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## Chapter 9

# AGROBIODIVERSITY IN AMAZÔNIA AND ITS RELATIONSHIP WITH DARK EARTHS

CHARLES R. CLEMENT<sup>1</sup>, JOSEPH M. MCCANN<sup>2</sup>, NIGEL J. H. SMITH<sup>3</sup>

<sup>1</sup>*Instituto Nacional de Pesquisas da Amazônia, INPA, Manaus, AM, Brasil.* <sup>2</sup>*Division of Social Sciences, New School University, New York, NY, USA.* <sup>3</sup>*Department of Geography, University of Florida, Gainesville, FL, USA*

### 1. INTRODUCTION

Amazônia still contains both pre-Colombian concentrations of indigenous crop plant genetic diversity (Clement, 1999a, 1999b), the major component of agrobiodiversity<sup>1</sup> of interest to indigenous and traditional Amazonian societies, and clear evidence of indigenous technologies used to manage the local environment and its biodiversity<sup>2</sup> (Balée, 1989; Clement, 1999a; Denevan, 2001), although much of both was lost after European conquest (Clement, 1999a, 2003). The combination of these technologies certainly increased carrying capacity, allowing the development of advanced chiefdoms based on local food security, with the large populations observed along the main rivers at contact (Piperno and Pearsall, 1998; Denevan, 2001).

One of the most interesting and durable environmental modifications was the creation of Amazonian Dark Earths (Smith, 1980, 1995; Woods and McCann, 1999), including both *terra preta do índio* and *terra mulata* (as defined by Sombroek, 1966), whose origin (Neves et al., 2003) and other characteristics are the subject of this volume. Given the interaction among pre-Colombian technologies, an obvious question is 'What is the relationship between native (and early exotic) agrobiodiversity and Dark Earths?' Specific questions that will allow us to answer

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<sup>1</sup> Agrobiodiversity or agricultural biological diversity includes all components of biological diversity of relevance to food and agriculture and all components of biological diversity that contribute to sustaining the key functions of agro-ecosystems. It follows that agrobiodiversity has two levels: (1) Genetic resources for food and agriculture. This encompasses all cultivated and domesticated species, including their wild relatives and managed stocks of wild animals and plants. (2) Components of agrobiodiversity that provide ecological services. This includes, for instance, beneficial organisms that control pests, soil organisms that process nutrients for crop plants, pollinators, and plants that contribute to controlling erosion or stabilizing the water balance (GTZ, 2003). In this paper we will concentrate on level 1.

<sup>2</sup> Biodiversity or "Biological Diversity" means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (CBD, 2003).

this include 'Are there indicator plant or crop species for Dark Earths?' and 'How are they related to the centers and regions of crop genetic diversity at contact?' and, if they are, 'Do Dark Earth sites act as reservoirs of Amazonian crop genetic diversity?' The answers to these questions about agrobiodiversity and Dark Earths will contribute to our understanding of human adaptations to *Amazônia*, both during the mid to late Holocene and in the present. This contribution attempts to answer these questions from the literature, in order to determine if they are interesting enough to merit further research.

## 2. AGROBIODIVERSITY

Clement (1999a) defined crop plant domestication as a co-evolutionary process by which human selection on the phenotypes of promoted, managed or cultivated plant populations results in changes in the population's phenotypes and genotypes that make them more useful to humans and better adapted to human intervention in the landscape. Once humans begin to select and propagate individuals within a plant population, the domestication process is initiated and the population is considered to be domesticated to some degree. Thereafter it is considered to be a component of a region's agrobiodiversity.

A continuum of modification due to continued selection and propagation extends from wild through incipient to semi-domesticated to domesticated, with a special case at the beginning of the continuum: incidentally co-evolved populations (many of which are more commonly called weeds today), which take advantage of the human disturbances in the landscape (Rindos, 1984; Spahillari et al., 1999). Ecologically, these are pioneer species adapted to disturbed and transitional environments, hence are 'pre-adapted' to colonize landscapes disturbed by humans and 'offer' themselves to humans for whatever use may be made of them (Ford-Lloyd and Jackson, 1986). In the literature on crop origins and domestication, these pioneer species are often called weeds (Ford-Lloyd and Jackson, 1986; Harlan, 1992), even though this is not the current plant science definition (see Major et al., 2003, for another viewpoint). We will use the definition current in the crop domestication literature since we are dealing with agrobiodiversity. Also, by definition, a fully domesticated population cannot survive if abandoned by humans, even in the environment of its wild ancestor (Harlan, 1992).

The above definition clearly states that human actions are essential, both to select and to propagate, with all that these actions imply. Hence, Clement (1999a) defined landscape domestication as a conscious process by which human manipulation of the landscape results in changes in landscape ecology and in the demographics of its plant and animal populations, resulting in a landscape more productive and congenial for humans. The intensity of manipulation may vary widely, from promotion through management to cultivation, with each succeeding category requiring greater labor and knowledge investment. Cultivated landscapes are created by the complete transformation of the biotic landscape, generally starting with the elimination of the original vegetation, to favor the growth of a few selected food

plants and other useful species. Denevan's (2001) state-of-the-art review examined numerous indigenous technologies used for landscape domestication.

Dark Earths are a product of this landscape domestication process, hence the landscapes that contain them were originally cultivated landscapes and may be so today. Dark Earths were formed as a result of the more intensive cultivation practices and more permanent settlement patterns (Woods and McCann, 1999; McCann et al., 2001; Denevan, 2001; Neves et al., 2003). They do not appear to form under the shifting cultivation methods that became prominent in the wake of indigenous depopulation and adoption of steel tools after European contact (Denevan, 2001).

