Chapter 23

HISTORICAL ECOLOGY AND FUTURE EXPLORATIONS

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1. INTRODUCTION

> ...there are no environmental limitations to the development of agriculture, only cultural limitations. "Agricultural potential" is a cultural phenomenon; it is not something inherent in nature that can be measured, that exists independent of culture. Today, with available technology, agriculture can be carried out anywhere on earth. Whether it is or not in any given habitat is dependent on whether the culture involved has the necessary technology, and whether or not there is a perceived need in relation to the costs involved (capital, material, labor) (Denevan, 1982: 181).

Soils in Amazônia are traditionally thought of as a given, limited homogeneous resource labeled as poor or marginal for agriculture. Historically and ethnographically, the strategy of settlement and farming in Amazônia is to colonize new farmland (a form of agricultural expansion) and use them for 2-3 years until crop yields decline and/or weeds become too much of a problem, abandon the field and move on to a new location (e.g. slash-and-burn agriculture and now increasingly modern ranching in the tropical forest). Agricultural intensification, increasing yields through addition of labor, fertilizers, irrigation (infrastructure), mechanization, and capital to unit area of production has had limited success in Amazônia. Amazonian Dark Earth (ADE)[1] may represent a significant case of agricultural intensification by Native Americans, the artificial creation of new, highly productive soils. The investment of energy, materials, and resources into permanent farmland near settlements apparently had positive results based on the archaeological evidence for size and longevity of occupation on these sites. The form and internal variation of ADE provides insights about patterned human

[1] Amazonian Dark Earths (ADE) have been referred to as *Terra Preta de Indio*, Indian Black Earth, Black Earth Soils; Black Earth Sites, Anthropogenic Dark Earths, Anthrosols, Anthropic Soils, *Terra Preta Arqueológica*, and *Tierra Negra*.

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activities within pre-Columbian settlements that produced them. Research on ADE may also contribute to contemporary rural development.

Historical Ecology provides an interesting framework to discuss Amazonian Dark Earth (ADE). The basic premise is that Native Amazonians did not adapt to nature, but rather they created the world that they wanted through human creativity, technology and engineering, and cultural institutions (Balée, 1998; Denevan, 2001, Stahl, 1996; Erickson, 2000a).[2] Focus is on the human history rather than natural history of the environment contextualized within an historical and cultural tradition. For example, Balée's "model of agricultural regression" (1994) states that present-day native farmers and foragers live off resources in their environment that were created by the efforts of hundreds of generations of previous occupants of the landscape. Humans do not adapt to a given natural environment, but rather are exploiting the past, complex human history of the landscape; partaking in the accumulated landscape capital created by their ancestors. Rather than passive responders or adaptors to a given environment as stressed in the traditional approaches[3], historical ecologists view humans as active agents in their interaction with nature who promote change and continuity through culture. The landscape, the central conceptual structure for historical ecology, is the physical manifestation of the long-term human history of the environment. The goal is to document and understand the long-term creation of the environment as we know it today. This understanding may provide models for strategies of conservation and management of the environment in the present and future.

ADE is an excellent example of an anthropogenic (human-created) landscape feature, one of many past human activities permanently embedded in the landscape that continue to structure the environment and are still exploited by native peoples today. In fact, ADE was prominent in two classic publications that critique the widely accepted idea that Amazonian tropical forests are pristine wilderness (Balée, 1989; Denevan, 1992a).

It is the key role that soils have played in the history of thinking about the past, present and future of the Amazon Region that makes this volume about ADE so timely and important. ADE was recognized by scholars in the last century, but remained relatively unknown to Americanist scholars until the 1980s (Myers et al., 2003; Woods, 2003). The volume surveys the history of research about ADE and presents detailed analyses and new interpretations about the content, origin, use, maintenance, and sustainability of these anthropogenic soils (anthrosols). The authors of this volume demonstrate that Amazonian peoples were capable of transforming soil horizons, improving nutrient availability and recycling, altering hydrology, changing vegetation succession, and capturing sediments; but they also created or constructed new productive soils. These terms "create" and "construct" capture the scale and significance of what Amazonian people did to improve their

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[2] For surveys of Historical Ecology, see Balée (1989, 1994, 1998), Crumley (1994), Denevan (1992, 2001), Stahl (1996, 2000), Scoones (1999), Little (1999), Zimmerer and Young (1998), and Balée and Erickson (in prep.).

[3] Historical ecology stands in sharp contrast to theoretical perspectives of cultural ecology, human ecology, ecological anthropology, sociobiology, and evolutionary biology approaches in social sciences that have been applied to Amazônia (Balée 1989, 1994, 1998).

environment for human existence and development. Whether these regional-scale anthropogenic impacts were negative or positive over the short and long term continues to be debated and will be discussed in a later section of this chapter.

Soils have long played a key role in the structuring of our understanding of past and present Amazônia. When humans and soils are discussed at the same time, it is usually framed in terms of environmental limitations or possibilities or progressive human degradation of landscapes through overuse and erosion. In trying to understand why civilizations rarely developed or if present, soon collapsed in regions of tropical forest, scholars (Steward, 1948; Meggers, 1954, 1971; and others) proposed that poor soils were environmental limitations to cultural development. According to the Meggers' "Theory of Environmental Determinism" (1954), swidden agriculture (slash-and-burn agriculture, shifting cultivation) developed as an adaptation to these poor soils (summarized in Myers et al., 2003). Because classic swidden requires large tracts of forest for the periodic establishment of new fields after abandonment of exhausted plots, Amazonian societies could never maintain sufficient population density for the development of complex societies. The relatively low social complexity, nomadism of foragers and small villages of mobile slash-and-burn farmers of the ethnographic record were recognized as modern day representative analogs of static cultural development. Based on ethnography, Carneiro (1960, 1961) responded that manioc production under slash-and-burn could be quite productive and sustain large, permanent villages of 1000-2000 people. Small group size, frequent settlement change, and endemic warfare was blamed on protein scarcity, added to the list of environmental limitations of Amazônia in the 1970s (e.g. Carneiro, 1970; Gross, 1975). Meggers softened her view in later publications about environmental limitations, but continues to deny archaeological evidence for dense populations and complex societies in the Amazon (e.g. Meggers, 2001).

Few contemporary scholars accept the hypothesis of environmental limitations and lack of cultural development in the Amazon Basin. Archaeological, ethnographic, and historical research over the past 30 years has demonstrated that Amazonian peoples developed complex societies, developed sustainable and often intensive agriculture, packed people on the landscape for thousands of years, and built the environments they desired.[4] The research on ADE provides important additional evidence that shows that Meggers and followers were incorrect. They made the mistake of assuming that peoples recorded in the ethnographic record, in particular their subsistence practices and level of socio-political complexity, were representative of the past. Meggers and colleagues fall into the trap of assuming that swidden agriculture practiced today throughout the Amazon to be typical of the use of these landscapes in the past. Lathrap et al. (1985: 54) came to the conclusion many years ago that "shifting slash and burn agriculture was a secondary, derived, and late phenomenon with in the Amazon Basin". According to Lathrap (1987), the labor for opening up forest using the slash-and-burn technique became worthwhile

[4] Recent general summaries of Amazonian prehistory and history include Myers (1992), Neves et al. (2003), Neves (1999), Carneiro (1996), McEwan et al. (2001), Oliver (2001), Stahl (2002), Denevan (2001), Whitehead (1996), and Viveiros de Castro (1996).

only with the introduction of productive and storable races of maize. More recently, Denevan (1992b) argues that slash and burn was probably not common until the introduction of metal axes and machetes by Europeans; thus, the extensive agriculture practiced today on ADE and elsewhere tells us little about original pre-Columbian practices. Authors of this volume conclude that slash-and-burn did not contribute to the formation of ADE.

Instead of slash-and-burn, Lathrap (1970, 1987; Lathrap et al., 1985) pointed out that good agricultural land is found on the annual flood-enriched soils of levees of the river floodplains. Farmers in the seasonally inundated savannas built raised fields (Denevan, 1966, 2001; Erickson, 1995; Walker 2003) (Fig. 1). Carneiro (1960, 1961, 1970, 1996) and Lathrap (1970, 1977) highlighted the importance of manioc and fish in sustaining large sedentary populations. Others highlighted the importance of palms and fruits as important sources of protein in addition to fish (Beckerman, 1979; Clement, 1999a, 1999b). Roosevelt (1980, 1991) showed that the introduction of maize some 2000 years ago created conditions for the rise of complex societies in the central and lower Amazon. The contribution of agroforestry for permanent production throughout the Amazon Basin was recognized in the 1980s (Denevan and Padoch, 1988; Posey and Balée, 1989).

Figure 1: A landscape of raised fields north of Santa Ana de Yacuma, Llanos de Mojos, Bolivia.

Authors of this volume have presented detailed histories of ADE research (Glaser et al., 2003; Mora, 2003; Myers et al., 2003; Sombroek et al., 2003; Woods, 2003; also Smith, 1980; Mora et al., 1991; Denevan, 2001; and others). The history of research shows an interesting cycling of discovery, neglect, and rediscovery of the importance of ADE since the earliest references in the 19^{th} century. Referring to his now famous article about ADE published in 1980, Nigel Smith states "I got two reprint requests for that article. Nobody was ready to hear it" (N. Smith quoted in Mann, 2000b). Since the 1960s, ADE studies have traditionally been the domain of archaeologists, ethnographers, ethnobotanists, geographers, and soil scientists working individually. Since the late 1980s, most ADE research has been increasingly interdisciplinary and multidisciplinary as highlighted in this volume and recent publications, symposia, conferences, workshops, and popular press (Mann, 2000b, 2002a, 2002b).

The contributors of this volume explicitly or implicitly grappled with the paradox facing all archaeologists who attempt to explain and understand the past. The peoples and processes that produced ADE existed in the distant past while our systematic observations (archaeological and soil stratigraphy and artifact analysis, ethnographic and historical analogy, experiments, and laboratory analyses) of ADE are done in the present, temporally removed from the processes that produced them. In order to understand the past from present day observations, systematic "bridging arguments" or a "middle range theory" is needed to link the past and the present. In this volume, various forms of explicit analoga are employed (e.g. archaeological, ethnographic, historical, experimental and cross-cultural). Despite the problems inherent in the misuse of the analoga discussed above, I agree with many authors of this volume who argue that we can learn important lessons about the origins and formation of ADE through constructing testable models based on experiments, archaeology, history and ethnography. Assuming continuity of traditional agriculture from the pre-Columbian to present ignores the historical dimensions of conquest and post conquest policies on native peoples. As authors of this volume point out, Native Amazonia was massively depopulated during the Colonial period and the large and complex societies of the central Amazon Basin disappeared, along with much of their knowledge system, technology, cultivation strategies, and crops (Clement et al., 2003; Myers et al., 2003).

I organize my comments as a series of interrelated and overlapping questions, themes, and issues that are raised by various authors of this volume about ADE: 1) definitions, 2) the significance of geographical distribution, 3) pre-Columbian community settlement patterns, 4) formation processes, 5) temporal dimensions, 6) intentionality, 7) relationship to pre-Columbian societal complexity, 8) resource management, 9) biodiversity and agrodiversity, 10) contemporary society, 11) future directions and potential application and 12) conservation, management, and value as cultural heritage.

2. DEFINING AMAZONIAN DARK EARTHS

The authors in this volume are in agreement that the basic characteristics of ADE are their dark color, richness in charcoal-derived carbon, high fertility, and human origin. Beyond this, there is little agreement. The diversity of approaches for characterizing and identifying ADE are highlighted in this volume. The authors concur that ADE should not be defined too narrowly because of the rich variation within and between ADE (Kämpf et al., 2003). The lack of a single definition or clearly defined suite of characteristics for identifying ADE is obviously frustrating for some of the participants in this volume. At this point in the study, flexible definitions that recognize the variation are healthy.

How is ADE soil identified? The principle criterion is dark color. Various issues can be raised about color. How dark do soils have to be in order to be identified as ADE? Is a simple threshold on a Munsell color chart reading sufficient? Could soils be of radically different colors but have the same composition and formation process? What "natural" soil benchmark is used for comparison? At what point does archaeological soil (soil of archaeological settlements, monuments, middens, and earthworks) become ADE? Are ADE without the presence of archaeological artifacts anthropogenic? The authors of this volume grapple with these questions and provide some answers. In an attempt to address the issue of continuous distribution of soil color from brown or gray to black, scholars working in the central Amazon Region (Sombroek, 1966) introduced the term *terra mulata* ("brown soils") for the large transitional zone around *terra preta* (the classic ADE).

The diverse meanings of ADE and potential problems of communicating between scholars of different disciplines were clearly represented in the 2002 TPA Workshop and in this volume (Kämpf et al., 2003). By relying on a vague definition of ADE, we potentially open ourselves to charges of over- or underestimating the geographic extent and importance of ADE. On the other hand, a overly narrow definition might ignore the rich variation of ADE reported in this volume. Kämpf et al. (2003) consider the dynamic, historical and variable nature of ADE as a subset of general anthrosols (soils produced through human activities) for their Archaeo-pedological Classification. Their new classification is an attempt to combine insights from various disciplines to address the variability and continuous variation of ADE.

