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Chapter Eight: Ethnoarchaeology of Foraging and the Case of Vanishing Agriculturalists in the Amazon Basin

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Abstract

Debates about ancient Amazonian social organization have evaluated characterizations from a range of sources that include ethnographically documented foraging societies and archaeological discoveries suggestive of sedentized agriculturists. This study uses qualitative ethnoarchaeological data about foraging and small-scale horticulture among the Pumé of Venezuela, and Lewis Binford's quantified database of foraging groups and environmental parameters, to develop a testable model that predicts the conditions under which Amazon Basin foragers would (or would not) intensify subsistence to the point of incorporating maize and other cultivars; as well as the conditions for reversing the process. Specific expectations for the archaeological and paleoenvironmental record are proposed as indicators, and assessed relative to what we currently know from the archaeological record.

Keywords: Foraging subsistence, intensification, manioc, maize, ethnoarchaeology, Pumé Indians, Lewis Binford, Amazon Basin

To Lewis Binford, unanticipated variability represented an opportunity for learning (1983). In Amazon Basin prehistory, the apparent disjuncture between ethnographically observed foragers and archaeological evidence for intensive agriculture and aquaculture represent just such an opportunity. In favor of the forager scenario, nutrient-poor soils, high standing biomass, and scanty, dispersed food resources below the forest canopy appear to condition for high mobility and organizational simplicity (D. Gross 1983; Johnson 1982; Meggers 1992, 1996; Ross 1978; Sponsel 1989, Torres Trueba 1969).

By the time of anthropological study in the Amazon Basin, small, mobile societies did predominate. Recent research agrees that intensive slash-and-burn cultivation can strip soil of nutrients and essential structure, rendering a tropical forest ecosystem as "vulnerable as a hemophiliac" (Weischet and Caviedes 1993:276). Yet discoveries of organic-rich anthropogenic soils (Arroyo-Kalin 2010, Heckenberger et al. 2003, Mora et al. 1991), extensive prehistoric earthwork features (palisades, berms, moats, fish enclosures, human-made islands [Erickson 2000; also see Cleary 2001 p. 75 for summary]), and abundant decorated ceramics (Roosevelt 1994, Mora et al. 1991) are suggestive of large, sedentized communities beginning at c. 2,500 B.P. Paleobotanical remains of *Manihot spp, Dioscorea spp*, and maize (*Zea mays spp.*) suggest mixed-crop cultivation in the forested uplands (Denevan 1992; Heckenberger et al. 2003; Smith and Heckenberger 2009), with intensive maize agriculture on river floodplains (Dickau et al. 2012, Mora et al. 1991, Roosevelt 1980, 1991, 1993, 1994). Is it possible to reconcile these alternative bodies of evidence?

The theater for these events is the vast Amazonian ecosystem of c. 6.1 million km^2, comprised of diverse habitat types with variable potential to support human populations. River floodplain areas (the *várzea*) contain silt and organic-rich soils that support an array of aquatic prey species. The convergence of multiple ecosystems in the várzea offers a variety of resources (Denevan 1992; Lathrap 1968; Meggers 1996; Roosevelt 1980, 1994). However, the várzea makes up only a small fraction of the Amazonian landbase relative to the drier, upland *terra firme* (Heckenberger 1998; Wilson 1999).

If várzea areas were capable of supporting large, sedentized populations as argued by Denevan (1992); Roosevelt (1994) and others, assumptions about ecological limitations of the Amazon Basin on human populations need to be reconsidered. True, initial immigrants would have found that much of the biomass in neotropic forests is inaccessible to humans, but pockets of high productivity do exist (Cleary 2001). These would have opened opportunities for enterprising and observant foragers.

Part of the explanation for the discrepancy between ethnographically observed foragers and archaeological evidence of agriculturists is external to environmental capacity (Cleary 2001; Denevan 1992; Forline 2008). Upheavals in Native Amazonian societies from European incursions included military attacks, slavery, and disease. Survivors retreated to remote areas or would have been reduced to ‘jockeying’ for introduced goods and services. One example is shrinking village size and complexity in the Xingú River drainage at the time of European contact is attributed to colonization (Heckenberger 1998, Heckenberger et al. 2003, Smith and Heckenberger 2009). There is evidence that the Guajá of the eastern Amazon abandoned floodplain agriculture after contact and began foraging in interfluvial zones and headwater areas (Forline 2008). These disruptions would have reduced populations dramatically and had devastating effects on political structures and ethnic identity.

These disruptions didn’t play out on an even stage, however. Varied habitats and thousands of years of human occupation established a range of ‘pre-contact’ types of social organization and it is reasonable to expect that European incursions would have affected agricultural societies differently than foragers. To explore variability in social organization we need to describe *initial conditions*, in Binford’s sense (2001) of the basal system state from which likelihood of major change can be predicted.

Initial conditions of Amazon Basin agriculture are intensified foraging and small-scale horticulture of the Holocene. An important source of reference information is the foraging lifeway of people living under similar conditions today. Warnings about ethnographic analogies as simple proxies for the past (sensu Heckenberger 1998; Roosevelt 1994) are well-taken, but it’s possible to anticipate patterning in the archaeological record by discerning relationships between *linked variables* in ethnographic and archaeological data sets.

