mugumamp and Warrawau are based on tephrochronology (i.e., the lie of R ash in paleosurface features) and on radiocarbon dates for a paleochannel at the latter (Denham 2003a). ^cDitches at Warrawau, Kana, Tambul, and Haeapugua have been radiocarbon dated (Denham 2003a). ^dThe dating of “intensive cultivation” at Kana and Ruti is based on tephrochronology (i.e., the lie of R ash) and should be considered provisional at both sites (Denham 2003a). ^eThe stratigraphic relationship between R ash deposition and the earliest Phase 3 ditch at Kuk is uncertain (Denham, Golson, and Hughes 2004).

Bananas (*Musa spp.*)

Bananas (*Musa spp.*) are an important cash and subsistence crop in the tropics and subtropics (De Langhe et al. 2009). The most significant fruiting bananas are derived from species of *Eumusa* section, principally *Musa acuminata* (genome A) and *Musa balbisiana* (genome B). Formerly, *Eumusa* bananas were presumed to be Southeast Asian domesticates, whereas bananas of sections *Australimusa* and *Ingentimusa* were considered indigenous to the New Guinea region (Simmonds 1976a; Stover and Simmonds 1987; Yen 1973).

According to recent research, the initial stages of the domestication of most *Eumusa* cultivars can be traced to *Musa acuminata* ssp. *banksii* populations, which are indigenous to the New Guinea region; parthenocarpy is inferred to have arisen in this species first (Perrier et al. 2009). *Musa acuminata* ssp. *banksii* contributes to the genome of several different groups of banana cultivars, including some of the Pacific plantains (AAB), Western and Central African plantains (AAB),

East African cultivars (AAA), as well as the yellow Cavendish banana (AAA), which is the most widely grown and consumed plantation cultivar today (e.g., Kennedy 2008). The enormous diversity of modern *Eumusa*-derived banana cultivars represents complex geodestication pathways, including multiple subspecific and specific domestications, progressive parthenocarpy and seed suppression, the creation of diploids and triploids, interspecific and intersubspecific hybridization, and somatic mutation (Perrier et al. 2009).

Interpretations suggesting early domestication of *Musa spp.* in the New Guinea region have received some archaeobotanical corroboration. Phytoliths of *Eumusa* type date to ca. 10,000 years at Kuk Swamp in the highlands, with subsequent banana cultivation inferred from high *Musaceae* phytolith frequencies, including those of *Eumusa* type, in association with archaeological features from 7,000 to 6,500 years ago (Denham et al. 2003; Lentfer 2009). Multidisciplinary evidence suggests the dispersal of bananas westward from New

Table 1. Summary of wetland archaeological excavations and evidence for prehistoric agriculture in the interior of New Guinea

Site name ^a	Altitude (m)	Location	Main field seasons	Principal publications
Tambul	2,170	Upper Kaugel Valley	1976	Golson 1997
Mogoropugua	1,890	Tari Basin	1980	Ballard 1995:193–195; Golson 1982:121
Minjigina	1,890	Upper Wahgi Valley	1967	Golson 1982:121; Lampert 1970; Powell 1970:172–174
Ambra Crater	1,760	Upper Wahgi Valley	1999	Sniderman et al. 2009
Haeapugua	1,650	Tari Basin	1991–1992	Ballard 1995, 2001
Kindeng ^b	1,600	Upper Wahgi Valley	1968	Unpublished
Warrawau (Manton's)	1,590	Upper Wahgi Valley	1966, 1977	Golson 1982:121, 2002; Golson et al. 1967; Lampert 1967; Powell 1970:142–146
Kuk	1,560	Upper Wahgi Valley	1972–1977, 1998–1999	Bayliss-Smith and Golson 1992a, 1992b, 1999; Denham 2003a, 2003b, 2004a, 2005a; Denham et al. 2003; Denham, Golson, and Hughes 2004; Golson 1977, 1991; Golson and Hughes 1980
Mugumamp	1,560	Upper Wahgi Valley	1977	Harris and Hughes 1978
Kana	1,480	Middle Wahgi Valley	1993–1994	Muke and Mandui 2003
Ruti Flats	480	Lower Jimi Valley	1983–1985	Gillieson, Gorecki, and Hope 1985; Gillieson et al. 1987; Gorecki and Gillieson 1984, 1989

Note. This table is an updated version of Denham 2007, table 5.1.

^a Other wetland sites have been inspected by archaeologists, although none was investigated in detail. For example, the site at Kotna (1,580 m) in the Upper Wahgi Valley was village land under drainage for coffee. The site was visited by Jack Golson and John Muke in 1988, at which time they sought permission to record features exposed in drain walls. Permission was refused, but while waiting they were able to look at some stretches of drain wall, in which ditches comparable to those of Phase 5 at Kuk were exposed (Jack Golson, personal communication, 2002).