Archaeologists, who identify and map ADE, tend to rely on the discipline's soil classifications and interpretations that rarely agree with those defined by modern soil science. Archaeologists are experts at recognition and interpretation of a wide range of anthropogenic soils associated with human activities on sites and landscapes. Soil scientists focus on the horizons in the profile and consider anthropogenic features as noise, perturbation and disturbance. In contrast, archaeologists define the visually and/or texturally obvious anthropogenic features in the profile and treat the horizon formation as noise, perturbation, and disturbance. To the archaeologist, "natural" soils are only interesting in terms of defining the boundaries of the anthropogenic soils (i.e. site boundaries; sterile boundary under site, and so forth). Archaeologists are most likely to focus on the internal variation of ADE: faint patterns, changes of texture, color, context, fill, and features to extract function and meaning. Without the internal heterogeneity within a site, we could not do archaeology. Soil scientists are less concerned with these soil nuances and attempt to characterize features representative of larger spatial areas. The approach proposed by Kämpf et al. (2003), and to a certain degree, traditional archaeology dedicated to building chronologies, focuses on profile descriptions of small, often deep, excavations through ADE (or sites) which emphases vertical continuity and disjuncture. Since the 1970s, archaeologists have used large areal excavations often combined with sampling to recover spatial patterning of human activities and lifeways throughout the site, emphasizing a horizontal perspective. Kämpf et al. (2003) discuss the contrasting approaches used by archaeologist and soil scientists in regard to ADE and highlight the benefits of combining both approaches. ADE research can benefit from both the general chronological approach and spatial morphology of settlement and agriculture approach (e.g. Heckenberger et al., 1999; Petersen et al., 2001; Kern et al., 2003; Neves et al., 2003; and others). I agree with the Kämpf et al. (2003) plea for collaboration between archaeologists and soil scientists.

The practice of traditional archaeology is framed within the site concept (e.g. critiques by Dunnell, 1992; Fotiadis, 1992). A site is a basic discrete unit of analysis defined by concentrations of artifacts indicating settlement or other activity assumed to reflect human behavior. I argue that adherence to the "site concept" limits our understanding of historical ecology in the Amazon Basin. The concept of landscape within Historical Ecology and archaeology of landscape are powerful alternatives to site-based approaches and are what links archaeology to historical ecology. Rather than focus on arbitrarily defined sites, landscape approaches try to understand human activities that occur between traditional sites and across larger areas at multiple scales. In this perspective, human activity is viewed as continuous over the landscape rather than spatially contained within traditional sites. Despite new innovative methods for archaeological survey, recovery of human residues, and "non-site" landscape approaches for defining between-site human activities (e.g. Stahl, 1995), Amazonian archaeologists are drawn to "sites," usually pre-Columbian settlements, defined by conspicuous surface concentrations of pottery, lithics, and charcoal (the most commonly preserved archaeological materials).

By extension, ADE research has adopted the site concept. Are ADE discrete spatial units of analysis as presented in this volume? How can a typical black earth site be measured if it has no clearly defined boundaries or edges? Most archaeologists and historical ecologists now recognize that the earth's surface is covered with continuous distribution of artifacts and evidence of human transformation of the landscape, making it difficult, if not impossible to clearly define boundaries. For example in the agroforestry literature on the Amazon Basin, every landscape has been transformed to some degree by thousands of years of human activities (burning, selection for economic species, weeding, and artificial disturbances). The contributors of this volume often contrast ADE with the surrounding forest soils based on the assumption that the ADE are anthropogenic and the forest is "natural". What if the benchmark against which ADE is identified and defined is also anthropogenic? If the entire Amazon Basin is to some degree anthropogenic as some historical ecologists argue, the possibility of finding a totally pristine natural soil in Amazônia after thousands of years of human disturbance for comparison as a benchmark is unlikely. The concept of domestication of landscape

(Clements et al., 2003; discussed below) may provide an alternative to the site concept.

Most ADE discussed in this volume are entire sites or a subset of traditionally defined sites (most covering hectares). The boundaries of an archaeological site and its ADE do not always correspond such as in the case of the Açutuba site on the Rio Negro where surface artifact scatters much larger than the ADE (Heckenberger et al., 1999) or the Araracuara sites on the Caquetá river where ADE in the form of *terra mulata* extends far beyond the distribution of artifacts (Mora et al., 1991). How big does a black earth footprint have to be in order to be called ADE (Fig. 2-3). Many archaeological occupation sites have discrete middens that meet the content criteria of ADE; but they are of small-scale contexts within the larger archaeological site (e.g. an individual garbage pit, lens of midden on an abandoned house floor, or post holes packed with dark midden). In addition to color, Kern et al. (2003) stress that ADE have a greater depth of anthropogenic A horizon than typical forest soils (30-60 cm vs 10-15 cm). Although the cultural strata of most archaeological sites correspond to the modern A Horizons; there are many exceptions such as those that are deeply buried paleosols or are so thick that post-abandonment soil formation processes have not created a deep A Horizon.

Figure 2: Amazonian Dark Earths in formation. An elevated platform made from an old canoe to collect kitchen debris for later use in house garden, Rio Massai, Colombia.

Figure 3: Amazonian Dark Earth in formation: An elevated platform of wood filled with organic matter, Rio Massai, Colombia.

3. THE SIGNIFICANCE OF THE DISTRIBUTION OF AMAZONIAN DARK EARTHS

The total geographical extent remains unknown. Various authors (Kern et al., 2003; Neves et al., 2003; Sombroek et al., 2003) summarize new information about the geographic distribution of ADE in Amazônia from systematic archaeological and pedological surveys. Sombroek et al. (2003) estimate that ADE covers 0.1-0.3% or 6,000-18,000 km^2 of the total Amazon Basin (6 million km^2). ADE is reported for most of the major rivers of the Central and Lower Amazon Region. Most are associated with bluffs overlooking *várzea* near larger active or abandoned river channels and a few have been found on *terra firme* away from main rivers. Dispersed ADE are reported from certain riverine locations in the Upper Amazon of Peru, Ecuador, and Colombia.

Kern et al. (2003) cite recent surveys documenting ADE "every 5 km along the *igarapés*, and an over-all spatial coverage of one per 2 km^2". In the Upper Xingú region, Heckenberger (1998) estimates large ring-plaza villages, many of which have ADE, are spaced several kilometers apart. In the Upper Madeira river, ADE is distributed 1 per 2 km^2 (Miller, 1992: 220). High densities of ADE are reported for the Central Amazon Basin (Nimuendajú, 1952; Denevan, 1996, 2001; Heckenberger et al., 1999). Although the best-known ADE are large (ranging from 500 ha for the Santarém site, 200 ha for the Belterra site, 80 ha for the Manacapuru site; and 90 ha for the Altamira site; Smith, 1980, 1999; Denevan, 2001 and authors of this volume), 80 % of the known ADE are less than 2 ha (Kern et al., 2003; Fig. 15).

The densest distribution and largest ADE are associated with archaeological settlement sites along the middle and lower courses of the major rivers (Smith, 1980: 562-563; Petersen et al., 2001: 91) or "on the margins or confluence of streams and rivers or near falls" (Kern et al., 2003). As discussed above, in the past scholars have highlighted the distinctions between the potential resources of the larger floodplains (*várzea*) and interfluvial or upland regions (*terra firme*) which was reflected in the archaeological record as larger, more permanent settlements and associated with more complex societies established along major rivers and less permanent settlements and simpler societies associated with interfluvial regions. According to these scholars, the large, dense populations of the *várzea* were sustained by fish and other aquatic resources and farming the rich, annually renewed, floodplain soils of white water (sediment-rich) rivers. Thus, it is not surprising that ADE would be associated with large rivers.

In the 1980s, scholars began to challenge the assumption that the interfluvial uplands (*terra firme*) were homogeneous and resource poor (Moran, 1991; Viveiros de Castro, 1996; Whitehead, 1996; Heckenberger, 1998, Neves, 1999; Wüst and Barreto, 1999). Thus, finding ADE in *terra firme* is not surprising (Smith, 1980; 1999; Balée, 1989, 1994; Costa et al., 2003; Myers et al., 2003; Neves et al., 2003). Although inland, most *terra firme* ADE are on bluffs above smaller upper tributaries and streams. These ADE sites are generally smaller and more dispersed than those associated with larger rivers (Smith, 1980).[5] The large inland ADE the Belterra Plateau between the Tapajos and Curua rivers and along the Arapiuns river reported in this volume and by Smith (1999) are prominent exceptions. Nimuendajú (1952: 11) reported *terra firme* ADE associated with deep and wide artificial wells.

In an important revision of the floodplain vs. interfluvial (*várzea* vs. *terra firme*) hypothesis about Amazonian cultural development, Denevan (1996, 2001: 102-114; Myers et al., 2003) pointed out that most prehistoric, historic, and present large settlements are located on the *terra firme* bluffs overlooking an active (or what was at one time) channel of the river rather than on the floodplains of the Amazonian drainage. The Bluff Model highlights the advantages of this location: direct access to floodplain and interfluvial resources, canoe transportation, defense, and dry locations for year-round settlement. Denevan also points out that most pre-Columbian sites on bluffs are ADE, often surrounded by *terra mulata*. The large ring plaza villages of the Upper Xingú River are examples of bluff ADE over-looking floodplains in the smaller upper drainages (Heckenberger et al., 1999). As Kern et al. (2003) state, "…ADE are present in practically all types of eco-regions and landscapes," but based on their maps and those of others, the largest and most numerous are found adjacent to lower and central courses of larger rivers (supporting the earlier interpretations of Carneiro, Lathrap, Denevan, Roosevelt, and others regarding the ecological advantages of access to rivers over inland locations for settlement and cultural development).

Returning to distribution of ADE, I would like to stress two points 1) ADE have not been found everywhere within the Amazon Basin and 2) long-term permanent human settlement does not necessarily result in ADE. ADE are less common the Upper Amazon of Peru, Ecuador and Bolivia, Rio Negro drainage, Orinoco drainage, the Llanos de Mojos of the Bolivian Amazon, and the northern part of the Amazonian drainage basin. Why did ADE form in some areas and not in others? Is the absence of ADE a product of differences in classifications of soils, lack of archaeological and soil survey in these regions, or burial, erosion, leaching, and destruction of ADE sites? Denevan (2001: 114, footnote 4) suggests that lack of reported ADE in the Western Amazon may be due to "lack of awareness".[6] Only a small sample of the Amazon Basin has been systematically surveyed for archaeological sites; and future research will probably identify new ADE in these regions. On the other hand, many scholars are now familiar with the concept of ADE and actively looking for sites; thus, the geographical distribution may be real and significant. Did these areas originally have ADE that disappeared because of overexploitation, poor management, and/or natural processes of decomposition, erosion and leaching? Although unlikely, these possibilities should be addressed. An examination of the patterning of spatial and temporal distribution and cultural traditions where ADE is found provide some insights.

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[5] Myers et al. (2003) report large *terra firme* ADE such as the Oitavo Bec site covering over 120 ha (citing Woods and McCann 1999: 12) and the Comunidade Terra Preta site covering 200 ha (citing Smith 1999: 26).

[6] Denevan shows that sites such as Yarinacocha are actually ADE (*terra mulata*) on a bluff overlooking the Ucayali river floodplain. Lathrap later identified several ADE in the Ucayali drainage (cited in Eden et al., 1984).

Does settlement size and duration play a role in whether or not ADE is formed? Most scholars seem to agree these are important factors. Were the cultures of regions without ADE less evolved and lacking in socio-political complexity compared to those with ADE? A brief examination of two areas that share a similar site plan but not ADE is instructive. The ditched enclosures or ring-ditch sites are elegant patterns of ditches and embankments covering several hectares to several square kilometers located on forest islands and river bluffs in the NE Bolivian Amazon (Denevan, 1966; Arnold and Prettol, 1988; Erickson et al., 1997; Erickson, 2002; Siiriainen et al., 2002). The Bolivian sites are probably part of larger related cultural phenomena of ring plaza settlements associated with complex societies reported for the Upper Xingú, Guaporé/Itenez, and Madeira river drainages (Miller, 1992, 1999; Heckenberger, 1998; Heckenberger et al., 1999). ADE is associated with many of these sites on the Upper Xingú, central Madeira, and Guaporé/Itenez rivers while those of northeastern Bolivia do not have ADE.[7] The present day border between Bolivia and Brazil (the Guaporé/Itenez River) may mark a cultural boundary. This also roughly marks the present day transition between high canopy tropical forest and savanna. The Bolivian sites have not been adequately dated but appear to be late prehistoric. The Brazilian sites have a long chronology; and thus, ADE may have formed through longer continuous occupation.

Could the presence and absences of ADE be associated with differences in terms of natural resources, environments, soil types, agricultural practices, or settlement type? These geographical distributions suggest that the differences may be cultural rather than environmental. Basic cultural explanations may account for ADE. Organic matter placed directly in fields and “used up” under cultivation vs. organic matter accumulated to form ADE for later use as farmland are significant farmer decisions that could determine the presence or absence of ADE (Fig. 2-3). In some cases, Amazonian riverine communities dispose of garbage by tossing it into the river. Stocks (1983) reports that the Cocamilla of Peru discard garbage into local lakes that is said to increase the populations of the fish they consume. In contrast, the Tukanoans of the Colombian Amazon (Chernela, 1982) and the Ka’apor of eastern Brazil never dispose of garbage in the rivers (Balée, 1994). A simple decision about garbage may determine whether settlements produce or become ADE or not. In cultures where garbage was tossed into rivers, streams, and lakes, no *terra preta*-type ADE would form; in others where garbage was deposited and accumulated on or near the settlement, terra preta-type ADE could form.

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[7] Dougherty and Calandra (1983) report finding ADE in Bella Vista near the juncture of the Guaporé /Itenez and Blanco rivers. I surveyed the area in 1995 and 1996 and recorded many ring-ditched enclosures but no ADE. Local farmers consider these non-ADE sites to be the best soils and intensively farm them. Walker (2003) reports dark soils with and without midden on forest islands in the northern Llanos de Mojos.