Thus, germane characteristics of foragers and small-scale gardeners -- the predecessors of farmers –- are an essential frame of reference to structure research about anticipated archaeological correlates of early agriculture (Binford 2001; Johnson 2008; Yu 2006). Understanding the basal or reference human ecology for the Amazon in the Contact period of c. 600 years ago implicates foraging system change *during preceding periods*. Identifying the conditions likely to precede a transition from foraging to farming will allow me to predict when intensive agriculture would (or would not) have occurred in the Amazon Basin. Archaeological indicators of such pre-conditions of the agricultural transition can then be evaluated relative to what we know about the archaeological record.

Establishing this frame of reference is best accomplished with methods to model foraging behavior that were pioneered by Lewis Binford (1980, 1983, 2001). More than any other anthropologist, Binford elucidated variability in foraging systems and explored conditioning effects of habitat, neighbors, and other factors. This paper discusses the foraging niche and intensification relative to incipient agriculture, and then identifying patterns in a relevant but independent empirical data set: Binford’s (2001) comprehensive ethnographic database of foraging peoples.

Figure 8.1 about here.

These quantitative and comparative data data are augmented with qualitative observations about the Pumé, a foraging-gardening group residing in south-central Venezuela (Gragson 1989; Greaves 1997, 2006, Leeds 1961, Mitrani 1988, Petrullo 1939). I lived in a traditional Pumé community during 1992-93 and observed them dealing every day with conditions and situations that are germane to the interface between tropical foraging and agriculture.

Tactical Responses to a Packed Landscape and System Transformation

Coping tactics that precede the transition to food production should be predictable and observable. Intensification, defined as any practices that increase productivity of food sources per unit area (Binford 2001; Thoms 1989), is one important tactic. A major driver is growth in local population density (Binford 1983; Thoms 1989). Immigration, climatic fluctuations, and socio-political aggregations that increase numbers of people per local area may drive the change from serial occupations of single areas to shift to contemporaneous occupation of multiple ones (Binford 1983). This has major implications for subsistence: a foraging group must now meet its needs with a smaller land base.

The concept of niche is useful in describing subsistence fluctuations and transformations (Binford 2001, Johnson 1997, Yu 2006). Described as the dynamic articulation between a group of ‘actors’ and their habitat (Binford 2001:33), a generalized niche includes a greater proportion of species in the diet, and a specialized niche, a smaller proportion (Binford 2001). Any human foraging niche is elastic, but not infinitely so: foragers approaching the limits of their niche develop labor-intensive tactics to increase resource productivity, including competition, new extraction techniques, and new energy sources (Binford 1983, 2001). All other things being equal, diverse environments can accommodate the niche-broadening process for longer than resource-poor environments before subsistence transforms to another organizational level (Binford 2001:163).

A hypothetical Amazon foraging group could cope with niche pressure by investing labor to extract more energy from familiar foods, and/or exploiting new foods that are harder to procure or process (Binford 2001). Depending on the local resource base, adding new species is a phased process: meat is a preferred food for our species, so it is expected that foragers would shift to smaller game. They may also begin to target aquatic resources or domesticate terrestrial animals (Binford 1983). Terrestrial game animals are scarce and often nocturnal in the Amazon, so foragers would likely emphasize aquatic resources if readily available, with wild plants coming in 'third.'

Comparing Intensification of Aquatic Prey and Wild Plants

Amazonian aquatic food species include a wide variety of fish, as well as reptiles and mammals. I focus here on fish as they are more numerous and diverse and a better option for intensification. In addition, seasonal dependence of migratory fish on ocean productivity offsets local fluctuations, and migrations can offer access to huge numbers.

In the Amazon, aquatic productivity varies according to season. The rainy season is December to May in the east and southeast, and this is reversed in the northwest. Thus rainfed flows are entering the Basin during most of the year (Mora 2003), but local flows can vary dramatically. Rainy season brings an influx of oxygen and nutrients from mountains upstream, and many fish migrate inland from the ocean to access increased foraging opportunities (M. R. Gross *et al*. 1988). Fish are taken with nets and traps at bottlenecks or riffle-pool interfaces where species density is high, but they eventually disperse in the abundant waters and become difficult to procure.

In dry season, water levels drop. Some fish emigrate to the ocean, and some tributaries become ponds in which the remaining fish become hyper-concentrated. They can be taken with bow and arrow, hook and line, and traps. Piscicide is an excellent example of intensified fishing: *Tephrosia sinapou* roots are pounded and swished around in the water, and the poison blocks oxygen intake so that fish float to the surface. Among the Pumé, fish are scooped by the basketful in a festive mood by the whole community (Gragson 1989; Greaves 1997; Yu 1997). This allows me to predict that initial forager intensification of aquatic prey likely occurred in or near the várzea, and primarily during the dry season.

The Pumé adjust subsistence according to rainy and wet season variation. Fishing activity decreases during the wet season but terrestrial game become constricted due to flooding and hunting activity increases. However, plants make up the great majority of wet season food. Wild roots grow large, nutritious, and good-tasting, and fruit comes into season. In the community of Doro Aná during 1992-3, Pumé women provided over half the food by weight during this season. Daily takes of up to 35 kg. of wild roots and other plant foods were common (Greaves 1997, Yu 1997). Post-reproductive age Pumé women were particularly busy, visiting multiple patches per trip and making several trips per week.