At contact (1540 AD for Amazônia), the Amazon basin contained at least 138 crop species in different stages of domestication (Clement, 1999a; Table 1), found in a mosaic of concentrations of diversity: centers, regions and micro-centers of crop genetic diversity (Clement, 1999b). Most of the important crops, such as those used for food security, technological applications and recreation, were widely distributed. The most domesticated also presented distinct landraces in different regions (e.g., pupunha (*Bactris gasipaes* Kunth, Palmae); Clement, 1988).

Table 1: Number of families, genera and species that were probably present in Amazônia at contact, ordered by degree of domestication (for a detailed list of species see Clement, 1999a).

	Incipient Dom.		Semi-Domesticated		Domesticated	
	Native	Exotic	Native	Exotic	Native	Exotic
Families	17	6	21	11	3	19
Genera	27	9	22	13	16	26
Species	36	9	28	13	19	33
Species	45		41		52	

This agrobiodiversity includes species that are candidate indicators of Dark Earths. Weeds are also strong candidates, both because some gave origin to crops and because some may be 'regressed' crops, but no similar compilation of their diversity has been carried out to date in Amazônia, although various Brazilian compendiums list numerous Amazonian species (Major et al., 2003). Since European conquest, a wide diversity of Old-World species has been added to the Amazonian crop and weed repertoires, and most, if not all, are also candidate indicators due to their inadequate adaptation to Amazonian agro-ecosystems, i.e., they grow best on the best soils. J. Major (pers. comm., 2003) observed that the majority of weed species on Dark Earths near Manaus, Amazonas, Brazil, are cosmopolitan, apparently with few if any Amazonian native species, which reinforces the idea that they may be good indicators.

## 3. INDICATORS

An *indicator* is "One who or that which indicates or points out", while *indicate* is "1. To be or give a sign of; signify. 2. To direct attention to; point out. 3. To express or make known." (Funk and Wagnalls, 1976). Brooks and Johannes (1990) provide a comprehensive discussion of plant indicators of ancient anthropogenic modification of soils. They include examples from Europe, Africa, temperate and boreal North America, Central America, and Jamaica, but do not mention Amazonia. Although Salée (1994) discusses numerous plant indicators of domesticated landscapes in eastern Amazonia, no general-purpose classification of indicators has been attempted for cultivated landscapes, especially those containing Dark Earths. Here we attempt such a classification, identifying four possible categories of indicators (Table 2); in the following two sections we provide examples from Amazonia for each, in the latter section ordered by presumed degree of domestication of the plants.

We will not attempt to determine why a plant species might be an indicator of Dark Earths, as this question is likely to be species-by-location specific. Possible reasons include, but are not limited to (J. Lehmann, pers. comm., 2002): the favorable soil environment (abundant P and Ca, maybe reduced N, especially for legumes; better soil aeration); the favorable biological environment (species' interactions, such as microbial symbiosis); or simply because humans lived on Dark Earths and cultivated certain species which remained on-site.

Table 2: Summary of examples of possible indicator species\* for Amazonian Dark Earth ordered by probable degree of domestication (following Clement, 1999). See text for other possibilities.

Degree of Domestication	Indicator types			
	Limited to ADE	Out-of-range	Out-of-habitat	Dominance
Wild	Not applicable	No data	Sumauma	Arrow cane
Incidentally co-evolved (weed)	No data	No data	No data	Jurubeba
Incipient	Unlikely	Caiaué	Murumuru	Brazil nut
Semi-	Possible	Sapota	No data	Tucumã
Domesticated	Annuals?	Many fruits	No data	Coca (ipadu)

See text for scientific names.

#### 3.1. A Crop Species, Landrace, Weed (or other Plant) whose Distribution is Limited to Dark Earths

This is the ideal indicator, as the crop, landrace, weed or other plant occurs only where humans created Dark Earths. At the species level this is the least likely of all indicators, as Dark Earths were created during the Holocene, the same period in which crop populations were domesticated, and no domesticates attain the status of a new species unless they are polyploid (Simmonds, 1979). Hence, by definition, no

crop species will qualify as a Dark Earth indicator unless it is a recent auto- or allopolyploid that was identified and conserved during the Holocene.

However, Dark Earths are remarkably like Anderson's (1952) "dump heaps", the environmental context for his theory of crop domestication. It is important to recognize that these dump heaps were not only refuse middens, but included disturbed and enriched environments close to human habitations, especially homegardens and intensively managed areas, as pointed out by Lathrap (1977). Anderson proposed that in these enriched disturbed spaces closely-related taxa, otherwise geographically isolated, repeatedly came into contact, and they therefore offered a prime setting for introgression and hybridization (Stebbins, 1985). Exceptional polyploid individuals that may occasionally spring up in this environment could be easily recognized, preserved, and selected by humans, with potential for additional genetic modifications to take place rapidly (Anderson, 1952).

While our current knowledge of native Amazonian and early exotic crop cytogenetics, and infraspecific genetic diversity and distribution may be too rudimentary to definitively identify a polyploid or landrace that is a Dark Earth indicator, this possibility is worth pursuing. We might start by examining populations of crops associated with Dark Earths that are likely relicts of former indigenous agroecosystems, and/or for which distinct landraces already are known. *A priori*, annuals are more likely to offer a polyploid or Dark Earth landrace than are perennials, because their generation spans are shorter. Examples of possible relicts from the Santarém region and elsewhere include cará do Índio (*Dioscorea trifida* L. f., Dioscoreaceae), hot peppers (*Capsicum chinensis* Jacq., Solanaceae) and tobacco (*Nicotiana tabacum* L., Solanaceae). Weeds also merit examination (see Major et al., 2003).