4 AMAZONIAN DARK EARTHS AND COMMUNITY SETTLEMENT PATTERNS

Archaeologists have become increasingly aware of the importance of cultural behavior and concepts regarding trash and its patterned, non-random disposal (e.g. Schiffer, 1987). As patterned trash disposal, ADE may provide insights into how people conceptualized and assigned cultural meaning to garbage (trash) and its proper disposal. Native Amazonians are known in the historical and ethnographic literature as "clean" people. Traditional villages are commonly described as clean, well maintained, and orderly. In the Upper Amazon, native peoples carefully sweep debris on and around house floors and house clearing to the outer edges of the village or hamlet daily (DeBoer and Lathrap, 1979; Zeidler, 1983, 1984; Siegel and Roe, 1986; Stahl and Zeidler, 1990). The cleared area of settlement has rich symbolic meaning as culturally domesticated social space distinguished from the wild, undomesticated space of the forest beyond. A clean village is part of community pride and great effects are made to prepare for important feasts. Clearings provide protection of bare feet against cuts by broken pottery and lithics and snakebite and for removal of decaying organic materials that harbor disease pathogens. Formal garbage disposal was critical for maintaining health in the large populated urban centers of late prehistory.

ADE are highly variable in size, form and depth of deposit. A working assumption held by most of the authors in this volume is that the size and depth of ADE are directly associated with population size of the settlement and settlement duration.[8] Another assumption, although less discussed, is that the shape or "footprint" of ADE is associated with community pattern that reflects underlying social organization. Large, multicomponent (occupied for long periods of time by groups of people defined by distinct pottery styles and traditions) sites are found throughout the Amazon Basin regardless of whether ADE is present. Thus large size and long occupation duration are necessary, but not sufficient, explanations for ADE formation. In the following section, I explore two ideas: 1) presence and absence of ADE due to differences in settlement type and garbage disposal patterns, and 2) forms (spatial footprints) and internal heterogeneity of ADE reflect community settlement patterns and/or processes of settlement establishment and reestablishment of settlement space through time.

[8] Archaeologists assume that site size relates to population size and importance. Presence and absence of internal features (cut stone, standing architecture, and earthworks) and certain types of artifacts (elite vs. commoner pottery; objects suggesting craft production and trade) are also used to rank site importance within the regional settlement system and infer socio-political organization. Most sites in late prehistory are multicomponent and it is often difficult to determine the size and importance of each occupation. Most archaeologists reject the Pompeii premise (that site abandonment preserves direct evidence of human activities) and acknowledge that complex cultural and natural formation processes during and after occupation transform the archaeological record. Archaeologists tend to have a narrow definition of sites as a settlement, limited to domestic and household or urban activity areas (defined by architecture and densely distributed artifacts). In the case of native Amazônia, the typical settlement or community extends beyond the domestic space to include a vast landscape of infields and outfields, managed forests, hunting territories, and paths that connect them.

Could ADE patterns and forms be associated with a certain type of settlement design or village plan? Myers (1973) classified historical and ethnographic accounts of traditional community patterns into "linear" and "non-linear". Linear (one axis considerably longer than the other) includes "lines of houses community" (Fig. 5C) and "multifamily longhouse community" (Fig. 5D). While these basic categories of community pattern account for all ethnographic settlements or archaeological sites, Myers' study presents many valuable testable models. The "lines of houses community", composed of end-to-end houses parallel to a long plaza overlooking a lake or river, is common in the Napo and Ucayali Rivers of the Peruvian and Ecuadorian Amazon. Garbage is disposed of in middens behind the houses and/or in front of the plaza (Fig. 5C) (DeBoer and Lathrap, 1979; Siegel and Roe, 1986). Myers (1973) attributes the pattern to the exigencies of a linear high ground in the form of narrow levees or bluffs along rivers. The large towns of continuous band of houses for kilometers along the Central and Lower Amazon River reported by early explorers were large versions of the lines of houses community (summarized in Denevan, 1996, 2001; Myers et al., 2003). Apparently many settlements had houses arranged on streets facing public plazas with temples and men's houses. Formal roads leading to the interior are also described. The accounts are not specific about trash disposal patterns but one would assume that the pattern would be wide linear midden(s) (Fig. 5C).

The "multifamily longhouse community" or, made up of a single or multiple longhouses (*maloca*) with up to 100 families (400 people) per house is common in the northwest Amazon (Myers, 1973). The "multifamily long house community" of the northwest Amazon is linear because the domestic structure is much longer than wide (100 m long x 15 m wide; rectangular, oval, or combination in footprint). Garbage is tossed outside the house clearing along the axis of the longhouse (Fig. 5D).

Myers (1973) provides archaeological examples of linear ADE from the Upper Amazon that may have been formed by linear communities of lines of houses or single long houses. As Smith (1980) points out, the linear ADE in the Central and Lower Amazon extend hundreds of meters back from the bluff edge; thus, these communities must have had multiple rows of lines of houses. Many of these settlements may have been associated with the historical Tapajós chiefdom and archaeological ADE of a predominately linear type (Nimuendajú, 1952; Denevan, 1996, 2001). Nimuendajú (1952) reports 65 Tapajós sites most of which are ADE and estimates that the total number is probably double.

Myers' non-linear pattern (circular, oval or amorphous in footprint) ranges from the "isolated single family house community" (Fig. 4A1-A2; Fig 7A1-A2) to the large "central plaza type community" (Fig. 5E1, Fig. 6). I also add an intermediate type: the "multifamily roundhouse community" found in the Orinoco River drainage (Fig. 4B, Fig. 7B) (Wilbert, 1981) and the "house lot community" based (Fig. 8G) (discussed below). The "isolated single family house community" and the "house lot community" are common throughout Amazônia today. A single extended family house is surrounded by a 30-m diameter cleared area with a shallow "doughnut-shaped" ring of refuse around the clearing created through daily sweeping (Fig. 4A2; Fig. 7A2) (DeBoer and Lathrap, 1979; Zeidler, 1983, 1984; Stahl and Zeidler, 1990). Another hypothetical disposal pattern would be accumulation of garbage into a single heap (Fig 4A1, Fig. 7A1). Refuse also accumulates under the house on the house floor, especially near cooking hearths (DeBoer and Lathrap, 1979).

A larger scale version of the above is the "multifamily roundhouse community" in which all reside within a single structure of 15 m diameter (Wilbert, 1981). The pattern of garbage disposal is expected to form a large doughnut shaped ring around the house and public plaza cleared area (Fig. 4B; Fig. 7B).

"Multiple longhouse communities" of the northwest Amazon and "multiple roundhouse communities" of northern South America are made up of various multifamily houses that together produce non-linear settlement pattern (Fig 8 F1-F2). Some of the larger communities are arranged around plazas. Garbage is either swept into a ring beyond the clearing of the cluster of long houses (Fig. 8 F2) or in rings around each individual house (Fig. 8 F1). I would also add the "house lot community" based on traditional Maya urbanism (Killian, 1992). These are characterized by relatively regularly dispersed independent households with patterned spatial organization of house, outdoor activity areas, midden, and gardens (Fig. 8G).

The "central plaza-type community" is the most highly structured, non-linear community (Fig. 5E1, Fig 6) (Myers, 1973). Those described for the Bororo, Gê, and Carib-speaking peoples in Central Brazil are made up of a circular ring (or concentric rings) of up to 8-31 houses around a circular plaza of 110-300 m diameter. Communities of over 140 houses for up to 1600 people arranged in 3 rings around a plaza are documented (Nimuendajú, 1946; Bennett, 1948; Myers, 1973; Wüst 1994; Wüst and Barreto , 1999).[9] Garbage is placed in individual piles up to 10 m "behind" the houses that face the plaza (ibid.; Heckenberger et al., 1999). Over time, the piles of midden form a doughnut shaped ring beyond the house circle creating what would be a 350 m diameter or 10 ha site (Myers, 1973). Myers predicts that the sweeping effect in the plaza and the mounding effect in the midden would create slight topographic differences. Variations include a central plaza-type community with a square or rectangular plaza and a street like arrangement of 4-8 multifamily longhouses each holding 30-200 families described for the Tupinamba of the Brazilian coast village of 4-8 houses, each housing 30-200 families (Lowie, 1948: 16). Colonial documents for Bolivia report large towns and villages of thousands of inhabitants with central plazas with up to 400 houses on streets, presumably organized as a rectangular or square grid (Denevan, 1966). The distribution of midden would probably be similar to that of the central plaza-type community or the house lot community. Myers (1973) notes that central plaza-type communities would be much easier to defend using ditches and palisades than linear villages.

Most small, dispersed shallow lenses of ADE on *terra firme* are probably isolated single family house communities but with a center type ADE [see below] instead of the doughnut shaped ring. The oval and elliptical mound ADE of the

[9] Yanomamö villages in Venezuela and Brazil are a variation of this type but consist of a single roundhouse enclosing a central patio open to the sky. Discrete trash heaps are created outside the main village (Smole, 1976: 68).

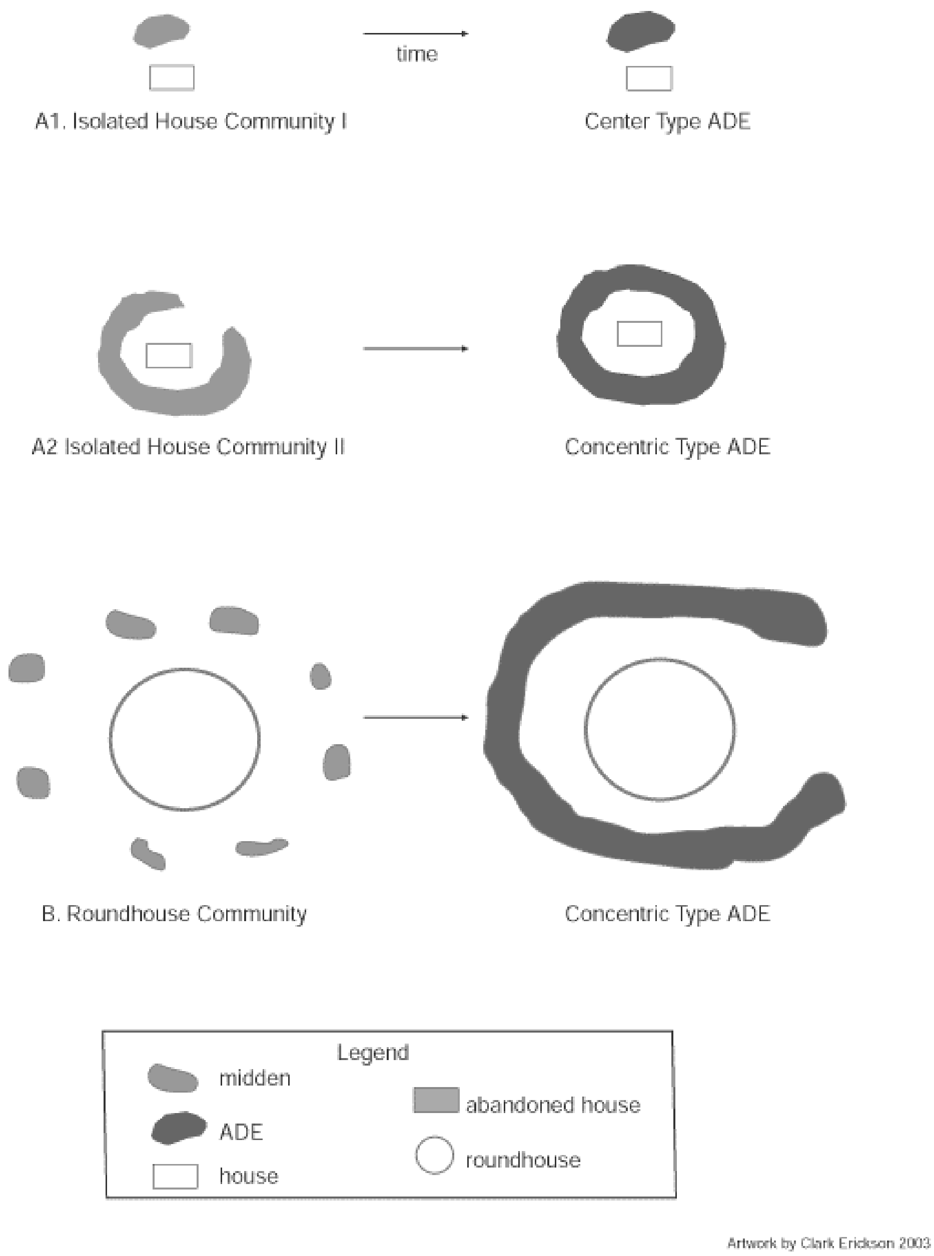

Figure 4: Hypothetical scenarios for basic ADE formation associated with the isolated house community and the roundhouse community.