It's likely that most of the Amazon forager diet during wet seasons prior to food production was wild plants. Initial intensification of plants would have been favored in the terra firme uplands where aquatic resources were distant, and in the várzea during wet season when aquatic prey were harder to procure. In other words, plant-based intensification *is feasible in a wider range of circumstances than aquatic prey* in the Amazon Basin. Intensification could include addition of new plant varieties, followed by manipulation to increase yield (Binford 1983, Headland and Bailey 1991).

An example of intensified wild plant use from the Pumé is the tree nut chinakarú (*Panopsis rubescens*). Inside each nut pod is an almond-shaped bean, delicious when boiled with salt. However, procurement and processing costs are high; after long trips to dispersed groves, women must carry the nuts home, hammer them open, scrape off the bitter inner membrane, and boil them for about an hour. The chinakarú harvested by one woman in one day cooks down to about a saucepan-full.

Another Pumé tactic of plant intensification is vegetatively propagating wild tubers and corms by re-planting stem sections after harvest (see Figure 8.2, below). While gathering, women often direct family members to weed around wild food plants to reduce competition for sunlight and soil nutrients. Other measures include opening up the canopy with low-burning fires or propagating wild species near natural openings or human-made ones like manioc gardens. Easy access to cultivated and wild plant species in one spot is clearly desirable.

Figure 8.2 about here.

Cultivars, Native and Non-native

Let's visualize a hypothetical Amazon foraging group that has exhausted their repertory of intensification tactics. Eventually, manipulation of wild species generates indigenous cultivars, a process that should vary in tempo and mode according to properties of the habitat. Locally adapted crops preserve resistance to disease and predation and the ability to flourish under local soil and water conditions.

Several indigenous South American root crops were developed in the middle Holocene (also see Posey's interesting 1985 study of Kayapó strategic semi-domestication). Manioc or cassava (*Manihot esculenta*) is familiar to those who enjoy tapioca or *yuca dulce*, but the bitter variety contains toxic cyanogenetic glycosides. Bitter manioc must be peeled, ground, wrung out, and cooked before it can be eaten (Carneiro 1983; Greaves 1997; Roosevelt 1980; Yu 1997). Traditional processing technology is bulky, including stone or ceramic griddles and grinders of heavy wooden boards embedded with animal teeth or stone chips.

The Pumé cultivate bitter manioc (*bai ekará)* in small gardens established through slash and burn at intervals in the gallery forest (Gragson 1989; Greaves 1997; Mitrani 1988; Leeds 1960; Petrullo 1939). Most bitter manioc is propagated vegetatively. Once established, these toxic plants can be left alone safely for months (Greaves and Kramer 2013).

Manioc harvest and consumption are highest during wet season, when the roots are fat. A 10-kg. load takes an average women four to eight hours to process into a stack of about 20-30 dried *tambai* cakes and a potful of sweetish boiled liquid. Pumé women commonly embed other household chores in this arduous task. During harvest season the women of a household may process manioc once or twice a week.

For ancient Amazonian foragers, indigenous tropical cultivars would have been compatible with mobility needed to access important wild resources. There are also nutritional reasons that foragers would maintain access to wild foods. A recent comparative study among the Pumé (Greaves and Kramer 2013) concluded that wild roots are desirable compared to cultivated varieties because

1. Wild roots provide similar caloric returns to manioc and have higher protein content.
2. Returns are higher on average, being limited only by the number of patches visited rather than garden size and productivity.
3. Wild roots contain no toxins and don't require laborious processing.
4. Wild roots taste better and are more filling in fighting hunger (p. 268).

Given this comfortable equilibrium between wild and indigenous cultivated foods, what might lead foragers to become interested in exotic cultivars? Discoveries of maize at the Parmana site near the Orinoco River basin are cited for population expansion, sedentism and nucleated settlements (Roosevelt 1980, 1991). Maize does have useful characteristics: it can be rapidly broadcast-planted and harvested in one season and requires little processing, and in the tropics maize harvest season is offset from manioc harvest by several months.

Nevertheless, tropical foragers might hesitate to invest in maize for several reasons. The risks and costs of tropical maize cultivation affect productivity, even when modern technology is available (Balee 2006). The earliest teosinte was domesticated in the tropical deciduous forest of southern and western Mexico (Piperno and Pearson 1998), but true maize was developed in the central-western uplands. As cereal crops are not adapted to tropical environments, they require continual breeding for disease-resistant strains (Weischet and Caviedes 1993). Trial cultivations of even disease-resistant maize yield little under traditional farming practices (e.g., small dispersed fields, random cultivation, no weeding or fertilizer).

Substantial yields of tropical maize require major investment in large fields, row cultivation, application of at least 80 kg. per hectare of fertilizer, and frequent weeding (Ibid p. 231). Maize must be harvested rapidly and stored immediately (difficult in a tropical climate). In contrast, tubers are self-storing underground and can be harvested throughout the wet season (Greaves and Kramer 2013).

The implications of maize cultivation for Amazon Basin foragers and forager-gardeners are obvious. Maize required a dedicated labor force on call, curtailing access to and more importantly, information about wild resources. As put by a Nunamiut man: “When I’m here in one place, I don’t know what’s going on over there,” (Binford 1983:204). In an example from the Pumé, the community of Doro Aná received periodic government distributions of seed maize. But they simply boiled and ate most of it within a few days, remarking that they were unwilling to guard maize fields against deer and rabbits.