### 3.2. An Out-of-Range Crop, Weed (or other Plant)

This is an interesting possibility that requires rather detailed knowledge of the ecological range of a crop or weed's ancestral and modern populations. At present, our knowledge of crop distributions is rarified for all but the major indigenous and exotic crops, so the information list below is only a preliminary proposal. An indicator of this type may not be useful throughout Amazônia but might be useful regionally, where data may be more abundant. A recent survey of palms identified in archaeological sites (Morcote-Rios and Bernal, 2001) highlights the difficulty of using an out-of-range indicator, since many candidate indicators in this family had their ranges modified by humans and most botanists still consider the modern range as "natural".

Post-conquest exotics, such as mango (*Mangifera indica* L., Anacardiaceae), maxixe or West Indian gherkin (*Cucumis anguria* L., Cucurbitaceae), and *Citrus* spp. (Rutaceae), can also be out-of-range indicators. For example, in the Rio Arapiuns and Rio Negro basins, where the Ferralsols and Acrisols of the uplands are infertile, these crops are often only viable on Dark Earths. However, they also do well on other soils in other environments (e.g., the high várzeas of white water rivers; see Zarin (1999) for floodplain soils and Jordan (1985) for a general

discussion of Amazonian soils). The spontaneous occurrence of papaya (*Carica papaya* L., Caricaceae) on Dark Earths in the Arapiuns and lower Negro basins might be considered an indicator of this type (but also of type-3, see below), because it is native to northern Central America.

### *3.3. An out-of-Typical-Habitat Crop or Weed (or other Plant)*

This is a refinement of the previous idea and would be most useful locally, but perhaps also regionally. The idea here is that any crop or weed's ancestral populations are best adapted to a specific habitat, which will always differ from that of a Dark Earth, given these were created during the Holocene. Hence, if a crop or weed otherwise adapted to habitats common in the lower Tapajós River basin, for example, was commonly found on Dark Earths (including in the Tapajós River basin), it would be an out-of-typical-habitat indicator. This type of indicator also requires detailed ecological knowledge of a crop or weed's ancestral and modern populations at a local and regional scale, which is often rarified or absent in Amazônia.

A possible example of an out-of-habitat indicator from the lower Negro and Tapajós regions may be the weedy papaya, already mentioned as a possible type-2 indicator. Current residents of the Rio Arapiuns rarely plant any sort of papaya in their home-gardens, but it nonetheless occurs spontaneously in great numbers on some Dark Earth sites after disturbance, but not elsewhere. In cases where this type of indicator occurs spontaneously on Dark Earths as a result of favorable soil characteristics, with no active help from humans, it may be technically inaccurate to say they are out of their typical habitat. Rather, they are exploiting analogous anthropogenic extensions of their "natural" habitats in atypical geomorphological contexts.

### *3.4. A Crop, Weed (or other Plant) With Greater Density, Dominance or Frequency on Dark Earths than Elsewhere*

This idea has already been extensively used to identify plant species that are indicators of human disturbance in general, for example by Balée (1989, 1994). Some kinds of anthropogenic forests (defined by tree species of this indicator type) often occur on Dark Earths (Balée, 1989), but more information will be needed to determine how frequently this occurs throughout Amazônia. This fourth type of indicator is the most inclusive of the possible indicators. By definition, any type-1 indicator, which would occur exclusively on Dark Earths, would also qualify as the most extreme case of this type of indicator. Likewise, range extension indicators would fit the criteria within the extended part of the range, and habitat extension indicators would qualify at a still finer spatial scale of analysis. This may be a very useful indicator in the long run, but the rarified database currently available limits its use today.

In the Santarém region, and elsewhere, various species occur with greater density, dominance or frequency on Dark Earths than they do on other soil types in

the vicinity. They include various herbaceous, vine and tree species representing a range of positions on the domestication continuum from wild [e.g., arrow cane or cana de flecha (*Gynerium sagittatum* Beauv., Gramineae, camapu (*Physalis angulata* L., Solanaceae), chumbinho (*Lantana camara* L., Verbenaceae), envira preta (various genera of Annonaceae), jurubeba (*Solanum jurubeba* Rich., Solanaceae), tiririca (*Scleria pratensis* Lindl., Cyperaceae)] to incipiently domesticated [e.g., bacaba (*Oenocarpus bacaba* Mart., Palmae), Brazil nut (*Bertholletia excelsa* H. and B., Lecythidaceae), cupuaçu (*Theobroma grandiflorum* Schum., Sterculiaceae), inajá (*Attalea maripa* (Aubl.) Mart., Palmae), mucajá or macaúba (*Acrocomia aculeata* (Jacq.) Lodd. ex Mart., Palmae), sumauma or kapok (*Ceiba pentandra* (L.) Gaertn., Bombacaceae), taja (*Caladium bicolor* (Aiton) Vent., Araceae)] to semi-domesticated [e.g., cacao (*Theobroma cacao* L., Sterculiaceae), carirú (*Talinum triangulare* (Jacq.) Willd., Portulacaceae), ingá (*Inga edulis* Mart., Leguminosae Mimodoideae), malva (*Urena lobata* L., Malvaceae, from Africa), taperibá (*Spondias mombim* L., Anacardiaceae), timbó (*Lonchocarpus utilis* Smith, Leguminosae Papilionoideae), tucumã (*Astrocaryum aculeatum*, G. Mey, Palmae)] to fully domesticated [e.g., achira (*Canna edulis* Ker., Cannaceae), cará do Índio, ipadu (*Erythroxylum coca* Lam., var. *ipadu* Plowman, Erythroxylaceae), maracujá (*Passiflora edulis* Sims, Passifloraceae)].