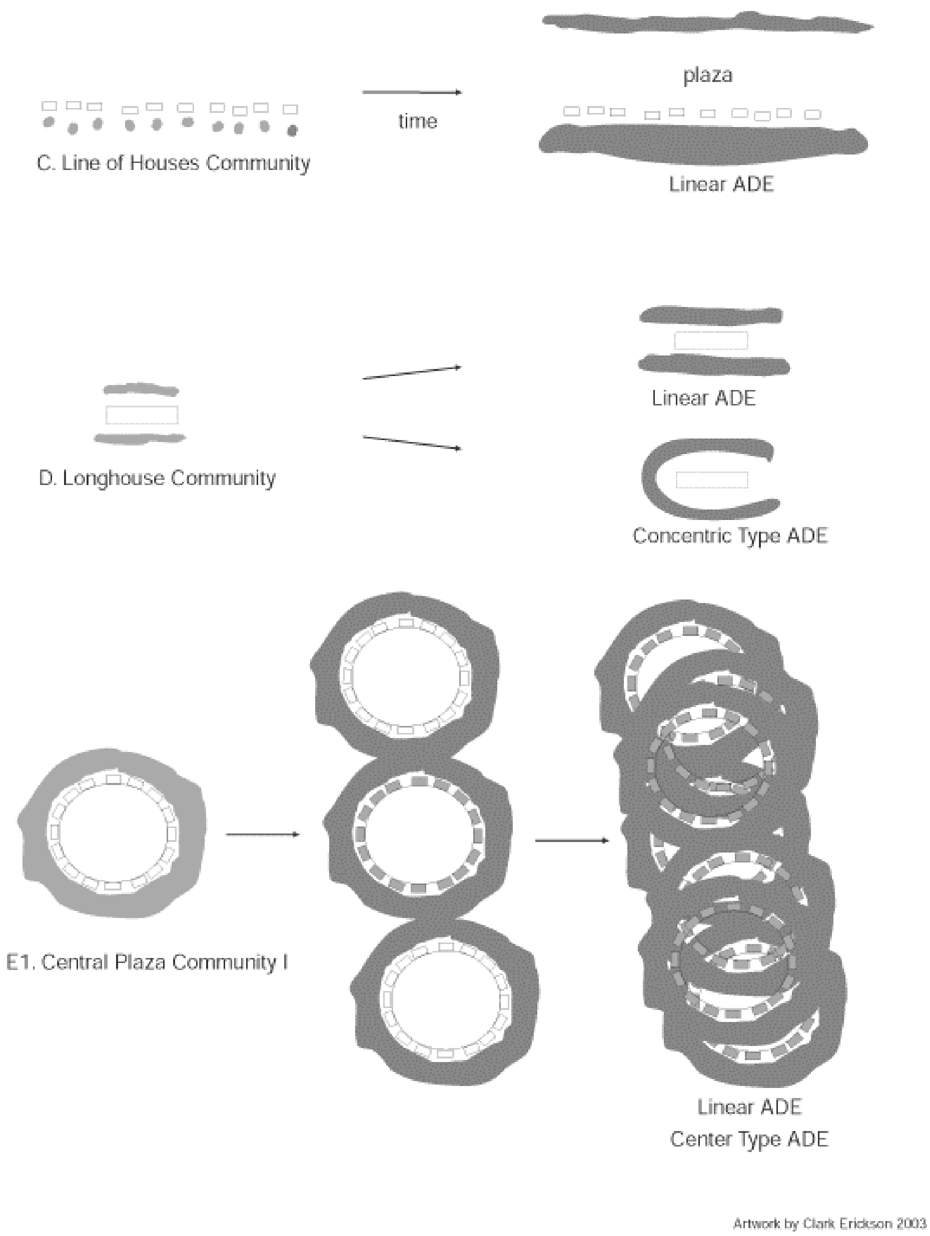

Figure 5: Hypothetical scenarios for ADE formation associated with the line of houses community, longhouse community, and the central plaza community.

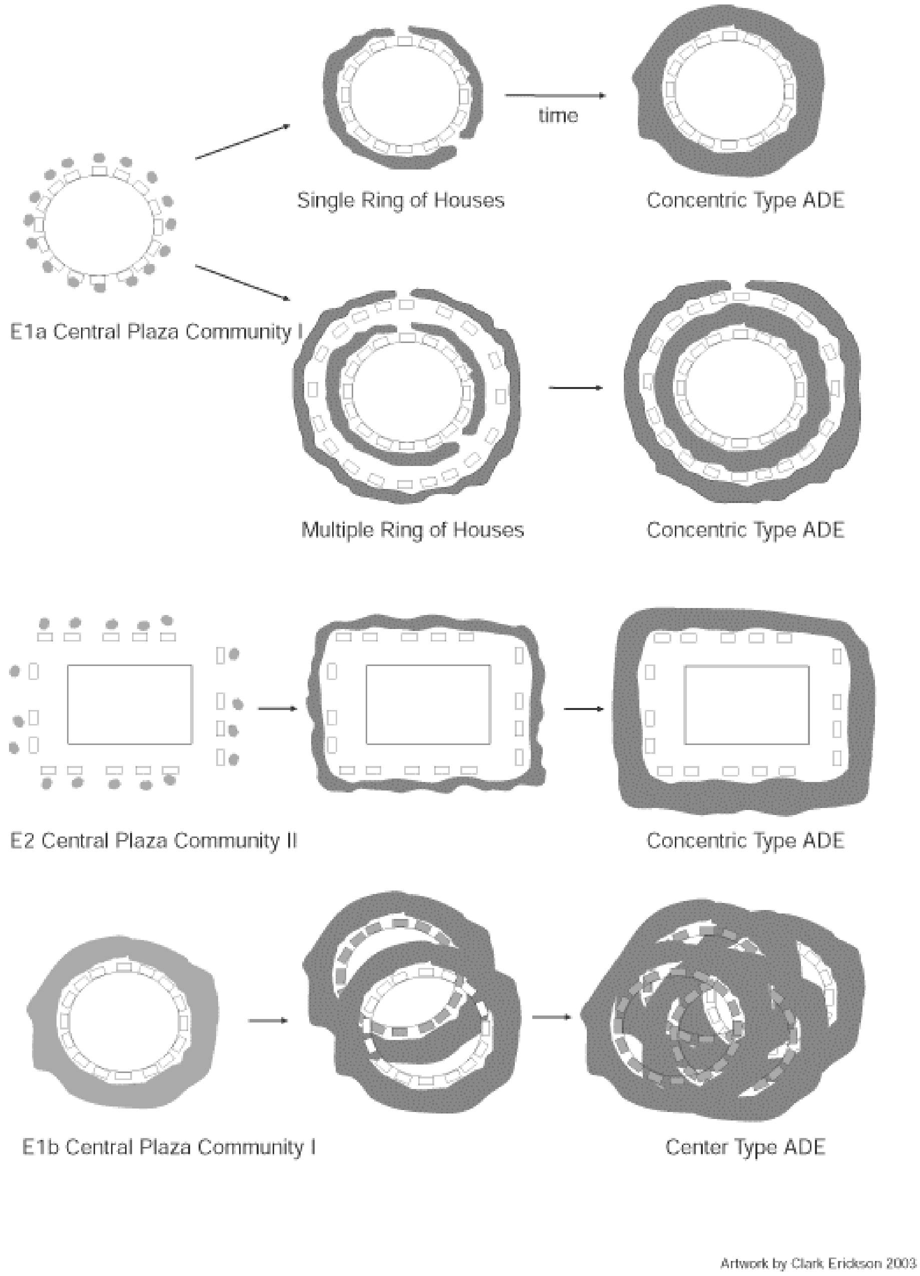

Figure 6: Hypothetical scenarios for ADE formation associated with the central plaza community.

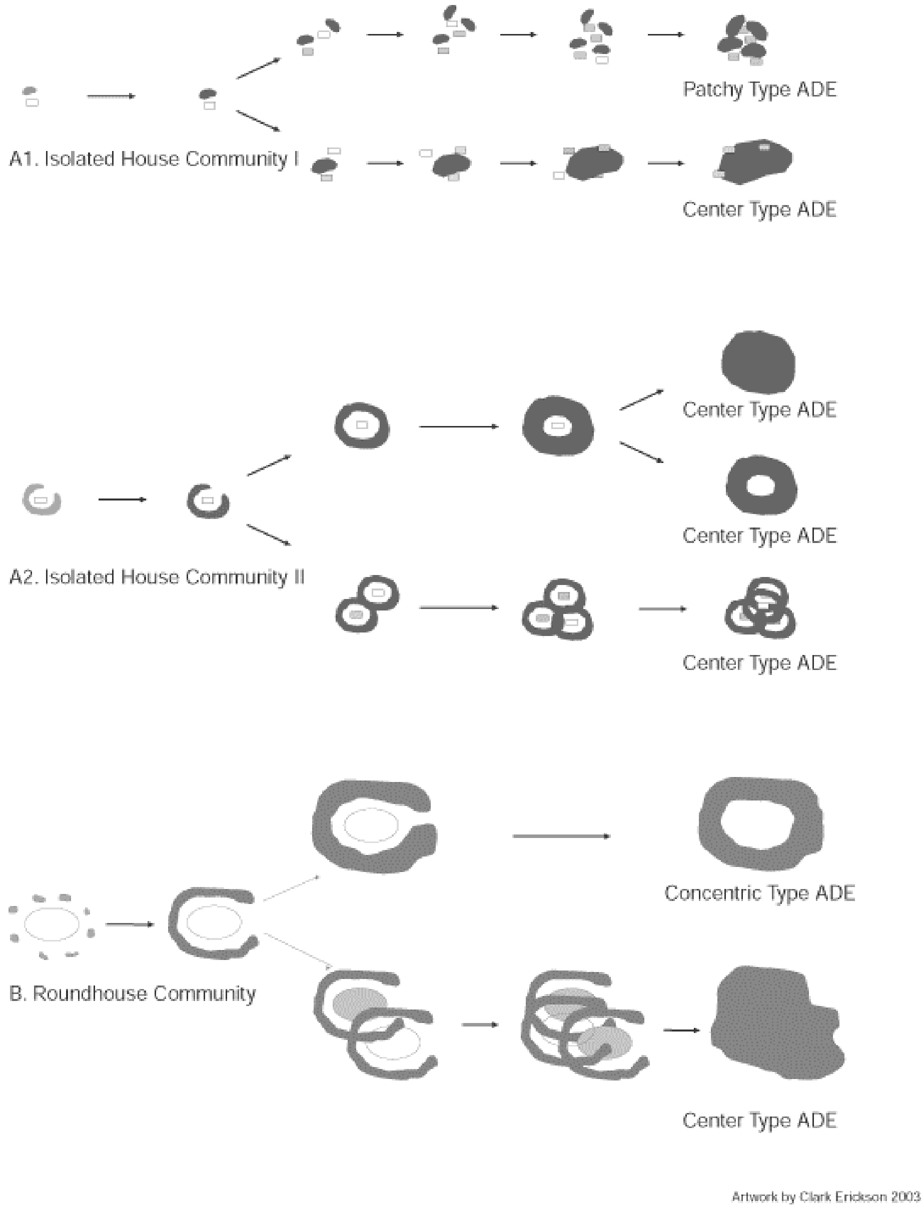

Figure 7: Hypothetical scenarios for ADE formation associated with the isolated community and roundhouse community.

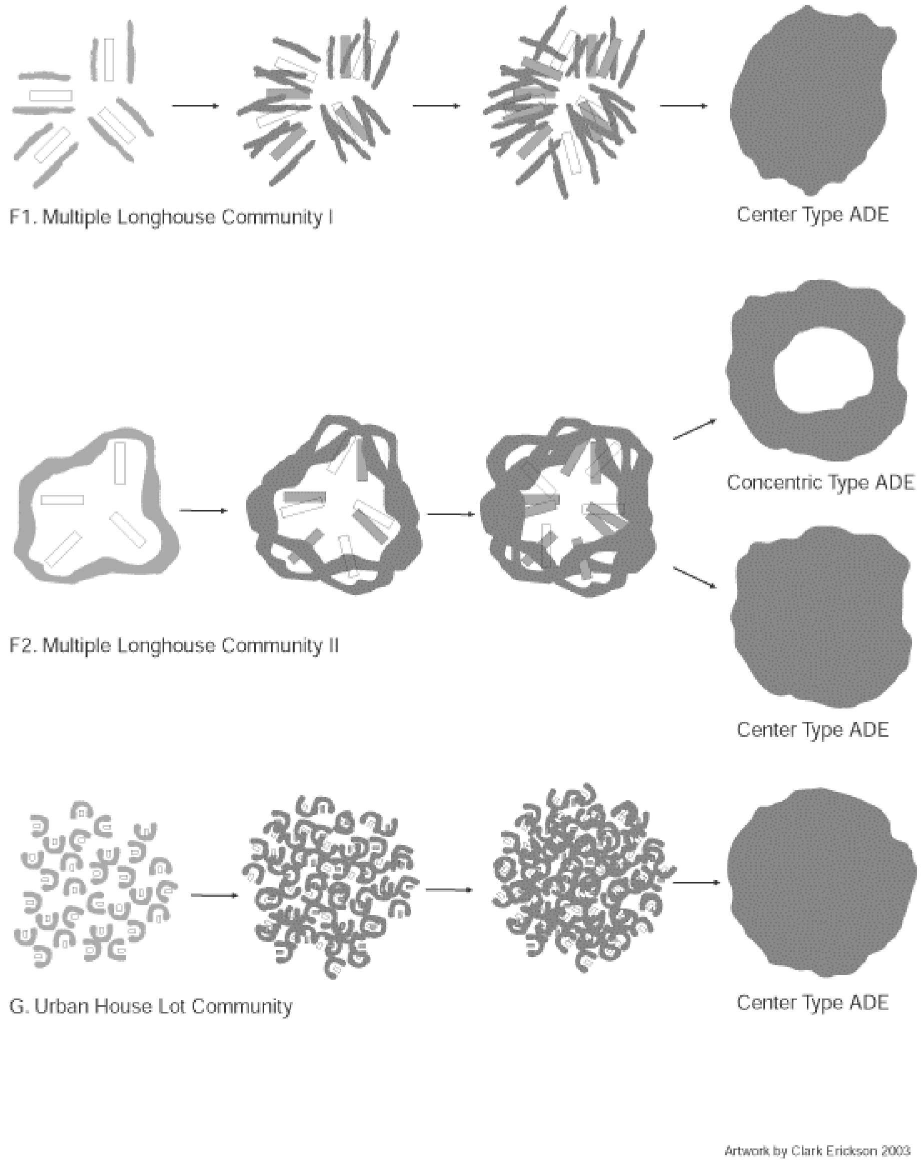

Figure 8: Hypothetical scenarios for ADE formation associated with the multiple longhouse community and urban house lot community.