This directly observed evidence counters Darwinian explanations (*sensu* Piperno and Pearsall 1998) for adoption of intensive food production as adaptive, unidirectional, and inevitable. Sedentism would have been prerequisite to adoption of agriculture, as evidenced by post-contact ethnographies: among Native Australians and Pacific Northwest tribes, wheat and potatoes were reluctantly adopted only *after* enforced settlement (O’Connell and Hawkes 1981; Thoms 1989).

This reference information is synthesized into a model for intensification and transition to agriculture in the Amazon basin:

Maize is adopted after a sequence in which wild food intensification, then indigenous crops, cease to meet the needs of consumers. The speed and intensity of maize adoption should vary inversely with the availability of aquatic resources and productivity of indigenous cultivars.

Tempo and Mode of Forager Intensification

To evaluate the usefulness of the model I turn to an independent but related body of information: Binford’s database of foraging peoples and data about their home environments. Modern weather data are not a proxy for the period preceding Amazonian agriculture, but the relative stability of Holocene landscapes and climates in this region warrants the use of modern data to evaluate of the model’s utility.

Climate, Habitat, and Modes of Tropical Forest Foraging

To characterize Amazonian climatic and environments in terms germane to subsistence, tropical South American areas within the value of yearly average rainfall >150 cm and average annual temperatures of 77ºF/25ºC are examined. Here, “growing season” temperatures occur year-round so the only limits on primary productivity (plants) are precipitation, soil nutrients, and access to sunlight. The Amazon River and its many tributaries play a vital role in resource distribution, delivering seasonal pulses of nutrients during wet season.

Binford’s database of 340 ethnographically known foragers includes 73 cases from habitats in or near the Amazon Basin. Binford (2001) uses known organizational properties of foragers to make projections of foraging lifeways into habitats where foragers no longer reside.

Figure 8.3 about here.

Figure 8.3 shows weather stations for which expected foraging subsistence emphasis is shown based solely upon climate and environment (e.g., population packing and its influences have not yet occurred). About half the Amazon locations are predicted to have strong reliance on aquatic resources for at least half the year. Neotropic aquatic foods serve as the primary protein source whenever available, especially in the dry season. In the equatorial tropics, aquatic resources (excepting turtles) aren’t storable for long. Before commercial salt became available the only method of storage would likely have been smoking; the Doro Ana Pumé consumed smoked fish within five days or less due to risk of spoilage. This means that effective use of tropical aquatic resources is constrained temporally and spatially compared to wild plant resources. Binford’s projections for “not yet packed” Amazonian foragers show that, overall, reliance on aquatic resources varies inversely with reliance upon wild plant foods.

Figure 8.4 about here.

Let's turn to Amazon foraging subsistence focus based on *known* ethnographic cases of foragers who have become packed after thousands of years (packing threshold value is c. 9.1 persons/km^2 [Binford 2001:375] based on global ethnographic patterning). Here, wild plant gathering (excluding all cultigens) dominates subsistence *regardless of availability of aquatic resources*.

What accounts for this disparity between unpacked (habitat-influenced) and packed (neighbor-influenced) forager subsistence? One possibility is post-contact impacts on fisheries; Amazonian fish populations are vulnerable to cultivation, mining, ranching, and/or urban development (M. Gross et al. 1988). However, studies among traditional African river fishermen show that yields are strongly linked with the level of effort rather than productivity *per se* (Bayley (1988). Too, packed populations of fishing specialists can lead to over-harvest, scarcity, or collapse. If this was true in the Amazon, foragers likely shifted away from aquatics and toward terrestrial plants for reasons *not* related to aquatic productivity.

Trajectories of Intensification and Changing Land Use

Proceeding from the ethnographically verified premise that size of the area of occupation and size of the foraging group are conditioned by properties of the habitat, Binford projects high foraging population densities (N persons/100 km^2) for Amazon Basin areas with ready access to aquatic foods (Figure 8.5).

Figure 8.5 about here.

As with the American Bottom and the great river floodplains of China, Amazon Basin river landscapes condition for dense forager populations. Fascinatingly, the empirical data on tropical forest foraging peoples across the globe today show that *all* are highly packed and intensified (Binford 2001) regardless of access to aquatic resources. This is likely because mutualistic relationships offer forager specialists in forest products ("bush meat," medicinal and dye plants, etc.) opportunities to trade with neighboring agriculturalists for carbohydrate-rich crops (Headland and Bailey 1991; Hoffman 1986; Kitanishi 2003; Turnbull 1968).

Thus, packed tropical foragers today who have no access to aquatic resources tend to establish mutualistic relationships with farmers or pastoralists (Binford 2001). In a world *before* farming neighbors existed, tropical gatherers without access to aquatic resources would have intensified yields of wild terrestrial plants, followed by experimentation with native crops.

In várzea environments, we can expect that wild resources and native cultivars would serve forager needs until a critical subsistence threshold was reached (from population shifts or growth, disruption of fishery productivity, etc.). Among forager-gardeners already densely packed and semi-sedentized from reliance on gardening and fishing, maize cultivation would shift from a liability to an asset. *Thus, when a subsistence threshold is reached among aquatic-dependent foragers, maize agriculture would result in rapid, large-scale effects to subsistence and settlement.* In the upland terra firme where maize cultivation requires major effort for irrigation and fertilization, there would be less incentive.