The usefulness of classifying Dark Earth indicators with respect to these 4 categories remains to be field tested, as does the identification of other possibilities. In the following two sections, we focus on the degree of domestication of the species that might be Dark Earth indicators, adding another dimension to the classification schema. But first, we review the archaeobotanical literature in an attempt to identify any agroarchaeological indicators.

#### 4. POSSIBLE AGROARCHAEOLOGICAL INDICATORS

The agroarchaeological literature on Dark Earths is still scarce and geographically widely scattered. The perceived problem of poor preservation of macro-plant remains under humid tropical conditions discouraged early archaeologists (Piperno and Pearsall, 1998), and the important tuberous crops of Amazônia [e.g., manioc (*Manihot esculenta* Crantz, Euphorbiaceae), cará and sweet potatoes (*Ipomoea batatas* (L.) Lam., Convolvulaceae)] are especially susceptible to decay. Recent analysis of pollen, phytoliths and other micro-plant remains from humid tropical settings has shown considerable promise for revealing patterns of ancient human activities and vegetation change in the humid tropics (Piperno and Pearsall, 1998; Pearsall, 2000), although they have been little used to date in Amazônia for archaeological research.

Pollen suffers from problems of preservation in soil, and while cores taken from the scattered suitably stable aquatic depositional environments may provide insights into broad patterns of prehistoric landscape domestication in Amazônia, sediment cores have not yet proven useful for producing more precise information on plants cultivated at a particular location. Phytoliths are frequently resistant to decay, but reliable methods of taxonomic identification, even at the genus level, are still being



developed, and the wide variation in number of phytoliths produced by distinct taxa makes it difficult to assess the relative abundances of the crops that produce them (Doolittle and Frederick, 1991). Flotation of organic remains often yields identifiable seed, wood and other fragments, which allow clear interpretation, and powerful new tools are now being developed to isolate and analyze the ancient DNA of such fragments (Brown, 1999).

The limitations and paucity of archaeobotanical information notwithstanding, here are a few examples worthy of note. Herrera et al. (1988) obtained archaeological pollen and identified numerous species, both crops and wild, at different time depths (630-1905 AD) at Araracuara, Colombia, but provided no estimates of abundance which would allow identification of pre-historic type-4 indicator species. With reference to the crops, manioc and sweet potato were present from the earliest levels (679-722 AD  $\pm$  50 years); beans (*Phaseolus vulgaris* L., Leguminosae Papilionoideae) appeared in the next level (722-766 AD  $\pm$  50 y); maize (*Zea mays* L., Graminae) appeared in the next level (766-878 AD  $\pm$  50 y); cashew (*Anacardium occidentale* L., Anacardiaceae) appeared in the next level (878-1463 AD  $\pm$  50 y). With the possible exception of sweet potato (whose origin is still being discussed), the crops mentioned are type-2 indicators. Many other families containing useful plants and/or crops were also identified but species level identification was not possible. Mora (2003) provides further information on this site.

At Açutuba, on the lower Rio Negro, Lee Newsom recently analyzed micro and macro plant remains from Dark Earths excavated from a burial mound (E. Neves, pers. comm., 2002). Newsom identified manioc and several species known for their use by Amerindians in hallucinogenic rituals (these may include types 2 and 3 indicators).

Morcote-Rios and Bernal (2001) reviewed the archaeological literature on palms and identified a long sequence of mucajá finds starting at 11,200 BP in the Santarém area; although they do not specifically mention Dark Earths, other authors do identify mucajá at Dark Earth sites (see below). Morcote-Rios and Bernal suggested that mucajá probably originated in a dry habitat in the South American lowlands and was spread northwards to Mexico. Piperno and Pearsall (1998) reviewed the evidence that Amazonian landscapes were drier at the beginning of the Holocene than at present, and the Santarém area is drier than other parts of Amazônia today (Salati, 1985), so that eastern Central Amazônia may be a center of origin of mucajá as a camp follower and incipient domesticate.

## 5. POSSIBLE AGROBIODIVERSITY INDICATORS

Frikel (1978) and Balée (1988, 1989) discussed local concentrations of specific species as indicators of human disturbance and management, some of which may be indicators for Dark Earths. These species can be ordered by their degree of domestication, although at a particular site this degree may vary depending upon time depth of human presence, importance of the crop, and conservation during and

after the Amerindian population nadir. The degree of domestication follows the classification scheme of Clement (1999a).

### 5.1. Wild

Arrow cane is common along white-water river banks in western and southwestern Amazônia, and was cultivated in eastern Amazônia for the fabrication of arrows (Le Coite, 1947: 200). The *caboclos* of the Arapiuns River, who hunt with guns, have little or no use for the grass and do not cultivate it today. It is nonetheless found at a few Dark Earth locations growing in robust, persistent patches, but apparently nowhere else (McCann and Woods, 2000). In the lower Rio Negro, a similar pattern was observed, although some *caboclo* fishermen apparently still do use it occasionally to make spears for fishing and, according to one informant, it will grow on soils other than Dark Earths if planted (McCann, 2003).

GYNERIUM

bambusa

A probable example of a type-3 indicator is sumauma in the region of Santarém, Pará. It is commonly found on the high white water várzeas and appears to be rare, if not absent, in the upland forests of the clear water Tapajós River and black water Arapiuns River basins, except on Dark Earths. According to local lore, the Indians planted this tree for the capacity of its roots to collect water that could be tapped when needed, a valuable attribute on the Planalto of Santarém, where streams are few and far between (Woods and McCann, 1999).