Marajoara culture on Marajó Island (Roosevelt, 1991) and the Bolivian Amazon (Denevan, 1966; Erickson, 2000b; Langstroth 1996) probably represent single or multiple long house communities (Myers, 1973). Archaeologically, the central plaza-type community includes the large central plaza sites often with arcs, circles, or rectangles of ditches and embankments described for the Upper Xingú Basin (Heckenberger, 1998; Heckenberger et al., 1999), Upper Madeira Basin (Miller, 1992, 1999), the Bolivian Amazon (Arnold and Prettol, 1988; Erickson et al., 1997; Siiriainen et al., 2002), the Açutuba and Osvaldo sites on the Rio Negro (Heckenberger et al., 1999), and ring plaza villages without earthworks for the Tocantins River Basin (Wüst 1994; Baretto and Wüst, 1999). The oldest central plaza-type community archaeological sites are those of the Valdivia Culture in Ecuador (3500 - 1500 BC) with a large rectangular plaza surrounded by a ring of densely clustered multifamily houses (Lathrap et al., 1977; Stahl, 1984; Zeidler, 1984; Lathrap, 1985; Lathrap et al., 1985; Raymond, 1993).[10] The majority of the central plaza-type community archaeological sites discussed above are concentric type ADE, in some cases with multiple rings of ADE such as on the Tocantins River (Wüst and Barreto, 1999). The primary settlement of the late prehistoric Tapajós culture is under the present day city of Santarém. The ADE is up to 1.5 m deep and estimated to cover 4-5 km^2 and assumed to be non-linear (Nimuendajú, 1952: 9; Smith, 1980; 1999; Roosevelt, 1999: 24).

Although both linear and non-linear community patterning are documented, Smith (1980) and Denevan (2001: 105) stress that most known ADE are *linear* (one axis longer than the other) and laid out parallel to the bluff edge and/or nearest active or once active river channel. The long axis of many of the larger ADE extends several kilometers (Smith, 1980; Denevan, 2001: 105); thus, we may be seeing the accumulated result of many communities established and reestablished along the bluff over thousands of years (discussed below).

Another distinction raised in this volume is “center type” and “concentric type” ADE that may also reflect community patterning and complex site formation processes. Sombroek et al. (2003) characterize the concentric type ADE as having a deep concentric ring(s) of ADE around a relatively clean central area (the classic doughnut shaped midden discussed above) and the center type ADE in which the deepest anthropogenic soil is in the center and tapers off towards the edges of the site (mound-like midden). The concentric type ADE (e.g. best documented archaeologically in the Tocantins and Upper Xingú river basins by Wüst and Barreto, 1999) is assumed to correspond to the single house community and multiple family roundhouse community if small, and the central plaza community and its variants if large.

The majority of ADE are center type: they have continuous distribution of black earth across the site and are deepest in the center with no evidence of an ADE-free central plazas (Sombroek et al., 2003). The center type ADE does not closely fit any of the community patterns discussed above. Does this mean that pre-Columbian community was of a form that is not represented in the ethnographic and historical literature or could it be the result of complex site formation processes? The center type ADE implies that 1) people lived on top of their garbage (e.g. the moundbuilder model where trash and fill are used to raise the settlement; possibly for visibility,

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[10] Clement et al. (2003), Hecht (2003), Hiraoka et al. (2003), Myers et al. (2003), and Silva (2003) describe similar cases of patterned trash disposal. Other trash disposal, composting, manuring, and recycling of organic matter are summarized in Denevan (2001).

drainage, or an expression of monumentality); 2) garbage disposal for fields was spatially discrete from residence (e.g. Kayapó enriched garden model); 3) each community maintained a single location to pile garbage (rather than sweep it into a doughnut shaped ring around the residential clearing); and/or 4) slight shifts of the community location or residences within the community over time distributed the midden across the entire site.

Sombroek et al. (2003) and Denevan (2001) suggest that ADE may have started off as a concentric type but became center type due to a "smearing effect" caused by periodic reestablishment of the community through slight movement of the center of the settlement. Scholars have documented this phenomenon for Xinguano, Gê, and Bororo communities (Heckenberger et al., 1999; Wüst and Barreto, 1999). In most cases, the community is moved several hundred meters because of "rotting houses, frequent deaths, internal disputes, warfare, and sanitary conditions" (Wüst and Barreto, 1999: 12).

These hypotheses could be tested archaeologically with careful horizontal areal excavations and sampling of larger sites and ethnographic contexts. Archaeologists have shown in ethnographic and archaeological cases that despite careful daily sweeping, some garbage remains on house floors due to the "trampling effect" (DeBoer and Lathrap, 1979; Zeidler, 1983, 1984; Siegel and Roe, 1986; Stahl and Zeidler, 1990; DeBoer, 1996); thus, the house clearing could accumulate continuous ADE given enough time. The buildup of midden on house floors and under storage racks over several years can be quite substantial.[11] Few studies of differentiation of cultural space and heterogeneity of ADE through mapping and excavation have been done. Nimuendajú (1952: 11) pointed out, "The surface of the black earth deposits is usually not flat but composed of a number of mounds, each several meters in diameter, and each probably representing a house site". In this case, the uneven surface of ADE may reflect the differential use of cultural space within the site. Heckenberger et al. (1999) detected a large rectangular plaza surrounded by artificial temple and/or elite residential mounds through surface topography, ditches, thickness of ADE, and distribution of artifacts at the Açutuba site.

In most ethnographic cases discussed above, garbage middens and domestic zones within the settlement are spatially discrete (garbage is swept or tossed beyond the house clearing or central plaza house circle clearing). If all organic matter and charcoal generated by the community were systematically gathered to create ADE outside the residential zone in piles, ring, or arc of midden, or directly in fields, there should be a large, relatively organic-free zone in the residential sector of each site, no matter what type of community pattern. Center type ADE probably forms where sites have been continuously occupied for long periods of time (for the reasons stated above). In large pre-Columbian settlements, it may not have been possible to dispose garbage far from the residence because of close neighbors; thus midden may have accumulated around and under houses as predicted in the house lot community

[11] Stahl and Zeidler (1990: 154 and Fig. 2) report 5-10 cm of buildup (mostly ash and charcoal) over a 4-year occupation of multifamily longhouses in the Ecuadorian Amazon. I have left the abandoned house footprints visible on the scenarios of Figures 6-10 to show this effect over time in the creation of center type ADE.

or multiple reestablishments of any community pattern in the same general location. Later inhabitants of the settlement would have to periodically decide whether to continue piling up new trash on the already established piles or rings inherited from their ancestors (maintaining a concentric type ADE) or to level the surface by filling in low spots with new trash (creating a center type ADE). In my experience digging archaeological sites in North and South America, organic matter, potsherds, and construction debris were used to level low spots, fill unused pits, and abandoned structures producing more dispersed distribution of localized ADE (creating greasy, black soils with considerable charcoal, ash, bone, and shell, what archaeologists usually referred to as "dark midden"). Most Amazonian peoples raise their house floors for improved drainage. Once organic matter has decomposed into mature ADE and not considered a health and aesthetic problem, it can be lived on or treated as transportable construction fill and fertilizer for agriculture. In this scenario, people literally lived on their garbage but only after it had been converted into harmless ADE.

The presence of the house garden may have been a determining factor in formation of the center type ADE. Many authors of this volume (Clement et al., 2003; Hecht, 2003; Hiraoka et al., 2003; Silva, 2003) discuss the importance of the house garden as the prototype for the formation of ADE. The gardens that regularly receive organic matter from food preparation and cooking are located near the kitchen (thus residence and garden spaces are in close proximity). In small settlements the garden is always adjoining the domestic space. As settlement size is increased, gardens can either be relocated outside the residential area or squeezed into spaces between houses (house lot community). There were fewer domestic animals (such as introduced pigs, goats, and chickens) to compete for house garden space in pre-Columbian settlements, thus house gardens may have been larger and more common than in modern villages. Over time, this strategy would generate a center type ADE.

5. AMAZONIAN DARK EARTH FORMATION PROCESSES

Although Amazonian soils are not as poor as presented in the traditional literature, ADE clearly stand out as anomalous. The authors of this volume agree that ADE are human produced or anthropogenic. Classic ADE from the Upper Amazon to the mouth of the Amazon are archaeological sites.[12] The *terra mulata* soils are also clearly human altered landscapes because most are associated with *terra preta* and archaeological sites. Because pottery, bones, shell, and other domestic debris is found throughout the soil profiles, ADE are sites of human occupation and probably farming rather than simply locations of naturally rich soil that were colonized for residential and agricultural use.

The authors concerned with the origins of ADE are interested in what archaeologists and geomorphologists since the 1970s have called "site formation processes" which include both natural and cultural transformations (Schiffer, 1987;

[12] Kämpf et al. (2003) mention rare cases of dark organic and carbon-rich soils without archaeological artifacts where identification as ADE is difficult.

Ruivo et al., 2003; Silva, 2003) or "middle range theory" (Binford, 1978). Kämpf et al. (2003) distinguish between "product" and "process" in ADE research. The product is relatively well known and agreed upon; the process is still in debate. The contributors of this volume agree that ADE are anthropogenic (associated with human settlement and/or farming) rather than natural. Most agree that the primary element in ADE formation is the concentrated accumulation of organic matter created through permanent settlement and farming in large farming communities.

ADE formation must be the result of a significant shift in human behavior and activity during late prehistory in the Amazon Basin. The distribution of ADE is "not associated with a particular parent soil type or environmental condition" (Kern et al., 2003), thus ruling out some environmental determinants.[13] Neves et al. (2003) and Petersen et al. (2001) state that the "basic precondition" for the formation of ADE is a lifeway based on sedentary villages and intensive agriculture. They argue that sedentism was a late phenomenon in the Amazon appearing around 2000 years ago. Most archaeologists accept the idea that sedentism began thousands of years before the widespread appearance of ADE (Lathrap, 1977; Roosevelt, 1991; Roosevelt et al., 1991), thus sedentism alone cannot account for the formation of ADE. The dates for raised fields throughout the Neotropics support the hypothesis of Petersen et al. that intensive agriculture was adopted between 1000 and 2000 years ago (Denevan, 2001) (Fig. 1).

Kämpf et al. (2003) divide the processes of formation of ADE and other anthrosols in the Amazon into three overlapping groups 1) "midden model" (Smith, 1980) based on "unintentional anthropic activities" related to permanent settlements and the accumulation of domestic refuse; 2) "agricultural model" (Denevan, 1998; Woods and McCann, 1999) based on "intentional anthropogenic activities" related to semi-permanent agriculture involving clearing and burning of vegetation; and 3) "moundbuilder model" based on "intentional anthropogenic activities" related to transformation of soils for raised fields and mounds (Fig. 9). In agreement with most other scholars, Kämpf et al. (2003) attribute *terra preta* ADE to the midden model and *terra mulata* ADE to the agricultural model. I disagree with their conclusion that the formation of *terra preta*-type ADE was unintentional.

All the contributors to this volume agree that domestic refuse generated in human settlements is the key component of ADE. Human refuse is assumed to include general kitchen debris, food remains, food processing wastes, feces, urine, house construction materials, pottery, lithics, shell, ash, and charcoal. As Costa et al. (2003) stress, the bulk of the organic refuse has decomposed or weathered beyond recognition or is lost through leaching and cultivation; thus, it is difficult to identify the origin and the percentage of contribution to ADE. Pottery, bone, shell, plant remains, construction materials, fuel, and lithics can be identified and quantified, although the relative durability of certain materials may bias our understanding of ADE. The authors of this volume use a variety of techniques for determining ADE components.

[13] Numerous scholars have discussed climate and environmental change in Amazônia (e.g., Piperno and Pearsall, 1998; Colinvaux, 2001; Meggers, 2001). As an anthropologist, I will focus on cultural explanations for the appearance and maintenance of ADE.

Figure 9: Stratigraphic profile of an eroded pre-Columbian raised field canal (left) and platform (right) in the Llanos de Mojos, Bolivia.

Most authors agree that the high percentage of charcoal (pyrogenic carbon or black carbon) that makes up over 1% of total mass distinguishes ADE from other anthropogenic or “natural” soils (Glaser et al., 2003; Kämpf et al., 2003; Kern et al., 2003; Sombroek et al., 2003; Thies and Suzuki, 2003). According to Glaser et al. (2003), ADE had 64 times more charcoal per unit volume than adjacent forest soils. Charcoal not only helps maintain fertility, but also is an important carbon sink. The authors attribute the stability of the organic component, and hence high soil fertility to the black carbon. If carbon is the key, the producers of ADE may have employed a special kind of burning or treatment of disposal of charcoal and ash that was distinct from Amazonian groups that created non-ADE anthropogenic soil under practicing similar contexts of settlement and agriculture. We can also infer that fuel must have been abundant and readily available because of the quantity of intact pieces of charcoal rather than ash. If fuel was scarce, we would expect more complete burning or reburning of any remaining charcoal from earlier fires reduced it to ash. This is remarkable given the large and dense populations living in pre-Columbian settlements and their demands for fuel.

I agree with Sombroek et al. (2003) that a higher level of charcoal in ADE than in surrounding forests is evidence of intentional management (contradicting the claim by Kern et al. (2003) that ADE formed under the Midden Model was “unintentional”). Native Amazonians apparently controlled the burning process in such a way that charcoal rather than ash was produced. Thus, these practices were important in the formation process of both the *terra preta* and *terra mulata* ADE.