^b The archaeological finds at Kindeng have not been cross-correlated with those at other wetland sites (Jack Golson, personal communication, 2001).

Guinea occurred within a pre-Austronesian time frame (Denham and Donohue 2009; Donohue and Denham 2009, 2010). *Musa acuminata* ssp. *banksii*-derived cultivars spread westward into eastern Island Southeast Asia, where they hybridized with other species and subspecies to produce more robust triploid cultivars that subsequently became widely dispersed throughout Southeast Asia and Africa, potentially to Kot Diji in Pakistan by ca. 4000 cal BP (Fuller and Madella 2009) and to Cameroon by ca. 2500 cal BP (Mbida Mindzie et al. 2001; cf. Neumann and Hildebrand 2009). These processes are suggestive of cultivation of bananas in parts of Island Southeast Asia before the advent of Austronesian language speakers from ca. 4000 cal BP.

Sugarcane (*Saccharum officinarum*)

Although widely perceived to be a snack food, sugarcane has been documented as a staple in parts of the eastern highlands of New Guinea (Daniels and Daniels 1993), and its importance in other regions in the past should be considered, especially as fodder. Sugarcane is an interspecific cultivar predominantly derived from the hybridization of *Saccharum robustum* and *Saccharum spontaneum*. The scenarios of sugarcane domestication are in some respects similar to that for Eumusa bananas, namely, initial domestication in New Guinea with subsequent westward dispersal and interspecific hybridization in Southeast Asia (Grivet et al. 2004). Although the origin and domestication of sugarcane has long been pre-

sumed to have occurred in New Guinea, alternative origins in East Asia have been proposed (Daniels and Daniels 1993) and are yet to be fully investigated.

The initial stages of sugarcane domestication were proposed to comprise the anthropic selection and domestication of a wild ancestor of *Saccharum robustum* in New Guinea (Simmonds 1976b:104–108). Lebot advanced this scenario in his evaluation of the molecular evidence to suggest that

S. robustum is the most likely precursor of sugarcane and was domesticated in New Guinea where human selection of chewing plants with sweet juice and low fibre produced the *S. officinarum* clones. Cultivars were subsequently differentiated in numerous distinct morphotypes via vegetative propagation and selection of somatic mutants. (Lebot 1999: 622–623)

Lebot (1999) concludes that “*S. officinarum* cultivars are derived from introgressions between wild forms of *S. robustum* and *S. spontaneum* in Melanesia” (623). Lebot envisages a similar domestication scenario for *Saccharum edule*, a plant cultivated in New Guinea for its aborted inflorescences. While agreeing that initial domestication of *S. robustum* occurred in New Guinea, Grivet et al. (2004) consider that the resultant cultivar dispersed westward to Southeast Asia, where it hybridized primarily with wild populations of *S. spontaneum* to produce *S. officinarum* as well as with other species to produce other cultivars.

Archaeobotanical evidence of any antiquity for sugarcane

Table 2. Plant domesticates from the New Guinea region that are significant food plants outside Melanesia

Botanical name	Common name	Reference
<i>Alocasia macrorrhiza</i>	Giant taro	Lebot 1999
<i>Artocarpus altilis</i>	Breadfruit	Zerega, Ragone, and Motley 2004
<i>Musa</i> spp. (<i>Australimusa</i> section)	Fe'i bananas	Sharrock 2001
<i>Colocasia esculenta</i>	Taro	Lebot et al. 2004
<i>Cyrtosperma chamissonis</i>	Giant swamp taro	Lebot 1999
<i>Dioscorea alata</i>	Greater yam	Malapa et al. 2005
<i>Musa</i> spp. (<i>Eumusa</i> section)	Bananas and plantains	Perrier et al. 2009
<i>Metroxylon sagu</i>	Sago	Kjær et al. 2004
<i>Saccharum officinarum</i>	Sugarcane	Grivet et al. 2004

Note. Some plants have undergone independent domestication events elsewhere (e.g., taro and aerial yam).

is nonexistent; the putative find from Yuku rock shelter in the New Guinea Highlands (Bulmer 1975:31) can be discounted given the uncertainty of its identification (Yen 1998: 31) and disturbance to the site (T. Denham, unpublished research). The only approximate chronological information for the origin of sugarcane is linguistic and tenuous; a term for sugarcane, “*CebuS,” reconstructs to proto-Austronesian, namely, the languages on Taiwan before the subsequent differentiation of Austronesian languages on Taiwan ca. 5,500 years ago (Blust 1984–1985; Pawley 2007). If the linguistic reconstructions are sufficiently specific, both botanically and chronologically, which is doubtful, then several stages in the domestication of sugarcane occurred before Austronesian language dispersal from Taiwan (Donohue and Denham 2010), including initial domestication of *S. robustum* in New Guinea, westward movement of the derived cultivar to Island Southeast Asia, and subsequent hybridization with *S. spontaneum*.