Carbua

### 5.2. Incipient Domesticates

The caiaué palm (*Elaeis oleifera* Cortés, Palmae) has an anthropogenic distribution in Amazônia (Wessels Boer, 1965), and appears to be a type-2 indicator for Dark Earths along the Madeira, lower Solimões and upper Amazonas Rivers (Barcelos, 1986; see also Balée, 1989), as well as in the lower Negro River (McCann, 2003). Another palm, the eastern tucumã (*Astrocaryum vulgare* Mart.) is mentioned by Balée (1988, 1989) as a general human disturbance indicator. It is often found on Dark Earths in the regions of Santarém, the Arapiuns River (McCann, 2003) and throughout eastern Amazônia (Balée, 1988, 1989), raising the possibility of it being a type-2 indicator, depending upon its region of origin. According to *caboclos* of the lower Rio Negro region, murumuru (*Astrocaryum murumuru* Mart., Palmae) is a typical várzea species that also occurs on upland Dark Earths (McCann, 2003), suggesting that it is a type-3 indicator. Future research is likely to identify more examples of indicator species adapted to várzea and other nutrient-rich environments.

Surveys at both the Samuel dam, near Porto Velho, Rondônia, and at Tucurui dam, in eastern Pará, found that urucuri (*Attalea phalerata* Mart. ex Spreng, Palmae) was restricted to patches of *terra preta* (Electronorte, 1992: 34). In eastern Amazonas State, Brazil, near the Balbina dam, archaeological surveys conducted on behalf of Electronorte found that inajá (*Attalea maripa* (Aubl.) Mart., Palmae) was always present on archaeological sites (probably Dark Earths), and tucumã and pupunha were often associated with these sites (Electronorte, 1992: 14-15).

Depending upon the natural range of these species, these citations suggest either type-2 or type-4 indicator status.

Heckenberger (1998: 639) reported that the incipiently domesticated mucajá occurs on past habitation sites (often Dark Earths) in the upper Xingú River. Hence, this species may qualify as an abundance indicator (type-4). In this part of southern Amazônia, mucajá may also qualify as a type-2 indicator, since we have just hypothesized above that the species may have originated in Central Amazônia, although even the Xingú can not be discounted as a possible center of origin and dispersal.

Brazil nut is cited by Balée (1989) as a frequent Dark Earth indicator in many parts of Amazônia; depending upon the area of occurrence it could be a type-2 or type-4. According to Oliver H. Knowles (pers. comm. to McCann, 1997), the distribution of Brazil nut in the Trombetas River basin provides an example of an out-of-range indicator (type-2). After many years of studying the forests in that region, Knowles noticed that the long-lived tree occurred on the eastern side of the Trombetas River in a widely spaced pattern that is typical in most of its range. On the west side of the Trombetas River, however, Brazil nut was entirely absent from the forests, except on *terra preta*, where it often occurred in dense stands.

### 5.3. Semi-Domesticates

In western Amazônia, sapota (*Quararibea cordata* Vischer, Bombacaceae) grows best on Dark Earths as far east as Tefé, Amazonas, Brazil (C. Clement, pers. obs., 1982). In Central Amazônia, Johannes van Leeuwen (INPA, pers. comm., 2002) suggested that the central Amazonian tucumã may be an indicator in some areas. The central Amazonian tucumã appears to occupy the habitat of the eastern tucumã in a broad swath through eastern Amazonas State, also preferentially on Dark Earths. Both are type-2 indicators. German (2001) showed that carirú (that she classified as a volunteer edible leafy vegetable but Clement (1999a) classified as a semi-domesticate) was found only on Dark Earths (25% of Dark Earth swiddens), although *caboclos* affirmed that it also grows in Ferralsol swiddens, where it does less well. In the Santarém region, carirú is one of the herbaceous species that appears to be found exclusively or predominantly on Dark Earths (McCann and Woods, 2000). This suggests that carirú may be either a type-2 or type-4 indicator.

### 5.4. Domesticates

The coca variety ipadu, which was domesticated in western Amazônia, adjacent to coca's center of origin in the Andes (Plowman, 1984), was observed both at Tefé, Amazonas (C. Clement, pers. obs., 1982), 500 km east of its modern distribution in western Amazônia, and at Santa Catarina and Nazario, Rio Arapiuns, Pará (McCann, 1999), nearly 1500 km east of its modern distribution. Ipadu's presence at Tefé was mentioned by various 19<sup>th</sup> century naturalists (Bates, 1863, vol. 2: 211; Spix and Martius, 1976: 164), although they didn't mention *terra preta de índio*.

### 5.5. Incidentally Co-Evolved Populations - Weeds

Although we have all observed weeds that may be indicators, none have been adequately studied to date (Major et al., 2003). One example is Herva de São Caetano (*Momordica charantia* L., Cucurbitaceae), an exotic weed commonly found in cities and towns in the Santarém and Manaus regions that can also be found on Dark Earths in sparsely populated interior regions (McCann, 2003). A native of India, it arrived in Brazil via Africa (Pio Corrêa, 1974) and is seldom cultivated for its fruit, in contrast to Africa and Asia, or even the Caribbean. Always weedy, it appears to do better in very disturbed, especially urban sites, and on Dark Earths.

## 6. RELATIONSHIP BETWEEN DARK EARTHS AND AGROBIODIVERSITY

While native fruit trees and other crops can be easily related to the various concentrations of crop genetic diversity in Amazônia, the current database is insufficient to permit other than a single generalization. Persistence of native American human populations may have been more likely on Dark Earths after conquest, and they may have been recolonized by humans more quickly as the native American population (accompanied by new immigrants) recovered from its nadir. Hence, they may have preserved more pre-conquest genetic resources than similar non-Dark Earth sites.