This specific burning was distinct from natural forest fires that periodically rage through Amazônia, burns used in swidden agriculture, and domestic fires in households of non-ADE sites or modern settlements (Glaser et al., 2003). Hecht (2003) suggests that the controlled "low biomass cool burn" of crop residues, weeds, and palm fronds practiced by the Kayapó combined with charcoal from cooking hearths could account for the charcoal in ADE. Anyone travelling through the Neotropics cannot fail to notice the ubiquitous smoky and smoldering fires found in rural and urban contexts. Amazonian peoples use regular low intensity burns to dispose of household garbage, weeds, and crop debris. In addition to trash removal, the smoke generated helps to keep insects at bay.

Most authors of this volume are also in agreement that carbon within ADE created a favorable habitat for beneficial microorganisms that may be the key to the creation and maintenance of high soil fertility (Woods and McCann, 1999; Falcão et al., 2003; Kern et al., 2003; Sombroek et al., 2003). Thies and Suzuki (2003) refer to studies that "…soils containing high levels of BC (black carbon) have correspondingly higher levels of microbial biomass and respiratory activity" and that "Amazonian Dark Earths are likely to contain several billion viable microorganisms per gram, representing many thousands of different species". Lehmann et al. (2003b) show that the conditions for biological nitrogen fixation are optimized in ADE.[14]

The authors are in general agreement that population density and duration are important factors in ADE formation; but few would concur that this is an adequate explanation. Most communities between AD 1 and 1500 were producing the same classes of domestic refuse, and large sedentary communities were widespread throughout the Amazon. Other than the frequency of charcoal, what was unique about the type or composition of refuse produced by dwellers of what would become ADE? There are few systematic studies to quantify the amount and type of domestic refuse produced by native Amazonians. I will briefly examine four classes of refuse that have not been adequately considered in this volume: fish and fishing, pottery, roofing thatch, and night soil.

Fish is a class of domestic refuse that may have played a key role in the formation of ADE. The debates about protein availability as an environmental determinant of cultural development in the Amazon in the 1970s highlighted the importance of fish in the diet of Amazonian societies (e.g., Lathrap, 1970; Beckerman, 1979; Roosevelt, 1980; Carneiro, 1996; Gragson, 1992; Erickson, 2000a). Many now agree that fishing (including shell fish such as gastropods and molluscs), combined with plant sources such as palm and fruit trees, provided much more of the protein for Native Amazonians than hunting. Could fish and fishing also contribute to the formation of ADE? As every author in this volume points out, most ADE are found on *terra firme* overlooking rivers, lakes, floodplains, and wetlands (Smith, 1980; Denevan, 2001; Kern et al., 2003). Kern et al. (2003) state, "Maps produced by archaeologists with the distribution of archaeological sites, show a

[14] If soil microorganisms are the key to understanding the fertility and sustainability of ADE, could Amazonian farmers have intentionally or unintentionally inoculated the soil with microorganisms in addition to creating the ideal habitat to speed the formation, maintenance, and reproduction of ADE (Woods and McCann, (1999)? We know that native peoples used many techniques of controlled fermentation for brewing, food preparation, and preservation.

predominance of sites placed on the margins or confluence of streams and rivers or near falls". It is well known that these are the best locations to fish in the Amazon. Could the source of nutrients so important for establishing and maintaining ADE discussed by Glaser et al. (2003) be remains of the processing, preparation, and the consumption of fish? The famous Araracuara ADE site in the Colombian Amazon is located on an unnavigable stretch of the Caquetá River where the settlement historically has been associated with portage of canoes, temporary camps of fishermen and travelers, and fishing. Archaeologist Agusto Oyuela (pers. comm.) has found ADE in similar locations along other rivers of the region. This hypothesis for ADE formation could be tested through archaeological recovery of the more durable parts of fish (scales and ooliths), ethnographic observation, controlled experimentation, and the identification of relevant molecular biomarkers (Woods personal communication). Sombroek et al. (2003) briefly mention the possible contribution of phosphate-calcium compounds from fishing and hunting and calcium from gastropods and molluscs. More recently, Lehmann et al. (2003a) attribute the high levels of phosphorus and the presence of combined calcium-phosphorus in ADE to massive accumulation of fish waste.

Most authors note that broken pottery (potsherds, sherds) and fired clay probably from dismantled fire hearths and burned wattle and daub structures are a major component of *terra preta* type ADE (Costa et al., 2003; Myers et al., 2003; Neves et al., 2003). Could fired clay in its various forms have contributed to the creation and maintenance of ADE? High frequencies of potsherds in the soil profile could affect drainage, texture, chemical and biological activity. Organic tempering materials (ash, shell, sponges, and Spanish moss) used in Amazonian pottery (identified by Costa et al., 2003) may also contribute to the formation of ADE. Pottery is so common in some pre-Columbian occupation mounds and forest island sites in the Bolivian Amazon that Robert Langstroth (1996) has coined the term "sherd soils" to describe them. Reading the methods sections of the laboratory analyses of ADE in this volume, I learned that pottery is systematically removed from soils during processing for soil analysis (e.g. Teixeira and Coimbra, 2003). I suggest that sherds should be included in soil samples and analyzed to determine their potential contribution to ADE.

Herbert Smith (Smith 1879 cited in Woods, 2003) suggested a connection between palm thatch and ADE in 1879. Gragson (1995) also suggests that economic palms contributed to ADE. He demonstrates that the thatch roofs of a typical Pumé community require 13,498 fronds of *Mauritia flexuosa*, which contains 3,373 kg of dry matter. Considering that thatch is replaced every 2-3 years and house poles of palm wood at somewhat longer intervals, the contribution of organic matter to settlements could be substantial.[15] When these figures are applied to the hundreds of large houses for towns described in early historical accounts before massive depopulation, the amount of organic matter is staggering. Because palm fronds are transportable on the backs of humans or by canoe, this may be an important non-

[15] A single Barí communal house is estimated to have 750,000 fronds cut from 125,000 palms of *Geonoma* spp. collected over a region of 40 km^2 (Beckerman, 1977 cited in Gragson, 1995: 178).

local source of organic matter. Sombroek et al. (2003) note that palms, possibly used as house thatch, have been identified in pollen analyses of ADE.

Woods (2003) briefly mentions night soil (human feces and urine) as contributing to phosphates in ADE. Systematic manuring using animal dung was a key component of the Plaggen soils of Europe. In contrast, Amazonian peoples had few domestic animals (muscovy duck, dog, and keeping of wild tamed animals and birds). Carvajal describes huge complexes of turtle pens in some of the towns he visited, a possible source of considerable organic matter. Human burials may have also contributed to ADE, especially after population density in settlements increased. Traditionally, Amazonian peoples buried their dead below house floors, in plazas, or in separate cemeteries. In some cases, bodies were cremated.

The authors of this volume suggest that some forms of ADE (*terra mulata*) may have been the long-term result of improving cultivated soils with organic matter through burning, mulching, composting, and fertilizing. Farmers may have done these activities within the fields, through transportation of mature organic matter from residences and from forest to fields, or some combination.

Most authors agree that carbon, in the form of charcoal, is an important element in ADE and may provide the explanation for the resilience of ADE to degradation and erosion and its ability to support microorganisms. The soils associated with swidden agriculture have been well studied in the Amazon and elsewhere. Although swidden is regularly practiced on ADE and produces charcoal (German, 2003), swidden agriculture does not produce ADE. Many scholars (Smith, 1980; Eden et al., 1989; Denevan, 2001; Myers et al., 2003; Sombroek et al., 2003) argue convincingly that swidden agriculture did not contribute to ADE nor was it an important farming strategy before the introduction of the iron and steel ax and machete.[16] Today, swidden farmers in the Bolivian Amazon generally burn and reburn (often numerous times) the fallen trees and debris from field clearing and preparation. Most tree trunks that do not burn are eventually cut up and used for fuel in the village or left to rot. Fires used to cook and provide warmth at night generally burn continuously, producing more ash than charcoal.

To intentionally increase levels of charcoal in the soils, native Amazonians may have practiced a special kind of burning under controlled conditions or what Sombroek et al. (2003) refer to as “controlled carbonization”. One possibility is that they used a reduced atmosphere burning similar to that employed to produce charcoal. The source of the charcoal in ADE is assumed to be from both primary forest and secondary forest around the settlement. Could the charcoal that formed ADE have been primarily from certain plants whose burning is more amenable to charcoal production? Experiments, ethnographic observations, and archaeobotanical analysis of fuel from ADE may provide clues to the sources (e.g. Mora et al., 1991; Piperno and Pearsall, 1998; Mora, 2003).

Controlled burning, and thus production of charcoal and ash, may have been more common in pre-Columbian Amazonian settlements than today. Large

[16] Sombroek et al. (2003) argue that slash-and-burn is unlikely to produce the levels of charcoal found in ADE (an estimated 3% of the carbon of the original biomass is incorporated into the soil; the rest is lost to the atmosphere during burning).

populations would have greater needs for high-quality fuel for cooking; smoke-preservation of foods; conversion of bitter manioc into storable flour and breads; salt making; pottery firing; and other domestic activities. As forests around the settlements were gradually turned into gardens, fields and orchards, firewood would be imported from longer distances (using water transportation and capture of driftwood). As settlements grew, ritual and feasting activities became more common and larger events consuming additional fuel for food preparation and pottery production (Neves et al., 2003). The technique of reduced atmosphere pottery firing is well documented in the archaeological record. Does this imply knowledge of charcoal making was employed in ADE production?

As Woods (2003) notes, the rate of deposition of organic matter must be greater than losses in order for ADE to form. Natural processes that contribute to losses included volatilization, leaching, and erosion "which are expected to be high in a hot, high rainfall and humid environment such as Amazônia". One means of effectively raising the ratio of inputs to losses would be the concentration of nutrients from a larger region to a small concentrated area that becomes ADE. This implies efficient transportation (canoes, canals, paths, roads) and organization of labor. Hunting, gathering, fishing, and offsite farming are typical activities that concentrate non-local organic matter in settlements.

I would add the losses due to crops extracting nutrients from farmed ADE. The balance between rate of deposition and loss highlights the inherent conflict between the simultaneous formation and maintenance of ADE through domestic activities and its use for agriculture. In order to fully exploit ADE for cultivation, farmers had to either inherit already formed ADE or wait many years before reaping the benefits of the ADE they produced . Based on archaeobotanical and sediment analysis, Mora et al. (1991: 77) document simultaneous use of ADE in Araracuara for settlement and farming of field crops and fruit trees. This temporal dimension of ADE formation has important implications. Farmers who created ADE through considerable labor had to wait for a period of time before being able to exploit their creation for farming. If farmers were inverting organic matter into fields that were immediately cultivated (as is the case of the Kayapó), the ratio of nutrient accumulation to losses for ADE formation and maintenance may have been disrupted. If continuous cropping was combined with regular nutrient additions and enrichment to the soils, organic matter accumulation may have offset the losses through use.

6. TEMPORAL DIMENSION OF AMAZONIAN DARK EARTHS

The formation processes of ADE include a temporal component. The depths of more than 2 m of ADE (average depth 0.73 m) suggests that they were formed over long periods of time (Smith, 1980). The authors of this volume agree that ADE could be formed by large groups of people over hundreds of years. Could ADE also be created by small groups of people over longer periods of time? Although the two scenarios may produce the same result, the archaeological signatures would differ. Based on Woods' insight, middens produced by smaller groups over long periods of time would be subject to higher nutrient losses through natural processes, possibly off-setting accumulation of organic matter. The number of sites covering a hectare or less demonstrate that small groups did create ADE.

Smith (1980: 564) estimates an accumulation rate of 1 cm per 10 years (or 10 cm per 100 years). Smith (citing C. Evans, 1964) also reports 1 m of ADE forming at sites on Marajó Island within 100 years (1 cm per year), but discounts the rate as impossible. For the ADE of the Lago Grande site, Neves et al. (2003) cite a figure of "a hundred years for forty centimeters of terra preta" or 0.4 cm per year. Using dates provided by Petersen et al. (2001: 97-101) and Heckenberger et al. (1999: 359, 367), I calculated rates of accumulation required to produce deep ADE. The 30-80 cm deep ADE at the 30-90 ha Açutuba site formed over 1800 years (360 BC and AD 1440) or 0.002 to 0.004 cm per year accumulation. In the Upper Xingú region, a depth of 40-50 cm of ADE in sites covering 0.3-0.5 km^2 formed over 700 years (AD 1000 and AD 1700) or 0.06 to 0.07 cm per year accumulation. The 75 to 90 cm [deepest] of ADE in the 32-ha Araracuara site formed over 900 years, or at a rate of 0.08 to 0.1 cm per year (Mora et al., 1991). Although these figures are crude estimates, the rates suggest that ADE formation is slow.

7. INTENTIONALITY AND AMAZONIAN DARK EARTHS

All authors of this volume agree that long-term permanent settlement in the same location is a key component of formation process of *terra preta*-type ADE, but not necessarily a complete explanation. Did Amazonian peoples intentionally create and maintain both *terra preta* and *terra mulata*-types of ADE for farming or was it the unintentional by-product of permanent settlement and semi-permanent cultivation? All authors of this volume agree that of *terra preta*-type ADE was the unintentional by-produce of long-term permanent settlement in the same location. The hundreds of years necessary to produce mature ADE also suggests that ADE formation was an unintentional process spaning many human generations. In contrast, most scholars believe that the formation of *terra mulata*-type ADE which implies intentional, possibly labor-intensive movement of organic matter from domestic contexts to fields, cutting and removing trees with stone axes, and systematic burning as part of semi-permanent agricultural activities (Sombroek 1966: 175; Andrade, 1986; Mora et al., 1991; Woods and McCann, 1999; Denevan, 2001; Mora, 2003; Myers et al., 2003; Kern et al., 2003).