Archaeological Correlates of the Transition from Foraging to Agriculture

The archaeological record supports expectations of early native neotropical cultivation compatible with mobility needed to access to wild resources. Fish remains do not readily preserve in acidic tropical soils and the technology of fish procurement is usually made of perishable organics (Yu and Cook, in review). So I will focus instead on plant foods, which have a more durable archaeological signature as ground stone and macrobotanical remains.

Early South American cultivars were developed in the middle Holocene, with genetic evidence indicating earliest manioc in northern Peru as early as 8,500 B.P., Panama by c. 7,600 B.P. (Piperno 2011, Piperno et al. 2000), and the Southern Amazon border region slightly later (Olsen and Schaal 1999). Piperno (2006) notes that bitter manioc appeared first, with sweet varieties appearing later. This is consistent with expectations for 'low maintenance' varieties being developed first by forager-gardeners.

Aside from starch grains and phytoliths (Ezell et al. 2006), ceramic griddles (*budares*) and grater teeth are the best indicators of bitter manioc. In the Eastern Amazon, budares appear at c. 3,600 B.P., concurrent with increased forest burning in the upland terra firme. Sites from the La Gruta phases in Middle Orinoco (Roosevelt 1980, 1993) contain numerous grater teeth and budares. The early strata at La Gruta indicate a strong aquatic focus, with fish, aquatic mammals, and turtles complementing terrestrial mammals and birds.

The lack of large, sedentized settlements, intensive use of the várzea, soil replenishment, and irrigation features in these early agricultural settlements indicates that early forager-gardeners kept their mobility options open. Bulky site furniture required to process toxic manioc would have focused mobility toward repeat occupations(s*ensu* Binford 1980), as would manioc gardens. This suite of developments enabled indigenous crops to expand rapidly northward from their area(s) of origin in southern South America (Piperno 2011, Piperno and Pearson 1998). The predominance of sweet manioc in the Amazon today (Piperno and Pearson 1998, Sheets 2009), supports the expectation that later sedentized groups could monitor and protect crops that are vulnerable to predators.

New Cultivars, "Old Chevies", and Reversibility

Archaeological evidence for maize includes manos, metates, built-up soil horizons, and large cultivated fields. Gradual adoption of maize in the Araracuara drainage of southern Colombia is indicated by maize pollen appearing together with manioc at c. 4,700 BP (Mora et al. 1991), followed by a delay of several hundred years before higher maize frequencies and evidence for intensive soil replenishment. Major labor investment is indicated by tons of várzea soils spread on the fields each year (Ibid). This, along with slow, low-heat burning to soils identified as *terra preta* (Smith and Heckenberger 2009), explains the success of prehistoric Amazonian maize agriculture compared to today's swidden techniques.

At Lake Geral and other Eastern Amazon sites, maize cobs always appear after bitter manioc, and are concentrated in the river floodplain or várzea along with evidence for large, socially ranked, sedentized communities (Piperno and Pearsall 1998). In the Orinoco Basin, grating teeth and budares are overlain by maize cobs, manos, and metates beginning at c. 2,700 B.P. (Roosevelt 1980), as in the western Brazilian Amazon (Neves 1998).

Intensive maize cultivation did not eliminate bitter manioc. At the Abeja site in Araracuara, Colombia, manioc was gradually augmented by maize but never totally replaced (Mora et al. 1991). Later, as fields reverted to forest, maize disappeared but dependable manioc continued to be planted (Ibid). This is consistent with the expectation that adaptive characteristics of indigenous cultivars ensured their maintenance alongside high-risk/high-productivity non-native crops. As Payson Sheets (2009) puts it, "I like to think of manioc like an old Chevy gathering dust in the garage that doesn't get much attention, but it starts right up every time when the need arises."

Indeed, archaeological evidence from the Xingu River indicates that, when combined with fish, manioc can support large, sedentized communities (Heckenberger 1998; Heckenberger et al. 2003; Smith and Heckenberger 2009). Any disruption to the delicate equation of high-cost to high-yield maize, such as a climatic disruption or shrinkage of the labor pool below a critical threshold, would favor the return of the "old Chevy" -- manioc.

Discussion and Conclusion

The model statement about conditioning factors for the transition from foraging to gardening to farming is partly supported. Initial forager intensification of wild plants probably took place in the terra firme uplands, and in the várzea during wet season. Manioc and other native cultivars were domesticated to intensify plant food options while minimizing loss of mobility, and wild resources continued in importance.

Várzea foragers would have become concentrated early, primarily from seasonal availability of aquatic resources supplemented by native cultivars. Thus when critical food supply thresholds were reached, already-packed populations needed a fast solution. The problem was exacerbated by difficulty of storage in the tropics (also see Johnson *et al.*, this issue). In the less productive uplands, smaller populations relied on a combination of wild plants and native cultivars.

When maize arrived, it was adopted in two different modes. Plant-dependent terra firme groups cultivated maize alongside manioc, but packed groups of the várzea invested heavily in maize agriculture, which became both necessary (given large numbers of people to feed), and feasible (given rich várzea soils, easy access to water, and a large labor force). Manioc continued to be grown in both habitats as a dependable complement and back-up crop. The paleo-botanical and settlement record for the Llanos de Mojos lowlands of Bolivia are an excellent example of these connected concepts (Dickau et al. 2012, Lombardo and Prümers 2010).