Taro (*Colocasia esculenta*)

Wild-type taro (*Colocasia esculenta* var. *aquatilis*), the precursor to cultivated taro (*C. esculenta*), has a pantropical distribution extending from northeastern India to mainland Southeast Asia, Indonesia, New Guinea, and northern Australia (Matthews 1995:108–114). The biogeographic and human processes that created this wild-type distribution are unknown (Matthews 1991). Some regions, however, such as New Guinea, have endemic species-specific pests (*Tarophagus* spp., Matthews 2003) and potentially species-specific pollinators (Matthews 1995), suggesting a long antiquity for the plant beyond that involving human management.

The locus of taro domestication has been variably determined based on different types of analysis, that is, from northeastern India (Kurvilla and Singh 1981) to eastern Indonesia (Lebot and Aradhyia 1991). Recent research suggests independent domestications of taro in Southeast Asia and New Guinea (Irwin et al. 1998; Lebot et al. 2004). The gene pools of diploid cultivars in Southeast Asia and New Guinea are clearly distinguishable, and each exhibits relatively low genetic diversity (Lebot et al. 2004). Based on current evidence, the interbreeding and intermixing of diploid taro populations in

Southeast Asia and New Guinea were prevented through reproductive isolation, whether geographically or culturally determined (Lebot 1999:624).

Archaeobotanical and paleoecological research indicates that taro was potentially exploited during the Pleistocene in Island Melanesia (Loy, Spriggs, and Wickler 1992) and on Borneo (Barton and Paz 2007). At ca. 10,000 cal BP, taro was exploited at Kuk Swamp in the highlands of New Guinea (Fullagar et al. 2006), and taro pollen was present in northern Australia (Haberle 2005) and lowland New Guinea (Haberle 1995). Despite the relative ubiquity of the plant, the potential exploitation of taro during the Pleistocene and early Holocene is significant because of the processing required to remove acidity and increase the edibility of wild types.

Greater Yam (*Dioscorea alata*)

The natural distribution and locus of domestication for greater yam (*Dioscorea alata*) are unknown. Current pantropical distributions of *D. alata* cultivars are generally accepted to result from human agency, namely, vegetative propagation of clones, even though the plant can become a persistent weed once established in a region. Morphological, enzymatic, and physicochemical characteristics are not solely due to somatic mutation and asexual reproduction; some sexual reproduction is represented (Lebot et al. 1998).

Limited intraspecific differentiation of *D. alata* cultivars reflects geography, morphology, isozymes, and physicochemical characteristics, but there are few correlations among attributes (Lebot 1999:624–625; Lebot et al. 1998; Malapa et al. 2005). For example, the high degree of morphological variation within *D. alata* represents phenotypic elasticity and not genotypic variation (Malapa et al. 2005). Effectively, widely dispersed cultivars are clones with a narrow genetic base (Lebot 1999:625).

Several authors consider the New Guinea region to be the locus of initial *D. alata* domestication because it exhibits the greatest morphological variation and genetic diversity (Coursey 1972, 1976; Lebot 1999; Martin and Rhodes 1977). As De Candolle noted (1884:13), however, the determination of origin should be based on the elimination of all artificial

forms (namely cultivars) and not on the diversity of cultivars. Perhaps the most compelling evidence for Wallacea and Sahul being the locus of origin of *D. alata* is the genetic proximity of this species to two other yam species derived from the same regions, *Dioscorea nummularia* and *Dioscorea transversa* (Malapa et al. 2005:928). Although circumstantial, the New Guinea region seems to be the place of *D. alata* origin and domestication from which cultivars were dispersed clonally across the globe.

There is no definitive archaeobotanical evidence for *D. alata* predating ca. 3500 cal BP (Paz 2005). Nonspecific yam residues dating to the early Holocene have been identified on stone tools in Island Melanesia (Barton and White 1993) and at Kuk Swamp (Fullagar et al. 2006). The reporting of "*Dioscorea* sp., possibly *D. alata*" (Barton 2005:66) at Niah cave in Borneo should be treated as provisional. Despite the ambiguities of archaeobotanical, botanical, and genetic evidence, the proposed domestication of *D. alata* in the New Guinea region is currently the most plausible interpretation. Clones were subsequently dispersed over a wide geographical area, including Island Southeast Asia, Southeast Asia, and Africa as well as eastward into the Pacific.