As an historical ecologist, I am convinced that Amazonian peoples knew what they were doing in regard to settlement, agriculture and other activities that involved environmental transformations over the short and long term. Amazonian farmers today are certainly knowledgeable about the soils that they chose to cultivate and we can assume that was the case in the past. *Terra preta*-type ADE probably began to form under conditions of permanent settlement. Settlements are the result of cultural decision-making and choices of settlement location and longevity are intentional, conscious acts. Based on excavations of pre-Columbian settlements and observations in historical, ethnographic, and contemporary contexts, we assume that patterned treatment and disposal of trash is also cultural and intentional. But was the intent to create ADE? The creation of midden that resulted in ADE is primarily a cultural formation process (although natural processes of decomposition, weathering, and bioturbation certainly played a role). Farming is another process (Fig. 1, 9). Most Amazonian houses past and present had adjacent house gardens (Lathrap, 1977). The house garden is a form of intensive agriculture that receives kitchen wastes and is the primary midden in Amazonian settlements (Clement et al., 2003; Hecht, 2003; Hiraoka et al., 2003). If the ethnographic cases are relevant to the past, ADE was probably exploited for cultivation both during and after its formation.

8. RELATIONSHIP OF AMAZONIAN DARK EARTHS TO PRE-COLUMBIAN SOCIETAL COMPLEXITY

Large scale ADE first appears between 450 BC and AD 950 (Petersen et al., 2001: 100-101; Neves et al., 2003). Petersen et al. (2001: 100) state that the appearance of ADE is "broadly synchronous" throughout the Amazon Basin, although 1400 years is a considerable span of time. They note that in most cases, the earliest dates are from the Central and Lower Amazon associated with the Amazonian Polychrome tradition (in agreement with arguments about the geography and timing of Amazonian cultural development (Lathrap 1970; Lathrap et al. 1985; Brochado 1984)).

What was the unique "kick" or combination of cultural, economic, technological, social or political factors that triggered ADE formation on a vast scale throughout the Central and Lower Amazon in late prehistory? Neves et al. (2003) and Petersen et al. (2001) stress sedentism as the motivating factor ("long-term intensive settlement"). They argue that manioc and intensive exploitation of riverine resources made sedentism possible. This is an unsatisfactory explanation because sedentism, manioc, and aquatic resource use appeared thousands of years earlier in the Amazon (Roosevelt et al., 1991; Piperno and Pearsall, 1998; Oliver 2001). Lathrap (1970, 1977) suggested that the domestication of bitter manioc that could be detoxified to produce a storage product created the context for population growth, larger settlements, warfare, and more complex socio-political organization in the millennium before the appearance of ADE. Roosevelt (1980, 1991) has argued that it was the adoption of maize as a storable protein resource around 2000 years ago that triggered socio-political complexity in the Central and Lower Amazon. Maize was the staple of the Tapajós (Nimuendajú, 1952: 14, Footnote 5) while manioc was the staple of cultures in the Upper Xingú region. Both are late prehistoric inhabitants of ADE sites. As many archaeologists have noted, the period when ADE appears in the archaeological record is characterized by fancy polychrome pottery, larger vessels, elaborately carved stone objects, and increased local and regional interaction through trade, exchange, feasting, warfare and alliances (Lathrap, 1970; Lathrap et al., 1985; Roosevelt, 1991; Heckenberger et al., 1999; Petersen et al., 2001; Myers et al., 2003; Neves et al., 2003). Whatever the trigger(s), most scholars agree that these changes were associated with population growth and subsequent population pressure in many diverse ecological contexts in Amazônia and increased social interaction (Lathrap, 1970; Roosevelt, 1980; Brochado, 1984; Carneiro, 1996; Oliver, 2001; Peterson et al., 2001).

Was maintaining residence in the same place for many, possibly hundreds of, successive generations necessary to produce ADE?[17] Factors range from environmental (desire to control prime real estate with access to multiple resources, river transportation, and farmland; Denevan's Bluff model) to cultural (a strong sense of place and identity), and political (territoriality driven by warfare, competition, and alliances) (Carneiro, 1970; Lathrap, 1970; Denevan, 1996, 2001). Late prehistoric Amazonian warfare may have been a factor in settlement location, longevity, and community pattern with a selection for centralized, densely packed settlements on river bluffs that could be defended with earthworks and palisades (Carneiro, 1970; Lathrap, 1970; Heckenberger, 1998). The new sociopolitical systems documented at regional scale permitted huge populations to occupy larger settlements than were possible under less complex institutions (Heckenberger, 1998; Heckenberger et al., 1999; Neves et al., 2003).

Because large dense populations are often markers of socio-political complexity, are ADE necessarily associated with or the product of centralized complex societies? Neves et al. (2003) correlate ADE with cultural phenomena appearing 2000 years ago such as earthmoving, long distance trade, impressive polychrome pottery styles, intensification of agriculture, sedentism, roads, and plaza ring ditch settlements which imply increasing hierarchical, socio-political organization. Mora (2003) directly associates ADE with the appearance of chiefdoms in the Upper Amazon Basin. Although many Amazonian societies were probably hierarchically organized and complex by late prehistory, the causal relationship between complex society and ADE is poorly demonstrated.

Other questions about the necessary association of ADE and socio-political complexity can be raised. Kämpf et al. (2003, citing Miller, 1999) report ADE dating to 4,800 years BP, much earlier than any evidence for chiefdoms and states in the Amazon. In addition, if site size is associated with socio-political complexity, it is worth examining the entire range of ADE. Although emphasis in this volume has been on the larger ADE, Kern et al. (2003) point out that most ADE are small (80 % of the known ADE sites cover less than 2 hectares.). Archaeologically, small ADE probably represent individual homesteads, hamlets and small villages of farming societies (Myers, 1973; Smith, 1980). Whether these were the lower rungs of a regional, hierarchically organized socio-political organization has not been adequately determined. Although the cultural phenomena that sparked ADE formation may be associated with sociopolitical complexity, these small sites show that small communities were capable of creating ADE. Density of settlement

[17] Contrary to contemporary interpretations of Amazonian site formation, Meggers (2001) argues that large Amazonian sites can be formed over time by repeated cycles of occupation, abandonment, and reoccupation by nomadic peoples. Numerous scholars have demonstrated that the archaeological record does not support Meggers' claim (DeBoer et al., 1996, 2001; Heckenberger et al., 2001). Amazonian foragers, given enough time, do have a substantial, permanent impact on their environments (Balée, 1994; Politis, 1996; Rival, 2002). Rival (2002) argues mobility as an age-old practice in contrast to Balee's (1994) proposal that foraging is a post-Colonial survival strategy.

population was probably more important than total number in the formation of local ADE.

The labor, energy, and costs involved in the creation, use, and maintenance of ADE are also unknown. If the estimates of Mora et al. (1991) are correct, high, sustained labor input was necessary to create the extensive ADE documented throughout the Amazon Basin (discussed below). Was ADE produced by small groups of people over long periods of time or large groups over short periods? Does ADE formation and management require complex social organization or could small autonomous groups have done it? The variation in size and depth of ADE suggests that it was associated with dispersed households, hamlets, villages, and large urban settlements.

9. AMAZONIAN DARK EARTH AS RESOURCE MANAGEMENT

We see the end result of ADE formation in the archaeological record and soil profiles. The process that produced ADE must be inferred through multiple lines of evidence. I believe that Amazonian farmers would recognize the benefits of ADE as it was forming. If so, both *terra preta*- and *terra mulata*-types of ADE were created through intentional and deliberate activities, possibly even involving planning and design rather than unintentional by-products of long-term settlement. As such, ADE are part of a lost indigenous knowledge system, a form of resource creation and management governed by a set of cultural rules, logic, knowledge, and behavior. Until we know more about how ADE was created, it is difficult to address issues of resource management, appropriate technology, and sustainability. Experiments, ethnographic analogy, and cross-cultural analogy can help revive the lost indigenous knowledge system. Insights provided by Hecht (2003), Posey (1998) and WinklerPrins (2001) are important advances.

Is ADE a sustainable resource management system? The fact that (1) ADE are well preserved, stable, and resistant to leaching, erosion, and mineralization (possibly even "growing" as suggested by some scholars) after 400 to 500 years of neglect and/or use, and (2) archaeological dating demonstrates that many ADE were occupied for 900 years or more (Smith, 1980; Denevan, 2002; Kern et al., 2003; Lehmann et al., 2003a; Mora, 2003; Neves et al., 2003) are indications that ADE are sustainable (or at least the human lifeway that produced them was sustainable). The degradation, destruction and loss of ADE today is due to physical removal of the sites, not overuse or declining soil fertility. Abandonment of ADE used for farming today appears to be due to the increase in labor dedicated to weeding (weed invasion) rather than soil nutrient depletion through overuse (German, 2003; Major et al., 2003). ADE are remarkably resistant and resilient.

10. AMAZONIAN DARK EARTHS, BIODIVERSITY, AND AGRODIVERSITY

The relationship of ADE to biodiversity and agrodiversity is poorly understood. Some authors (Clement et al., 2003; German, 2003; Major et al., 2003) have proposed that because of their high soil fertility, ADE could be rich reserves of biodiversity, at least in terms of economically useful species for humans past and present. One could also infer from this that game animals hunted by Amazonian peoples are also more abundant because of ADE (since they tend to feed on the same economic species as humans). Balée (1989, 1994; Balée and Campbell, 1990) provides an excellent analysis of the economic species, the floral and archaeological signature, and biodiversity associated with ADE in central Brazil. Historical ecologists point out that the combination of human-enhanced soil fertility, continual disturbance, and selection for economic species can raise biodiversity and increase biomass. The weedy species, feral crops, and semi-domesticated trees commonly associated with long-term human activities and disturbance (especially old paths, fields and settlements) are important elements of agrodiversity and valuable *in situ* genetic reserves (Balée, 1994; Brookfield, 2001; Clement et al., 2003; Major et al., 2003).

On the other hand, more human interference is often equated with deforestation, excessive disturbance, and creation of secondary forest and grasslands, changes that are often attributed by natural scientists as detrimental to Amazonian biodiversity. If pre-Columbian urban settlements that formed ADE were as large and as densely occupied as assumed in this volume, there was little tropical forest left within and around the sites. Ethnobotanical analysis demonstrates that there was little or no forest present at the ADE of Araracuara when occupied and farmed (Mora et al., 1991). The vegetation within and around the large ADE described in this volume was probably field and managed forests of tree crops. "Natural" biodiversity may have been completely replaced by agro-diversity on these ADE (borrowing from Brookfield, 2001). Historical ecologists and New Ecologists question the received wisdom that old forests with continuous canopy, the traditional image of ideal wilderness and optimal forest succession, are necessarily the only or best kind of diversity or the healthiest environment (e.g. Botkin, 1990; Zimmerer and Young, 1998). Graham (1998, 1999) argues that high biodiversity in the Maya region may be due to pre-Columbian urbanism rather than its absence.

Although unproven, ADE probably supports higher biodiversity and biomass, especially after abandonment of the site for settlement, than non-ADE landscapes.[18] Various authors (Clement et al., 2003; German, 2003; Major et al., 2003; Mora, 2003) stress that it is possible to measure modern biodiversity on ADE. Inferring pre-Columbian biodiversity and agrodiversity in Amazônia is more difficult but possible (e.g. Mora et al., 1991; Piperno and Pearsall, 1998; Stahl, 2002). As authors of this volume have shown, soil biota and beneficial biological processes are enhanced in ADE and the diversity of soil organisms should be included in calculations of ADE biodiversity.

11. AMAZONIAN DARK EARTHS AND CONTEMPORARY SOCIETY

Pre-Columbian urban societies in the Amazon figured out successful and efficient ways to sustain large and dense populations, produce surpluses, and manage wastes.

[18] Because most of the Amazon Basin is influenced by humans, distinctions between ADE and non-ADE landscapes are more matters of the degree of anthropogenic transformation than culture vs. nature.

Is ADE relevant to waste management and agricultural development in contemporary Amazônia? Two questions must be asked: "How did they do it?" and "Can we replicate the process?" The authors of this volume have clearly demonstrated that ADE has much greater agricultural potential than typical non-anthropogenic soils in the Amazon Basin. The possibility of supporting current and future populations in Amazônia on smaller units of land through agricultural intensification is attractive, especially when framed in terms of conservation and management of biodiversity and cultural diversity. The archaeological record shows that ADE sites were occupied by large populations for long periods of time in what are often referred to as marginal environments, a clear indication of success and sustainability. Thus, deciphering the "secret" of ADE formation and maintenance may have considerable modern applied potential.

The huge and rapidly expanding "jungle cities" in the Brazilian, Ecuadorian, Colombian, Bolivian, and Peruvian Amazon produce prodigious quantities of organic urban waste. In the recent past, garbage was simply disposed of by tossing it into the rivers, lakes, or around settlements. Today, disposal and management of garbage has become an important aesthetic, health, and development issue. The systematic recycling and use of the organic matter component of urban garbage is relatively new. Tons of Brazil nut shells produced by the Brazil nut extractive industries are used for generating electricity to supply the city of Riberalta, Bolivia. Urban organic wastes have been used to restore the dry tropical forests of the Guanacaste region of Costa Rica (Janzen, 2002). Authors of this volume (Hiraoka et al., 2003) provide additional examples of management.