These results are consistent with a global sample of agricultural transitions analyzed by Johnson (2008), which shows late, intensive adoption of introduced cultivars in productive riverine areas and more gradual adoption in habitats favoring terrestrial gathering. The issue of Contact-era transitions from maize agriculture "back to" foraging in the Amazon may be explained by the necessary linkage of intensive maize agriculture in tropical settings with sedentized, easily mobilized labor forces.

Mora *et al*. calculate that 245 tons of alluvial soil or 90 tons of forest litter are required to produce a 1-cm thick fertile layer over one hectare (1991), and each field would need replenishing yearly (Ibid). Substantial layers of river-bottom soil, indicated by alluvial silt, organic debris, and algae, were transported and placed by hand on upland maize fields in the Colombian Amazon during periods of intensive maize cultivation (Ibid). Thus a small reduction in local labor force would quickly render maize agriculture infeasible.

Archaeologically, we should see rapid abandonment of intensive maize agriculture around the time of European contact. Groups fleeing the now-hazardous várzea for the terra firme would have turned to dependable wild plant foods and bitter manioc. This should be visible archaeologically as a corresponding increase in occupation of more remote headwater or interfluvial areas.

I can now adjust the model:

Maize is adopted intensively by tropical foragers when where intensification based on aquatic resources and/or indigenous crops no longer meets the needs of consumers. Intensity of initial maize adoption should vary inversely with availability of aquatic resources. Aquatically-fuelled populations who reach packing thresholds should adopt intensive maize cultivation rapidly. Any disruption in the labor force should lead to rapid abandonment of intensive maize agriculture and renewed emphasis on indigenous cultivars and wild food plants.

In the study of major cultural transformations, it is hard to over-state the contributions that Lewis Binford made to scientific exploration of human lifeways, and foraging in particular. Using a research strategy that he pioneered, I used ethnographic information about intensification tactics of foragers to develop predictive statements about tempo, mode, and reversibility of agriculture in the Amazon Basin.

These predictions can be operationalized in future archaeological research. Implications include habitat types where ancient agricultural settlements may be expected, the sequence of appearance and disappearance of maize grinding and storage technology, and evidence for fertilization and water management. Combining testable scientific methods with qualitative information about traditional lifeways indicates that indigenous methods of horticulture, and later, agriculture, were capable of supporting sizeable communities in the Amazon Basin under the right conditions —- most importantly availability of a large labor pool and access to healthy aquatic ecosystems. Amazon Basin lifeways were thus adaptively flexible to changes in local conditions, producing a variable and predictable body of archaeological evidence.

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References

Arroyo-Kalin, M., 2010. The Amazonian Formative: Crop Domestication and Anthropogenic Soils. Diversity 2, 473-504.

Bailey, R.C., Headland, T.N., 1991. The tropical rain forest: Is it a productive environment for human foragers? Human Ecology 19, 2, 261-285.

Balee, W.L., 2006. The historical ecology of a complex landscape in Bolivia. In: Balee, W. L. Erickson, C. L., Erickson, (Eds.), Time and Complexity in Historical Ecology: Studies in the Neotropical Lowlands, Columbia. University Press, New York, pp 187-233.

Bayley, P.B., 1988. Accounting for effort when comparing tropical fisheries in lakes, river-floodplains, and lagoons. Limnology and Oceanography 33,4 part 2, 963-972.

Binford, L.R., 1980. Willow smoke and dogs tails: hunter-gatherer settlement systems and archaeological site formation. American Antiquity 45, 4-20.

Binford, L.R., 1983. In Pursuit of the Past. Thames and Hudson, London.

Binford, L.R., 2001. Constructing Frames of Reference: An Analytical Method for Archaeological Theory Building Using Hunter-Gatherer and Environmental Data Sets. University of California Press, Berkeley.

Carneiro, R.L., 1983. The cultivation of manioc among the Kuikuru Indians of the Upper Xingu. In: Hames, R. B., Vickers, W. T. Vickers (Eds.), Adaptive Responses of Native Amazonians. Academic Press, New York, pp. 65-111.

Cleary, D., 2001. Toward an environmental history of the Amazon: from prehistory to the nineteenth century. Latin American Research Review, 36, 2, 65-96.

Denevan, W., 1992. The Pristine Myth: The Landscape of the Americas in 1492. Annals of the American Association of Geographers 82, 3, 369-385.

Dickau, R., Bruno, M.C., Iriarte, J., Prümers, H., Betancourt, C.J., Holst, I., and Mayle, F.E., 2012. Diversity of cultivars and other plant resources used at habitation sites in the Llanos de Mojos, Beni, Bolivia: evidence from macrobotanical remains, starchgrains, and phytoliths. Journal of Archaeological Science 39, 2012, 357-70.

Erickson, C.L., 2000. An artificial landscape-scale fishery in the Bolivian Amazon. Nature 408, 190-193.

Ezell, K.C., Pearsall, D.M., Zeidler, J.A. Zeidler, 2006. Root and tuber phytoliths and starch grains document manioc (Manihot esculenta) arrowroot (Maranta arundinacea) and llerén (Calathea sp.) at the Real Alto site Ecuador. Economic Botany 60, 2, 103–120.