Observations from the Santarém region support this idea. Dark Earths currently support a much greater diversity of crops than the adjacent Ferralsols and Acrisols (Woods and McCann, 1999: 8). Because of this, and the high fertility of these soils, they are highly favored for settlement, cultivation, hunting and resource extraction, even when located in very inconvenient, isolated places. According to *caboclo* residents, this was true also for their parents and grandparents, many of whom left the arid *sertão* during the 1800's and 1900's to colonize a region emptied of its indigenous inhabitants by the end of the 18<sup>th</sup> century. Even Confederate families fleeing the American Civil War were attracted to these locations in the vicinity of Santarém. Some Dark Earth locations may have been more or less continuously occupied (e.g. in the alto Rio Maró, where Mundurucu families live on Dark Earths their ancestors may have created), while others were 'discovered' only recently (McCann, 2003).

While suggestive, a sustained historical human presence and currently high agrobiodiversity does not mean that this diversity is necessarily of pre-conquest origin. The longevity of crop germplasm persistence is a complex question, and certainly depends as much on the unique history of each location as on the crop repertoire left by indigenous people, the crops' life histories and growth habits (Clement, 1999a). It is important to note also that numerous exotic crops were introduced after European contact, and quickly incorporated into indigenous agroecosystems.

## 7. DARK EARTHS AS AGROBIODIVERSITY RESERVOIRS

This raises the question of the importance of Dark Earths as genetic reservoirs, given the genetic erosion that has occurred in Amazônia since conquest (Clement, 1999a). Near urban centers, such as Manaus, Dark Earths are being intensively used for vegetables and some fruit, mostly exotic. At Açutuba, near Manaus, German (2001) highlights the *caboclo* belief that Dark Earths are better for both native American vegetables, e.g., sweet and bell peppers (*Capsicum annuum* L., Solanaceae), tomato *Lycopersicon esculentum* Mill., Solanaceae), squash (probably *Cucurbita moschata* Duch. ex Poir., Cucurbitaceae), red bean and maize, and for exotic vegetables, e.g., cucumber (*Cucumis sativus* L., Cucurbitaceae), West Indian gherkin, okra *Abelmoschus esculentus* (L.) Moench, Malvaceae), onion (*Allium cepa* L., Liliaceae) and watermelon (*Citrullus lanatus* Matsum. and Nakai, Cucurbitaceae). Papaya is another important cash crop grown on Dark Earths near Manaus (McCann, 2003) and near Santarém (I. Falesi, pers. comm., 2002). A similar situation is evident in the Arapiuns River basin (but see below), where corn, beans, squash, yams, and tobacco, along with the non-native watermelon, gherkin, *Citrus* spp and coffee (*Coffea* spp., Rubiaceae) are among the crops cultivated predominantly or exclusively on Dark Earths (Woods and McCann, 1999: 8). Local farmers have found that these crops are unproductive on the impoverished Ferralsols and Acrisols of the region, unless fertilized (which is often too expensive for smallholders). They grow their manioc staple on the common clay soils, reserving the Dark Earths for the more nutrient demanding crops.

Within about a day's travel of Santarém, most of the Dark Earth produce, especially watermelon, beans, and corn, is destined for market. Nearer to Santarém, the market demand for Dark Earths is manifested most extremely in the excavation and transport of *terra preta de índio* to fill raised planting beds for the intensive cultivation of vegetables for market. Around Manaus and Santarém, as well as smaller towns including Monte Alegre and Juruti, the most accessible Dark Earths are mined for potting soil for landscaping (Woods and McCann, 1999: 12, 2001; McCann, 2003). During a recent field excursion, participants of the Terra Preta Nova International Workshop (Manaus, July, 2002) were fascinated and horrified to witness a sod farm enterprise exploiting the high fertility of Dark Earths. The sod was harvested several times a year for sale in Manaus, and with each harvest, several centimeters of the *terra preta* were removed. Needless to say, this site had no remaining native agrobiodiversity. In addition to these market pressures, urban areas pose a direct threat to the agrobiodiversity of Dark Earth areas simply through their physical growth, whereby the Dark Earths are covered over or bulldozed during the construction of roads, buildings, and neighborhoods, as occurred recently in Manaus, where 300 burial urns were destroyed at a single Dark Earth site.

It appears then, that near-urban centers and where market pressures predominate, Dark Earths are less likely to serve as reservoirs for crop genetic diversity. In the cases of truck farms and peri-urban neighborhoods expanding onto Dark Earths, there is the possibility that some weeds and crop seeds may persist. A sod farm,

however, leaves little opportunity for the persistence of even weeds, and any viable crop seeds are soon removed with the soil. It may also be possible that seeds transported with soil will encounter conditions adequate for germination and growth at their destination, but if they do, the prospects for survival in the long run are probably very slim, except perhaps in the case of particularly aggressive and competitive weed species.

These examples of negative impacts notwithstanding, it is important to point out that market pressures of urban centers do not necessarily erode agrobiodiversity and they can even help preserve it (Zimmerer, 1991). In comparison to rural areas, the larger, more concentrated populations of cities can accommodate a greater diversity of market products, including not only modern varieties and exotic crops, but also the more obscure native crop varieties and wild harvested species. In the Peruvian Andes, for example, rare, but prestigious and culturally important varieties of potatoes are preserved by the more affluent farmers closer to market centers, because they have the luxury to grow things other than the bare necessities for survival (Zimmerer, 1991).