ADE is an excellent example of the capture, processing, composting, and recycling of organic and inorganic soil nutrients on a huge scale in pre-Columbian urban contexts. What can be learned from the past and what of this knowledge can be applied today? Several authors promote the ideas of using urban garbage to create new productive ADE. The pros and cons of applied ADE research are briefly addressed in this volume. Looking to the past (in this case, applying pre-Columbian technology) to resolve today's problems is often criticized as naïve or worse. The historical processes, technologies, and environmental, demographic, and cultural contexts that produced ADE may be completely alien to the contemporary world. The production, management, and use of ADE raise some obvious health, economic, and aesthetic issues.

The wastes produced by urban populations in Amazônia today are loaded with toxins, synthetics, and diseases; quite different from those produced by native peoples. Sombroek (1966: 261) and Sombroek et al. (2003) discuss the economic issues that need to be addressed to reestablish or create new ADE. Sombroek et al. (2003) conclude that it is theoretically possible but probably not economically feasible due to high labor, storage, and transportation costs relative to benefits.[19]

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[19] Although assumed to be high, no author attempts to estimate the labor involved in production and maintenance of ADE. Through archaeobotanical and sediment analysis, Mora et al. (1991: 79) determined that much of the ADE of Araracuara was alluvial silt and aquatic algae from the floodplain up to 2 km away. According to calculations based on experiments, they conclude that "…245 tons of silt and algae or 90 tons of mulch would be required to cover one centimeter of topsoil over one hectare". One ADE covers 32 ha and is 1 m deep (Mora et al., 1991: 81) which implies considerable labor input. Although

What can be done to encourage rural and urban peoples to participate in ADE studies and applications? Certain incentives such as those suggested for carbon sequestration by international agencies could be used to promote ADE. According to Sombroek et al. (2003), an increase of 5-10% of ADE would mean a significant sequestration of atmospheric carbon in the soil. According to the authors in this volume, an important process in the creation of ADE was massive and sustained incomplete burning to produce charcoal that was incorporated into the soils. Lehmann et al. (2002) promote "slash and char" as a means to this end. The conversion of urban organic wastes into useful charcoal is intriguing, but has obvious disadvantages (Madari et al., 2003). Large-scale burning is considered by nearly everyone (environmentalists, conservationists, green politicians, and development planners) to be the anathema of contemporary environmental resource and biodiversity management. Charcoal production throughout the world is blamed for much atmospheric degradation and deforestation.

12. FUTURE DIRECTIONS AND POTENTIAL APPLICATION

As pointed out by many authors of this volume, most claims about long-term fertility, agricultural potential, and sustainability of ADE are anecdotal. Well-designed experiments to reproduce ADE based on insights from archaeology, geography, ethnography, history, agronomy, soil science and other disciplines as discussed in this volume are critical. Long-term experimental ADE plots and controls should to be established in native communities and agricultural stations. Experiments such as those reported in this volume are a step in the right direction (Lehmann et al., 2003a; Sombroek et al., 2003). Intensive agriculture such as permanent orchards and house gardens may provide better models for ADE formation, use and maintenance than slash-and-burn (Denevan, 2001; Hecht, 2003; Hiraoka et al., 2003; Myers et al., 2003).

I propose the following issues as research priorities:

1) *Define Criteria for Identification of ADE and its variants:* A widely acceptable suite of archaeological, physical, and chemical criteria and inexpensive efficient methods for the identification of ADE are needed. Also, soil criteria will permit accurate identification and mapping of *terra mulata* or Preceramic period sites where potsherds may not be present. According to many authors in this volume, *terra mulata* are probably more common than the classic *terra preta* soils.

2) *Systematic archaeological and soil surveys of the Amazon Region*: Despite the recent excellent research on ADE, we still do not know the total geographical extent or full range of variation of ADE. Systematic archaeological and soil surveys to create a basic inventory of ADE in a Geographic Information System (GIS) would

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most pre-Columbian ADE formation was probably not as labor intensive as that proposed for Araracuara, the figures provide insights into the scale of soil transformation. Controlled experiments and cost-benefit analysis could address and resolve these issues.

be a good start. GIS would also be an excellent tool combined with multispectral analysis of aerial and satellite imagery to efficiently map ADE. Predictive modeling could be done remotely once the unique signatures or indicator species of the vegetation canopy on ADE are defined (e.g. Balée, 1989; Clement et al., 2003, German, 2003, Major et al., 2003).

3) *Cultural Resource Management Plan for ADE*: As archaeological sites, ADE should be identified, registered, mapped and evaluated as cultural resources. The systematic surveys reported in this volume are a good beginning. Management implies careful assessment of the impact of urban and agricultural development on ADE and steps that can be taken to conserve them for the future.

4) *ADE Content Analysis*: Although many of the elements that make up ADE have been documented through archaeological, ethnobotanical, and soil analyses, the total range of components and their frequency remain elusive. In addition the contribution of different sources of organic material need to be quantified. Sophisticated analysis of pre-Columbian biodiversity from middens (Stahl, 2000; Mora, 2003) and fine-grained analyses in this volume provide examples of how this could be done.

5) *Ethnoarchaeology, Ethnography, and Ethnoscience of ADE*: Although most contemporary scholars do not assume that the present-day ethnographic record represents the past, studies of native peoples and rural farmers can provide important analogies or models to test against the archaeological record (David and Kramer, 2001). Indigenous knowledge about fauna, flora, and climate is better known than soils in the literature on Amazônia. Studies of indigenous and modern folk classifications of soil, life history of artifacts, cultural views about garbage and sanitation, patterns of disposal, midden formation, and recycling in traditional societies would augment those presented in this volume.

6) *Experiments in ADE Formation, Maintenance, and Use*: Archaeologists have learned that experiments are often the only means of understanding past technologies and indigenous knowledge systems, especially those that have no modern analoga. Experiments in construction and use of abandoned agricultural systems such as raised fields and terraces have provided important insights. The controlled experiments proposed by various authors in this volume will be valuable.

7) *Comparative Research on ADE*: Is ADE a unique Amazonian phenomenon or is it similar to black earths reported in other parts of the world? Cross-cultural analogy regarding ADE and other anthropogenic soils in a global perspective remains under investigated. Woods (2003) briefly discusses ADE in a comparative perspective. The vast literature on anthropogenic transformation of the environment may provide insights (e.g. Fairhead and Leach, 1996; Redman, 1999; Brookfield, 2001).

8) *Computer Modeling and Simulation of ADE*: Many of the unanswered questions about ADE may be answered through modeling of carbon sequestration and carbon cycling as proposed by Sombroek et al. (2003). Multiscale modeling from local to regional to global scale may be possible. Because ADE and other strategies used by pre-Columbian Amazonian peoples impacted most of the basin, robust and powerful models will be needed. The experiments, ethnoarchaeology, and mapping of ADE could provide the basic data to construct and test these models.

9) *Biodiversity and ADE*: Countering contemporary ideas that most human interaction with the environment are negative, several authors of this volume point out that ADE may have actually improved biodiversity in both the short and long term. More detailed comparative studies of ADE and adjacent non-ADE could test the premise proposed by historical ecologists that human activities can increase biodiversity. The hypotheses posed by Clement et al. (2003) regarding ADE as sites of agrodiversity and genetic reserves of useful plants need to be investigated.

13. CONSERVATION, MANAGEMENT, AND VALUE OF AMAZONIAN DARK EARTHS AS CULTURAL HERITAGE

Most obvious contemporary uses of ADE are for farming and as mines for construction fill, potting soil, and archaeological treasures (Woods and McCann, 1999; Hiroaka et al., 2003), both of which are incompatible with the importance of ADE to the scholarly community as archaeological sites and cultural heritage, stores of indigenous knowledge, locations of biodiversity, and carbon sinks (as discussed in this volume). As an archaeologist, I am concerned about the continuing destruction of ADE as cultural resources, a view shared by many of the authors of chapters of this volume. The looting of artifacts in ADE for private collections and museums is particularly disturbing. The report of over 300 urn burials destroyed at a single ADE site near Manaus is sobering (Clement et al., 2003). The distribution of ADE unfortunately often corresponds to areas of contemporary urbanism, road building, agricultural expansion, and population growth especially in the Brazilian Amazon. The Taperinha site near Santarém with the earliest pottery in the Americas and the oldest documented ADE (7,000 BP) has been removed as construction fill (Roosevelt et al., 1991). Hiraoka et al. (2003) and Woods and McCann (1999) document the mining of ADE for commercial soils for urban gardeners. It is possible that when the insights of the scholars (this book for example) are more widely publicized, the exploitation and destruction of ADE will increase. As most of the authors of this volume would agree, ADE under poor management is not a renewable or sustainable resource. A proactive stance by scholars and the public is needed because the process of destruction has already begun in earnest.

Can existing ADE be sustainabily used and managed? Could new ADE be created to take the pressure off the original ADE? Do representative ADE deserve protection and management as cultural heritage? As archaeological sites and national cultural patrimony, ADE ideally fall under national and international legislation designed to protect, manage, and interpret cultural resources. Cultural

Resource Management is new to the Amazonian region and difficult to operationalize given poor funding and inadequate promotion of its benefits. Local governments, farmers, and landowners would probably reject taking valuable ADE farmland out of production for its protection. Because local and national protection is unlikely, could ADE fall under the protection and management of international agencies? The World Heritage designation of archaeological sites, monuments and landscapes by UNESCO is intended to protect and manage scarce cultural resources. To be nominated as a World Heritage site or cultural landscape, the location must be "unique" and of "outstanding universal value" (UNESCO, 2002). According to UNESCO's operational guidelines, ADE could fall under the category of cultural landscape or archaeological site. UNESCO designation provides funds and training for local protection and management of nominated locations.

Are pre-Columbian ADE, modern settlement, and farming necessarily incompatible? Lived-on and farmed ADE may be the best means to protect them. The simplest solution may be the continued occupation and use of ADE by native peoples and small farmers for settlement and farming which may have a positive effect in protecting, maintaining and regeneration of ADE. One of the largest ADE is possibly preserved under the cities of Santarém and Belém (Nimuendajú, 1952; Smith, 1980; Roosevelt, 1991, 1999; Kern et al., 2003). Promoting, interpreting, and protecting ADE as cultural heritage to the public, government, and international agencies will be a challenge. Some of the strategies for promoting eco- and cultural tourism could be adapted for protection and management of ADE. Triple alliances between archaeology, native peoples, and conservation of biodiversity have been forged with some success in Latin America (Kayapó, Sirionó and Xinguano examples). The potential links between biodiversity and ADE could be exploited for protection under traditional nature parks and reserves. Clement et al. (2003) suggest that the diverse species of economic plants, feral domesticates, and crops growing on relatively undisturbed ADE may be "genetic reservoirs" of landraces thought lost with depopulation and European conquest. We can assume that the biodiversity and agrodiversity where ADE is regularly mined and farmed for market crops has probably been lost forever.

A less tangible, but important "value" of ADE for contemporary society is as a record of an indigenous knowledge system, an ethnoscience, or appropriate technology, in this case a possibly sustainable landuse strategy that has become lost over time. Publications about ADE by Charles Mann (2000a, 2000b, 2002a, 2002b) and the documentary *Search for Eldorado* (DOX Productions, 2002) are examples of how the popular media can be used to capture the public's imagination. The idea that native peoples constructed agricultural soils where none existed is a powerful concept. As Mann points out, the Woods and McCann (1999) hypothesis about living and reproducing anthrosols has considerable appeal with both the public and scholars.

Other potential "values" of ADE research are the protection, promotion and regeneration of the native culture of the descendants of the people who made ADE. Documentation of indigenous resource management (Ka'apor; Kayapó examples) increases the appreciation of indigenous knowledge, countering the idea that native practices are backward, primitive holdovers from the past. On the other hand, over-promotion can result in creating new Myths of the Noble Savage.

14. CONCLUSIONS

As stressed in this volume, ADE should not be treated as simply a soil science phenomenon. It is obvious that the formation and maintenance of ADE are the result of a complex and dynamic interaction of culture, settlement, technology, and production strategies. Continued multidisciplinary, interdisciplinary research as exemplified in this volume, is the best approach to understand ADE. These studies combine fieldwork,participant observation, and bench science of archaeologists, anthropologists,geographers, scientists, geneticists, and botanists. The authors of this volume stress the importance of the human dimension in our understanding of soil formation, use, and management. Amazonian peoples took soils that are generally considered marginal in terms of nutrient availability, texture, drainage, and depth and turned them into productive farmland through their management of organic matter from urban settlements.

Increasing knowledge of ADE has important implications for the interpretation and understanding of Amazonian prehistory and history. In contrast to traditional views stressing environmental limitations for cultural development, ADE is evidence of large dense populations, permanent residence, and sustainable lifeways that continue to effect contemporary inhabitants of the Amazon. ADE is one of many strategies developed by Native Amazonians to thrive in what has been called a counterfeit paradise.

ADE was one of many strategies used by native peoples to transform the Amazon Basin. Historical ecologists argue that all environments in Amazônia are to some degree anthropogenic and have complex, dynamic human histories. These transformations probably go back to the first human colonizers of the region over 10,000 years ago who brought with them one of the most powerful pre-industrial tools for landscape management: fire. Foragers, settled farmers, and later urbanized town inhabitants from the late Pleistocene to the present have played a role in shaping the Amazonian landscape as we know it. ADE are just one of many anthropogenic soil modifications which included creation of physical infrastructure such as terracing, raised fields and more subtle regional transformations such as induced upslope erosion and downstream sediment capture, fish weirs, earthworks for settlements, transportation, and agriculture (Balée, 1994; Stahl, 1996; Erickson, 2000a; Denevan, 2001). Native American manipulation of the genetics, number, and distribution of crops and non-domesticated economic species; house gardens and fields; and agroforestry are examples of indirect modifications of soils and local environments.

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