Forline, L., 2008. Putting history back into historical ecology: Some perspectives on the recent human ecology of the Brazilian Amazon. Journal of Ecological Anthropology 12, 1, 69-74.

Gragson, T.L., 1989. Allocation of Time to Subsistence and Settlement in a Ciri Khonome Pumé Village of the Llanos of Apure, Venezuela. Unpublished PhD Dissertation, Pennsylvania State University, University Park.

Greaves, R.D., 1997. Ethnoarchaeological Investigation of Subsistence Mobility, Resource Targeting, and Technological Organization among Pumé foragers of Venezuela. Unpublished PhD Dissertation, University of New Mexico, Albuquerque.

Greaves, R.D., 2006. Forager landscape use and residential organization. In: Sellet, F., Greaves, R. D., and Yu, P. (Eds.), Subsistence, Material, and Demographic Approaches to Mobility. University Press of Florida, Gainesville, pp. 127-152.

Greaves, R.D., and K. Kramer, 2013. Hunter-gatherer use of wild plants and domesticates: archaeological implications for mixed economies before agricultural intensification. Journal of Archaeological Science 41 (2014) 263e271

Gross, D., 1983. Village movement in relation to resources in Amazonia. In: R. Hames and W. Vickers (Eds.), Adaptive Responses of Native Amazonians. Academic Press, New York, pp. 429-449.

Gross, M.R., Coleman, R.M., McDowell, R.M., 1988. Aquatic productivity and the evolution of diadromous fish migration. Science 239, 4845, 1291-1293.

Headland, T.N., Bailey, R.C. 1991. Introduction: Have hunter-gatherers ever lived in tropical rain forests independently of agriculture? Human Ecology 19, 2, 115-122.

Heckenberger, M.J. 1998. Manioc agriculture and sedentism in Amazonia: the upper Xingú example. Antiquity 72, 633-648.

Heckenberger, M.J., Kuikuro, A., Kuikuro, U.T., Russell, J.C., Schmidt, M., Fausto, C., Franchetto, B., 2003. Amazonia 1492: Pristine Forest or Cultural Parkland? Science 301, 1711-1714.

Hoffman, C.L., 1986. The Punan: Hunters and Gatherers of Borneo. UMI Research Press, Ann Arbor.

Johns, T., 1989. A chemical-ecological model of root and tuber domestication in the Andes. In: Harris, D. R., Hillman, G. C. (Eds.), Foraging and Farming: the Evolution of Plant Exploitation. Unwin Hyman, London, pp. 504-519.

Johnson, A., 1982. Reductionism in cultural ecology: the Amazon case. Current Anthropology 23, 4, 413-28.

Johnson, A.L., 2008. A method for anticipating patterns in archaeological sequences: projecting the duration of the transition to agriculture in Mexico--a test case. In: Webster, L. D., McBrinn, M. B. (Eds.), Archaeology Without Borders. University Press of Colorado, Boulder, pp. 89-106).

Johnson, A.L., Gil, A., Neme, G., Freeman, J. (in press). Working at Theory-Building: Testing Models of Plant Intensification and Maize Use in Central Western Argentina. Journal of Anthropological Archaeology.

Kelly, R.L. 1995. The Foraging Spectrum. The Smithsonian Press, Washington, DC.

Kitanishi, K., 2003. Cultivation by the Baka hunter-gatherers in the tropical rain forest of Central Africa. African Study Monographs, Suppl. 28, 143-157.

Lathrap, D.W., 1968. The 'hunting' economies of the tropical forest zone of South America: an attempt at historical perspective. In: Lee, R. B., Devore, I. (Eds), Man the Hunter. Aldine, Chicago, pp. 23-29).

Leeds, A., 1961. The Yaruro incipient tropical forest horticulture: possibilities and limits. In: J. Wilbert (Ed.), The Evolution of Horticultural Systems in Native South America: Causes and Consequences. Antropológica Supplement No 2. Editorial Sucre, Caracas, Venezuela, pp. 13-46.

Lombardo, U., and Prümers, H., 2010. Pre-Columbian human occupation patterns in the eastern plains of the Llanos de Moxos, Bolivian Amazonia. Journal of Archaeological Science, 2010, 1875-85.

Meggers B.J., 1992. Prehistoric population density in the Amazon basin. In: Verano, J. W., Ubelaker, D. H. (Eds.), Disease and Demography in the Americas. Smithsonian Institution Press, Washington DC, pp. 197-205.

Meggers B.J., 1996. Amazonia: Man and Culture in a Counterfeit Paradise, revised edition. Smithsonian Institution Press, Washington DC.

Mitrani, P., 1988. Los Pumé (Yaruro). In: J. Lizot (Ed.), Los Aborígenes de Venezuela, Vol. III, Etnología Contemporánea II Caracas. Fundación La Salle de Ciencias Naturales Venezuela, pp. 147-213.

Mora, S., 2003. Early inhabitants of the Amazonian tropical rainforest. Latin American Archaeology Reports No. 3, University of Pittsburgh, Pittsburgh.

Mora, S., L. Herrera, F., Cavelier, I., Rodriguez, F.C., 1991. Cultivars, Anthropic Soils and Stability: A Preliminary Report of Archaeological Research in Araracuara, Colombian Amazonia. Latin American Archaeology Reports No. 2, University of Pittsburgh, Pittsburgh.

Neves, E., 1998. Twenty years of Amazonian archaeology in Brazil (1977-1997). Antiquity 72, 277, 625-632.