Implications for Understanding Plant Domestication Mosaics in Island Southeast Asia

There is no doubt that the New Guinea region was a major center of plant domestication (Lebot 1999). It is also important to note that the crop domestication histories and dispersals outlined above do not follow similar historicogeographical pathways. These plants are unlikely to have spread westward from New Guinea as part of a coherent (horti)cultural package, although dispersal of crop associations may have potentially occurred from Island Southeast Asia to other regions, such as to parts of mainland Southeast Asia, South Asia, and Africa. Bananas and sugarcane are suggestive of westward dispersal from New Guinea with subsequent hybridizations in Southeast Asia. Taro is suggestive of independent domestications in New Guinea and Southeast Asia with geographical and cultural isolation between cultivar gene pools. Greater yam is suggestive of domestication in New Guinea with subsequent widespread dispersal of clonally reproduced cultivars. Presumably some plants did not move, such as taro and some yams (e.g., *Dioscorea bulbifera*; Lebot 1999), because they were relatively ubiquitous resources across New Guinea and Island Southeast Asia, were subject to varying local forms of management and domestication, or were less significant than alternatives and can therefore be assumed not to have been highly prized trade items (Denham 2010).

In the absence of archaeobotanical verification, there seems to have been a westward movement of bananas and sugarcane precursor from New Guinea before the arrival of Austronesian language speakers from Taiwan after 4000 cal BP. These dispersals were facilitated by interisland interaction within Island Southeast Asia (Bulbeck 2008; Donohue and Denham 2010);

localized exchange networks between islands resulted in the net transfer of ideas and things over vast regions. The plants would have been moved and planted rather than solely being tradable commodities exchanged via long-distance voyaging. At present, it is not clear whether crop plants spread together with practices of cultivation and processing or whether cultivars were introduced and adopted into preexisting plant exploitation mosaics across Island Southeast Asia. The time depth of these practices and dispersals across Island Southeast Asia is similarly enigmatic, although they seemingly predate 4000 cal BP.

In sum, it is proposed that people in parts of Island Southeast Asia practiced forms of cultivation before Austronesian language dispersal. At present the history of these presumably nascent agricultural practices is unknown, and it is unclear whether they were in situ developments or were introduced from Asia or New Guinea. Arguably, people inhabiting parts of Island Southeast Asia had comparable orientations to plant resources to those documented for parts of New Guinea, including plant management, vegetative propagation, and cultivation.

Conclusions

In this article, a multidimensional model of early agriculture has been applied at two different scales of analysis: a contextual application at the landscape scale and a comparative application at the regional scale. The emergence and transformation of agriculture in the highlands of New Guinea is discussed with respect to multidisciplinary evidence from the Upper Wahgi Valley. In contrast to previous publications, which have emphasized environmental and technological transformations, the focus here has been on the changing nature of domesticatory relationships through time. A similar theme was applied to understanding the dispersal and non-dispersal of crop plants from New Guinea to Island Southeast Asia; the focus was on crop-plant domestication and dispersal with a view to eliciting an impression of plant exploitation mosaics that are, in the main, currently invisible to archaeological and paleoecological research.

The variability in plant exploitation practices and crop plants witnessed for New Guinea in the recent past and reconstructed for the distant past are likely to apply to parts of Island Southeast Asia before any Austronesian influence on the region. Plant exploitation mosaics are likely to have included parts of Island Southeast Asia and New Guinea for much of the Holocene as well as other parts of Near Oceania and potentially northern Australia. Food plants (and plants used for other purposes) were incorporated in varying degrees of domestication into these plant exploitation mosaics as evidenced by the westward dispersal of *Musa* bananas and a domesticated form of *Saccharum robustum* (sugarcane precursor), which indicates that the region's inhabitants had an orientation to plant resources that plausibly included forms of cultivation.

The framing of early agriculture within a broader set of human-environment relationships is intended to free discussion from conceptually restrictive debates regarding definitions and causation. The multidimensional perspective outlined here is designed to be an enabling framework for interpretation rather than to be prescriptive. Viewing early agriculture through the multidimensional lens of human-environment interactions provides an integrated perspective to understand how agriculture emerged and transformed in the past. Instead of prioritizing one epiphenomenon of agriculture, most often domestication, the generic framework encompasses biological, environmental, social, and technical domains. Although illustrated with respect to the evidence from New Guinea and Island Southeast Asia, the concepts have broader applicability. The comparative application of this generic framework would enable commonalities and differences, both of kind and emphasis, to be determined from the diverse multifaceted expressions of early agriculture in different regions of the world.

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