Further from major and minor urban centers, population density may determine the frequency of use of Dark Earth sites, and cultural history is certainly also important. Ease of access to markets is certainly a factor that influences the frequency and manner of use of Dark Earths. The traditions, land tenure rules, labor availability (Zimmerer, 1991), settlement patterns and population density of the potential users, and the abundance, size, distribution pattern, and fertility characteristics of the Dark Earth patches relative to surrounding soils can all be important factors determining whether and how a particular patch will be used, and generally how the patches in a particular region are used. For example, German (2001) observed that Dark Earths are poorly used at Santa Isabel do Rio Negro, which is within a region of crop genetic diversity defined by Clement (1999b), and also one of the least densely populated parts of Amazônia. Likewise, according to Acevedo and Castro (1993), Dark Earths are of little or no importance to the black descendants of *quilombos* who now live in the Rio Trombetas region. They have a small, dispersed population and probably have no cultural history of use of Dark Earths to remember. Even where Dark Earths are highly esteemed, such as in the Arapiuns River basin, the frequency and duration of cultivation and habitation of Dark Earth locations decreases with increasing remoteness and decreasing population density. In cases where Dark Earths are seldom if ever cultivated, they are unlikely to serve as reservoirs for short-lived and shade-intolerant crops or weeds requiring an open, disturbed habitat. On the other hand, long-lived forest tree species such as Brazil nut (see above), or shade-adapted understory species (e.g., cacao and cupuaçu) may persist indefinitely, regenerating on the site. J. McCann (pers. comm.) observed very large mango trees (an Asian exotic) surviving on Dark Earths in advanced successional forest, with ample recruitment of seedlings in the understory. Barbasco (*Derris elliptica* Benth., Leguminosae Papilionoideae, an Asian native) may survive for decades after being closed over by the forest canopy. A few *caboclos* in the upper Arapiuns River report observing this plant persisting at remote interior Dark Earth sites. Remote Dark Earth sites in the Arapiuns River

basin are also highly valued for their fruiting trees (e.g. various palms, taperibá), which provide edible fruit and attract game.

Thus, a Dark Earth location may serve as a reservoir for some types of agrobiodiversity even if it has not been re-occupied, cultivated, or even visited a single time since abandonment. In the Napo River region of Upper Amazônia, local tribes not only refrain from cultivating Dark Earth sites, they fear them as havens for dangerous spirits and carefully avoid them altogether (G. Reichel-Dolmatoff, pers. comm. to J. McCann, 1994). Nonetheless, these places serve as active genetic reservoirs, where shamans risk the wrath of dead ancestors unless they maintain and conserve the valuable germplasm found there, and make it available to their people.

There is also the possibility that some plants may persist in the form of dormant tubers or seeds until conditions are right for sprouting of the vegetative plant parts or germination of seeds. For most plants we know very little about how long they are able to survive in the soil bank, but recent research has shown that many seeds may remain viable for decades and even centuries (Spahillari et al., 1999). *Caboclos* in the Santarém region have observed that at some Dark Earth locations, peppers, cará do índio, papaya and maxixe sometimes sprout spontaneously after the forest vegetation is cleared and burned in preparation for planting. Further study will be required to determine which, if any, of these volunteers represent unique, distinct varieties, whether they are ancient local varieties or more recent arrivals, or even hybridized progeny of both (Levin, 1990), and what is the mechanism of their persistence.

Considering the attractiveness of Dark Earth locations to new colonists, some of the crops present are probably descendants of crops planted during the last 200 years of recolonization. In this case, the predominantly Nordeste stock of colonists may have introduced varieties from their homelands or beyond. The *Capsicum* and *Dioscorea* germplasm was probably mostly of local origin, taken from local varieties still being cultivated in the region, and perhaps also from relict crops they found persisting on the Dark Earths, in the same way as occurs today. In the case of the exotic maxixe – and the *Citrus*, mangoes, and other exotic crops that persist on Dark Earths – we know that they could not have been present in the region prior to their respective dates of introduction. Papaya probably arrived in Amazônia shortly before the Spanish. It appears that relict populations are somehow surviving on Dark Earths, even in regions where papaya is not cultivated or harvested (e.g. upper Rio Arapiuns) or where volunteers are actively destroyed as weeds (e.g. at least one location in lower Rio Negro).

In the absence of deliberate or unintentional dispersal by humans, there are two possible explanations for the appearance of these spontaneous crops: 1. they germinated from viable seeds, or sprouted vegetatively from living tubers or roots already present in the soil bank prior to the clearing and burning; or 2. they are secondary colonists whose seeds (or other plant parts) arrived after cutting and burning. Papaya seeds, for example, are known to remain viable for decades, and germinate with a rise in temperature that would be accompany a new clearing (Wood et al., 2000). Therefore, as long as the interval between clearing or cultivation episodes is not too great, the soil seed bank may be the source of the volunteers. At the same time, this fast-growing, weedy tree, with bird-dispersed

seeds, is also well suited for secondary colonization of the newly opened, fertile site from another Dark Earth location (or cultivated field in areas where they are cultivated). Pepper seeds also have a certain longevity in soil, and they also are dispersed by some birds (Tewksbury and Nabhan, 2001). In contrast, yams would probably be wholly dependant on humans to reach another Dark Earth island. Local farmers would have to value them enough to conserve some tubers from those individuals that sprout spontaneously for planting elsewhere. In the Arapiuns, yams and maxixe are typically grown only on Dark Earths, peppers in home gardens, and none in abundance, increasing the probability that the volunteers are not derived from modern varieties.

Dark Earths with a history of more intensive and more frequent cultivation and habitation will tend to serve as reservoirs for another group of species. For example, ipadu, though long-lived, rarely flowers and is unlikely to survive very long in dense shade. Other Dark Earth indicators from the Santarém region mentioned above, such as mangos, citrus, taperibá and cana de flecha may be included in this category. Likewise, the mucajá, inajá and tucumã palms prefer disturbed habitats typically requiring a more sustained human presence. From these examples, it is apparent that we are just beginning to explore the role of Dark Earths as reservoirs of agrobiodiversity.