O'Connell, J.F., Hawkes, K., 1981. Alyawara plant use and optimal foraging theory. In: Winterhalder, B. (Ed.), Hunter-gatherer Foraging Strategies. Chicago University Press, Chicago, pp. 99-125.

Olsen, K.M., and B.A. Schaal, 1999. Evidence on the origin of cassava: Phylogeography of Manihot esculenta. Proc. Natl. Acad. Sci. USA 96:5586–5591.

Petrullo, V., 1939. The Yaruros of the Capanaparo River, Venezuela. Smithsonian Institution, Bureau of American Ethnology, Anthropological Papers No. 11, U.S. Government Printing Office, Washington DC:

Piperno, D.R. 2011. The Origins of Plant Cultivation and Domestication in the New World Tropics: Patterns, Process, and New Developments. Current Anthropology 52 (Supplement 4):S453-470.

Piperno, D.R. 2006. Identifying manioc (Manihot esculenta Crantz) and other crops in pre-Columbian tropical America through starch grain analysis: a case study from Panama. In Documenting Domestication: New Genetic and Archaeological Paradigms. M. Zeder, E. Emschwiller, D. Bradley, and B.S. Smith, eds. Pp. 46–67. University of California Press, Berkeley.

Piperno, D.R., Ranere, A.J., Holst, I., Hansell, P., 2000. Starch Grains Reveal Early Root Crop Horticulture in the Panamanian Tropical Forest. Nature 407:894-897

Piperno, D.R., Pearsall, D.M., 1998. The Origins of Agriculture in the Lowland Neotropics. Academic Press, New York.

Posey, D.A., 1985. Indigenous management of tropical forest ecosystems: the case of the Kayapó Indians of the Brazilian Amazon, Agroforestry Systems 3, 2, 139-158.

Roosevelt, A.C., 1999. The Maritime-Highland-Forest Dynamic and the Origins of Complex Society. In: Salomon, F., Schwartz, S. (Eds.), History of the Native Peoples of the Americas. South America, Part 1, Cambridge University Press, New York, pp. 264-349.

Roosevelt, A.C., 1980. Parmana: Prehistoric Maize and Manioc Subsistence along the Amazon and Orinoco. Academic Press, New York.

Roosevelt, A.C., 1989. Resource management in the Amazon Basin before the European Conquest: beyond ethnographic projection. In: Posey, D. Posey, Balee, W. (Eds.), Natural Resource Management by Indigenous and Folk Societies in Amazonia. New York Botanical Garden Advances in Economic Botany No. 7, New York, pp. 30-61.

Roosevelt, A.C., 1994. Amazonian anthropology: strategy for a new synthesis, In: Roosevelt, A. C. (Ed.), Amazonian Indians from Prehistory to the Present: Anthropological Perspectives, University of Arizona Press, Tucson, pp. 1-29.

Ross, E.B., 1978. Food taboos, diet, and hunting strategy: the adaptation to animals in Amazon cultural ecology. Current Anthropology 19, 1, 1-36.

Sheets, P., 2009. University of Colorado website, www.sciencedaily.com/releases/2009/06.090616133940.htm.

Smith, M.J., Heckenberger, M.J., 2009. Amerindian Anthrosols: Amazonian Dark Earth Formation in the Upper Xingu, In: Woods, W. I., Teixeira, W. G., Lehmann, J., Steiner, C., WinklerPrins, A., Rebellato, L. (Eds.), Amazonian Dark Earths: Wim Sombroek's Vision, Springer Publishers, Heidelberg, pp. 163-191.

Sponsel, L.E., 1989. Farming and foraging: a necessary complementarity in Amazonia? In: Kent, S. (Ed.), Farmers as Hunters: the Implications of Sedentism, Cambridge University Press, Cambridge, pp. 37-45.

Thoms, A.V., 1989. The Northern Roots of Hunter-Gatherer Intensification: Camas and the Pacific Northwest. Unpublished PhD Dissertation, Washington State University, Pullman.

Torres-Trueba, H.F., 1969. El sistema de roza y las posibilidades de desarrollo cultural en la region tropical del amazonas. America Indigena 29, 1, 73-88.

Turnbull, C., 1968. The Forest People. Touchstone Books, New York.

University of Colorado at Boulder 2009 June 17. Maya Intensively Cultivated Manioc 1,400 Years Ago. Science Daily. Retrieved November 26, 2010, from http://www.sciencedaily.com/releases/2009/06/090616133940.htm

van der Merwe, N.J., Roosevelt, A.C., Vogel, J.C., 1981. Isotopic evidence for prehistoric subsistence change at Parmana, Venezuela. Nature 292, 536-538.

Weischet, W., Caviedes, C.N., 1993. The Persisting Ecological Constraints of Tropical Agriculture, John Wiley and Sons, New York.

Wilson, D.L., 1999. Indigenous South Americans of the Past and Present. Westview Press, Boulder CO.

Yu, P.L., 1997. Hungry Lightning: Field Notes of a Woman Anthropologist. University of New Mexico Press, Albuquerque.

Yu, P.L., and J. Cook, 2014. Scale and organization in traditional salmon fishing: insights from ancient technology of the Upper Columbia River. In: Yu, P. (Ed), Rivers, Fish, and the People. University of Utah Press, Salt Lake City.