We can raise four hypotheses that may be worth testing:

1. Continuity of human presence on Dark Earth sites contributes to maintenance of agrobiodiversity, as it does in other environments;
2. Rural human population density contributes to continuity of Dark Earth use and agrobiodiversity maintenance;
3. Distance to market determines the species composition maintained on Dark Earth sites;
4. Access to market opportunities influences smallholder decisions on which crops to grow, or how otherwise to use Dark Earth resources.

Numerous variables related to the Dark Earth sites themselves may be important for the maintenance of agrobiodiversity, such as:

1. Quality of Dark Earth soil and surrounding soils;
2. Size and spatial arrangement of Dark Earth patches;
3. Character of surrounding and competing vegetation, which effects soil seed banks and their respective longevity;
4. History of use and management of Dark Earths (frequency / intensity / type / species / cultivars);
5. Customs / traditions / knowledge of users;
6. Access to Dark Earth parcels (tenure system).

## 8. SUMMARY AND FUTURE DIRECTIONS

Although our understanding of the past and present relationships between agrobiodiversity and Dark Earths remains rudimentary, we have identified various crops and weeds that appear to serve as indicators of Dark Earths in Amazônia. The



quality of these indicators ranges from possibly strong to weak to unknown. The spatial scale of their utility is poorly known for most, although it appears that most are limited to a regional or sub-regional scale, with few, if any, serving as strong indicators throughout the basin. This is consistent with Amazônia's character as a rich and complex ecological, historical and cultural mosaic, with high and patchily distributed agrobiodiversity, and Dark Earths of various types and qualities.

We attempted to classify indicators into four principal types, and hierarchically within each according to degree of domestication. This proved difficult in most cases due to insufficient information. Among those species that could be classified, many qualified for placement in two or more indicator categories (e.g., Brazil nut, papaya), as many out-of-range (type-2) and out-of-habitat (type-3) indicators also qualify as abundance indicators (type-4) in particular places and at particular spatial scales of analysis. As we learn more about the plants that serve as indicators of Dark Earths, and the role of Dark Earths as reservoirs of diversity for those indicators, this preliminary classification schema may be refined.

While there is much to learn about existing Amazonian agrobiodiversity, our understanding of how it is linked to the past is even more limited. There is no shortage of theories attempting to explain prehistoric subsistence patterns and agricultural technologies, but the direct evidence (e.g., macro- and micro-plant remains in archaeological contexts) required to test these theories is sorely lacking. Archaeobiology has made great contributions to our understanding of crop origins and dispersals, and ancient agricultural systems throughout the world, but few researchers have applied its methods in Amazônia. Nonetheless, recent research by Santiago Mora and colleagues (Mora, 2003) in Colombia and currently by Lee Newsom at Açutuba, near Manaus, show that archaeobiology is producing meaningful results. Methodological innovations currently underway (Brown, 1999; Mora, 2003) show promise for greatly improving our capacity to learn about the agrobiodiversity of the past, and its relation to that of the present.

Thus far our discussion of agrobiodiversity has included mostly cultivated and associated plants, with no mention of that very important, but often overlooked component of agroecosystems, the soil biota. Soil microbiology remains a vast, largely unexplored frontier, nowhere more so than in the humid tropics. However, this situation has begun to change rapidly, as new technologies allow the use of increasingly sophisticated methods for studying the soil biota, especially with respect to the extraction and classification of DNA from soil. The large quantity and complex structures of carbon in Dark Earths pose particular challenges for microbiological study (Thies and Suzuki, 2003), but the research also holds particular promise for addressing many of the unresolved questions relating to Dark Earths. These include questions concerning origins, formation processes, persistence, replication, and for our purposes, agrobiodiversity. Mycorrhizal fungi and various bacteria species are among the organisms for which important symbiotic relationships with crops have been identified (Glick, 1995; McCully, 2001; Rodriguez and Fraga, 1999; Sturz et al., 2001).

M. de Lourdes Ruivo (pers. comm. to McCann, 2002) and her colleagues at the Museu Paraense Emílio Goeldi compared the microbiota of Dark Earths in two regions with that of adjacent Ferralsols, focusing on fungi. They found substantially

higher diversity in the Dark Earths, including a distinct fungal genus found in both Dark Earth locations, but absent from the Ferralsols. The fungus-like actinomycete bacteria, important decomposers of organic matter, were also over-represented in the Dark Earth samples. Study of soil biota of Dark Earths has also begun at the meso scale, with similar findings of greater diversity, greater biomass, and taxa found only on Dark Earths (L. Kriger, pers. comm. to McCann, 2002), though any direct associations of these species with cultivated plants are unknown. Hence, it may be possible to identify microorganisms that are indicators, perhaps even of type-1 – those confined to Dark Earths.

Finally, with much of native Amazonian agrobiodiversity already lost, and an unknown proportion that remains at risk, a priority should be placed on increasing our very limited general knowledge of this diversity. Plant genetic studies to identify local landraces, and ethnoecological study of locally adapted agroecosystems where much of the remaining diversity is preserved and perpetuated are important areas of research in this endeavor. Dark Earths may generally maintain greater agrobiodiversity than other soil types, and they are more likely to harbor genetically distinct populations of plants that are no longer viable in the modern market. Some of these, such as the cará do Índio of the Arapiuns, are akin to tree species whose principal seed dispersers are now extinct. They are what Janzen and Martin (1982) refer to as ‘the living dead’, clinging to existence for the time being, but with grim prospects for long-term survival in the absence of a substitute symbiont. Whether it be Amerindians, *caboclos*, colonists or crop geneticists, in order for these living-dead crops to survive someone must serve as the cow that replaced the gomphotheres.

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